DETAILED GEOLOGICAL STUDIES IN THE STEWART COMPLEX, NORTHWESTERN BRITISH COLUMBIA

by

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Abstract

This study presents new data on the geology of this region, much of which is relevant to the tectonic evolution of the Western Cordillera and to the concept of metallogenesis in northwestern British Columbia.

The writer's geological studies have involved the relationships between mineral deposits, geological structures, and lithology. The results are based on original work which involved the geological mapping of an area of about 3,500 square miles, most of which was completely unknown. Discussion of the economic geology of the area represents original contributions based on detailed studies of the major mineral deposits.

The study area includes part of the eastern contact of the Coast Plutonic Complex with the west central margin of the successor Bowser Basin. Geologically, geographically and economically the country rocks of the area form a well defined entity that the writer has called the Stewart Complex. Sedimentary, volcanic and metamorphic rocks bordering the Coast Plutonic Complex, range in age from Middle Triassic to Quaternary.

The bulk of the country rocks within the Stewart Complex belong to the Hazelton Group which can be described as a unit comprising material mainly of an intermediate or andesitic composition.

The writer has defined several distinct periods of metamorphism, plutonism, volcanism, and sedimentation, marked by deformation and erosion. The intensity of deformation as expressed by the intraformational relationships has apparently decreased since the mid-Triassic Tahltanian Orogeny, although plutonism as measured by the

apparent volume of granitic material increased in apparent activity and reached a climax in the Tertiary.

Within this orogenic cycle metallogenesis, related to volcanic, sedimentary, and plutonic processes during each major tectonic phase, has combined to produce broad mineral zoning, and a large array of mineral deposits which represent major events within the evolution of this area which serve to characterize this portion of the Western Cordillera. The fissure vein and replacement vein deposits in the Stewart Complex comprise a common group of simple ore and gangue minerals.

The major massive sulphide deposits include the Granduc property at Granduc Mountain, and the Hidden Creek, Double Ed, Redwing, and Bonanza properties at Anyox.

Porphyry deposits include the molybdenum deposit at Kitsault, and the copper-molybdenum property at Mitchell-Sulphurets Creeks.

Résumé

Cette étude présente des nouvelles données concernant la geologie de cette région, plusieurs de quelles sont relevant à l'évolution tectonique du Corilllera de l'oeust et au concept de métallogénie de la partie nord-oeust de la Columbie Brittanique.

Les études geologiques de l'écrivain se concerne de la rélation entre les gisements de minerai, les structures géologiques, et la lithologie. Les resultats se sont fonde de l'oeuvre originelle de la cartographie geologique d'une superficie d'environ 3,500 milles carrés, la plupart de quelle était complétèment inconnus. La discussion de la geologie economique de cette region représente des contributions originelles fondi sur les études détaillés de gisements minerai principaux.

La région de l'étude comprend une partie du contacte orientale de la "Coast Plutonic Complex", avec la partie oeust-centrale de la marge du basin successeur Bowser. L'ecrivain à donné le nom "Stewart Complex", aux roches consolidées qui sont si semblable en géologie, géographie et économie. Les roches sedimentaires, volcaniques et mètamorphiques aboutissant le Coast Range Complex ont des âges Triassique moyen jusqua Quaternaire.

La plupart des roches consolidées dans le Stewart Complex font partie au groupe de Hazelton avec une composition intermédiaire ou andesitique. L'écrivain à définit plusiers périodes distincte de métamorphismè, plutonismè, volcanismè et sedimentation caracterisé par déformation et érosion. Depuis la phase tectonique Tahltanian, d'age triassique, l'intensité de déformation vue dans les rélations intraformationelles s'est évidemment mais le plutonismè, mesuré par le volume du matériel granitique, s'est augmenter et à ateint une gradation dans le Tertiaire.

La métallogénie associé avec les procès volcanique, sedimentaire et plutonique durant chaque phase tectonique plus importante s'est combiné avec le cycle orogènique pour produire une zonation extensive des minerai et un grand étalage de gisements minerai. Ces gisements représent les evenments les plus importants

de cette région et caractérise cette partie du Cordillera de l'oeust dans le complex de Stewart. Les gisements de filon de fissure et filon de remplacement comprend un groupe simple de minerai.

Les gisements les plus importants de sulfures massif sont le Granduc situé au mont Granduc et le Hidden Creek, Dougle Ed, Redwing et Bonanza à Anyox.

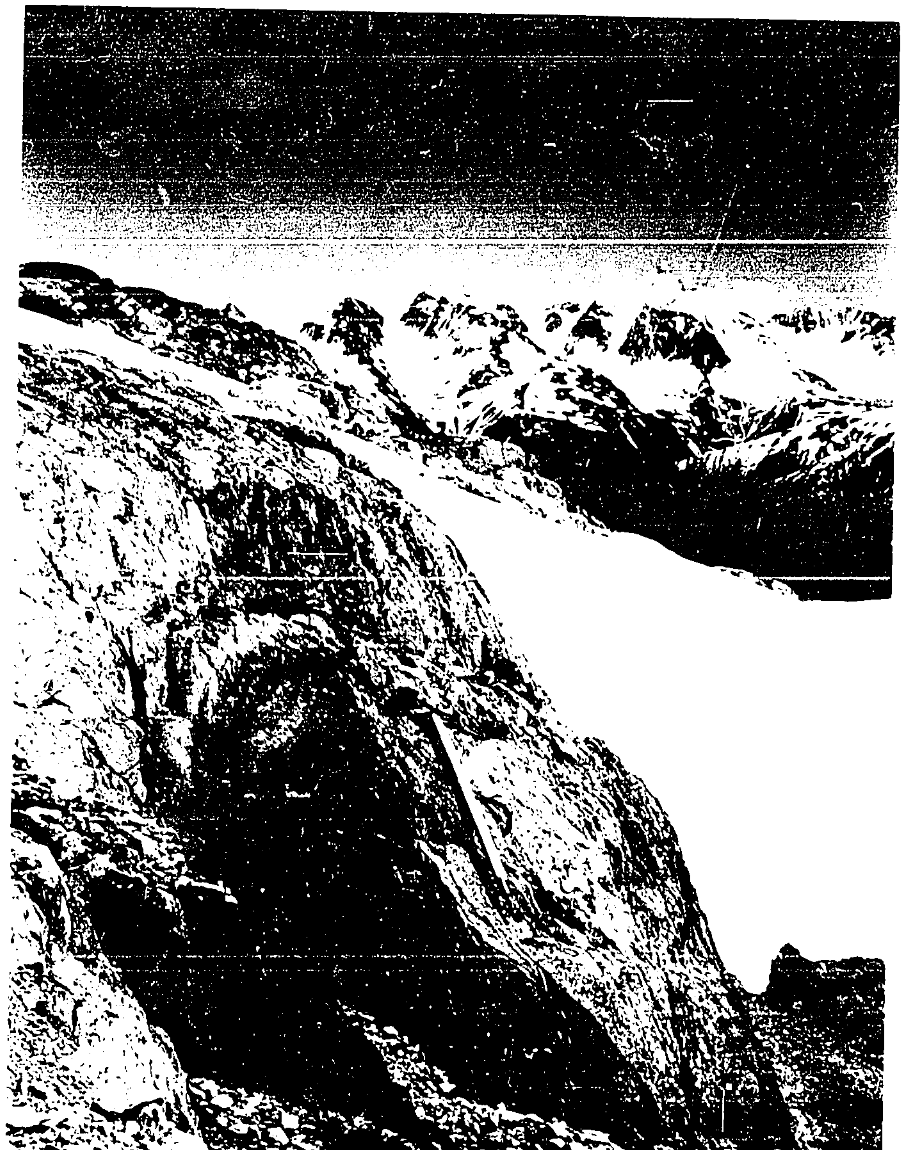
Les gisements de molybdenum à Kitsault et le gisements de cuivre-molybdenum à Mitchell-Sulphurets Creek sont du type porphyre.

DETAILED GEOLOGICAL STUDIES

IN THE STEWART COMPLEX,

N. W., B. C.

Betty Creek strata, Bear River Ridge and looking east to Mount Otter in the Cambria Range.



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Chapter 1

Introduction

The Stewart Complex, generally referred to in this thesis as the study area, is in northwestern British Columbia between latitudes 55 degrees 15 minutes and 56 degrees 45 minutes north, and longitudes 129 degrees 15 minutes and 130 degrees 45 minutes west. The object of this study is to present and discuss the new data on the geology of this region, much of which is relevant to the tectonic evolution of the Western Cordillera and to the concept of metallogenesis in northwestern British Columbia.

Most of the writer's geological work in the Stewart Complex has been of a detailed nature, mainly involving the relationships between mineral deposits, geological structures, and lithology. The results, presented here for the first time, are based on original work which involved the geological mapping of an area of about 3,500 square miles, most of which was completely unknown, or at the best poorly known. The writer's discussion of the economic geology of the area, also presented here for the first time, represents original contributions based on detailed studies of the major mineral deposits.

The geological maps accompanying this study include the maps of the Stewart Complex (Fig. 2), which is in three sheets (Sheet A, Unuk River; Sheet B, Salmon River; and Sheet C, Anyox) and the detailed map of the Stewart area (Figs. 3a, 3b, 3c). The geological maps are indexed on Figure 1, to show their order and relationships. The geological maps are also accompanied by geological cross sections (Figs. 4a and 4b).

The study of the Stewart Complex which the writer initiated in 1964, and continued until 1970, was sponsored by the British Columbia Department of Mines and Petroleum Resources.

Nature of the Field Work

The initial work in the Stewart area was completed utilizing the few available roads. In 1966 work continued north of Stewart into the Bowser Basin aided by part-time helicopter transport to move camps and make a few traverses. In 1967 a month was spent in the Anyox area until a short term helicopter contract was negotiated for the Unuk River section. The last reconnaissance work was completed during 1968 using a small boat on Portland Canal and Observatory Inlet.

Most of the area north of Stewart and between Alice Arm and Bear Pass was mapped using British Columbia Government air photographs. Base maps on a scale of 1 inch to one-half mile were compiled by the writer for the Unuk River section and interim maps of a scale of 1 inch equals one-half mile published by the British Columbia Department of Lands and Forests were used in the rest of the area. Detailed topographic maps are still not available for much of the region and the Federal Government 1 inch to 4 mile maps provided the only available contour information.

Location and Accessibility

The town of Stewart at the head of the Portland Canal, which is near the centre of the area, has been the main locus of activity since 1900. The means of transportation to outlying points in the area are still largely by coastal freighter and by aircraft. The Cassiar-Stewart highway proposed to link the north coast with the British Columbia interior has been nearly completed for quite some time and a forestry road from Terrace, which penetrates as far as the Nass River at Meziadin Lake, has just been joined to the Stewart Road by a small bridge across the river near the lake. The Granduc Mine, near the junction of the North and South Leduc Glaciers has been connected to the concentrator site at Summit Lake by a 12-mile tunnel, which in turn connects to Stewart by way of a 32-mile, all-weather road. Other mine access roads in the area include the Kitsault River road which joins the old Torbrit and Dolly Varden Mines to Alice Arm.

Previous Work

Mineral exploration was started in the general area about 1885 when placer miners on their way out of the Cariboo prospected Observatory Inlet and its arms north of the Nass River. Subsequently the Unuk River, Stewart, Portland Canal, Anyox and Alice Arm districts became the focus of extensive prospecting, and in 1905 Fred Eugene Wright, while investigating the geology of southern Alaska, was directed to explore the Unuk River which flows into Behm Canal. His results were put at the disposal of the British Columbia Department of Mines and published in the 1906 Annual Report (Minister of Mines, B.C., Ann. Rept., 1906, pp. H68-H74). It was not until 1920 that this area was reported on directly by George Clothier, resident engineer, and in 1935, J.T. Mandy produced a report and geologic map for the Unuk section. At Stewart geological investigations commenced in 1906 with a report by H. Carmichael, Provincial Assayer. The first comprehensive geological study in the Portland Canal area was produced by R.G. McConnell (1913) of the

Geological Survey of Canada. This was followed in 1919 by J.J. O'Neill's work which was incorporated into a study of the Salmon River district by S.J. Schofield and G. Hanson (1922). Later Hanson studied the Bear River and Stewart map-area (1929) and incorporated these projects into a regional study of the Portland Canal area which included the then active Stewart, Alice Arm, Anyox and Maple Bay mining camps. This report has served the industry as the major reference to the geology and mineral deposits of the Portland Canal area. At Hyder, Alaska, Westgate (1920) and Buddington (1929) of the United States Geological Survey made geological studies of the Alaskan portion of the Portland Canal. Buddington and Chapin (1929) also produced the first comprehensive study of the geology and mineral deposits of southeastern Alaska including small parts of adjacent British Columbia.

All of the above works, including many descriptions in subsequent Annual Reports of the British Columbia Minister of Mines, have helped lay the foundation for the geological studies that have followed in recent years. The Geological Survey of Canada Map 9-1957, Operation Stikine, is the most recent attempt to compile the geology of the area north of Portland Canal between latitudes 56 degrees and 59 degrees along the east margin of the Coast Plutonic Complex. In 1959 Pan American Petroleum Corporation examined and compiled the geology of a large block of ground in the Bowser Basin from latitudes 54 degrees 45 minutes to 58 degrees between longitudes 126 degrees 20 minutes and 130 degrees 20 minutes providing useful regional concepts.

W.R. Bacon (1956) of the British Columbia Department of Mines mapped the international boundary section between Salmon Glacier-Summit Lake and Mount Willibert including the Granduc mine area tying together for the first time the Leduc River and Portland Canal geology. In 1959 and 1960 geologists, directed by G.W.H. Norman of Granduc Mines, Limited, mapped the Unuk River area from Granduc north to Tom Mackay Lake in detail with special reference to the mineral deposits. These maps, on a scale of 1 inch equals one-half mile, were used as a field guide and in preliminary compilations of the western half of the Unuk River sheet for this study.

These major projects combined with special property reports by members of the British Columbia Department of Mines during the 1940's and 1950's, constituted the available information on the geology of parts of the map area.

Since 1960 the Bowser Basin and the adjoining Coast Mountains area have undergone almost continuous exploration for metals and hydrocarbons. Properties such as the Granduc and British Columbia Molybdenum Mines have become economic and new mineral deposits have been located in previously inaccessible locations and also where recent glacial retreat has exposed new ground for prospecting. The geology and mineral deposits of the Alice Arm section have been undergoing continuous study since 1964 by N.C. Carter of the British Columbia Department of Mines and Petroleum Resources. Some of this material has been published in the Annual Reports of the British Columbia Minister of Mines and Petroleum Resources.

The Hyder, Alaska, quadrangle first compiled by Buddington (1929) was restudied by members of the United States Geological Survey, Alaskan Mineral Resources Branch in 1967-1968 under the direction of James G. Smith. This study has not yet been published, but the pertinent information has been made available to the writer and partly integrated into this report.

Scope of the Present Study

The main purpose of this study has been to determine the general geological setting of the mineral deposits and mineralized areas within the thesis area, and to relate both to the broader regional framework. Areas with important mineral deposits or significant mineralization have, in the course of the survey, received considerably more attention than the apparently unmineralized sections. The geology of most of the area, with the exception of the Cambria Icefield, has been compiled at a scale of 1 inch to one mile for this presentation.

The regional setting has been determined by extensive study of published and unpublished reports and discussions with other workers in the area. Subdivision of the stratigraphic succession and correlation between the various areas has been difficult because of rapid facies changes, many local disconformities, lack of fossils in critical areas, and the extensive snow and ice cover. In September, 1971 a concensus regarding stratigraphic terminology for Mesozic rocks in northwestern British Columbia was reached in discussions between geologists of the Geological Survey of Canada and the British Columbia Department of Mines and Petroleum Resources, including the writer and H.W. Tipper, who are both directly involved. Recent work has shown the essential tectonic unity of the whole Jurassic sequence which includes all of the rocks currently known as the Bowser and Hazelton Groups. The term Bowser Group has been rejected because it has been used previously in Alaska for other rocks. It is expected that the new terminology presented in this report will establish a stratigraphic basis for other studies in this region.

Methods of Study

The writer has traversed most of the Stewart Complex personally, and has examined the major mineral deposits and mineralized areas in detail. The various rock units have been examined by both macroscopic and microscopic methods involving hundreds of hand specimens and thin sections. The texture and mineralogy of the various ore minerals have been examined in polished sections and also by x-ray powder methods. Fossil assemblages collected by the writer have been examined and identified by W.R. Danner at the University of British Columbia, and by paleontologists of the Geological Survey of Canada at Ottawa.

Terminology

The writer has attempted to follow the generally accepted rock classifications such as found in Williams, Turner and Gilbert (1954). For the epiclastic volcanic rocks, the writer has followed the recent definitions and classification of Fisher (1961, 1966). The metamorphic rocks have been generally classified according to the facies concept recently outlined by workers such as Barth (1962), Mehnert (1968), and Miyashiro (1967), and certain locally important units, the cataclasites, have been described utilizing the definitions of Knopf (1931) and Spry (1969).

The nomenclature of the stratigraphic units has been presented within the terms outlined in the code of the American Commission on Stratigraphic Nomenclature (1961, 1970).

Acknowledgements

I wish to express my gratitude to Dr. John S. Stevenson who guided and critically reviewed the thesis, and to supervisors Drs. E.W. Mountjoy and W.H. McClean. Drs. J.A. Elson, V.A. Saull, R.G. Webber, R.F. Martin, and H. Helmstaedt provided valuable critical comment and helpful suggestions.

Thin sections and polished sections were prepared by R. Player, lapidary, Mineralogical Branch and chemical analyses were made by analysts of the British Columbia Department of Mines and Petroleum Resources.

Geologists James T. Fyles, N. Haimila and R.V. Kirkham assisted the writer during parts of the 1966 and 1967 field seasons. Capable assistance was also provided by field assistants Brian Moore, Wolfgang Schamberger, Robert Thorburn, Allan Mann, Kenneth Bradley, Robert Lamb, Bruce Palmiere, Barry Richards, Keith Hooey, and Geoff. Field during the field seasons from 1964 to 1968.

Chapter 2

Physiography and Glaciation

Physiography

The topography of the area can be described as a complex mountainous region dissected by stream erosion and modified by glaciation. Most of the map-area lies within the Boundary Ranges of the Coast Mountains. The boundary between the adjoining Skeena Mountains and Nass Basin has been shown by Holland (1964) to trace a curving line extending north from the Nass River, east to Kinskuch Lake, past the west end of Meziadin Lake to the east end of Bowser Lake to intersect the Iskut River. The map-area east of this line lies in the border zone between the Nass Basin and Boundary Ranges.

Three fairly distinct divisions can be devised for the uplands on the basis of general geology. There are noticeable topographic differences between the erosion forms in the granitic, volcanic and sedimentary rocks. In the vicinity of the international boundary northwest of Stewart a large portion of the area is covered by permanent icefields, through which many nunataks project. Most of the terrain below 6,000 feet elevation presents a crudely rounded appearance while the mountains above that show serrate ridges, horn peaks, and alpine glaciers. Local relief varies considerably from a few thousand feet in the Nass Basin to 6,000 feet along the fjords with the maximum of over 8,000 feet along the Bowser River. The highest peaks in the area are north and east of Stewart. These include Mount Jancowski (9,800 feet), Mount Patullo (8,955 feet), Mount Mitre (8,900 feet), as well as many more peaks and ridges which exceed 7,000 feet. This topographic high lies east of the main "granite" contact (Fig. 1) and forms a crudely ovoid upland area extending from Kitsault Lake to the south, northerly through the Mount Jancowski-Mount Mitre massif, to the Unuk River-Treat Creek boundary.

Within the general map-area the major fjords and valleys trend northerly to northeasterly, and are interconnected by easterly dissections. Experienced aircraft pilots use this system to their advantage in cases of low ceiling and fog, even making, for example, the Granduc to Stewart trip via the Francmackie-Bowser River-Meziadin Lake-Bear River Pass route. The areas above the low valleys and divides are covered by extensive icefields and most of the valleys contain glaciers. In general, permanent snow and ice cover most of the highland from Kitsault Lake to the Unuk-Treaty divide. Within this area several specific icefields have been outlined and named. These include the Cambria Icefield located east of Stewart, the Todd Icefield north of Bear River Pass, and the large Francmackie Icefield which extends from the Chickamin River north to Treaty Creek. Winter landscapes present scenes of seemingly infinite whiteness, whereas in summer the country offers a variety of fjordland, densely forested slopes and extensive alpine scenery.

Drainage

Large streams channel runoff and meltwaters from the study area either directly into the coastal fjords or by circuitous paths into the Nass River system. The Boundary Range mountains are drained by the

Iskut River at the extreme northwest corner of the Unuk map-area, by the Unuk, Leduc, Chicamin, Salmon and Bear Rivers northwest of Stewart and the Kshwan, Kitsault and Illiance Rivers southeast of Stewart. The Unuk River, one of the few large antecedent streams in southeastern Alaska, which rises about 55 miles from the head of Burroughs Bay on Behm Canal, transects almost the full width of the Coast Range and drains the western limits of the major Francmackie Icefield. It is separated from the Iskut River by the broad, low divide across Prout Plateau and by a very narrow, low divide from the easterly flowing Teigen and Treaty Creeks. The Leduc River, which heads on the British Columbia side of the boundary at the Leduc Glacier, is tributary to the major Chickamin River which drains the southwest limits of the Francmackie Icefield and heads in Behm Canal. The Salmon and Bear Rivers, which empty into Stewart, drain the central highland area. The Bear River valley forms one of the few low divides on the north coast between deep water and the interior of the province. The Stewart highway makes use of this divide to gain access to the Nass Basin and eventually to join with the Cassiar road and the main Alaska highway.

Most of the major rivers in the coastal area follow deeply dissected narrow valleys leading from the major icefields and glaciers. Near the fjords the valleys broaden and are generally floored by flat gravel plains incised by the braided stream channels. At the river mouths, broad marine deltas extend into the tidal waters.

Most of the smaller streams along the coastal section drop precipitously from the ridge tops and icefields almost directly into the fjords and have little or no bottom sands and gravels, and seldom form deltas. Inland, along the major rivers, the tributary streams generally have high gradients and are channeled along rock structures. Many of these streams carry a considerable load of detritus and alluvial fans have been built up along the lower sections near the valley bottoms.

Along the east side of the map-area, the major drainage reaches Portland Canal by the Bell-Irving-Nass River system. Steep streams rising in the highland lead into easterly flowing rivers which empty directly into the Bell-Irving or Nass or via Bowser and Meziadin Lake. The Bell-Irving River-Teigen Creek confluence marks the northern limit of the Nass Basin which extends south to the Skeena River at Hazelton. The Bell-Irving has eroded through the thick gravel, sand and silt deposits that floor this extremity of the basin and cut into the underlying Hazelton Group sediments. The piers of the Bell-Irving bridge, located east of Surveyors Creek, are both anchored in country rock. The river has been known to rise 40 feet in a day and in the spring thaw carries a heavy load of ice. The low areas of the Nass Basin contain extensive swampy sections through which streams from the Boundary Ranges meander, split and join, and finally empty into the Nass.

The common occurrence of U-shaped and hanging valleys, the rounded nature of the low hills, numerous lakes and drumlin-like forms in the Nass Basin indicate extensive glaciation. Ice from the Boundary Ranges and Skeena Mountains moved along the Bell-Irving trench into the Nass Basin to escape along the Nass River. Ice moving from the highland west to the coast flowed into the fjords along the present coastal drainage system. During the present stage of glacial retreat, which is still continuing, drainage reversals have occurred to mark adjustments to the evolving topography. Recent drainage of several lakes such as Tide, Summit, and Strohn are examples of this phenomenon. Periodic rapid outflows of water (jökulhlaup) from Summit Lake have been described by the writer in this thesis. Isostatic readjustments of the region are indicated by the presence of marine estuarine deposits exposed along the Bear and Salmon River valleys which form benches along the slopes which indicate an overall recent uplift of about 500 feet. At Anyox, along the west side of Granby Bay, a series of marine beaches or terraces which rise to about 700 feet above sea level attest to the rebound from glacial depression.

Glacialogical Studies

Introduction

The writer has attempted to reconstruct the recent historic pattern of glacial events in the study area from a variety of evidence, part of which includes the local climatic record.

Much of the area lies within the coast district of British Columbia and is characterized by moderate temperature and heavy precipitation. High local relief and icefields cause wide variations in weather even along the fjords. Eastwards from the wet coastal section the temperature and precipitation changes perceptibly to a drier, interior continental climate.

Meteorological records have been kept at various mines as well as at Stewart since about 1908 but most are fragmentary and there are no records for most of the area outside the coastal section. The Stewart records indicate that since 1908 the coastal and adjoining area has had an increase in average mean temperature from about 36 degrees Fahrenheit to the present 42 degrees Fahrenheit. This has been attended by a significant increase in precipitation and generally coincides with the local rapid glacial ablation since 1920. The change in temperature and precipitation has resulted in increased growth of coastal underbrush since 1930. This has also been noted for the interior along the Bowser-Meziadin Lake section and is probably related to the overall change in the regional macroclimate.

A summary of the local weather records and glacial movements has been presented in Figure 5. Data for the plots were derived from Department of Transport meteorological reports. The records for the Stewart station are incomplete but they are the only extensive ones available. Weather records were maintained at the Premier mine during the periods 1926-1948 and 1951-1952; they are also somewhat fragmentary but the fluctuations at Premier appear to be comparable to those at Stewart as well as to those kept at Anyox for the period 1911-1935. The apparent comparability of the widely separated stations has been taken here to indicate that the single Stewart station can serve to indicate fluctuations throughout the study area. Analysis of the plots indicate an increase in average temperature with a corresponding increase in average winter snowfall. Other factors controlling climate have not been investigated, so that for the present the available temperature-precipitation plots must suffice and are considered evidence regarding historical regional thermal vagaries controlling local glaciation. From

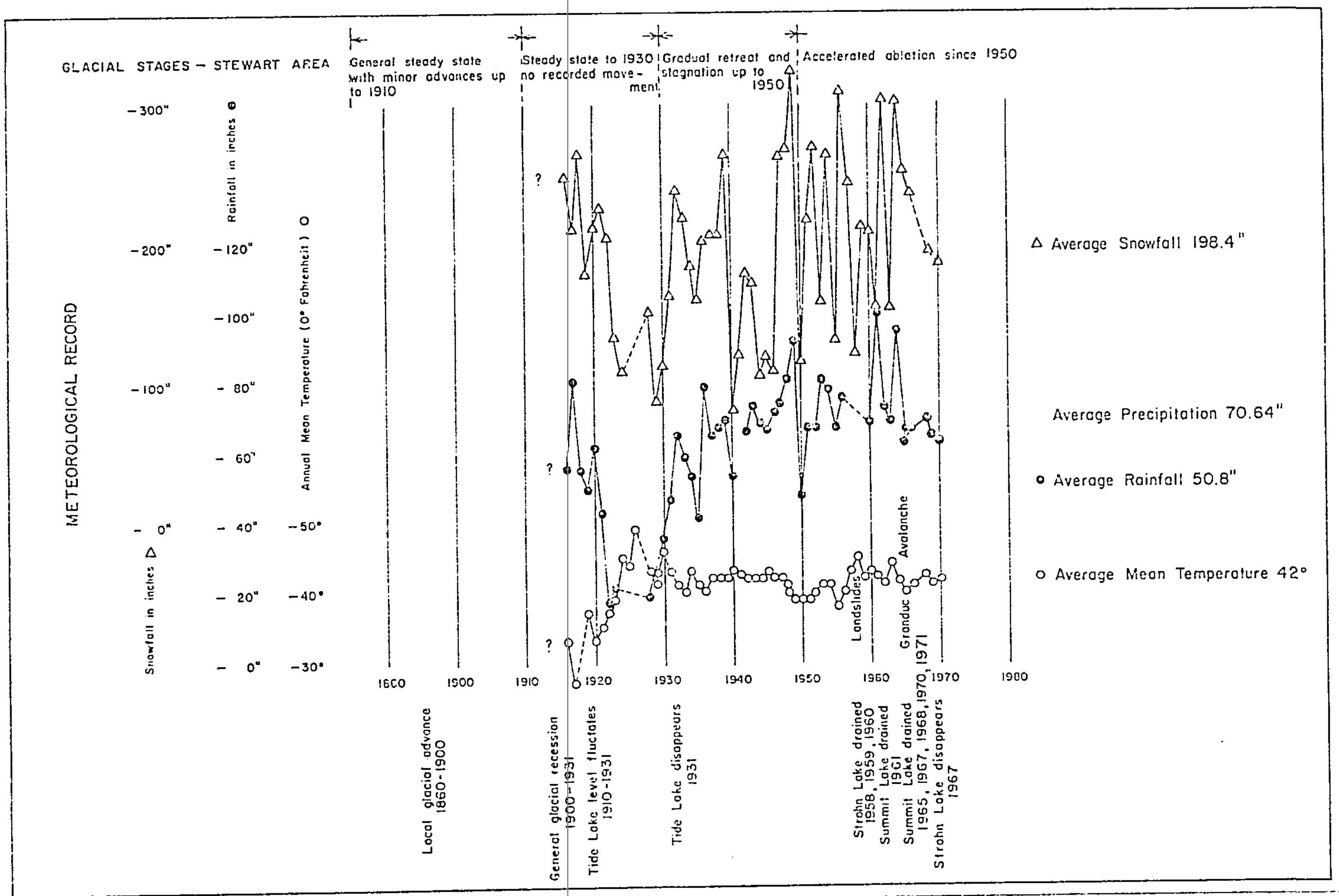


FIG. 5 Glacial-meteorological record, Stewart.

the precipitation plot a number of self evident climatic variations are visible. Between 1910 and 1920 a fairly steady increase in average mean temperature was recorded which has since been followed by a more or less uniform warmer climate. As generally follows, the average precipitation has increased since 1930 and appears to have levelled off paralleling temperature. The decade 1920-1930 shows an anomalous deviation of low precipitation with accompanying higher mean temperatures and as shown in the notes on the plot (Calendar of Events) the sudden disappearance of Tide Lake resulted. The general stages and events recorded in the area have been related to temperature and precipitation on Figure 5 along with some significant local events.

Studies in coastal areas of adjacent Alaska (Klotz, 1907) and nearby Stikine (Kerr, 1948) indicated a glacial recession up until the 1860's, then a short rapid ice front advance, followed by a recession which has continued to the present. Presumably the glacial events in the Stewart district have followed this pattern.

Changes in the local macroclimate have been substantial in the last 90 years as evidenced by such events as the shrinking of the glaciers, the formation and drainage of Tide Lake and Strohn Lake, and the events which are now leading to the extinction of Summit Lake.

In Scandinavia, unlike northwestern British Columbia, extensive weather records are available for analysis. Hoinks (1968) has plotted and analysed masses of data, and has suggested that the glacier recession of the last few decades seems to be caused by the fact that during the ablation season the meso-scale weather conditions have become much less cyclonic than in the decades 1886 to 1895 and 1906 to 1915.

On the larger scale and with very little data the writer has attempted to date the so-called "Little Ice Age" (Mathes, 1942) which has affected large parts of the Western Cordillera.

During the summer of 1968 pieces of tree trunks frozen into one of the glaciers north of Tide Lake Flats were recovered from the ice at an elevation of 2,500 feet. A section of one tree was submitted to the Federal Forestry Laboratories in Vancouver, and was identified as a yellow cedar (Chamaecyparis nootkatensis), about 120 years old. Special studies performed on the wood indicated that the tree had been buried in fresh water for about 500 years and then frozen into glacial ice for a subsequent 500 to 1,000 years. At present yellow cedar grows locally only on the coast, and this discovery suggests that yellow cedar previously grew well inland at a fairly high elevation, possibly greater than 4,000 feet, where only dwarf alpine plants and lichens are now found. Souther (1971) mentions finding large logs under two receding glaciers, at the head of Sutlakine and Samotua Rivers, both of which are now entirely above the timberline. He implies from this that a mature forest existed in these sections during the warm period which preceded the Little Ice Age. The yellow cedar age obtained by the writer indicates that the warm period preceding the alpine glaciation in the Coast Mountains lasted until about A.D. 1000. The writer's tree ring measurements, on the high moraine, of about 500 years (Mathes estimated 450 years in southeastern Alaska) indicates the maximum was about A.D. 1500 along the east margin of the Coast Mountains. At Adams Inlet, Glacier Bay National Park, southeastern Alaska, well documented studies by McKenzie and Goldthwait

(1971) indicate a complex distribution of glaciers during the Neoglacial time. The results indicate that an intraglacial warm period, the Hypsithermal, represented by buried forests, occurred between 7050 and 4150 B.P. By 1700 B.P., Neoglacial ice advanced into Adams Inlet and a retreat correlative with the Little Optimum (A.D. 1150-1300) then followed. A readvance and stillstand of Neoglacial ice was recorded between A.D. 1100 and 1700 and late Neoglacial ice reached its maximum advance about 150 to 250 years ago (or as late as A.D. 1835). Recent deglaciation on the Adams Inlet area has been more or less continuous.

The yellow cedar from the Bowser River section probably grew during the Little Optimum, recognized in southeastern Alaska as a Neoglacial retreat, and suggests fairly uniform conditions throughout the Coast Mountains at the time. Data concerning the late Neoglacial along the east margin of the Coast Mountains is very scant, but the writer's moraine date (500 B.P.) possibly correlates with the A.D. 1100 to 1700 readvance and stillstand. The late Neoglacial Adams Inlet advance indicated by McKenzie and Goldthwait has not yet been recognized along the eastern margin to the writer's knowledge.

Glaciation

The distribution of present-day snowfields and glaciers in the Western Cordillera indicates to a degree the major centres of the Pleistocene Cordilleran ice-sheet. The extensive icefields that still exist northwest of Alice Arm in the Boundary Ranges indicate one of the major centres of accumulation.

Details concerning the Cordilleran ice-sheet in the southern Boundary Ranges are lacking, but ice movement near Stewart generally appears to have been easterly out from the Coast Mountains into the Nass Basin, then southerly, eventually reaching the Hecate Depression via the present Nass and Skeena River lows. In the northern Boundary Ranges, Souther (1971, p. 9) has suggested that the ice converged on the Taku Valley from the northeast and southeast and then flowed southwesterly along the valley into Stephens Passage near Juneau. These concepts contradict the early views of Kerr (1948) and others that the ice-sheet simply flowed northeasterly from the Coast Mountains into the central Cordillera.

Two stages or major advances of the Cordilleran ice-sheet and occasionally three have been recognized (Holland, 1964, p. 103) and following the demise of the ice-sheet, alpine glaciation has been dominant. Portland Canal and Observatory Inlet represent two of the longest fjords cutting the Coast Mountains and like most, presumably owe their depth to overdeepening by glaciation, erratics in the Anyox area indicate a southerly ice movement towards the Pacific coast. Recent soundings along these fjords show that between Stewart and Portland Inlet the water depth averages about 150 fathoms with a maximum of about 250 fathoms in the Maple Bay section. Depths of 2,574 feet in Finlayson Channel and 2,898 feet in Chatham Strait in southeastern Alaska have been attributed to glaciation.

In the area covered by this thesis the main features representing the Pleistocene glaciation include U-shaped valleys, hanging tributary valleys and truncated spurs. Recent Alpine glaciation, still very much in evidence, has tended to obscure or remove most traces of the Cordillera ice-sheet.

In the Unuk River and Stewart areas there is evidence to support the belief that the recession of the Cordilleran ice-sheet was followed by a warm, moist period termed the "climatic optimum", then by a cool period that Matthes (1942) called the "Little Ice Age", which reached a maximum about 450 years ago (Mathews, 1951, p.378). The writer has utilized a high-level moraine (Plate 1) found throughout the Unuk and Stewart areas for campsites and helicopter pads and in the course of cutting timber has counted tree growth rings which gave a maximum of 500 years and suggest a local maximum ice advance and stillstand at about 1500 A.D. More recent advances and retreats of the local glaciers have been recorded throughout the area. At present most of the glaciers are retreating normally at about 150 feet per year in the terminal areas exposing fresh rock outcrop for prospecting. The Granduc Mine located in 1951 on the edge of the South Leduc Glacier, had been walked over only three years previously in 1948 indicating the importance of deglaciation to mineral exploration in this region.

Glaciers and Icefields

Four icefields overlie large parts of the report area. The Francmackie, Cambria, Todd, and Outre icefields are the southernmost members of the extensive permanent snow and ice cover that blankets the Boundary Ranges of southeastern Alaska and northwestern British

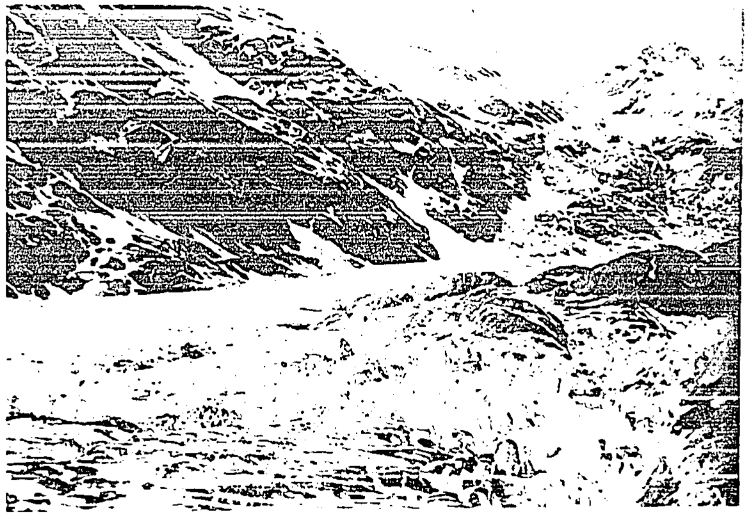


Plate 1. Salmon Glacier - Summit Lake area, showing high level moraine outlined by snow.

Plate 2. Ice worms (Mesenchytraeus solifugus), South Leduc Glacier. X1

Columbia from Alice Arm north to the Yukon Territory. The Francmackie Icefield, which lies along the western part of the study area, covers about 400 square miles and extends from the Chickamin River north to the Unuk River-Treaty Creek divide. The Cambria Icefield, which has an area of 300 square miles, extends from Alice Arm to Bear River Pass. The smaller Todd Icefield lies north of Bear River Pass and extends to the Bowser River. Outre Icefield lies along Bear River Ridge between Mount Dolly and Mount Jancowski. All these icefields lie above 4,000 feet in elevation and generally exhibit a smooth rolling surface through which project many steep rock ridges and horn peaks. These icefields give rise to dozens of valley glaciers of which the Francmackie is the largest and the Salmon is the most accessible. Most of the specialized glaciological studies in the Boundary Ranges have been carried out in southeastern Alaska where access has been relatively easy and scientific interest intensive. Glacial studies in northwestern British Columbia have generally been casual in nature until the last decade. With the exception of detailed studies related to the Granduc mine project most of the glaciological studies in the Boundary Ranges are supervised and initiated by United States institutions.

In 1911 McConnell (1913, pp. 8-10) placed stakes on Bromley Glacier to measure ice flow and recession. Subsequent geological maps in the area showed outlines of a few glaciers but no specific glaciological studies were mentioned in the various reports. It was not until 1954, when detailed glacial studies were initiated in connection with the Granduc mine project, that the local ice regime was seriously investigated. Before the access tunnel route could be chosen it was necessary for the mine operators to known the ice depth of the Salmon, Berendon and Francmackie glaciers. It was also important concerning future mine portal sites to know if the local glaciers were advancing or receeding. Also at the same time, core holes were drilled through the South Leduc Glacier to assist in outlining the ore bodies. Studies based on the ice drilling started in 1954 have been periodically reported by W.H. Mathews (1956, 1957, 1958, 1959, 1964). As part of the International Hydrological Decade (I.H.D.) a Glaciological Subdivision of the Inland Waters Branch was established by the Federal Government in 1965 and because of easy access, the Berendon and Salmon glaciers were chosen as part of the Cordilleran project started in 1966.

The writer has also collected considerable information from local prospectors who have used the glaciers and icefields for many years to gain access to mineral deposits. Additional information gathered from old photographs and maps, together with personal observations made during the geological mapping of the Stewart Complex suggests that glacial ablation in the southern Boundary Ranges has been continuous but oscillatory since about 1900.

Until 1927 the rate of glacier toe recession of the larger glaciers was about 50 feet per year and vertical ablation at the 3,000 foot elevation level was about three feet per year. Since then the average recession and vertical ablation has increased until at the present time the average toe recession of the major glaciers is about 150 feet per year and the vertical ablation at 3,000 feet elevation is approximately 50 feet per year. At the Granduc Mine, the South Leduc Glacier has thinned about 1,000 feet vertically between 1948 and 1971 (Fig. 6), at an average of 50 feet per year. Crude measurements by the writer on the Chickamin Glacier, located south of the Granduc Mine in neighbouring southeastern Alaska, indicate that ablation in this sector has exceeded the rates measured in adjacent British Columbia.

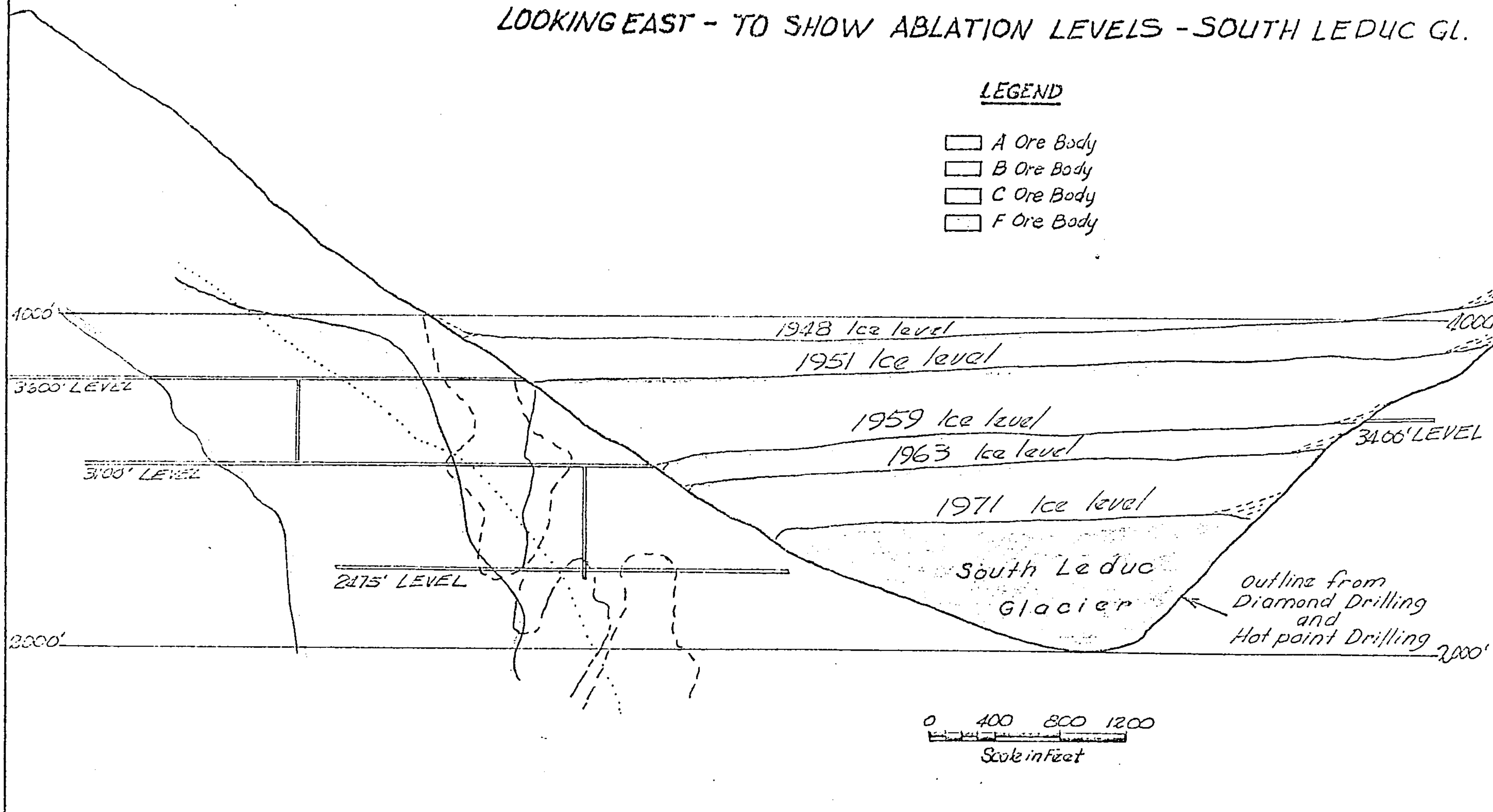
Self-dumping Ice-dammed Lakes

The self-dumping ice-dammed lakes found in the Coast Mountains have been described by Marcus (1960, p. 90) as formed by the retreat of a tributary arm from the trunk glacier and he indicated that they represented an eighth type to be added to Hutchison's (1957) classification of lakes.

Three large glacier-dammed lakes are known in the thesis area and two have been observed annually by the writer since 1964. Tide Lake, which now exists only as a small pond, was located along what is now known as Tide Lake Flats between the present terminus of the Francmackie Glacier and the terminus of the Berendon Glacier, Prior to its demise in 1930-1931, the maximum extent of the lake, now marked by a sharp high-water line, was about 9 square miles and ranked with the largest ice-dammed lakes in Alaska (Stone, 1955, 1963). Summit Lake, which lies between Berenden Glacier and the Salmon Glacier, has an area exceeding 2 square miles at maximum and is somewhat larger than Tulsequah Lake and compares with the largest mentioned by Stone (op. cit.). Strohn Lake, located in Bear River Pass, was considerably smaller in area and compared in size to the pond

FIGURE 6 LONGITUDINAL SECTION OF GRANDUC MINE

LOOKING EAST - TO SHOW ABLATION LEVELS - SOUTH LEDUC GL.



Outline adapted from Norman and McCue (1966) currently found at the south side of the Francmackie Glacier, or about 5 x 10^6 square feet. The writer has not attempted to present the hydrological details of these lakes in this study, but has been concerned with the history and apparent behaviour of the self-dumping lakes. Mathews (1965) presented a partial synopsis of the self-dumping phenomenon of Summit and Strohn Lakes, and one assumes that the more recent observations by the Inland Waters Branch on Summit Lake will get into the literature.

Tide Lake

Tide Lake Flats immediately north of Summit Lake represents the bottom of a recently emptied ice-dammed lake, one of several found along the Salmon-Bowser River Valley. Tide Lake was held in check by Francmackie Glacier (Fig. 2A), but because of glacial ablation and recession, during the period 1921 to 1931, the lake has permanently emptied, leaving a large, virtually flat valley bottom upon which an airstrip was constructed in 1965 to serve the Granduc tunnel project and mill construction. Water draining from Summit Lake, Berendon Glacier, Betty Glacier, and small tributaries were impounded by the toe of Francmackie Glacier forming a lake 6 miles long, 1¼ miles wide, and at least 500 feet deep at its highest level. This level is still marked conspicuously by a sharp high-water line. With the retreat of the Francmackie Glacier, the lake level dropped to about 160 feet at its north end where it was impounded by a cross-valley moraine. Subsequently the moraine dam was breached and the lake disappeared for the last time in 1930-31. The lake derived its name from the seasonal and annual fluctuations in water level brought about by oscillations of the Francmackie ice dam which impeded outward stream flow. Various local inhabitants indicate that the Bowser Valley was subject to periodic flooding, probably related to these oscillations.

Summit Lake

Summit Lake is one of the few existing ice-dammed lakes found in the Stewart district which have been active in recent years and have been responsible for considerable damage to property. It lies at the head of Salmon Glacier, at about elevation 2,700 feet, 18 miles north-northwest of Stewart. Overflow from the lake normally flows north across a rock sill into the Bowser River system, which heads here at the toe of Berendon Glacier. Summit Lake water has followed the northerly path since its origin, when the receding Salmon Glacier left an enclosed basin between the valley walls.

On December 26, 1961, the entire volume of Summit Lake coursed south, a distance of about 8 miles, under Salmon Glacier into the Salmon River and then into the head of Portland Canal at Hyder, Alaska. The first dumping of the lake waters was not seen, but two watchmen on duty at the Silbak Premier mine heard the roar of the escaping water and the crashing of ice blocks. Most of the Silbak Premier road from Thirteen Mile to Riverside was washed out, leaving the watchmen stranded. Small Dolly Varden trout living in Summit Lake were dumped out and a few were found in pools alongside the rearranged Salmon River. Fortunately, dykes of snow bulldozed into place prevented the river from overflowing into the village of Hyder.

The lake began filling again the following May, and remained more or less static until December 1, 1965, when the entire lake again discharged under the ice into the Salmon River, this time destroying 6 miles of the road just reconstructed by the Granduc company. This road, which connects Hyder to Tide Lake Flats, was opened in August, 1965, and follows the east side of the Salmon Glacier and Summit Lake. Drivers commuting regularly between Stewart and the Tide Lake camp reported that two to three days previously to the dumping of Summit Lake, the Salmon River turned almost black with silt.

Summit Lake filled for the third time beginning in late May, 1966, and discharged on September 17, 1967. During the discharge the Granduc company and ice research crews of the Hydrology Division, Department of Energy, Mines and Resources of Canada recorded hydrological data.

A fourth discharge took place from November 10 to 13, 1968. The lake had partly filled during an abnormally brief summer and heavy rain and snow in September and October raised the water to a high level, but not as high as the levels recorded prior to the previous outbursts. In this discharge the Salmon River rose about 8 feet above normal but road and other damage was largely averted.

Summit Lake filled again in 1969 and the water reached a high level in early August 1970. After heavy rain the lake dumped on August 17 for the fifth time, tearing loose and flattening the steel cantilever bridge at Ninemile and undermining six miles of the main road (Stewart Map sheet). By August 22, the lake had completely emptied and the volume of water flowing down the upper Salmon River diminished to a mere trickle of slightly milky, unusually clear water. Summit Lake began to fill rapidly and in late September there was still no obvious sign of muddy lake water entering the Salmon River. Observations at the lake were next to impossible because of fog and snow, but compared to previous dumpings the lake seemed to fill more rapidly.

By August 24, 1971, the lake level had reached within 90 feet of the high water mark when the Salmon River turned muddy and the lake emptied completely within four days (Plate 3). The volume of water involved in the 1971 jökulhaup was considerably less than preceding events because between August 1970 and August 1971 the ice dam advanced north from the 1967 limit to the 1961 position. In early August, 1971 the entire front of the ice dam fractured, tilted, and began to float north. When the ice front retreat reached the 1967 position on August 24 the lake emptied south under Salmon Glacier.

The ice dam at the south end of Summit Lake is about 5,000 feet wide. In the period 1961 to 1968 the dam as a whole retreated about 2,800 feet south, and has been even farther at the southeast corner, where considerable meltwater enters the present lake. The ice has also thinned substantially at the centre and along the east side of the Salmon Glacier south of the lake, increasing the tendency of the ice barrier to float at high-water level, which normally

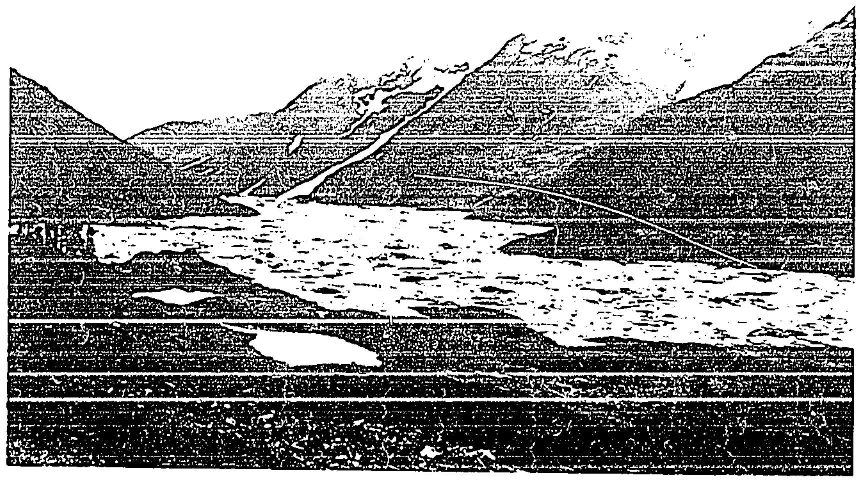


Plate 3. Summit Lake 1971, partly drained, looking south.

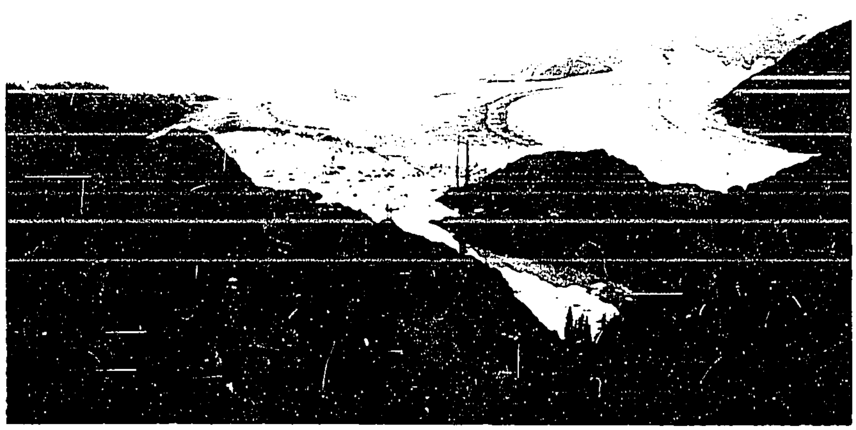


Plate 4. Salmon Glacier, folded moraine, looking south.

occurs in late fall or early winter.

Survey records on the size and movements of Salmon Glacier are sparse up until about 1957. However, 1910 maps show the elevation of the ice barrier at the south end of Summit Lake as about 3,400 feet. The present elevation is roughly 2,800 feet, indicating a thinning which is clearly shown at the old Outland Silver Bar property on the west side of the glacier, where veins originally worked by adits from the ice before 1920 are now 700 feet above the present ice surface.

Strohn Lake

Strohn Lake existed as a glacier-dammed lake unitl August 27 1967 when the ice dam receded sufficiently to allow a free flow between the lake and Bear River (see Salmon River map sheet). Following the retreat of Bear Pass glacier since 1930 and the exposure of a pitted outwash fill on the east flank of the glacier, water was impounded in a small lake which, during high-water stages, flowed east into Strohn Creek. On October 19, 1958 following heavy rain and snow, Strohn Lake suddenly drained west under the Bear Pass Glacier and into Bear River. Downstream, three timber bridges crossing the Bear River Valley were torn loose, the road was inundated and the village of Stewart and airport threatened. Fortunately, the old Portland Canal Short Line roalroad embankment protected the village and the main steel bridge held. The lake drained again in October 1959 and October 1960, causing more damage in Bear River Valley. The local Department of Highways cut a deep trench east from the lake in 1961, but the water drained again west in October 1961 and October 1962. During the winter of 1962-63 the

Department of Highways cut a 55 foot deep trench across the nose of the ice dam using explosives and powdered coal, but fortunately the established drainage under the glacier toe remained open. From 1964 to 1967 the ice tongue melted rapidly and the dam was breached August 27, 1967. Since then the Bear River Glacier has retreated leaving a moderate sized lake which normally flows west into the Bear River, but which, at high water, also flows east into Strohn Creek.

Discussion

According to Thorarinsson (1939) the drainage frequency of an ice-dammed lake is determined by the rate at which the empty basin refills to nine-tenths the height of its ice barrier. This rate is in turn controlled by climate, temperature, and precipitation, but as Marcus (1960) has emphasized the mechanics of drainage are mainly hypothetical because few investigators have been able to monitor the entire event.

As a result of observations at Tulsequah Lake during the lake drainage stage Marcus (op. cit) suggested a preliminary floating stage at which the leading edge of the dam became heavily crevassed marking extreme bed disturbance. When the broken ice floated beyond what he termed the critical barrier (zone) the water level provided hydrostatic lift which, in turn, gave the water temporary access to the floor and an escape route opened.

The outbursts from Summit Lake have not been periodic but seemingly erratic. At no time has water escaped over the top of the Salmon Glacier indicating that the escape routes have been subglacial. Each outburst from Summit Lake has been preceded by snow fall above the 4,000 foot elevation and a correspondingly heavy flow of water into the lake. Then, generally, when the abnormal inflow corresponded to high lake level the lake has drained. The writer has monitored the lake since 1964 and has observed the entire sequence for the 1968 and 1971 outbursts. In 1969 the lake reached the high level mark and the ice front retreat was noted. Instead of draining under the ice the lake drained north into the Bowser River until August 1970. The 1968, 1970 and 1971 ice-dam retreated to the 1967 zone and the lake drained. In 1969, although the water level was abnormally high, the ice front did not retreat to the 1967 line (Fig. 7).

The evidence based on observations at Summit Lake supports Marcus' concept of the critical zone. It is also evident that at Summit Lake, temperature and precipitation are determining mechanisms only when the water level at the ice barrier has a static head sufficient to be changed to a dynamic force capable of opening routes through the critical zone.

The writer has examined the bottom of Summit Lake several times after the recent jökulhlaups. Unlike Tide Lake Flats the bottom is undulating with several prominent rock ridges covered by only a centimeter or two of silt, with the intervening basins protected by stratified mud and silt. Rock types and structures can be traced along the lake bed. The critical zone area at the ice dam has not yet been seen, but judged on the appearance of the lake bottom just to the north, this section probably represents an equally hummocky area and marks a sharp change in slope akin to ground conditions at an icefall. The change in slope at the critical zone of the Summit Lake ice dam is also indicated from the seismic studies carried out by a University of Toronto team in 1957 (Doell, 1963). Until 1971 the writer was of the opinion that Summit Lake was doomed within 5 to 10 years, but having charted the oscillatory movement of the ice dam which in effect acts as a lock, it now appears that the lake will last several decades assuming the dam is periodically replenished by the surging Salmon Glacier.

Surging Glaciers

In general, the glaciers in the Unuk River-Stewart-Anyox map-area are receding in a normal fashion at or near the rates observed. As previously mentioned, the ice dam at Summit Lake, at elevation 2,800 feet, advanced about 800 meters between August 1970 and August 1971. Survey measurements made by the writer from base stations on the Granduc road during the period 1965 to 1971 have been plotted along with old data on Figure 7 to show the position of the ice dam between 1922 and 1971. Although the plots suggest surges between 1950 and 1965, the 1970-71 surge noted by the writer marks the only recorded observation of surging glaciers in this area as well as in the Coast Mountains in British Columbia. Surging glaciers have been observed in many areas outside the Coast Mountains and the Steele Glacier in the Yukon in particular has been studied intensively since

1966. Babcock (1967) indicated that during the few days he photographed the Steele Glacier in August 1966, the toe of the glacier advanced at 37 feet per day. He indicated that during the period 1951 to 1966 the toe advanced 7.5 miles, or about 2,590 feet per year, a pace equalled by the Salmon Glacier (800 m) during the 1970-71 surge.

Post (1969) has identified 204 surging glaciers in western North America, 35 of which have occurred since 1960, but he found no evidence of this in the Coast Mountains of southeastern Alaska and British Columbia, the Olympic Mountains, Cascade Ranges and the Sierra Nevada. Post has pointed out that the surging glaciers are characterized by chaotic broken surfaces, repeated loops or folds in the medial moraines or ice banding, sheared margins, and large vertical and horizontal displacements. He has defined a surging glacier as one which periodically (15 to 100+ years) discharges an ice reservoir by means of a sudden, brief, large-scale ice displacement, which moves 10 to 100 times faster than the glaciers normal rate between surges.

On the basis of deep ice drilling results on the Salmon Glacier just east of Summit Lake, Mathews (1959) indicated that the average surface velocity of the Salmon Glacier was 91 meters per year, with an overall velocity of 77 meters per year (Fig. 8). The 1970-71 surge of Salmon Glacier measured at 800 meters by the writer fits the lower limit suggested by Post and compares to the motion measured by Babcock at the Steele Glacier. The surface of Salmon Glacier (Plate 4) exhibits both large scale and small scale folds in the medial moraines, and the area at the ice barrier has a chaotic broken surface. The writer, therefore, suggests that Salmon Glacier, although possibly unique, is a surging glacier, marked by the defined characteristics, and has probably surged periodically since 1922.

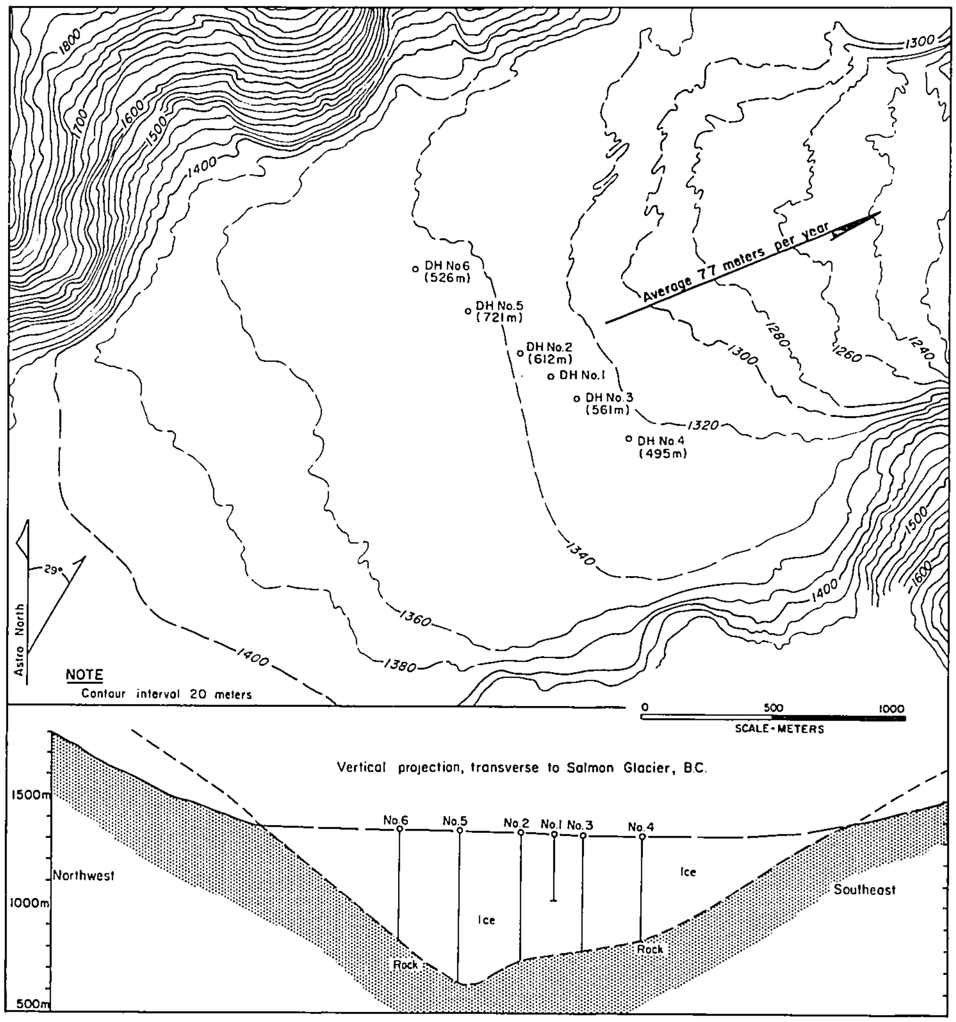


Figure 8. Salmon Glacier - plan and vertical section.

Post (op. cit., p. 229) has suggested that in general glacial surges are not related to earthquakes, avalanches, or local increases in snow accumulation, but are movements related and due to remarkable instability which occurs at periodic intervals in certain glaciers. He also suggested that there appears to be isolated relationships between surging glaciers and extensive fault zones and volcanism, and that bedrock characteristics and sub-glacial temperature anomalies could be factors. Llibourty (1965) and Weertman (1967) have both argued the mechanics of glacier sliding as functions of bedrock character and sub-glacial water to explain rapid glacier motion, but their mathematical models are extremely difficult to apply in the field. Llibourty (1969, p. 185) recently suggested that glacier dynamics could not be approached without making fluctuations disappear by smoothing, and in doing so allows one to study mass balance and kinematic waves, but not an ice fall, the extreme end of a glacier, or crevasse systems. This seems to rule out Salmon Glacier for detailed mathematical analysis.

At Berendon Glacier, on the north end of Summit Lake, one of the few mass balance studies in the region was carried out by Untersteiner and Nye (1968) as a special project related to the Granduc mine. The portal of the 12 mile long access tunnel to the mine site at South Leduc Glacier lies at elevation 2,475 feet, about 100 feet above the glacier margin. The operating company was interested in the possibility of an ice advance and how long it would take. Untersteiner and Nye concluded on the basis of air photograph studies that Berendon Glacier was not a surging mass (no folded moraine) and that a change in mass balance of +70 cm per year would cause the glacier to override the tunnel project in about 40 years disregarding major fluctuations or changes in the local microclimate. So far the writer has not made any study of the Berendon Glacier, but when the tunnel was driven heat flow measurements were taken and it was noted that the highest rock temperatures were found under Berendon Glacier (Fig. 3C). As Post (op. cit.) suggested, sub-glacial temperature anomalies may be related to glacial surges and this instance is probably worth examining particularly in view of the recent erratic climatic variations recorded at Stewart (Fig. 5).

Glacial Deposits

Remnants of an old high level moraine on the west side of Summit Lake, which has a low northerly slope, possibly accounted for by rebound, suggests a dormant glacial phase previous to the more recent one (see Plate 1). Tree growth ring measurements on the high terrace in Bear River Valley indicate an approximate age of 485 to 500 years, suggesting a local ice advance about A.D. 1500. Later stages have not been dated in the immediate area.

As the present Salmon Glacier retreats, it leaves behind a flat-floored gravel valley bottom which is reworked by the issuing river. The smaller glaciers have little or no load and leave only polished rock flanked by marginal moraines to mark their existence. Likewise, melting snowfields floored with ice leave behind either bare, polished rock or thin patchy moraine consisting of rubble which is well rounded and which is generally more abundant where siltstones form country rock.

Apart from the minor excavations of a few small alpine cirques, the most apparent effect of glaciation on the map-area has been the smoothing and rounding of the country rock and transport of morainal materials. Transported talus is prominent on the larger glaciers as moraines on the ice and plastered along steep valley walls where glaciers existed only recently.

Other glacial deposits include lake sediments at Tide Lake Flats and those recently exposed for a short time under Summit Lake. The Tide Lake glacial silts have been reviewed by Hanson (1932), who examined cutbanks of the Bowser River which flows through the old lake bed. He suggested that although only about 15 feet of silts and varved clays were exposed, the lake sediments were possibly 150 feet thick near the outlet. From this estimate and assuming the varves averaged less than 1 inch thick, Hanson calculated that the maximum sediment thickness represents a possible 2,000 years accumulation or more. Hanson mentioned that the varves were intercalated with reddish fluvial material and noticed the pink colour of the tributary streams in warm weather, both of which phenomena can still be observed.

Since Tide Lake disappeared more than 35 years ago the natural processes of erosion have been active in the valley. Bowser River has wandered across the flats and cut through the clays into gravels at the south end. At the north end near the barrier moraine the river is deeply incised into varved clays and sands. The normal regimen of local ice retreat suggests that as ablation proceeds glaciofluvial materials are left immediately forming the valley floor and lacustrine sediments are deposited over these as a thin blanket such as at Summit Lake. Tributary streams, especially those on the east side of the valley, have spread extensive alluvial deposits across the valley and are intercalated with the lake sediments.

As Maag (1969, p. 47) has suggested, there are several opinions on the possible formation and survival of thinly laminated sedimentary deposits in periodically dumping ice-dammed lakes. Hanson (1932) showed the presence of at least 15 feet of varved clays at Tide Lake and recent erosion has cut deeper exposing at least 45 to 50 feet of thinly laminated sediments. Pettijohn (1957, p. 163) and Weidick (1963, pp. 112-113) both suggested that quiet conditions of sedimentation were necessary for the formation of varved deposits, whereas Larsen (1961, p. 160), Thorarinsson (1939, pp. 237-238), and Maag (op. cit., pp. 47-49) have given examples of varved or laminated deposits formed and preserved in periodically draining ice-dammed lakes. Hanson's (op. cit.) suggestion that the Tide Lake varved sediments represented 2,000 years accumulation is probably large, considering the fact that glacial ice filled the Tide Lake valley only 500 years ago.

Ice Worms

As part of glaciological research in the area by the writer, specimens of ice worms have been collected from several localities. These have been identified as Mesenchytraeus solifugus, but specific varieties are so far unnamed and await detailed research. They abound in portions of the major ice areas in the region, specifically the Cambria and Francmackie icefields. Generally they are black or brownish-black, have a distinct earthworm-like appearance and commonly attain a length of one-half to three-quarters of an inch, rarely exceeding one inch (see Plate 2). They have been seen most commonly in surface sinkholes in the ice and along meltwater channels where the ice and water are mainly clear and free of rock debris. They have been found in these locations in bright summer sun and have been seen to leave their ice channels and move on to the clean ice surfaces in direct warm sunlight. This environment appears to exist best between elevations of 2,500 to 3,500 feet and glaciers with gentle north slopes appear to be preferred. Ice worms have also been found at lower elevations (1,500 to 2,500 feet) in the glacier toe areas living about 2 feet under the ice surface. Like their life cycle, the ice worm's diet is largely unknown, however micro-organisms such as "red snow" (the algae *Chlamydomonas nivalis*) may play a part and additionally vitamin A from the atmosphere may dissolve the ice water to provide sustenance.

Landslides

Small landslides are seen in many of the valleys in the report area. Most are small rock slides that represent sloughed well-jointed country rocks forming the steep valley walls so typical of the area. Many of the recent rock slides are located near the terminal zones of valley glaciers where, with recent ablation and the removal of the supporting glacier, the unstable rock slopes have collapsed. Virtually all of these simple rock falls are marked by small scars exposing fresh country rock.

Two landslides of moderate dimensions, obvious because of their size and because they rest on glaciers, have been shown on the Unuk River map sheet. One lies south of Treaty Creek on Tim Williams glacier and the other south of the Bowser River, east of Mount Jancowski, on Haimila Glacier. Both, visible on the 1956 (B.C.) air photographs, lacked new vegetation and are probably less than 20 years old. The slide on Tim Williams Glacier is the largest of the two with a volume estimated at 1.3×10^7 m^3, which is comparable in size to the smaller Blackhawk-type landslides (Shreve, 1966, p. 1640). The surface of this slide has a hummocky, imbricate structure, irregularly crossed with low medial ridges and as seen from the air, compares favourably in appearance with a braided stream. The debris consists of various local rock types and the marginal moraine along the firn line on the east slope is largely missing. Although comparable in some respects to the Blackhawk-type slide it differs significantly in that it apparently represents mainly mobilized rock debris rather than collapsed country rock.

The second slide, at Haimila Glacier, with a volume of about 2×10^6 m^3, is fairly typical of many similar slides in the general area and also elsewhere in the Coast Mountains, as for example on Scimitar Glacier, Mount Waddington (see B.C. photo. 551:76 in Holland, 1964). The Haimila Glacier slide is characterized by an enlarged basin-shaped lobe with a prominent distal rim up to 80 feet high and an elongate tail connecting the head to the glacier margin and steep valley wall. The Haimila Glacier slide and others examined by the writer are also characteristically traversed by well developed tension cracks which extend to and correspond in detail with the fracture pattern in the underlying glacier (Plate 5).

At Bromley Glacier, just east of Stewart, the writer observed the process leading to the formation of certain lobate slides. The

Plate 5. Lobate landslide, Haimila Glacier.

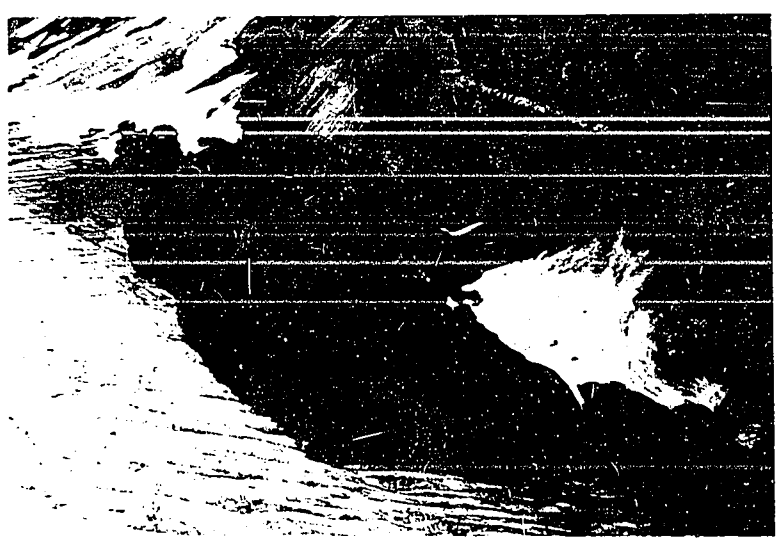


Plate 6. Lobate landslide, Bromley Glacier.

valley wall on the west side of Bromley Glacier is fairly steep, marked by deep gullies and has little moraine cover except at the ice margin. The 3,000 foot high rock wall along the west side of Bromley Glacier is topped by the Cambria Icefield which gives rise to the glacier (Fig. 2B). When snow and ice avalanches break from the cornices along the top of the west wall they are channelled downslope by funnel-shaped gullies which terminate at the base of the rock wall at the edge of the glacier. Snow and ice avalanches were seen to fall the first 1,000 feet as blocks and sheets, then farther down the gullies the colour of the snow began to darken and the speed progressively decreased as country rock and talus were included, forming a slurry which became a mudflow near the base of the slope. One of the mudflows, probably larger than most, extended across the glacier margin forming a small, but recognizable lobe-shaped slide. One of the recent Bromley Glacier slides is shown in Plate 6, to illustrate the dished lobe and transverse fractures in a recent slide.

At Tim Williams Glacier the east slope above the ice is also fairly steep, cut by deep gullies and capped by snow. In this example it is possible that an extensive snow cornice broke off, picked up talus, country rock, as well as moraine, and formed a slurry which flowed onto and along the glacier producing a hummocky, ridged debris mass with the crudely braided-like aspect.

To the writer's knowledge, this type of recent avalanche slide onto ice has not been recognized or described previously and the process described by the writer, on the basis of personal observation, which is initiated by a dry avalanche and culminates in a mudflow is a departure from the commonly invoked landslide mechanisms. Shreve (op. cit., p. 1642) suggested that although water and mud as lubricants are strong possibilities in some Blackhawk-type slides, the evidence at Sherman Glacier pointed to a dry snow and air slurry. The hypotheses of air layer lubrication is usually applied to the huge rock-falls of the Blackhawk type where distal slide rims have climbed as high as 450 m up opposing valley walls. The slides described by the writer have not been seen to traverse the opposite margin of the small glaciers and never approach the high velocity-low friction situation involved in Blackhawk slides.

The simple lobate slides described in the study have all fairly short "tails" compared to the Scimitar Glacier slide, but appear to be similar in other respects. The writer suggests that the length of the slide tail is in part a function of glacier movement. The lobe usually rests at some distance from the ice margin and therefore in a zone of higher ice velocity than at the rock-ice contact. As a result, the head or lobe of the slide moves downstream at a relatively higher velocity than the tail with the result that the tail becomes elongated and thinned with time.

At the head of King Creek, on the western limit of the Unuk River map sheet, several glaciers have been partially covered by extensive slides of recent volcanic ash and cinders. Many of these ash slides are characterized by dozens of cone-shaped distal lobes up to 30 feet high perched on ice pedastals, and by long slide tails. Shreve (*op.cit.*, p. 1642) noted that the most interesting and puzzling of the minor features of the Sherman landslide (Blackhawk-type) are the cones of tightly packed, finer grained debris piled at the angle of repose atop boulders throughout the slide.

At the head of King Creek, the recent volcanic ash is piled on the snowfield along the ridge crest and occasionally slides into the adjoining cirques filling in crevasses and moving downslope as more or less compact masses which end up on the glaciers. The cones appear to represent parts of the slide which travelled downslope along the glaciers as unique units shaped en route by motion, and leaving their tails to mark their path. The puzzling cones on Sherman landslide, consisting of fine grained material, may like the King Creek cones represent a distinct slide phase initially involving only fine grained rock particles.

Chapter 3

General Geology

Introduction

This thesis represents a geological study over a period of six years, in the field and laboratory, of the Unuk River, Salmon River and Anyox map areas.

The Unuk River-Salmon River-Anyox map-area includes part of the eastern contact of the Coast Plutonic Complex with the west central margin of the successor Bowser Basin. Geologically, geographically and economically the country rocks of the area form a well defined entity that the writer has called the Stewart Complex. Sedimentary, volcanic and metamorphic rocks bordering the main intrusive, range in age from Middle Triassic to Quaternary. The detailed stratigraphy of the entire area is not completely known, principally because of the extensive icefields, poor accessibility, and the complex nature of the Mesozoic succession. North of Stewart, fossil evidence coupled with certain marker horizons have been used to outline and separate Triassic and Jurassic formations. Permian rocks were not specifically identified in the study, although thick Permian carbonate units have been found immediately east of the Bell-Irving River at Oweegee Peak (Fig. 1). In the map-area south of Stewart, fossils are rare or non-existent with the exception of the Kitsault River section where Hanson (1921) and Carter (pers. comm.) have collected undiagnostic Mesozoic fossils. South of Stewart, the Hazelton formations are still tentative because they are based on structural continuities, apparent lithological similarities, and homotaxis.

TABLE OF FORMATIONS

Sedimentary and Volcanic Rocks

Era		Period or Epoch	Formation	Lithology
CENOZOIC		Recent	Map-unit 20	Unconsolidated deposits; landslide; volcanic ash; hotspring;
			Map-unit 19	Basalt flows; cinders and ash;
		Pleistocene and earlier	Map-unit 18	Basalt flows; lacustrine sediments; glacial outwash;
		Unconformity		
MESOZOIC	Hazelton Group	Upper Jurassic	Map-unit 17 Nass Formation (2,000'±)	Siltstone, greywacke, sandstone, argillite, conglomerate, limestone, coal;
		Middle Jurassic	Map-unit 16 Salmon River Formation (6,000'+)	Conglomerate, greywacke, sandstone, argillite, limestone;
			Map-unit 15 (3,000'±)	Rhyolite, rhyolite breccia, tuff;
			Map-unit 14 Betty Creek Formation (8,000'+)	Pillow lava, andesite and basalt flows;
			Map-unit 13 (2,500'±)	Volcanic breccia, conglomerate, sandstone and siltstone; tuff; siltstone; chert and limestone.
		Unconformity		
		Lower Jurassic	Map-unit 12 Unuk River Formation	Volcanic breccia, conglomerate, sandstone; tuff; conglomerate; sandstone; rhyolite; limestone and chert;
			Map-unit 11	andesite pillow lava; andesite and basalt flow lava.
		Unconformity		
	Takla	Upper Triassic	Map-unit 10 (3,000'±)	Volcanic breccia, conglomerate, sandstone and siltstone; conglomerate, sandstone, siltstone; tuff; limestone and chert.

Plutonic Rocks

Coast Plutonic Complex

Era	Period		Lithology
CENOZOIC	Late Tertiary	Map-unit 9	Diorite, granodiorite, basalt.
		Dykes and sill Intrusive Contact	
	Early Tertiary	Map-unit 8	Quartz diorite, granodiorite monzonite, quartz monzonite, augite diorite, feldspar porphyry.
		Intrusive Contact	
		Map-unit 7	Granodiorite, quartz diorite, quartz monzonite, granite.
		Intrusive Contact	
MESOZOIC	Middle Jurassic	Map-unit 6	Granodiorite, diorite.
	Lower Jurassic	Map-unit 5	Diorite, syenodiorite, syenite.
	Upper Triassic	Map-unit 4	Diorite, quartz diorite, granodiorite.

Metamorphic Rocks

Era	Period or Epoch	Formation	Lithology
MESOZOIC	Tertiary	Map-unit 3	Hornfels, schist, phyllite, minor gneiss and migmatite.
MESOZOIC	Jurassic	Map-unit 2	Hornfels, schist, semi-schist, phyllite, cataclasites.
	Triassic or earlier	Map-unit 1	Gneiss and migmatite.

The nature of Triassic-Permian boundary cannot be determined in the map-area, but the relationship found at Oweegee Peak, a few miles to the east of the area, suggests a deformed, unconformable contact. To the north toward Telegraph Creek, where both Permian and Triassic rocks are well exposed, the nature of the Triassic-Permian boundary is still uncertain even though the Permian rocks which probably underlie part of the Bowser Basin have been studied by several petroleum exploration companies. Fusilinid studies on thick carbonate rocks exposed along the Scud River (Pitcher, 1960) indicate an Early and Middle Permian assemblage. Thickening of the section by folding and faulting is probable. At Oweegee Dome the Permian carbonate units have been deformed and eroded, and are overlain unconformably by black Upper Triassic shales. In summarizing a study of the Bowser Basin, Fitzgerald (1960, Pan American Petroleum Corporation, private report) stated that,

> "the Mississippian, Pennsylvanian, and Permian rocks overlie an older intensely folded highly metamorphosed sequence and are themselves separated by an internal unconformity at the base of the Permian."

These in turn are generally overlain unconformably by Triassic rocks which are predominantly agglomerate, tuff, and andesitic flows with a probable total thickness of 13,000 feet.

Within the Stewart Complex, Upper Triassic rocks are found only along the Iskut-Unuk River section. The Upper Triassic strata which include diagnostic fossil assemblages, are predominantly green epiclastic volcanic units. These include volcanic breccias, marbles, sandstones, and siltstones which form prominent horizons near the top of the sequence. The known Triassic succession in this area has an approximate thickness of at least 3,000 feet.

Triassic rocks are overlain in the area by the Jurassic Hazelton Group composed of sedimentary, volcanic and green epiclastic volcanic rocks. The contact with the Triassic rocks varies from place to place, generally exhibiting a disconformable to unconformable relationship. The Hazelton Group is now defined to include all the Jurassic rocks in the map-area. It is divisible into four major lithostratigraphic divisions represented by one Early Jurassic, two Middle Jurassic, and one Late Jurassic formation. The Lower Hazelton appears to be a predominantly volcaniclastic sequence marked by extensive pillow volcanic members as well as widespread thin marble lenses. This sequence has generally been delimited by field mapping and paleontological data north of Stewart, but to the south at Anyox and Alice Arm the Lower Jurassic strata has been delimited by homotaxis. The thick Triassic and Lower Jurassic Hazelton sequences are lithologically monotonous and similar and hence difficult to separate without structural and fossil information. The lower Middle Hazelton unit has been traced from the Unuk River to Alice Arm and forms one of the few easily recognizable stratigraphic units in the Stewart Complex, and may represent the most prominent Jurassic unit within the Bowser Basin. These rocks generally overlie the Lower Hazelton and Triassic with angular discordance. The lower Middle Jurassic unit, which has been named the Betty Creek Formation (Grove, in preparation), consists of a thick succession of red and green epiclastic volcanics resting unconformably on Lower Jurassic and older rocks, and is in turn overlain by the Middle Jurassic Salmon River Formation. Recently part of the Stikine map-area (Map 9-1957) has been restudied, and pillow lavas previously described as Triassic have been assigned to the Middle Jurassic (Souther, 1969), which is in keeping with field studies by the author.

In the Stewart Complex, the Betty Creek Formation is overlain conformably to disconformably by the mainly marine, thinly bedded Salmon River Formation which includes siltstones, greywackes and minor volcanic units. The Salmon River Formation is in turn overlain by the marine Nass Formation which forms the bulk of the surficial strata in the western Bowser Basin. Elsewhere in the Bowser Basin the Nass Formation and its equivalents are overlain by significant thicknesses of marine-continental sedimentary formations of Cretaceous or Tertiary age called the Skeena Group. These rocks have not been positively identified in the western part of the basin near Stewart.

Small Quaternary volcanic piles and flows are scattered throughout the Stewart Complex but are areally insignificant compared to those found in the northern part of the Bowser Basin.

Along the west side of the study area the structure is dominated by the Coast Plutonic Complex. The plutons of this extensive belt are known to include Middle Jurassic and Tertiary intrusions. Within the map-area granodiorite is the dominant rock type of the major intrusions which are flanked by numerous smaller satellite diapiric and tadpole-like plutons named the Skeena Intrusions (Grove, 1968) (Fig. 1). They include a large variety of rock types and appear to range in age from Late Triassic to Tertiary. Some of the most extensive dyke systems known in the western Cordillera are prominent features in the Stewart Complex and range in age from Jurassic to Tertiary.

Along the undulating main contact of the Coast Plutonic Complex a number of prominent reentrants are marked by the presence of gneisses, migmatites, and some pegmatites.

Deformational metamorphism is important and is found expressed as cataclasite and shear zones largely restricted to competent Triassic and Lower Jurassic rocks. Extensive weathered alteration zones generally related to the shear zones are areally prominent. The Stewart Complex is one of several areas along the margin of the Bowser Basin that is noted for many sulphide mineral deposits and is responsible for a major part of the mineral production of the Western Canadian Cordillera.

Permian

Rocks of Permian age have not been identified within the study area, but they have been found nearby, just west of Snippaker Creek and east of the Bell-Irving River at Oweegee Dome (Fig. 1). At Oweegee Dome where the writer has made only preliminary studies, a steep dipping Triassic sedimentary unit and a Permian carbonate succession are overlain unconformably by members of the Nass Formation. The Oweegee section has received some attention recently because of petroleum exploration in the area but this has generally been limited to air photograph studies because of the rugged terrain. Results of seismic and gravity surveys east of the Meziadin Hinge (Fig. 1) indicated the presence of a thick carbonate unit comparable to the Permian at Oweegee Dome at a depth of about 10,000 feet along the Ritchie Anticline (Fig. 1), (Pan American Petroleum Corporation, 1959, private report). In 1969 a consortium of major exploration companies set up a drill rig on the anticline but the unit only reached 6,700 feet before winter conditions forced abandonment of the project.

External Relationships

Permian rocks are known in widespread parts of the Western Cordillera and are generally considered as part of the extensive Pennsylvanian-Permian Cache Creek Group. Where fossiliferous, the group has been subdivided into units, but in general the Permian record is scanty and the lack of detailed facies information makes paleogeographic interpretation difficult. Recent tectonic syntheses of the Western Cordillera by Gabrielse and Wheeler (1961) and Roddick et al.(1967), suggest that the Western Cordillera has evolved as a complex eugeosynclinal belt which existed from Proterozoic to mid-Mesozoic time. By Permian time in southeastern Alaska and northwestern British Columbia the eugeosyncline had evolved into the parallel Alexander Subtrough, incipient Coast Geanticline and Whitehorse Subtrough (Fig. 9). In southeastern Alaska, the Permian as outlined by Buddington and Chapin (1929) includes a lower sedimentary and volcanic unit unconformably overlain by cherty limestones. In the Stikine River area (Map 9-1957) the Permian is represented by a succession of limestone units locally intercalated with chert, shale and sandstone. In southeastern Alaska the Permian rocks overlie older strata as well as intrusive rocks and in adjacent northwestern British Columbia they rest unconformably on metamorphosed country rocks of possible Carboniferous age. Brew (1968) suggested that the southeastern Alaska-northwestern British Columbia section marked a tectonically "more active" area generally lying east of the Coast Geanticline. The western margin of the Mesozoic Bowser Basin, including the Bear River Uplift, and Stewart Complex (Fig. 1) lie within this more active area.

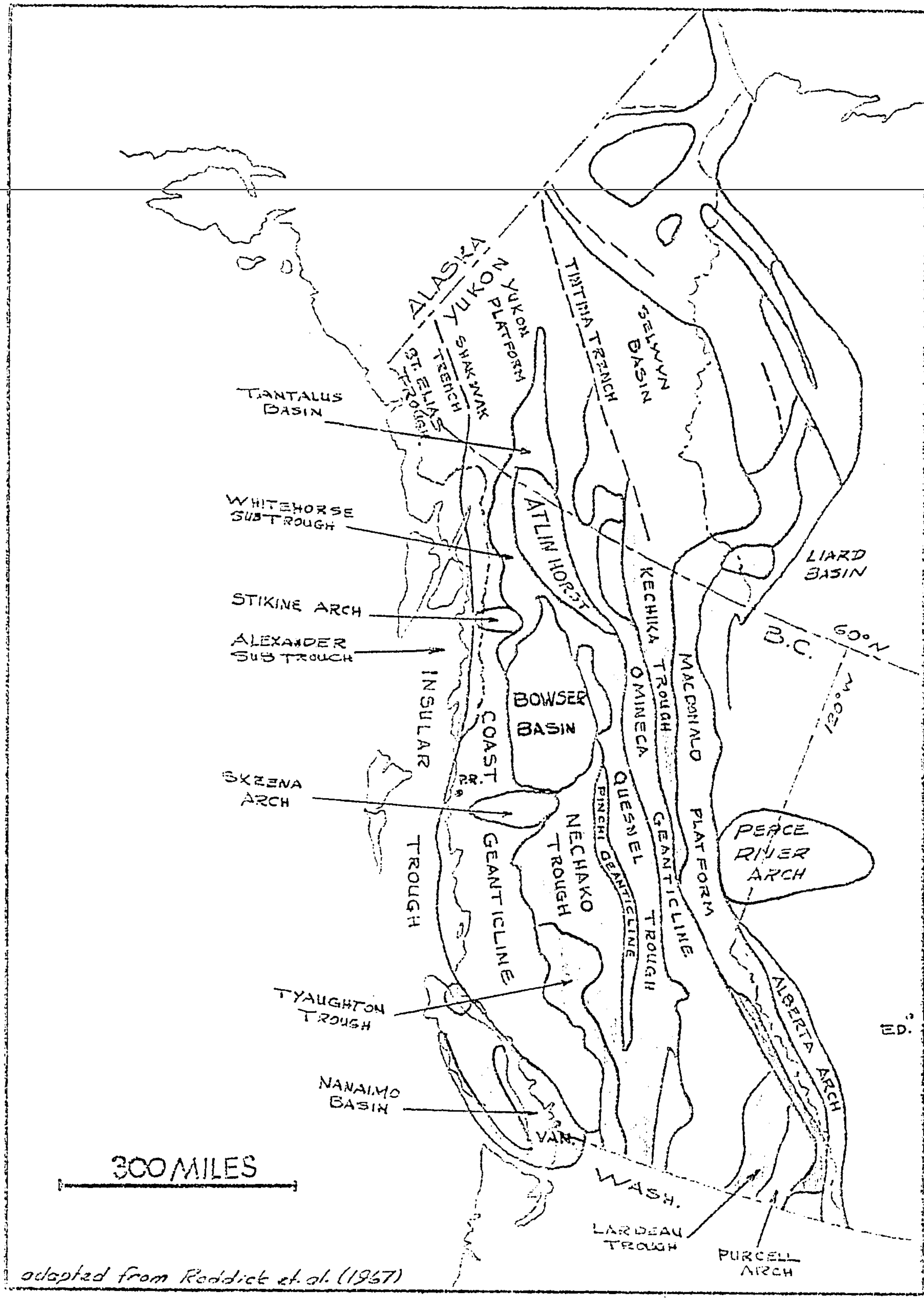


FIG. 9 Tectonic framework, Western Cordillera.

At Oweegee Dome the relationship between Triassic and Permian strata has been confused by deformation and complicated by angular unconformities. The picture is incomplete but in places overturned Permian carbonate members lie on Triassic and Lower Jurassic units and are in turn overlain directly by Upper Jurassic sedimentary rocks. Brew (1968) indicated that the Upper Permian through Middle Triassic record in southeastern Alaska is difficult to interpret but suggested that the Alexander subtrough persisted through the Permian into Late Triassic time and later. Middle Triassic (?) pillow lava and massive basaltic flows have been identified in southeastern Alaska but Brew's proposal (1968, pp. 112-113) to join the Late Permian to Middle Triassic Alexander Subtrough across the Coast Geanticline to the Whitehorse Subtrough currently lacks field evidence of this link. In the Stikine River area near Telegraph Creek fine grained siliceous sediments containing the Middle Triassic pelecypod Daonella overlie disconformably Permian carbonates (Kerr, 1948). In the lower Stikine River area (GSC Map 9-1957) Lower and Middle Triassic rocks appear to be missing and at Oweegee Dome in the Bear River Uplift only Upper Triassic rocks have been identified.

Uppermost Permian rocks in northwestern British Columbia in the Atlin and Tulsequah areas contain the fusilinid Yabeina (Souther, 1971). As previously noted, these units are overlain by Middle Triassic sediments defined by the pelecypod Daonella. South of the Telegraph Creek area, along the east margin of the Coast Geanticline, Permian units have been outlined as far south as Terrace but the youngest of these contain Parafusilina denoting a Lower Guadalupian age (Fitzgerald, private report). At Oweegee Dome, Triassic units overlie Middle Permian carbonates but the present evidence suggests tectonic thinning as well as periodic erosion in this area. A correlation fence diagram for the section between Telegraph Creek and Terrace, outlining the reconstructed edge of the Mesozoic Bowser Basin is shown in Figure 10.

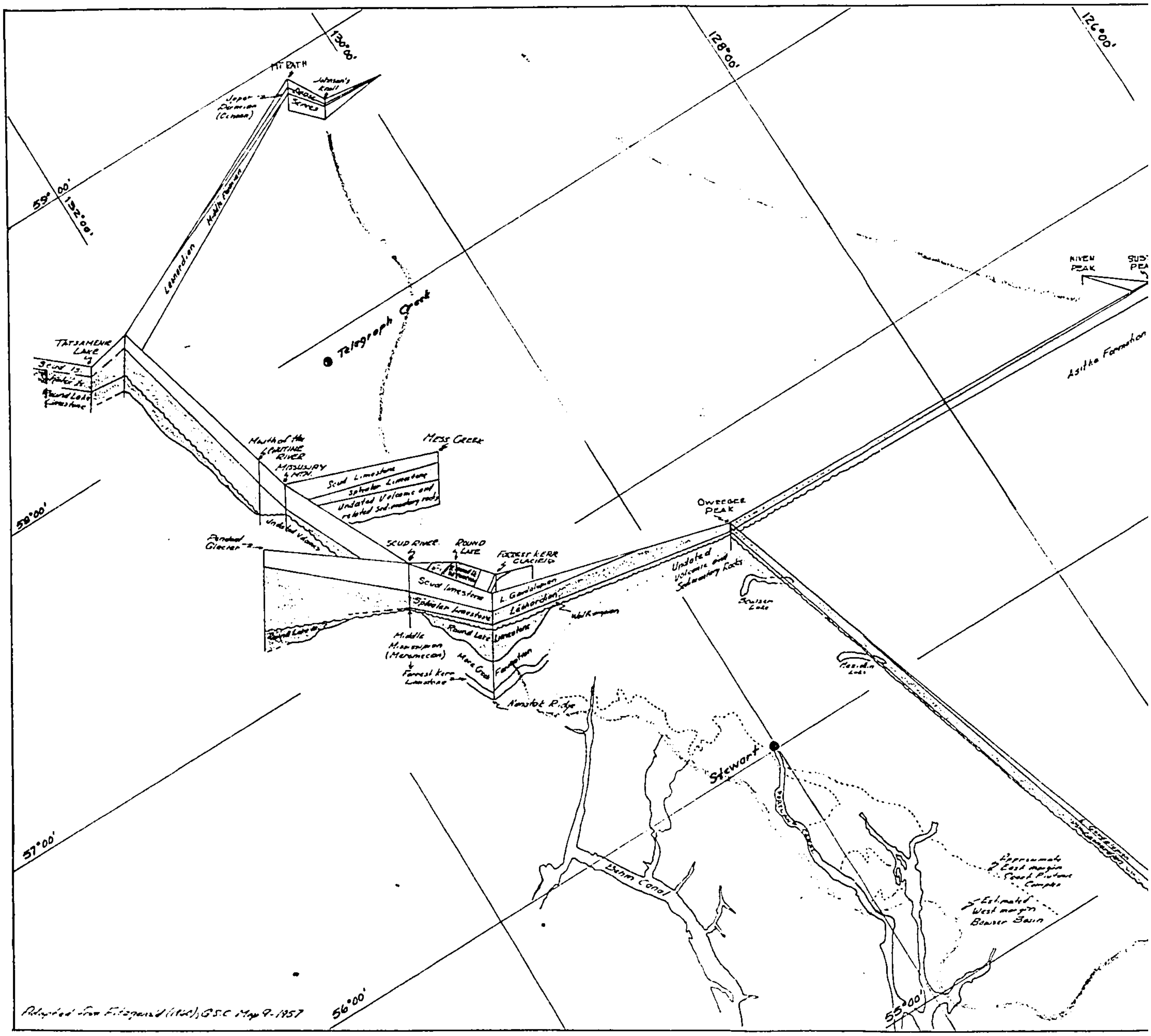
With the possible exception of the Tulsequah area where Lower and Middle Triassic rocks have been postulated by Souther (1971), the available evidence suggests that the Coast Geanticline was emergent during latest Permian time with no connection between the Alexander and Whitehorse subtroughs. The writer suggests that the extensive Late Permian-Early Triassic uplift of the Coast Geanticline essentially marks the demise of the Western Cordillera eugeosyncline and the onset of extensive erosion and volcanism leading to Mesozoic basin development.

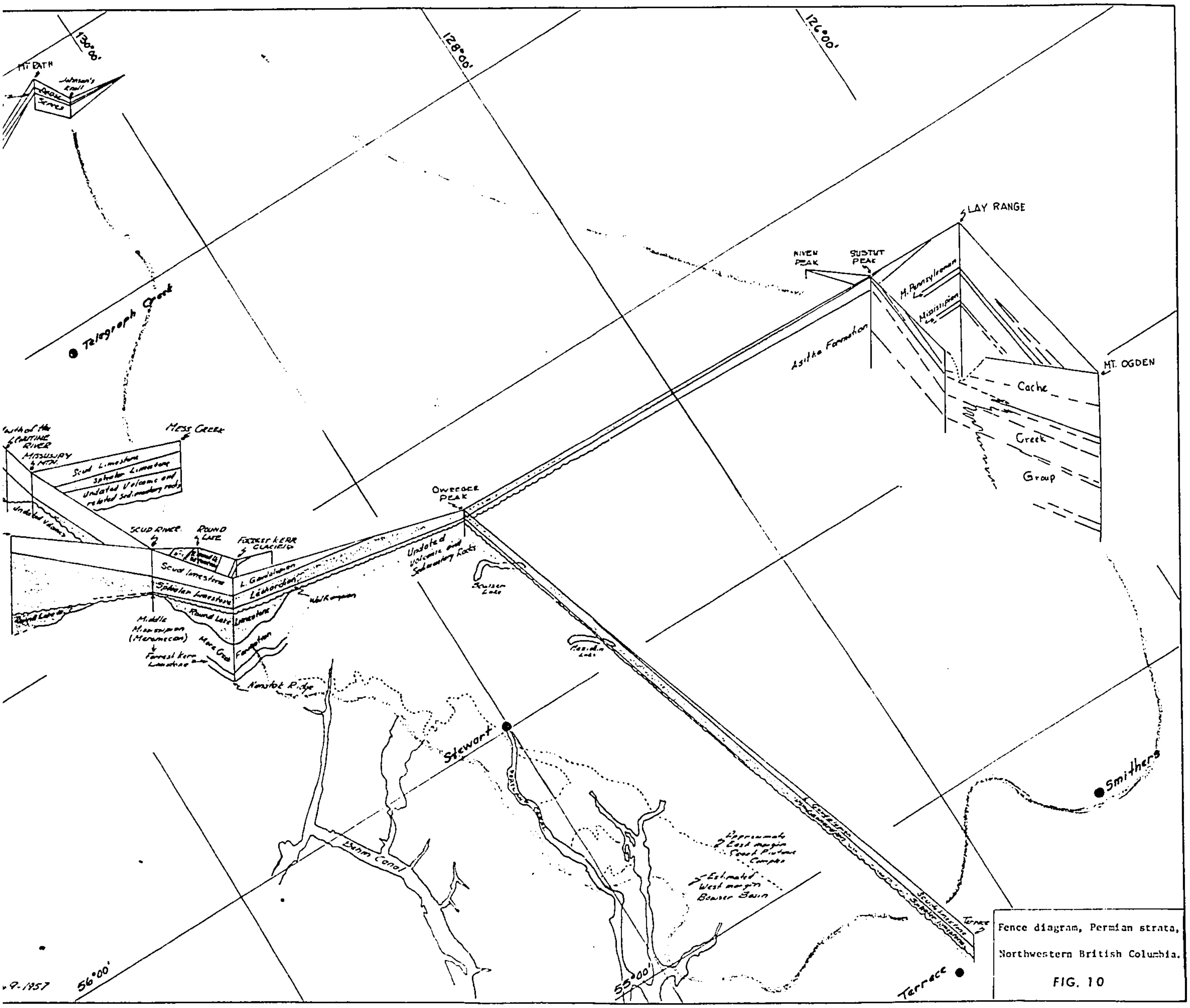
Mesozoic

Sedimentary and Volcanic Rocks

Nomenclature of Mesozoic Rocks in Northwestern British Columbia

Almost a century has passed since the first reconnaissance geological mapping of the Mesozoic sedimentary and volcanic rocks of northwestern British Columbia was initiated by G.M. Dawson. Since that first work, little more than half the rocks have been studied during the course of sporadic reconnaissance mapping. It is only in the last ten years, and mainly instigated by mineral exploration, that detailed lithostratigraphic studies have ensued. These studies will eventually resolve the complex and confused Mesozoic nomenclature promulgated


130°00'
128°00'
126°00'
59° 00'
132°00'
58°00'
57°00'
56°00'
55°00'
Telegraph Creek
TATSAMENIE LAKE
MESS CREEK
Scud Limestone
Sphaler Limestone
SCUD RIVER
ROUND LAKE
Round Lake Limestone
OWEEGEE PEAK
NIVEN PEAK
Asitka Formation
Stewart



Fence diagram, Permian strata, Northwestern British Columbia.

FIG. 10

throughout Cordilleran geologic literature.

Two group names, Hazelton and Takla, which once dominated Mesozoic nomenclature and to which most western Cordilleran Mesozoic rocks were assigned, have in recent years been joined by the term Bowser Group, adding significantly to the confusion. Initially these group names were applied on the basis of spatial relationships to the original areas, but in the apparent general absence of definitive fossil assemblages the names have spread indiscriminately on the basis of comparable lithology.

The results of the detailed geological studies by the writer in the Stewart area, extended to include the entire Stewart Complex, have made it necessary, and indeed possible, to redefine the nomenclature of the Mesozoic rocks of northwestern British Columbia. Detailed geological studies in the Smithers area by R.V. Kirkham (pers. comm.), working at the same time, corroborated the writer's results. On the basis of this new information, H.W. Tipper of the Geological Survey of Canada selected part of the Smithers area to restudy the Mesozoic succession. At a recent meeting attended by the writer and H.W. Tipper, members of the British Columbia Department of Mines and Petroleum Resources, and the Geological Survey of Canada, it was decided that it was imperative and now possible to revise Mesozoic nomenclature. Nomenclature problems, a redefinition of the Hazelton Group, and new lithostratigraphical units are discussed below.

Development of the terms Hazelton, Takla and Bowser in Central and Northwestern British Columbia

In 1877 Dawson (p. 250) introduced the term Porphyrite Group to designate apparently igneous rocks in north-central British Columbia.

Dawson (op. cit.) redefined the succession characterized by andesite porphyry as the Porphyritic Series, and suggested that they underlay and were intercalated with the Jackass Mountain Series and together these rocks bridged the gap commonly found in British Columbia between the Jurassic and Cretaceous. Later Dawson extended the name Porphyrite Group to many lithologically similar rocks in central British Columbia and as such the term was incorrectly applied to a variety of lithologic units including Paleozoic, Mesozoic and Cenozoic strata.

Leach's studies (1906-09) of the Mesozoic succession in the Hazelton-Telkwa area of central British Columbia outlined water-lain pyroclastic and sedimentary rocks in the Telkwa, Bulkley, and Skeena valleys which he considered to be equivalents of the Porphyrite Group outlined at Telkwa. In 1909, Leach (1910, p. 62) introduced the term Hazelton Group for the essentially sedimentary unit with the upper part correlated with the Jurassic Fernie Group of Alberta, on paleontological evidence. The Hazelton Group was overlain by the coal-bearing Cretaceous Skeena Series with the division between the two placed below a prominent conglomerate member. After further work, Leach (1911, p. 93) abandoned the term Porphyrite Group and introduced his new Hazelton Group.

In succeeding studies, Malloch (1912, pp. 72-90; 1914, pp. 76-77) in the upper Skeena River, and McConnell (1914, pp. 58-59) in the lower Skeena River, followed Leach's interpretations. At Telkwa, MacKenzie (1916, pp. 62-63) mapped the volcanic rocks as the Hazelton Formation and the overlying coal-bearing sedimentary rocks as the Skeena Formation. Later, J.J. O'Neill (1919, pp. 81-94) mapped all the volcanic and sedimentary rocks in the Hazelton district as Hazelton Group and placed them in the Late Jurassic.

In 1922, after mapping a small part of the Stewart area (Salmon River district) Schofield and Hanson (1922) outlined Mesozoic nomenclature and lithology in British Columbia and suggested local geographic names for the major rock units but indicated a favourable correlation and their preference for the Porphyrite Group. In their discussion they emphasized the apparent Late Jurassic age of the Porphyrite Group, the characteristically volcanic nature of the members, and the probably unconformable relationship with the younger Skeena Series. This 1922 description was the last published application of the name Porphyrite Group for Mesozoic rocks in British Columbia.

In the years between 1920-1932, Hanson explored the extensive area from the headwaters of the Bowser River (Summit Lake), along Portland Canal to Alice Arm and southeasterly through Hazelton to Smithers. In his reconnaissance surveys between Stewart and central British Columbia (1923, pp. 35-51; 1924, pp. 29-46) Hanson's examination of Leach's type Hazelton suggested a correlation with his formations in the Stewart and Alice Arm districts. He therefore suggested the adoption of the general name Hazelton Group and the abandonment of the formational names. Continued mapping in the Alice Arm district by Hanson (1926, pp. 100-119) and in the Smithers area by Jones (1926, pp. 120-143), suggested that the Hazelton group consisted of four divisions with the youngest being a late Jurassic formation overlain unconformably by the Skeena Formation. Later, in his report on the Portland Canal area (Mem. 175, 1935, pp. 5-6) Hanson briefly outlined the Porphyrite-Hazelton-Skeena problem. He indicated that rocks roughly correlative to both the Porphyrite Group and the Hazelton Group occur in many places in western British Columbia and that, in general, their ages were difficult to determine. He suggested that the units in the west-central part of the province, found to consist mainly of volcanic rocks and clastic sediments and to be between Paleozoic sediments and the Skeena Series, should be called Hazelton Group. He also suggested that in the Portland Canal area the country rock, volcanic and sedimentary rocks were correlative to the Hazelton Group and were, in part, of Jurassic age. Hanson's interpretation found wide usage and persisted until recently.

A new phase in the problem of Mesozoic nomenclature commenced when Armstrong (1944) produced compilation maps for the Hazelton and Smithers map areas. He agreed with Kindle (1937) that the Hazelton Group formed a continuous succession with the younger Skeena Series and therefore combined the Skeena Formation with the upper sedimentary member of the Hazelton Group. As a result, the Hazelton Group was then considered to form a continuous succession from Lower Jurassic to Lower Cretaceous. When Duffell (1952) re-examined the Whitesail Lake map area south of Hazelton, he mapped the Upper Triassic, Jurassic and Lower Cretaceous as separate rock units and restricted the Hazelton Group to the Jurassic succession.

The name Takla Group was introduced by Armstrong (1949, p. 51) as a result of his field work in the Fort St. James map area of east-central British Columbia and was defined as an apparently conformable succession of interbedded volcanic and lesser sedimentary rocks ranging in age from Upper Triassic to Upper Jurassic. However, the only diagnostic fossils found in the Takla Lake section were thought to indicate a Late Triassic and Early Jurassic age. At the same time Lord (1948) working to the northwest in the McConnell Creek area, found sedimentary and volcanic strata containing Early, Middle and Late Jurassic fossils and extended Armstrong's Takla Group to include this assemblage. Armstrong and Lord apparently agreed to this revision and interpretation that the Takla Group represented an apparently conformable Upper Triassic to Upper Jurassic succession.

Tipper (1959, pp. 7-8) disagreed with this presentation because Roots' (1954) work in the Aiken Lake area, immediately north of McConnell Creek, indicated only Upper Triassic and Lower Jurassic strata. He suggested that Frebold's (1953, pp. 1229-1246) summary of the Jurassic of Canada, which illustrated the Takla Group spanning the Jurassic period and Upper Triassic, as well as the presentation of the Hazelton Group as a Middle and Upper Jurassic succession, fitted the evidence at hand. Later (1963, pp. 18-19), Tipper indicated that the Takla Group was re-defined as an Upper Triassic and Lower Jurassic marine assemblage, resting unconformably on the Paleozoic Cache Creek Group and overlain unconformably by the Hazelton Group. He indicated (op. cit., p. 23) that the fossil evidence in the Nechako River area was scarce and the only definitive specimens were indicative of a Late Triassic age.

As a result of Operation Stikine (Roots, 1957), Tipper (op. cit., pp. 23-24) re-defined the Hazelton Group as including Lower and Middle Jurassic strata and introduced a new name, Bowser Group which he indicated comprised a sedimentary succession of Late Jurassic and Lower Cretaceous age. The Bowser Group was then suggested to include strata previously mapped as both Skeena Formation (or Group) and Hazelton Group.

Duffell and Souther (1964, pp. 23-24) briefly reviewed the nomenclature confusion and suggested that in the Terrace area, located in west-central British Columbia, the upper limit of the Hazelton should be placed at the upper limit of the Cardioceras-bearing beds which unconformably overlie the Hazelton Group, and that the lower limit of the Hazelton Group would be at the top of the Lower Jurassic as suggested in the Whitesail and Nechako map areas. In effect, they suggested that the Takla Group would include Upper Triassic and Lower Jurassic strata; that the Hazelton Group would be restricted to a Middle Jurassic age; and that the new Bowser Group, which would include Upper Jurassic and Lower Cretaceous strata, would encompass part of the Hazelton Group and completely replace the Skeena Group. Until the writer's study, the Mesozoic nomenclature has remained in this confused state.

Nomenclature of Mesozoic Rocks in the Portland Canal Area

A summary stratigraphic correlation chart listing the main contributors to Mesozoic nomenclature for parts of the Portland Canal area is shown in Table 1. Hanson (op. cit., 1935) suggested that the name Hazelton Group was applicable to the sedimentary-volcanic succession and that the Nass and Bitter Creek Formations, as originally designated by McConnell, appeared to be a single continuous series. He also suggested that the name Bear River Formation could perhaps be retained for all the volcanic rocks in the area. Locally, the use of the formational names as well as Hanson's concept of the Hazelton Group persisted until 1957.

Map 9-1957, Stikine River Area, with its southerly map boundary at 56°00' latitude includes part of the Portland Canal area. Hanson's

Table 1. Correlation of rock formations of various investigators in the Portland Canal area

*Intrusive

Era	Period and Epoch	McConnell, 1913	Schofield and Hanson, 1922	Hanson, 1929	Buddington, 1929	Hanson, 1935	Grove
Cenozoic	Quaternary	Superficial deposits	Pleistocene and Recent	Recent and Pleistocene	Pleistocene and Recent	Recent and Pleistocene	Surficial basal
	Tertiary					Tertiary - basaltic lava flows	(Sustut
Mesozoic		Later diorite porphyry dykes	Lamprophyre dykes Quartz diorite dykes Augite porphyrite stock	Dykes	Coast Range intrusives	Dykes	(Skeena
			Coast Range Batholith Premier sills	Coast Range intrusives Augite porphyrite and related intrusives		Coast Range intrusives	
		Nass Formation	Nass Formation	Nass Formation	Not mapped	? Hazelton Group ?	Nass Forn
		Bear River Fm.	Salmon River Fm.	Bear River Fm.	Hazelton Group		Salmon Ri
			Bear River Fm.				Bitter Cr
		Bitter Creek Fm.	Not mapped	Bitter Creek Fm.			Unuk Rive
		Not mapped	Not mapped	Not mapped	Not mapped	Not mapped	Takla Gr

Table 1. Correlation of rock formations of various investigators in the Portland Canal area

*Intrusive units not shown (see Fig. 17).

Schofield and Hanson, 1922	Hanson, 1929	Buddington, 1929	Hanson, 1935	Grove, 1972*	Period and Epoch	Era
Pleistocene and Recent	Recent and Pleistocene	Pleistocene and Recent	Recent and Pleistocene	Surficial deposits, basalts	Quaternary	Cenozoic
			Tertiary - basaltic lava flows	(Sustut Group)	Tertiary	
Lamprophyre dykes Quartz diorite dykes Augite porphyrite stock	Dykes	Coast Range intrusives	Dykes	(Skeena Group)	Upper	Cretaceous
Coast Range Batholith Premier sills	Coast Range intrusives Augite porphyrite and related intrusives		Coast Range intrusives		Lower	
Nass Formation	Nass Formation	Not mapped	? Hazelton Group ?	Nass Formation	Upper	Jurassic
Salmon River Fm.	Bear River Fm.	Hazelton Group		Salmon River Fm.	Middle	
Bear River Fm.				Bitter Creek Fm.		
Not mapped	Bitter Creek Fm.			Unuk River Fm.	Lower	
Not mapped	Not mapped	Not mapped	Not mapped	Takla Group	Upper	Triassic

suggestion that the Bear River Formation volcanics and Bitter Creek-Nass Formation sediments were discrete series was taken literally, but his concept of the Hazelton Group as a Jurassic succession suffered a setback. As a result of Operation Stikine and the reconnaissance work at Bowser Lake, the concept of an areally extensive sedimentary unit named the Bowser Group, unconformable upon the Hazelton Group, was introduced. This nomenclature was adopted throughout central and northwestern British Columbia and subsequently defended by Tipper (1963), Duffell and Souther (1964) and others.

Shortly after beginning work in the area, it became apparent to the writer that the striking disagreement between Hanson and later workers in respect to the Hazelton would necessitate considerable further research on the larger Takla-Hazelton-Bowser problem. The writer has undertaken this problem in this thesis and has solved it to the satisfaction of the groups concerned.

Regional mapping of the Stewart Complex lying between the Iskut River and Alice Arm was completed in 1968, resulting in a complete revision of the geology of the area. It has been shown by the writer that the nomenclature devised for the Stewart Complex is applicable to the western margin of the Bowser Basin on the evidence of both lithostratigraphic relationships and fossil assemblages. The composite stratigraphic section for the Stewart map-area (see Fig. 1) shown in Figure 11, represents part of the complete succession in the Stewart Complex and illustrates the revised terminology.

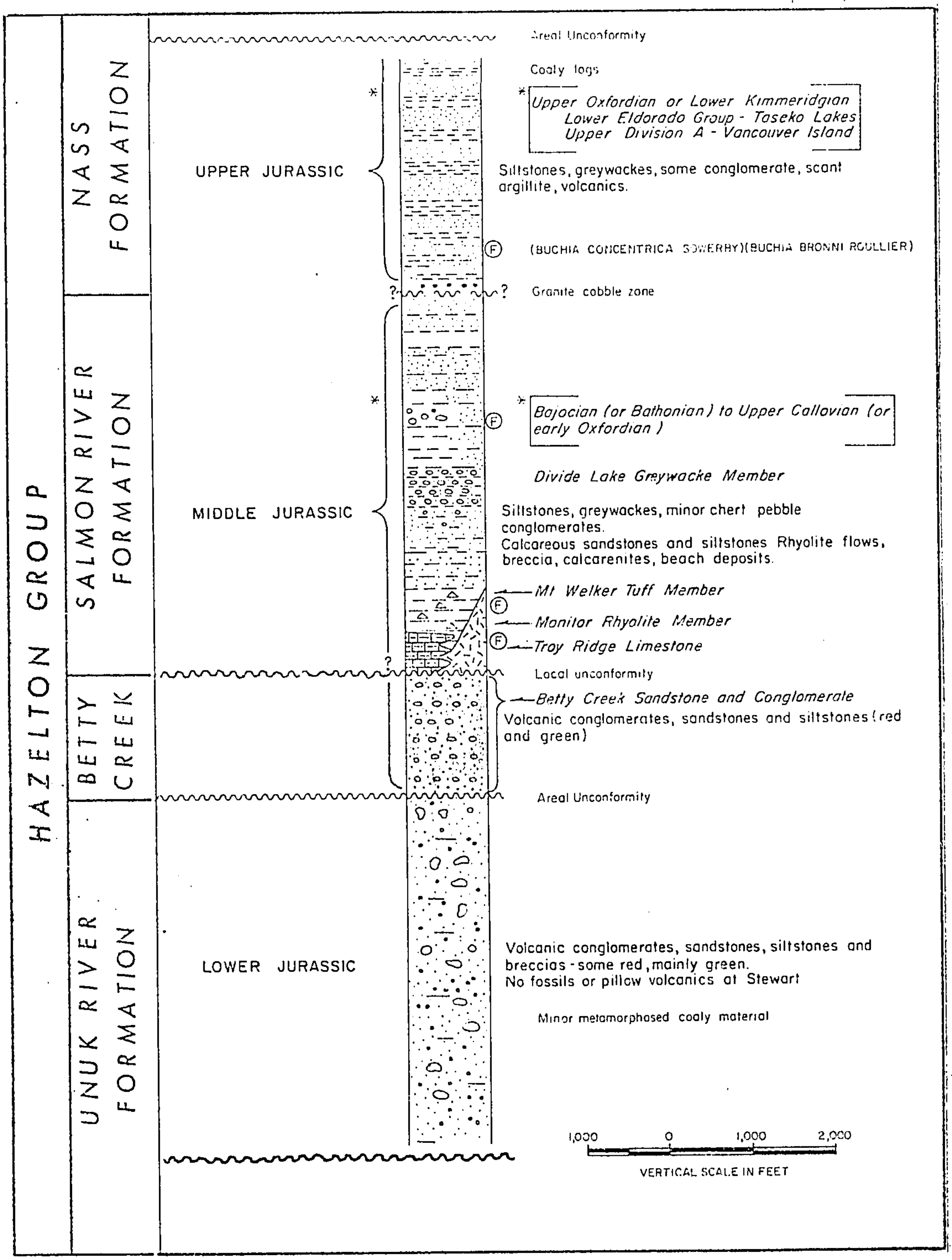


FIG. 11 General stratigraphic column, Stewart area.

Triassic

Triassic and Older

Triassic (and older?) rocks occur as large areas within the Columbian Intermontane Belt of the Western Cordillera, but occur only as small areas within the Coast Plutonic Complex and in the Insular Fold Belt (Fig. 9). In central and northwestern British Columbia the known record of early and mid-Triassic strata is fragmentary and the age of these rocks has commonly been inferred on the basis of apparent relationship to the Permian carbonate units. The general absence of fossils and horizon markers within the Triassic assemblage outlined in the Unuk River map-area has, so far, made it difficult to subdivide this sequence into viable map divisions. Map 9-1957, Stikine River Area (Geol. Surv. Canada), indicates the presence of undivided Triassic rocks (Map Unit 8) in the salient west of the Unuk River, between the Iskut River and the Alaska boundary. These areas are indicated to represent pendants within the Coast Plutonic Complex or areas directly bordering the complex. The section along the Unuk River north of Granduc Mine was mapped by Norman (pers. comm.) who showed that on the basis of new fossil assemblages that the McQuillan Ridge and Harrymel Creek sections, shown on Map 9-1957 as Jurassic volcanic rocks and intrusive rocks respectively, included definite Upper Triassic strata. The extent of the belt of Triassic rocks along the Unuk River has since been expanded by the writer.

Upper Triassic (Map-unit 10)

Upper Triassic rocks have been fairly well documented in recent years in the Western Cordillera and the inference is that these strata including eugeosynclinal volcanics, pelites and limestones were widespread (Brew et al., 1966). The Upper Triassic is particularly well known in the Insular Fold Belt along the axis of the Alexander subtrough in southeasternAlaska, the Queen Charlotte Islands and Vancouver Island (Brew, 1968; Jeletzky, 1970). In central and northwestern British Columbia the situation has been clouded because of the increasingly more confused Takla-Hazelton nomenclature problem outlined in this report. Tipper (1959) redefined Armstrong's (1949) Upper Triassic-Lower Jurassic Takla Group as a typically eugeosynclinal sequence consisting largely of volcanic flows and breccias with only local involvement of section derived wholly or mainly from the erosion of earlier groups. He retained Armstrong's concept that the Takla Group included both Upper Triassic and Lower Jurassic rocks although in his Nechako River map-area (1963, p. 23) his only key fossil was Halobia sp. Tipper's (1959) emphasis of certain red bed units in the Nechako River area introduced a widely held concept that the Upper Triassic rocks of central British Columbia were marked by distinct strata of terrestrial origin. Later he indicated (Tipper, 1963, p. 19) that the red bed sequence was not typical of the Takla Group.

In northwestern British Columbia Kerr (1948) subdivided the Upper Triassic of the Taku River area into the King Salmon Group of clastic sedimentary rocks, the Stuhini Group of mainly volcanic rocks, and the Honatka Formation Limestone. Souther (1971) has remapped the Tulsequah area and has redefined the Upper Triassic nomenclature in that area. He has extended the definition of the Stuhini Group to include all Upper Triassic volcanic and sedimentary rocks lying above a mid-Triassic unconformity and below the Norian Sinwa Formation.

Distribution

In the Stewart Complex the writer has outlined and mapped a northerly trending, wedge-shaped belt of Upper Triassic country rocks extending along the Unuk River from McQuillan Ridge north about 30 miles to the Iskut River. This belt includes rocks which were shown on Map 9-1957 (Geol. Surv. Canada) as Jurassic and Upper Jurassic-Lower Cretaceous sedimentary, volcanic and intrusive rocks.

The belt of Upper Triassic rocks is cut by the Unuk River and continuity of outcrop is hindered further by extensive permanent snow and ice. Below the snowline the vegetation is dense and outcrop is limited to steep gullies, canyons and cliffs.

Lower Jurassic rocks have been found between King and Fewright Creeks, but these were previously mapped as Triassic (Map 9-1957). Triassic rocks shown on the same map (Map 9-1957) at the head of King Creek have also been included in the Lower Jurassic on the basis of new fossil evidence. Just outside the present map area Upper Triassic strata up to 5,000 feet thick (from air photographs) have been identified at Oweegee Peak (Oweegee Dome), where a thick Permian carbonate succession appears to have been faulted into juxtaposition in an apparent high angle overlying relationship. As indicated, the writer has not studied this area in detail because of poor weather. The evidence so far gathered indicates that the Triassic and older country rocks outcrop as structural highs, brought to the present surface as the result of complex folding, faulting, and erosion. The writer was not able to identify any part of the drill core from the exploration hole drilled by Dome et al. (1969) south of Oweegee Dome on the Ritchie Anticline as equivalent to known Triassic.

No macro- or micro-fossils were found by the various company and government geologists who examined the core, leaving the section in doubt as to the actual presence of any Triassic rock in the 6,700 foot core section.

Lithology

The rarity of fossils and the absence of any persistent horizon marker makes correlation of the Upper Triassic rocks in the Unuk River area difficult except in the broadest sense. On McQuillan Ridge the mappable succession comprises a thick assemblage of interbedded green volcanic conglomerates, sandstones and siltstones with andesitic and basaltic volcanics, and thin lenticles of grey carbonate, calcarenite and quartzite which are prominent along the upper ridge. Crystal and lithic tuffs, thin-bedded grey cherts, and quartz sandstones are intercalated with the epiclastic volcanic rocks. The rocks of McQuillan Ridge are complexly folded in detail and evidence of banding is seen in the thin deformed limestone units. The major structure represents an upright northeasterly trending, open anticlinal fold. The anticline or possible dome has been truncated by Tertiary plutons and the west-central part of the ridge has been penetrated by at least one pluton of probable Upper Triassic age. Access to the complete stratigraphy of the succession is limited to the flanks and axial zone at the head of Cebuck Creek. The bulk of the rocks along the steep Unuk River and Gracey Creek flanks of the ridge are thick-bedded grey weathering, green volcanic conglomerates and sandstones with intercalated lenticular andesite flows, thinly banded calcareous siltstones and volcanic sandstones,and minor crystal and lithic tuffs. Toward the top of the ridge and the axial section of the fold, the bedding in the epiclastics is thinner and thin banded grey cherty limestone lenses are more abundant. At the head of Cebuck Creek several quartzite lenses up to 70 or 80 feet thick, intercalated within volcanic conglomerate and sandstone, form part of the carbonate rich section.

The unaltered epiclastic volcanic rocks are largely composed of fresh andesitic fragments within a matrix of rock fragments, plagioclase and quartz clasts. Augite clasts are common with quartz and plagioclase fragments in the matrix of several fine grained epiclastic units in which the rock clasts are porphyritic andesite. The volcanic conglomerates and sandstones are characterised by rapid facies changes, local unconformities, channeling and by occasional graded bedding which gives the rocks a banded appearance. The carbonate lenses consist of grey sugary calcite and generally conform to bedding in the enclosing sediments. The lenses are generally less than 500 feet long and rarely exceed a few tens of feet in thickness; most have an irregular nature presumably as a result of local boundinage. Assuming a reasonable structural interpretation, the section at McQuillan Ridge includes about 3,000 feet of predominantly sedimentary material.

One group of fossils was collected on McQuillan Ridge from the east side above Gracey Creek. Poorly preserved fragments of pelecypods and ammonites found in thin bedded volcanic conglomerates included specimens tentatively identified as Halobia sp. which indicates a possible Karnian age. The collection was apparently lost in transit to Ottawa for determination, but material from the same area had fortunately been submitted previously by Norman (see Appendix II).

The Upper Triassic belt extends north of McQuillan Ridge along the west side of Harrymel Creek towards the Iskut River. Like McQuillan Ridge the exposures are limited to creeks, some ridge lines and the open areas below ice and snow. The structure appears to be considerably more disrupted than at McQuillan Ridge as evidenced by the overturned plunging folds north of King Creek and the convergent structures outlined immediately west of Harrymel Creek. The lack of distinctive horizon markers leaves the structure generally unresolved.

Like the lower part of the McQuillan Ridge succession, the country rocks in the King Creek section are monotonous crudely bedded green volcanic conglomerates and sandstones crudely outlined as generally steep dipping, northeast trending lenticular units. Lithic wackes and siltstones intercalated in the sequence form discrete units several hundred feet wide and comprise up to 40 per cent of the section. Apparent thicknesses are probably misleading because of small scale folding and paucity of continuous outcrop.

Towards Cinder Mountain and at a higher level in the succession limestone lenses, calcarenite, and siltstone units with intercalated epiclastic volcanic rocks dominate the section. A folded limestone unit immediately southeast of Cinder Mountain represents one of the few large limestone members within the known local Upper Triassic rocks. North of Cinder Mountain the sequence consists of poorly exposed, generally northeasterly trending volcanic conglomerates and breccias. A significant part of this section, as indicated on the geological map, has undergone alteration.

Several fossil collections were made south of Cinder Mountain from calcareous shales and siltstones. Monotis subcircularis, of probable Norian age, was found above the thick limestone lens near Cinder Mountain and the belemnite, Aulococeras sp. was collected by Norman (see Appendix II) two miles south of Cinder Mountain.

Structural Relationships

The internal structural relationships of the Upper Triassic rocks in the Unuk River area are not well known because of the lack of litho-structural control. The nature of the convergence of the lenticular units,west of Harrymel Creek particularly, strongly suggests that the succession is not internally conformable. The relation of the small structural remnant of Norian strata to the underlying Karnian succession is obviously unconformable.

External relationships of the Upper Triassic strata with the Hazelton Group rocks, the various plutons and volcanic rocks are fairly clear. The Upper Triassic rocks are overlain on the east and west by Lower Jurassic Hazelton Group rocks with both disconformable and unconformable relationships. Deformation along the Gracey Creek-Harrymel Creek contact between rocks of similar aspect causes some problems as to the exact location of the contact. The Middle Jurassic Betty Creek Formation structural remnants are generally flat lying and rest with distinct unconformity on Upper Triassic units near Nickel Mountain.

The McQuillan Ridge Formation has been intruded by several small plutons. The south contact with plutonic rocks also marks the main eastern margin of the Coast Plutonic Complex. The small plutons along the Unuk River are probably of late Upper Triassic age. Detailed mapping along the west slope of McQuillan Ridge has revealed several swarms of dykes, some of which appear to predate the main phases of the Tertiary Coast Plutonic Complex.

Metamorphism

The belt of Upper Triassic country rocks has suffered several phases of metamorphism and local deformation related to periodic plutonism. Contact, or thermal metamorphism, expressed as narrow ragged aureoles is marked by induration, variable recrystallization, and the presence of fine to coarse grained green-brown hornblende. These thermal zones are well developed, or at least best seen along the eastern contacts of the two small quartz diorite plutons of probable late Upper Triassic age, and along the length of the Tertiary Coast Plutonic margin. The hornblende porphyroblasts are visible in outcrop up to 300 feet from the intrusive contact in volcanic conglomerates and sandstones where, in certain instances, sedimentary clast grain size appears to have been faithfully reproduced in the metamorphosed graded beds. Well formed dark brown hornblende crystals up to three-eighths of an inch long have been observed in the volcanic sandstones, whereas in the siltstones the grain size of the acicular amphibole averages 3 to 5 microns. The amount of metamorphic hornblende appears to vary considerably from about 5 per cent to almost 95 per cent in thin laminae which represent metamorphosed calcareous siltstone units. Hornblende is typical of the thermal aureole developed along the south end of McQuillan Ridge where the Upper Triassic sequence has been transected by the extensive Tertiary biotite granodiorite plutons. This zone is generally about 200 feet or less wide and is also marked by local deformation. Both fine grained brown biotite and green-brown hornblende are typical of this aureole in which induration and variable recrystallization were noted. At Flory Lake, on the west side of McQuillan Ridge, several generations of granodiorite to diorite dyke swarms have criss-crossed the predominantly andesitic volcanic conglomerates, sandstones and siltstones. Metamorphism in these rocks is limited to indurated contact zones a few feet wide in which incipient tremolite-actinolite has been developed at several stages. Early basic dykes cut by later granodiorite dykes show limited induration but pyroxenes in the dyke rocks have not been altered.

In general, amphibolite-grade metamorphism in the Upper Triassic rocks along McQuillan Ridge and Harrymel Creek can be related to several periods of plutonism as evidenced by direct spatial relationships. North of Cinder Mountain the writer has outline a narrow zone of altered volcanic conglomerates and breccias in which green-brown hornblende has also been well developed at the macroscopic scale. These rocks are overlain directly by unaltered Lower Jurassic strata along the east side and are gradational with Upper Triassic volcanic conglomerates, sandstones, and siltstones on the west side. There are no exposures of any pluton of mappable size in the section and the younger dykes are relatively widely spaced and not abundant. These altered rocks are weakly gneissic but are not notably deformed. Structural relations with the southerly part of the Upper Triassic belt are obscured by ice, snow, and the recent volcanic flows. This section may therefore represent an uplifted, eroded segment of regionally metamorphosed strata of Triassic or older age.

Origin

The Upper Triassic country rocks of the Unuk River area are composed mainly of angular, poorly sorted andesitic material probably derived from adjacent volcanic terrain. The porphyritic andesite and basalt flows intercalated within the succession are texturally comparable to the transported clastic fragments in the epiclastic rocks. The occurrence of both augite-plagioclase basalt lenses and augite clasts in the sedimentary sequence also suggests rapid transport of clastic materials directly into the basin of deposition from adjacent volcanic highlands. The rapid lateral changes in thickness and lithology, the visible interdigitation of sedimentary beds and volcanic flows, and the presence of local unconformities suggests active tectonic conditions during deposition of the Upper Triassic strata.

Age and Correlation

The fossil collections from the Harrymel Creek and McQuillan Ridge localities were sent to paleontologists of the Geological Survey of Canada for identification but were apparently lost in transit. Monotis was identified by Professor W.R. Danner of the University of British Columbia.

The meagre fossil evidence coupled with the crude structural interpretation suggests that the bulk of the Upper Triassic rocks in the Unuk River Belt are of a Karnian age. The small area of probable Norian rocks appears to represent a synformal calcareous unit unconformably overlying the folded older units.

On the basis of the available evidence the extensive early Upper Triassic strata of the Unuk River area yielding the diagnostic fossil Halobia are probably correlatives of Souther's (1971) King Salmon Formation, which he has placed within the Stuhini Group, and they are also probably correlatives of the Takla Group of the Nechako River area outlined by Tipper (1963). The name McQuillan Ridge member is proposed for the early Upper Triassic strata in this thesis area.

The Norian strata near Cinder Mountain appears to be lithologically similar to Souther's Sinwa Formation which yielded the diagnostic Monotis subcircularis Gabb and Halorites cf. H. americanus. The Sinwa Formation and its equivalents have proved to be one of the most useful horizon markers in northwestern British Columbia. The Sinwa Formation, named by Kerr (1948), commonly consists of a grey, usually petroliferous, white-weathering limestone which varies in thickness from a few feet to more than 2,000 feet (Souther, 1971, p. 30). It has been correlated with Norian limestone units both north and east of the Taku River section. In the Atlin map-area Aiken's (1959) Carboniferous limestone has been re-examined and is now correlated to the Sinwa Formation (Souther, 1971). To the east, in the Dease Lake map area (Gabrielse and Souther, 1961) and in the Cry Lake map area (Gabrielse, 1962), thin limestone members of Norian age are correlated with the Sinwa Formation.

Identification of a Norian Sinwa Formation correlative in the Unuk River area indicates the widespread nature of the unit and its usefulness as a tool in restudying the complex early Mesozoic era in the northern Western Cordillera.

The Takla Group Problem

In the Stewart Complex, Upper Triassic sediments have been identified only where diagnostic fossil assemblages have permitted some lithological control. The Upper Triassic and Lower Jurassic country rocks in this section of the Bowser Basin are strikingly similar and somewhat comparable in general lithology so that lithologic correlation without paleontological control would generally be inadvisable. Although it has been suggested that the Sinwa Formation limestone has widespread application as a horizon marker, the concept has not been useful in the southern half of the Bowser Basin area because of the generally lenticular nature of most Upper Triassic limestone members (Fig. 12). The presence of comparable prominent Lower Jurassic limestone units introduces problems in correlation.

Recent work in the Smithers map area by Tipper (1971) has confirmed Kirkham's work (pers. comm.) and shown that the Upper Triassic section compares lithologically to the Takla and Nicola Groups of the Quesnel Trough. These Upper Triassic units include massive grey limestones, dark green pyroxene-bearing basaltic breccias and tuffs, argillite, conglomerate and andesitic feldspar porphyry or breccias; this lithology, marked by the extensive pyroxene-bearing lavas, has few similarities to the writer's Unuk River section where porphyritic augite basalts form only a minor part of the succession. To the north, near Telegraph Creek, at Mess Creek, the writer has re-mapped the Upper Triassic succession. This includes predominantly porphyritic augite basalts (Grove, 1969). Farther north, at Tulsequah, Souther's (1971)

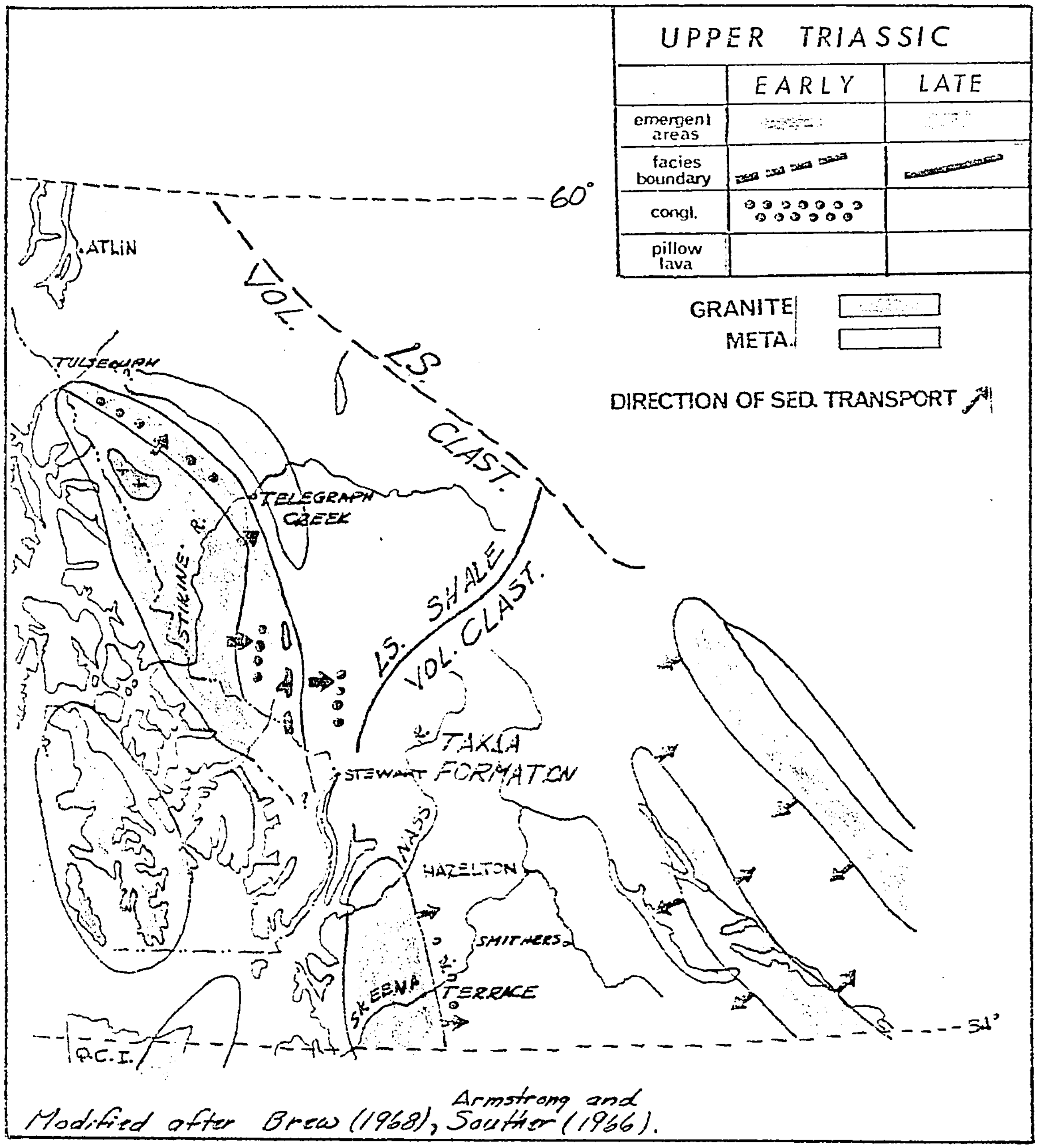


FIG. 12 Paleogeographic map, Upper Triassic, Northwestern British Columbia.

Stuhini Group includes two assemblages of volcanic and volcanic-sedimentary rocks each apparently related to separate loci of volcanism with broad overlaps and many rock types common to both.

At the present time, in view of the very limited detailed information available on the Upper Triassic assemblages in northwestern British Columbia, it is not meaningful to make broad regional correlations. As Tipper has indicated (pers. comm.) the current usage of the term Takla Group follows Armstrong's (1944) definition and will be used until further work allows refinement of the terminology. For the present, the Takla problem remains unresolved but it seems certain that, as a result of the work in progress, Armstrong's Takla Group will be redefined to include only Upper Triassic strata as has been shown, by the writer, in the separation of the Upper Triassic and Lower Jurassic strata in the Stewart Complex.

Jurassic

Hazelton Group

The Hazelton Group in the Stewart Complex includes, in ascending order, the Unuk River Formation, the Betty Creek Formation, the Salmon River Formation, and the Nass Formation (see Table of Formations). The assemblage includes ubiquitous clastic sedimentary units intimately intercalated with volcanic flows, epiclastic volcanic rocks, pyroclastic rocks, and interbedded limestones. The rocks are predominantly andesitic or derived from andesitic flows. The Unuk River Formation is a thick accumulation of thick-bedded epiclastic volcanic conglomerates, sandstones, marine siltstones, pillow lavas, and carbonate lenses. The Unuk River Formation is overlain unconformably by three primarily sedimentary units.

The Betty Creek Formation is a well bedded unit which comprises red and green volcanic breccias, conglomerates, and sandstone, and includes andesitic flows and pillow lavas. It is overlain with general conformity by a thin-bedded, colour striped, marine siltstone and greywacke unit called the Salmon River Formation. The uppermost unit, the Nass Formation, is again a dominantly thin-bedded, colour banded unit much like the Salmon River Formation upon which it rests disconformably. Very generally, the Hazelton Group can be described as a unit which includes a variety of discrete rock strata of differenct aspect, extent and uniformity. The most widespread characteristics, essentially universal to the assemblage, are the general intermediate or andesitic composition of the various units, the commonly fresh nature of the primary rock components, and the clastic texture of the sedimentary members. These features have been obscured in many places within the Stewart Complex by polyphase plutonism, metamorphism, alteration and widespread mineralization.

The Hazelton Group is best exposed at the northern end of the Stewart Complex in the Unuk River and Treaty Creek areas, which are unfortunately inaccessible except by helicopter during rare periods of good weather. No complete exposures of the group are known near Stewart, Alice Arm, or Anyox in the southern part of the complex. In spite of extensive detailed search it also appears that the only definitive and extensive fossil zones are north of Stewart. The Unuk River Formation is of Upper Hettangian, Upper Pliensbachian, and Lower to Middle Toarcian age (early to late Lower Jurassic). The Betty Creek Formation is of middle Bajocian age. The Salmon River Formation is of late middle Bajocian to lower Callovian age. The Nass Formation, within the confines of the Stewart Complex, is of Lower Oxfordian to Upper Kimmeridgian age, but because diagnostic fossil assemblages are lacking may include as young as Albian.

The existing terminology of the Hazelton Group is one of the most confused, complicated, and contentious nomenclature problems in the Western Cordillera. The previous discussion on the "Nomenclature of Mesozoic Rocks, Northwestern British Columbia" covers the broad aspect and development of the Hazelton problem, whereas the following discussion briefly reviews the problem in terms of the Stewart Complex. The writer has also included the historical development of the problem of Hazelton nomenclature in the Stewart Complex in Appendix III.

Detailed mapping by the writer in the Stewart area (Fig. 3) has shown that the Bitter Creek Formation of McConnell, the Nass Formation of Schofield and Hanson, and the Bitter Creek Formation of Hanson (1929) are structural remnants of a formerly extensive unit now called the Salmon River Formation by the writer (Grove, 1973) (see Table 1). Hanson's (1935) concept that all the sedimentary units in the Portland Canal district belonged to a single continuous series, locally divided by volcanic bodies, has been discarded by the writer on the basis of extensive mapping within the Stewart Complex and detailed mapping in the Portland Canal section. Hanson's (1935) view of the Hazelton Group in this area was based on limited field studies and inferred from apparent similarities to Dawson's (1875) Porphyrite Group in north-central British Columbia and Leach's (1910) Hazelton Group. Detailed field work within the Stewart Complex by the writer has shown that the Bowser Group, as designated by Duffell and Souther (1964) includes parts of the units included by the writer with the Unuk River and Betty Creek Formations and most of the Salmon River and Nass Formations. New studies have shown that the Bowser Lake succession, designated as the type Bowser Group section, has a Middle Bajocian age (Frebold and Tipper, 1970, pp. 9-10) and not the Upper Jurassic to Lower Cretaceous age assigned by Duffell and Souther. The term Bowser has also been used in Alaska for a considerable time (U.S. G.S. Bull. 1056-A, 1957, p. 49) for well documented Middle Jurassic sediments. The writer has, therefore, rejected the term Bowser Group as applied by Duffell and Souther (1964) and Souther (1966) as unworkable.

Recent work by the writer, by Tipper (pers. comm.) and in the Smithers area, has indicated that "Hazelton Group" is a viable term that can be applied readily to all or most of the Jurassic rocks of the Bowser Basin. The term Bowser Group, once casually applied to widespread Middle and Upper Jurassic marine rocks and to Cretaceous marine and non-marine rocks in the Bowser Basin, has now been abandoned and these rocks are now re-assigned to the Hazelton and Skeena Groups. The nomenclature problem and misuse of the term Bowser Group was first recognized by the writer as a result of detailed stratigraphic studies in the Stewart map area (Fig. 3). Stratigraphic relationships found in the Stewart map area were subsequently found to hold for the Stewart Complex and recent studies by H.W. Tipper in the Smithers area have confirmed these relationships. As a result of discussion and mutual agreement between geologists of the Geological Survey of Canada and the British Columbia Department of Mines and Petroleum Resources, the term Hazelton Group used in future will be as set out in this thesis.

Unuk River Formation (Map-units 11, 12)

The lower Jurassic Unuk River Formation (Grove, 1973), described here for the first time, is a stratified volcanic-sedimentary sequence. Scattered areas of uppermost Unuk River Formation in the Stewart and Portland Canal districts of the Stewart Complex were mapped in the past by early workers as Bear River Formation or as Hazelton Group (Table 1). As a result of the writer's study of the Lower Jurassic rocks of the Stewart Complex, the Unuk River Formation, as defined here, now supersedes and replaces the previous descriptions and nomenclature. The lithology, age, and structural relations of the formation are now fairly well known, particularly the uppermost part of the sequence. This formation is the oldest of the Hazelton Group and unconformably overlies Triassic and older units. In turn, the Unuk River Formation is overlain by the younger members of the Hazelton Group with angular unconformity.

Within the Stewart Complex the formation is best exposed in the Unuk River area where this formation as well as the Upper Triassic rocks are strongly deformed. The base of the formation has not been identified outside the Unuk River-Treaty Creek area. The type locality for the formation is along the east side of the Unuk River (Fig. 2A). The Unuk River Formation includes diagnostic Hettangian, Upper Pleinsbachian, and Lower to Middle Toarcian fossil assemblages, and spans most of the Lower Jurassic period (Table 2). The formation is a mappable unit throughout the Stewart Complex, distinguished and delimited on the basis of lithologic characteristics.

Table 2. Correlation table for the Jurassic in the Canadian Cordillera

Epoch	Stage	Queen Charlotte & Vancouver Islands		Southern Yukon & B.C. (North of Lat. 54°)	Southern B.C. (South of Lat. 54°)	Unuk River - Salmon River Anyox Area
UPPER JURASSIC	TITHONIAN: Upper Tithonian	unknown		Buchia fischeriana (Yk)	Buchia terebratuloides Buchia fisheriana	?
	TITHONIAN: Portlandian = Lower Volgian		unknown in Queen Charlotte Islands	unknown	Buchia piochii	?
		Buchia blanfordiana B. n.sp. aff.piochii			Buchia blanfordiana Buchia n.sp. aff.piochii	?
		Buchia mosquensis			Buchia mosquensis	?
	TITHONIAN: Upper Kimmeridigian	unknown				
	Middle Kimmeridigian			Buchia mosquensis?		
	Lower Kimmeridigian Upper Oxfordian	Buchia concentrica		Amoeboceras, Buchia concentrica (B.C.)	Buchia concentrica	Amoeboceras Hyatt, Plasmatoceras Buckman, Buchia concentrica
	Lower Oxfordian	Cardioceras		Cardioceras (B.C.)	Cardioceras	?
MIDDLE JURASSIC	Upper Callovian	unknown		?	unknown	Cylindroteuthis, Trigonia Haidaia
	Middle Callovian	Cadoceras (Vanc.Is.)		Lilloettia, Cadoceras (B.C.)	Lilloettia, Cadoceras	
	Lower Callovian	Kepplerites (Q.C.I.)		Paracad-oceras, Kepplerites (B.C.)	Paracad-oceras, Kepplerites	Keraiceras Spath.
	Bathonian Upper Bajocian	unknown		unknown	unknown	?
	Middle Bajocian	Stephanoceras, Teloceras, Stemmatoceras, Zemisteph-anus, Chondroceras on Q.C.I. Volcs on V.Is.		Stephanoceras in Yuk. Stephanoceras, Stemmat-oceras, Zemistephanus, Chondroceras, Sonninia (B.C.)	Stephanoceras, Stemmat-oceras, Zemistephanus, Chondroceras, Sonninia, Graphoceras	Ctenostrean gikshensis McLearn Sonninia, Trigonia, Ostrea Pleuromya
	Lower Bajocian	unknown		unknown	Tmetoceras, Erycites	?
LOWER JURASSIC	Aalenian	?		?	?	?
	Upper Toarcian	?		Grammoceras	Phlyseogrammoceras Grammoceras	?
	Middle Toarcian			Phymatoceras, Peronoceras (B.C.)	?	Haugia
	Lower Toarcian	Harpoceras Dactylioceras (Q.C.I)		Dactylioceras	Harpoceras	Dactylioceras
	Upper Pliensbachian	unknown		? - - - - - - - - - Amaltheus, Paltarpites, Arieticeras, Leptale-oceras	unknown	?
	Lower Pliensbachian	Fanninoceras Tropidoceras, Crucil-obiceras, Acantho-pleuroceras		Prodactylioceras Becheiceras (B.C. Platypleuroceras (B.C.)		
	Upper Sinemurian	Echioceras Asteroceras		unknown	Echioceras Asteroceras	
	Lower Sinemurian	Arniotites		Paracoroniceras, Arniotites	Coroniceras, Arnioceras	Cardinia, Weyla
	Upper Hettangian	unknown		Psiloceras canadense (B.C.)	Psiloceras canadense	Psiloceras canadense, Weyla Pleuromya, Arieticeras
	Lower Hettangian			Psiloceras erugatus (Yk)	Psiloceras aff P. Planorbis	?

Distribution

The distribution of the Unuk River Formation is widespread throughout the Stewart Complex (Fig. 2). The geological maps illustrate the significant strata which comprise the sequence and show the fossil localities. Glacial and ice cover, as well as rugged topography (Fig. 3) limit the areas which can be studied in detail.

Lithology

The Unuk River Formation is represented by thick-bedded epiclastic volcanics and lithic tuffs, and also in part by a close association of extensive pillow lavas, carbonate lenses, and thin-bedded siltstones. The colour of the rocks grades from bright brick red to apple green, and includes greys, mottled purples and maroons. Thin, massive volcanic flows are found as part of the sequence, but are generally limited in individual extent and difficult to trace. Most of the sedimentary rocks are composed of angular clasts which are fairly fresh and exhibit poor sorting. The early workers in the Portland Canal district generally referred to these variously as greenstones, tuffs, porphyries, and volcanic fragmentals.

Lower Member

Because the formation is moderately folded and extensively faulted the writer has subdivided the Unuk River Formation into three members. The lower member is best exposed along the axial zone of the regional dome outlined between Treaty Creek and Jack Glaciers, and east of Twin John Peaks at West McTagg Glacier (Fig. 13). The section immediately west of Treaty Glacier, representing the lowermost exposed

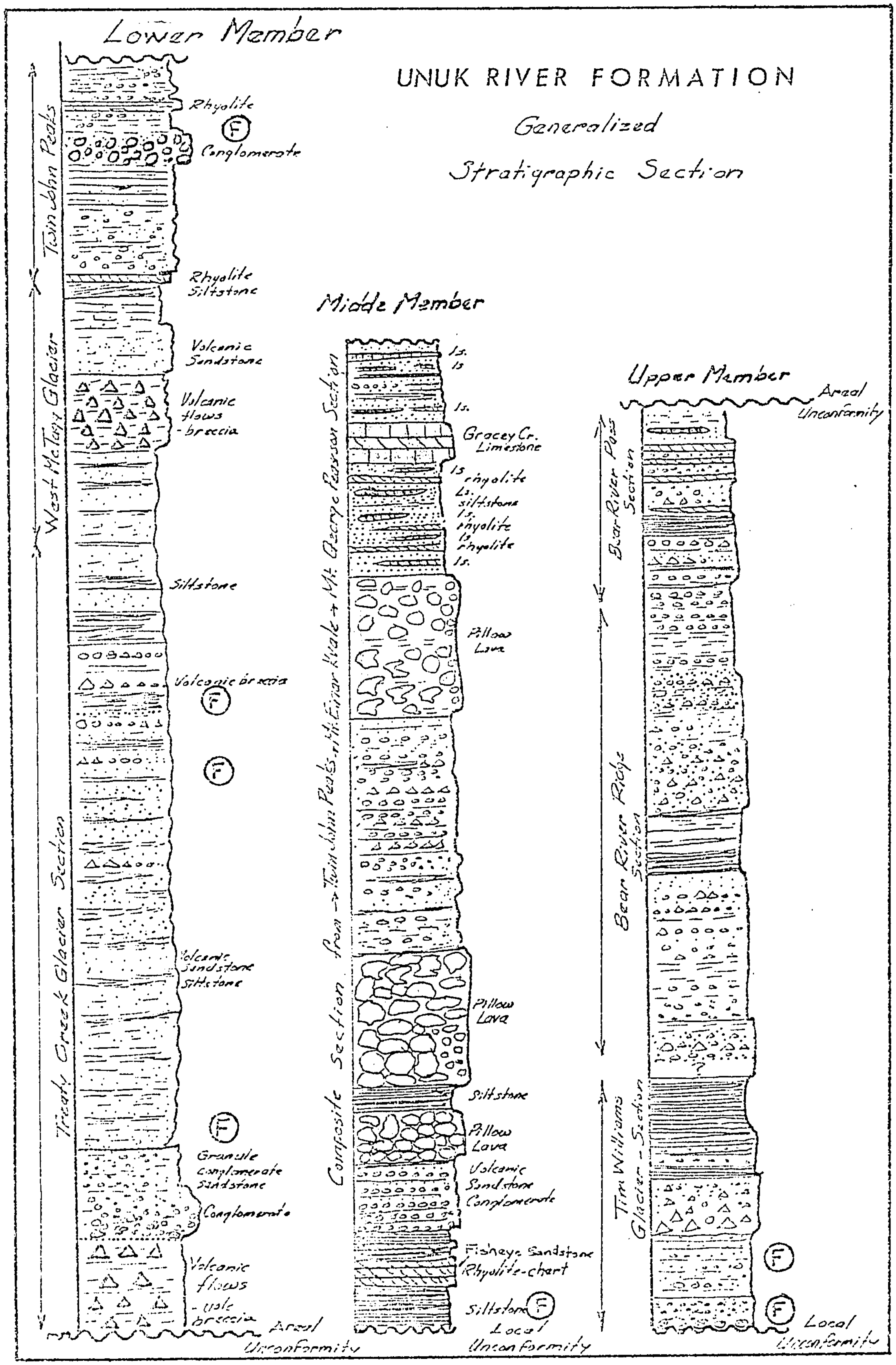


FIG. 13 Stratigraphic column, Lower Jurassic, Unuk River Formation.

part of this member, includes well bedded grey epiclastic volcanic conglomerates, lithic tuffs, and volcanic sandstones intercalated within massive volcanic bressias, porphyritic and andesitic volcanic flows, marked by thin lenses of black argillaceous siltstone and colour banded sandstones. Many of the thin sedimentary units are calcareous and generally include poorly preserved fossil fragments. The volcanic flow rocks are generally pyritic, extensively altered and occasionally marked by malachite stain. The general alteration is probably related to the swarm of northerly to northeasterly syenodiorite dykes that cut through the section.

Towards the northwest, above the thick conglomerate and basal volcanics, the rocks are dominated by alternating, evenly bedded, dark siltstones and grey-green volcanic sandstones with occasional bands of volcanic conglomerate, and thinly striped tuffaceous bands. The rocks have been cut by dykes and are generally indurated, highly fractured, and commonly marked by narrow graphitic faults. The strata exhibit planar bedding, rarely show sedimentary structures and display alternations of inches thick, fine grained dark siltstone bands intercalated with grey-green sandstone, greywacke, and volcanic conglomerate which are generally a few feet to ten feet thick, suggesting a rhythmically deposited sedimentary sequence. Apparent graded bedding in the greywacke units was studied with the aid of thin sections; this type of bedding was found to be related to a variable content of carbonaceous material rather than to grain size gradation. Volcanic conglomerates towards the upper part of this section contain well rounded fossiliferous (bryozoa) limestone boulders up to one foot in diameter, and various round mud concretions, whereas conglomerates in the lower part contained the occasional fragment of biotite-hornblende granodiorite gneiss. At Jack Glacier, the sedimentary rocks are overlain by a thick pyroclastic sequence comprising green andesitic volcanic agglomerate, green, buff and red lithic tuff, and intercalated finely banded volcanic sandstone and siltstone. The agglomerates lens out to both east and southwest and, in both directions, are gradational into volcanic conglomerates, sandstones and siltstones (Plate 7). The agglomerates in turn are overlain by alternating, well banded volcanic sandstones and siltstones which are, in part, gradational easterly into massive thick volcanic breccia and volcanic conglomerate.

To the west, in the direction of Twin John Peaks, at Bruce Glacier, the planar bedded volcanic sandstones, siltstones and volcanic breccias are conformably overlain by a thinly banded graphitic, argillaceous siltstone horizon which has been traced from near the toe of Bruce Glacier, south past the east side of Twin John Peaks into Sulphurets Creek where it is overlain by Middle Jurassic sediments (Fig. 2A). This dark, 150 to 800 foot thick lens is overlain by a thick, uniform blanket of green, poorly stratified, weakly foliated andesitic volcanic conglomerate which has been traced about 16 miles from Storie Creek south across Sulphurets Creek into the Ted Morris Glacier area where the rocks are obscured by the icefield. The uniform volcanic conglomerate is in turn overlain by a thick, well stratified, mainly red lithic tuff zone, in which rare west plunging scour channels occur (Plate 8). This in turn is overlain by a 300 to 500 foot thick,

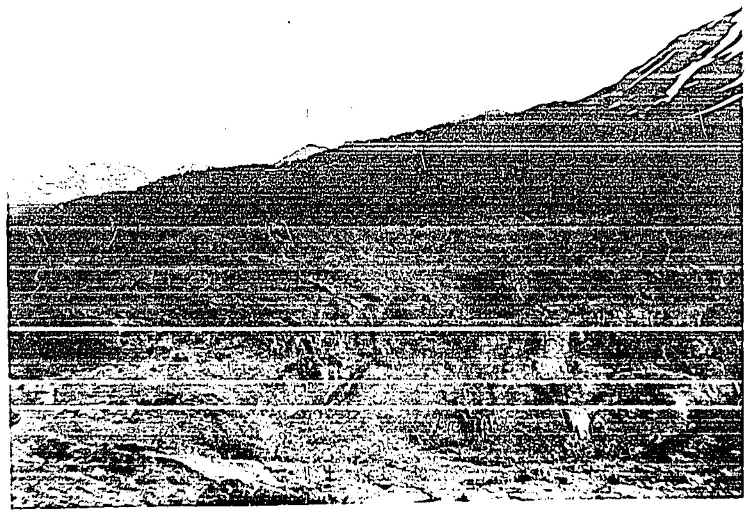


Plate 7. Unuk River strata, Jack Glacier area, looking east.

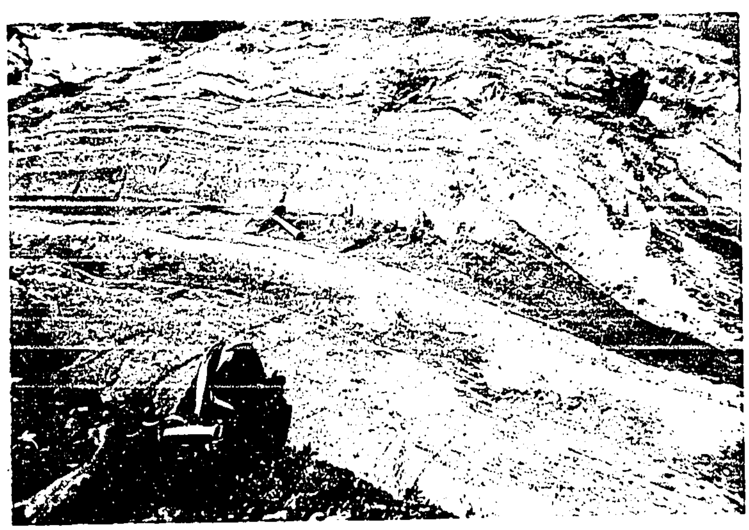


Plate 8. Lithic tuff, Unuk River strata, looking west.

poorly sorted polymictic conglomerate in which cobbles and boulders of well rounded hornblende diorite and basalt are in a red, crudely laminated, pebbly sandstone matrix. This coarse conglomerate has been traced along the east side of Twin John Peaks for a distance of about eight miles. The conglomerate itself has been removed by erosion at both ends, and the overlying, well stratified, green andesitic volcanic conglomerates and intercalated lithic tuffs occur as irregular, partly eroded lenses. West of Twin John Peaks, along the east wall of the Unuk-South Unuk River valley, the lower member is unconformably to disconformably overlain by the fossiliferous members of the middle member of the Unuk River Formation.

The lower member, measured across the northwesterly flank of the major Brucejack Dome, includes a total of about 28,000 feet of volcanics and sediments, cut by swarms of small dykes and minor plutons (Appendix I, Section 3). As indicated in the description of the strata, the individual beds are characterized by a general lenticular nature, with overlapping and transitional relationships within lateral zones suggesting facies sequences and a mackerel structure.

The volcanic flows, principally altered andesitic agglomerates and volcanic breccias within the sequence, are laterally gradational with equivalent andesitic volcanic conglomerates and sandstones suggesting mainly in situ deposition and erosion. The volcanic sandstones, greywackes, lithic wackes and siltstones are immature sediments lacking well defined sedimentary structures such as graded bedding or current cross-bedding. They are best described as lithologically monotonous grey, planar bedded, fine grained deposits which suggest either cyclic sedimentation or interrupted sedimentation. The red and green lithic wacke, lithic tuff and massive greywacke beds in the upper part of this succession are also characterized by moderate lateral extent and planar bedding. There is, however, a noticeable amount of clastic basalt and augite clasts in the upper red and green assemblage along with minor thin flows of moderately altered augite basalt. The volcanic conglomerates and other conglomerates in the upper section also contain many pebbles and cobbles of augite basalt indicating local extrusion and rapid erosion and burial. The boulder conglomerate overlying the red and green tuffs and conglomerates, contains abundant fresh hornblende diorite, augite basalt, andesite, chert, and quartz as pebbles, cobbles and boulders in a brick red matrix, indicating closely related deposition and erosion, partly channelled along the broad depression they now occupy.

Provenance

The general close association and the rapid lateral facies changes of the volcanic and volcaniclastic units essentially demonstrate the close genetic relationship between the volcanic flows, volcanic breccias, conglomerates, immature sandstones and tuff units. The limestone boulders in the conglomerate zone have been derived from a Permian source to the west, as have the gneiss fragments localized in the lower conglomeratic units (Fig. 14). Extensive thinly banded rhyolite and associated chert in the upper part of this sequence near Twin John Peaks suggests widespread acid volcanism within the sequence

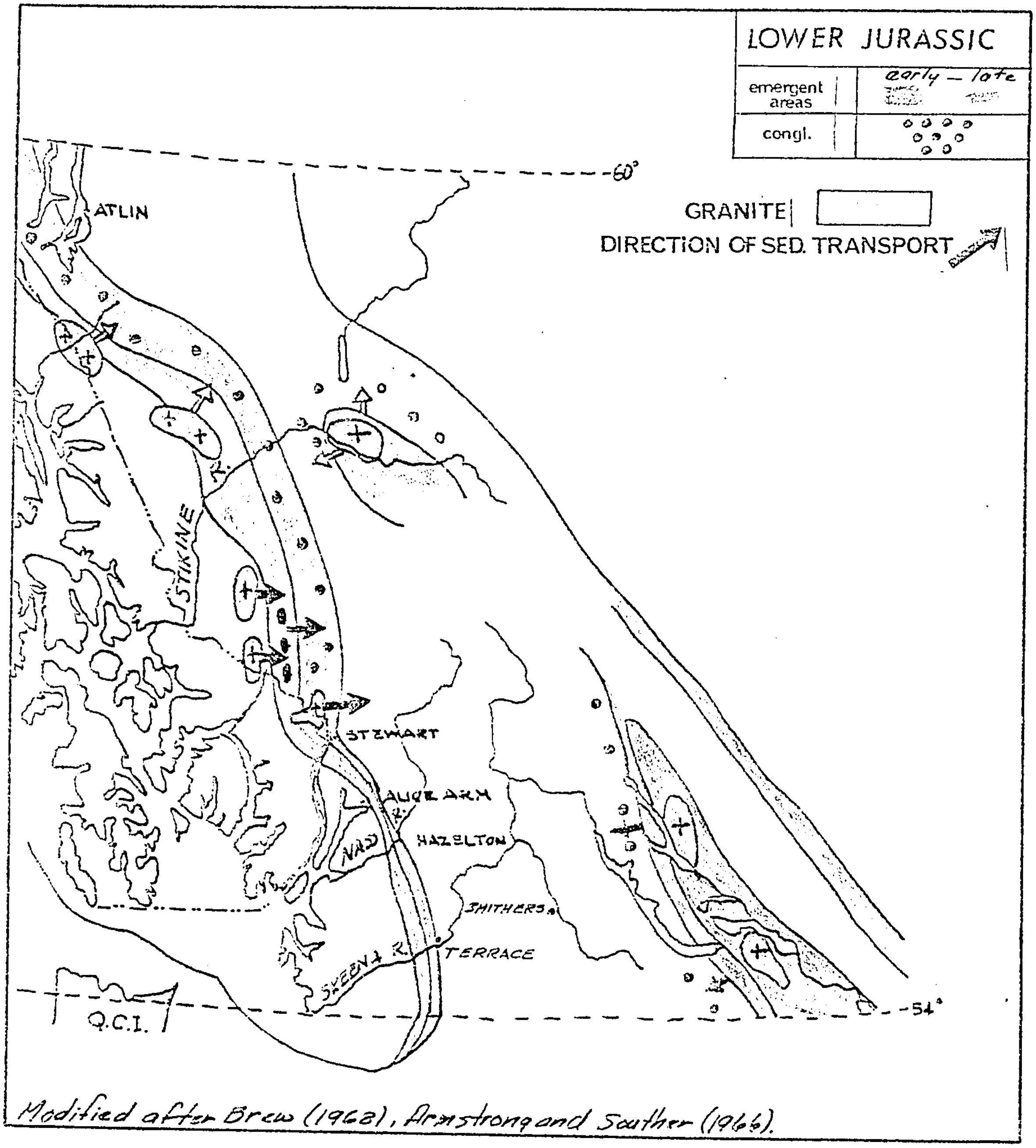


FIG. 14 Paleogeographic map, Lower Jurassic, Northwestern British Columbia.

during a local change from marine to volcaniclastic deposition. The red boulder conglomerate at the top of this succession includes cobbles of hornblende diorite similar to Late Triassic rocks exposed only eight miles to the southwest along McQuillan Ridge.

Depositional Environment

The apparently tabular, altered andesitic units forming the lower part of this member are thought to represent simple volcanic flows rather than sills. The dominance of the alternating planar sedimentary units in the succession display a strongly developed hydrodynamic control. Beds in Flysch sequences, consisting of alternating fine sand to silt and shale units, are commonly bounded with parallel surfaces. But planar strata are not restricted to flysch units and many types have been described. Field and flume studies (Simons and others, 1965) have shown that planar beds are known to be characteristic of both the upper and lower flow regimes. The presence of the armoured mud balls in the conglomerates is the main evidence at hand to suggest these beds were deposited in shallow marine conditions (Bell, 1940; Hawkes, 1962). The few sedimentary structures mentioned, suggest that the members of this succession were eroded from a rapidly uplifted andesitic highland. Extrusion, fragmentation, and local erosion were part of the overall process which shed vast quantities of volcanic debris into a shallow marine environment. Ammonites, pelecypods, and other fossils identified in the lower member of the Unuk River Formation have been interpreted by Danner (pers. comm.) as representative of a near shore, mainly neritic environment.

Age

Rocks of the lower member of the Unuk River Formation contain an abundance of poorly preserved fossils (Appendix II). The collections have been examined by Professor W.R. Danner of the University of British Columbia who kindly made tentative identification and assessed their environment, and by Dr. H. Frebold of the Geological Survey of Canada, who examined the collections in detail. The dateable collections apparently represent a Hettangian fauna, characterized by the presence of *Psiloceras canadense* Frebold and *Weyla* sp.

Along the crest of Twin John Peaks the lower member is unconformably overlain by the middle member of the formation, although along strike the relationship rapidly changes to a simple disconformity at the extreme south limit of the red conglomerates. Farther south the middle and lower members are conformable.

In the Storie Creek section the lower member is overlain by a canoe-shaped trough of the early Bajocian Betty Creek Formation and elsewhere by thin slabs of Betty Creek and blanket-like Salmon River Formation.

Middle Member

The middle member of the Unuk River Formation is exposed in the folded, deformed section between Shirley Mountain, near Tom McKay Lake, and Mount George Pearson. The succession presented in this thesis is a composite section compiled from the Twin John Peaks-Mount Madge and Mount Einar Kvale-Mount George Pearson geological sections. Portions of the distinctive basal Twin John Peaks strata have been mapped east of Mount George Pearson where scattered nunataks are exposed, indicating the extensive lateral continuity of the units and providing stratigraphic control.

The channelled, eroded conglomerates at the top of the lower member are overlain by extensive carbonaceous, thinly banded, black to buff siltstones traced from Bruce Glacier south past Twin John Peaks into the icefield at Unuk Finger Mountain. The unit contains abundant moderately preserved fossils including huge specimens of Weyla sp., as well as Arieticeras sp. indet., suggesting an Upper Pliensbachian age (Appendix II). Features used in determination of tops in this section included channel scouring and the presence of intraformational conglomerates, as well as apparent normal graded bedding. The siltstone and underlying conglomerates have been intruded by the Twin John Peaks hornblende diorite plug and show weak induration and foliation along contact margins. The siltstone is immediately overlain by bright green volcanic tuffs, comparable to those in the lower member (Plate 8), and are gradational into a thick epiclastic volcanic conglomerate, sandstone unit which includes a 500 foot thick spherulitic rhyolite-chert member, here named the Fisheye Sandstone (Plate 9). This spherulitic zone is best developed north of Twin John Peaks where it is laterally gradational with rhyolite breccia and finely banded rhyolite. The massive rhyolite breccia extends south past Twin John Peaks into the Sulphurets Creek section. Equivalent spherulitic rhyolite-chert sandstones have also been mapped in the icefield east of Mount George Pearson. Comparable rhyolite units have been described by Sutherland Brown (1968) as part of the

Kootenay facies of the early Tertiary Masset Formation of Queen Charlotte Islands and by Buddington and Chapin (1929) in southeastern Alaska. In thin section, the well banded glassy white rhyolites and rhyolite breccias are seen to be extensively altered to an irregular inhomogenous sericite-carbonate matrix in which rare lath-like unzoned plagioclase (An_{20-25}) and rounded clear quartz phenocrysts have been preserved. Rock fragments, chert, and minor pyrite are recognizable, but all primary structures or textures appear to have been completely obliterated by alteration and minor deformation. The glassy nature of the hand specimens is not preserved in thin section, and the fine banding so well displayed in the outcrops is related to microscopic ribbons of recrystallized quartz occurring in _en échelon_ streaks through the felted matrix. The spherulitic Fisheye sandstones north of Twin John Peaks are only slightly altered and deformed. The eyes in the rock occur either as separate, slightly flattened ovoids marked by lenticular central cavities, and by colourless grey chert fillings, or as necklace-like aggregates enmeshed in a sandy, banded feldsphathic matrix (Plate 10). In thin section the glassy eyes comprise an outer zone of closely packed beaded quartz, one to several cm thick with variable fillings of plumose chalcedonic quartz. The weakly foliated matrix in the rock is slightly altered, recrystallized sodic plagioclase.

The eyes in this rhyolitic unit constitute a geopetal and indicate that the ovoids and the cherty filling formed while the main unit was horizontal. The unit has been dated by fossils as probably Pliensbachian. It is unconformably overlain by early Bajocian

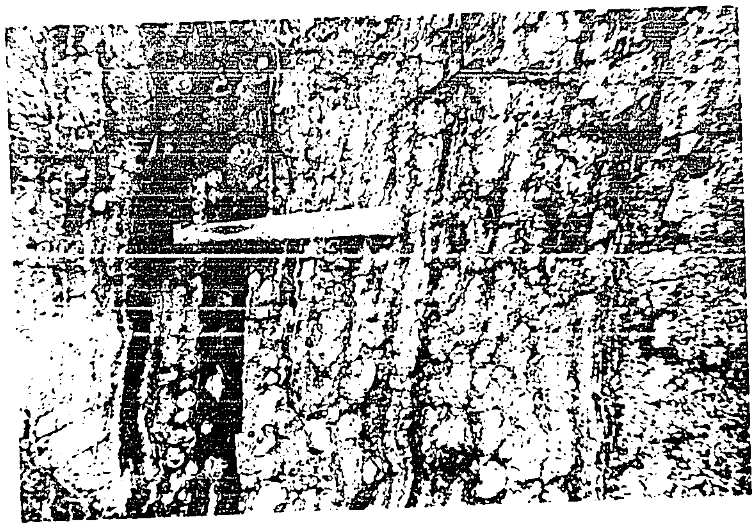


Plate 9. Spherulitic (Fisheye) sandstone, Unuk River strata, Twin John Peaks area.

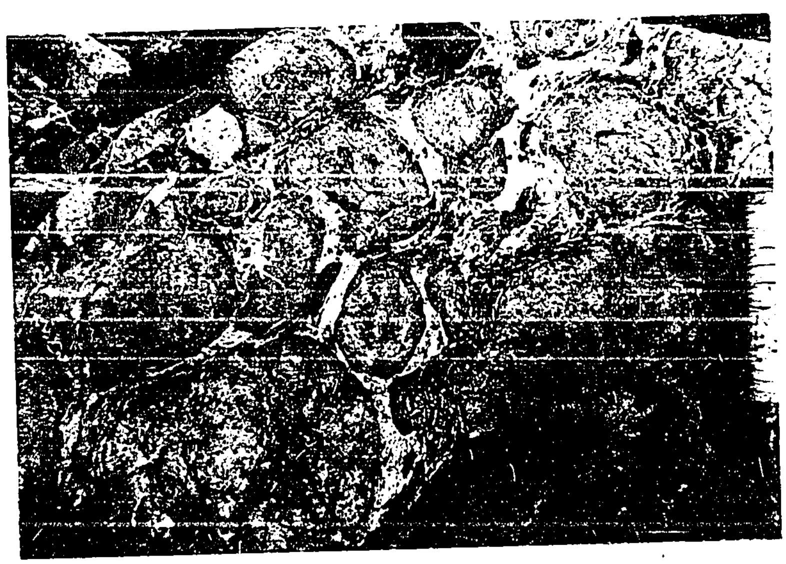


Plate 10. Pillow lava, limestone matrix, Unuk River strata.

sediments thereby indicating that the folding of the Unuk River Formation was during Toarcian to Aalenian time. Towards the Lee Brant pluton, the alteration and deformation in the rhyolite section increases. Alteration and deformation of this unit is complex and can be related to pre-Middle Jurassic basic intrusion at Twin John Peaks, pre-Bajocian regional folding, and Tertiary plutonism. In addition, the degree of dynamic metamorphism increases towards the South Unuk cataclasite zone.

The thick, chert-rhyolite horizon is overlain by a thinly striped, indurated, foliated carbonaceous siltstone, which in turn is disconformably overlain by a generally featureless massive green volcanic conglomerate, generally marked by induration and deformation related to the various intrusions. This more or less continuous sedimentary succession is overlain directly by a sequence of thick, extensive pillow volcanics shown on the geological maps (Figs. 2A and 2B) as extending from Granduc Mountain to Twin John Peaks. The pillow volcanics occur as essentially discrete lenses within the green conglomerate sequence and near Twin John Peaks they are, in part, intercalated in an extensive siltstone horizon. The pillow lavas have been traced as discrete lenses up to six miles long and from about 800 to 6,000 feet thick. Although essentially massive, the pillow volcanics include thinly laminated cherty lenticles, minor siltstone lenses and some limestone. The sedimentary structures in the enclosing volcaniclastics and in the minor sedimentary lenses within the pillow bands indicate that the succession is upright with tops facing west. Viewed from the air, the pillow bands exhibit a monotonous dull green, uniform mosaic, largely uninterrupted by intrusives.

The pillow bands which form such a conspicuous part of the middle Unuk River Formation are very similar in structure and composition throughout their extent. The individual pillows are tightly packed, typically ellipsoidal, bolster-shaped and bun-shaped, and average three to four feet in diameter. Each pillow is rimmed by a narrow, chilled rind or margin, with the interstices of the pillows occasionally filled by vuggy coarse grained quartz-epidote segregations. The pillows are crudely jointed, although a weak radial pattern appears to dominate, but more typically the pillow margin is marked by closely spaced concentric layers comparable to an onion. The pillows are all highly vesicular and the vesicles or amygdules have generally coalesced, but individually are usually about 2 mm in diameter. In thin section even the freshest looking material is completely devitrified and altered to felted masses of cryptocrystalline amphibole, plagioclase, quartz, and epidote. It was not possible to determine the original mineralogical composition of the pillow volcanics optically and the extensive alteration precluded useful chemical analyses, but similarities in preserved textures and mineral remnants to local flows suggest an andesitic composition. As an assemblage, these pillow masses are characterized by coarse abundant vesicles and amygdules, concentric onion skin joints, weakly developed radial joints, and extensive alteration which in many individual pillows is concentrated in the core.

The northern edges of the zone of pillow lenses, west of Twin John Peaks, have a fine grained dense grey limestone matrix (Plate 10).

The pillows in the margins of the flows, which are from one foot to two feet in diameter, are considerably smaller than the individuals at Mount Madge and display well developed glassy, concentrically layered margins in part veined by the limestone matrix. These small pillows are mainly globular, amydaloidal, and highly altered and, using Carlisle's terminology (1961), they are called isolated pillows, and the bulk of the units consist of close-packed pillows.

The massive pillow lava bands along the South Unuk River appear to be conformable within the mainly andesitic volcanic conglomerate and graphitic siltstone sequence. This sequence also includes thinly banded, deformed rhyolite lenses, thin recrystallized grey limestone bands, one to four feet thick quartzite lenses, and thin bedded quartz pebble conglomerates. As indicated on the geological maps and in the stratigraphic section (Appendix I) the succession overlying the pillow lava zone includes a thick assemblage of thinly layered, discontinuous, sedimentary lenses. This assemblage includes a variety of green to brown andesitic lithic and crystal tuffs, volcanic sandstone, banded chert and rhyolite, quartzite, volcanic conglomerate and a multitude of limestone lenses of various sizes. The largest limestone unit, the Gracey Creek lens, forms a 600 foot thick band traceable from Sawyer Glacier north to Lee Brant Creek, but it, as well as most of this sequence, lies within the South Unuk cataclasite zone. Like most of the limestone lenses it exhibits some local folding, boudinage, and general recrystallization. Some of the white and blue-grey limestone lenses at the margin of the cataclasite zone exhibit thin marginal zones, partly or largely composed of fine grained blue-grey gypsum plates where they are intercalated with carbonaceous siltstone and greywacke units. In general, the Gracey Creek and other limestone bands in the section are typically recrystallized and characterized by a white-buff to blue-grey mottling so typical of the Quatsino limestone on Vancouver Island (pers. obs.). Partial chemical analyses of the limestones from this section show that, in general, they contain less than one per cent MgO and very little iron.

The main characteristic of the middle member is the abundance of pillow lavas and limestone, which comprise 20 to 30 per cent of the section, as well as the diversity of the sediments. Rhyolite, chert, quartzite, volcanic tuff, siltstone, conglomerate, and thin, altered, andesitic volcanic flows are prominent rocks in the succession. The rocks are generally grey or green in colour and have been moderately altered and deformed. Small plutons as well as numerous dykes cut the succession adding to the generally disturbed character.

Provenance

The similarity of the basal sedimentary and volcanic rocks in this member to the upper part of the lower member suggests a continuity of periodic andesitic and basaltic volcanism with associated rapid erosion and local deposition. The sequence is mainly sedimentary with locally intercalated, shallow, submarine pillow lava, overlain by rhyolite flows, chert horizons, thin-bedded quartzites, limestones, and volcaniclastics.

Depositional Environment

Pillow lavas are generally accepted as having been extruded under submarine conditions and Moore (1965) suggested that the vesicularity and bulk density of pillow lavas show a systematic change with depth. Jones (1969) pursued the use of pillow lavas as depth indicators in Iceland and outlined two classes, one of which showed a systematic vertical variation in vesicularity and vesicle size which he related to inferred water depth at time of eruption and emplacement. The average vesicle diameter measured in Unuk River pillow lavas is about 2 mm, which from the combined Moore-Jones plot of vesicular diameter against inferred depth (Jones, op.cit., p. 188), indicates a depth of submarine emplacement of about 300 meters.

It is suggested that the gradation in size from the large bolster type, close-packed pillow at Mount Madge to the small globular isolated pillows near Twin John Peaks along the northerly margin of the flows, indicates the paleoslope down which the pillows rolled, and were dumped into muddy, marl deposits. The rhyolites, rhyolite breccias, and spherulitic rhyolite zones are gradational and intercalated with tuffaceous units, and were deposited following deposition of the shallow water red and green strata. In sharp contrast to the red colour dominating the top of the lower member, the middle member units are mainly grey and green. Feldspathic sandstones and quartzites are intercalated with thin rhyolites, gypsiferous limestones, carbonaceous siltstones and shales. The detailed lithological relationships are not clear because of alteration and cataclastic deformation. The carbonaceous shales, siltstones and volcanic sandstones associated with limestone lenses may indicate, as Weeks (1957) suggested, that decomposition of organic matter in a local environment may have raised the pH sufficient to have caused the precipitation of limestone. The close association of rhyolite volcanism with these units may have aided the precipitation of the carbonate which was also accompanied by sulphate deposition, now partly represented by gypsum. The quartz pebble conglomerates and sandstones with the limestone and rhyolite suggests mature reworked deposits, possibly beach deposits, similar to reworked deposits such as Shepard (1960) described for the Mississippi Delta. The evidence suggests protected lagoonal or coastal barrier conditions near a volcanic highland intermittently supplying volcanic flows and volcaniclastics. This condition would require an essentially quiet, or steady state, littoral environment marked by periodic marine incursions. The concentration and accumulation of the thick mixed sequence implies a crudely balanced rhythmic process.

Age

The basal section of the middle Unuk River Formation includes a moderately well defined Pliensbachian fossil assemblage (Appendix II) and is directly overlain in the Tom McKay Lake section by early Bajocian sediments. The relation to Toarcian members of the succession is poorly defined because of faulting, cataclastic deformation, and erosion along the western limit of the thesis area, and by the icefield southeast of the Treaty Glacier Section.

Upper Member

The upper member of the Lower Jurassic Unuk River Formation has been separated from the middle and lower members on the basis of structural relationships and limited paleontological evidence. The upper member has the most extensive distribution of the three members and occurs west of Harrymel Creek between the Unuk and Iskut Rivers (shown on Map 9-1957 as mainly Upper Jurassic-Lower Cretaceous and Triassic sediments and granodiorite). Another area is inferred to occur, on the basis of structural relationships, west of the Treaty Glacier section at Tim Williams Glacier, shown on Map 9-1957 to consist of Late Jurassic-Cretaceous sediments. Abundant, moderately well preserved, thin shelled pelecypods and the ammonite Dactylioceras sp., collected from the Tim Williams Glacier area and specimens of Hildocerataceae from the Snippaker Creek area, provided paleontological evidence that supports the writer's structural interpretation. The correlation between the Tim Williams Glacier section, the Bowser River, Bear River Ridge and Bear River Pass areas is based on structural and lithological relationships. The strata throughout this general area are similar in aspect and have not been as extensively deformed as at the Snippaker Creek area.

The Tim Williams section includes a fossiliferous basal conglomerate intercalated with argillitic siltstones and overlain by a quartzose sandstone conglomerate with minor lithic and crystal tuff bands. The fossiliferous polymictic conglomerate consists of poorly sorted granodiorite, andesite, and basalt pebbles embedded in crudely layered, blocky, dark grey greywacke forming beds and lenses from one to ten feet thick. The measured thickness of this partly exposed unit is about 400 feet along the margin of the west fork of the glacier.

The pebble conglomerate grades rapidly into gently dipping grey-green greywacke and quartz granule conglomerate which also contains abundant fossil fragments. This bed is conformably overlain by intercalated massive green volcanic breccia and agglomerate, mostly comprised of amygdaloidal and porphyritic andesitic fragments, thinly banded lithic and lapili tuffs, grey-green volcanic sandstone and thinly bedded shale (Fig. 13).

The Bear River Ridge section has been mapped in detail (Fig. 3) and although it has not been represented as part of the type Unuk River Formation, it will be described here to facilitate the description and understanding of the upper member. The rocks comprising the Bear River Ridge section have been referred to in the old reports of McConnell (1913), Schofield and Hanson (1922), Westgate (1922), Hanson (1929), Buddington (1929), and Hanson (1935), as a thick sequence of shallow, west dipping greenstone, agglomerate, tuff, and/or breccia forming part of the Bear River Formation or the Hazelton Group of unknown but probable Jurassic age (see Table 1). The internal structural relationships of the various units forming this sequence were not described by any of the early workers, and they all generally failed to recognize the extensive cataclasite zones that affect the sequence in both the Salmon River and Bear River areas. The early workers apparently made no attempt to join the geology on opposing sides of the ridge and, as a result, they failed to recognize the Betty Creek Formation which provides such a useful marker horizon throughout the Stewart Complex. The relationships of the upper Unuk River Formation and younger rocks generally have been ignored or completely misunderstood.

At Bear River Ridge (Fig. 3) the upper Unuk River is dominated by green coloured, interfingering clastic sedimentary units of predominantly volcanic origin. Siltstones and lithic greywackes are intercalated with coarsely layered volcanic clastic rocks. The siltstones and greywackes provide local markers as well as significant structural evidence. The volcanic conglomerates, breccias, and sandstones have been differentiated by such macroscopic features as grain size and texture, as well as structural contacts, but the fine grained tuffs and similar cataclasites required microscopic study in order to clarify and discriminate the various rock types.

Distribution

The geological map shows that the upper Unuk River Formation extends over most of the area, forming the steep valley walls. The upper stratigraphic limits are accurately recognized where the formation is overlain with apparent angular unconformity by the younger sedimentary and volcanic rocks.

Lithology

It is apparent that the majority of the country rocks in Salmon River district, originally termed the Bear River volcanics, have been affected by dynamic metamorphism and are mainly cataclasites. In general, sufficient primary structures and textures are preserved to allow the sedimentary character of these rocks to be identified. The least altered and deformed strata lie east of Cascade Creek on the upper slopes of Bear River Ridge where they are partly overlain unconformably by Salmon River Formation sediments. Metamorphic equivalents of this unit are described in the chapter on structural geology.

Colour, grain size and texture have been the principal parameters used in this study to define the lens-like units outlined on the geologic map (Fig. 3). With rare exception all the undeformed Unuk River rocks in the Stewart district exhibit a clastic or fragmental texture and are poorly sorted. All the strata of the local Hazelton Group rocks represent detrital, mostly non-marine materials, rapidly transported in an aqueous medium and accumulated under the influence of gravity. With minor exceptions, the fragments and matrix are composed of relatively uniform porphyritic andesitic rocks, angular quartz and plagioclase. The individual lenses shown in Figure 3 are distinguished by predominant particle size and colour, but few are completely homongeneous. Breccias, for example, include thin, fine grained units and commonly grade laterally into conglomerate and sandstone with intercalated siltstone lenses.

Fairly typical volcanic breccias are illustrated in the Mount Dillworth and Premier areas (Plates 11 and 12). In these two examples, the first represents a purple breccia in which porphyritic purplish cobble and boulder sized fragments occur in a reddish-purple sandstone matrix which forms less than 40 per cent of the rock. In the second type, which marks the other extreme, green angular boulders up to 3 feet long occur in a green sandstone, conglomerate matrix. All variations exist between these two extremes. Significantly, these coarse members, which have undergone only slight cataclasis, stand up as cliffs and form the backbone of Bear River and other ridges.

Volcanic conglomerates and sandstones are present as minor

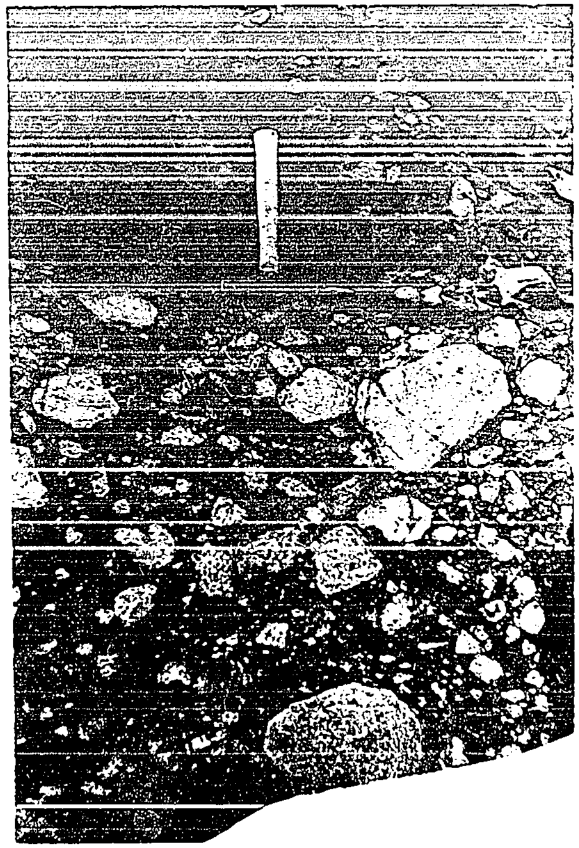


Plate 11. Volcanic breccia, Unuk River strata, Mount Dillworth area.

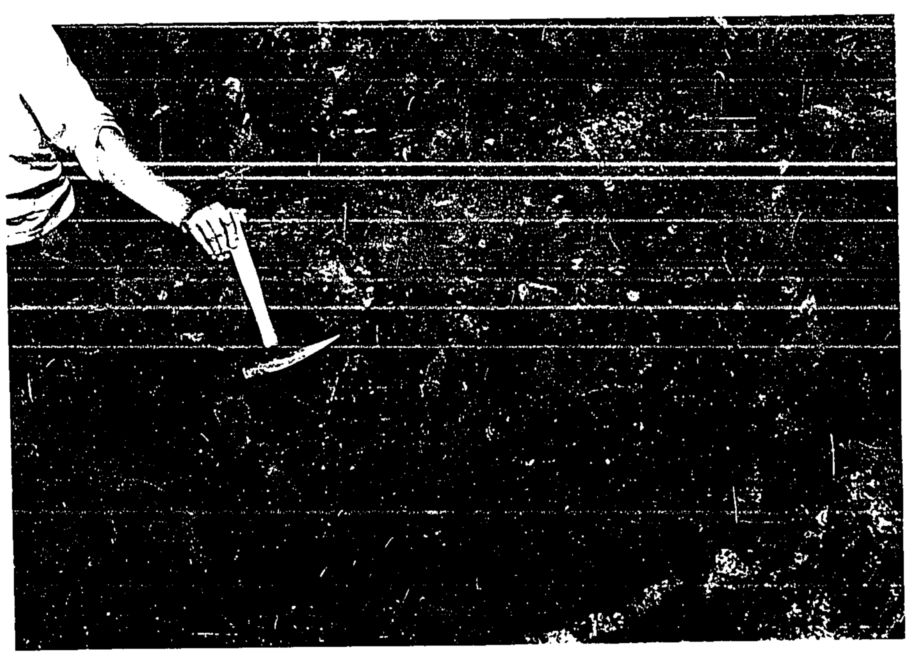


Plate 12. Volcanic breccia, Unuk River strata, Premier area.

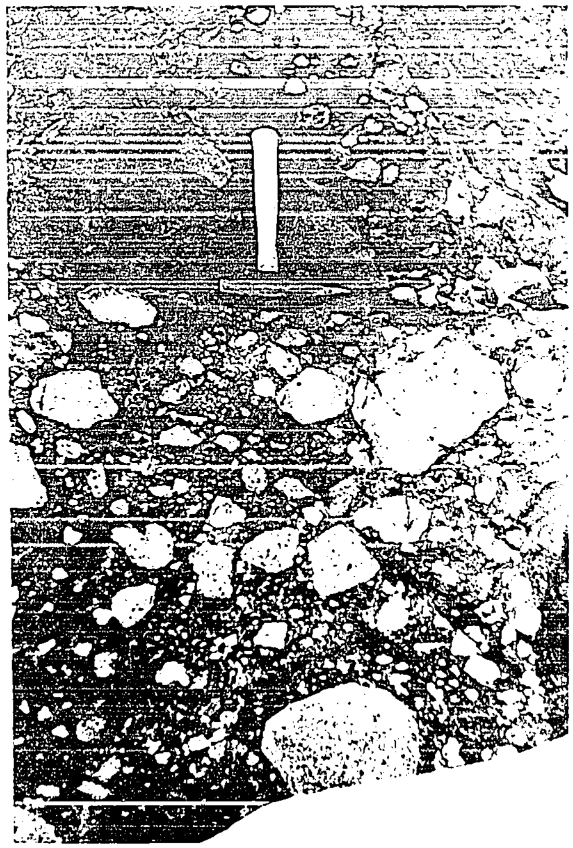


Plate 11. Volcanic breccia, Unuk River strata, Mount Dillworth area.

Plate 12. Volcanic breccia, Unuk River strata, Premier area.

lenses intercalated within the breccias (Fig. 3, Map Unit H4) as well as mappable units. Sandstones and conglomerates in the Salmon River area are prominent along Summit Lake, where they are found as thick green massive units intercalated with scattered thin siltstones, sandstones, and rarely, lenticular green pebble conglomerates.

Volcanic sandstone and tuff are ubiquitous throughout most of the upper member, occurring as thin-bedded, well laminated strata. All the sandstones are relatively thin-bedded, greenish strata, exhibiting angular clastic grains and poor sorting. Red sandstones are present as distinct lenses within green sandstone-conglomerate assemblages but are most prominent as intercalations in massive breccias. The major red beds are noted on the geologic map (Fig. 3).

Many of the volcanic sandstones and conglomerates of the upper member exhibit prominent angular plagioclase and hornblende clasts which, in indurated members, give the rocks a pronounced porphyritic appearance. Hornblende clasts, which are ubiquitous in the green sandstones and conglomerates, have not yet been seen in the red beds. Sphene and apatite are common accessory minerals in almost all the sandstones. Some of these sandstones may, in part, be classified as lithic or crystal tuffs. Field differentiation of the thin-bedded or laminated silty sandstones is generally difficult and requires microscopic study; in fact, most of the distinguishing textures of the fine grained epiclastics and various cataclasites are discernible only in thin sections.

Relatively few significant differences exist between epiclastic volcanics in the Bear River and those in the Salmon River Valley. On the geologic maps the writer has attempted to illustrate the lenticular nature of the individual epiclastic lenses on the east side of Bear River Ridge and to show their relationships to rock units in the Salmon River Valley. Overlying Bowser sediments and snow have, in part, obscured the Hazelton rocks, but there is sufficient continuity to show that the Bear River and the Salmon River Valley sequences are all part of the same assemblage.

Microscopic studies of volcanic epiclastics in the Salmon River district have revealed a fairly uniform texture and composition of the rock and mineral fragments. Most of the rock clasts are fine grained porphyritic andesite in which plagioclase is ubiquitous as lath-like phenocrysts. Quartz, plagioclase feldspar, hornblende are typical mineral clasts. Only quartz, present in small amounts, is rounded. Hornblende, although common as angular clasts, is generally altered to chlorite in pseudomorphs which are difficult to distinguish from augite. Plagioclase is common to all the rocks in the Hazelton epiclastics, it has a relatively uniform composition, as various optical determinations indicate only a range of An_{27} to An_{35} with the average $An_{32 \pm 2}$. This composition suggests an andesitic origin. Unlike plagioclases in the local igneous rocks, the volcanically derived plagioclase in the epiclastics exhibit normal but not cyclic zoning. Othoclase and microcline clasts are rare in most of these rocks, but accessory zircon, apatite, and iron oxide are common. In some of the volcaniclastics the red and purple colour has been related to the state of oxidation during deposition. Iron hydroxides are present in varying amounts in all the purple, red and green epiclastic members. Although the exact proportion of iron oxide has not been determined chemically, some red sandstone samples contain up to about 40 per cent by volume.

Most of the epiclastics are relatively unaltered. Minor sericite, chlorite, and carbonate alteration is essentially universal in the rock and mineral clasts forming the matrix.

In the Bear River Pass area (Fig. 2B) the sequence includes pyritic, propylitized, deformed, thick, fine grained amygdaloidal andesitic volcanic flows irregularly intercalated with argillaceous siltstones. Near the top of the volcanic sequence, the thick flows are followed by thin lenticular rhyolite, rhyodacite and dacite flows intercalated within a thinly layered siltstone and greywacke sequence which is disconformably overlain by the Betty Creek strata (Fig. 13).

Provenance

Detailed mapping of the Stewart area has shown that the upper member of the Unuk River Formation is dominated by volcaniclastic units with lesser volcanic pyroclastics and flows, and minor fine grained marine sediments. At the Bear River Ridge, the various epiclastic volcanic units have been traced sequentially from volcanic breccias to conglomerate sandstone and siltstone along strike. The detailed evidence suggests that andesitic volcanism marked by extensive thick, volcanic breccias was concentrated immediately east of Bear River Ridge.

Less extensive, thin volcanic flow sequences were recognized in the Tim Williams Glacier, Snippaker Creek and Anyox areas. Most of the volcaniclastic debris in the upper member can be directly related to a northerly trending extrusive belt extending along Bear River Valley towards Tim Williams Glacier. The southerly extension of the zone passes through the Georgie River and Anyox pendants where andesitic extrusions were apparently less extensive. Granodiorite pebbles in the basal conglomerate at Tim Williams Glacier suggests regional uplift and unroofing of the Coast Geanticline prior to andesitic extrusive activity. This belt of volcanism roughly coincides with the later axis of regional doming, although the centre of activity appears to have shifted to the south as compared to the previous early Lower Jurassic volcanism.

Depositional Environment

Sedimentary structures in the volcaniclastic rocks which form the bulk of the upper member are mainly simple planar bedding, rare current cross-bedding, and the occasional mud ball horizon in fine grained units. The presence of metamorphosed coal intercalated through the epiclastic material, the extensive thick red beds in the upper section, and rhyolite flows suggests shallow brackish to marine conditions intimately associated with a linear shield-like volcanic highland.

Age

The lowermost part of the upper member of the Unuk River Formation contains abundant fossils that include the lower Toarcian ammonite Dactylioceras sp. and poorly preserved Hildocerataceae, as well as various intermediate thin-shelled pelecypods. The Unuk River Formation is unconformably to disconformably overlain by the early Bajocian Betty Creek Formation, marking the upper limit of local Lower Jurassic sedimentation and volcanism. The apparent lack of Aalenian fauna in the Stewart Complex as well as the relationship to the younger Betty Creek suggests non-deposition between the Lower and Middle Jurassic epochs. Frebold and Tipper (1970) have not recorded the presence of Aalenian fossils in the Canadian Cordillera, but suggested (op. cit., p. 16) that uplift and erosion, among many explanations, could account for the apparent absence of the late Lower Jurassic beds (Table 2).

Discussion

The Lower Jurassic Unuk River Formation includes a thick succession of volcanic, volcaniclastic, and sedimentary rocks that range in age from Hettangian, through Sinemurian and Pliensbachian to Toarcian. It appears from the evidence presented by the writer, and the information provided by Frebold and Tipper (op. cit) that the Unuk River Formation, at present, represents the most complete Lower Jurassic section known in the Western Cordillera. The Hettangian lower member of the Unuk River Formation is the only well defined sequence in the Canadian Cordillera that includes volcanics (Fig. 13). All other known Hettangian sections are entirely sedimentary (Frebold and Tipper, op. cit., p. 9). No diagnostic Sinemurian fauna have yet been discovered in the Unuk River Formation,but the presence of poorly preserved Weyla sp.? in the upper part of the lower member implies such a zone. Upper Pliensbachian strata, characterized by the presence of the diagnostic ammonite

Arieticeras sp. indet., are found in the lower part of the middle member of the Unuk River Formation west of Twin John Peaks. The Toarcian has been recognized at Treaty Glacier and is characterized by the diagnostic Dactylioceras (Frebold and Tipper, op. cit., p. 6), and by poorly preserved specimens of Hildocerataceae.

The evidence presented by the writer indicates that the Lower Jurassic of the Stewart Complex, in part represented by a great thickness and variety of volcanics, was in contrast to the rest of the Western Cordillera, an area of relative stability (Frebold and Tipper, op. cit., p. 18). It follows that the successor Bowser Basin, which the writer has suggested was initiated at the close of Late Triassic, received a significant supply of detritus thoughout most of the Lower Jurassic epoch from the extensive volcanic highland situated along the Coast Geanticline (Figs. 9 and 14).

The fact that the Lower Jurassic strata in the Stewart Complex represent an epoch of unusual stability may help to explain the presence of the Granduc massive copper sulphide deposit which occurs at Granduc Mountain within a deformed part of the Pliensbachian Unuk River Formation. The writer has discussed this ore deposit in Chapter 5 and has concluded that the massive sulphides were formed by, or related to, a locally stable, restricted, volcanogenic-sedimentary environment, represented by sediments and volcanics found above the pillow lavas in the middle member of the Unuk River Formation (Fig. 13).

Betty Creek Formation (Map-units 13 and 14)

The Middle Jurassic Betty Creek Formation was first recognized and mapped by the writer in the Stewart area (Fig. 3) and later extended throughout the Stewart Complex. This distinct volcaniclastic unit was not recognized by previous workers in the general area. Recognition of this unit and its stratigraphic relationship to the underlying Unuk River Formation has provided a key to understanding the tectonic development of the region. The recognition of the Betty Creek, together with the Lower Jurassic Unuk River, Middle Jurassic Salmon River, and Upper Jurassic Nass Formation, has made it possible to establish and formalize the terminology of the Hazelton Group.

The Hazelton Group (Table 1), first defined by vague reference to the Hazelton area, was thought to comprise a single volcanic sequence, the Bear River Formation, and two sedimentary units. It was considered by Hanson (1935) to be mainly a marine sedimentary assemblage which included discrete volcanic units. More recently, Duffell and Souther (1964) introduced the term Bowser Group, which they felt best expressed the regional stratigraphic relationships. The Bowser Group, defined as an Upper Jurassic-Lower Cretaceous unit (Duffell and Souther, 1964; Souther, 1966) has been shown as including large parts of Hanson's Hazelton Group. The writer's work in the Stewart Complex has shown that the Bowser Group in fact includes Lower Jurassic, Middle Jurassic and Upper Jurassic strata. As previously indicated, Bowser Group has been discarded in favour of the redefined, more useful term, Hazelton Group.

Two Middle Jurassic units, both part of the Hazelton Group, and defined by the writer (1972) as the Betty Creek and Salmon River

Formations, were first traced as mappable units in the Stewart Complex.

Lithologic members comprising the Betty Creek Formation are shown on the geological maps (Figs. 2 and 3) and in the stratigraphic column (Fig. 11). Because of excellent exposures and accessibility at Betty Creek it is proposed as a type area for this formation.

The Betty Creek Formation is characterized by intercalation of planar bedded, bright red and green volcaniclastics, with sporadic, intercalated, andesitic volcanic flows, pillow lavas, chert and carbonate lenses.

Distribution

The Middle Jurassic Betty Creek Formation occurs throughout the Stewart Complex as structural remnants unconformably overlying Upper Triassic and Lower Jurassic rocks from Iskut River to Alice Arm. The pillow volcanic sequence underlying Salmon River Formation sediments at Anyox has been homotaxially correlated with the Betty Creek. Relatively small pillow lava units associated with carbonates, and intercalated within fossiliferous Betty Creek epiclastic volcanics occur immediately west of Todedada Lake. There, they are overlain by fossiliferous Middle Jurassic Salmon River siltstones. At Mount Jancowski the Betty Creek strata include poorly exposed andesitic flows, brightly coloured volcanic epiclastics, and minor basalt flows. The Jancowski massif, with a relief of about 8,000 feet, consists mainly of Betty Creek strata. The thickness of the formation in this synclinal zone probably exceeds 10 to 12,000 feet (Figs. 2 and 4). The relationships between the Unuk River, Betty Creek and Salmon River Formations are also well exposed in the

Mitchell Creek area (Plate 13) where the essentially flat lying, faulted Betty Creek overlies the Unuk River Formation and is unconformably overlain by thin-bedded, marine Salmon River siltstones. The implications of these structural relationships are discussed in Chapter 4.

Lithology

At Betty Creek the strata consist of intercalated beds of red and green epiclastic volcanic sandstone and conglomerate. These have been subdivided into four map units, mainly on the basis of colour by which they are readily recognized in the field.

Most of the rock fragments in these rocks consist of andesitic volcanics similar in colour and composition to the underlying Unuk River volcanic epiclastics. The fragments in the poorly sorted conglomerates and sandstones are angular and vary considerably in grain size (Plates 14 and 15). The largest clasts are up to 10 cm but the average is about 1 to 2 cm. The poorly sorted sandstone particles, like the cobbles, are also angular suggesting rapid deposition. Thin section examination shows the volcanic sandstones to consist largely of rock fragments and from 10 to 40 per cent plagioclase clasts. Alteration of the fragments is variable, but commonly includes minor chlorite and sericite. The oxide which gives the sandstones their bright brick red colour lies in the intergranular material that forms up to 20 per cent by volume of the matrix.

The red sandstone member (Fig. 3, Map Unit B4), which underlies the dark siltstone on the west side of Troy Ridge, forms a conspicuous

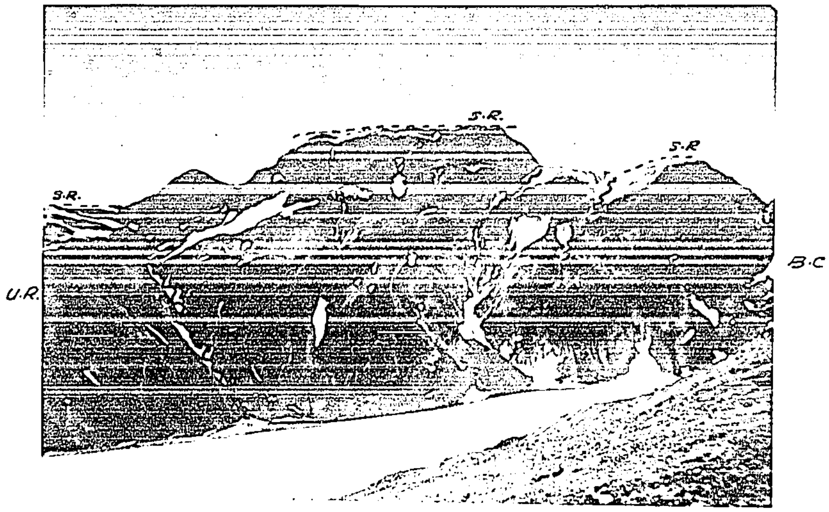


Plate 13. Betty Creek strata, showing relationships with Unuk River and Salmon River strata, at Mitchell Creek, looking north.

Plate 14. Epiclastic volcanic conglomerates, Betty Creek strata, Betty Creek section, looking south.

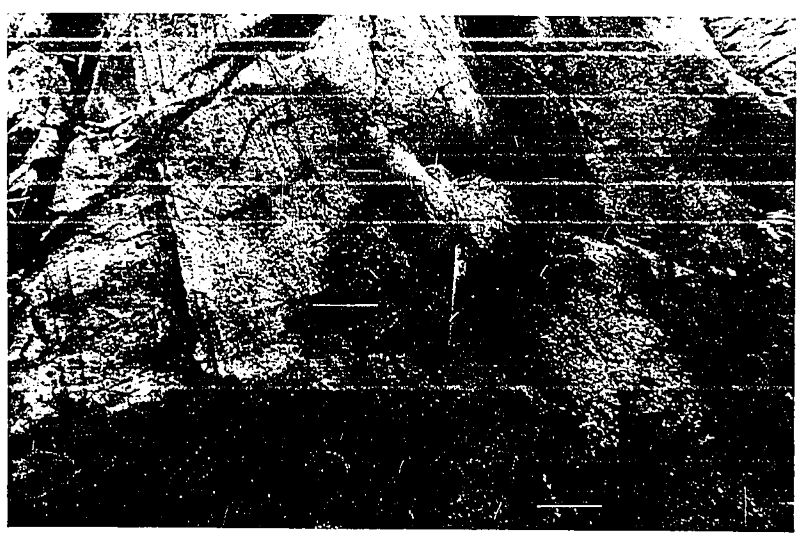


Plate 15. Epiclastic volcanic conglomerates, Betty Creek strata, Betty Creek section, looking south.

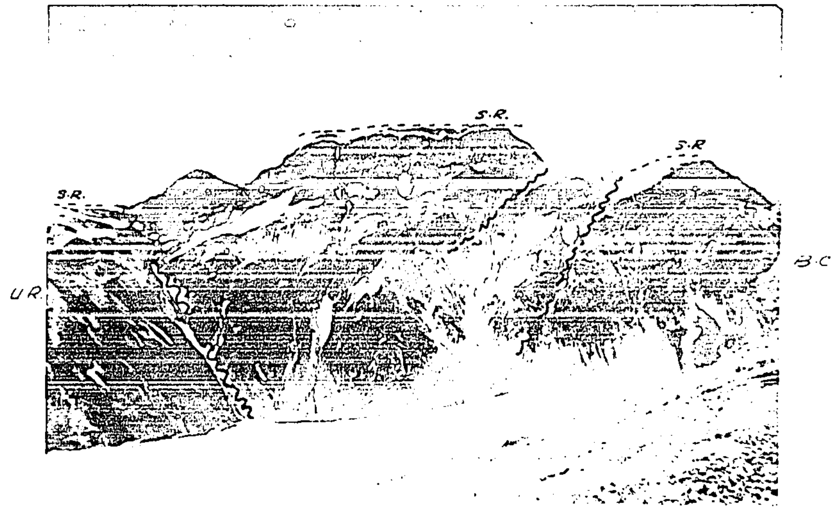


Plate 13. Betty Creek strata, showing relationships with Unuk River and Salmon River strata, at Mitchell Creek, looking north.

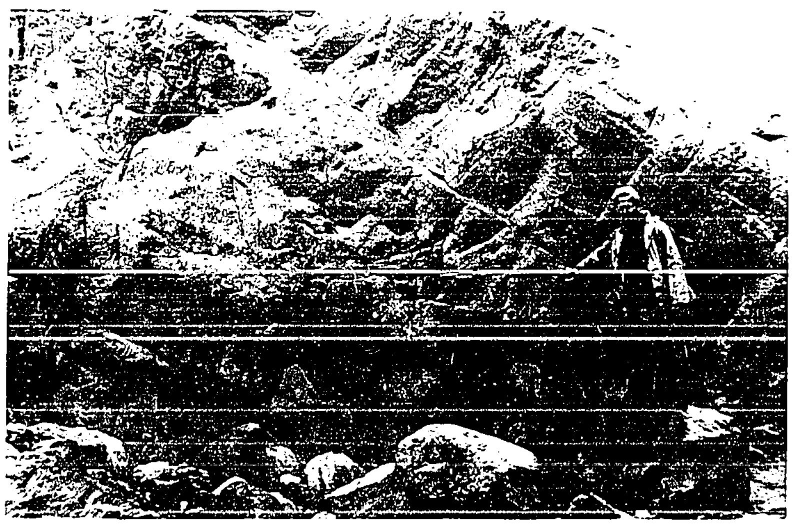


Plate 14. Epiclastic volcanic conglomerates, Betty Creek strata, Betty Creek section, looking south.

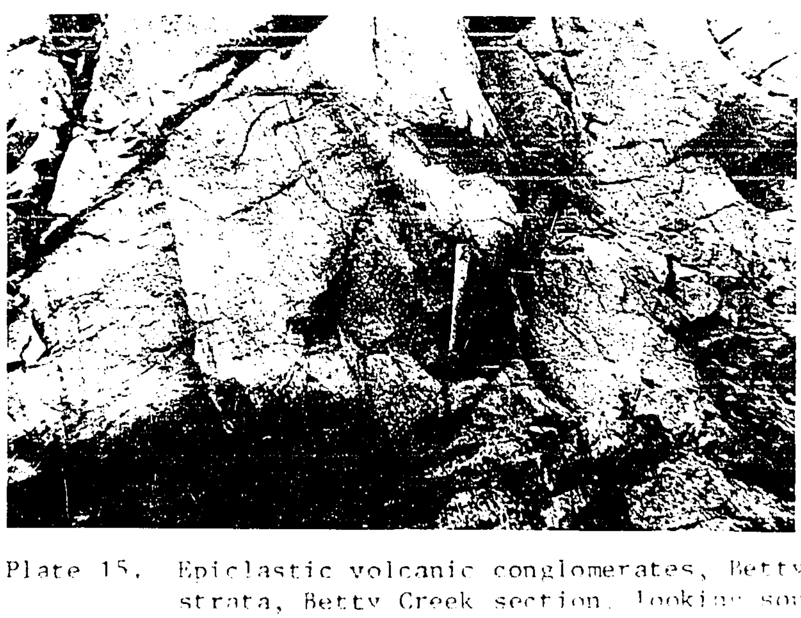


Plate 15. Epiclastic volcanic conglomerates, Betty Creek strata, Betty Creek section, looking south.

bed that has been traced from Mount Jancowski towards the south end of Summit Lake where it lenses out. The red and green strata continue south along the upper part of Bear River Ridge as easily traceable beds disconformably underlying the dark Salmon River siltstones. At Mount Bunting, a rapid facies change from red and green conglomerate and sandstone to red breccia is accompanied by a large increase in apparent thickness. To the west the red breccia lenses out rapidly into a thin red sandstone. The red breccia has been intruded by the Portland Canal dyke swarm, and the emplacement of the dykes appears to have caused dilation and produced an anomalously thick section. The breccia is composed largely of angular green andesitic (porphyry) volcanic fragments forming up to 50 per cent of the rock within a matrix of bright red conglomeratic volcanic sandstone. Other large fragments embedded in the red matrix include purplish-red sandstone blocks and small scattered black volcanic scoria fragments. Blocks one foot across predominate, and blocks up to 3 feet long are common.

At Betty Creek the measured thickness of sandstone and conglomerate is about 2,500 feet. The vari-coloured sandstones and conglomerates just south of the Betty Creek section are distinguished by having thin, irregular lenses and blebs of pale blue or brick red chert in the matrix. Commonly these chert lenses conform to the bedding planes and produce a bright colour striping.

At Anyox the exposed Betty Creek Formation includes a thick, monotonous, succession of generally easterly dipping green pillow lavas. These pillow lavas were previously assumed by Hanson (1935), as well as other workers in the area, to represent an extensive amphibolite pluton intrusive into the siltstones. The pillow volcanics, sediments, volcanic flows, and cataclasites in the central and western part of the Anyox pendant were also referred to in the older literature as intrusive amphibolite. In the sense of Carlisle's (1963) terminology, the andesitic pillow lava sequence is dominated by close-packed ellipsoidal pillows (Plate 16). Structure in the thick volcanic pile has been determined by tracing zones of isolated pillow breccia and broken pillow breccia (Plate 17). The Anyox pillow sequence is separated from the layered volcanics in the Maple Bay area by parallel normal faults and by the central schist zone. The entire sequence dips easterly at low to moderate angles and forms the Anyox Syncline (Fig.2C, 17). Relationships of the pillow lavas to the overlying Salmon River siltstones are clear and indicate a general conformity, although certain sections of the contact have been deformed and exhibit limited faulting and small scale folding. At certain well exposed sites, the undeformed simple gradation from close packed Betty Creek pillow lava to chert, carbonate and overlying Salmon River siltstone is readily observable (Plate 18).

The pillow sequence may be as thick as 10,000 feet but this is an estimate based on the reconstructed geological sections. However, diamond drilling in the Hidden Creek Mine area has shown that both the pillow lavas and the overlying siltstones are at least 5,000 feet thick. The lavas are mainly extensively altered, olivine-free andesite and andesitic-basalts. The individual pillows are about two to three feet in diameter, and the interstices of the pillows are commonly veined

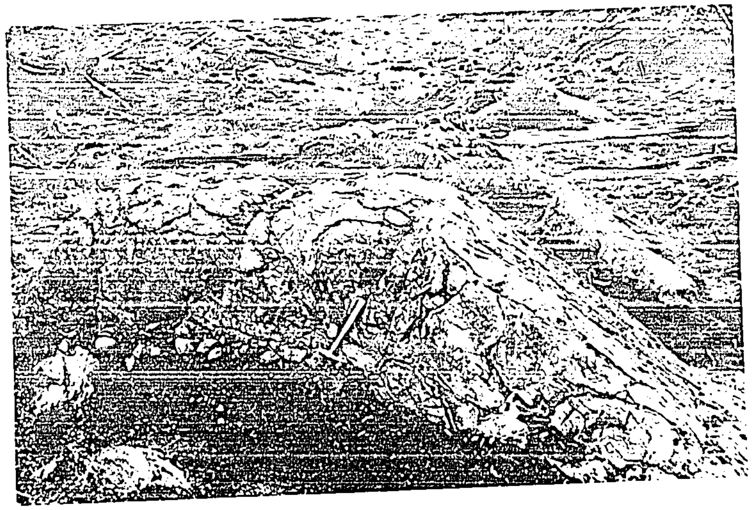


Plate 16. Close-packed pillow lava, Betty Creek strata, Anyox area.

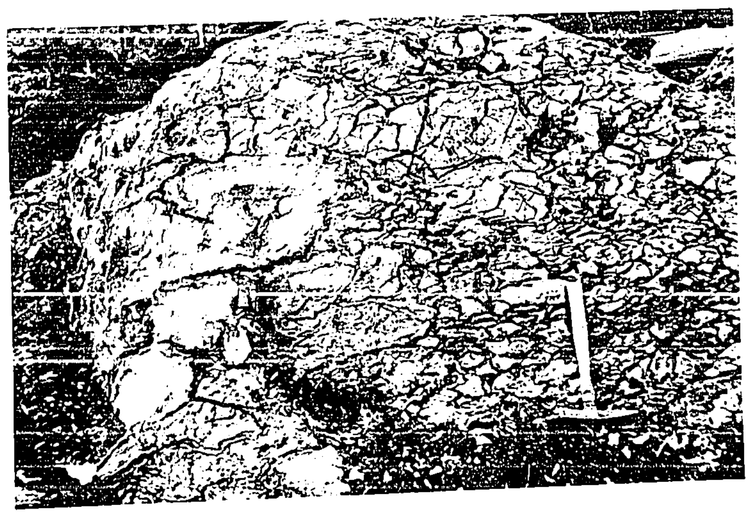


Plate 17. Pillow breccia, Betty Creek strata, Anyox area.

Plate 18. Transition chert zone between Betty Creek pillow lava and Salmon River siltstone.

by coarse grained quartz and epidote. The pillow rims are generally thin, although occasionally rims up to 3 or 4 cm thick have been observed. Radial jointing is a random feature and concentric joints, which are so prominent in the Unuk River pillows, appear to be entirely absent from the Betty Creek pillows. Most of the pillows are amygdaloidal, porphyritic units in which the glassy content has been completely devitrified and largely replaced by alteration products. The composition of the plagioclase in most of the thin sections examined was too altered to determine closely, but ranged from about An_{40} to An_{60}. The presence of pyroxene in these altered rocks is only suggested by amphibole pseudomorphs; no olivine was observed. The rock now consists mainly of a very fine grained felted mass of acicular actinolite, minor grains and clumps of epidote, plagioclase remnants, along with minor fresh brown biotite and apatite, pyrite and leucoxene as accessory minerals. In the porphyritic pillows, euhedral, altered plagioclase laths 3 to 8 mm long comprise from 10 to 20 per cent of the rock. Because of the general alteration, the pillows in the Anyox section show few recognizable vesicles or microvesicles, and may be comparable to Jones' (1969, p. 189) type-2 pillow lava which he suggested represented final eruptive phase, degassed lavas extruded along the submerged flanks of emergent volcanoes.

Zones of isolated pillow breccia and zones of broken pillow breccia and breccia were recognized mainly in the upper 2,000 feet of the pillow lava sequence. These units are generally a few tens of feet to 100 feet thick and form completely gradational zones within the close packed pillow lavas. In these units the transition between the pillow types is lateral along flow margins and between flows rather than a vertical transition as emphasized by Carlisle (1963, p. 55). Towards the top of the pillow sequence, largely marked by the overlying Salmon River Formation siltstone unit, pillow flattening is more pronounced, broken pillow breccia more abundant and tuffaceous lenses are common. The pillows rapidly become smaller in certain areas, such as Bonanza Creek (Plate 18), where the small pillows are immediately overlain by thinly banded chert which in turn is gradational into the overlying Salmon River calcareous siltstone and greywacke. Elsewhere this unique contact is marked by carbonate zones and occasionally by disseminated pyrite-pyrrhotite mineralization. The major massive sulphide ore bodies in the Anyox area are all concentrated at or near this contact in the underlying cherty-calcarerous pillow lavas. Other pyrite-pyrrhotite-chalcopyrite mineralization recently found west of the contact is localized in the broken pillow breccia zones.

Provenance

The regional distribution pattern of volcanic flows and volcaniclastic rocks indicates that much of the material comprising the Betty Creek Formation has been extruded, eroded, and deposited locally. The thick piles of lavas appear to extend in a northerly direction through the Anyox pendant, roughly parallel to the axes of the major late Lower Jurassic folds. The depositional sites for the volcaniclastic debris were along the flanks of this eruptive zone and between the major volcanic centres.

Deposition Environment

The fossil collections from the Betty Creek Formation contain abundant triginoid pelecypods, as well as indeterminate fragments of other thick shelled pelecypods which indicate a near-shore environment. The presence of scattered, metamorphosed coaly material throughout the clastic section also indicates intermittant shallow, perhaps brackish marine conditions. The suggested configuration of isolated volcanic centres surrounded and buried in their own debris, indicates emergent shield-like volcanic areas shedding debris into broad shallow basins and occasionally venting pillow lavas along the margins from emergent or shallow submarine vents during the late stage eruptive phases.

Age

The Betty Creek Formation overlies the eroded Toarcian upper Unuk River Formation and is in turn overlain by the middle Bajocian Salmon River Formation. Indeterminate pelecypods, belemnoids, gastropods and deformed ammonoids are distributed through the greywacke strata in the Betty Creek sequence in most of the area north of Stewart. Diagnostic fossil assemblages from the Mitchell Creek section (Appendix II) suggests the age of the Betty Creek Formation as either lower or middle Bajocian.

Souther (1970) has recently re-mapped part of the Spectrum Range and has redefined the extensive volcanic section in the Iskut River sector as Middle Jurassic on the basis of new fossil collections. This sequence, once thought to be Upper Triassic in age, was included by Armstrong and Souther (1966) in a northerly trending pillow lava trough of Triassic age that also included the Unuk River and Anyox pillow volcanics. Souther's redefinition (op. cit.) of the Iskut River pillow lavas as Middle Jurassic lends support to the writer's correlation of the Anyox pillow lavas with the Betty Creek Formation.

Salmon River Formation (Map-units 15 and 16)

The Middle Jurassic Salmon River Formation was originally defined by Schofield and Hanson (1922, pp. 12-15) on the basis of mapping in the Salmon River district. They defined the unit and the type area as follows:

> "This formation occupies a semicircular area around the southern base of Slate Mountain. The eastern edge of the mass passes under the slate exposed along the shores of Long Lake and on Bear River ridge; the western edge of the area extends northward as a narrow band which passes under the glacier that caps Mount Dilsworth. Another area of these rocks occupies the lower slopes of Big Missouri ridge below the Fortynine group of mineral claims."

The type area was remapped in detail (Fig. 3) and the 300 foot conglomerate unit does not exist, although thin lenticular chert conglomerates intercalated within argillaceous siltstones do occur, and unconformably overlie the Lower Jurassic volcaniclastics in this section. The term Salmon River Formation is well established in the literature and has been retained by the writer for the complexly folded, thinly bedded, siltstone-greywacke sequence found along the original type area. Schofield and Hanson (op. cit., p. 13) applied the term Nass Formation locally to this unit apparently assuming it was a correlative of McConnell's (1913, pp. 17-18) Nass Formation originally defined in the

Bear River Pass-Meziadin Lake area (Fig. 2B).

The Mount Dillworth section was retained as the type area for the Salmon River Formation because it is adjacent to Betty Creek, and is now accessible from the new Granduc road. The Salmon River Formation may be characterized as a thick assemblage of complexly folded, colour banded, siltstones and lithic wackes, primarily of andesitic origin (Fig. 11; Appendix II). The lower part of the succession is marked by extensive, thick lenses of grey weathering greywacke (Plate 19), occasional thick littoral deposits, rhyolite, chert and carbonate lenses.

The siltstones and sandstones of the Salmon River Formation have been described in the earlier literature as the Bitter Creek Formation (McConnell, 1913, p. 6), the Nass Formation (Hanson, 1922, p. 13), the Salmon River Formation (Schofield and Hanson, 1929, p. 12), the Hazelton Group (Hanson, 1935, pp. 6-13), and latterly, the Bowser Group (Duffell and Souther, 1964). Most commonly these rocks have been called argillites, slates, slaty argillite, shale, greywacke, and sandstone, with conglomerate, limestone, quartzite, tuffs, etc., included as minor components.

On the basis of the new interpretation of the Middle Jurassic sequence in the Stewart Complex, the writer has also revised the paleogeography of the Bowser Basin (Fig. 15).

Distribution

Salmon River strata occur as trough-like structural remnants within the Stewart Complex overlying early Middle and Lower Jurassic and Triassic country rocks. The formation also extends along the

Plate 19. Siltstone-greywacke sequence, Salmon River strata, looking west, Mount Dillworth area.

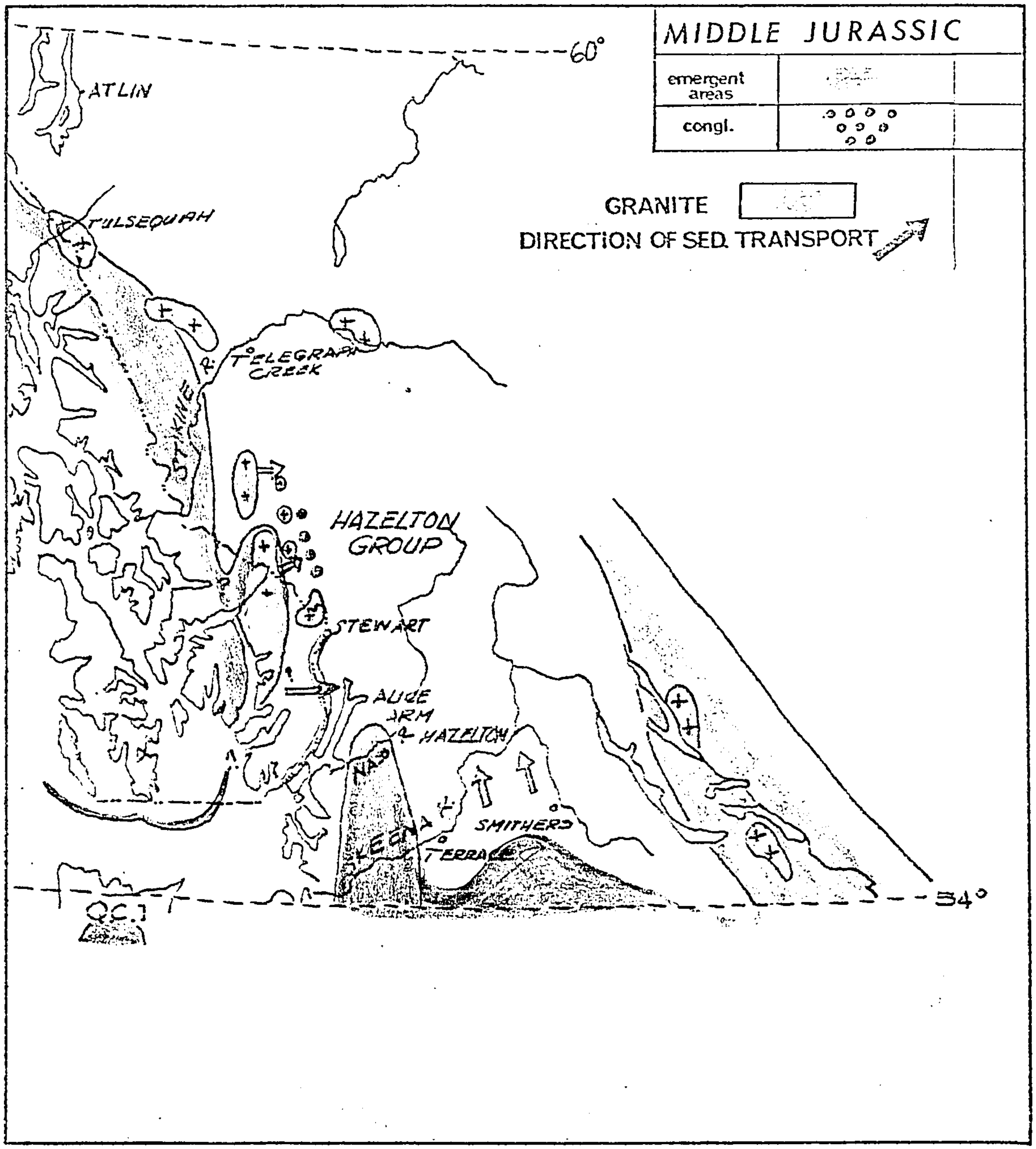


FIG. 15 Paleogeographic map, Middle Jurassic, Northwestern British Columbia.

easterly flank of the Stewart Complex where it forms a thick, overlapping apron-like cover across the older rocks (Fig. 2). Within the confines of the Bowser Basin, an equivalent unit has been recently outlined by Tipper (1971) in the Smithers area. Elsewhere in the Western Cordillera no distinction has been made between the Salmon River and the younger Nass Formations, and the Skeena Group.

Lithology

Conspicuously colour banded, splintery to blocky-weathering siltstones form the most common rock types of the Salmon River Formation. The term argillite has been commonly applied almost exclusively to these rocks, but on examination under the microscope, clay-size material appears to be restricted to the matrix and few true argillites were found. Colour variations in the siltstones are limited to combinations of shades of grey, buff and black, with dark greyish-black most common. The colour generally indicates the grain size and approximate composition. Black, usually suggests a carbonaceous, high clay matrix with very fine silt-sized quartz, feldspar and rock clasts. With an increase in rock and mineral fragments and a concomitant decrease in clay and organic material the colour generally grades from black, through grey to buff. Most of the siltstones examined are poorly sorted rocks and are composed of roughly equal quantities of very fine grained mineral and rock fragments. Lenses of well sorted calcarenite and quarzite were found interspersed within the siltstone sequence. These occur as thin lenses and beds that blend with the siltstones and are most prominent within the lower or basal siltstone member. Black and white chert pebble conglomerates were found within the basal siltstones on the ridge at the northwest end of Long Lake and along the west slope of Mount Dillworth. At Long Lake, indurated black and white chert pebble beds, about 30 feet thick, are intercalated within banded siltstones. Elsewhere in the area, pebble conglomerates are restricted to thin layers, mostly in the main greywacke member.

In the Mount Dillworth-Divide Lake area a poorly sorted deposit at the base of the Salmon River Formation represents the main fossiliferous horizon in this unit. This dark coloured, poorly bedded, lenticular horizon consists of a large variety of pebble and cobble size sedimentary and vesicular volcanic fragments. This bed, first located by Schofield and Hanson (1922), has been extended north and south of Divide Lake by the writer, and new fossil locations have been found on the west side of Mount Dillworth in the same horizon. The unsorted, irregular nature of this deposit and the abundance of thick shelled pelecypods suggests deposition in a littoral zone.

Siltstones, minor pebble conglomerates, quartzites, and calcarenites persist over a fairly extensive part of the central Stewart Complex. Without the conglomerate or the equally obvious Monitor Lake rhyolite member it would often be difficult to delineate the base of the Salmon River Formation.

Two main areas of greywacke occur within the Mount Dillworth-Bear River Ridge section of the siltstone-sandstone sequence (Fig. 3). The two areas which flank Mount Dillworth appear to merge, but continuity is obscured by heavy snow, high cliffs, and complex structure. Both areas of greywacke lie within the siltstone several hundred feet above the siltstone base. These impure sandstones are predominantly dark grey lithic wackes that are wholly volcanic in nature and differ only in grain size from the siltstones. Feldspathic wackes, quartz greywackes, greywackes and arkosic wackes are included in the sequence. Most of these rocks form fairly massive beds several feet to a few tens of feet thick, intercalated within thin-bedded striped siltstone (Plate 19). In the Mount Dillworth area these greywackes comprise about 40 per cent of the Salmon River sequence. Thinly bedded pebble conglomates exhibiting graded bedding, and siltstone breccias are common in the thick sandstones. Without exception all these greywackes appear to lens out locally and are not recognized elsewhere in the Stewart Complex. Buddington (1929, pp. 20-21) mentions similar greywacke zones in the Hyder district where they are intercalated with siltstones. At this time it is difficult to correlate these greywackes or similar sandstones which recur throughout the Bowser Basin with those on Mount Dillworth because of the lack of macro-fossils and the lack of distinctive lithologies in the enclosing siltstones.

In general, Salmon River rocks in the Stewart area are only weakly indurated or locally phyllitic. Sporadic, fine grained andalusite developed in thin-bedded argillaceous lenses suggests a regional low amphibolite grade of metamorphism. On Slate Mountain striped siltstones have been weakly metamorphosed to platy phyllites, not slates as the name of the mountain implies. Minor graphitic zones and faults are common but relatively unimportant except in relation to geophysical exploration methods.

Rhyolite and rhyolite-breccias of the Salmon River Formation at Monitor Lake represents the main area of these rocks recognized in the Stewart Complex (Fig. 3). Rhyolites noted by Hanson (1929, p. 8)

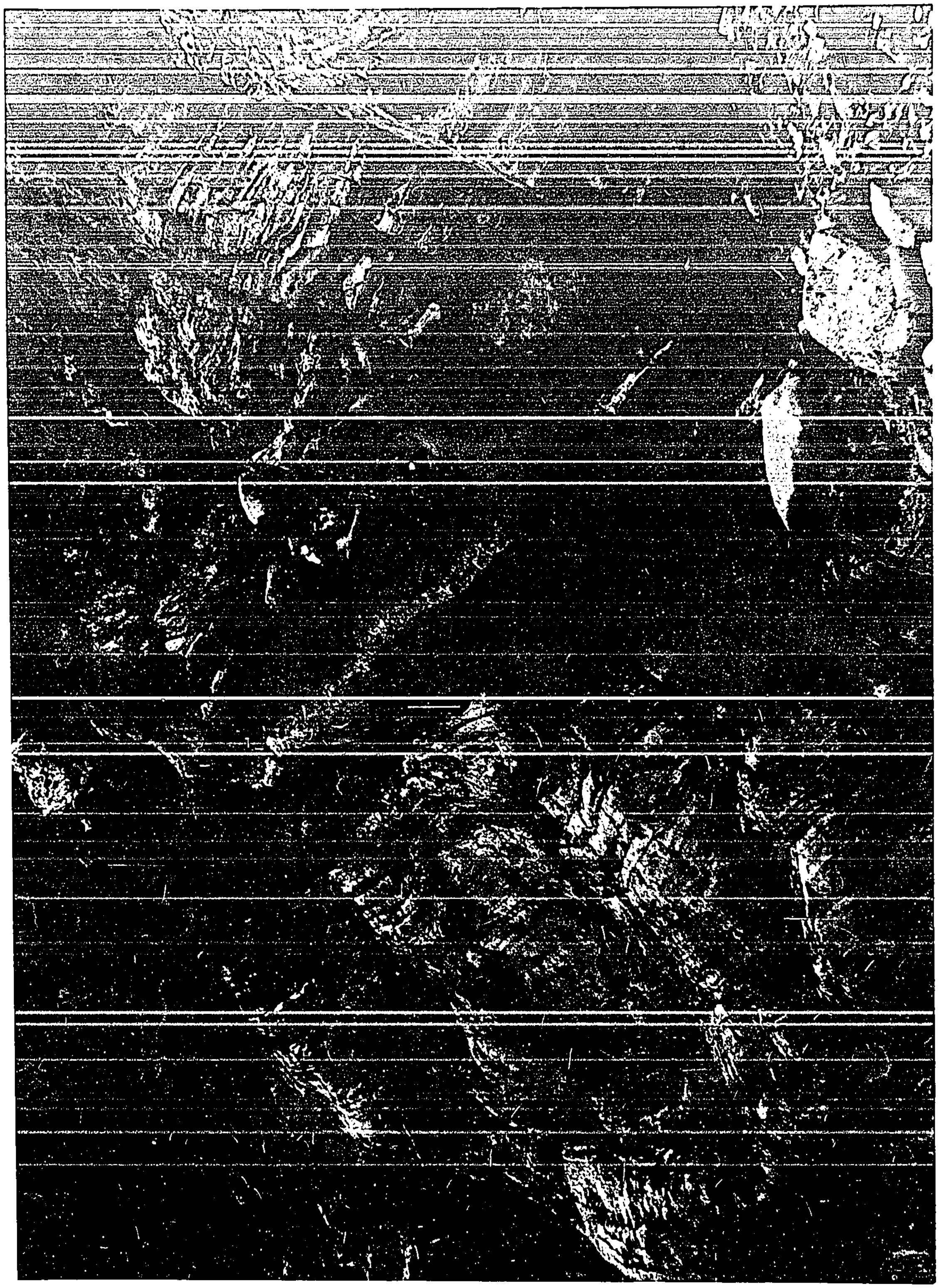
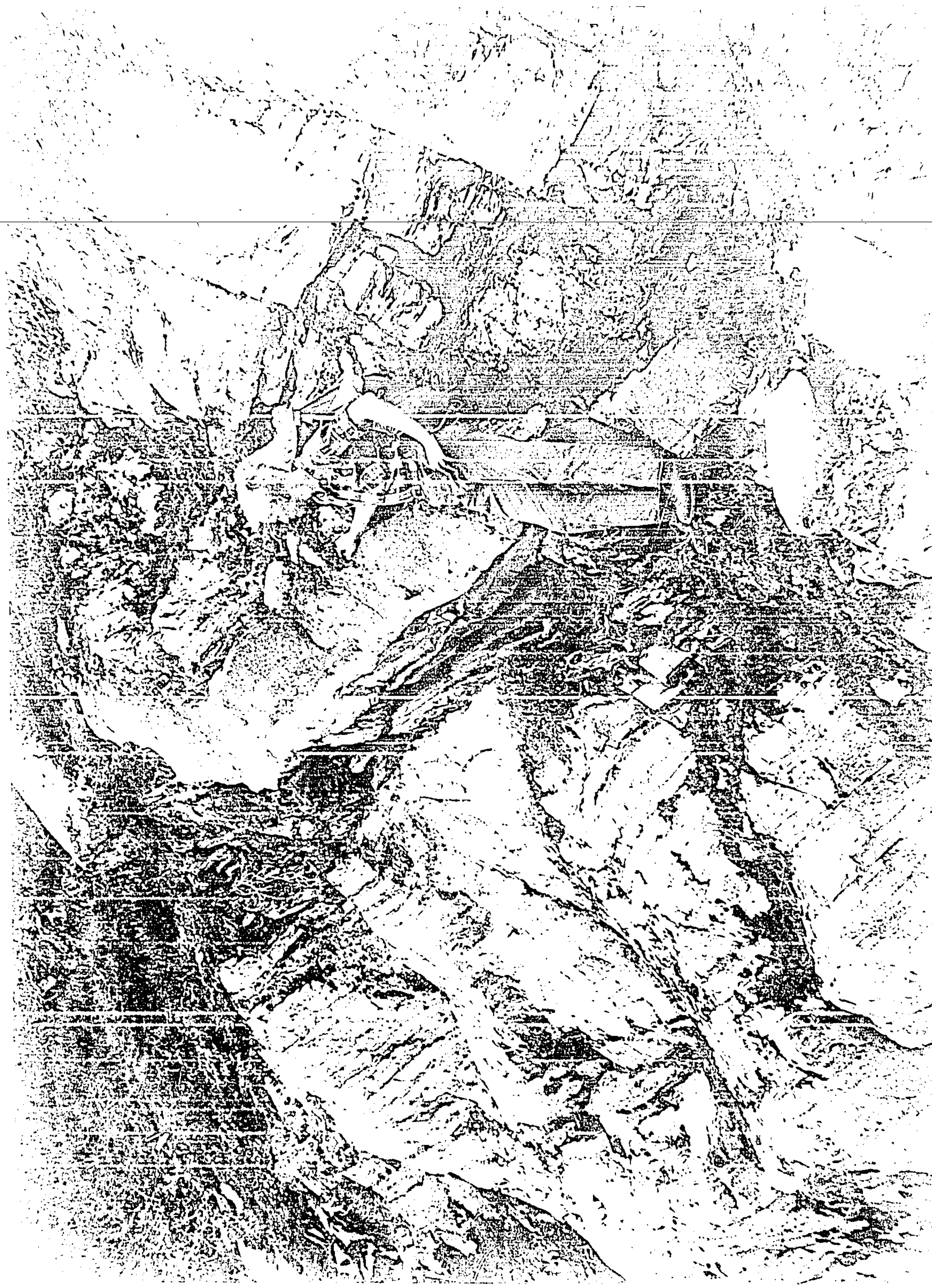


Plate 20. Transition zone between Betty Creek and Salmon River strata, Mount Dillworth area.



in the Marmot River area, on close examination, are clearly epiclastic volcanic sandstone and crystal tuffs.

The massive rhyolite and rhyolite breccia that surround Monitor Lake lie unconformably on Hazelton epiclastic sandstone and conglomerate and appear to be intercalated within the lowermost sequence of the Salmon River siltstone-greywacke. The Monitor Lake rhyolite member is conspicuous because of the light, greyish-green colour and scattered light buff plagioclase phenocrysts, but mainly because of numerous pipe vesicles that traverse the rock. For the most part, the vesicles are perpendicular to the layering and cross-sections are elliptical in the plane of a very weakly developed schistosity. The void in these rocks produced by the tubes amounts to about 10 per cent. These tubes average 5 mm in diameter and appear to extend for several centimeters through most of the rock. In thin section the rhyolite is composed of very fine grained quartz and sodic plagioclase. Minor carbonate, sericite, and scattered chlorite was found in all thin sections. A similar bed, about 2 m thick, intercalated with finely bedded sandstones and conglomerates, was located at the northeast end of Divide Lake also at the base of the Salmon River Formation.

At Monitor Lake the vesicular rhyolites are intercalated with thin-bedded, fine grained dolomitic limestone, sandstone and striped siltstone. The total thickness of the zone is difficult to measure because of folding and the lenticular nature of the members. Thickness is estimated to be about 700 m (Fig. 11). Within the massive white-weathering rhyolite, flow tops as well as indications of flow banding are apparent and suggest that the individual flows averaged 3 to 4 m thick. Several of the flows are intercalated with thin lenticular masses of dense grey limestone. Although plagioclase and quartz clasts as well as rhyolite rock particles form only about one per cent of the limestone, they are conspicuous in hand specimen as well as thin section. Under the microscope the limestone is seen to be a thinly laminated clastic rock with undetermined, distinct dark spheres of probable organic origin measuring 0.2 mm in diameter scattered throughout. It appears from the fine silt intercalations and clastic textures that the limestones were deposited by stream action rather than as simple chemical precipitates.

The rhyolite breccia which underlies the thin-bedded rhyolite-limestone sequence was judged to be about 100 to 150 m thick, but the very irregular nature of the deposit suggests a complex outline partly determined by the uneven topography of the underlying Hazelton epiclastics. The breccia, which weathers white, is characterized by irregular, closely packed blocks. In outcrop and thin section the rocks forming the breccia and massive flows are similar in composition. Where traversed by narrow shear zones, both breccia and flow rocks have a greenish cast indicating sericitization. Minor siltstones as lenticles are common in both the breccia and the flows. A lens of thinly laminated, tuffaceous, green sandstone and dolomitic limestone, 20 to 30 m thick, is well exposed on the west side of Troy Ridge (Fig. 3). It lies between the Betty Creek red sandstone-conglomerate unit and the main Salmon River black siltstones and greywackes in approximately the same stratigraphic position as the Monitor Lake rhyolite-limestone-breccia member. This tuffáceous zone (Plate 20) clearly illustrates the sedimentary nature of the sequence. The zone probably represents a transitional phase between the relatively restricted environment of the rhyolite flows and breccias, and similarly restricted sedimentary deposition. Elsewhere in the study area this stratigraphic interval is generally marked by a sharp and pronounced colour contrast, or by a disconformity underlying coarse, unsorted, clastic littoral deposits.

Obviously, the previous description of the type section at Mount Dillworth does not apply in detail to all the Salmon River strata exposed in the Stewart Complex. In the Sulphurets Creek section, the base of the extensive structural trough is marked by a granodiorite boulder conglomerate which unconformably overlies the Unuk River Formation. At Anyox the thick, folded Salmon River Formation overlies, with apparent conformity to disconformity, much of the Betty Creek pillow lava sequence. As previously outlined, the pillow lavas are in part overlain by and gradational with thinly banded cherts and carbonate lenses and, like the Mount Dillworth section, the basal siltstone-greywacke section contains calcarenites and pods of limestone. Apart from variations related to the local depositional environment, the Salmon River Formation appears to represent a broadly uniform, clastic marine sequence. These rocks generally exhibit very low porosity and permeability and well sorted sandstones or coarse units are rare.

Provenance

The Salmon River Formation has not been subjected to a detailed paleocurrent study. The occurrence of the granodiorite pebbles and cobbles in the basal part of the Sulphurets Creek trough suggests an initial derivation from the nearby Coast Plutonic Complex which was probably unroofed for a short period at the close of the Betty Creek volcanism. Crossbedding, slump folds and bottom markings are observed in parts of the unit, but the section is complexly folded. Slump folds are common in argillaceous members but these are generally difficult to differentiate from tectonic units. Armstrong and Souther (1966) suggested that in the northerly marginal part of the Bowser Basin, the presence of certain distinct sedimentary rock clasts indicates that the transport of coarse clastics was from the north towards the south. The evidence from the Stewart Complex generally suggests nearby volcanic highlands as the source areas.

Depositional Environment

The main Salmon River sequence appears to represent accumulation in a rapidly subsiding marine basin. Local concentrations of near-shore fossils, including fossil logs in the littoral deposits, suggests the presence of marine, brackish and fresh water units as part of a repeated transitional sequence. The lack of cross channel scouring of the coarse greywackes, pebble conglomerates and boulder conglomerates into underlying siltstones, and the presence of marked planar bedding of these units, indicates deposition in shallow water. These appear to be similar to the floodplain deposits described by McKee and others (1967) at Bijou Creek, Colorado. Armoured mud balls are common in many of the argillaceous siltstone units overlying the conglomerates, again suggesting shallow marine conditions of deposition. The presence of extensive rhyolite flows at the base of the formation suggest shallow or even emergent extrusion of the rhyolite member with concomitant carbonate deposition, erosion and rapid deposition *in situ* prior to marine sedimentation. The limestone concretions within the basal siltstone sequence appear to be either secondary concretionary structures or early diagenetic features rather than primary carbonate beds.

Age

The Salmon River Formation rests unconformably on the Lower Jurassic Unuk River strata and overlies the Bajocian Middle Jurassic Betty Creek sequence with conformable to disconformable relationships. Fossil assemblages which are moderately abundant within the Salmon River strata suggest an age ranging from Bajocian (or Bathonian) to Upper Callovian or early Oxfordian (Table 2). Frebold and Tipper (1970) concluded that both the lower and upper parts of the middle Bajocian are widely distributed in British Columbia and in the Rocky Mountains, where it is represented by the Rock Creek Member of the Fernie Group. They also indicated (1970, p. 12) that the upper Callovian is not known anywhere in the Canadian Cordillera. Several fossil collections from the Salmon River Formation (Appendix II) have been identified as early and upper Callovian. In certain conformable sections in the Stewart Complex it appears that the Betty Creek and Salmon River strata represent an almost continuous depositional sequence ranging from lower Bajocian, through upper Callovian into the overlying upper Oxfordian (Table 2).

Nass Formation (Map-unit 17)

McConnell (1913, pp. 17-18) described and defined the Upper Jurassic Nass Formation as consisting largely of weakly deformed dark argillites confined to the mountain summits north and south of Bear River Pass and extending eastwards to the Nass River and probably beyond. The formation was maintained as a major unit until Hanson (1935) incorporated it into his revised Hazelton Group. Later the same rocks became part of the Bowser Group (Map 9-1957; Duffell and Souther, 1964).

McConnell's definition was essentially valid but also included part of the sequence that the writer has distinguished as the Salmon River Formation. The two units were originally separated by the writer on the basis of a granodiorite cobble conglomerate recognized within the assemblage in the Surprise Creek section (Fig. 2B). H.W. Tipper (pers. comm.) later informed the writer "that the occurrence of this conglomerate below the *Buchia concentrica* zone (see Fig. 11) was identical to the occurrence in Taseko Lakes and Mount Waddington, and furthermore was analogous to Crickmay's stratigraphy in Harrison Lake." As shown on the accompanying geological maps of the Stewart Complex (Fig. 2), the Nass Formation includes part of the Bowser Group which Rigby (1969) has estimated to include more than 26,000 feet of thin-bedded mudstone and siltstone, thin to thick-bedded greywacke, massive to thick-bedded greywacke pebble to cobble conglomerate, and minor thin limestone, carbonaceous shale and coal. Rigby (*op. cit.*) compiled his section along the northeastern margin of the Bowser Basin during a field study of the Tertiary Sustut Basin.

In the Stewart Complex, the Nass Formation unconformably to disconformably overlies the Salmon River Formation, and includes an Oxfordian to Kimmeridgian fossil assemblage. The top of the Nass Formation is not known in this area but Tipper (pers. comm.) has indicated that at Skeena Crossing near Terrace, Upper Jurassic equivalents of the Nass Formation are unconformably overlain by the Hauterivian Stage of the Lower Cretaceous Skeena Group.

The Nass Formation is entirely limited to the area of the Bowser Basin where it forms the main surficial unit in the western part of the basin. At Surprise Creek, where an intraformational conglomerate was recognized by the writer between the Salmon and Nass Formations, the Nass sequence exhibits complex folding, but an approximate 2,000 foot section was measured. The 20 foot thick conglomerate unit forming the base included hornblende granodiorite cobbles and pebbles, chert pebbles, and greywacke and argillite fragments in grey siltstone. This is overlain by one to ten foot thick, fossiliferous, medium grained calcareous sandstones intercalated within an 800 foot section comprised mainly of thin banded, splintery weathering siltstones, with thin partings of black shale. The upper 1,200 feet is mainly thinly bedded grey to black blocky siltstone with occasional thin black shale partings and brachiopod fragments.

Provenance

The basal granodiorite conglomerate found along Surprise Creek suggests that the Texas Creek granodiorite or similar Middle Jurassic plutons localized along the Coast Range Geanticline was unroofed prior to Nass sedimentation. Apart from this apparent easterly transport of material into the Bowser Basin, evidence obtained by the writer at Oweegee Dome (Fig. 1) suggests local highland areas within the basin which also shed material radially into the Bowser Basin (Fig. 16).

Depositional Environment

The Nass Formation sediments represent deltaic accumulation of materials mostly reworked from older volcanic terrains. Local beds of abundant marine fossils occur associated with fossil logs in conglomeratic members. The very even sandstone and conglomerate beds, and the lack of channeling in the underlying siltstones suggests some deposition in relatively shallow water.

Age

The age of the Nass Formation, on the basis of local relationships and fossil assemblages, is Oxfordian to Kimmeridgian (Appendix II). On the basis of the relationships observed by Tipper at Skeena Crossing and in the Smithers area, the upper limit of the Nass Formation is indicated from the unconformably overlying Hauterivian to Albian Skeena Group.

Skeena Group

There are no known members of the Lower Cretaceous Skeena Group within the area of the Stewart Complex, although Fitzgerald (1959) suggested the presence of a thick, possibly correlative, unit along the east flank of the Ritchie Anticline (Fig. 1). Tipper (pers. comm.) has described the Skeena Group as an essentially micaceous shale and sandstone unit, whereas the Nass Formation rocks contain very little and the Salmon River Formation rocks have no visible mica. Marine fossils are extremely rare, but the Skeena Group may be definitely identified by the presence of angiosperms. Tipper (pers. comm.) characterizes the Skeena Group as a

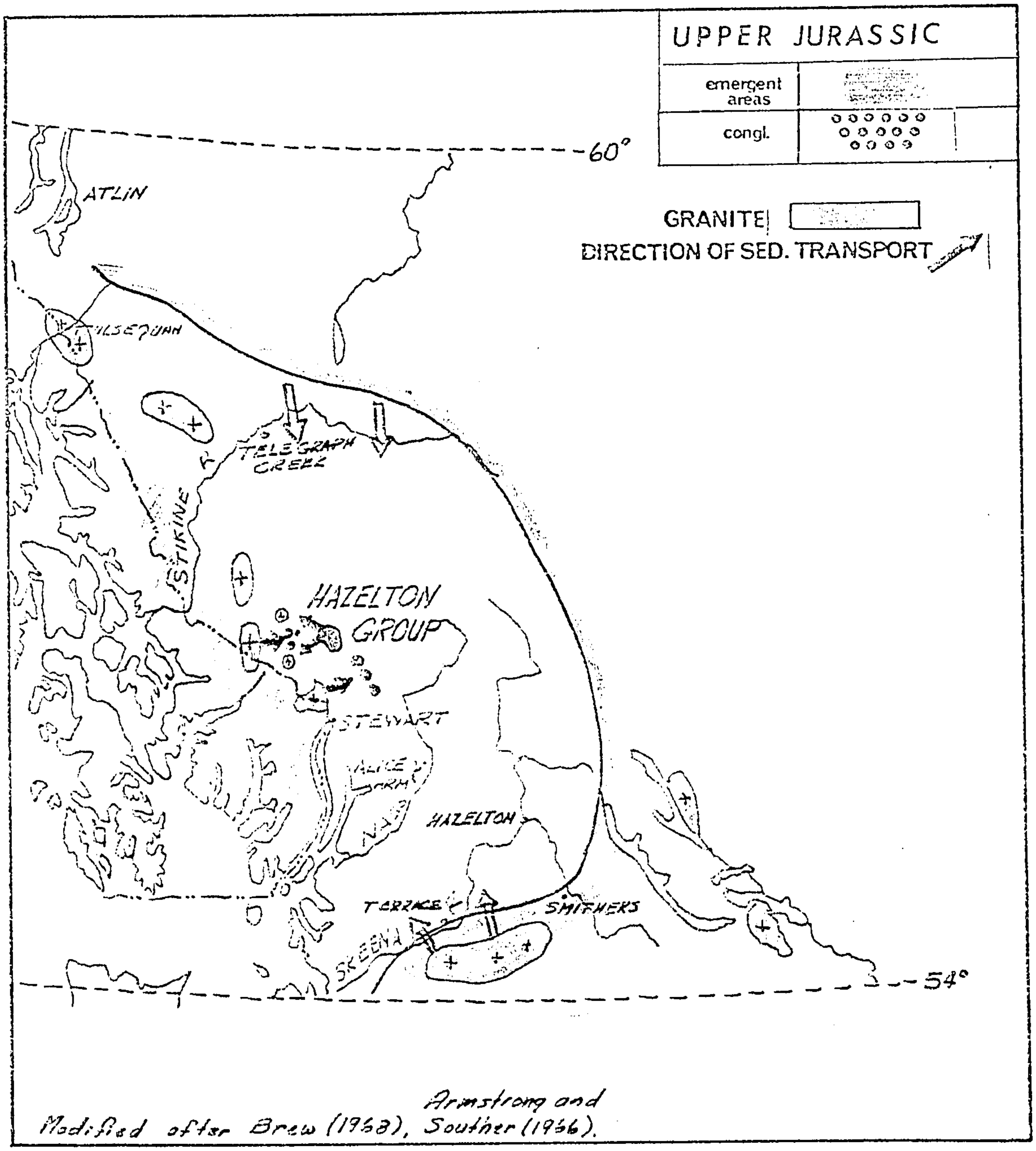


FIG. 16 Paleogeographic map, Upper Jurassic, Northwestern British Columbia.

monotonous shale, sandstone assemblage, exhibiting a micaceous matrix, with no sedimentary structures, and as containing significant coal deposits such as those at Telkwa near Smithers.

Cenozoic

Quaternary

Introduction

There are at present no known active volcanoes in the Western Cordillera of British Columbia. Although hot springs are widespread in all the volcanic districts of both the eastern and western parts of the Cordillera, they have not been catalogued in detail in the western part. In northwestern British Columbia, the abundant Cenozoic volcanics and hot spring deposits had generally been of passing interest until Souther's (1970) detailed study of the Edziza peak volcanic complex, located immediately southeast of Telegraph Creek. Holland (1964), in his presentation of the distribution of many of the Tertiary and Recent volcanic centres in British Columbia has shown that the main districts are found in the Coast Mountains north of Vancouver, and in the Stikine Plateau-Coast Mountain region north of Stewart.

The general location, distribution and extent of Pleistocene and Recent volcanics in the writer's study area is shown in Figure 1, with the detailed locations and outlines of the volcanic flows and cones shown on the Unuk River and Anyox map sheets (Figs. 2A and 2C).

The Pleistocene and Recent volcanic rocks in the Alice Arm district form a spatially discrete group of basaltic flows and cinder cones localized along the southern limit of the Bear River Uplift (Fig. 1). The Recent volcanic flows and cinder cones shown in the Unuk River map sheet (Fig. 2A), form part of the extensive group of Cenozoic volcanics that trends about due north from Revillagigedo Island in southeastern Alaska along the Unuk River to the Stikine River at Telegraph Creek, and extends as far as the Yukon border. The Edziza Peak volcanic complex described by Souther (op. cit) lies near the central part of this linear cluster which has an overall length of about 280 miles.

Pleistocene and Earlier (Map-unit 18.)

Seven areas of flat lying basaltic flow lavas found east of Alice Arm unconformably overlie folded, eroded Nass Formation sediments, forming remnants of a once more extensive plateau unit which extended for at least 6 miles along the highland south of the Illiance River The largest of these remnants forms Widdzech Mountain, which has an area of about one square mile and presents a steep sided, mesa-like form in sharp contrast to the surrounding rounded hills. The flows are flat lying units of variable green colour, about 25 to 50 feet thick, and are marked by prominent columnar joints. The petrology of these rocks, according to Carter (1964, 1967), is fairly uniform and relatively simple. The basalts exhibit trachytic and porphyritic textures with plagioclase (An_{40-60}) phenocrysts, that form up to 25 per cent of the rock, set in a fine grained matrix of clinopyroxene, olivine and magnetite. The relationship of the flows to the underlying older country rocks is unconformable and well defined in the Clary Creek area where the contact is marked by angular breccia that includes country rock fragments set on a scoriaceous matrix.

The age of these flows, determined by the whole rock, K/Ar method

(Carter, pers. comm.), is about 350,000 years, or mid-Pleistocene. These basalts are the oldest Quaternary volcanics known in the area. The extensive Aiyansh alkali basalt flows (Figs. 1 and 17), described by Sutherland Brown (1969), is of Recent age (220 ± 130 years) and somewhat larger than the Iskut River flow.

Recent (Map-unit 19)

Recent volcanic flows, cinder cones, hot springs and ash sheets found within the limits of the study area are restricted to the Iskut River-Unuk River segment at the extreme northwest corner of the Stewart Complex. Several of these flows, including part of the Lava Lake flow (Fig. 2A), were first shown on Map 9-1957. The writer has added the Tom McKay Lake, King Creek, Snippaker Creek, Fewright Creek and Unuk River flows, cones, ash piles and volcanic ejectments to the above group.

Volcanic Flows

All of the mappable Recent volcanic flows shown on the Unik River map sheet (Fig. 2A) lie west of the prominent South Unuk cataclasite zone, one of the most extensive deformed belts within the Stewart Complex. All of these flows occupy topographic lows created by stream erosion and subdued or modified by Pleistocene and Recent glaciation. Two Recent flows located immediately south of Tom McKay Lake, too small to be shown on the map, occupy small depressions and have a lateral extent of only a few hundred feet.

Most of the Recent flows appear to represent single phase, short-lived cinder cones with associated flows of blocky olivine basalt. The composition and aspect of the rock forming these flows is generally similar, consisting of vesicular, spongy-looking, porphyritic, black olivine basalt. The matrix is typically fine grained with felted, acicular plagioclase forming the bulk of the rock. Fine grained, angular fresh olivine is scattered through the matrix where it forms up to 8 per cent of the rock. Vesicles, which typically make up to 50 per cent of the rock, randomly contain calcite and chert fillings. On a larger scale the flows are mainly simple, uneven slabs with irregular surfaces, uneven thickness and variably developed columnar jointing. The Unuk River flow is marked by a prominent steep margin at Border Lake where most of the pile comprises jagged, more or less vesiculated platy slabs and fragments, and compares to the rubble lavas described by Rittman (1962) from Sicily.

The flow extending east from Cinder Mountain into Harrymel Creek is largely covered by a small glacier and its relation to the Cinder Mountain volcanic pile is uncertain. This flow is well exposed at the toe of the glacier, and exhibits interesting relationships between the ice, glacial till and basalt. The flow consists of variably vesicular, olivine basalt in which blocks of similar composition are generally visible. The preserved surface has an irregular, ropy nature and the unit is marked by well spaced columnar joints. It overlies a thin, irregular till-like unit which in turn overlies glaciated country rocks. The flow is itself overlain by till and varved clays which are now largely blanketed by the small glacier.

The Recent volcanic pile in the King Creek canyon has a different profile from the Copper King flow, but the relations suggest a comparable sequence. Here the stream cuts through the edge of the basalt pile exposing part of the section. The creek bottom is overlain in part by varved clays and basal boulder clay about 20 feet thick. These are overlain by a 3 foot thick, flat lying, vesicular basalt flow which in turn is overlain by 10 feet of stony, well banded clays. This basal section is overlain by several hundred feet of steeply piled vesicular basalt blocks, thin flows, and irregular pillow units. Most of these basalts are similar in general aspect and overall composition. The rock is generally black, with up to 50 per cent vesicles which rarely show any filling, and the matrix of the rock consists of fine grained, lath-like plagioclase (An_{50-60}) in which fine grained interstitial olivine is scattered. Coarse grained plagioclase laths form random phenocrysts between the ovoid vesicles.

The Cinder Mountain volcanic pile stands out against the ice and snow as a turreted, blunt spire, pocked with a multitude of small caves and holes. It represents a flat lying accumulation of thin flow, ash, and pyroclastics of a more or less uniform aspect. Flows at the top of the pile are reddish-grey, slightly friable and marked by calcite-chert amygdules up to 2 cm across, and by prominent tubules of variable shape and diameter. In thin section the rock consists of felted, fine grained plagioclase laths, irregularly replaced by fine grained calcite and iron oxides. The amygdules consist entirely of medium to coarse grained calcite which randomly contain central ovoids of coarse grained chert. These flows do not contain any recognizable olivine or mafics and appear not to be more andesitic than the other Recent flows described (Fig. 17).

The two small flows located due south of Tom McKay Lake consist almost entirely of basaltic pillow lavas which grade laterally into breccia blocks and reworked marginal material. Both have small craters in which pipe-like breccia cores containing siltstone and sandstone blocks are mixed with the basalt. Both masses have diatreme-like characteristics and compare favourably with shallow seated diatremes that occur in similar surficial environments (D.P. Gold, pers. comm.).

Volcanic Ash and Cinder Cones

Volcanic ash and cinder cones are prominent features at the head of the Canyon Creek where they stand out against the snow, ice and granitic country rocks. The glaciers flowing into Canyon Creek carry surficial secondary ash cones formed by slides and are marked by several ash accumulation bands. The writer has also noted and collected glassy basaltic ash, probably spread by westerly winds across the area into the Leduc Glacier and Twin John Peaks areas.

The evidence gathered from the Stewart Complex and adjacent area indicates that Quaternary and Recent volcanism in this part of the Western Cordillera has been sporadic and spatially restricted to two main districts. The Alice Arm-Nass River volcanic district appears to represent an easterly trending belt, not previously recognized, in which alkali-olivine basalt volcanism has been periodically active during the Pleistocene and Recent epochs. This belt includes the 220 year old Aiyansh flow, so far dated as the youngest in Canada, as well as the mid-Pleistocene Widdzech Mountain plateau basalts.

The group of flows in the Unuk-Iskut River section are mainly olivine basalts of fairly recent age. Relations with local glaciers and glacial sediments indicate that at least two pulses of extrusion occurred. Thermal springs at Julian Lake on Snippaker Creek and in the King Creek canyon are tepid sodium carbonate-sodium chloride,iron oxide rich waters which, according to J. Berkosha (pers.comm.), have been flowing for at least 15 years, but are now cooler and show a decreased flow. This group of Quaternary volcanic flows and thermal springs represents the south end of an extensive belt of Quaternary volcanics which extends north to Edziza Peak.

Discussion.

Souther (1970) has reviewed volcanism in the Canadian Cordillera and has pointed out that the Quaternary volcanics in British Columbia include two main composition types: 1) short-lived cinder cones and blocky flows of alkali-olivine basalt, and 2) highly differentiated lavas ranging from picrite basalt, through alkaline andesite and dacite to rhyolite. The Alice Arm-Nass and Unuk-Iskut flows belong to the former and the Edziza Peak complex illustrates the latter. The Edziza Peak volcanic pile was initiated during the Paleocene and has built up as a shield-dome complex with Recent blocky alkali-olivine basalts and cinder cones now flanking the complex. Souther (1970) has generally related the volcanism to the north-south trending Mess Creek graben with the implication that the entire Quaternary volcanic belt, extending from Behm Canal to the Yukon border, has been fault controlled (op. cit., pp. 560-562). Kuno (1966) noted that the general circum-Pacific volcanic suite shows a progressive change from tholeite at the continental margin through high-alumina basalt to an inner zone of alkaline-olivine basalt which he has related to increasing depths of magma generation along a Benioff zone dipping under the continents. The presence of the alkali-olivine basalts in the Unuk River section at the south end of the northerly trending belt, lends credence to Souther's (1970) suggestion that the Western Cordillera currently lacks an active Benioff shear zone. Souther (1970, p. 565) has also proposed an east-west belt of Quaternary volcanics extending across the Western Cordillera between 52° and 53° latitude, which he correlated spatially to large dyke swarms as well as to extensive oceanic fracture zones. The writer has outlined an east-northeasterly belt of Quaternary volcanics on Figure 1 which includes the Alice Arm and Nass alkali-olivine basalts near the coast and extends across the Western Cordillera to join the volcanic centre near Bear Lake. Dyke zones are prominent features in the Nass-Alice Arm section, however a direct relationship to crustal fractures has not been confirmed.

Culbert (1971) has also attempted to develop regional patterns on the basis of hotspring and Quaternary volcanic distribution in a study intended to show relationships to mineral deposits in southern coastal British Columbia. His general pattern of volcanics and hot springs compares to that of Souther (op. cit.) but did not include the Alice Arm volcanics in his discussion. Generally, he has related the thermal centres and volcanic zones to what he called the axial fracture zone which extends along the axis of the Coast Plutonic Complex which, on geophysical evidence, he assumes has been a line of differential movement.

The Quaternary volcanics in the Unik River and Alice Arm sections have extruded through Mesozoic sediments, volcanics and massive Tertiary plutons. The small basaltic diatreme-like units south of Tom McKay Lake have been extruded through relatively shallow surficial siltstones. Mudge's (1968) study of shallow seated laccolithic masses and sills suggests that such relations indicate parent magma at relatively shallow depth. Small pillowed flows are also apparently common throughout Souther's major north-south Quaternary volcanic belt (G.S.C. Map 9-1957, marginal notes). Mudge (op. cit.) has suggested that the mechanism of shallow intrusion is probably controlled by interfaces such as bedding in sediments or master fractures in granitic masses. The writer has not recognized a possible extension of Souther's (1970) Mess Creek graben but the small alkali-olivine basalt flows in the Unuk River section imply a regional structural relationship.

Surficial Deposits

Pleistocene and Recent Deposits

The surficial deposits in the map-area are mainly in the river valleys, deltas, and along ice margins. Deposits on the hillsides are normally thin and deposits on the glaciers are scattered. Above timberline the glacial veneer is limited to rock rubble and erratics.

The major valleys are floored by sands and gravels deposited by the major streams. Tributary streams loaded with sand and gravel dump part of their load along alluvial fans and small deltas that coalesce with the main stream. Talus and rubble brought down by snowslides as well as material sloughing away from the steep rock slopes mantle the edge of the valley floor. At the head of Portland Canal the Bear River has formed a broad estuarine delta which merges with the nearby Salmon River delta. Both Hyder and Stewart are built on river sediments elevated a few feet above high tide. Hanson (1929, p. 16) mentioned that between 1909 and 1927, the Bear River delta advanced a total of 540 feet along the west side of Portland Canal. At the present time estuarine deposits are accumulating and the piles of the old railway wharf are now submerged at high tide. This is because the sediments have either undergone compaction or have slumped along this section of the delta.

Marine silts, clays, and sands that are located in the Salmon and Bear River valleys and have been described by McConnell (1913, p. 22), Hanson (1929, p. 16), and Buddington (1929, p. 39), indicate that the Portland Canal district has undergone post-glacial uplift of at least 500 feet.

Coast Plutonic Complex

Introduction

The Coast Plutonic Complex presents the most extensive exposure of plutonic rock in the Canadian Cordillera and represents one of the largest post Precambrian plutonic complexes in the world. This unit extends 1,100 miles from the southwest Yukon, through southeast Alaska and British Columbia, into Washington State. In width the complex ranges from 50 to 60 miles to a maximum of about 120 miles opposite the north end of Vancouver Island (Fig. 9). The complex has an area of approximately 55,000 square miles, of which an area of 40-45,000 square miles lies entirely in British Columbia. Physiographically, the complex is expressed as the Coast Mountains. The Coast Mountain system has been subdivided by Holland (1964) into the northern Boundary Ranges, central Kitimat Ranges, and southern Pacific Ranges. The central Kitimat Ranges present considerably lower summit elevations than the Boundary and Pacific Ranges and are conspicuous by the lack of large icefields. To date the only extensive geological study of the Coast Plutonic Complex has been in the more accessible central Kitimat Ranges between Portland Inlet and Alert Bay.

The various earlier reports on the geology of the complex have suggested the presence of an extensive granitic Coast Range batholith of essentially Jura-Cretaceous age in which various country rock pendants occur; these reports gave credence to the concepts of igneous intrusion and magmatic stoping. Most of the early geological work was confined to the plutonic margins (Dolmage, 1923; Buddington, 1927, 1929; Kerr, 1948) and consisted of shore-line and reconnaissance geological mapping. In the southern part of the batholith the studies of Phemister (1945) and latterly by Bacon (1957) suggested a magmatic origin and passive magmatic intrusion. Smith and Stevenson (1955, pp. 816-817) indicated that in many places the batholiths transect the country rock structures, that in some places much of the country rock was pushed aside, and that trend lines around the southern end of the Coast Range batholith were probably formed by broad-scale and strong lateral pressures transmitted through magma. In Buddington's (1959) review of granite emplacement he summarized his own work in southeastern Alaska with reference to the Coast Range batholith. He suggested (op. cit., p. 702) that the intrusions in the northern Coast Range batholith were characteristic of bodies emplaced in the mesozone, that the southeastern part of the batholith and country rocks exhibit characteristics of the catazone, and that the northeastern part appears to belong to either the upper part of the mesozone or the lower part of the epizone. He also suggested that the Texas Creek granodiorite pluton at Hyder on the east side of the batholith (Portland Canal) is representative of the transitional epizonal-mesozonal type of batholith. Kerr (1948) who mapped the eastern margin of the Coast Range batholith in the vicinity of the Skeena and Iskut Rivers, suggested at least six to ten distinctive intrusive phases ranging in age from Triassic to Cretaceous. Buddington (op. cit., p. 712) interpreted Kerr's youngest discordant phase as epizonal, the dome-shaped masses as mesozonal and the Triassic hornblende diorite as catazonal intrusions.

Duffell and Souther (1964) studied part of the eastern margin of the Coast Plutonic Complex in the Terrace area and concluded that the Coast Intrusions in that section comprise a composite batholith of granitoid rock that resulted from separate emplacements of granitic material over a long period of time, at least throughout a large part of the Mesozoic era. The age relations were definitely not clear, however, and inferences were drawn from intrusive relations found well east of the border of the complex. Later, Roddick (1966) working near Vancouver concluded from detailed studies that the plutonic rocks of the complex formed in wet eugeosynclinal rocks by crystallization and material transfer during the gradual or sporadic uplift of the Coast Mountain belt.

In 1962, the Coast Mountains project of the Geological Survey of Canada was initiated in the Prince Rupert area and comprised the first extensive study of the Coast Plutonic Complex, from the eastern to western boundaries. Hutchison (1970) has presented a study of the metamorphic framework and plutonic styles of the Coast Plutonic Complex in the Prince Rupert area. The Coast Mountain project has shown that in the Kitimat Ranges the complex is characterized by broad, irregular, generally concordant gradations between plutonic masses and metamorphic country rock. The apparent pattern is that of alternating zones of homogenous plutonic rock and migmatite, gradational into weakly gneissic plutonic rock. The structure outlined by gneissic layering, numerous metamorphosed inclusions, and the long direction of the individual plutons, trends northwesterly and approximately parallel to the margins of the complex in this region. Because the older names applied to the Coast Plutonic Complex, Coast Range batholith, and Coast Intrusions, implied a predominantly granitic or massive plutonic terrain, they now serve no useful purpose and present a misconception of the complex. The Coast Mountains project as well as many of the early studies have indicated an abundance of amphibolitic inclusions throughout the complex that, in general, cannot be directly related to the nearest country rocks; this implies some movement within the plutonic complex.

Souther (1971) has subdivided the Coast Plutonic rocks near Tulsequah into three members including a foliated quartz diorite of Lower to Middle Triassic age, a central complex including intrusive and some metamorphic rocks, and younger, non-foliated quartz monzonite masses.

It now appears that about two-thirds of the Coast Plutonic Complex falling within the Canadian section has been mapped at reconnaissance scale. Very small sections have been studied in detail. The 15,000 square miles of the complex lying within the Boundary Ranges of south-eastern Alaska is still largely unknown except for the accessible coastal sections. A review of the published literature on the Coast Plutonic Complex suggests a body of various plutonic styles, with rapid changes in composition, including plutons ranging in age from Ordovician to Tertiary.

Roddick (1966) and Hutchison (1970) suggest that the most common rocks in the Coast Plutonic Complex are, in order of abundance: quartz diorite, granodiorite; diorite, dioritic migmatite and gabbro; acidic gneisses; metasedimentary and metavolcanic rocks; quartz monzonite; and minor unmetamorphosed inclusions. Roddick (1966, p. 76) suggested that, in general, diorite and quartz diorite are more common in the western part of the complex, and biotite-bearing granodiorite and quartz monzonite in the eastern part. Roddick (op. cit.) and Hutchison (1970) have projected the quartz diorite line (Moore, et al., 1962) through the Prince Rupert area where they have shown it as roughly corresponding to the eastern margin of the Coast Plutonic Complex. Hutchison (op. cit.) presented radiometric ages from the Prince Rupert area which he interpreted as representing three parallel northwesterly trending zones within the Coast Plutonic Complex. The oldest age group, Lower Cretaceous, was at the west, intermediate ages, Upper Cretaceous in the central zone, and the youngest, Tertiary on the east. He also suggested that the plutonic styles show autochthonous relationships on the west, para-autochthonous in the central zone, and allochthonous in the east. On the basis of admittedly insufficient evidence and by comparison with the better known Sierra Nevada batholith, Hutchison (op. cit., p. 400) suggested that the rock of the Coast Plutonic Complex has not received an appreciable amount of direct contribution from the mantle. He also presented the anomaly that although the Coast Plutonic Complex presents a deeper level of erosion than the Sierra Nevada, it has younger isotopic ages.

In all, the fragmentary studies cited here point up the complexity of the Coast Plutonic Complex, areas of apparent agreement, much disagreement, and the need for continued directed studies.

The writer's contribution in this thesis to the study of the Coast Plutonic Complex is limited to the eastern margin between the Iskut River and Observatory Inlet.

Unuk River-Salmon River- Anyox Map Areas

The writer's field work between Observatory Inlet and the Iskut River (see Fig. 1), has resulted in delimiting this portion of the Coast Plutonic Complex and in defining the general composition and internal relations of the plutons, the presence of a previously unrecognized gneiss-migmatite complex, and the external relationships of the Coast Plutonic Complex with the country rocks. The overall relationships between the major elements of the geology displayed in Figures 1 and 17, and in the geological maps (Figs. 2 and 3), as well as certain detailed relationships are described in this thesis for the first time and represent a new and original contribution to the knowledge of the geological evolution of part of the Western Cordillera.

Maps and reports by Hanson (1929, 1935), Schofield and Hanson (1922), and McConnell (1913) dealt briefly with the plutonic rocks in the Portland Canal district and only limited attention was paid to plutonic relationships. Buddington (1929) studied part of the plutonic complex at Hyder where he recognized and described several phases and facies of the plutons, the relationships to country rocks, and most significantly, he suggested a spatial relationship between one of the plutons and the extensive mineralization in the adjacent Salmon River Valley. The writer has retained Buddington's nomenclature but has attempted to refine his concepts particularly in respect to the Stewart area.

In the thesis area the writer has subdivided the eastern margin of the Coast Plutonic Complex into a number of intrusive phases. These include: the Texas Creek pluton of probable Middle Jurassic age; the

Hyder pluton and related bodies of Tertiary age; and an undivided group comprising part of the Central Gneiss Complex. The contact zone of the marginal Texas Creek and Hyder intrusive phases with the Mesozoic country rocks has been mapped in detail (Figs. 2 and 3), but the limits of the central gneiss complex, as well as its overall composition and structure, has only been examined in terms of general relationships. The Coast Range Project, conducted by the Geological Survey of Canada (Hutchison, 1970), has delineated the Central Gneiss Complex south of Observatory Inlet, but the extensive section within Alaskan territory, which is vital to the writer's study, has not yet been studied by the United States Geological Survey.

Middle Jurassic

Texas Creek Pluton (Map Unit 6)

The Texas Creek phase of the Coast Plutonic Complex and related dyke rocks was first recognized and mapped as a distinct older intrusive phase by Buddington (1929), who separated it from the surrounding younger granitic intrusives on the basis of structural relationships. The pluton lies along and west of the Salmon River between Hyder and Summit Lake, and the maximum westerly extent is near the terminus of the Chickamin Glacier, where the Francmackie Icefield limits observations. The exposed area of the Texas Creek is about 75 square miles and is therefore intermediate in size when compared to the plutons that are shown in the Prince Rupert area by Hutchison (1970). Buddington's map as well as his observations shows that the contact of the Texas Creek granodiorite with intruded Hazelton Group country rocks is sharp, smooth and sinuous. This is true along

Texas Creek and the southerly igneous contact, but along Salmon Glacier, where the writer has mapped the district in considerable detail, the contact is extremely irregular and gradational (Fig. 3).

The Texas Creek pluton is particularly well exposed along the steep hillsides above Salmon Glacier; the contact on the west slope of Bear River Ridge in the Silbak Premier Mine area is well exposed in fresh rock cuts along the Granduc road. The importance of the Texas Creek mass and its relationship to mineral deposits was pointed out by Buddington (op. cit., pp. 22-23), who also first recognized the significance of these plutonic rocks near the Premier orebodies:

> "It is probable that the porphyries with which the Premier orebodies in British Columbia are associated are outlying stocks genetically associated with the Texas Creek batholith."

Very generally, the core of the main Texas Creek pluton can be described as a foliated, medium grained, porphyritic granodiorite. The rock mass has not been thoroughly mapped west of the Alaska boundary, but a general impression is as follows. The main phase appears to be typically massive, mottled grey to greenish-grey in colour, with orthoclase phenocrysts up to 3 cm long comprising less than 15 per cent of the rock. Mafics, in which dark green altered hornblende predominates, make up to 12 to 15 per cent of the principal phase, and of this amount fine grained brown biotite comprises up to one-third or about 5 per cent. The accessory minerals, interstitial magnetite and sphene, together form only about 1 per cent of the rock. In summary, the most noticeable characteristics of the principal phase or "core" of the Texas Creek pluton consists of the coarse pink orthoclase phenocrysts and the coarse grained dark brown horbblende crystals embedded in a generally grey, andesine plagioclase matrix. The mineral content is not uniform and the macro-variations are commonly sharp (Plate 21).

Border Phase of the Texas Creek Pluton

The rocks referred to under this heading essentially comprise all that portion of the Texas Creek pluton found along the margins of the Salmon Glacier. The contact zone as shown on the geological maps is irregular and variable in both nature and composition, consisting not only of intrusive Texas Creek rocks, but also altered country rock inclusions and gradational, altered country rock equivalents. In this restricted area the general limits of the complex border zone lie between the lower slope of Big Missouri Ridge on the east and Cantu-Mount Bayard Ridge on the west. On the Alaska side, south of the Salmon Glacier, this contact zone is not as irregular or as complex. In his paragraph on contact metamorphism, Buddington (op. cit., p. 37) noted:

> "One of the most amazing features of the geology of this district is the almost complete failure of the Texas Creek intrusives to produce any observable contact metamorphism in the country rock. This is more striking when contrasted with the contact-metamorphic effects which the Boundary granodiorite, the Hyder quartz monzonite, and their associated porphyry dykes have produced in the same kind of country rock and in the Texas Creek granodiorite itself."

West of and along the Salmon Glacier, the border phase of the Texas Creek pluton has a generally green or muddy green, spotted appearance with irregular slashes of orange-red, representing zones of altered country rock inclusions. At the south end of Cantu Mountain,

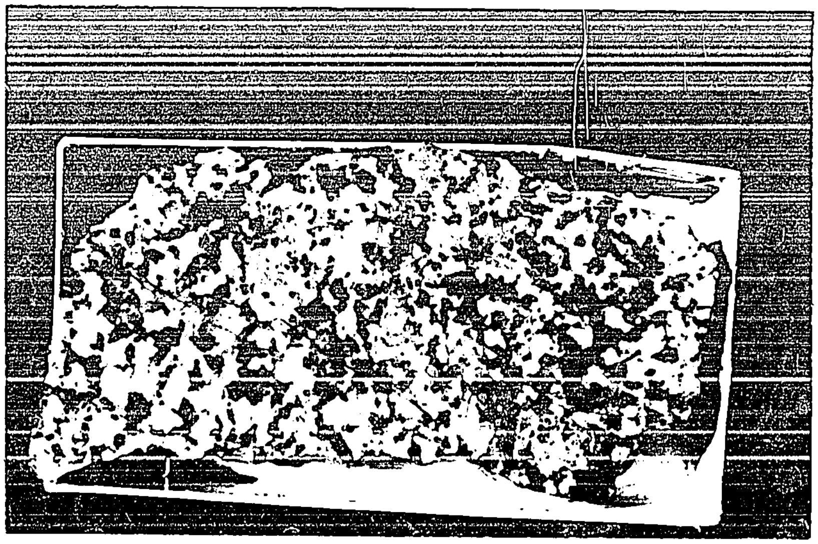


Plate 21a. Hand specimen, Texas Creek pluton, Ninemile area, Salmon River district, half size.

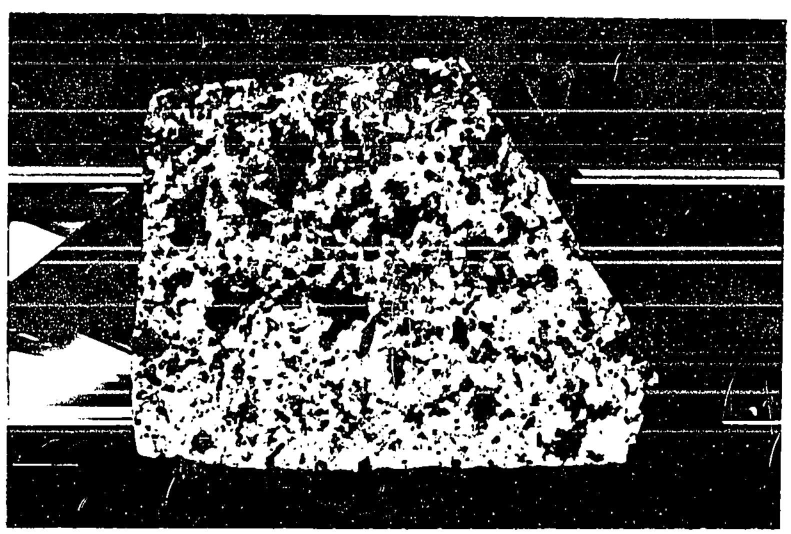


Plate 21b. Hand specimen, Texas Creek pluton, Riverside area, Salmon River district, half size.

near the Mineral Hill inclusion zone, the granodiorite is a fine to medium grained, grey hornblende biotite granodiorite, similar in appearance to the core rocks. Away from the inclusions this phase grades rapidly into the green porphyritic hornblende granodiorite-quartz diorite border phase which extends north along the Salmon Glacier. The spotted or blotchy appearance is caused by the dark brown hornblende and pink-grey orthoclase phenocrysts set in a green matrix. Quartz blebs up to one cm in diameter are common, but recognizable biotite is rare. Where weathered, the rock has taken on a spotted light grey to almost white appearance, except in pyritic fractured zones where oxide coats the surface.

East of Salmon Glacier and Salmon River, the same mottled green Texas Creek border phase grades perceptibly into green Hazelton epiclastic volcanic conglomerates. The outcrops are generally clean below the glacier trim line and the distinction between intrusive and country rocks is fairly easy. This is also true along the new road section where the rock cuts are deep and almost continuously expose fresh rock. In the surrounding bush the distinction is more difficult.

The essential distinctions between the core rock and marginal phases of the Texas Creek granodiorite are the differences in composition and colour. The grain size, porphyritic texture and general structure are fairly uniform and suggest a unit plutonic mass. The border phase is distinguished by the green colour, the lower content of potash-feldspar phenosrysts, and the near absence of biotite. Buddington's (1929, p. 26) petrographic work suggested a deficiency of quartz in the contact facies of the Texas Creek pluton when compared to the core of the pluton.

Inspection of 25 thin sections from the core zone showed an average of about 20 per cent quartz, whereas the quartz content in 15 fairly fresh specimens from the Salmon Glacier border zone varied from about 10 per cent to 15 per cent. Late quartz as veins, veinlets, and interstitial blebs is a typical feature of the granodiorite along the contact and this, along with other alteration, has limited petrographic studies in this section to rather minor amounts of fresh material.

Generally, the border phase of the Texas Creek pluton possesses an overall uniformity of texture, grain size, mineral composition, and general mineral relationships. A common intense alteration of all the plagioclase to an intimate mixture of very fine grained sericite and epidote with minor chlorite, carbonate and biotite causes striking colour variations. Most of the perthitic orthoclase grains in the border phase are rimmed and veined by albite. In six thin sections, the plagioclase was found only partly altered and it was possible to determine the composition as about An_{40}. Within the gradational zone, between plutonic material and the clearly recognizable Hazelton Group volcanic conglomerates, the plagioclase porphyroblasts were found optically to be within the range An_{30-34}. As noted in the description of the epiclastic volcanic rocks in this area, the average plagioclase composition in these rocks was also determined as about An_{32}. In areas where the primary structures in the epiclastic rocks were obscured, such as along the west side of the Cascade Creek cataclasite zone, where all rocks are extensively altered, the contact between the pluton and the country rocks was located by determining the plagioclase composition in this section. Elsewhere, as noted by Buddington (op. cit.), the contact relations between the pluton and country rocks are simple and well defined.

In the Texas Creek-Salmon River area, the Texas Creek pluton is wholly discordant with the steeply inclined northerly trending members of the Lower Jurassic Unuk River Formation and deformed equivalents. The steep contact zone, as marked by limited induration and minor deformation developed in the country rocks, suggests a broad, westerly dipping, fairly flat roof. In his summary of granite emplacement, Buddington (1959) recently cited the Texas Creek granodiorite as representative of the transitional epizonal-mesozonal type of batholith. He cites (op. cit., p. 694) the main reasons for this transitional classification as being the steeply discordant contacts and flat roofs, the common aplite and pegmatite dykes in the contact zone only, and the presence of other associated aphanitic and porphyritic dykes, which are all indicative of epizonal plutonism. The observations that the Texas Creek mass is foliated and has intruded "closely folded" country rocks were used as his criteria for a mesozonal character. Indeed, the easterly contact along Salmon River Valley appears to fit his mesozonal classification more closely than he was aware as is indicated by the complex emplacement-replacement relationships, extensive assimilation and flaring walls.

Age of the Texas Creek Pluton

The age of the Texas Creek pluton cannot be determined closely from its external relationships with the sedimentary and volcanic contact rocks except in a general manner. The intrusion, deformation and replacement of Lower Jurassic Unuk River Formation members suggest a maximum age of about only 170 m.y., while the presence of equivalent granodiorite pebbles and cobbles within the base of Lower Oxfordian Nass Formation members indicates a minimum age of about 145 m.y. Potassium-argon determinations on biotite from fresh Texas Creek granodiorite gave an age of 106 m.y. and K/Ar determinations on hornblende from the same samples gave an age of 206 m.y. (Table 3; Smith, pers. comm.). The best fit from the available information suggests that the age of the Texas Creek pluton is about 160 m.y. or Middle Jurassic. The Texas Creek pluton is probably genetically related to widespread early Middle Jurassic volcanism which, as previously outlined, includes extensive andesite-basalt pillow lava at Anyox and in the Bowser River-Treaty Creek section, as well as rhyolite at Monitor Lake and rhyolite flows in the Bear River Pass section.

To date, the Texas Creek pluton and its equivalents in the Stewart area represent the only known, well dated, Middle Jurassic plutonism in southeastern Alaska. Hutchison (1970) showed the location of one Late Jurassic K/Ar age determination (139B, 133H) on quartz diorite located near the eastern limit of the complex. This apparently isolated and anomalous pluton, first reported by White, Harakal and Carter (1968), has only recently been related (Carter, pers. comm.) to a zone of plutons that extends easterly across interior British Columbia between Morice Lake and Babine Lake. The zone has been further related to the Omineca belt of intrusions (Fig. 1) by both Carter (pers. comm.) and Tipper (pers. comm.). The information accumulated by Carter and Grove (1972) to date has not shown the presence of other Middle Jurassic plutons along the eastern margins of the complex between Terrace and Stewart. In the Sulphurets Creek section (Fig. 2A), the writer has described extensive

Table 3. Radiometric age dates, Middle Jurassic and Tertiary Plutons.

Sample No.	Mineral	Age* (m.y.)	Location and unit
68ASj-52	Bio	49.2	U.S.-Canadian border on Hyder-Stewart Road. Hyder qm.
68ASj-163	Bio	49.2)	Small nunatack in Chickamin Glacier, about 1 mile NNW of Mount Jefferson-Coolidge. Hyder qm.
68ASj-163	Hbl	48.7)	
68ADn-75	Bio	50.9)	Ridge between Boundary Glacier and Texas Glacier. Boundary grd.
68ADn-75	Hbl	50.3)	
68ASj-196A	Bio	43.7)	Porphyritic quartz monzonite, a separate intrusive from the Hyder qm. Mouth of Davis River.
68ASj-196A	Hbl	52.5)	
68Asj-160	Bio	106)	Texas Creek granodiorite. East side Ferguson Glacier.
68ASj-160	Hbl	206)	

*All analytical results ± 3%.

biotite granodiorite pebble and cobble conglomerates in basal members of the lower Middle Jurassic Salmon River Formation structural remnant. This granitic material is uniform and is unlike the Texas Creek rocks. To the writer, this evidence suggests the presence of nearby Middle Jurassic (or older) plutons within the Coast Plutonic Complex other than the Texas Creek pluton. Similar biotite granodiorite rocks, part of a small plug and dykes complex, have been shown on the Unuk River geology map sheet just east of the Unuk River on the McQuillan Ridge where younger Hyder phase rocks show cross-cutting relationships. To the north and northwest, in the Stikine River (Map 9-1957) and Tulsequah areas (Souther, 1971), various plutons have been shown but no definite Middle Jurassic units have been determined.

The evidence presented here clearly shows that the eastern margin of the Coast Plutonic Complex includes dykes, stocks, and batholiths of probable Middle Jurassic age. These plutons are generally granodiorite in composition and include gradational phases of quartz diorite, and are commonly similar in general aspect to the more extensive Tertiary plutons.

As previously indicated, pebbles and cobbles of granodiorite are localized at the contact between the Middle Jurassic Salmon River Formation and the Upper Jurassic Nass Formation. This has been interpreted as an extensive erosional event affecting a large part of the Western Cordillera, and has been generally referred to as the Nassian Orogeny (White, 1959). The writer suggests that Middle Jurassic plutons, represented by intrusive phases such as the Texas Creek granodiorite, are more widespread in the Coast Plutonic Complex than generally recognized

(Fig. 18). It is also apparent that Middle Jurassic volcanism, represented by extensive pillow lavas at Anyox and Treaty Creek, and by widespread andesites and rhyolites in the Stewart Complex is more important in the Western Cordillera than generally understood.

Tertiary

Hyder Pluton (Map Unit 7)

The Hyder pluton comprises part of the Coast Plutonic Complex and has been partly described by Hanson (1929, pp. 13-15), and by Buddington (1929, pp. 29-32), who named the unit. At Hyder and Stewart the Hyder pluton is very well exposed in road cuts and along the Salmon River, Bear River and Portland Canal. Elsewhere along the eastern margin of the Coast Plutonic Complex the Hyder phase plutonic rocks are best exposed along tidal zones, canyons and ridge crests. Access is only by helocopter or small boat to most of the outcrop area, and the marked tendency of the plutonic rocks to form rather steep, smooth valley walls greatly limits study. Because the Hyder pluton is not known to contain any significant mineral deposits and,with the exception of the Stewart, Hyder and Anyox sections, it has not been examined in detail by the writer. The overall aspect of the Hyder pluton is fairly uniform, although mapping at Stewart and Anyox has shown rapid mineral variations and gradation within small areas.

In this thesis the Hyder pluton includes the zone of quartz monzonite and granodiorite that extends along the east margin of the plutonic complex from the Unuk River area, southeast along the Alaska

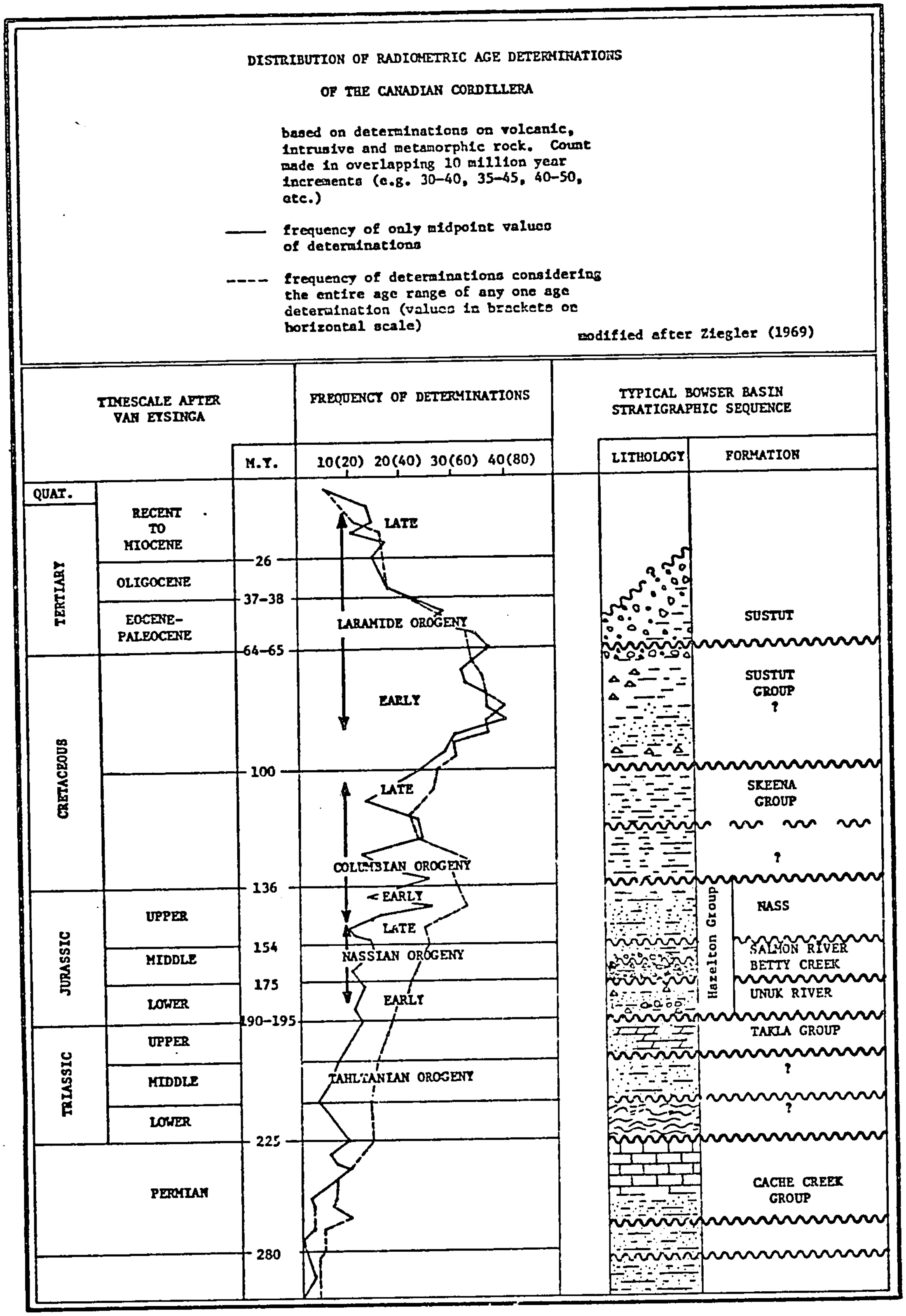


FIG. 18 Distribution of radiometric age determinations of Canadian Cordillera.

boundary through the head of the Portland Canal to Observatory Inlet and Alice Arm. The overall length of this zone is about 110 miles and the width of the zone, which varies from 8 to 20 miles, averages about 10 miles. The main bulk of the exposed Hyder pluton is limited on the west by the central gneiss-migmatite belt and on the east by Mesozoic country rocks. Similar rocks extend southerly into the Terrace area (Carter and Grove, 1972) and northerly into the Stikine River area (Kerr, 1948; Map 9-1957), where the plutonic rocks are described as mainly quartz monzonite, granodiorite and granite. The writer has shown the general limits of the main Hyder pluton on Figure 17; this figure also shows an extensive swarm of satellite plutonic masses localized east of the main plutonic margin within the Stewart Complex. The satellite dykes, stocks and plugs, some of which are correlatives of the Hyder pluton, will be described separately in a following section.

The Hyder pluton is distinguished from the older Texas Creek granodiorite on the basis of mineral composition and colour. In overall aspect, the Hyder pluton is medium grained, porphyritic and light pink to light grey, speckled with fine grained black biotite or hornblende, or both. A predominantly biotitic phase lies north and west of Marmot Bay, while a hornblende-rich phase lies to the south and along the Marmot River. Buddington (1929, p. 30) also noted zoning west of the Salmon River, where the quartz monzonite grades into granodiorite forming the interior of the Coast Plutonic Complex in this area.

In thin section, the Hyder pluton is granitic. The plagioclase which forms from 20 to 55 per cent of the rock is typically euhedral with strong oscillatory zoning, variably altered to very fine grained sericite. The general composition of the plagioclase is about An_{36-38} but the range $An_{20\pm2}$ to $An_{46\pm2}$ has been recognized between the leucocratic to melanocratic phases. The potash feldspars, which commonly form large phenocrysts, generally consist of microcline and perthitic orthoclase and form 25 to 55 per cent of the rock. The potash feldspar content varies from 65 per cent in leucocratic phases to 10 per cent in the melanocratic phases.

The ferromagnesian minerals are represented by both fine grained biotite and fine to medium grained hornblende. Together these two minerals generally comprise from 2 to 10 per cent of the rock and they are seldom extensively altered and can usually be discerned in hand specimen. In addition to the variation in the amount of predominant ferromagnesian mineral in the rock, already noted above, there is also an indication of grain size variation apparently associated with the texture of the rock. That is, in the fine, even-grained quartz monzonite near Hyder, the biotite is black and fine grained, whereas in the strongly porphyritic rock, to the east at Stewart, the brownish-black biotite is medium to coarse grained. The gradation from porphyritic biotite quartz monzonite to hornblende granodiorite is readily apparent in the excellent rock exposures between Stewart and the Marmot River. The transition here from biotite to hornblende granodiorite is fairly sharp, and these phases of the Hyder pluton are distinct in aspect and composition from Texas Creek pluton.

The small, ovoid pluton which intrudes the Texas Creek pluton just west of the Salmon Glacier (Figs. 3, 17) was originally mapped and named the Boundary granodiorite by Buddington (1929, pp. 32-38). He described the Boundary pluton as a massive, light coloured rock predominantly composed of white plagioclase with scattered grains of pink orthoclase, glassy quartz, black biotite and hornblende. Both the biotite and hornblende are euhedral, each forming 6 to 7 per cent of the rock and are partly replaced by the feldspars and quartz. The plagioclase is typically complexly zoned and has an average An content of andesine. Alteration is widespread although minor and includes fine grained chlorite, magnetite and sericite. Buddington (1929, p. 32) suggested that this unit could be confused with the surrounding Texas Creek pluton and, because of its composition, represented a less advanced stage of differentiation than the Hyder pluton.

From Mount Bayard, near the contact of the Texas Creek and Boundary plutons, the Hyder pluton trends northwesterly in a sinuous manner. This trend leads to the main bulk of the Frankmackie Icefield, and the rocks in this extensive area are known only from scattered nunataks and ice margin exposures. The granitic rocks in this section are massive, white weathering, pink porphyritic, biotite-hornblende granodiorites very comparable in aspect and composition to the isolated Boundary granodiorite. The grey-white plagioclase, which forms about 45 to 50 per cent of the rock, is strongly zoned and ranges in composition from andesine to oligoclase. Pink orthoclase, which forms conspicuous phenocrysts and constitutes about 15 to 20 per cent of the rock, appears to be less abundant at country rock contacts where it is also finer grained as compared to the interior of the pluton. Glassy, interstitial quartz forms about 25 per cent of the rock. Biotite and hornblende together generally amount to 10 per cent or less, with the hornblende commonly more prominent near the contact with the country rocks. The overall composition of the exposed Hyder pluton in this large area is probably granodiorite with lesser areas of quartz monzonite.

The bulk of the Hyder pluton, extending from Stewart south through Hastings Arm to the south limit of the map area, is characterized by fresh, white weathering, massive, or rarely, weakly foliated rock which locally varies from granodiorite to quartz monzonite. Weathering of the rock has been localized by widely spaced joint systems to form ridges that are steep-walled with rounded crests, called "Yosemites" in the physiographic terminology. Along the fjords, particularly Observatory Inlet, the steep walls are puckered by huge glacial grooves (Plate 22).

Most of the Hyder pluton is medium to fine grained, commonly porphyritic, and usually contains about 10 per cent black biotite and hornblende. As previously noted, at Stewart the mafic components of the Hyder pluton change abundance rapidly within small outcrop areas creating an apparently continuously changing sequence. The plagioclase in the pluton is grey-white, shows oscillatory zoning, resorbed grain boundaries, and generally has an andesine to oligoclase composition. Quartz is interstitial,makes up from 15 to 35 per cent of the rock, and along with the pink, coarsely perthitic potash feldspar gives the rock an overall pinkish hue.

In the Anyox area, the Hyder pluton is particularly well exposed along Observatory Inlet adjacent to and just south of the Anyox pendant.

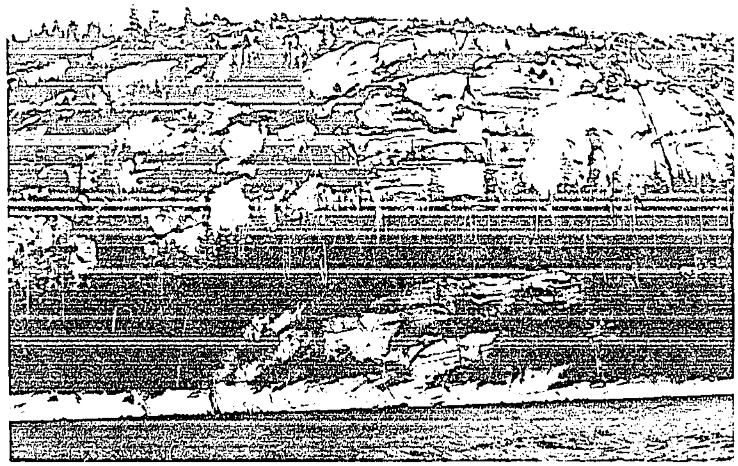


Plate 22. Glacial grooves, Hyder pluton, Observatory Inlet area, looking east.

Plate 23. Sill-like phases, Hyder pluton, Anyox area, looking west.

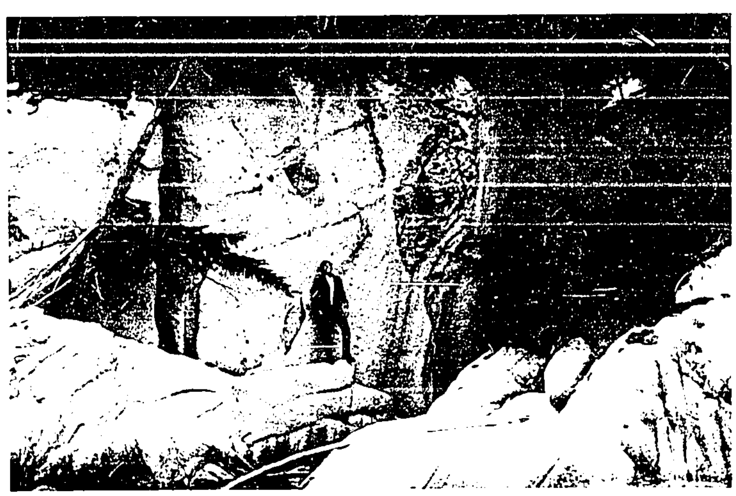


Plate 24. Inclusions, Hyder pluton, Observatory Inlet area, looking west.

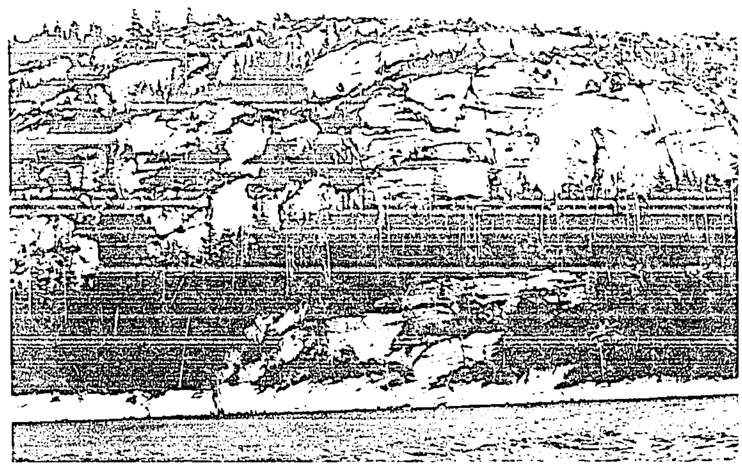


Plate 22. Glacial grooves, Hyder pluton, Observatory Inlet area, looking east.

Plate 23. Sill-like phases, Hyder pluton, Anyox area, looking west.

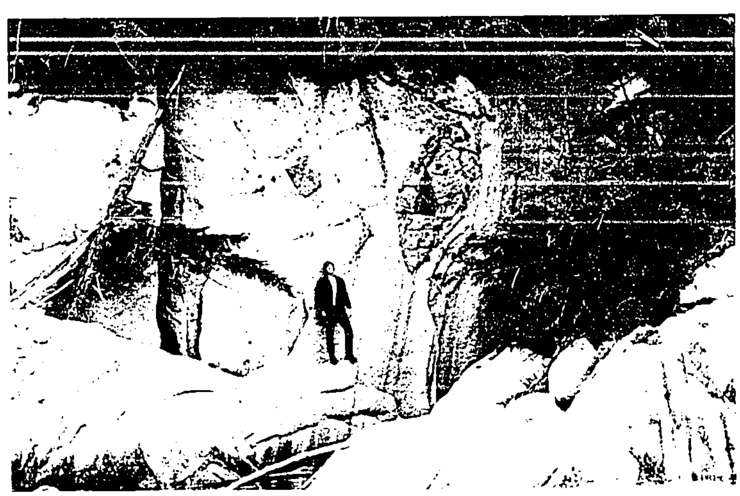


Plate 24. Inclusions, Hyder pluton, Observatory Inlet area, looking west.

The shoreline is fairly low and the rock has been completely denuded by the old smelter fumes, several huge fires, and by the heavy rains. Here, the apparently simple, massive rock is seen to comprise a layer cake sequence comprised of fine, medium and coarse grained, sill-like quartz monzonite members, with knife edge contacts. Many of these non-foliated units are about 10 to 30 feet thick and were traced for hundreds of feet (Plate 23). Elsewhere, the porphyritic coarse grained sections were seen to contain large block-like granitic inclusions (Plate 24), and were traversed by numerous aplite dykes. Near the contact of the Hyder pluton with the country rocks forming the Anyox pendant, black, medium grained biotite forms up to 15 per cent of the rock, and the quartz content is about 35 per cent. The quartz-rich, biotite zone was traced along the main pendant contact zone and was found to have a highly variable width, generally averaging less than one half mile, but seemingly related to the attitude of the country rocks. That is, the zone was widest in the pluton at Observatory Inlet where the gently folded siltstones are only gently dipping, and the narrowest where the Hyder pluton cuts across the steep lying volcanics and cataclasites.

The Hyder pluton is generally altered and comprises clouded, or sericitic plagioclase, chlorite-magnetite alteration of the biotite and hornblende, as well as occasional pervasive secondary epidote, quartz and pyrite.

Accessory minerals common to the Hyder granodiorite-quartz monzonite are apatite, magnetite and sphene. Molybdenite has been noted as a frequent constituent, particularly in the quartz-rich, biotitic zones. The molybdenite commonly occurs as discrete flakes with quartz on joint surfaces, as discrete interstitial flakes with rosettes in quartz veins, and as veinlets criss-crossing small areas of the pluton. To date, with the exception of the few molybdenite occurrences just south of Anyox, there has been little interest in the Hyder pluton as an economic source of molybdenite.

It is difficult to estimate the relative amount of pendant or inclusion material within the Hyder pluton, but as seen in the excellent exposures along Observatory Inlet, one would estimate from these exposures that the pendant material amounts to about 20 per cent. The distribution of inclusions appears to be random throughout the length of the pluton. The relationship of the vast majority of inclusions to the nearby country rocks is unknown, but the large pendants appear to be structurally continuous with the nearby country rocks suggesting little else than generally passive emplacement.

The westerly contact zone of the Hyder plutonic phase and the gneiss-migmatite complex has been defined by the writer only in the Anyox district. Here the contact was drawn between the uniform, massive Hyder pluton and the highly variable gneisses and migmatites with a high degree of confidence. Although the Hyder phase appears to roughly parallel compositional layering in gneisses and schlieren near the contact, the gross northwesterly trend of the pluton transects the dominant northerly trending gneisses at a moderate angle. In the Leduc River area northerly trending gneisses are also cut at an oblique angle by the Hyder pluton (Fig. 2A).

The eastern contact of the Hyder pluton with the Hazelton Group sedimentary and volcanic rocks is generally sharp, steep, marked by associated dykes, minor shear zones, and a few examples of rheomorphic breccias. Narrow, indurated hornfelsic margins, and large roof pendants appear to be characteristic. The eastern contact zone is generally simple and discordant and fits Buddington's (1959) concept of an epizonal Tertiary intrusive.

Buddington's (1959) examples from the Coast Plutonic Complex appeared to him to indicate catazonal and mesozonal emplacement in Alaska and epizonal to transitional epizonal-mesozonal in the Portland Canal-Stikine River section. However, he has suggested (op. cit., p. 732) that the Coast Plutonic Complex of southeastern Alaska and adjacent British Columbia is principally mesozonal. In terms of Read's (1957) Granite Series, the Hyder pluton exhibits generally allochthonous relationships and is probably epizonal. Krauskopf's (1968) very cogent, and pointed review of the Inyo Batholith, pointed out the numerous problems regarding batholiths and batholithic emplacement that are impossible to solve. He made several remarks which seem fairly pertinent at this point (1968, p. 16):

> "The vexing problem of granite emplacement, may have a similar unreal aspect. Again this is a field problem, and again the field evidence is hopelessly contradictory. Does the problem have meaning? Is there reason to expect that the position of a pluton will have some definite relation to surrounding rocks and structures?"

Contact relationships between the Anyox pendant and the surrounding Hyder plutonic phase provided the writer with a field example worth pondering in respect of the question of emplacement as raised by Krauskopf. The northern contact of the Hyder pluton with the Hazelton

Group rocks of the Anyox pendant is sharp, nearly vertical, has a narrow indurated, weakly hornfelsic contact margin, lacks any detailed indications of deformation, and suggests passive epizonal emplacement. The pendant rocks and their structures are continuous with the main body of country rocks at Alice Arm and suggest that the mass has not foundered. The southerly contact of the pendant is well exposed and exhibits multiple contact relations. On the Portland Canal side, the contact is steep and sharp near the shore and follows the stratigraphy. Inland, the pluton cuts obliquely across the cataclasite zone exhibiting uneven, complex gradations. In the central zone the contact is sharp and virtually flat where the pluton underlies the pillow volcanics (Plate 25). Then, towards Observatory Inlet, the granitic contact shelves under the Anyox syncline at a low angle and has been located by diamond drilling at shallow depths in Bonanza Creek. No evidence of emplacement related to deformations was recorded along the contact described. At Tauw Creek, at the south end of the pendant, a small stock-like projection of the main Hyder phase has been emplaced along the axial plane zone of the Bonanza syncline and the tip of this spear-like mass has caused extremely complex deformation in the axial zone (Plate 26). This section is comparable to Mehnert's migmatite front (1968, p. 280), and a comparison of the photographs would show the similarities.

Age of the Hyder Pluton

Lithologic relationships between the Hyder pluton and country rocks indicate only that the batholith has intruded late Upper Jurassic

Plate 25. Contact between Tertiary Hyder pluton and Betty Creek pillow lavas, Anyox area, looking northwest.

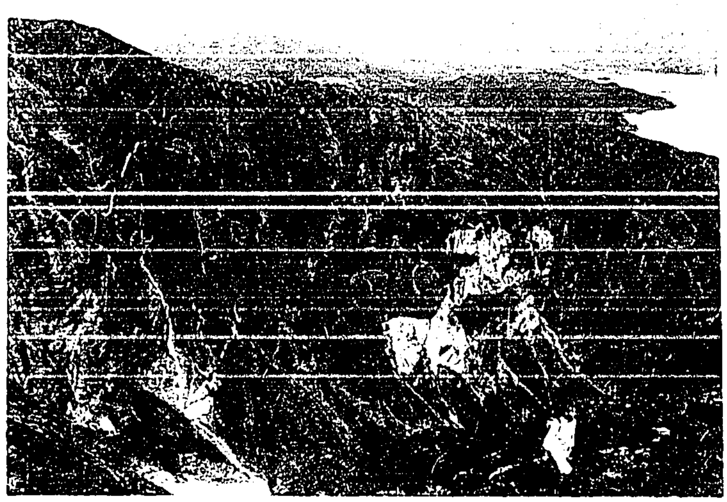


Plate 26. Migmatite front, between Tertiary Hyder pluton and Salmon River strata, Anyox area, looking north.

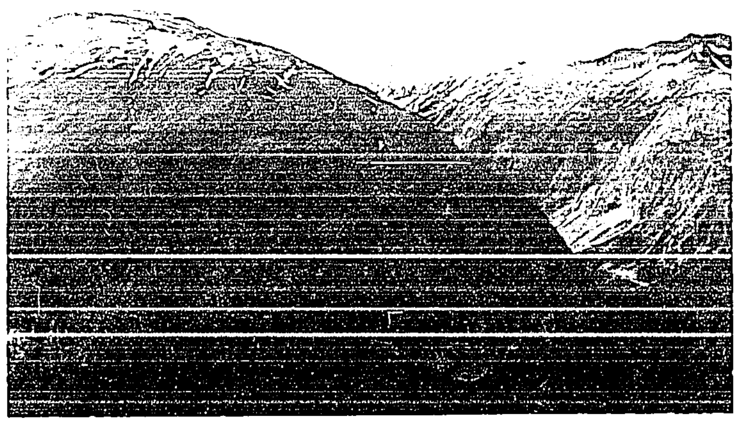


Plate 25. Contact between Tertiary Hyder pluton and Betty Creek pillow lavas, Anyox area, looking northwest.

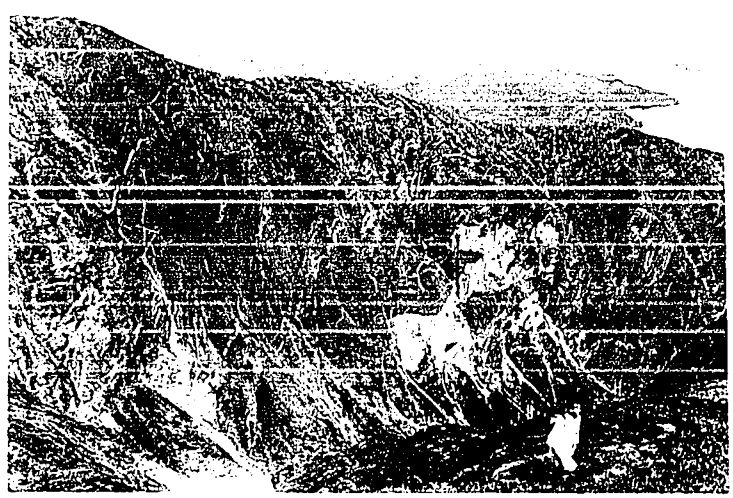


Plate 26. Migmatite front, between Tertiary Hyder pluton and Salmon River strata, Anyox area, looking north.

sediments. However, absolute age determinations on samples taken from the Hyder phase in both the Stewart and Anyox-Alice Arm districts indicate Tertiary emplacement. Near Stewart absolute age determinations by the United States Geological Survey using K/Ar methods gave dates from 47-51 million years (± 2-3 m.y.). The detailed results provided the writer are shown in Table 3 (page 168). Regarding the Hyder pluton, Smith (pers. comm.) stated:

> "Potassium argon determinations by the U.S. Geological Survey on five samples of granitic rocks from the Hyder area indicate two intrusive episodes. The younger episode took place 45-50 million years ago. The numbers for the Hyder and Boundary rocks are firm, but all we can say at this point about the Texas Creek is that the Texas Creek is older than the other Coast Mountain intrusions and its K/Ar clocks were affected by the 45-50 m.y. intrusions."

In the Anyox-Alice Arm district, Carter (pers. comm.) has made several absolute age determinations on the Hyder plutonic phase using K/Ar equipment at the University of British Columbia. His results indicate a range of 48-51 m.y. for the crystallization of the pluton.

Hutchison (1970) has outlined three regional plutonic zones trending northwesterly, parallel to the trend of the Coast Mountains. The youngest, eastern allochthonous zone to which the Hyder plutonic phase is related has yielded ages grouped about 45 m.y. ± 4 m.y. Souther (1971) has outlined an Upper Cretaceous or early Tertiary phase of the Coast Plutonic Complex at Tulsequah but the only absolute age determination he reported was 69 m.y. from a non-foliated quartz monzonite batholith. To the south, in the Bella Coola-Ocean Falls area, Baer (1969) reported the probable existence of late Tertiary, post-kinematic granites and basalts, but he did not provide absolute age data.

As a result of the recent field work it is most probable that the Hyder pluton represents one of many Late Cretaceous-Tertiary granitic plutons localized along the eastern margin of the Coast Plutonic Complex.

Discussion

Gilluly (1972) has suggested that the apparent abundance of Tertiary intrusions in the North American Cordillera (e.g. Fig. 17) is not a direct measure of their real abundance. As the writer has indicated, the Middle Jurassic plutons, for example, have not been generally recognized, and these as well as other older plutons have generally been included in the past within Upper Jurassic, Cretaceous and Tertiary plutonic zones (Roddick, 1966, pp. 78-79).

The writer suggests, both the current concept that the Coast Plutonic Complex includes mainly Upper Cretaceous and Eocene plutons (Roddick, 1966) and the older concept that the Coast Range batholith was a mainly Upper Jurassic-Lower Cretaceous event, require modification. It is now apparent that the Coast Plutonic Complex includes plutons ranging in age from Ordovician (?) to Tertiary. It is also apparent that unlike the Late Triassic to Late Cretaceous Sierra Nevada batholith (Kistler and others, 1971), which was emplaced along divergent linear trends, the Coast Plutonic Complex has evolved within a single, narrow belt. Kistler and others (1971) suggested that the present positions of loci of age groups of batholithic rocks can be explained by the drift of the North American continent across a linear zone of high heat flow, or by a heat source and continent moving relative to each other, and that magmatic events in the mantle instigated the massive introduction of granitic rock forming the Sierra Nevada batholith. Kuno (1959, 1966) and Dickinson (1968) related magma production to under thrusting of oceanic lithosphere, to which they accounted the chronology and areal distribution of the plutonic rocks of North America and contemporary orogeny of the continental margin. Hutchison (1970) has suggested that the absence of ultrabasic rocks in the Coast Plutonic Complex indicates there has been no appreciable direct contribution from the mantle. It therefore appears that the Coast Plutonic Complex has no direct similarity to the Sierra Nevada batholith and the question of its ultimate origin, as Hutchison (1970) has stated, must await more detailed studies.

The writer has previously drawn attention to the close spatial and temporal relationships between the Middle Jurassic Texas Creek pluton and the Middle Jurassic Monitor Lake rhyolite member. Miyashiro (1967) has also indicated the broad contemporanity of the granitic plutons and rhyolite rocks of the Ryoke-Abakuma metamorphic belt. He (op. cit., p. 423) suggested that the "granite-rhyolite" association may be characteristic of the low P/T type of regional metamorphism. He (1967) also indicated that this association may be related to relatively shallow depths of formation of granitic and metamorphic rocks. The evidence presented in this study and by Buddington (1959), indicates that the Texas Creek pluton was emplaced in relatively shallow epizonal-mesozonal environment, and was probably related to low grade regional metamorphism marked by sporadic andalusite developed in certain Middle Jurassic siltstones.

It is now generally presumed that the large composite batholiths of orogenic belts are emplaced in the upper crust beneath a cover of their own volcanic ejecta (Hamilton and Myers, 1967; Hamilton, 1969; Dickinson, 1970). This hypothesis assumes that the emplacement of plutonic rocks and the extrusion of volcanic rocks are roughly contemporaneous events, and that the parent magmas are cogenetic. Hutchison (1970) has supported this concept and suggested that the plutons of the Coast Mountains represent the deep section of volcanoes. In the Stewart Complex, the Texas Creek pluton and the various Middle Jurassic volcanics appear to be very closely related in time and space, supporting the above hypothesis. James (1971) has also indicated that evidence from the volcano-plutonic complexes of the Andes supports the theory of consanguineous intrusive and extrusive rocks. It therefore appears to be a reasonable conclusion that the thick andesitic volcaniclastic and volcanic Triassic and Jurassic assemblages found in the Stewart Complex are generally related to relatively shallow magma emplacement in part, at least, localized within the Coast Plutonic Complex.

Central Gneiss Complex

Metamorphic rocks are concentrated in three areas, at the margin of the Stewart Complex, along the east contact of the Tertiary Hyder pluton, and west of the complex in the relatively unknown Alaska section. The bulk of the metamorphic rocks in association with the Tertiary plutons constitute the eastern margin of the Coast Plutonic Complex. Within the complex the metamorphic rocks include mixed, banded gneiss, migmatite and minor gneissic plutonic rocks.

The recent metamorphic map of the Canadian Cordillera compiled by Monger and Hutchison (1971) illustrates the general northwesterly trend of the metamorphic belts in the Coast Ranges of British Columbia. A simplified metamorphic map of part of the Western Cordillera (Fig. 19) has been included with this study to show the relative position of the Stewart Complex within the regional metamorphic environment.

Gneisses and Migmatites (Map-unit 1)

Portland Canal Area

Monger and Hutchison (1971) have indicated the Portland Canal-Observatory Inlet area comprises massive granitic material, however the writer has shown that the Central Gneiss Complex extends to the contact with the massive Hyder pluton, that is, to within about 10 miles of the east margin of the Coast Plutonic Complex. The Portland Canal district includes a variety of gneisses, generally of a granodioritic to quartz monzonitic composition, marked by well developed foliation, abundant microcline and extensive quartz-rich zones.

The granitoid gneisses are mainly coarse, even grained, pinkish to grey, moderately well foliated rocks that occur in northerly trending lenses, and are commonly gradational between augen gneiss and banded gneiss. The mineralogical composition of the granitoid gneisses is simple, and on the basis of 15 samples averages 30 per cent quartz, 18 per cent microcline, 38 per cent plagioclase, about 11 per cent biotite, with minor hornblende, and minor apatite, sphene and opaques. Quartz is generally interstitial, and shows moderate undulatory extinction near

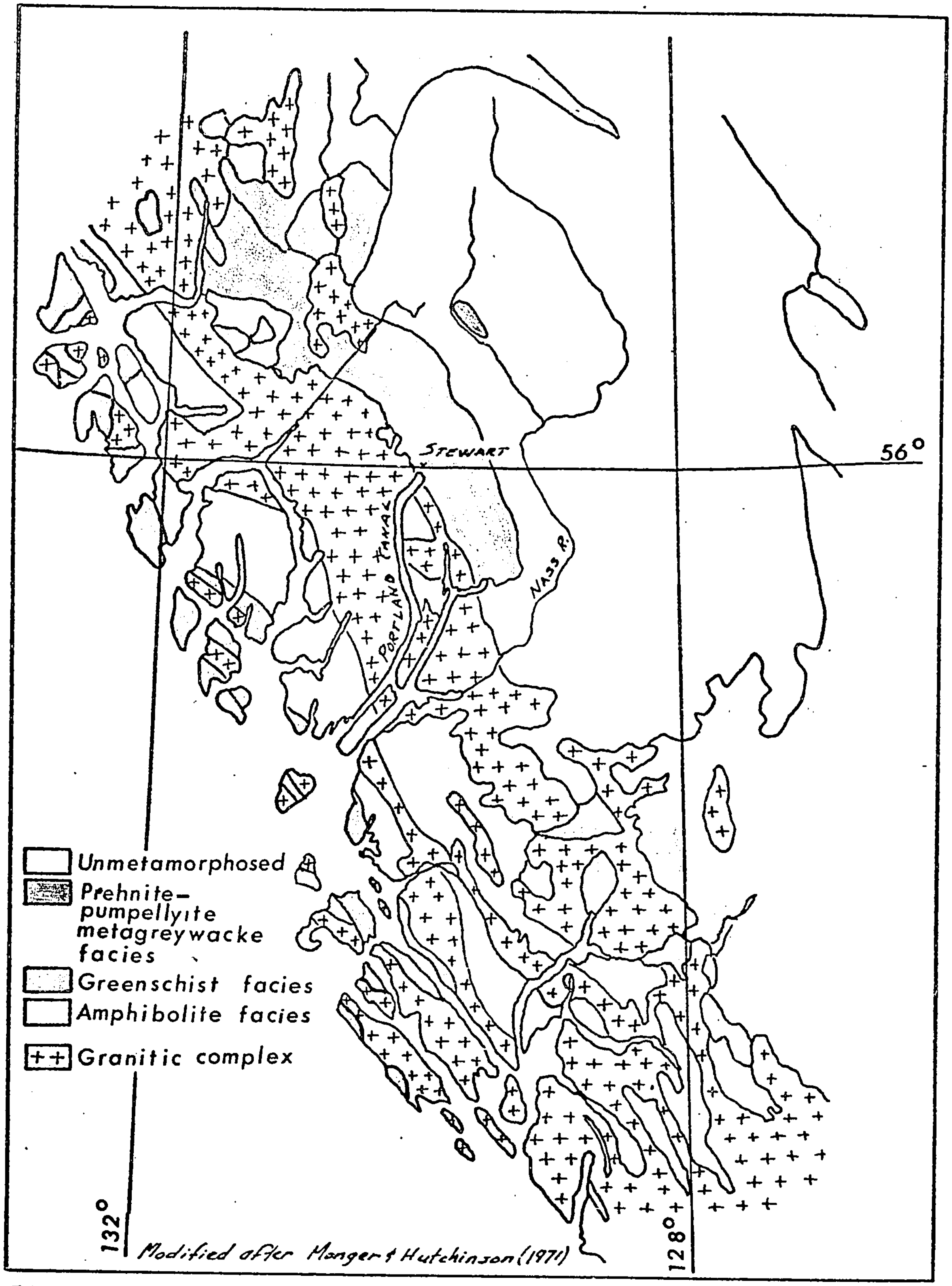


FIG. 19 Metamorphic belts, Northwestern British Columbia.

contacts with augen gneisses, but is otherwise clear and undeformed. The plagioclase is euhedral, rarely zoned, and shows considerable variation in the amount of sericitic alteration. The composition of the plagiocalse is about An_{28}. Microcline typically shows grid twinning, and generally replaces plagioclase along grain rims and cleavage planes. The microcline is variably porphyroblastic and 2V determinations with the universal stage give values between 84^{o} and 88^{o}. Biotite, in part moderately altered to chlorite, is a dark brown to pale green in colour. The composition of these gneisses is usually that of granodiorite, although considerable variation towards quartz monzonite and more mafic-rich phases occurs.

Augen gneisses occur as gradational phases within the coarse grained granitic gneisses and as lenses between grey gneisses and banded gneisses. The zones are generally difficult to trace, but excellent exposures are found at Hattie Island where it is reported that the augen gneiss was once quarried for headstones. The augen gneisses are generally pinkish, very coarse grained, and occur as northerly trending lenses or bands. They are typically moderately foliated, and mineral lineation is rare. The augen gneisses are generally concordant with the grey and banded gneisses; these contacts are also commonly marked by local faulting. The mineralogy of the augen gneiss, like the granitoid gneiss, is simple and the composition based on 8 samples indicates about 25 to 30 per cent quartz, 35 to 55 per cent microcline, 20 to 30 per cent plagioclase, 5 to 10 per cent biotite, and minor accessories including apatite, sphene, epidote and opaques. The gneissic texture relates to the parallel development of the biotite folia, quartz stringers and fine grained aggregates of plagioclase and microcline. Microcline generally occurs as euhedral single crystal porphyroblasts, but variations and gradations to porphyroblastic aggregates are common. The microcline exhibits cross-hatched twinning, and generally appears to be the latest mineral to crystallize and forms veinlets cutting plagioclase. Several 2V measurements on microcline gave results between 84^{o} and 86^{o}. The plagioclase is generally euhedral, weakly zoned and commonly altered and was found to have a composition of An_{28}. Biotite in these rocks is brown to light brown and commonly chloritic. The augen gneisses are principally leucocratic quartz monzonites although like all granitic rocks in the area, they show rapid variations within short distances in both femic and mafic constituents.

The migmatites are well exposed along Portland Canal where they appear to comprise up to 40 per cent of the gneiss complex. There may be two generations or more in this belt related to periodic anataxis and plutonism, but only one recognizable stage is conspicuous within the main zone. The Georgie River pendant has been cut by the Tertiary Hyder quartz monzonite and the pluton margins are enveloped by a 500 foot wide agmatitic zone in which rotated blocks of indurated, hornfelsed country rocks are veined by a reticulate stockwork of quartz-feldspathic material (Fig. 2C). Within the main gneiss complex, the migmatite content appears to increase towards the southwest where, at the boundaries of the study area, broad zones of mixed mafic and granitic gneisses grade into rheomorphic breccia and agmatite complexes. Structure in these zones, as outlined by foliation in the gneisses, swings rapidly and suggests gently dipping to flat lying gneiss zones.

The most spectacular development of migmatite in the study area is found along Tauw Creek, near the southeast corner of the Anyox pendant, where a quartz-rich granitic stock has penetrated the axial zone of the Hidden Creek Syncline. The migmatite zones, exposed on the vertical canyon walls, include a complex composed of concentric shells, the outermost represented by indurated, generally biotitic siltstone with inner shells of quartz-feldspathic gneiss, biotite schist and coarse grained quartz-microcline pegmatite (Plate 26). Several of these magmatite fronts are found in the sediments in this area and appear to correspond to similar structures in Greenland (Mehnert, 1968, p. 280, Fig. 110).

Banded gneisses are prominent in the Belle Bay area, where they are intercalated with augen gneiss, grey gneiss and migmatite. In these zones the dark banded gneisses consist principally of medium grained black biotite with variable quartz, plagioclase and minor microcline. The leucocratic bands are fine grained and generally have a granodioritic composition.

Unuk River Area

The small area of northerly trending gneisses shown on the Unuk River geology map (Fig. 2A) represents the oldest rocks known in the study area. The gneisses are overlain by Late Triassic and Lower Jurassic country rocks with apparent fault relationships. Clasts of gneiss in the Hettangian member of the Unuk River Formation indicate the presence of a pre-Lower Jurassic metamorphic complex to the west. The adjoining southeastern Alaska area has extensive snow and ice cover and has not yet been mapped. As a result, information about the extent of this pre-Late Jurassic metamorphic zone is not available.

In the Unuk-Leduc area, opposite Granduc Mountain, the metamorphic zone includes banded gneisses, transitional zones of augen gneiss, pegmatites, and swarms of dykes. The Tertiary granitic plutons transect the gneiss structure and have narrow contact metamorphic aureoles. To the east, the gneisses are bounded by the South Unuk cataclasite zone, but the contact is hidden beneath the North and South Leduc Glaciers.

The gneisses which comprise the bulk of the remnant are thinly layered, fine grained, light and dark coloured hornblende and biotite gneisses. The mafic rich gneisses are interbanded with coarse grained, thick layered granitoid gneiss, and augen gneiss, and are cut by irregular tourmaline-bearing, quartz-rich pegmatites. The hornblende gneisses are fine grained, dark coloured, and generally form layers about one cm wide within more quartzose layers. The quartz content ranges from 5 to 35 per cent; the plagioclase, which is typically unzoned, has a composition of about An_{26} to An_{28} and comprises 25 to 40 per cent; the hornblende is dark brown to bluish-green, commonly altered to biotite, chlorite and epidote, and forms up to 45 per cent of the dark layers. In light coloured layers, brown biotite ranges from 5 to 15 per cent and hornblende forms up to 10 per cent, although much has been altered to epidote, chlorite and magnetite. In granitoid bands, biotite is the dominant mafic mineral and microcline forms from 30 to 50 per cent of the weakly foliated layers. Plagioclase in these units, which has a composition of about An_{28}, is typically fresh and lacks optical zoning. The augen gneisses are marked by clump porphyroblasts of microcline and are quartz-rich with medium grained biotite and plagioclase comprising the matrix. The gneisses vary considerably in mineral content, but simple granodiorite gneisses are the principal rock type.

Discussion

Hutchison (1970) has indicated that the pattern of metamorphism in the Coast Plutonic Complex is typical of progressive regional metamorphism, and from west to east ranges from green schist facies through amphibolite facies. The eastern limit of highest grade, sillimanite-cordierite zone roughly extends from Ramsden Point (where Portland Canal joins Observatory Inlet), southeasterly to the Skeena River (Fig. 19). The gneisses east of this line along Portland Canal and Observatory Inlet comprise simple mineral assemblages, including biotite and K-feldspar, and represent amphibolite facies regional metamorphism (Miyashiro, 1967, p. 278). The writer has recognized sporadic andalusite in the Middle Jurassic siltstone at Anyox, related to pre-Tertiary regional metamorphism, which indicates amphibolite facies of regional metamorphism (Miyashiro, 1961, p. 279; Turner, 1968).

If, as Hutchison (1970) has suggested, these regional metamorphic mineral assemblages are all part of one facies series, then the assemblages lie within the Barrovian facies series outlined by Hietanen (1957). If the andalusite, found at Anyox, represents a valid regional metamorphic mineral phase, the local assemblages would lie within the lower pressure Idahoan facies series (Miyashiro, 1967, pp. 284-285). As Hutchison (op. cit.) has pointed out, this long, narrow complex belt has probably evolved through several regional metamorphic cycles, repeated plutonism, and sequential block uplift.

The overall similarity of the gneisses in the Unuk River and Portland Canal areas suggests a genetic relationship. The two areas are now completely separated by the intrusive Hyder pluton, but by projection, the two segments appear to be co-structural. This apparent continuity suggests that the gneisses west of Anyox, along the Portland Canal, are at least pre-Lower Jurassic in age, and may, like the Unuk River zone, be Middle Triassic or older.

Souther and Armstrong (1966) and Souther (1971) have suggested a Middle Triassic or older age for regionally metamorphosed strata in the Tulsequah area. The evidence of a probable pre-Devonian crystalline Complex as outlined by Misch (1966) in the northern Cascades, and the pre-Devonian metamorphic complex in southeastern Alaska (Brew et al., 1966) gives an approximate age for the beginning of the evolution of the Coast Plutonic Complex The evidence previously cited, indicating at least two younger periods of regional metamorphism, suggests a continuous complex evolution within the gneiss complex that is related to polyphase plutonism.

Satellite Plutons

Introduction

The writer has mapped and studied one of the most extensive concentrations of satellite plutons known along the eastern margin of the Coast Plutonic Complex. The location of these bodies within the Stewart Complex, and their relation to the major tectonic elements are shown in Figures 1 and 17. Most of these bodies and their relationships and implications are described here for the first time.

Because all the earlier work in the study area represented only small fragments of the Stewart Complex, the large number and diversity of these individual plutons and complexes were never recognized. It was not until the writer's mapping that the concentration of such diverse plutons was found to be spatially restricted to the Stewart Complex, and confined to a belt bounded on the west by the Coast Plutonic Complex and on the east by the Meziadin Hinge.

The length of the belt between Alice Arm and the Iskut River is about 110 miles, and the width, which varies from 10 to 25 miles, has its maximum in the Unuk River area, and the minimum at Alice Arm. The satellite belt parallels the margin of the north-northwesterly margin of the Coast Plutonic Complex transecting the northerly grain of the country rocks. Many of the individual plutons are semi-concordant, whereas major dyke swarms trend northwesterly and northeasterly and are strongly discordant with the local fabric. The plutons which range in age from Late Triassic to Late Tertiary have a wide range of rock compositions, from gabbro through syenite, diorite, quartz diorite, granodiorite, to quartz monzonite. Many of these satellite plutons have related metallic sulphide mineralization and one, the Lime Creek pluton, near Alice Arm, is currently being mined, and the operation, the B.C. Molybdenum mine, represents the second largest molybdenum producer in Canada. Because of their large number, and to simplify discussion, the satellite plutons will be described according to groups.

Most of the known mappable plutonic units are illustrated on the geological maps (Figs. 2 and 3).

Upper Triassic (Map Unit 4)

Character and Extent

The McQuillan Ridge pluton is an elongate, irregular, northerly trending mass lying between the South Unuk River, Harrymel Creek and Unuk River junctions. The pluton is fairly well exposed along the north end of McQuillan Ridge, above Cebuck Creek, and the high cliffs above the Unuk River. It has a length of about six miles and a width from one half mile to one mile. The pluton exhibits gradational zoning from massive, coarse grained, white weathering quartz diorite in the central part of the pluton to a medium grained hornblende diorite at its south end. Although the northern part is poorly exposed, and has been cataclastically deformed it is thought to be principally melanocratic granodiorite. In the field the distinction between the country rocks and the pluton is easily made at the sharp contacts, but is more difficult along the southeastern margin where the pluton grades into altered, stratified, volcanic conglomerates over a distance of several hundred feet, a gradation that is presumed to represent local granitization. The country rocks have been indurated along most of the contact to form a generally narrow hornfels zone marked by conspicuous euhedral brown hornblende.

Near the contact the hornblendes are from one to three cm long and 50 feet from the contact they are only one to two mm long.

With rare exception, specimens examined in thin section show that the mafics and feldspars in the pluton have been extensively clouded by chlorite or sericite. The plagioclase is andesite; it is zoned, shows albite twinning, and is altered. The quartz and some potash feldspar is fine grained, and both are largely interstitial. Fine grained magnetite, angular sphene, and apatite are common accessory minerals in the rock. Altered poikiloblastic brown hornblende is the major mafic mineral and generally forms from 12 to 15 per cent of the rock; two to five per cent secondary red-brown biotite occurs in altered, deformed zones. The principal alteration minerals noted in the Cebuck Creek section were epidote and calcite as veinlets and interstitial aggregates.

Age

The age of the McQuillan Ridge pluton has been inferred as Upper Triassic from stratigraphic relationships. Country rocks intruded by the pluton have been dated as Karnian age on the basis of Halobia sp. bearing strata. Pebbles, cobbles, and boulders of hornblende granodiorite, identical with material forming the pluton, are found in a thick Lower Jurassic conglomerate near Twin John Peaks (Fig. 2A). The presence of other Triassic plutons along the eastern margin of the Coast Plutonic Complex lends some support to the Late Triassic age assigned to the McQuillan Ridge pluton.

A large massive magnetite-chalcopyrite deposit lies above Cebuck Creek immediately adjacent to the McQuillan Ridge pluton where limestone lenses appear to have been the locus of extensive skarn type mineralization.

The pluton, mineral zone, and country rocks have been deformed in this section, but the spatial relationships of the intrusive and skarn zone has generally been assumed to represent a contact metamorphic association,

Lower Jurassic (Map Unit 5)

Unuk River Intrusions

Several small plutons, apparently of a Lower Jurassic age have been recently mapped in the western part of the Unuk River map sheet (Figs. 2A, and 17). These include deformed hornblende diorites along the South Unuk River, small syenite masses at Sawyer Glacier, a syenodiorite complex at Mitchell-Sulphurets Creeks, hornblende gabbro plutons at Twin John Peaks and King Creek, and a small pipe-like gabbro pluton at Nickel Mountain.

The Nickel Mountain pluton, and the syenodiorite complex at Mitchell-Sulphurets Creeks are currently being explored by mining companies because of associated mineralization. The altered nickeliferous gabbro pluton at Nickel Mountain has been studied by Jeffery (1966) and Grove (1968), and the Mitchell-Sulphurets syenodiorite complex has been extensively studied (Grove 1968). The other plutons in this group were originally mapped by various mining companies during the course of detailed mineral exploration studies. This group of plutons has been called the Unuk River Intrusions by Norman (personal communication) who directed mineral exploration for the Granduc company during 1959 and 1960.

The hornblende diorite plutons just north of Granduc Mountain have intruded Lower Jurassic and older country rocks and lie along the South Unuk cataclasite zone. These plutons are entirely discordant and are characterized by well developed gneiss banding and mineral differentiation. The mineral components include crushed brown hornblende, plagioclase (An_{45-60}), minor quartz, and apatite, sphene, and magnetite as accessories. There are no known mineral occurrences related to these intrusions.

The two syenite stocks at Sawyer Glacier lie within the South Unuk cataclasite zone and are highly deformed. These rocks appear to consist almost entirely of red, perthitic microcline which exhibits grid twinning and appears to represent maximum microcline. The rock is weakly sericitic, but principally appears to have suffered intense cataclasis. Fragments within the finely crushed matrix include microcline crystals up to 20 cm long. Both plutons cut across mixed Lower Jurassic sediments and volcanics with no apparent evidence of metasomatism, or contact metamorphism. Copper and molybdenum mineralization is present in the country rocks, but is not directly related to the syenites.

These two unusual plutons appear to represent either low temperature intrusions, or as suggested by Martin (personal communication) they may have been formed by hydrothermal processes related to local basic magma differentiation. The writer has not attempted to solve this complex problem here because of the lack of details concerning these plutons as a result of rugged topography, poor exposures and extreme deformation.

The syenodiorite complex in the Mitchell-Sulphurets area has been described as a zoned intrusion grading transitionally from diorite at the south end through monzonite, syenite, and quartz monzonite to alaskite granite at the north end (Grove, 1968). The elongate, dyke-like pluton is surrounded by a broad alteration halo, characterized by coarse grained porphyroblastic orthoclase, quartz, sericite, and pyrite. The associated broad alteration zone which is developed in Lower Jurassic epiclastic volcanics and tuffaceous sandstones includes both disseminated copper, and vein type molybdenite mineralization. The complex zone is presently being explored by Granduc Mines Ltd., and this area is being studied as a current thesis project. The nature of the mineralization related to the intrusive has been discussed in Chapter 5.

The age of the Unuk River Intrusions has been inferred on the basis of stratigraphic relationships. The hornblende diorite and syenite plutons which have intruded Lower Jurassic sediments and volcanics have been deformed by late Lower Jurassic deformation. The gabbroic plutons have intruded Lower Jurassic country rocks, and the syenodiorite pluton which has intruded the middle member of the Unuk River Formation has been partly eroded and then covered by Middle Jurassic strata. The general relationships between these plutons and the country rocks indicate that intrusion was completed before the onset of Late Jurassic-pre Middle Jurassic erosion.

If the syenite stocks do represent low temperature hydrothermal products their deposition suggests an essentially non-orogenic environment and possibly regional tension. The general northerly trend of the Unuk River Intrusions, as opposed to the dominant northwesterly trend of the Permian to Tertiary Coast Plutonic Complex, and the apparent spatial relationship of the Unuk River Intrusions to the northerly trending Lower Jurassic cataclasite zone lends support to the postulated tectonic pattern.

Tertiary or Older (Map Unit 8)

Kitsault Intrusions

This group includes at least five small plutons that occur along a narrow, northwesterly trending belt between Alice Arm and Teigen Creek (Fig. 17). These plutons are irregular in shape and are discordant with the country rocks. These plutons are extensively altered and have been cut by numerous lamprophyre and diorite dykes. They are characterized by a porphyritic texture, extensive alteration, and are generally accompanied by minor mineralization. The rock varies considerably in texture and apparent composition. Where relatively fresh, the rock is greenish grey, medium grained, with plagioclase phenocrysts set in a crowded fine grained plagioclase matrix of 1 to 2 mm plagioclase crystals (about An_{30}), altered biotite, and fine grained quartz. The generally pervasive, carbonate-sericite alteration has produced a greenish, massive, pyritic rock marked by plagioclase phenocrysts, and is locally called a feldspar porphyry. These rocks show a textured and compositional similarity to the Premier dykes which are described in a later section.

Mineralization associated with these plutons includes disseminated and replacement chalcopyrite-pyrite in the adjacent country rocks, as well as minor quartz-sulphide fissure veins within the plutons. No major mineral deposits have been associated with the Kitsault Intrusions to date.

The age of these plutons is difficult to determine. They have intruded Middle Jurassic Salmon River strata and have been cut by the Oligocene dyke swarms. At the present they are considered Tertiary or Older, but like the Glacier Creek plutons may represent Cretaceous plutonism.

Glacier Creek Intrusions (Map Unit 8)

Stock-like porphyritic augite diorite plutons are found at Glacier Creek, Long Lake, and at the entrance to Bear River Pass. The distribution of this rock type is shown on Figures 2, 3, and 17.

In appearance these augite diorites are distinct from the nearby Texas Creek and Hyder batholithic masses, as well as from the many satellite plutons found within the marginal belt. The rock is massive, dark brownishgreen, and spotted by coarse euhedral crystals of dark brown altered augite which commonly forms 15 to 25 per cent of the mass. The matrix is generally fine- to medium-grained and dark green. Apart from the augite phenocrysts the mineral content of the rock is difficult to determine macroscopically because of a pervasive alteration. Exposures of these plutons are excellent and the uniform aspect from area to area is impressive.

Thin section studies of these dark green rocks reveal that most of the component minerals are altered. Generally, the augite has been partly replaced by chlorite and sheaf-like bundles of fine grained quartz. The matrix in which these phenocrysts are set commonly consists of a very fine grained felted mass of secondary sericite, black oxides, epidote, and plagioclase needles. The rock is traversed by fine veinlets of ramifying quartz and calcite in hair line fractures. Pyrite is disseminated throughout the matrix and phenocrysts as well. Preserved, primary pyroxene and plagioclase have been determined as augite, and calcic andesine (Plate 27). Primary quartz or alkali feldspar was not recognized although Hanson (1929, op. cit., p. 13) refers to orthoclase as a primary constituent, and termed the rock on Glacier Creek an augite syenite. As previously indicated, most of the plutons in the Stewart Complex are characterized by phase variations. Although the Glacier Creek plutons have been termed augite diorite for the sake of simplicity, monzonitic and syenitic phases occur, but the extensive alteration of the primary material has made precise identification difficult. McConnell (1913, p. 18) termed these rocks augite porphyrite which, although not generally acceptable now, provides a classification for local use.

In outcrop areas these plutons are fairly small, but in the Glacier Creek section just northeast of Stewart, the presence of outliers as well as bleached, indurated siltstones in deep cuts and gulches implies a larger

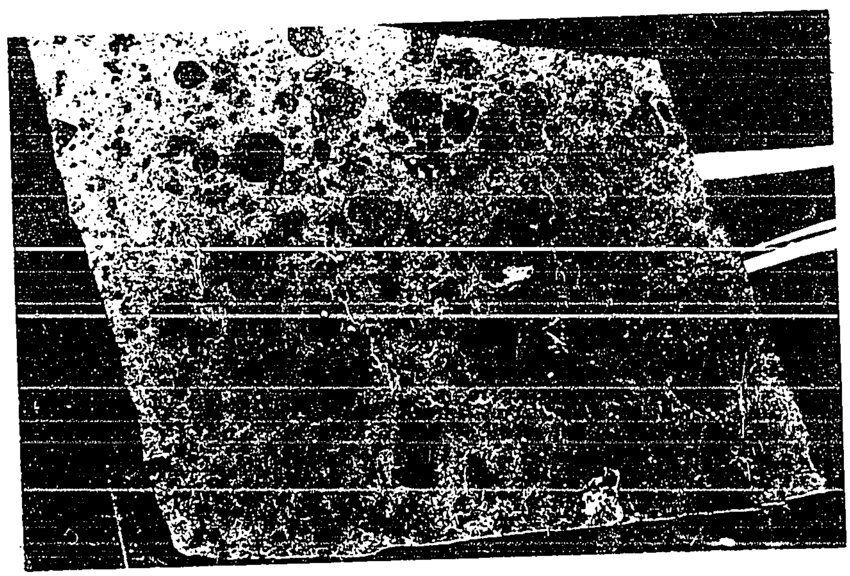


Plate 27. Hand specimen, Glacier Creek pluton, half size.

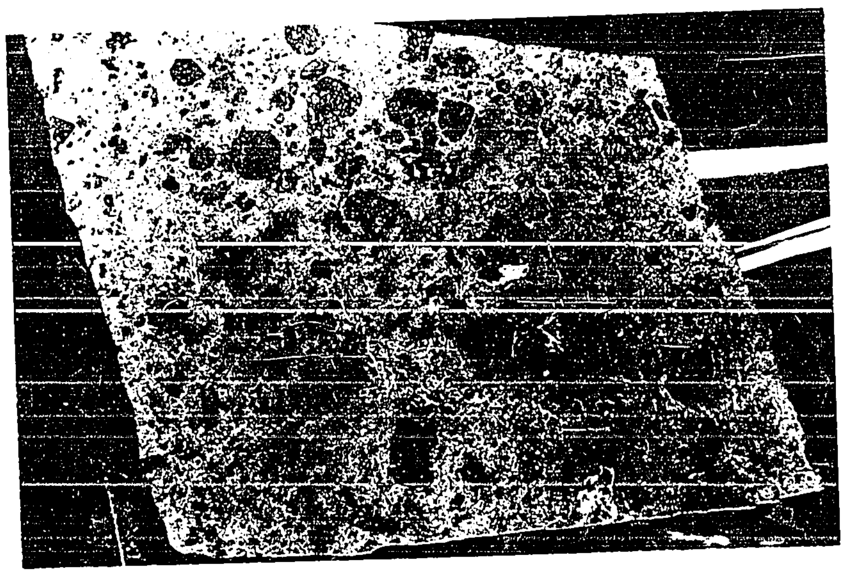


Plate 27. Hand specimen, Glacier Creek pluton, half size.

mass at shallow depth. All of these plutons have apparently concordant contacts with the stratified country rocks, but close observation of the contact zones shows many sill-like and even dyke-like apophyses.

The Glacier Creek plutons have intruded Middle Jurassic Salmon River Formation rocks, and in turn have been intruded by numerous Tertiary granitic and lamprophyre dykes. Until other evidence is collected, these plutons are therefore assigned to an Early Tertiary period of emplacement.

The Glacier Creek plutons have been cut by en échelon groups of coarse, milky white vuggy quartz veins in which sulphide pods and shoots have been localized. Many of these veins have been extensively developed, but no major deposits have been found to date. A number of vein-like, transitional-replacement, quartz-sulphide deposits have also been discovered in the country rocks immediately adjacent to the Glacier Creek stock.

Tertiary

The large satellite Tertiary plutons and extensive Tertiary dyke swarms have a composition and aspect similar to the Hyder pluton. These satellite plutons include the Lee Brant Creek stock, Summit Lake stock, Bitter Creek stock, and Strohn Creek stock (Figs. 3 and 17). Each has an elongate, ameoboid form and sharp, steep, discordant contacts marked by narrow biotite or hornblende hornfels zones which are cut by extensive dyke and sill-like apophyses. For purposes of description these four plutons have been grouped together as the Divelbliss Creek Intrusions, largely because of similarity in size, spatial relationships and apparent lack of known significant mineralization.

At least twenty small stocks and plug-like intrusives have been outlined south of the Divelbliss Creek group of stocks which, because of their similarity in size, composition, and often significant molybdenite content, have been called as a group the Alice Arm Intrusions. These plutons are granitoid massive units with a quartz monzonite composition, sharp, steep, intrusive contacts with narrow biotite hornfels zones, and are less than one half mile in diameter. The best known of this group is the Lime Creek stock which is currently being mined for molybdenite.

Divelbliss Creek Intrusions

Lee Brant Pluton

This pluton or stock is the largest of the group, with a length of about eight miles and an average width of about two miles. The stock lies east of the South Unuk River and is partly cut by Lee Brant and Divelbliss Creeks where the rock is moderately well exposed. The west edge of the Frankmackie Icefield and several small glaciers overlap the main body leaving only small parts accessible for study.

The rock forming the stock is a massive coarse to medium grained grey weathering pinkish quartz monzonite which is closely jointed and sheds large slabs into the small valleys. The colour index of the rock is generally less than 10, with coarse grained fresh biotite the predominant dark mineral. Hornblende, which is usually present is medium grained, and locally forms the significant mafic constituent near the intrusive margins. In thin section the plagioclase is weakly altered, shows strong reversed oscillatory zoning, and occasionally exhibits resorbed grain boundaries. Perthitic orthoclase is preserved as large phenocrysts and with quartz forms the interstitial matrix partly replacing plagioclase. The biotite is reddish-brown, fresh, and present as randomly oriented euhedral crystals. The accessory minerals are pyrite, magnetite, apatite and angular sphene as crystals and clumps up to 3 mm long.

The quartz monzonite stock has sharply discordant contacts with the surrounding country rocks; narrow indurated, hornfelsic zones have been developed in both the Unuk River and Salmon River formations. At Lee Brant Creek the hornfels zone developed in epiclastic volcanic conglomerates, sandstones, and siltstones is about one half mile wide and marked by a general induration and erratic development of fine grained brown hornblende. At Divelbliss Creek the country rocks have been invaded by numerous apophyses of the pluton and medium grained hornblende diorite dykes. Elsewhere the induration is variable, and the east marginal contact is weakly sheared, with some pyrite, pyrrhotite, and minor chalcopyrite mineralization exposed in the small reentrant south of Unuk Finger Mountain. Along the southeast margin of the pluton the intrusive shows sharp contact relations, extensive dykes, with little alteration or deformation in the country rocks (Plate 28). Like the major plutons in the area the Lee Brant pluton exhibits variable contact relationships, most of which suggest passive emplacement in an epizonal environment.

Summit Lake Pluton

The Summit Lake pluton has been included with the Divelbliss Creek Intrusions mainly because of its similar size, contact relationships, general aspect and somewhat similar composition (Figs. 3 and 17). It shows some differences, however, which set this pluton apart from virtually all the satellite bodies in the general area. The Summit Lake pluton has a length of about four miles and a width of about one mile, with the long axis oriented in an easterly direction, or approximately at right angles to the northerly trend of the country rock, as well as the marked northerly trend of virtually all the individual satellite massives. It differs also from the Divelbliss and Alice Arm intrusions, in that the predominant mafic constituent is coarse grained hornblende, with minor biotite (Plate 29). The rock composition is granodiorite.

The Summit Lake pluton is well exposed near Summit Lake, and access to the pluton from the Granduc road and from the Granduc tunnel at elevation 2,475 feet is good (Fig. 3). Approximately 3.6 miles of the stock is exposed in the tunnel and this section was sampled at 500 foot stations in addition to the normal surface samples. This stock is therefore one of the most thoroughly studied plutons in the area. When the tunnel section was washed down the most apparent feature of the rock was the almost continuous gradation and variation in colour and quartz content over distances of only a few feet with no particular dominant mineral trend apparent. In the entire length of the tunnel only one small sulphide bearing quartz vein or lens was intersected. Small, generally hand-sized, inclusions of fine grained, indurated country rocks are visible throughout the tunnel section and appear to form about 25 per cent of the stock. Joint sets are variable and generally widely spaced, and the fault zones in the stock consist of narrow cataclasite zones.

In thin section, the rock exhibits extensive alteration of the plagioclase, hornblende, and biotite. The plagioclase has an apparent andesine composition as estimated on fresh grains in less altered zones. The euhedral hornblende is almost entirely altered to a spotted, fuzzy

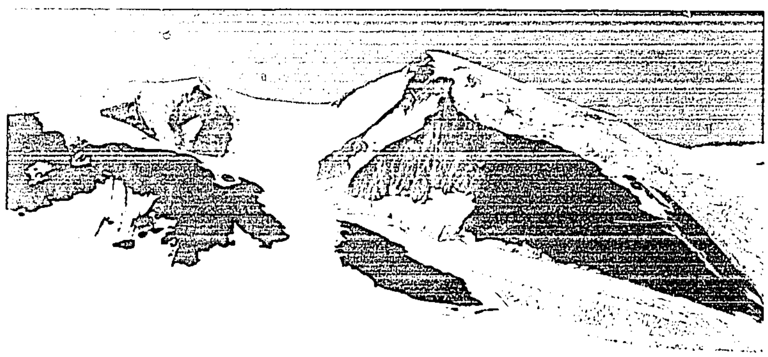


Plate 28. Contact Lee Brant pluton with Unuk River strata, Unuk River area, looking north.

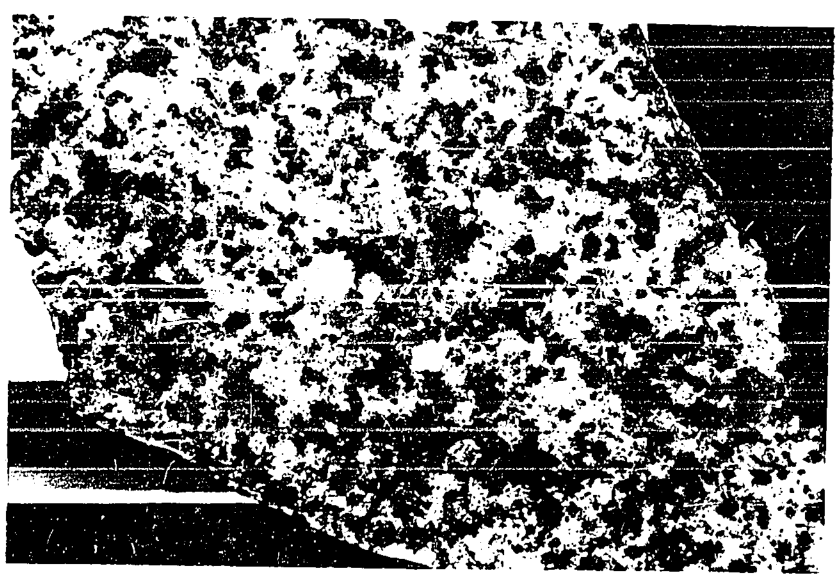


Plate 29. Hand specimen, Summit Lake pluton, half size.

aggregate of chlorite, calcite, quartz, and occasional epidote. The biotite is altered to chlorite, quartz, and iron oxides but retains its characteristic book-like forms. Together, the altered hornblende and biotite form from 5 to 35 per cent of the rock with hornblende alone comprising about 2 to 25 per cent. The grain size of both the hornblende and biotite varies continuously from about 5 mm to 15 mm, with the coarse material localized in the western part of the stock. As noted, the quartz content is quite variable ranging from 15 to 35 per cent. Unlike most of the plutons described in this study this rock contains negligible accessory minerals.

The contact of this pluton with the Hazelton Group country rocks is clearly intrusive and marked by a narrow pyritic, indurated zone at its west end, and by an irregular broad zone at the north end of Summit Lake. In the latter, brown hornblende crystals up to four inches long have been developed in epiclastic volcanic conglomerates at the contact; fine grained secondary hornblende may be seen in the sediments up to one half mile east of the contact.

The Summit Lake pluton has intruded Middle Jurassic Salmon River Formation members, and in turn has been cut by a variety of Late Tertiary dykes and quartz veins. The pluton has been grouped with the Divelbliss Creek Intrusions because of gross similarities, but it could be an outlier of the Middle Jurassic Texas Creek, or one of the younger Cretaceous-Tertiary plutons. No mineral deposits are known to be directly related to this pluton.

Bitter Creek Pluton

The Bitter Creek pluton, and related granitic dykes forming part of the extensive Portland Canal dyke swarm (Fig. 17) have been exposed by deep erosion along the Bear River Valley. Rock exposures in road cuts are excellent. A small quarry on the road near the south margin of the pluton gives access to fresh material.

The Bitter Creek pluton is marked by impressive variations in texture and apparent composition. At the quarry site the rock is a uniform grey to mottled pinkish-grey granite speckled with black biotite; it is generally coarse grained, and invariably porphyritic along the contacts. Watery-grey quartz as blebs up to one quarter inch comprises about 20 to 25 per cent of the rock while the remainder is largely coarse grained pink alkali feldspar which is commonly twinned. Medium grained biotite which forms less than 2 per cent of the rock is the only apparent mafic mineral, and medium grained molybdenite is the most readily observed accessory mineral. In this zone the rock is fresh, typically hypidiomorphic, with perthite forming up to 65 per cent by volume, plagioclase (An_{20-22}) about 51 per cent, quartz about 20 per cent, slightly chloritic biotite about 1 per cent, and sphene, apatite, and black opaque minerals present in only minor amounts. The molybdenite appears to be confined to quartz veinlets filling hair line fractures and has not been found in commercial quantities.

Northward, towards the central portion of the stock the texture grades from coarse grained granitic, to fine grained porphyritic. Only quartz blebs up to one eighth inch, and fine grained greenish biotite are discernible in hand specimens of the porphyry. Microscopically, the porphyry consists mainly of quartz and microcline-perthite as phenocrysts in a very fine grained quartz, alkali feldspar, and plagioclase ($An_{28\pm2}$) matrix. Chloritic, fine grained biotite and black opaque minerals form less than 2 per cent of the rock. The alkali feldspar content is about 40 per cent, and this central part of the pluton is therefore a quartz monzonite.

The northeast narrow margin of the Bitter Creek stock is unlike the main central zone quartz porphyry and the coarse grained, porphyritic southerly edge. Rather than being predominantly pink, this phase is greenish-grey with medium grained buff feldspar and brown biotite as phenocrysts in a fine grained matrix. In thin section the buff phenocrysts, which form about 35 per cent of the rock, are strongly zoned plagioclase with a composition of about $An_{32\pm2}$. The matrix is predominantly a similar plagioclase, some orthoclase, 15 to 20 per cent fine grained interstitial quartz, 3 to 5 per cent biotite, about 1 per cent black opaque minerals, and minor apatite. This phase can be termed porphyritic quartz diorite, but because of the highly variable alkali feldspar content the average composition is difficult to determine.

In summary, the Bitter Creek pluton consists primarily of medium to coarse grained biotite quartz monzonite which is gradational into very coarse pink granite on the southwest, through pink quartz porphyry into a fine grained grey-green quartz diorite on the northeast. Outward and upward from the main mass, the stock has sent out innumerable dykes which form the main belt of dykes in the Portland Canal area.

Strohn Creek Pluton

The Strohn Creek pluton was recognized by McConnell (1913), but it has never been described until the present study. The stock lies about four miles west of Meziadin Lake and is well exposed in road cuts in Bear River Pass (Figs. 2 and 15). It has an exposed area of about five square miles; the long axis of the pluton trends northerly. Aeromagnetic surveys (Fitzgerald, 1960), indicate that the stock has a shallow easterly dipping contact, and has a considerably greater subsurface extent.

The rock is a pinkish, massive, coarse grained, quartz monzonite. The colour index is less than 10 and biotite is the most abundant mafic constituent. Potash feldspar is discernible from the plagioclase in outcrop and commonly forms large phenocrysts. Molybdenite is visible in the rock along the road where fresh rock surfaces are accessible.

In thin section the rock is fresh with a hypidiomorphic-granular texture. The plagioclase (An_{22-28}) is subhedral with complex reversed zoning and complex twinning, and shows only minor saussuritization. Clear quartz and perthitic microcline form the ground mass and partly replace the plagioclase. Biotite and minor hornblende form small unaltered anhedral crystals with random orientation. The common accessory minerals are apatite, zircon, and magnetite. Molybdenite was seen only on fracture or joint surfaces with quartz.

In this area the pluton has intruded along the east dipping contact between siltstones and the underlying epiclastic volcanic conglomerates without producing significant deformation. The contact is sharply defined and marked by dykes and sills. Mineral deposits occur in the area but these are not known to be directly associated with this intrusive.

The Strohn Creek pluton has not been dated by K/Ar methods, but like the Alice Arm Intrusions which it resembles, has intruded the Middle Jurassic Salmon River Formation and was probably emplaced in the Tertiary period.

Alice Arm Intrusions

Plutons included within the group of Alice Arm Intrusions all lie within the southern half of the study area. These plutons are granitoid, quartz monzonite stocks that contain significant molybdenite either as an accessory mineral, or in some places in commercial amounts. These intrusives are typically ovoid, less than a mile in diameter, and usually show several strongly contrasting phases (Fig. 17). The contacts with country rocks are sharply defined with a narrow biotitic hornfels zone typically developed where the stocks have intruded siltstones and greywacke units. The plutons currently placed in this group form a narrow northerly trending belt extending from the central Bear River Pass section south through the Cambria Icefield to the Alice Arm district where eight stocks are clustered near the margin of the Coast Plutonic Complex. The belt of Alice Arm Intrusions extends south of the thesis area to include a small cluster of plugs localized along the Nass River Valley, as well as other scattered, small bodies localized near the margin of the plutonic complex in the Terrace area (Carter and Grove, 1972).

The best known and most extensively explored of these plutons are in the Alice Arm district where one of these, the Lime Creek stock, today comprises the second largest molybdenite producer in Canada. These plutons were not shown on Hanson's Portland Canal map but he did mention (1935, p. 37) the presence of molybdenite at Lime Creek and at the Tidewater property, and the apparent relationship of this mineralization to small granitic bodies. In the last decade these stocks have received considerable attention from the mining industry and the detailed geology of the stocks in the Alice Arm district has been given by Carter (Ann. Repts. Min. Mines, B.C., 1964, 1968), and Woodcock, and others (1966).

The small quartz monzonite plutons outlined in the Bear River Pass area are relatively inaccessible and have not been carefully examined.

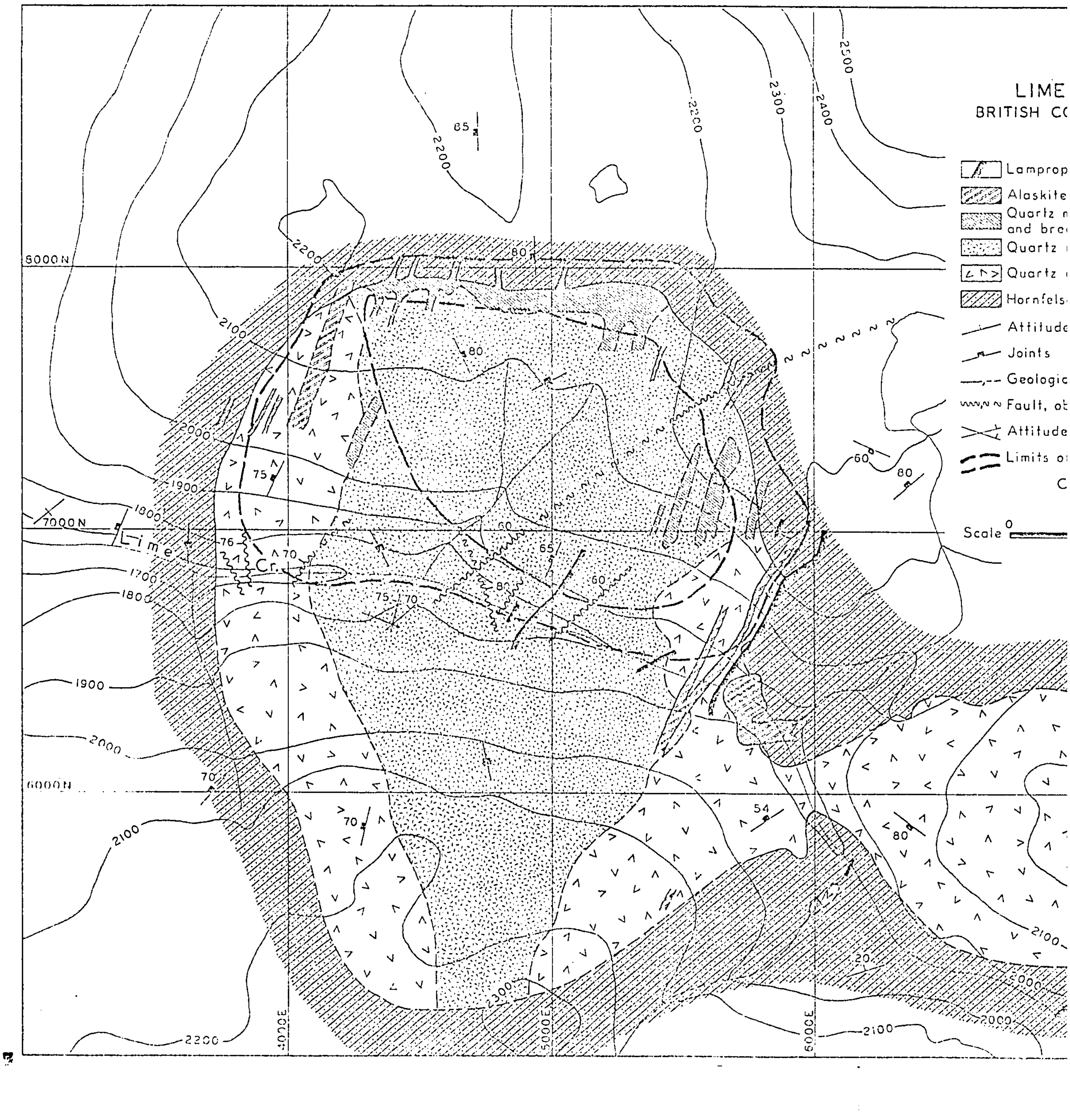
The McAdam Point pluton was first recognized in 1965 because of exposure by recent glacial ablation, and the geology of the intrusive was described by Grove (1965, p. 52-55). This rock was first exposed only at the margins of part of the Bromley Glacier, but recent ablation has exposed more of the pluton at the ice margin below the ice fall. It appears to be an ovoid mass like most of the Alice Arm Intrusions, with a diameter of about 2,500 feet and exhibits a central area of coarse grained quartz monzonite that grades through granodiorite to a quartz diorite phase on the east side under the ice fall. The quartz monzonite is uniformly pink, and porphyritic, with potash feldspar phenocrysts up to 12 mm long distributed through the coarse grained matrix. It consists of 10 to 15 per cent quartz, 35 to 40 per cent plagioclase (An_{26}), 30 to 35 per cent perthitic orthoclase, and 3 to 5 per cent fine grained black biotite. Molybdenite is a minor constituent and occurs as rosettes and as plates along grain boundaries in the rock. Quartz-molybdenite veins cut the quartz monzonite phase as well as filling hair line fractures in the indurated country rock near the contact. The stock has intruded Lower Jurassic Hazelton Group meta-quartzites and greywackes. The McAdam Point stock can be visited by helicopter but the rock exposures are only accessible with difficulty from the ice.

In the Alice Arm district eight small stocks have been extensively explored, on the surface and by diamond drilling (Fig. 17). As mentioned, the Lime Creek stock is being mined, and the Roundy Creek stock is currently being explored. The Lime Creek stock is briefly described here and a geology map (Fig. 20) has been included to show the relations that are more or less typical of this group of intrusions.

The Lime Creek stock is concentrically zoned with a central section of porphyritic quartz monzonite grading outwards into quartz diorite at the east and west contacts. Molybdenite mineralization is localized in the north central half of the stock where the quartz monzonite has been extensively replaced by potash feldspar, extensively veined by quartz, and cut by alaskite and lamprophyre dykes. The relatively unaltered quartz monzonite at the south side of the stock is leucocratic, medium grained, and relatively massive. Normally zoned plagioclase (oligoclase-andesine), potash feldspar, and interstitial quartz comprise the bulk of the rock. Biotite and hornblende have been extensively altered to chlorite and fine grained secondary brown biotite.

The contacts of the stock with the Upper Jurassic Nass Formation siltstones and greywackes are sharp, disconformable, and characterized by the presence of a 200 to 500 foot wide biotite hornfels zone.

The Lime Creek pluton and other members of the Alice Arm Intrusions in the thesis area intrude Upper Jurassic Hazelton Group members and have been cut by numerous Late Tertiary dykes. Absolute age determinations by the K/Ar method made at the University of British Columbia have shown that these plutons were intruded in an episode which took place 50-53 million years ago (White, Harakal, and Carter, 1968).


LIME
BRITISH C(
Lamprop
Alaskite
Quartz
and bre
Quartz
Quartz
Hornfels
Attitude
Joints
Geologic
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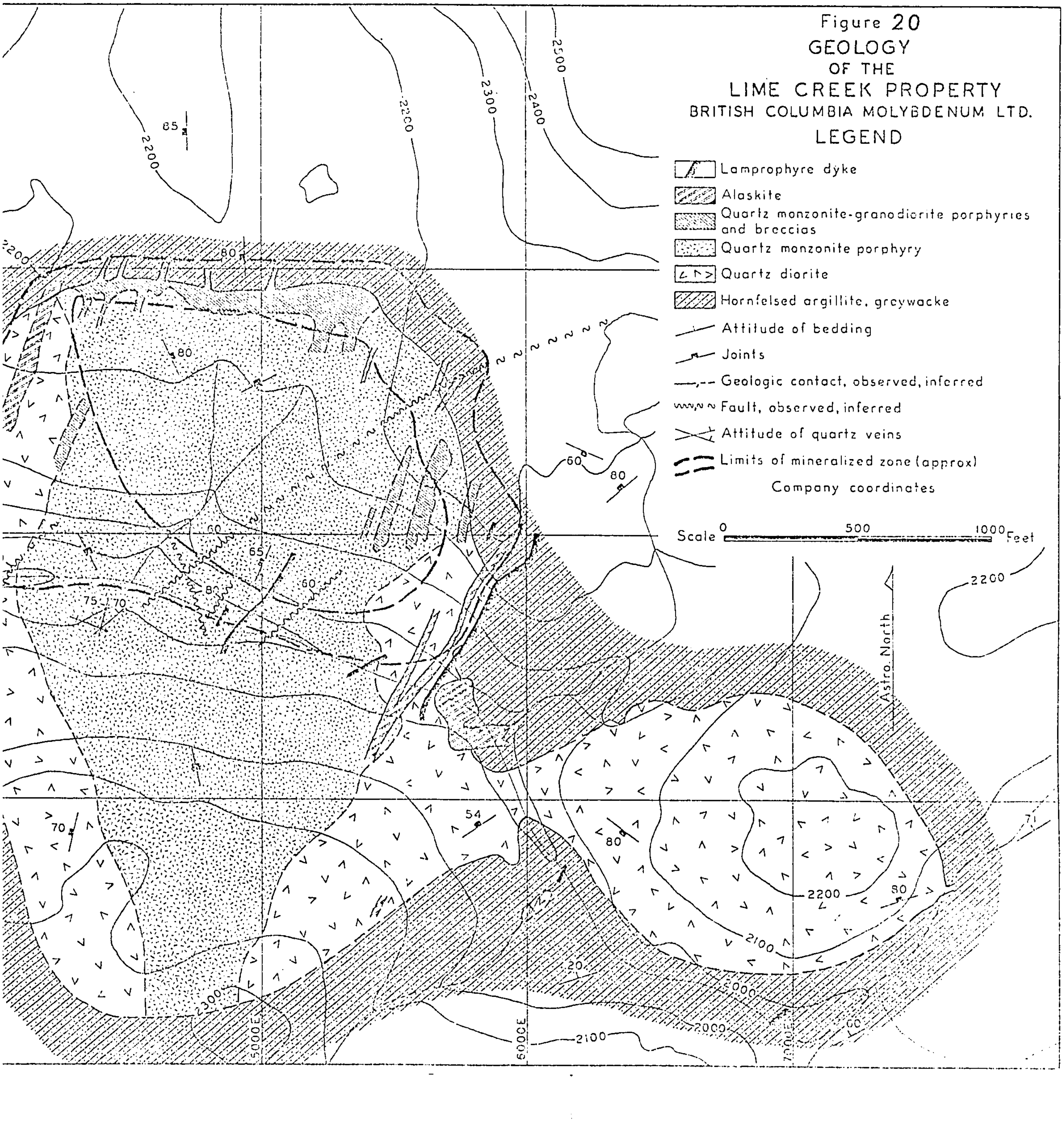
Figure 20
GEOLOGY
OF THE
LIME CREEK PROPERTY
BRITISH COLUMBIA MOLYBDENUM LTD.
LEGEND
Lamprophyre dyke
Alaskite
Quartz monzonite-granodiorite porphyries and breccias
Quartz monzonite porphyry
Quartz diorite
Hornfelsed argillite, greywacke
Attitude of bedding
Joints
Geologic contact, observed, inferred
Fault, observed, inferred
Attitude of quartz veins
Limits of mineralized zone (approx)
Company coordinates
Scale 0 500 1000 Feet
Astro North
5000E
6000E
7000E
2200
2300
2400
2500
2100
2000

Dyke Rocks

One of the outstanding geologic features of the Stewart Complex is the extensive array of dykes and dyke swarms. In order to present this vast assemblage of plutons, the writer has grouped the dykes on the basis of comparable composition, texture, and relative age. Many of the dykes are grouped naturally as swarms which exhibit certain characteristics presumed to be typical of the swarm. Some of the mappable dykes and dyke swarms are shown on the geological maps (Figs. 2 and 3) and the major swarms are illustrated on Figure 17, to show spatial and temporal relationships. The dykes and dyke swarms show dominant northwesterly and northeasterly trends, and several of the groups appear to follow at least two directions. The number of dykes in the area is unknown but they probably form up to 10 per cent of the rock in the area, but of more importance is the apparent localization of dyke swarms in mineralized areas and the presence of mineral deposits in dykes.

Portland Canal Dyke Swarm

The location and extent of the Portland Canal swarm has been outlined on Figures 3 and 17. Both McConnell (1913) and Hanson (1935) showed the Portland Canal swarm as a single unit extending from Mount Dickie, east of Stewart across the Bear River Valley and Bear River Ridge. Hanson extended the western limit to the lower slopes of Mount Bayard where the swarm is beautifully exposed (Plate 30). As a result of work in the Stewart district, and mapping of the Stewart Complex by the writer, the Portland Canal dyke swarm has been shown to be one of several _en échelon_ swarms spatially related to the margin of the Coast Plutonic Complex. The Portland Canal swarm is the most extensive of these and has been traced in detail from Mount Bayard to Mount Dickie, and extended another nine miles to Mount Trevor, located in the centre of the Cambria Icefield. Southeast from Mount Trevor outcrop is poor, but similar dyke material, possibly part of the Portland Canal swarm, has been traced into the west Kitsault Glacier area. The known length of the Portland Canal dyke swarm is 26 miles and the inferred length about 35 miles, making it one of the most extensive swarms in the Western Cordillera.

Many individual members of the Portland Canal swarm have been shown on Figure 3, especially west of Long Lake where they are mappable units. East of Long Lake across Bear River Ridge and towards the Bitter Creek stock, the swarm has been shown diagrammatically by coloured lines to represent from 10 to 15 sub-parallel dykes. The spacing and length of these lines indicates the complexity of the swarm.

On the east side of Bear River Ridge, thick-bedded volcanic conglomerates and breccias, which form the country rock show stratification, but within the zone of dykes these primary features have been completely destroyed by the hundreds of dykes which form up to 90 per cent of the total rock mass. Towards the valley bottom in the Bitter Creek section this myriad of tentacle-like dykes coalesces to form the Bitter Creek pluton. Eastwards, the dyke swarm again spreads from the stock into the country rock extending for many miles to the southeast. In the Stewart district this dyke swarm can be illustrated as a multi-fingered hand with the palm at Bitter Creek and the fingers extended upwards and outwards.

The attitude of the dykes and dyke swarm is strongly influenced by the structure and competence of the country rocks. As shown on Figure 3 the dykes in the Portland Canal swarm apparently curve arc-like

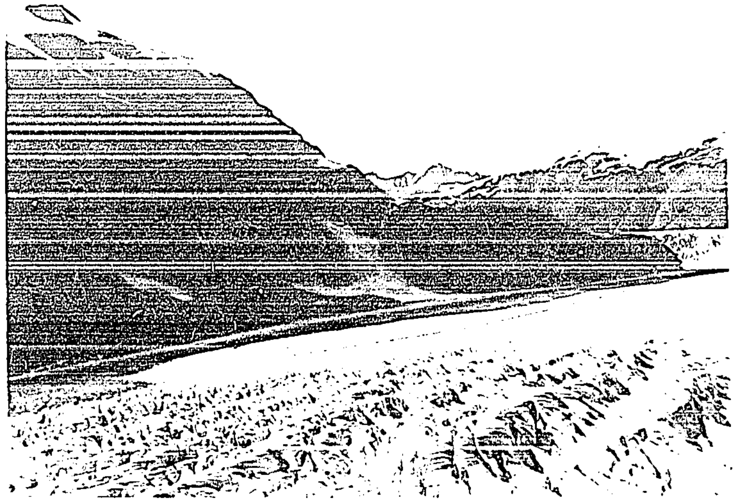

Plate 30. Portland Canal dyke swarm cutting Unuk River and Salmon River strata, Salmon Glacier area, looking west.

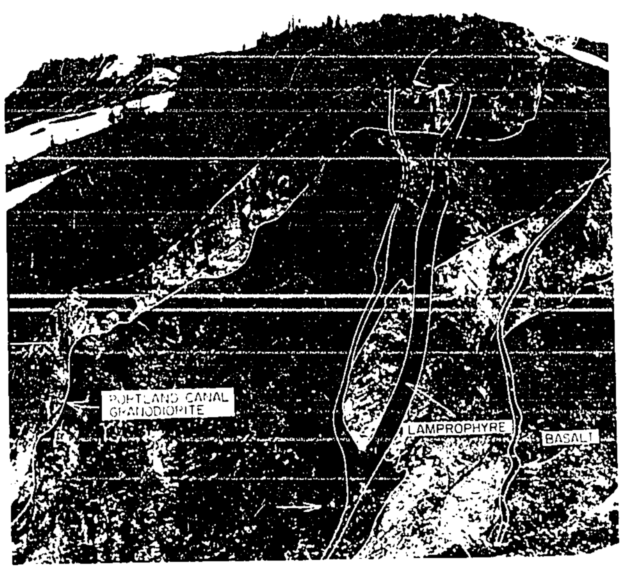

Plate 31. Portland Canal swarm members, cutting Salmon River strata, and cut by lamprophyre dykes, Mount Dillworth area, looking west.

between Bear River Ridge and Salmon Glacier where the country rocks are siltstones and greywackes. The most prominent curve, a sharp northward bulge between Long Lake and Cascade Creek on the south slope of Mount Dillworth marks the area of injection into fairly flat lying, thin-bedded sedimentary rocks forming the axial zone of the Dillworth syncline (Plate 31). To both the east and west of this syncline where the dykes cut massive epiclastic volcanics, the dykes are nearly vertical and have a constant trend. But in the flat sediments the dykes have been intruded sill-like along bedding planes to produce a layer cake effect.

Some indication of apparent size of the large dykes in this swarm is given on the geologic map. The larger dykes are up to 450 feet thick and extend for thousands of feet in length and depth. Probably some at least extend down into an underlying larger mass like the Bitter Creek pluton. The multitude of small dykes included in the swarm, measuring from a few feet to 200 feet thick which are not shown separately on the map, appear to form a complex, almost reticulated, network which encompasses the pluton core. The spacing between dykes decreases, and the number of dykes increases toward the main pluton.

Within the swarm, the individual dykes vary both in texture and composition. Granite, quartz monzonite, granodiorite, and quartz diorite are the common compositional types (Plate 32). Changes or variations in the texture and composition take place within the individual dykes as well as within the swarm.

Similar dykes are found west of Mount Willibert where many extensive granodiorite and quartz monzonite dykes form a small swarm that lies west of the main Portland Canal swarm. The dykes in this zone appear to

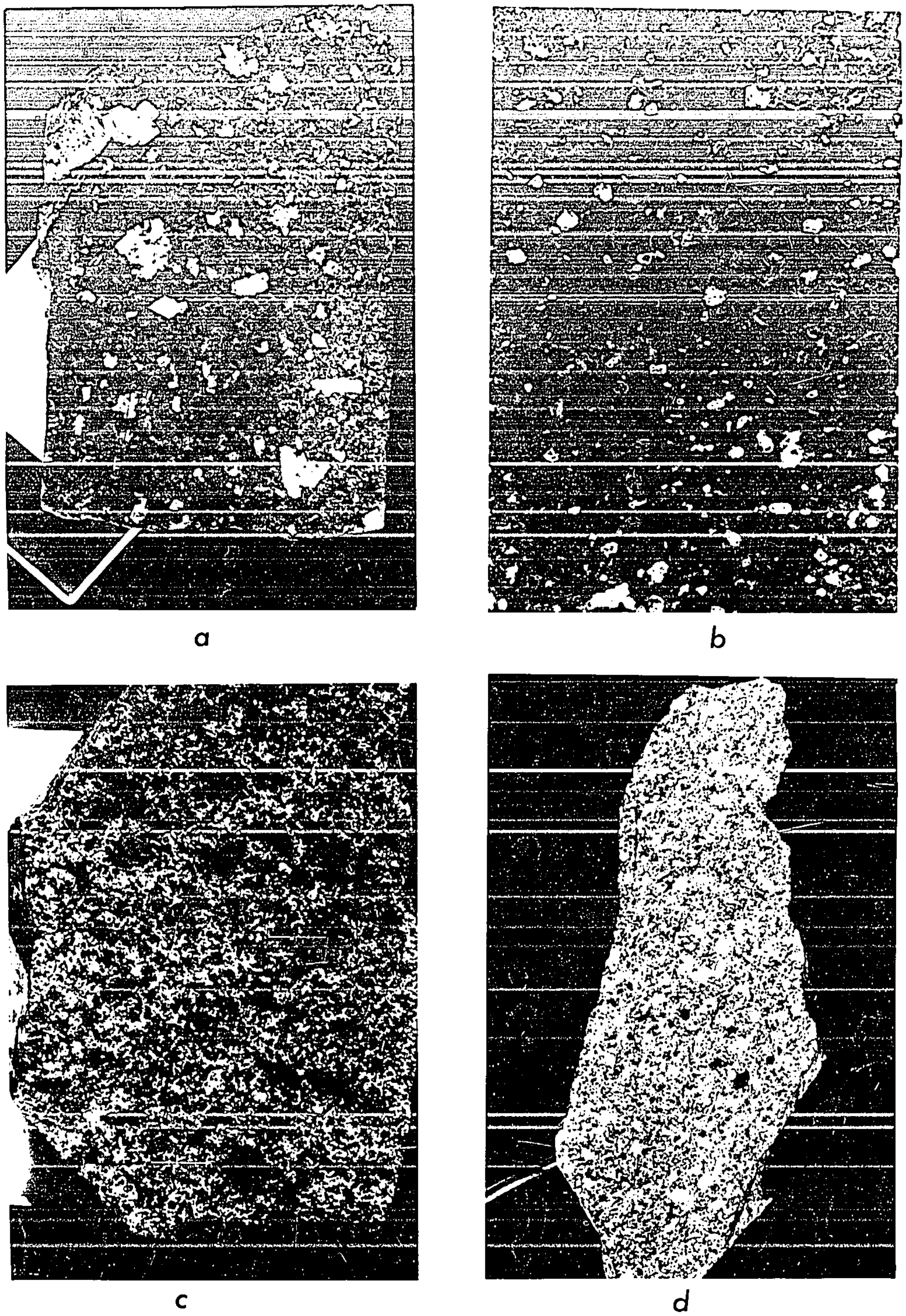

Plate 32a. Hand specimen, Portland Canal dyke, half size.

Plate 32b. Hand specimen, Premier dyke, half size.

Plate 32c. Hand specimen, Bear River Pass dyke, half size.

Plate 32d. Hand specimen, lamprophyre dyke, half size.

be apophyses of the Hyder pluton, and like the Portland Canal dykes cut the Texas Creek pluton. Other small dyke swarms correlated with the Portland Canal group have been mapped along the east slope of American Creek, in central Bear River Pass at Mount Dolly, the Georgia River area, and in the Anyox pendant.

In the Stewart district the Portland Canal dyke swarm has served as a locus of late quartz-sulphide mineralization. Many of the dykes in the swarm have been fractured and faulted, and the openings preferentially filled with pods and lenses of commonly silver-bearing, quartz-sulphide (Plate 31). None of these deposits has been a large producer but the dykes have attracted exploration groups for many years.

Although none of the Portland Canal dykes has been dated by radiometric methods, the field evidence supports a relationship with the Late Tertiary Hyder plutonic phase.

Premier Dyke Swarm

The swarm of northwest trending dykes along the international boundary between Cantu Mountain and Mount Willibert has been named the Premier dyke swarm because the Premier orebodies are within the swarm. The dykes of this swarm are not to be confused with "Premier Porphyry" and "Premier Sills" referred to in the older literature. The term "Premier Sills" was used by Schofield and Hanson (1922, p. 21-22) for a variety of rocks in the Premier mines area that they felt were primarily characterized by the presence of pink alkali feldspar phenocrysts. In distribution, they were localized in the international boundary area between Premier and Indian Lake within the present Premier swarm of dykes. Hanson (1935, p. 21) envisioned a stock of orthoclase porphyry about 2 miles in diameter from which sill-like tongues extended north for several miles. Other investigators (Burton, 1926; Means, 1923) regarded the sill-like "Porphyries" as stock-like intrusions.

These early workers all stressed the difficulty of recognizing these sills especially in zones of deformation because of their highly variable textures. They all failed to recognize the epiclastic nature of the country rocks and as a result failed to recognize that the Premier Porphyry and its related sill-like extensions was actually metasomatized, deformed country rock.

It can be seen on Figure 3 that the Portland Canal dyke swarm and the Premier dyke swarm have the same general northwesterly trend, and both are somewhat complicated by other crosscutting dyke swarms. The Premier swarm has been selected for study because of its distinct textural characteristic and local economic significance. Several dykes of the Premier swarm can be viewed along the Silbak Premier mine roads, the Granduc road, and in the canyon of Cascade Creek.

In general, the Premier dykes are up to 150 feet thick, and are distinguished by their porphyritic texture and colour from members of other swarms (Plate 32). Pinkish to buff plagioclase ($An_{40\pm2}$) phenocrysts, one eighth to one quarter inch long, form up to 45 per cent of the rock. The greenish grey to dark grey matrix generally consists of fine grained plagioclase and quartz, and accessory apatite, sphene, zircon, and black opaque minerals, largely magnetite. Other phenocrysts present include quartz, hornblende, and orthoclase, but these are relatively inconspicuous except in good fresh outcrop. Blebby quartz averages about 10 to 15 per cent, acicular hornblende 5 to 15 per cent, and alkali feldspar (myrmekitic orthochase) 15 to 20 per cent. Secondary alteration is variable and is indicated in outcrop by shades of green. Most of the dykes are quartz diorite but minor monzonite phases are present. Although the dyke rock is generally fairly uniform in grain size, coarse grained phases marked by large orthoclase phenocrysts are evident, and have an appearance suggestive of the marginal phases of the Texas Creek pluton.

Like the Portland Canal dyke swarm, the trend of the Premier swarm, and of individual dykes within it, indicates changes in competency in the country rock. In the Cascade Creek section sharp curves in trend occur where the dykes cross from massive epiclastic volcanics to cataclasites, or into massive altered country rock. The branching of the dykes illustrates the presence of persistent local fracture patterns with northwesterly, easterly and northerly components. For these reasons the dyke swarm patterns and their lithologies are indicators of physical-chemical conditions and therefore are possible guides to mineralized areas.

Only one other dyke swarm with a comparable texture and composition has been recognized within the Stewart Complex. This small swarm is found in the cirque at the head of the South Leduc Glacier where the light coloured dykes stand out against the dark volcanic rocks forming Scotty Dog Mountain. These dykes are not very accessible, but excellent fresh samples are available in the medial moraines on the glacier.

The Premier Dykes transect the margin of the Texas Creek batholith and Lower Jurassic strata. In turn they have been cut by Late Tertiary lamprophyre dykes, and are probably Tertiary in age. Absolute age determinations have not been made on the Premier dykes up to the present.

Bear River Pass Dyke Swarm

These fine grained diorite dykes are well exposed in the Bear River Pass canyon where they form an extensive northerly trending swarm. Other large diorite dyke swarms have been mapped at Granduc Mountain, north of Francmackie Glacier, at the northwest end of Summit Lake, south of Premier, along the Kitsault River Valley, west of Alice Arm, and in the Maple Bay-Anyox areas.

Some of the Bear River Pass dykes are a dense massive, fine to medium grained diorite, and others are equigranular quartz diorite. They are generally similar in size and composition to the Premier dykes, but differ markedly in texture (Plate 32). The Bonanza ore deposit, located at Bonanza Creek south of Anyox, has been cut by many dark diorite dykes which are part of an extensive swarm visible along the walls of the Bonanza Creek Canyon.

The diorite dykes show considerable local textural variations from fine grained equigranular to porphyritic types, with plagioclase (An_{50}) phenocrysts forming from 10 to 55 per cent of the rock. Hornblende and pyroxene, which form variable portions of the dyke rocks, are generally extensively altered to chlorite and secondary biotite.

In individual size, the Bear River Pass dykes range from a few feet wide to a maximum of about 100 feet. In places, as in the Anyox area individual dykes have been traced for up to three miles. These dykes may be seen in large numbers along the shoreline in Alice Arm and Observatory Inlet. The dykes generally show narrow chilled margins against hornfelsed country rocks. Where the country rock is siltstone, tremolite is typically developed.

In general, these dykes show considerable internal textural and compositional variations, and exhibit variable contact effects with the various country rocks. Known contact metamorphic mineralization related to these dykes includes auriferous pyrite, nickeliferous pyrrhotite, molybdenite, and pyrite-chalcopyrite, as well as ubiquitous magnetite.

In the Anyox area the Bear River Pass dykes cut the Hyder pluton and related dykes, and appear to be more or less contemporaneous with the lamprophyre dyke swarms of the area.

Lamprophyre Dyke Swarms

Lamprophyre dykes are fine grained dark green to dark grey rocks which cut all the competent rock units in the map area with the exception of relatively minor basaltic dykes. The lamprophyres are common to most of the area, but the zones of apparent concentration have been outlined on Figure 17 to indicate their relationship to the Portland Canal and Premier swarms. They are distinguished from the country rock by their rusty weathering, spotted grey colour and blocky joint habit (Plate 32).

Microscopically these spessartite dykes are characterized by fine grained lath-like andesine plagioclase, brown hornblende, and minor augite set in a felted matrix of very fine grained andesine plagioclase and acicular hornblende with minor accessory apatite, sphene, and magnetite. Alteration of both phenocrysts and matrix to sericite, chlorite, epidote, calcite, and quartz is typical with the result that the original quartz in the matrix is difficult to distinguish from secondary quartz.

The lamprophyres are found with three distinct trends. These are northwesterly, northeasterly, and northerly, and are commonly crosscutting. Unlike the Portland Canal and Premier swarms which have a single prominent northwest trend, the various trends of the lamprophyres appear to be more or less evenly distributed in all three directions except in the central Stewart District where the northerly direction predominates. The relationships between the lamprophyres, other intrusions, and mineralization are well illustrated in the thesis area (Plate 31).

Lamprophyre dykes and dyke swarms are prominently displayed in virtually every known mineralized area. They are, however, essentially ubiquitous and would not of themselves provide a unique clue to mineral deposit location. Lamprophyre dyke swarms are also prominent in southeastern Alaska where Smith (personal communication) has recently suggested that the strong northeasterly fracture trend which appears to have controlled fjord development is related to regional emplacement of the northeast trending lamprophyre dyke swarms. His recent studies have shown an exceptionally strong correlation between the swarms, fractures and fjord development. Portland Canal is one of the rare exceptions to the northeasterly trend and in this section northerly trending lamprophyre swarms (Bear River Pass area) are probably more common than the northeasterly dykes.

Carter (personal communication) has made age determinations by the K/Ar method on a number of lamprophyre dykes in the Alice Arm and Anyox areas. The results indicate that the lamprophyre dyke swarms (and diorite) were emplaced about 32 to 34 million years ago, that is, during the Oligocene.

Contact Relationships of the Plutons

The plutonic rocks described in this thesis present a variety of contact relationships with their wallrocks. Although the geologic maps accompanying this thesis display large scale features, inherent limitations must leave the small scale phenomena to description in the text. The real argument for considering the subject of contact relationships is that significant economic mineralization in the Stewart Complex is localized at or near unusual or irregular contact areas.

Plutons

Within the confines of the Stewart Complex the various igneous plutons comprise rock types that vary considerably in physical and chemical properties. The general result of intrusion as shown on Figure 2, and as noted by the many early workers, has been the formation of apparently smooth, steep contacts with little or no extensive metamorphic effects (Hanson, 1929, p. 13-15; Buddington, 1929, p. 37-39). In the overall view, dynamic metamorphism observed as limited to within tens of feet of the contacts is reflected in narrow chlorite schist zones. Thermal metamorphism has been generally regarded as a negligible effect of plutonism in the area with little mention except for the garnet-epidote assemblage that Buddington (1929) recognized along the west slope of Mount Dolly. Regional metamorphism was not mentioned by the original workers in the Portland Canal district because the evidence for it is still somewhat sparse.

Contact relations between the various members of the Unuk River Intrusions have been briefly described in this thesis to vary from narrow hornfels zones to extensive pyritization, feldspathization, and silicification which has been accompanied by widespread chalcopyrite and molybdenite mineralization. At the margins of the Late Triassic McQuillan Ridge pluton, the contact effects include minor induration as well as fairly extensive hornblendization of country rocks.

In the Stewart area, the Texas Creek granodiorite pluton has had a variable contact alteration effect on the country rocks. The alteration appears to be related to the compositional variation of the pluton which, where combined with strongly contrasting country rocks, formed areas marked by exceptional gold, silver, lead, and zinc mineralization. The Salmon Valley contact zone is now well exposed and shows the complex relations between the Texas Creek pluton and the country rocks. Areas of hornblendization, feldspathization, silicification, and pyritization, as well as structural deformation are well marked. The limit of the Texas Creek pluton contact metasomatism along the Salmon Glacier section is an arbitrary line, the silica line, drawn southeasterly along Noname Lake to the east side of Cascade Creek, then southeast past Premier where it swings southwest to the international boundary (Fig. 3). This line roughly separates the country rocks on the basis of microscopically recognizable silicification. Megascopic, as well as thin section study also shows that the amount or degree of alteration decreases from the contact eastward to this line. Along Cascade Creek where the actual contact is vague, the intrusive grades almost imperceptively from coarse grained hornblende granodiorite through medium grained granitized country rocks to altered country rock. In this area the granitized country rocks have been completely altered to a metasomatic, porphyritic hornblende granodiorite. Orthoclase porphyroblasts occur randomly in these greenish rocks, or occasionally as elongate zones such as in the Premier area where the name Premier Porphyry has been applied to the altered zone. Apart from the obvious hornblende and alkali feldspar alteration, the country rocks are variably indurated, silicified, and pyritized. The amount of visible pyrite appears to decrease eastwards from the main contact. The decrease is not regular because of variations in the country rock and other complicating features such as younger dykes. Within certain areas such as the ore zones, the country rocks have been almost completely replaced by fine grained quartz.

The Hyder quartz monzonite batholith has a steep, low grade contact zone where it has cut the various country rocks. Along the contact with the older Texas Creek pluton cataclasis is general along with erratic alteration of the intruded granodiorite. On Mount Dolly where apophyses of the Hyder pluton cut epiclastic volcanic rocks, the country rocks have been extensively indurated, partially epidotized, and variably silicified up to a mile away from the main contact. Generally, though, the contact is marked only by a narrow indurated zone which occasionally exhibits secondary amphibole. Nickeliferous pyrrhotite was noted in the narrow indurated contact zone at the head of Fewright Creek, as well as in other zones near the Iskut River.

Contact relationships of the various Cretaceous and Tertiary satellite plutons have been described in this thesis in particular reference to mineralization. The general impression is that the plutons were emplaced passively with minor marginal alteration, generally manifested as narrow indurated, or hornfelsic zones in the country rocks accompanied by erratic mineralization.

Dykes

Contact relationships between the various dykes and numerous country rocks are commonly quite inconspicuous. Because the dykes occur singly or in swarms, the contact deformation and alteration can be either almost a skin shear effect, or a compound shattered, highly deformed zone. The latter is common in the Portland Canal dyke swarm where the dykes cut the Salmon River siltstones. Where the more basic dykes cut massive green Unuk River volcanic rocks the dykes are bordered by well defined bands of red to purple country rock. This can be seen easily at the toe of the Salmon Glacier in the green Texas Creek granodiorite or in the less deformed epiclastic volcanics east of Premier. In the red volcanics the dykes produce a purple contact zone, and in the purplish country rocks the colour change is to black. These changes appear to be simple oxidation effects. Generally the contact relations are restricted to simple shearing, limited induration, and minor development of fine grained pyrite. Along Salmon Glacier where the main belt of dykes crosses the marginal deformation zone of the Texas Creek batholith the country rocks are exceptionally blocky or broken.

Cataclasites and Schists

Four major cataclasite zones have been mapped in the Stewart Complex (Fig. 17). These include the South Unuk, Cascade Creek, Bear River, and Maple Bay zones which all trend northerly across Lower Jurassic country rocks, and are partially obscured by overlying Middle Jurassic strata, and have been partially destroyed by Tertiary intrusions. These zones have been recognized by the writer, and are briefly described here as a group for the first time. All of these zones include significant mineral deposits, and are important to the understanding of tectonics and metallogenesis in the Stewart Complex. The most extensive of these zones, the Unuk River, includes the massive sulphide deposits of the Granduc mine.

Cataclasites

South Unuk Cataclasite Zone

The South Unuk cataclasite zone represents the most extensive known deformational zone within the Stewart Complex, and includes the large Granduc sulphide ore deposit and several lesser mineralized zones. The South Unuk zone has been partly outlined by Norman (1962) as the result of a detailed mineral exploration programme during 1959-1960, along the South Unuk River. The Granduc Mountain section was first mapped by Bacon (1956) during the early exploration period at the mine, when he outlined the general geology of the section between Summit Lake and the Alaska border, three miles west of Granduc Mountain.

The geology of the section from the Alaska border north through Granduc Mountain and along the South Unuk-Harrymel lineament to the Iskut River is shown on Figures 2A and 2B. The rocks along the northerly trending cataclasite zone essentially parallel structure in the sedimentary, volcanic and plutonic rocks that comprise the middle member of the Unuk River Formation (Fig. 13). The stratigraphy of the Unuk River Formation has been previously described in this chapter, and the structural relationships of the major South Unuk zone to the country rocks, and within the local tectonic framework have been described in Chapter 4. The following description will generally deal with the Granduc Mountain portion of the cataclasite zone which represents the widest and most accessible section.

Macroscopic Features

The cataclasite zone at Granduc Mountain is about one mile wide and extends from the North Leduc Glacier, east to about the centre of the mountain. From west to east the zone includes broad areas of calc-silicate cataclasites, mylonites, and mixed mylonite-phyllonites. Most of the rocks are marked by more or less vertical, northerly trending layering or banding that is best developed in the central mylonite zone, and includes most of the known Granduc ore zones. These rocks, and the ore, have been cut by dykes of several ages which have in turn been offset by several graphitic fault zones.

The cataclasite zone includes a broad section essentially composed of weakly to moderately recrystallized, deep green, skarn-like material, generally too fine grained in hand specimen to determine the mineralogy. The mylonites, including boudinaged limestone lenses, breccia, and ultramylonite are generally marked by knife edge, dark and light green bands a few millimeters to several centimeters thick which can be traced for tens of meters. The lenses of fine grained limestone are usually a blue to buff white, marked by thin colour bands and are generally only a few meters thick but have been traced underground for hundreds of feet in the west side of the ore zone. The ultramylonites are weakly foliated, cherty looking, grey white lenses localized in the ore section where they comprise distinct layers a few meters to 10 meters thick and have been traced for several hundred meters within the workings. The phyllonites are dark brown to black, minutely banded massive units marked by very fine grained biotite, and commonly characterized by ribbons, and augen of glossy white quartz. Breccia, and fine breccia lenses or pods are scattered throughout the mylonite-phylonite sequence at various sizes ranging from small fragments to large blocks. These units are generally black to purplish black, marked by undeformed remnants a few millimeters to several centimeters in diameter, and generally lack any directional texture. They are generally thought to represent deformed diorite dykes (Norman and McCue, 1966).

Microscopic Features

Most of the rocks in the South Unuk zone have been identified as various sediments or bedded volcanics in the past because of the well developed banding, and because of the very fine grained nature of the units. The microscopic study of these units has revealed their real nature and has helped outline the main cataclasite zone for the first time.

In thin section the medium to light green calc-silicate rocks are seen to consist of alternating bands and lenses up to several millimeters wide of fresh clastic green diopside and epidote, with scattered lenses and clumps of recrystallized calcite, apatite, very fine grained magnetite and clastic sphene. The grain size of the coarse material is generally 1.0 mm and the fine matrix is much less than 0.1 mm Scattered plagioclase clasts and clumps generally form less than 5 per cent of the rock, and quartz which commonly occurs as clear grains typically exhibits ribbon texture (Plate 33).

Strongly boudinaged carbonate lenses along the west margin of the cataclasite zone are very fine grained, dense, and completely recrystallized. Calcite forms most of these units with minor rounded quartz beads, scattered garnet and occasional lenses of epidote and magnetite. The grain size is generally about 0.1 to 0.2 mm, although considerably coarser material usually envelopes the inclusions in the carbonate (Plate 34).

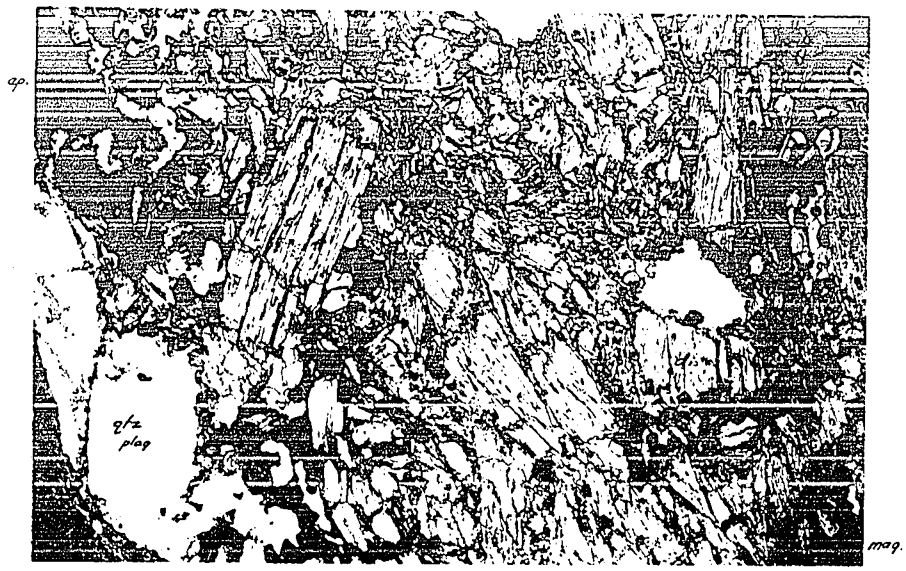

Plate 33. Cataclasite, South Unuk cataclasite zone, Granduc Mountain area. Photomicrograph, X30.

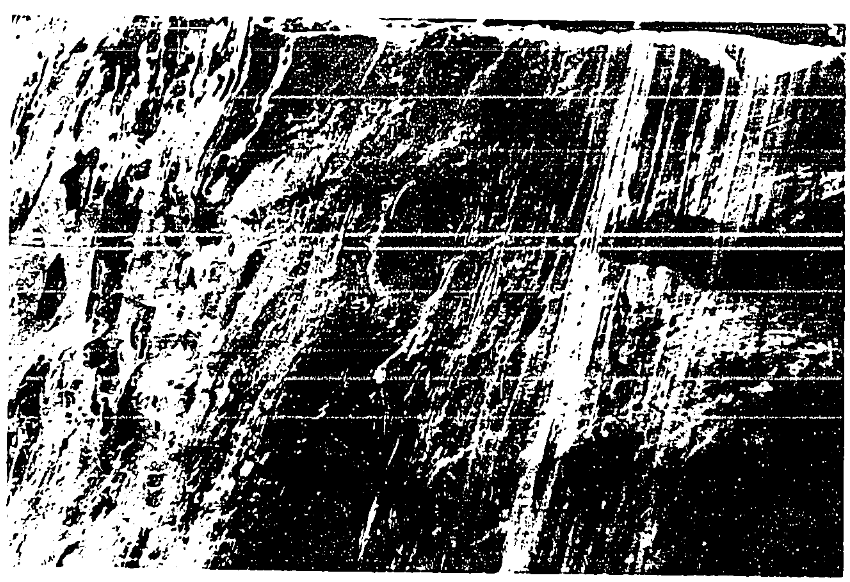

Plate 34. Deformed limestone strata, South Unuk cataclasite zone, east side North Leduc Glacier.

The mylonite zone includes a variety of rocks separated on the basis of microscopic textures. These include mylonite, blastomylonite, hartschiefer, layered mylonite and ultramylonite. These units are finely crystalline to cryptocrystalline, usually well foliated and exhibit various degrees and gradations of recrystallization. Blastomylonites exhibiting weakly foliated, clear recrystallized ribbon quartz and quartzose matrix, are typically thick banded and are interbanded within millimeter scale layered mylonite, phyllonite, layered mylonite and epidote-diopside cataclasite laminae. The layered mylonites generally include clastic hornblende or epidote-diopside rich lamellae interlayered with weakly to moderately recrystallized quartz and minor feldspar layers (Plate 35). Simple mylonites consisting of feldspar, tourmaline, epidote, or diopside clasts appear to be moderately graphitic and well laminated. In hand specimen these simple mylonites are usually an even grey-green and only weakly pyritic. Plagioclase clasts in these mylonites are angular, fresh, show little or no banding or twin lamellae, and are generally about 0.5 mm in size while the matrix is usually cryptocrystalline. The ultramylonites are entirely cryptocrystalline, lack significant component clasts, and lack good foliation. Phyllonite-mylonite and phyllonite are typically graphitic, finely crystalline, to cryptocrystalline and commonly contain tourmaline, epidote or diopside clasts (Plate 36). The finely crystalline biotite is brown, fresh and forms 15 to 20 per cent of the individual layers. Finely crystalline apatite, calcite and magnetite are variable components throughout the sequence, although the most extensive zones appear to lie within the mixed carbonate, calc-silicate members near the west limit of the cataclasite zone, and west of the ore bearing mylonite-phyllonite section. The apatite, calcite, and magnetite rich layers also

Plate 35. Mylonite: epidote-diopside, quartz-feldspar layers, South Unuk cataclasite zone, Granduc Mountain area. Photomicrograph, X30.

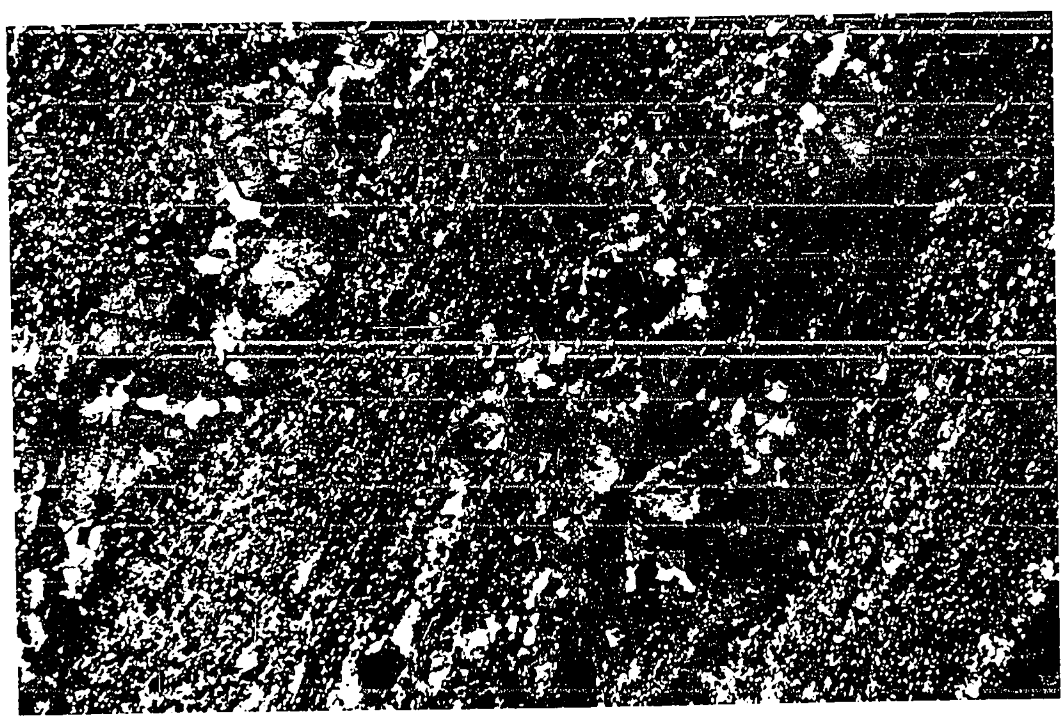

Plate 36. Phyllonite, showing tourmaline as clasts, South Unuk cataclasite zone, Granduc Mountain area. Photomicrograph, X30.

exhibit fold structures on both an outcrop (Plate 37) and a thin section scale (Plate 38).

Discussion

The various members of the complex cataclasite zone show considerable variation in the degree of recrystallization, but the grain size of the crushed and neo-minerals shows general constancy. Secondary alteration of the mineral components is rare even in the surface exposures. The degree of metamorphic differentiation in these rocks as expressed by layering of the epidote, diopside, hornblende, apatite, magnetite and quartz is striking. Compared to the mylonites developed from the andesitic, volcaniclastic sequence in the Cascade Creek zone, and the simple Maple Bay zone, the degree of mechanical differentiation and development of a layered fabric is outstanding. Few of the clasts in the Unuk River mylonites show evidence of post-tectonic deformation although the zone has been extensively faulted with the production of wide graphitic shears. Ovoid to flattened, clear recrystallized chert, or quartz pebbles in the mylonite-phyllonite section, parallel to the foliation, and apparently parallel to the primary structure, are common in the phyllonite members (Plate 39). Spry (op. cit., p. 211) suggested that a simple flattening related to tectonic movement which produces an orthorhombic fabric indicates non-rotational movement.

The mineral aggregate of the South Unuk cataclasite zone includes a low temperature mineral assemblage. Country rocks, plutons, dykes, and sulphide lenses have been deformed under high pressure, low temperature conditions producing a relatively uniform sequence of rocks, once thought to comprise a simple siltstone-sandstone succession.

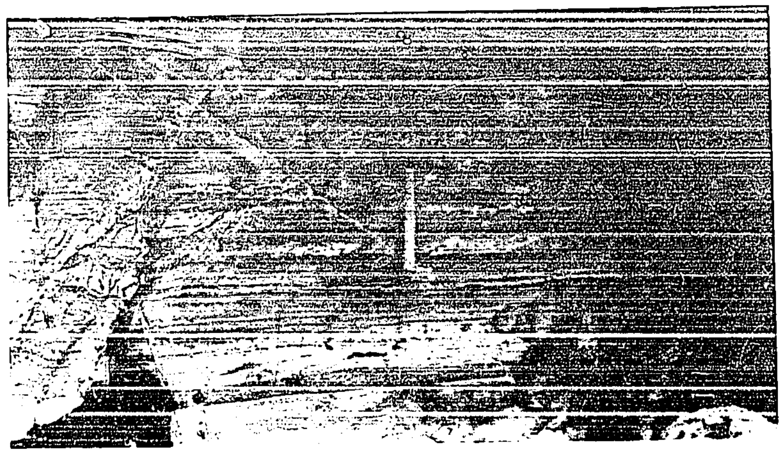

Plate 37. Mylonite, showing banding, South Unuk cataclasite zone.

Plate 38. Mylonite, showing apatite-magnetite laminae, South Unuk cataclasite zone. Photomicrograph, X30.

Plate 39. Mylonite-phyllonite, showing flattened quartz pebbles. Photomicrograph, X15.

Cascade Creek Cataclasite Zone

The Cascade Creek zone extends northerly from southeastern Alaska through Premier and along the east slope above Salmon Glacier to Mount Dillworth where Middle Jurassic strata overlie and conceal the zone. The rocks in this zone were originally called volcanics by Schofield and Hanson (1922) and Hanson (1929, 1935), but the rocks were recognized as cataclasites by the writer while mapping the detailed geology of the mineral deposits located along Cascade Creek. The original country rocks along the zone, and partially preserved within it, are Lower Jurassic Hazelton Group epiclastic volcanic conglomerates, sandstones, breccias and lithic tuffs. In the cataclasite zone, particularly in the altered mineralized zones at the Silbak Premier mine, deformation, alteration, and quartz replacement have combined to obscure most of the primary rock structures and textures.

Cataclasites are the most significant rock units in the Salmon River district. All of the major ore deposits, including the Silbak Premier have been found in altered cataclasites derived from green volcanic conglomerates and sandstones. The localization of economic mineralization in these rocks will be discussed in Chapter 5.

Macroscopic Features

These rocks are largely composed of deformed, partially crushed, massive-bedded, fine to medium grained volcanic conglomerates or breccias, with thin intercalated sandstones.

The cataclasites include various mylonites, phyllonites, kakirites, as well as some schists all of which occur as non-discrete zones cross-cutting mappable lithologic strata. The cataclasites include rocks which are shades of green, black, red, and purple, whereas the associated well-developed schists are a homogenous buff or light green.

The coarse cataclasites have been recognized as a heterogenous accumulation of angular to subangular fragments of andesitic composition embedded in a clastic volcanic sandstone matrix, generally also of andesitic composition. Some of these coarse cataclasites retain the original sedimentary colours. The fine grained cataclasites are commonly marked by an inch scale layering which resembles primary bedding, and because of the feldspar clasts have been described as tuffaceous or porphyritic volcanics. These rocks are noticeable in the Premier area, and are commonly marked by prominent bands of feldspar clasts, the larger of which crudely resemble phenocrysts. The metamorphic banding generally trends northerly, dips at a low angle to the west, and may be misconstrued as relict bedding. Lenses with coarse feldspar clasts intercalated within finely layered bands have the appearance of porphyritic sills injected within a predominantly volcanic assemblage.

All of these cataclasites have a foliated appearance, and are marked by a submetallic greyish to greenish aspect. The foliation is variably developed depending on the spatial proximity to intrusive contacts and zones of shearing. Areas of schist are noted on the geological map as discrete lenticular zones such as may be seen at Summit Lake, or in the area between Big Missouri and Premier (Fig. 3). On the Alaskan side of the border, as noted by both Westgate (1921) and Buddington (1929) these cataclasites are apparently featureless in outcrop. At Premier however, deformation has not been so completely pervasive and the textures of the original rocks are commonly visible.

Microscopic Features

The true nature of the Salmon River cataclasites is revealed in thin sections where the texture, composition, and alteration can be observed. In the great majority of the cataclasites of the district, the parent material is still recognizable. These are referred to as kakirites (Knopf, 1931) or more generally as cataclasites (Plate 40). A few, recognized under the microscope, have reached an extreme stage of granulation and are referred to as mylonites.

Macroscopically these mylonites are black, red, or purple and vary considerably in colour. They are generally recognized by a dense, fine grained pseudoporphyritic texture. The relict crystals are either plagioclase or quartz, one of which predominates, comprising from 8 to 50 per cent of the rock. The plagioclase clasts all fall within the composition range An_{28-32} with the range An_{30-32} characterizing the bulk of the specimens examined. They are typically angular, with marginal strain effects and are enveloped within a very fine grained granulated matrix composed of quartz, feldspar, sericite, or chlorite, as well as iron oxide "dust" which imparts either black, red, or purple tones to the rock. The quartz eyes are always ovoid with clear sharp outlines that seldom exhibit marginal strain effects but commonly contain undulatory extinction bands (Plate 41).

Most of the mylonites have quartz or feldspar as eyes but a few samples taken from purple lenses south of Hog Lake have relict rock fragments as eyes, and are properly called kakirites. In these, the augen consist of plagioclase (An_{30}) porphyry fragments, embedded in a finely granulated feldspathic matrix containing abundant iron oxide which envelopes each fragment and imparts a black colour to the rock.

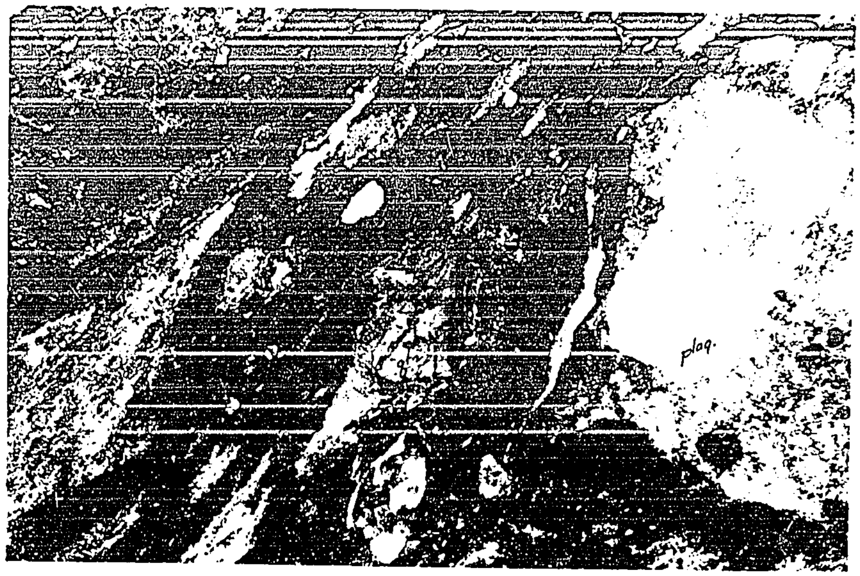

Plate 40. Cataclasite, Cascade Creek zone, Premier area. Photomicrograph, X30.

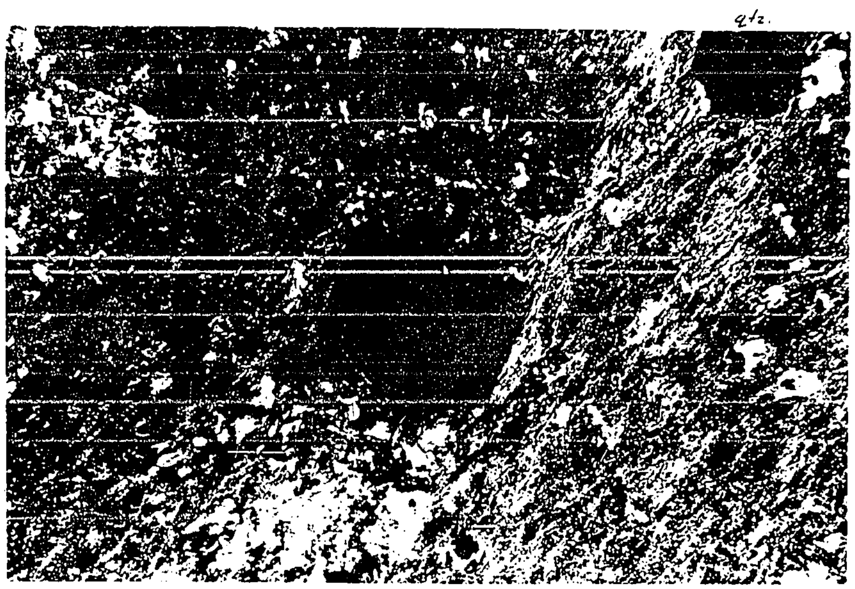

Plate 41. Cataclasite, Cascade Creek zone, Premier area. Photomicrograph, X30.

Relict hornblende grains have been recognized either as partially altered fragments, or as vague ghosts in several of the black mylonites in which inclusions and fragments of apatite and rarely sphene are ubiquitous. These rocks occur as lenses within the extensive schist zone west of Silver Lake and the parent material is not preserved, but it was probably a medium to coarse grained hornblende quartz diorite related to the nearby Texas Creek granodiorite.

If one disregards alteration the grain size of these mylonites appears to be fairly uniform. The augen of quartz plagioclase, or rock fragments consistently average about 1.5 to 2 millimeters. The matrix particles consisting of granulated minerals, iron oxides and alteration products are generally one twentieth the size of the eyes or less.

Discussion

Alteration has primarily affected the matrix of the mylonites which is commonly traversed by very fine grained replacement quartz, carbonate, or epidote. Sericite and chlorite are common minor constituents of the matrix which introduces a weak lamellar fabric to these rocks and may have been in part produced by indirect componental movements, that is, as a result of intergranular diffusion and crystalloblastesis. The fact that the mylonites are spatially related to the schist zones suggest tectonic deformation was operative, and was aided in recrystallization by chemical processes.

Alteration

Alteration is a prominent feature of the deformed parts of the Hazelton succession. Quartz, potash feldspar, pyrite, and hornblende are common as alteration products in the cataclasites, either as discrete mineral grains, or as colour and textural variations. Cataclasis itself was low grade, and merely caused crushing and distortion of the volcanic sediments. Metasomatism related to intrusion in the Coast Plutonic Complex has variably altered some of these cataclasites, producing either simple silicification and pyritization, or a variety of minerals. Only in the well developed schists in the Noname Lake area, however, have the rock textures been sufficiently obscured by metasomatism to hide their true character. The study of alteration requires the use of a microscope, but some minerals resulting from recrystallization can be identified macroscopically. A crude measure of the nature of such microscopic alteration is given by the colour of the cataclasites. The dark green foliated rocks are generally chloritic, whereas the very light green rocks are usually sericitic or quartzose.

Schists

Schists developed in the Lower Hazelton Group are really next in importance to the cataclasites. The areas in which mappable schists are found have been outlined in Figure 2 and are most prominent east of Summit Lake. The schists form complex shear zones in the Hazelton country rocks and commonly include minor lenses of mylonite and cataclasite. These shear zones are small, but economically important because of the mineral deposits which lie within them.

Macroscopic Features

The schists can usually be distinguished from the associated cataclasites on the basis of colour and texture. True schists are rare and the term "semischist" is probably a more accurate description. Schistosity or foliation, however, is well developed and readily measured. A few scattered relict plagioclase clasts up to 5 millimeters are discernible in the schists. They all contain 5 to 10 per cent of fine to medium grained cubic pyrite as well as varying small amounts of fine magnetite. Carbonate appears to be ubiquitous, and is found as scattered grains or veinlets with quartz cutting the schistosity. The surface expression of these schist zones has been manifested as extensive bright red and orange gossans, and as shallow depressions that are particularly prominent on the extensive open slopes above the Salmon Glacier. In hand specimen, the schists are commonly friable and marked by vug-like pores where sulphide and carbonate grains have been leached.

Microscopic Features

In thin section the schists consist of very fine to fine grained aggregates of muscovite, plagioclase, chlorite, quartz, and carbonate as well as accessory pyrite and black oxide. Sericitic muscovite generally makes up 25 to 40 per cent of the matrix with the other components varying widely. A few small remnants of parent rock are commonly visible and indicate the low grade of the dislocation metamorphism which produced these schists from original volcanic sandstones and conglomerates. Residual plagioclase clasts are extensively altered and have an approximate composition of An_{28-32} indicating an essentially andesitic character similar to the surrounding cataclasites. Quartz and calcite are common alteration minerals which together comprise from 10 to 70 per cent of the schists. These latter have a faint greenish white colour and lack the well defined fissility of the normal schists.

Discussion

On the basis of macroscopic and microscopic examination the schists can be classified mineralogically as quartz plagioclase sericite schists with more or less accessory pyrite, magnetite, and carbonate. It is concluded that these schists have been produced from Lower Jurassic Hazelton volcanic sandstones by low grade dislocation metamorphism accompanied by metasomatism. The intercalation of kakirite and mylonite with schist suggests that the kinetic process was selective, favouring volcanic conglomerate and breccia, while the alteration process aided the development of muscovite, chlorite, etc. in the more homogenous sandstones.

Origin of the Deformed Rocks

In the foregoing descriptions it has been indicated that the extensive and important cataclasites, mylonites, and schists have been derived from pre-existing sedimentary and volcanic country rocks. Abundant relict textures still evident in spite of dynamothermal metamorphism leave little doubt as to their origin. Surface weathering and limited recrystallization have locally obscured the diagnostic features and have led, in the past, to various erroneous identifications which have stressed a simple sedimentary or volcanic origin and have disregarded metamorphism.

The differential movements that produced the cataclasite zones appear to have been related to a single pre-, or early Middle Jurassic tectonic event. Temporal and spatial relations between the Cascade Creek zone and the Middle Jurassic (or older) Texas Creek pluton as well as the marked northerly alignment of pre-Middle Jurassic satellite plutons suggests that deformation preceded extensive plutonism. Textures and mineral relationships in the cataclasites suggest high pressures, low temperatures, and essentially dry conditions. Textures in the schists indicate that recrystallization outlasted the deformation event.

CHAPTER 4

Structural Geology

General Tectonic Setting

The Stewart Complex is located within the west central eugeosynclinal part of the Alaska-Canada segment of the North American Cordillera. King (1966) has recently summarized this geosyncline as one containing mainly Middle and Late Paleozoic and Mesozoic sediments and volcanics that were invaded or transformed during Mesozoic time by granitic plutons on a grand scale. He suggested that during and after the mid-Mesozoic orogeny successor basins were developed along the Pacific Coast within the framework of the pre-existing Western Cordilleran geosyncline. The major tectonic units of western Canada, including the successor basins, are illustrated on Figure 9, and the position of the Stewart Complex with respect to the successor Bowser Basin is shown on Figure 1. The configuration of the Canadian Cordillera, particularly the western margin, has been of considerable interest in recent years.

On the basis of available geophysical data and comparative geology, Bostrum (1967) projected the course of the East Pacific Rise north from Oregon to include the Western Cordillera of British Columbia, southeastern Alaska, and the Yukon Territory where it meets the Franklin Rise. Bostrum (1967, p. 1823) suggested that the geophysical and geological evidence conspicuously reveals the fragmented tectonic nature of the Western Cordillera between southern British Columbia and Alaska, in southeastern Alaska, by the Lynn Canal-Chatham Strait fjord which marks the southerly termination of the Boundary Ranges of northwestern British Columbia. On the basis of seismic data, St. Amand (1957) indicated that the San Andreas-Alaska system appeared to be continuous with the Aleutian-Alaska belt of tectonism, whereas Girdler (1965) postulated that the northern extension of the East Pacific Rise terminated in the Gulf of Alaska. Sutherland Brown (1968) pointed out that the abyssal depths west of the continental slope off the Queen Charlotte Islands, which are at about 9,000 feet, are shallower than normal, and form part of the East Pacific Rise. The current view then is that the western Canada-Alaska segment of the Cordillera appears to be bounded along the coast by the East Pacific Rise and the Aleutian-Alaska belt of tectonism, now marked by the extensive transform fault system outlined by Tobin and Sykes (1968).

The Western Cordillera has been subdivided into three northwesterly trending belts of relatively unmetamorphosed stratified rocks, separated by two zones of crystalline metamorphic and granitic rocks (Gabrielse and Wheeler, 1961). Using current terminology, the major tectonic units of the Western Cordillera from west to east are the St. Elias-Insular Trough, Coast Range Geanticline, Whitehorse-Nechako Trough, and Omineca-Columbia Geanticline (Fig. 9). While the basement provinces of most of western Canada have been determined with some precision, the composition and possible presence of a Western Cordillera basement has been the subject of lengthy discussion. A recent interpretation of the basement provinces of western Canada by Ziegler (1969) is shown on Figure 21. Hutchison (1971) has recently stated:

> "Most fundamental in unravelling the history of the Coast Crystalline Belt is reconstruction of the scene at the western edge of the present North American continent in Precambrian time. Although no general agreement exists, evidence is accumulating that the Precambrian Shield reached to very near the present edge of the continent. Precambrian dates have been obtained from metamorphic

and plutonic rocks in southwestern California, in the Northern Cascades and in Alaska. Probably these do not represent isolated Precambrian pods but were in fact an extension of the main continental shield."

The broad regional setting of the Western Cordillera particularly in northwestern British Columbia, based mainly on the above evidence, and heroic hypothesis, suggests that a portion of the pre-existing edge of the Precambrian Shield underlies, or is involved in a Paleozoic-Mesozoic eugeosyncline complex which has been subjected to extensive plutonism and deformation. The tectonic elements are now expressed by essentially parallel northwesterly trending depositional troughs separated by geanticlinal crystalline complexes. The writer's thesis area, the Stewart Complex, lies astride the boundary between the Coast Range Geanticline and the Whitehorse-Nechako trough in the west central Alaska-Canada segment of the North American Cordillera. The local and regional tectonic framework within this setting has been studied and fabricated for the first time by the writer.

Tectonic Framework

The elements which form the tectonic framework of the Alaska-Canada segment of the Cordillera, have been outlined by White (1959), and Roddick, et al. (1967), (Fig.9). In a more detailed sense, the tectonic elements of the Western Cordillera, embracing southeastern Alaska and northwestern British Columbia, are presently known only from sporadic field studies, many of which were of a reconnaissance nature, and were not consistent in their approach and treatment of the rock units. Gabrielse and Wheeler (1961) summarized the tectonic framework of southern Yukon and northwestern British Columbia, and provided a general background for the

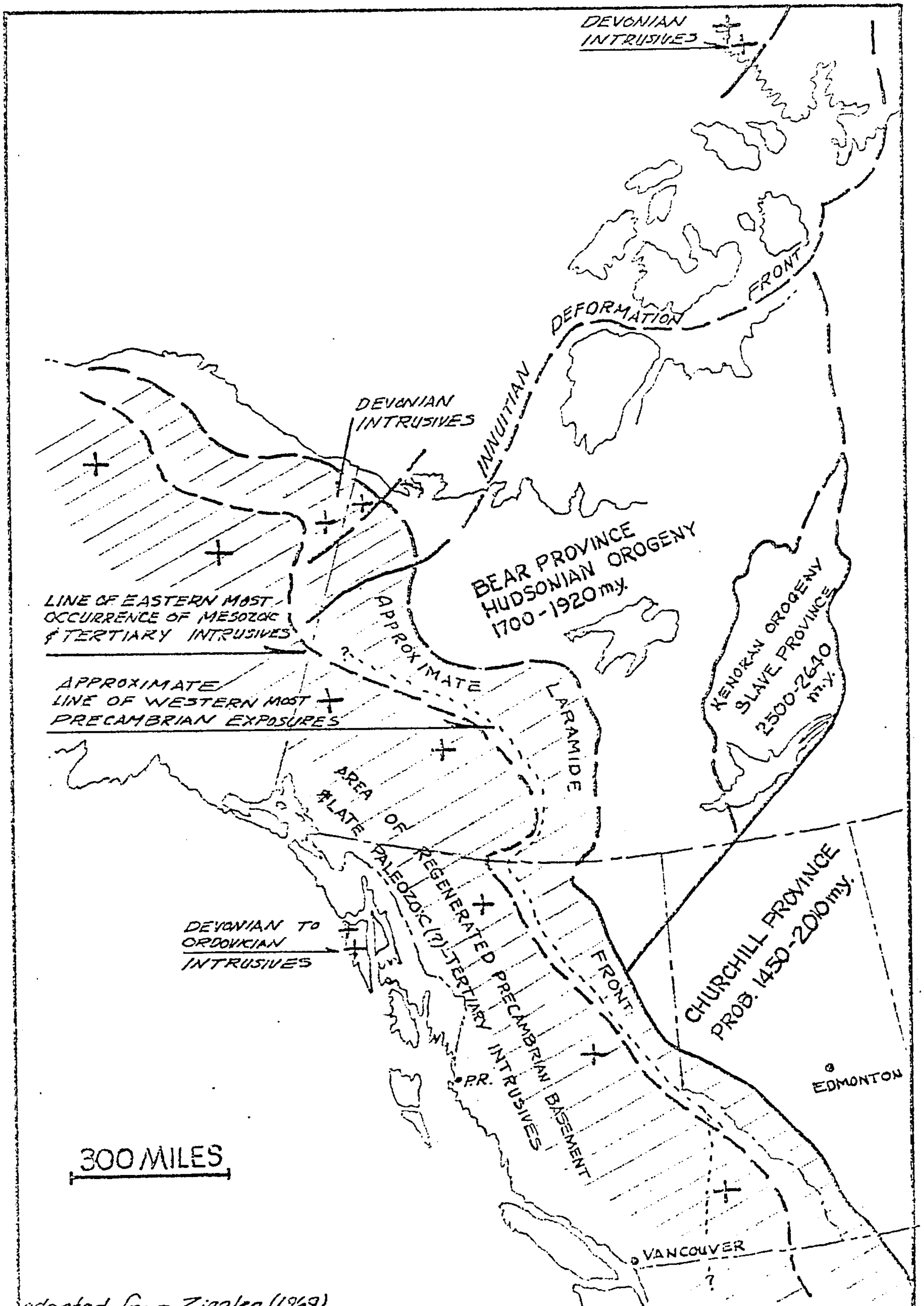

FIG. 21 Basement units, Western Canada.

more recent tectonic syntheses. Brew, et al. (1966) relied heavily on the geologic summaries by Buddington and Chapin (1929), Payne (1955), Miller, et al. (1959), and Gabrielse and Wheeler (1961) for the recent tectonic and structural history of southeastern Alaska. Souther and Armstrong (1966), Campbell (1966), Sutherland Brown (1966), Brew (1968), Hutchison (1970), and Roddick (1970) have all contributed summary results of the various widespread field programmes related to the synthesis of the tectonic history of the Western Cordillera.

The writer's work currently represents the only major structural study in the section between the Stikine Arch and Skeena Arch (Fig. 9). This study has also provided the only linkage between the interior belt of the Western Cordillera, and Hutchison's (1970) Central Gneiss Complex which has been shown as contiguous with the Wrangell-Revillegigedo metamorphic belt of southeastern Alaska (Buddington, 1959). To date the eastern margin of the Coast Plutonic Complex has been partly studied by reconnaissance geological methods, and detailed structural studies, particularly of large areas, are non-existent. Tectonic elements such as the Bear River Uplift, which includes the Stewart Complex, were not previously recognized, although in terms of importance these elements provide extensive structural and stratigraphic information, and are uniquely characterized by economic sulphide mineralization and have become the target of petroleum exploration.

The relative position of the idealized tectonic elements involved in the writer's study are illustrated on Figure 1. From west to east these elements include the Wrangell-Revillagigedo Metamorphic Belt, the Coast Plutonic Complex, and the Bowser Basin. The Bear River Uplift involves part of the Whitehorse Trough as well as part of the Bowser Basin and includes such minor elements as the Stewart Complex, Oweegee Dome, and Ritchie Anticline. The terms Bear River Uplift, Stewart Complex, and Meziadin Hinge have been introduced by the writer in order to describe these structural elements within the larger concept of the regional framework.

This study is concerned with the Unuk River-Salmon River-Anyox map-area, an area that lies within the Bear River Uplift, one of the best exposed and least accessible parts of the margin of the Bowser Basin.

Bowser Basin

The Bowser Basin has evolved from the parent sub-trough through geologic time as the result of a complex interplay of tectonic, volcanic, sedimentary and igneous events which have produced a northwest trending sedimentary basin about 100 miles wide and up to 300 miles long. The area of the basin is about 30,000 square miles which in terms of basin size is considered moderate; the depth, based on unit thicknesses proposed by various workers in the area appears to be highly variable. The basin is situated in a tectonically active zone evidenced by repeated periods of deposition, plutonism, metamorphism, uplift and erosion revealed in the known geologic sequence (Fig. 18). Surface data in the Bowser Basin are sparse, and subsurface information is essentially nil. Geophysical surveys including seismic and airborne magnetometer methods were attempted during 1959 by Pan American Petroleum Corporation (Fitzgerald, 1960), but the seismic results were inconclusive, and the aeromagnetic map essentially outlined only extrusives, intrusives, and the basin margins.

Presumably the tectonic depression presently known as the Bowser Basin was initiated by Late Triassic times. Rocks exposed along the periphery of the basin include Middle Mississippian, Pennsylvanian, and Permian which in part are known to unconformably overlie an older complex (Fig. 10).

The Carboniferous assemblage includes predominantly fine grained volcanics and marine sediments; carbonates which occur as lenticular masses become important late in the Permian. The thickness of the Permian is variable, but appears to be greatest along the west margin of the basin. Indications of post-Permian deformation are present at the Oweegee Peaks area where Middle Permian carbonates are overturned on tilted Triassic sediments. In the western part of the basin Triassic rocks are thick, predominantly non-marine volcanics and epiclastics with intercalated marine sediments. Epiclastic volcanics, flows, bedded cherts, limestones, and quartzites, which are common in the Bowser-Iskut section of the Stewart Complex, are overlain unconformably by Lower Jurassic marine sediments, pillow volcanics, carbonates, and epiclastic volcanics. Metasomatism of the Triassic sediments suggests that the erosional interval was preceded by granitic intrusion. Lower Jurassic rocks which at most places lie unconformably on the older strata, consist principally of clastics and volcanics along the western margin of the basin, whereas fine grained marine shales and sandstones appear to be dominant in the central section (Fitzgerald, 1960). Middle Jurassic pillow volcanics, rhyolites, epiclastic volcanics, and marine sediments have been mapped throughout the length of the Stewart Complex, along part of the Meziadin Hinge, as well as within the central portions. The Monitor Lake rhyolite unit appears to be the most extensive acid mass so far located within the complex and thin extensive correlatives have been mapped in the central Bear River Pass section. Areally, these rhyolite flows and stratigraphically equivalent andesitic to basaltic pillow volcanics mark widespread volcanism prior to the onset of mainly marine Nass sedimentation. Upper Jurassic Nass Formation marine sediments now cover a large part of the original basin. In the eastern Bowser Basin these sediments are generally overlain by Upper Cretaceous and Early Tertiary non-marine sediments which include some coal members. During the evolution of the Bowser Basin, the margins were marked by intrusive activity in the Paleozoic, Triassic, Jurassic-Cretaceous, and Tertiary. Cenozoic volcanic activity which is concentrated along the western margin indicates that the evolution of the basin is still in progress. Although relatively small in area, the Bowser Basin apparently includes a great thickness of sediments and because of this could be termed a hyperbasin (Kamen-Kaye, 1967). The depositional sequence involved in the evolution of the basin is still evident although the margins have been deformed by complex events including plutonism.

During the evolution of the Whitehorse-Nechako trough, and the development of the Bowser Basin, plutonism, deformation, and erosion marking periodic tectonic activity are represented by major unconformities in the pre-Mississippian, pre-Upper Triassic, pre-Lower Jurassic, pre-Middle Jurassic, pre-Lower Cretaceous, pre-Upper Cretaceous, and Recent. Plutonism was largely concentrated within or near the marginal crystalline belts which exhibit deep-seated regional metamorphism. Permian, Triassic, Middle and Late Jurassic plutonic activity culminated in the widespread epizonal Tertiary intrusives. Along the western margin of the Bowser Basin, particularly in the thesis area, simultaneous, predominantly andesitic volcanism and volcaniclastic deposition with associated cherty carbonates extended from the early Late Triassic to the late Lower Jurassic. This was followed by contemporaneous andesitic, rhyolitic and minor basaltic volcanic activity accompanied by calcareous marine sedimentation in the early Middle Jurassic which was succeeded by the thick widespread Middle and Upper Jurassic fine grained marine sedimentary sequences. Acidic volcanism such as recognized in the Tertiary of the Stikine River area sequences are missing, but Quaternary alkali-olivine basalts related to regional volcanic belts have been recognized.

Discussion

The writer's presentation of the tectonic setting and regional tectonic framework generally follows the well-accepted patterns outlined by Gabrielse and Wheeler (1961), Brew, et al. (1966), Armstrong and Souther (1966), Brew (1968), Souther (1970), and the extensive outline by Douglas (1970). The major tectonic units shown on Figure 9 are generally accepted, although the names have had a tendency to change with some alacrity in recent years. However, details such as the tectonic classification of the Bowser Basin, the age of the basin, and the outlines of the Bowser Basin are missing or appear to be contradictory. Information collected from the study of the Stewart Complex will help considerably in the formulation of a reasonable basin model.

The Bowser Basin has been described as a depositional area involving a thick succession of marine, brackish, and fresh water shales, greywackes and conglomerates comprising the Bowser assemblage of latest Upper Jurassic and Lower Cretaceous age (Armstrong and Souther, 1966). Douglas (1970, p. 438) suggested that following Nassian orogeny (Fig. 18) in the Western Cordillera, three discrete depositional basins, including the Bowser Basin were developed. Fitzgerald (1960) who has made the only regional field study of the Bowser Basin and surrounding area to date stated: "Superficially, the Bowser Basin is characterized by intensely folded sedimentary rocks ranging in age from Lower Jurassic to Lower Cretaceous". The writer has revised the Mesozoic nomenclature for northwestern British Columbia and has shown that the term Bowser Assemblage or Bowser Group, named for the sedimentary sequence near Bowser Lake is invalid, and that many of these rocks previously thought to include Upper Jurassic and Lower Cretaceous actually range in age from early Middle Jurassic to late Upper Jurassic, and comprise the upper part of the Hazelton Group. In the Smithers area where Tipper (personal communication) has re-examined the stratigraphic sequence he has identified a mainly sedimentary unit that overlies early Middle Jurassic tuffs and breccias, that range in age from Middle Jurassic to early Late Jurassic. In the northern part of the Smithers area Tipper has also identified late Early Cretaceous (Albian) Skeena Group marine and non-marine sediments that overlie the Late Jurassic rocks either unconformably or disconformably. The new interpretation of the Mesozoic stratigraphy renders the published concept of the age and extent of the Bowser Basin invalid.

Placing an areal limit on the outline of the Bowser Basin provides a possible clue to marking its initial development. Very approximately, if the Coast Range Geanticline and Omineca Geanticline are taken as the west and east limits, and the Skeena and Stikine Arches (Fig. 9) as the south and north boundaries, the basin is effectively bracketed in time and space. Tipper's (personal communication) work south of Smithers has shown that the Skeena Arch extends from Morice Lake easterly across the Nechako Trough to Babine Lake. The arch is fairly broad and includes Lower Jurassic rocks intruded by a westerly trending swarm of Lower Cretaceous Omineca plutons. The Stikine Arch has not been outlined as carefully as the Skeena Arch, but Souther (1971) has indicated the presence of a low emergent area in the region of the Stikine Arch in the Late Triassic. He suggested that beginning in early Jurassic the Coast Mountains Belt and the Stikine Arch were areas of high relief that shed clastic debris into the "Taku Embayment". The writer has presented evidence that the Lower Jurassic Unuk River Formation rests on uplifted, eroded Late Triassic and Permian strata along the western margin of the basin. Clasts of Triassic or older granitic and gneissic rocks probably derived from the uplifted Late Triassic Coast Range Geanticline form extensive conglomerate horizons in the lower and middle parts of the Lower Jurassic Unuk River Formation. The evidence gathered here from the Stikine Arch, Bear River Uplift, and Skeena Arch indicates that a distinct structural basin was developed during the Late Triassic-Early Jurassic interval from the pre-existing Whitehorse-Nechako Trough. The succession of andesitic volcanics and volcaniclastic sediments called the Hazelton group which range in age from early Lower Jurassic to late Upper Jurassic has been developed in the apparently discrete deposition site now called the Bowser Basin.

It is essentially impossible to show congruencies between the Bowser Basin, and known sedimentary models in that the paleocurrent systems for the bulk of the component basin strata are unknown or indeterminate. The model concept essentially developed in its modern formulation by Pryor (1960) and Potter (1959) and others, requires detailed knowledge of the current systems and arrangements of the major sedimentary elements.

The spatial relationship of the Bowser Basin within the regional framework is better known than the paleocurrent systems. Any attempt to classify such a feature requires a probabalistic approach and the use of a convenient analogue. At the present the United States Cordillera appears to represent the closest analogy and provides the best working hypothesis. Badgley (1965, p. 436-446) has compiled extensive geological and geophysical evidence and hypotheses. He has suggested a five-stage evolution of the

United States Cordillera starting with an island arc and associated eugeosynclinal complex in the late Precambrian to early Paleozoic. In the second late Paleozoic stage, he visualized a broad zone with numerous intermontane basins undergoing active differential subsidence rather than trough formation. In stage 3, the late Mesozoic-early Tertiary phase, palingenesis, which resulted in the generation of batholiths, and uplift were accompanied by compression as well as transcurrent motion. Uplift, accompanied by stretching, permitted gravity sliding off the geotumor eastwards into the miogeosyncline possibly causing compression along the Cordilleran foreland with the attendant uplift of Colorado and adjoining states. During the late Miocene following cooling and consolidation of stage 3, the belt suffered extensive erosion, then extensive intermontane sedimentation during the Pliocene. Stage 5, the present, is marked by extensive epeirogenic uplift and stretching throughout the Cordillera accompanied by volcanism and basin-and-range type normal faulting. Both Brew (1968) and Souther (1970) have reviewed the general role of volcanism in the tectonic development of the Alaska-Canada segment of the Western Cordillera and have suggested an evolutionary trend comparable to Badgley's. Tertiary geology is well recorded in British Columbia and Souther (op. cit.) has suggested that the general style of late Jurassic tectonism expressed by expanding uplift persisted throughout the Tertiary. While Tertiary orogeny involved uplift and normal faulting in the Western Cordillera, the miogeosynclinal Eastern Cordillera was deformed by northeasterly directed thrusting and décollement folding (Price, 1969).

The writer suggests that the Bowser structural basin (Badgley, op. cit., p. 463) can be classified as an epieugeosyncline (Kay, 1951), or post-orogenic basin (King, 1959) and has had a tectonic evolution comparable to the basin and range province of the United States Cordillera.

Bear River Uplift

The writer has introduced the term Bear River Uplift for a physiographic-geologic unit that is bounded by the granitic coastal Boundary Ranges of British Columbia and Alaska on the west, and by the sedimentary Skeena Mountains on the east. The northern limit of this uplift is represented by the Iskut River Valley and the southern margin by a low divide between Alice Arm and the Nass River. This physiographic unit includes minor mountain ranges which are higher than the adjacent coastal Boundary Ranges and Skeena Mountains, and are notable because of the presence of extensive icefields. The Bear River Uplift is distinctive geologically because of the presence of exposed Permian, Jurassic, and Lower Jurassic country rocks; these strata are not found in the adjacent areas. The term 'uplift' is a common term in the United States Cordillera used to denote a class of positive tectonic elements. The usage is adopted in this thesis. Badgley (1965, p. 488) has suggested that rapidly rising features, such as the Uncompahgre in Colorado, are frequently referred to as uplifts. The Bear River Uplift is defined as an apparently structurally controlled feature that has been uplifted and eroded at a faster rate than immediately adjacent basin sections. Lower and Middle Jurassic and older, sedimentary, volcanic, and metamorphic country rocks within the limits of the Bear River Uplift, blanketed by mainly Upper Jurassic marine sediments during the late phase of basin development, have been largely eroded, but trough-like sections of these younger Upper Jurassic rocks have been preserved as structural remnants within the uplift. The western portion of the Bear River Uplift has been extensively studied by the writer and has been named the Stewart Complex.

Stewart Complex

The Stewart Complex lies along the contact between the Coast Plutonic Complex on the west, the Bowser Basin on the east, Alice Arm on the south, and the Iskut River on the north (Fig. 1). A complex, as defined by the Commission on Nomenclature (1961, p. 651) is composed of diverse rock types of any class or classes and is characterized by complicated structure. The Stewart Complex includes diverse rock types characterized by complicated structure. More specifically, it includes rock units that have been subjected to polyphase plutonism, and polyphase metamorphism. The most important characteristic of the Stewart Complex which sets it apart from most areas within the Canadian Cordillera is the abundance of a diverse metallic sulphide mineralization which has been found in this unique rock mass. Although this complex has been extensively prospected, explored, and partially mapped geologically, the uniqueness of the area as a structural unit was never previously recognized. The structural geology of this complex has never been examined in terms of local and regional studies, and only in a few instances have any of the mineral deposits received detailed geological attention. The writer's study represents the first attempt to describe and correlate stratigraphy, structure, and mineralization within the complex.

The western limit of the Stewart Complex, including the Anyox and Georgie River pendants extends from Belle Bay north along the Portland Canal to Stewart, then swings northwesterly to intersect the Iskut River. Portland Canal separates the massive, granitic Hyder pluton, localized along the eastern margin of the Coast Plutonic Complex, from the gneiss complex between Belle Bay and Stewart. At Stewart, the Portland Canal lineament extends inland along the Bear River-American Creek Valley and intersects the Bowser River lineament at the Todd Creek junction where it is offset to the east, and continues northerly along Scott Creek. In the Bear River valley at Stewart, the Portland Canal lineament is marked by the narrow Bear River cataclasite zone. In the American Creek and Scott Creek areas a graphite shear zone marks the presence of the lineament. The field data indicates that the Portland Canal lineament which forms the southwest boundary of the Stewart Complex, represents a normal fault over a large part of its length.

The west boundary of the Stewart Complex is marked by the intrusive contact between the Coast Plutonic Complex and the country rocks. The contact exhibits smooth undulations, and marked reentrants in the Unuk and Leduc River sections represent old structures which have been truncated. The intrusive contact is generally steep, but the presence of the satellite Tertiary plutons suggests that the Plutonic Complex actually underlies part of the Stewart Complex at depth. It is suggested that the Anyox and Georgie River pendants represent an intrusive level comparable to the projected deep contact between the Stewart Complex and the underlying intrusives in the Unuk-Leduc River section.

The northerly boundary of the Stewart Complex is approximately along the Iskut River. Extensive chlorite to sericite schists developed along the easterly trending Iskut River Valley indicate a major fault which has offset the northerly trending Forrest Kerr-Harrymel Creek fault. The locus of the easterly trending Iskut River zone, the northerly Forrest Kerr-Harrymel zone and the north-northeasterly Iskut River zone forms the vent of the Quaternary Iskut River lava flow. The southerly limit of the Stewart Complex is marked by the line of Quaternary volcanic flows that occur just south of the east-northeasterly trending Alice Arm-Illiance River lineament.

The Meziadin Hinge marks the easterly limit of the Stewart Complex from Nass River to the Iskut River, and also partly represents the physiographic boundary between the Nass Basin and the Boundary Range mountains. In Figure 1, the Meziadin Hinge line has been drawn through the west end of both Bowser and Meziadin Lakes where well exposed Lower Jurassic volcanic rocks have been faulted, and covered by younger Hazelton sediments. The hinge line generally exhibits normal faulting with the east side depressed relative to the west. The Meziadin Hinge fault can be extended northwesterly along the Bell-Irving River Valley to intersect the Iskut River fault, and to the south it can be extended along the eastern margin of the Coast Plutonic Complex towards the Skeena River. It has recently been suggested that the major Fraser-Yalakom fault extends along the eastern margin of the Coast Plutonic Complex from southern British Columbia through Terrace to Tulsequah (Campbell, personal communicatinn). The Meziadin Hinge probably represents a 140 mile long segment of a major feature that passes from southern British Columbia to northern British Columbia along the eastern margin of the Coast Plutonic Complex, and may be related to the Denalai fault system of Alaska and the Yukon.

In summary, the Stewart Complex is bounded on the west by the intrusive margin of the Coast Plutonic Complex, and on the south, east, and north by high angle normal faults which are major regional tectonic features. It appears that the Stewart Complex has been essentially frozen to the east margin of the Coast Plutonic Complex, and has been involved in major uplift along with the Coast Geanticline, whereas the adjacent basin is separated by major normal faults and exhibits a relative depression.

Relations Between Formations

Late Triassic and Older

The oldest fossiliferous rocks in the study area are the Karnian and Norian strata that are found west of the Unuk River at McQuillan Ridge and west of Harrymel Creek. The McQuillan Ridge member is complexly folded in detail, but the major structure appears to represent an open, northeasterly trending anticlinal fold in part truncated by the extensive northerly trending South Unuk cataclasite zone. At Gracey Creek a northerly trending, pre-Karnian amphibolite grade gneiss zone is overlain unconformably by comparatively fresh, well bedded, northeast trending Karnian sediments and basalt flows. Crushed equivalents of these Karnian rocks are found along parts of the west side of Gracey Creek immediately above the gneisses. The creek appears to be controlled by a deformed 100 foot wide breccia zone which probably represents a major fault. The attitude of the fault zone is difficult to determine, but lineations in the Triassic rocks in this section that plunge northerly at about 18 degrees, indicate a low angle fault plane that is roughly coincident with the east slope of Gracey Creek. The nature of the fault movement between the pre-Karnian gneiss zone and the overlying Karnian rocks has not been determined, but a thrust fault here would be in keeping with the apparent compressional conditions as suggested for Oweegee Dome to the east. Both the gneiss zone and the Late Triassic rocks are truncated on the west by a salient of the Hyder pluton with little attendant deformation, and narrow contact metamorphism.

With the exception of the two mile wide section between the South Unuk River and Gracey Creek, and at Shirley Mountain, the contact between the Triassic rocks and the overlying Lower Jurassic Unuk River Formation is marked by an extensive cataclasite zone. In the Gracey Creek area the thick-bedded Lower Jurassic strata form northerly plunging slabs that overlie both the gneiss and Triassic sediments with fault relationships. At Shirley Mountain, metamorphosed Triassic or older rocks are unconformably overlain by Lower Jurassic sediments and pillow volcanics. The relationships between the Late Triassic rocks and the Jurassic rocks along the west limit of the Unuk River sheet have been totally obscured by the Francmackie Icefield, by Quaternary volcanic flows, and by the effects of deformation and plutonism.

Relations between the Late Triassic rocks and the older gneiss zone imply that simple compressional folds were developed before the thrusting of the Karnian rocks over the gneisses. The Lower Jurassic Unuk River Formation is generally in fault contact with the Late Triassic and older rocks, as for example at Gracey Creek where a normal fault relationship is indicated. Later cataclastic deformation along the Leduc-South Unuk-Harrymel lineament has completely obscured the contact relationships between the Triassic and Jurassic along most of the zone.

Souther (1971) has named the mid-Triassic uplift, folding, metamorphism and plutonsim which affected the northwestern Cordillera, the Tahltanian Orogeny (Fig. 18). It is roughly equivalent to White's (1959) Cassiar Orogeny, and marked the close of mid-Triassic volcanism, and preceded the Late Triassic volcanism and sedimentation. Formation of the gneiss belt outlined along the margin of the Coast Plutonic Complex between the Leduc River and Gracey Creek, may be correlated with the Tahltanian episode of regional metamorphism, although certain evidence put forth by Hutchison (1970) and others, also indicates a pre-Permian age for part of the Central Gneiss Complex.

Jurassic

Relationships between the formations comprising the Jurassic Hazelton Group are generally simple and clear. Extensive Tertiary erosion has exposed the relationships between the formations comprising the Hazelton Group within the Stewart Complex. Within the Lower Jurassic Unuk River Formation sedimentation and volcanism have been interrupted by unconformities marked by conglomerate units such as at Twin John Peaks, Mount Shorty Stevenson on Bear River Ridge, and Mount Rainey east of Stewart. Numerous local faults and minor unconformities as well as the major northerly trending pre-Middle Jurassic cataclastic zones have been mapped within the Lower Jurassic sequence and are shown on the Geological maps (Figs. 2 and 3). The folded, deformed Lower Jurassic Unuk River Formation is separated from the early Middle Jurassic Betty Creek Formation by an angular regional unconformity first recognized north of Stewart at Betty Creek which is also well exposed throughout most of the area of the Stewart Complex. Betty Creek deposition was followed by minor folding, faulting and extensive erosion before the deposition of the late Middle Jurassic Salmon River Formation. The Salmon River sequence includes mainly siltstones which were deposited on the Unuk River and Betty Creek Formations following limited deformation and general erosion which produced an uneven surface. The Upper Jurassic Nass River Formation, which includes a basal granodiorite cobble unit, was deposited across the Lower and Middle Jurassic Hazelton Group with an unconformable relationship to the underlying Salmon River Formation that is best displayed along the Meziadin Hinge. In the Tulsequah area where the time from Bajocian to Late Cretaceous was marked by erosion and non-deposition, Souther (1971) has related folding of the

Lower Jurassic units to Upper Jurassic deformation. This activity has generally been referred to as the Columbian orogeny by various workers (Fig. 18). In the Stewart Complex the writer has shown that the Lower Jurassic strata were deformed and intruded prior to Lower Middle Jurassic sedimentation. Because of this relationship, and the fact that the Middle Jurassic strata are relatively undeformed, the writer suggests that early Nassian orogeny (Fig. 18) was mainly responsible for post-Tahltanian, pre-Laramide deformation in the northwest and central Western Cordillera.

The absence of Cretaceous and Tertiary strata in the Stewart Complex, and large parts of the western Bowser Basin, expresses the extensive uplift and erosion that accompanied late Laramide orogeny.

Quaternary

Excluding glacial deposits and unconsolidated recent sediments, the basalts in the Unuk River and Alice Arm districts are the only known Quaternary deposits in the general area. These are unconformable on all older rocks and appear to be related to tensional volcanic belts (Fig. 1) first localized along graben-like features in the Tertiary.

Summary

In the area of this study there have been several distinct periods of metamorphism, plutonism, volcanism, and sedimentation, marked by deformation and erosion. The intensity of deformation as expressed by the intraformational relationships has apparently decreased since the mid-Triassic Tahltanian Orogeny, although plutonism as measured by the apparent volume of granitic material increased in apparent activity and reached a climax in the Tertiary.

Major Structures in the Stewart Complex

Introduction

Without exception the early workers in the Portland Canal district elected to almost completely disregard structural geology. Schofield and Hanson (1922, p. 34) suggested:

> "Salmon River area, in harmony with the other parts of the Coast range, has dominantly a folded structure, the folds trending in a northwesterly direction."

Hanson (1929, p. 16) made almost no reference to local structures except that, "Faults are probably numerous in the area". Later, Hanson (1935, p. 24) indicated a syncline was present in the Salmon River district and an anticline in the Bear River district, but these features were linked to a fold outlined at Alice Arm! These few statements constitute the entire knowledge of the structural geology of the Stewart Complex until this study.

Major structures in the Lower Jurassic have been largely concealed by the extensive Middle Jurassic cover and by the major icefields. Polyphase metamorphism, plutonism and widespread alteration have combined to obscure features in the vicinity of the major mineral deposits, but the large scale structures can be fitted into an overall pattern that is related to the tectonic development of the successor Bowser Basin as part of the evolution of the Western Cordillera in northwestern British Columbia.

In terms of economic mineralization the relationships between mineral deposits and rock structure have been a continuing major problem. During the 75 years of mineral exploration in the Stewart Complex all the mineral deposits have been located by traditional prospecting. Geological exploration has been completely retarded by the lack of a unified stratigraphic-structural framework on which to base even local exploration programmes. The writer has provided this framework, and has outlined the major structures including folds, faults, dyke swarms, alteration zones, and zones of deformation.

Major Folds in Lower Jurassic Rocks

The Unuk River Formation is moderately well exposed between the Unuk River Valley and Treaty Creek and as indicated on the geological map includes a variety of well bedded sedimentary and volcanic rocks which generally trend northerly with variations in rock attitudes that are related to major folds and minor warps. In the Bowser River district the Unuk River Formation has been considerably more difficult to interpret because of the mosaic of local faulting and of widespread rock alteration. In the Stewart district the individual formation members have been traced considerable distances and have provided moderate structural control. At Maple Bay the undeformed rock units have been traced in detail but the section lacks fossils and has been homotaxially related to the Unuk River Formation. The Alice Arm section mapped by Carter (personal communication) also lacks diagnostic fossils and the relationships shown by the writer are also based on homotaxial relationships.

Unuk River Folds

The well bedded mixed volcanic-sedimentary sequence exposed along the east valley wall of the South Unuk River extends from the Tertiary intrusive contact at the South Leduc Gracier on the south with a northwesterly trend to the vicinity of Twin John Peaks where the sequence swings northeasterly towards Star Lake then turns sharply southeast into the Treaty Glacier section. Top determinations along the main belt of exposed Unuk River Formation as well as in the scattered windows in the Francmackie Icefield suggest a major north-northwesterly trending domical structure extending from the Bowser River through Brucejack Lake towards the head of Storie Creek. The structural cross sections (Fig. 4A) illustrate the sub-parallel, assymetric north-northwesterly trending warps outlined within the boundaries of the major Brucejack dome. Along the western flank of the dome the major folds appear to be essentially homomorphic (Belloussov, 1960) similar folds inclined to the west. At Gracey Creek, the deformed upright slab of Unuk River Formation and the comparable strata along Harrymel Creek dip easterly and indicate preserved segments of an eroded, deformed syncline which previously occupied the general South Unuk-Harrymel section. In the Mitchell-Sulphurets Creek window, the major structure is a simple antiform or warp lying parallel to the axis of the major dome which has been fragmented by plutons and faults. Lower Jurassic strata in the Bowser River area display simple warp features difficult to interpret because of the fault mosaic, but they appear to represent undulations along the east flank of the major dome, and unlike the fold structures along the Unuk River, appear to be upright rather than assymetric.

In the Unuk River and Bowser River areas the bulk of the Lower Jurassic rocks are obscured by the Frankmackie Icefield, alteration, and younger Hazelton Group rocks. These younger rocks represent structural remnants that comprise sediments and volcanics deposited after uplift, faulting, deformation, and erosion. In the Tom McKay Lake section the tongues of Salmon River Formation shown in Figure 2A lie along deformed synclinal folds in the underlying Unuk River rocks.

American Creek Anticline

The American Creek Anticline is one of the many idiomorphic regional warps that have involved rocks of the Lower Jurassic Unuk River Formation. The open, slightly inclined nature of the American Creek Anticline is shown in Figure 4B (Sections A-A' to D-D'). This fold illustrates thickening and thinning of strata indicative of fold disharmony. The northern axial section of the anticline is well exposed in American Creek, and in Bear River Pass. North of Stewart, at Mount Mitre, the anticline plunges at about 15 degrees under younger sediments. To the southeast of Stewart the American Creek structure is partly exposed in the Bromley Glacier area where overlying Salmon River Formation rocks have been eroded.

The anticline has been weakly deformed by numerous dykes, and plutons, as well as faults which have combined to partly obscure the main structure southeast of Bear River Pass.

Bear River Pass Folds

The general structure, based on observations at Bear River Pass (Fig. 2B) as well as the restricted valleys north and south of the pass suggest an overall, uniformly gentle, east dipping sequence marked by gentle idiomorphic warps. The Mount Patullo and Willoughby Creek sections which lie along the eastern limits of the Stewart Complex have not been studied in detail, but the general impression of a simple, warped, essentially easterly dipping homoclinal succession, fits into the scheme devised for the Bear River Pass and Alice Arm sections.

Georgie River and Maple Bay Folds

The Georgie River Pendant includes a more or less uniform sequence of westerly to northwesterly trending epiclastic volcanic and sedimentary rocks dipping steeply to the south. Major folds were not recognized in this section, and in particular it was not possible to relate any apparent minor folds to the Marmot River area just to the north, or to the Maple Bay section to the south. Margins of the pendant are hornfelsed and the sequence has been extensively deformed and faulted.

At Maple Bay the Lower Jurassic pillow lava, sandstone, carbonate sequence forms an open northerly trending, broad syncline. Extensive cataclastic deformation and normal faulting have reduced the syncline to northerly trending parallel fault bounded segments. Many Tertiary plutons transect the older folds leaving the structure essentially undisturbed.

Alice Arm Folds

Hanson (1935, p. 24) suggested that in the Alice Arm district the major structure embraced the entire district, and appeared to be a northerly trending anticline. Recent mapping in this section by Carter (pers. comm.) has disclosed essentially idiomorphic northerly trending major folds in the rocks that underlie most of the area. Fossils in these rocks have not been useful so far for correlation, but for this thesis these rocks have been correlated with the Unuk River Formation.

Minor Folds

Folds in Hazelton rocks on a scale less than the American Creek Anticline were not recognized by any of the early workers in the Stewart Complex, but detailed mapping has shown that they do exist throughout the area and that they are important in terms of localization of mineral deposits.

Mount Rainey Syncline

The Mount Rainey Syncline represents a structural remnant underlain by intrusives, and unconformably overlain by deformed Middle Jurassic Salmon River strata. Exposed strata along Portland Canal present an apparent continuous homoclinal succession of green volcanic conglomerates dipping easterly at a moderate angle. Thin-bedded members intercalated with these rocks were traced into the Marmot Glacier area where steep north dips prevail and outline the structure as a northeasterly trending asymmetrical fold overturned to the east and plunging northeasterly at about 60 degrees. Drag folds and lineations mapped in thin-bedded sandstones in the Marmot River section show a steep northerly plunge.

Mount Bunting Syncline

The Mount Bunting Syncline has been partially exposed on the upper east slope of Mount Bunting by the recent ablation of ice and snow. The rocks forming the synclinal remnant consist of well bedded red and green Hazelton volcanic sandstones, conglomerates, and minor breccias. Strata forming the west limb trend north northwest with steep to vertical dips and along the easterly limb the beds dip north at 30 degrees to 70 degrees. The axial plane of the syncline trends north northeast and minor structures show that the fold plunges northeasterly at about 80 degrees. At the head of Donahue Creek clear stratigraphic relations show that the strata forming this minor fold trough unconformably overlie part of the lower Unuk River succession.

Summit Lake Folds

Westerly trending folds, forming a second set of minor structures in Hazelton epiclastic volcanics, occur along the west side of Summit Lake and in the Big Missouri Ridge section. Most of the epiclastics west of Summit Lake are thick-bedded, generally featureless conglomerates. Thin-bedded siltstones intercalated within part of the succession are well exposed to the north of August Mountain Glacier where westerly trending folds generally plunging at 60 degrees west have been mapped (Fig. 3A). West plunging minor folds were also mapped in fine grained volcanic sandstone strata on Big Missouri Ridge, west of Fetter Lake, where quartz-sulphide lenses similar to Big Missouri type mineralization have been explored. In this section, the mineralization appears to be localized along axial plane fractures developed in the thin-bedded, folded, tuffaceous volcanic sandstones.

Structures in Hazelton Rocks

Members of the Hazelton Group rocks in the Stewart Complex have been mapped as elongated lenticular masses. In the third dimension they are apparently lenticular as well, and illustrate what can be termed grossly a mackerel structure in which each lens overlaps the others. Weak foliation, minor folds, and some lineations are present to some degree in all the members of the assemblage. It appears that these structures have developed variably throughout the Hazelton Group and that they frequently exhibit a sense of selection based upon rock particle size and competency.

Minor Structures in the Stewart Complex

Foliation

Foliation, which in this thesis includes all secondary planar structures, has developed in a number of ways with varying degrees of complexity. In the Hazelton strata foliation is restricted to zones of deformation and is present in the various cataclasites, mylonites, schists, and rare gneisses. In the least deformed cataclasites foliation has been caused by smearing of the matrix with the production of shiny green, grey, or purplish laminations that transect primary features. In mylonites, the foliation laminae are more pronounced, and are accentuated by fine mineral layers. Most of the so-called purple tuffs and "Premier Porphyries" described in old reports in the Portland Canal district are actually cataclasites and banded mylonites. Semi-schists, and schists developed in the Salmon River Valley area exhibit planar structure resulting from the development of metamorphic minerals. Well foliated gneisses are rare, but alternating feldspar-hornblende laminations along the margins of the plutons are sometimes recognizable. The foliate rock structures are largely related to plutons or dykes as contact effects. The large cataclastic zones were developed in certain Hazelton members prior to actual magmatic penetration by plutonic wedging.

Folds

Small open folds appear to be characteristically developed in the fine grained strata, whereas only major folds affect the thick, coarse grained beds. As a result, small scale folds are concentrated in areas such as Big Missouri Ridge and Summit Lake where fine grained members are prominent. The minor folds in the medium grained Hazelton strata west of

Bear River Ridge have upright axial planes, and plunge steeply toward the west. East of American Creek where the rocks are uniform sandstones, minor folds are open undulations plunging easterly at a moderate angle. South, and east of Bear River, the rocks are generally coarse grained and massive except in the Marmot River area where minor folds in thin-bedded fine grained sediments plunge steeply north.

Lineation

Outside the main cataclasite zones, lineation is not a conspicuous structural element in Hazelton Group rocks of the Stewart Complex. Linear elements in the deformed volcaniclastics are largely elongate rock and mineral clasts, and elongate grooves lying in the foliation planes where they reflect lenticular mineral clumps. The generally uniform attitude of the lineations throughout the area is illustrated on Figure 3. In the Unuk River, and Cascade Creek areas lineations are more variable than elsewhere, but show a crude sub-parallelism for the minor fold axes.

Summary

The heterogeneous nature of the various strata of the Unuk River Formation has been amply illustrated by their variable response to deformation. The overall uniformity of the minor structural elements is expressed by their symmetry. Lineations for example, which have formed as a result of local pressure gradients, would have a much more complex pattern if the rocks had flowed freely, or if discrete segments of the area had responded at different times. It therefore seems likely that the Lower Jurassic rocks as a whole have been subjected to regional non-hydrostatic over pressures. Except for local schist development, mineral recrystallization has not been a major feature of the overall deformation. Usually, recrystallization is considered a thermally activated process initiated by such mechanisms as nucleation at certain energy levels. With high strain energy available, the temperature required to initiate nucleation and crystallization would be lowered. In this general area, evidence of metasomatism has only been found in limited zones where the combination of temperature, local overpressures, and a suitable diffusion gradient has occurred. The Premier area, near Stewart, where metasomatism has been described, is one of the best local examples where exacting physical-chemical conditions for metasomatism were met. Uniform structural features, combined with the evidence for limited recrystallization as indicated by the minor structural elements, suggest that the deformation was related to a regional tectonic event, the uplift of the Coast Geanticline, and related plutonism during the early phase of Nassian orogeny.

Major Folds in Middle Jurassic Rocks

Folds in Betty Creek Strata

Folds in the Betty Creek rocks are mainly large open flexures, generally related to erosional troughs formed in the Lower Jurassic, and older country rocks. Thin wedges of fossiliferous Betty Creek conglomerate blanket the easterly flank of the Brucejack Dome forming remnant, northeasterly plunging, synclinal sheets overlapped by younger formations at Treaty Creek. The bulk of the Betty Creek Formation, extending from Treaty Glacier to the Bowser River at Mount Jancowski, is a simple, basin-like feature that trends northwesterly, and plunges at a shallow angle to the southeast. From Mount Jancowski south to the top of Bear River Ridge, opposite Bitter Creek, the Betty Creek Formation is more synclinal in form. The Jancowski Syncline has its greatest development along the 9,800 foot high Mount Jancowski-Mitre Mountain massif, but the Betty Creek Formation thins rapidly to the south, roughly along the axis of the Divide-Long Lake Valley. The Jancowski Syncline has an assymetric profile, overturned slightly to the east, and from the top of Bear River Ridge at Mount Shorty Stevenson the canoe-shaped syncline plunges northerly towards the Bowser River at a shallow angle. At Bowser River the Jancowski Syncline has been transected by normal faults with the south sides depressed in relation to the north. The total length of the syncline, from Treaty Glacier to the top of Bear River Ridge, is 36 miles, and is one of the largest features in the area.

In the Bear River Pass section the conspicuous Betty Creek strata has blanketed the underlying Lower Jurassic sequence, filling in the old erosional surface, and has itself been left as irregular, slightly warped structural remnants, because of erosion.

In the Alice Arm district the correlatives of the Betty Creek strata are simple structural remnants blanketing part of the easterly flank of the underlying Lower Jurassic rocks much as it does in the Treaty Glacier section described above.

At Anyox, the volcanic flow and pillow lava comprise northerly trending assymetric open folds, moderately overturned to the east like the major Mount Jancowski Syncline. Parallel folds revealed in the pillow volcanic sequence at Anyox have an important bearing on the location of ore deposits in this area. The major fold involving the overlying Salmon River Formation as well has been called the Anyox Syncline (Fig. 2C).

Summary

Rocks comprising the Betty Creek Formation have been deposited as a thick blanket on the folded, faulted, and eroded Lower Jurassic Unuk River Formation. Normal faulting, and pre-late Middle Jurassic uplift and erosion has left irregular sheets of Betty Creek strata as structural remnants within the area of the Stewart Complex. Major folds in the Betty Creek Formation appear to be restricted to a northerly trending belt along the central part of the Stewart Complex where extensive northerly trending faults are localized. Minor folds, lineations, and foliations are essentially absent in the Betty Creek Formation except locally, in relation to faults, dykes, and small plutons.

Folds in Salmon River Strata

Bajocian Salmon River strata completely blanket the northerly, easterly, and southerly limits of the study area, and like the Betty Creek strata, this unit is found as structural remnants overlying the older rocks from Iskut River south to Alice Arm.

Major structural remnants of the Salmon River Formation are shown on the geological maps at Sulphurets Creek, Bowser River, Bear River Ridge section, Bitter Creek, Anyox, and Alice Arm districts. These remnants are all synclinal features marking trough-like basins of deposition in the eroded, deformed underlying Betty Creek and Unuk River strata. These trough-like basins generally trend northerly to northwesterly, and where best displayed usually represent upright, canoe-like, folds. They have all been subjected to variable plutonism, metamorphism, deformation, and alteration.

Along the northern limits of the Stewart Complex the edge of the overlapping Salmon River Formation has been mapped in some detail (Fig. 2A). The finger-like extensions of these rocks across the older Lower and Middle Jurassic strata are all localized along fault or shear zones in the older rocks where the Betty Creek and underlying Unuk River rocks have been extensively eroded. The entire sequence of Salmon River rocks in this area displays a disharmonic, non-planar, non-cylindrical fold pattern (Badgley, op. cit., p. 50-94) which is characteristic of both the Salmon River and younger Nass strata. The Dillworth Syncline, which lies just east of the Salmon Glacier between Mitre Mountain and Mount Shorty Stevenson on Bear River Ridge, will be described in some detail below as an example of structure in the Salmon River strata.

Mount Dillworth Syncline

The Mount Dillworth Syncline lies in a structural trough paralleling the American Creek Anticline, and astride the westerly limb of the anticline. The fold is open, slightly inclined, and exhibits fold disharmony typical of structures involving strata of variable competency and thickness. Overall, the fold has a canoe-like shape with the ends resting on the south shoulder of Mount Mitre and on Bear River Ridge at Mount Shorty Stevenson. From the northerly apex of the fold on Mount Mitre, the structure plunges south into Betty Creek at about 40 degrees. The keel section has a maximum thickness of about 6,000 feet in the Mount Dillworth section (Fig. 4B, Sect. C-C'). The plunge of the syncline from Mount Shorty Stevenson north into the main trough is about 25 degrees. The contact between Salmon River and older rocks outlining the Dillworth Syncline, shown on Figure 3, illustrates several complex digitations.

Salmon River siltstones and greywackes overlying competent Hazelton epiclastic volcanics illustrate such fold attenuation at the south end of Summit Lake whereas the smooth, apparently conformable zone along the west side of American Creek represents a contact between physically similar rock types. The geologic sections also illustrate various degrees of disharmonic folding within rocks of the syncline as related to variable rock competency. Minor folds are visible on all scales and present an interesting display of disharmonic features. In these rocks, and within the Dillworth Syncline in particular, the minor folds are complex, and particularly difficult to trace because of the general lack of marker horizons. The scatter of fold symbols in Figure 3 illustrates the multitude of mappable minor folds as well as their disharmonic nature. The complex folds mapped west of Little John Lake on Troy Ridge are perhaps the best expression of disharmonic folds in the sequence (Plate 19).

The Dillworth Syncline has been intruded by dykes and plutons accompanied by varying degrees of deformation. Faulting has been extensive, but stratigraphic displacement within the syncline appears to have been minor. The lack of good marker units precludes recognition of significant stratigraphic repetition by fault mechanism.

Minor Structures

The pattern of folds and minor structures in the Salmon River rocks has been summarized from detailed field maps on the geological maps presented with this thesis. The Salmon River strata have been preserved as structural remnants lying in contorted trough-like or canoe-shaped depressions in the underlying Hazelton. These troughs are partly tectonic, but they also reflect Middle Jurassic erosion, as indicated by the local unconformities. The fold structures developed within these rocks have been produced by their response to the depositional basin environment, and to later deformation.

Cleavage

Cleavage is apparent in the thinly laminated argillaceous siltstones of the Salmon River assemblage. Phyllites are prominent at Slate Mountain where the siltstones unconformably overlie Hazelton epiclastics and cataclasites (Fig. 3). The cleavage is parallel to the unconformity and has been generally assumed to have developed as a response to folding, thus Slate Mountain. However, detailed mapping in the area provides an alternative explanation. At Slate Mountain the Salmon River strata extend tongue-like across steeply dipping Hazelton conglomerates and mylonites. This irregular slab of thinly banded siltstones forms a homoclinal structure dipping north towards Long Lake. In detail, the siltstones are complexly folded with overturned, asymmetric folds dominant.

At the south end of the Slate Mountain overlap the cleavage and contact are generally horizontal, cutting across the steep axial planes of the minor folds. Cleavage in the thin phyllitic zone in the underlying Hazelton rocks is essentially parallel. Northerly through Slate Mountain cleavage patterns show no direct relationship to the minor folds. Well developed cleavage south of the Long Lake dam and along the west side of Slate Mountain cuts across all visible minor fold axes and parallels the small fault shown on Figure 3. Slate-like phyllitic siltstones are well developed along this section where the steep northerly trending fault-related cleavage has been superimposed on the undulating contact-controlled cleavage. The foliations exhibited are not flow cleavage, but instead are related to thrust faulting, and to the undulating main contact. This indicates mass epidermal sliding of Salmon River strata across the old surface with the production of slip cleavage. The name "Slip Mountain" would possibly be more apropos than "Slate Mountain".

The fault contact between the Salmon River siltstones and Betty Creek sandstones on the north side of Betty Creek also represents a zone where limited slip cleavage has developed. Steeply inclined competent sandstones, overlain by thinly layered siltstones have parted, producing a high angle fault with adjacent narrow foliated zones which dies out where the contact flattens.

Elsewhere foliated zones have been developed in Bowser rocks at the margins of the numerous intrusions and along the many fault zones.

The Portland Canal fissure zone, described by McConnell (1913, p. 30), represents an irregular shear zone developed along a northeasterly trending steep fault best developed in Salmon River siltstones. On Figure 3 the fault is shown extending from the Bear River Ridge across Glacier Creek towards Bitter Creek. Areally it represents one of the minor shears but it has assumed importance because of the occurrence of the many quartz breccia veins in it.

Cleavage in these rocks is generally steep, and parallels the fault zone cross-cutting the axial planes of the minor folds. Rather than a simple fault, the zone consists of numerous, closely spaced faults, and intersecting cleavage which generally tend to obscure primary S-planes. Eastwards along Glacier Creek the upright, northerly plunging minor folds are variably obscured by well developed cleavage that transects axial planes. In the Maude Gulch section the numerous intersecting cleavage systems are related to faults, isoclinal fold axes, and to the intrusive contact zones.

Conditions responsible for the imposition of foliate structure upon thin-bedded Salmon River Formation rocks appear to have been very simple. The requirements were, adjacent rock masses of different competency, and differential movement that would result from either intrusion or tectonic deformation.

Folds

Folds of different styles and at various scales are visible in almost all the Salmon River rocks. In size, the minor folds range from inch scale, enterolithic-like features, the nappe-like structures nearly one mile long, to simple troughs up to 5 miles long. The sheer multitude of structures precludes the using of a simple naming practice such as used for the folds in the older Hazelton rocks. Instead, generalized groups of folds will be named and described with examples in the following paragraphs.

Small scale ripple-like structures have been observed in thinly striped alternatingly grey-buff argillaceous siltstones such as exposed at the south end of Slate Mountain. In upright bands the ripple-like structures are erect with an amplitude seldom exceeding 1 to 2 cm. In all the laminae examined the peaked crests indicated stratigraphic tops. Where completely exposed the ripple-like structures exhibit separate peaks rather than the elongate ripple wave form. In foliated laminae, the ripple-like structures are asymmetric, and present a disharmonious fold form. This small scale feature possibly represents structures developed both by slip cleavage and by compactive forces which generated true enterolithic structures in certain favourable layers.

Folds larger than inch scale but less than 100 feet in amplitude are found in all the Salmon River Formation siltstones. These vary in form from simple, open, upright flexures, to complex recumbent folds. These are generally restricted to thin-bedded siltstones intercalated in sandstones. The small-scale isoclinal folding is typically found where the containing sandstone members are strongly flexed such as in the crest of a fold. Flexure folds are common on Mount Dillworth in siltstones intercalated within the sandstone unit. Biot (1964) has explained such internal buckling in multilayered structures in relation to folding wave-length as a function of layer thickness. His explanation appears to be substantiated in the multilayered strata comprising the Dillworth Syncline.

Complex isoclinal fold zones are common in thick siltstone units where deformation is associated with faulting and intrusion. The Glacier Creek-Maude Gulch section exemplifies such a zone where confused, large amplitude isoclinal folds abound. Such zones are shown on Figure 4B, sections $B-B^1$ to $D-D^1$ near Salmon Glacier along the east side of Long Lake.

Folds with amplitudes greater than 100 feet are common in the siltstone members within the Dillworth Syncline. These can be mapped by using marker horizons, and can also be traced on air photographs thereby providing lateral control. Figure 3 shows the most prominent of these minor folds. Along the west side of the main trough these folds are generally asymmetric and exhibit Z-fold, and box-like geometry. From

Long Lake the folds plunge northerly, and from the north slope of Mount Dillworth they plunge southerly into the trough. To the east towards Bear River Ridge the folds become upright. Within the siltstone units these folds show a mixture of concentric, and similar fold styles. Canoe-folds at outcrop and larger scales are common in the Divide Lake area.

The large amplitude minor folds such as the upright trough structures located along the east side of Summit Lake present few problems of interpretation. The large recumbent folds mapped in the sandstone unit west of Little John Lake required detailed mapping and analysis. One such nappe-like structure is shown on Plate 19 to illustrate a north-south section through the folds. These can be described geometrically as non-plane, non-cylindrical folds with non-cylindrical axial surfaces (Badgley, 1965). Confused fold is the term used here. These folds are best developed in the sandstone unit where the competent sandstone layers (grey, Plate 19) are sandwiched within sandy siltstones (black, Plate 19). The cross-sections on Figure 4B are at too large a scale to illustrate the east-west section through this area adequately.

The characteristic disharmonic folding found in the Salmon River strata is exemplified by the structure shown on Plate 19. Faults related to these curvilinear folds which can be seen at the left side of the photograph add to the complexity of these structures. With regard to fold size, these folds demonstrate the relationship of the larger minor fold structures to competent rock units.

Hidden Creek Syncline

The Hidden Creek Syncline at Anyox represents one of the smaller Salmon River structural remnants, but it is probably the most important feature of the group. All the major known massive sulphide deposits in the Anyox pendant lie at, or near, the contact between the pillow volcanics and the overlying siltstones.

Hanson (1935, p. 9) suggested, that at the Hidden Creek mine, the argillites (Salmon River Formation) dipped easterly at the surface, then westerly to a depth of 2,000 feet. Nelson (1948) indicated that these sediments, although folded, dipped westerly under the "amphibolites" which had intruded the sedimentary sequence; he therefore expanded Hanson's original description. This concept of intrusive relations between altered basic rocks, and the westerly dipping sedimentary sequence has been perpetuated in the literature for many years.

The writer has completely re-mapped the Anyox pendant in detail and defined the structural geology of the pendant for the first time. He has shown that the so-called intrusive amphibolite at Anyox is a thick pillow volcanic sequence in part conformably overlain by a thick calcareous siltstone and greywacke sequence. The major northerly trending synclinal structure that includes both the pillow volcanics, and the overlying siltstones, has been called the Anyox Syncline. The restricted, highly folded, northerly trending belt of Salmon River siltstones lying along the west side of Hastings Arm has been called the Hidden Creek Syncline (Fig. 2C).

The Hidden Creek syncline is a warped, northerly trending, shallow plunging structure, and like the Dillworth Syncline is overturned to the east. Minor folds in the rocks exhibit disharmonious relationships and are described as non-planer, non-cylindrical, folds with non-cylindrical axial surfaces. The axial plane section of the fold between Cascade Creek and Bonanza Creek has been penetrated by Tertiary plutons; these deform an already complexly folded section (Plate 26). Contact relations like those described for the Dillworth Syncline show a variety of small scale features developed in both the underlying pillow volcanics and overlying sediments. In the axial zone at Bonanza Creek the pillow lava sequence is gradational through banded cherts into the overlying calcarious siltstones. However, on both flanks of the syncline the two major rock types exhibit small scale, localized deformational structures. On the east limb of the syncline, the pillows have been extensively flattened, and display well developed mineral lineation parallel to the fold axis. The pillow volcanics along the upright to overturned west limb exhibit limited flattening, with mineral lineation oriented parallel to the major fold axis. This type of apparent simple shear would probably be included in Sander's (1930) B-tectonite class, typical of fabric developed where folds have been converted by simple compression from open to closed folds. Variable development of the minor structural elements south of Hidden Creek section, and the virtual absence of foliation, and lineation in the broad open fold to the north, suggests non-affine deformation, and relatively minor tectonic transport. In the description of the Mount Dillworth Syncline it was also indicated that the minor thrust movement which had taken place at Slate Mountain was probably related to simple gravity sliding of the syncline across, and partly involving the underlying older rocks.

Summary

The kinetics of the fold structures that involve Salmon River strata imply involvement with plutonic emplacement, and gravity tectonics. The former can be judged quickly from the geology maps and cross-sections, to have played a significant role at the margins of the plutons, and in the dyke swarms. The maximum observed width of the effect of intrusion in the Stewart area along the Texas Creek margin is about one mile. At Anyox, deformation related to the plutons has been minor and apparently restricted to the axial plane zone of part of the Hidden Creek Syncline.

The major role gravity tectonics has played in the development of fold structures in the Salmon River strata is evidenced by numerous slump features, and the dominance of minor confused fold structures within the stratigraphic sequence. These structures, which are found throughout the Salmon River sequence indicate a close relationship between gravity deformation, and basin subsidence.

Folds in Upper Jurassic Nass Formation Rocks

These rocks are found in peripheral areas of the Stewart Complex and apart from local mine studies have not been examined on a regional basis. Where these rocks have been examined and mapped, the minor fold structures exhibit fold disharmony like that described for the Salmon River Formation rocks, and at the present it is assumed that these complex structures have also evolved as a response to gravity tectonics, related to basin sedimentation, and subsidence.

Cataclasite Zones

Introduction

Several major cataclasite zones have been mapped in the Stewart Complex (Figs. 2 and 17). These structures had not been recognized by the earlier workers and their importance in localizing certain mineral deposits has been stressed in this thesis.

The major South Unuk River cataclasite-mylonite zone extends from the Tertiary granite contact south of Granduc Mountain north along the South Unuk River to join the Harrymel Creek lineament. The maximum width of the zone at Granduc Mountain is about one mile, and its overall length is about 28 miles making it the most extensive cataclasite zone in the Stewart Complex.

The Cascade Creek zone lies along the lower west slope of Bear River Ridge between Mount Dolly and Mount Dillworth for a known length of about 8 miles. The maximum width of the zone, about one mile, occurs along the Cascade Creek section immediately north of the Alaska border.

The Bear River zone extends north from Stewart along the lower valley slopes towards Mount Bunting and is less extensive than the Cascade Creek zone. A number of small, but well defined, cataclasite zones have also been shown on Figure 3.

A broad mylonite-cataclasite zone has been preserved at Maple Bay within the Anyox pendant, where it has a width of about 2 miles, and a length of 7 miles. A narrow mylonite zone in the Georgie River pendant is on strike with the Maple Bay zone and may have represented the northerly extension prior to the intrusion of Tertiary plutons.

It is significant that none of the cataclasite zones mapped were found to extend into the Betty Creek and Salmon River Formation strata. Also, as shown on Figure 2 the cataclasites were largely, if not exclusively, confined to acid lava, mixed conglomerate, sandstone, and limestone strata.

South Unuk Zone

The South Unuk cataclasite zone has been traced from the South Leduc Glacier, where it has been cut by Tertiary granite, thence north along the west slope of Granduc Mountain to the west slope of Mount George Pearson, where it constricts between the thick pillow volcanic unit and the hornblende diorite stock. It then trends northwesterly towards the lower east slope of the South Unuk River and past the Unuk River Junction to join the narrow Harrymel Creek fault zone which appears to die out towards the Iskut River. In this 28 mile length, the zone of deformation includes, or has followed, the carbonate rich sequence of the Unuk River Formation and has a steep to vertical dip and northerly to northwesterly strike that essentially parallels the attitudes of the involved members. At Granduc Mountain, the zone is bounded on the west by north trending, steep dipping gneisses and on the east side by faulted massive pillow volcanics, and foliated thick volcanic conglomerates. In this mile wide section the zone includes an extremely diverse group of metamorphic rocks consisting of calc-silicate cataclasites and mylonites, pelitic mylonites, ultramylonites, blastomylonites, boudinaged carbonate lenses, and phyllonites as well as the extensive sulphide lenses that constitute the Granduc ore deposit. The zone has been intruded by northwesterly trending Tertiary Hyder phase dykes, and cut by extensive northerly trending graphitic fault zones that have offset the young dykes and ore bodies. At Sawyer Glacier, the zone includes two deformed syenite stocks as well as the mixed sedimentary sequence marked by limestone lenses, tuffaceous sandstones, cherts, andesitic volcanic flows, and quartz boulder and cobble conglomerates. Towards Unuk River, where the amount of limestone and fine grained sediments decreases, the cataclasite zone narrows rapidly, and at Harrymel Creek becomes a simple, narrow, vertical, chloritic schist zone.

At Granduc Mountain, the cataclasite zone exhibits well developed colour banding, related to dark and light mineral segregations. The well developed striping, or banding, is typical of most of the length of the zone, and the extensive underground mine workings provide outstanding examples of metamorphic differentiation by mechanical deformation (Plate 37). Although Prinz and Poldervaart (1964) once suggested that examples of distinctly layered mylonites are rare, the Unuk River, Cascade Creek, and Maple Bay cataclasite zones are characteristically so well layered that they have generally been described as volcanic tuffs, sediments, and schists in the older literature (Norman, 1962). On a larger scale as in outcrops, the Unuk River zone displays macro-layering where coloured carbonate, mylonite, blastomylonite, phyllonite, ultramylonite, and kakirite layers as well as sulphide masses are intercalated. Most of the limestone lenses or bands within the deformed zone exhibit boudinage, and tight folding, as illustrated on the geological maps (Figs. 2A and 2B). Some of these lenses have been deformed, producing simple tight folds where the crestal sections are up to ten times the thickness of the stretched limbs, and extensive 20 foot thick lenses have been partly balled up into 400 foot thick piles similar to toothpaste squeezed from a tube. Other gross features in the zone include the syenite stocks which have been almost completely crushed leaving lumps of broken coarse red microcline crystals in a mylonitic feldspar matrix. Diorite dykes and stocks in the zone have been boudinaged and crushed to the extent that they warrant classification as kakirites. Rhyolite, chert, and quartz cobble and pebble conglomerate lenses that may be traced from the Sawyer Glacier area into the Granduc Mountain section are represented by the weakly foliated, thick ultramylonite lenses in the sulphide ore zone. Definite relationships have not yet been established between all the primary and deformed units. Sulphide and oxide bodies within the zone have also been deformed, and are preserved as overlapping pancake-like lenses within the mylonite-phyllonite-ultramylonite sequence.

Lineation in the cataclasite zone, measured either as mineral aggregates or drag folds, provides dispersed patterns probably related to variable differential movement, which in turn is related to the inhomogenous character of the components. The presence of strained microcline and quartz clasts within the well developed mylonite confirms the suggestion that stress was non-uniform during deformation (Theodore, 1970). At the Granduc mine rolls and warps along the mylonite zone correspond to thick sulphide sections mantled by ultramylonite sheets. Both the amount and the sense of movement within the Unuk River cataclasite zone is not presently known in detail but minor structures in many of the folded limestone lenses indicate a primarily horizontal differential movement. Norman and McCue (1966) suggested that the drag folds, developed in what they termed recrystallized argillites, siltstones, and tuffs, form one of the major ore controls at the mine, and record internal rotational movement formed by a relative movement of the west side of the Granduc ore section south and upwards.

Layering or colour striping in the mylonites and banding in other cataclastic rocks in the South Unuk cataclasite zone essentially reflect the mineral differentiation effected by the deformation. Brown hornblende, present as unaltered, broken or rolled, felted layers, forms the darker bands, broken angular diopside and epidote forms green layers, and quartz, feldspar, and recrystallized calcite occurs as intercalated light coloured bands. Recrystallization appears to be restricted to calcite, quartz, apatite, and magnetite (excluding sulphide minerals) with very fine grained fresh brown biotite prominent as discrete folia in the phyllonite layers. Lenses and streaks of fresh recrystallized quartz are characteristic of the phyllonites and were originally constituents of pebble conglomerates (Plate 39).

Discussion

The evidence presented here suggests that the bulk of the rocks forming the South Unuk cataclasite zone were formed as a result of directed, differential, destructive deformation without significant diaphthoresis within the limits proposed by Sander (1930), and related by Knopf (1931). As Knopf (op. cit.) and Theodore (1970) have suggested, the physical conditions that existed during mylonitization can be determined by a study of phase petrology and textural relations exhibited by the mineral components. As indicated above, the minerals in the pelitic and calc-silicate mylonites forming a large part of the zone remained stable, whereas the minerals of the carbonate lenses have undergone complete recrystallization. Chemical analyses of limestone from the cataclasite zone indicate the presence of about 0.23 per cent MgO. This MgO

content when related to Theodore's (1970, p. 444) temperature calibrations for Mg content of calcite in dolomitic marble, indicates that deformation in the Unuk River zone proceeded at temperatures less than 300°C. There is no evidence of partial melting in the cataclasites, epidote remained stable throughout the zone, and only minor recrystallization of a hydrous phase is indicated by biotite in the phyllonites. Assuming that significant Co_2 was generated by the recrystallization of the limestones in the zone, and that there was a high H_2O activity in certain parts of the zone, the physical evidence suggests that much of the rock in the zone deformed by shear at low temperature rather than by plastic flow in the presence of an aqueous fluid phase where rock strengths are negligible (Griggs and Blacic, 1965).

The South Unuk cataclasite zone cuts Lower Jurassic rocks, and at the head of Harrymel Creek is overlain by young Middle Jurassic sediments. It is suggested that the cataclasite zone was developed as a result of limited, local tectonic overpressures, possibly related to Middle Jurassic or earlier plutonism, represented near Stewart by Texas Creek intrusion, and in the Unuk area by granodiorite boulder conglomerates at the base of the Middle Jurassic Salmon River Formation.

Cascade Creek and Bear River Zones

The major Cascade Creek, and Bear River cataclasite units include cataclasites, mylonites, minor kakirites, semi-schists, and country rock panels. Both zones trend northerly, with easterly convexity, and minor structures developed within the zones indicate an overall moderate to steep westerly dip. Foliations measured within the zone vary widely, but lineations show a consistent westerly plunge.

The relatively small cataclasite zones north of Bear Lake, along American Creek, and in the Bear River Pass areas are more or less discontinuous zones not confined to continuous strata, and do not form discrete units. They are difficult to trace on the ground because of the topography, and cross-cutting dyke swarms. Rock types in these zones are cataclasites similar in aspect to those in the major zones.

In the petrographic description of the cataclastic rocks in the Cascade Creek zone, outlined in Chapter 3 it has been indicated that the parent materials of the extensive and important cataclasites, have been derived by sedimentary processes from a pre-existing sequence of epiclastic volcanics. Abundant relict textures still evident in spite of dynamothermal metamorphism leave little doubt as to their origin. Surface weathering and limited recrystallization have locally obscured the primary features and have led in the past to various erroneous identifications that stressed simple volcanic extrusive origins and disregarded the effects of metamorphism.

The dynamothermal metamorphism which has produced these rocks was essentially restricted to a narrow zone along the margin of the Texas Creek granodiorite and Hyder quartz monzonite intrusives where the volcanic sediments were crushed and later reconstituted by the plutonic invasion. The event was low grade, as indicated by the relict structures and textures, but it involved a complex interplay of cataclastic, and crystalloblastic processes. These produced the various mylonites, cataclasites and low-grade schists which now comprise most of the Unuk River strata in this zone. Textures in the schists suggest that recrystallization outlasted the deformational events. Undeformed micas were aligned in the schistosity produced during cataclasis and recrystallized quartz and plagioclase grains snow no obvious signs of strain or granulation.

Field relationships indicate that the Cascade Creek cataclasite zone has been truncated by Tertiary Hyder phase plutons, and is overlain by Middle Jurassic sediments in the Mount Dillworth section. The detailed studies in the area indicate that the zone was developed prior to Texas Creek plutonism and associated metasomatism, but that it was closely related in time to that plutonism.

Maple Bay Zone

The Maple Bay cataclasite zone includes a broad area of cherty looking, weakly foliated ultramylonites bounded on the west by chloritic biotite schists, and on the east by phyllonites. The variable foliation in these rocks is essentially vertical and northerly trending. In the central ultramylonite zone, where extensive irregular blocks of weakly crushed hornblendite are crudely aligned in a northerly direction, the zone has been closely faulted, and veined by extensive quartz-sulphide lenses. Rock exposures in this area are poor and details regarding the minor structural features and composition of the zone are scattered. The deformed zone and quartz veins have been transected by the Tertiary intrusives forming the north and south boundaries of the Anyox pendant.

Summary

The Unuk River, Cascade Creek, Bear River, and Maple Bay cataclasite zones are all steep, northerly trending structures developed in Lower Jurassic sedimentary and volcanic rocks, dykes, and small plutons.

Extensive Tertiary plutons related to development of the Coast Plutonic Complex have transected these structures leaving only remnants of what were probably more extensive features. The writer has speculated that because the record of sedimentation in the area restricts the age of the zones to a pre-Bajocian deformation, then the deformation responsible for the cataclasite zones was related to either Texas Creek or earlier plutonism. Definitive evidence for this relationship is not available, but deformation appears to have been a simple compressional event possibly related to geanticlinal uplift which produced northerly trending fold structures in the Lower Jurassic rocks. Also, most of the Lower Jurassic or pre-Middle Jurassic plutons have been intruded in northerly trending zones, and not in the dominant northwesterly trends that characterize the Tertiary structures.

The mylonitic structures in these cataclasite zones have been developed largely as a response to intense differential deformation accompanied by some metamorphic recrystallization. The temperature at which this mylonitization occurred in the Unuk River zone as indicated by MgO content in limestone is thought to be below 300°C. The apparent lack of chemical degradation of the finely comminuted plagioclase clasts in the ultramylonites, and the lack of chlorite in the biotite phyllonites, even under low temperature conditions suggests a generally dry metamorphic environment during mylonitization.

The high pressure, dry, low temperature deformational events recorded here appear to be essentially comparable to reported small scale or restricted zones found in many parts of the world such as Washington State (Snook, 1965), Japan (Nareki, 1966), Norway (Battey, 1965), and Scotland (Christie, 1960). Similar zones are unusually rare in the Western Cordillera literature. The general lack of recognition of cataclasite zones in the Western Cordillera can be partly attributed to an extensive cover of glacial debris, and to the general tendency to map banded fine grained greenish rocks as volcanic tuffs (Schofield and Hanson, 1922; Hanson, 1929, 1935, etc.) or as simple fault lineaments.

Faults, Lineaments and Fractures

Many of the major topographic features in this thesis area have been controlled by the presence of extensive faults and fracture systems along which apparent movement has been limited, but is of local importance. The location of many of the erosional features such as the fjords, glacier and river valleys often marked by abrupt direction changes, are attributed to these zones of limited movement. The air photograph coverage and the quality of the photographs generally is poor for most of the thesis area and as a result, only those features measured in the field are discussed.

Four fault systems can be deduced from the geologic map; these comprise dominant northwesterly, northerly, and northeasterly sets. However, in any attempted stress analysis the time factor, if included, would show that each set has been reactivated several times. The later faults affecting the majority of the rocks in the area mainly represent simple displacement features where rock competency has played a role in determining the attitude and the degree of development of the faults. Both strike slip and thrust faults are prominent in the Salmon River and Nass Formation rocks, but the former type are more extensive, involve the underlying Hazelton as well and include most of the faults shown on Figures 2 and 3.

The northerly trending fault system includes the structures which strike from 15 degrees west of north to 15 degrees east of north, and have steep west to vertical dips. Apparent movement along these northerly trending faults has been measured where possible and where significant, shows as contact offsets. The most prominent systems include the South Unuk and Bear River cataclasite zones and the Meziadin Hinge all of which have been described in previous sections of this thesis. Less obvious northerly trending features include the Mitchell Glacier, Bowser River, Summit Lake, Long Lake, and Bonanza Lake faults and fault complexes, as well as a multitude of less extensive structures.

The Mitchell Glacier fault is partially exposed in the Sulphurets-Mitchell Creek section in the middle of the Francmackie Icefield. The fault is essentially vertical and has offset the Middle Jurassic Betty Creek strata dropping the east side relative to the west. The Betty Creek section is over 3,000 feet thick east of the fault, but has been completely eroded on the west side of the fault at this locality. This faulted sequence is overlain by a continuous blanket of the Salmon River Formation which shows only slight shearing along the trace of the fault line (Plate 13). The Mitchell Glacier fault represents a normal fault of Bajocian Age with an apparent vertical movement of at least 3,000 feet in exposed section. Weak shearing in the Salmon River unit along the old fault line represents limited post-Bajocian movement.

The Long Lake fault has been traced from Glacier Point on Portland Canal north past Premier along the Long Lake Valley to join the American Creek extension of the Bear River cataclasite zone. The apparent length of this fault is about 30 miles and it represents one of the largest minor features in the report area. Like many of the faults in the area, it exhibits left-lateral strike slip movement; this has been measured at 1,500 feet near the north end of Divide Lake where the basal section of the Salmon River Formation has been offset. The vertical movement has not been measured directly but reconstructed sections suggest a possible displacement of about 3,000 feet at Long Lake where the west side has been depressed relative to the east (Fig. 4B). South of Monitor Lake the Long Lake fault splits into several components which offset Hazelton mylonites and cut off a northwesterly mineralized fault zone. In the Cooper Creek section, the Long Lake fault may terminate in the black mylonite band, but its possible extension is marked by a strong lineament which extends into the Premeir area. Along the length of the fault it is marked by only a narrow gauge zone seldom exceeding a few feet. No significant mineralization was found along the Long Lake fault zone.

At Granduc Mountain several steep subparallel northerly trending faults have cut through the ore zone offsetting both ore and Tertiary dykes. Apparent horizontal movement in the Western and Granduc faults measured on the dyke sections indicates right-lateral movement of several hundred feet.

In the Anyox area several parallel, steep, northerly trending faults have been outlined near Bonanza Lake where Middle Jurassic volcanics have been offset by normal pre-Tertiary faults and the Tertiary granite mass has been offset by apparent left-lateral movement. Extensive northerly trending faults have also outlined narrow blocks of sediments east of the Hidden Creek mine at Carey Lake.

Northwesterly trending faults are prominent in the Bear River and Salmon Valley districts. This system includes those structures that trend between about 25 degrees west of north to 60 degrees west of north and have generally steep dips. Field relationships show that these faults cut all the country rocks and cut or are cut by the other fault systems. The northwesterly faults are not as extensive as the northerly faults, and generally show less apparent strike slip movement. The Fitzgerald Creek and Dundee Creek faults, located on the west side of the Bear River opposite Bear Lake, are excellent examples of the northwest fault system. Fitzgerald Creek has been eroded along the narrow fault zone which transects the Salmon River-Unuk River contact as well as the Portland Canal dyke swarm. Strike slip movement is relatively minor, but the sense of dip slip is indicated by offset tuffaceous beds in Salmon River sandstones at the head of Lydden Creek. Here the fault geometry indicates a down movement on the east side and a fault scarp preserved at the head of the small cirque is over 100 feet high. The Fitzgerald Creek fault offsets quartz vein mineralization and northeasterly faults, but does not appear to be mineralized.

The Dundee Creek fault zone lies parallel to Lower Hazelton volcanic epiclastic strata and forms a wedge-shaped zone which widens towards the crest of Bear River Ridge where it is hidden by snow. The zone includes altered country rock fragments, such as phyllonites and chloritic schists and all the rocks are pyritized including the wallrocks. Scattered chalcopyrite as well as quartz sulphide veins were found in the zone and mineral exploration has been extensive in the area. The Dundee Creek zone disappears along the ridge where it is overlain by Middle Jurassic sediments. However, it is similar to the northwesterly schist zones along Summit Lake and may be related.

In the Summit Lake section the country rocks, including the schist zones, are cut by limited northwesterly faults which show strike slip movement. The somewhat sinuous Goat Creek fault at the southeast end of Summit Lake represents a partly contact controlled structure that appears to be confined to the Troy Camp trough. The nearby Mineral Gulch fault lies along the contact between competent Betty Creek sandstones and overlying Salmon River thin-bedded siltstones. It is offset by both northeasterly and westerly faults.

The northeasterly faults system includes structures which trend from north 30 degrees east to north 50 degrees east and have steep dips. These faults also cut most of the country rocks and cut off other faults. They are dominantly strike slip structures which, although less extensive than the Long Lake fault, have similar measureable movement.

The middle-Lower Jurassic contact along the west slope of Mount Dillworth has been offset by a number of short northeast trending faults which exhibit lateral offsets up to 1,500 feet. The Myrtle Creek fault offsets a nose of the Texas Creek pluton but dies out as a weak lineation in altered cataclasites at Noname Lake. The Cobalt Creek fault cuts dykes, granodiorite, cataclasites, and altered country rocks with minor strike slip separation and no recognizable vertical movement. It appears to die out in volcanic epiclastics but a lineament may mark its continuity to the south end of Long Lake. In the Silver Creek section the country rocks and cataclasites are offset by a number of northeasterly faults which cut late lamprophyre dykes and are erratically mineralized by late quartz sulphide veins.

The Portland Canal fissure zone (Hanson, 1929), which extends from the Bear River Bridge towards Bitter Creek, cuts a variety of country rocks and is one of several northeasterly faults mapped in the Bear River Valley section. At the south end the Portland Canal fissure sharply marks the smooth contact between Hyder quartz monzonite and Hazelton volcanic conglomerates and breccias. Where it swings into Salmon River Formation siltstones south of Glacier Creek, the dip decreases to about 45 degrees west and the simple fault becomes a complex fault at least 1,500 feet wide marked by extensive shearing. The zone continues northeasterly along Dunwell Creek. The width and complexity of the zone decreases to the northeast and the dip steepens to 70 degrees west. The fault apparently dies out in Salmon River siltstones south of the Bitter Creek pluton. The Bear Lake fault is the most extensive northeasterly fault structure in the Stewart area. It extends from Bear Lake to Bear River Pass as a steep walled gully with the minor exception of the Mosquito Creek section where its dip flattens to the west along the contact between volcanic breccia and Middle Jurassic siltstones. In the Bear River Pass section the fault disappears in a complex dyke zone.

The westerly trending faults range in strike from 15 degrees north of west to 20 degrees south of west and have steep dips. One westerly trending fault extends between Divide Lake and American Creek, but no movement was recognized. These faults are more prominent along the west slope of Mount Dillworth and Bowser River area where they offset north-easterly and northwesterly faults and the lower-Middle Jurassic contact. Strike slip separations of from 200 to 500 feet were measured on these structures. These faults appear to extend from the competent Lower Jurassic rocks into the more mobile younger strata where they die out as minor folds.

The thrust faults observed in the late Middle and Upper Jurassic rocks are primarily break thrusts such as seen on Plate 19, and although numerous, are not readily mappable at the scales used in this thesis, and have little local economic significance. These are clearly dependent upon pre-existing folding and can merge with local axial plane thrusts. The simple strike slip faults which dominate the area are best developed in the Salmon River Formation rocks and were formed at an intermediate to late stage of folding.

Quaternary faulting is apparent in many parts of the area where glacial moraine has been offset by apparently simple normal fault movements. In the Mitchell-Sulphurets Creek section vertical offsets from 30 to 50 feet have produced step-like features in the moraine and the northerly trending fault shown on the geological map (Fig. 2A), east of Little Tiegan Lake has dropped the east side of the moraine covered ridge at least 200 feet.

The various dyke swarms in the area have been intruded along fracture zones where the inhomogeneity of the country rocks has been reflected in swings in dyke attitude. The Premier dykes are good examples of this feature where they bend crossing the Cascade Creek cataclastic zone. The main Portland Canal swarm of dykes generally have a near vertical attitude in Hazelton rocks but where they enter fractured Salmon River Formation members they bend abruptly, often following bedding plane fractures. This is well illustrated in the area between Long Lake and Salmon Glacier.

Faults are common features in all the mines and mineral deposits in the Stewart Complex but have received exceptionally little attention to date, probably reflecting their generally small movement and minor role in controlling sulphide mineralization.

Field studies in the Stewart Complex have amply shown that rock deformation has been determined by the bulk behaviour of the various country rocks. The competency of the rocks involved in the deformation has also been shown to have been determined by such macroscopic factors as rock type, grain size, and strata thickness.

Simple rock fractures have not been subjected to any rigorous treatment in this part of the thesis but they have been considered significant in the study of mineral deposits. Fractures mapped during the detailed mine studies and the general field work were found useful as a means of discriminating between dyke rocks, various plutonic rocks, and other country rocks. At the Silbak Premier mine, for example, it was found that rock fracture sets could be used to differentiate between similarly appearing altered country rock cataclasite and the Premier Porphyry. Fracture studies are considered useful and meaningful in terms of detailed mapping and in the interpretation of regional tectonic forces. The amount of fracture data collected in this area was considered too erratic and limited to attempt statistical analysis. The air photographs for the area are of poor quality and this common study method was not used by the writer.

Summary

Faulting as defined by loss of cohesion, displacement, or loss of resistance has been recognized as of major importance in the Stewart Complex in regards to simple landscape evolution as well as the complex evolution of the major tectonic units. The bulk of the evidence presented in this thesis with respect to folding, faulting and sedimentation clearly indicates that the Bear River Uplift and Stewart Complex in particular, have been subjected to a sequence of tectonic events in which faulting has played a major role in controlling erosion and sedimentation, and a significant role in the development of the complexly folded late-Middle and Upper Jurassic Hazelton Group.

Tectonic Evolution of the Stewart Complex

The position of the Stewart Complex in relation to the major local elements of structure has been illustrated on Figure 1, and the position of the Bowser Basin within the framework of the Western Cordillera is shown on Figure 9. The geological maps (Fig. 2) included with this thesis include a segment of the Central Gneiss Belt of Hutchison (1970) and a zone of Jurassic and Tertiary plutons which together form part of the Coast Plutonic Complex. The Stewart Complex lies along the west margin of the Bowser Basin where, because of essentially continuous tectonic activity, an important part of the evolution of the Bowser Basin and adjoining Coast Plutonic Complex has been revealed.

Evidence for the pre-Permian history of the Coast Plutonic Complex and Western Cordillera has been mainly derived from southeastern Alaska or from more remote points. As indicated previously, scattered evidence from Alaska, Washington, and California suggests that the Precambrian crust extended nearly to the edge of the present continent (Fig. 20). In southeastern Alaska Buddington and Chapin, 1929) presented the first evidence for Early Paleozoic granite emplacement, as shown by the presence of granite cobbles in Silurian-Devonian sediments.

Radiometric age dates (Lanphere, et al., 1964, 1965) have indicated the presence of Ordovician (or Silurian) plutons at Annette Island near Prince Rupert and have outlined a 400 to 433 million years ultramafic complex west of Ketchikan. In Washington, Misch (1966) has implied the emplacement of early Paleozoic plutons which occur as part of a pre-Middle Devonian complex. Roddick (1966), Roddick et al. (1967), and Brew et al. (1966) have suggested that pulse-like activity extended through the Paleozoic becoming more frequent in the Mesozoic and culminating in the Late Cretaceous and Early Tertiary (Fig. 18). Gilluly (1972) has recently compiled the available radiometric age dates from plutonic and volcanic rocks in the Western Cordillera and has indicated that active plutonism has occurred as an essentially continuous process since the Carboniferous rather than as the widely separated major episodes as was once widely accepted. He suggested that the apparent dominance of Tertiary plutons relates more to accessibility for discovery than to actual volume of plutons.

The evolution of the Sierra Nevada of California (Kistler, Evernden and Shaw, 1971) and the Coast Plutonic Complex have followed similar trends. However, Hutchison (1970) has pointed out that, while the Sierra Nevada includes early mantle derived gabbroic and ultrabasic phases, none have been found in the Prince Rupert area. He indicated that the bulk of the plutons in this segment have been generated within the Central Gneiss Complex along parallel zones and probably represent a deeper level not now exposed in the Sierra Nevada. On the basis of the observed plutonic rock compositions recognized by Buddington (1927) in Alaska he proposed the concept, later expanded by Moore (1959, 1962), of a quartz diorite line that separated first cycle granitic rocks derived from eugeosynclinal volcanic and sedimentary rocks on the west from platform or crust derived granitic rocks on the east side of the line. Dickinson (1968) later suggested that this quartz diorite related to the depth of origin of (recent) volcanoes. Hutchison (1970) suggested that if this proposal could be applied to the Coast Mountains it would be to pre-metamorphic volcanic and intrusive rocks. The three major parallel zones outlined by Hutchison and others in the Central Gneiss Complex, represent a single Barrovian type metamorphic belt composed of uplifted blocks with the oldest on the west and the youngest on the east. These formed at the margin of a Precambrian crust and involved continuous small contributions from the mantle. In terms of the tectonic framework of the Western Cordillera in general, and the Stewart Complex in particular, the Coast Plutonic Belt has been a prominent structural feature in that framework.

In the Portland Inlet section Hutchison (1966) has shown the Central Gneiss Complex as Upper Paleozoic or older, and at Terrace Duffel and Souther (1964) indicated that Permian strata rested unconformably on a gneiss complex. Roddick (1970) has also indicated a Permian or older age for the Gneiss Complex southeast of Kitimat. At Anyox, and along Portland Canal a narrow belt of agmatitic migmatite comprising Hazelton Group strata veined by Hyder phase granitic material forms the margin of Hutchison's proposed eastern younger metamorphic zone. In the Unuk River and Leduc River section of the Stewart Complex, the equivalent amphibolite grade gneisses are overlain by Late Triassic and Lower Jurassic country rocks and are thought by the writer to represent Middle Triassic or older metamorphic rocks such as observed by Souther (1971) in the Tulsequah area. The writer has not found evidence for a Permian age of the gneiss complex although he did indicate that at Oweegee Peaks a thick slab of Permian carbonate has been faulted onto a steeply dipping Triassic sequence. The presence of the Late Permian carbonate sequence at Oweegee Peaks, where Late Triassic faulting and younger uplift have brought a small segment of the Paleozoic basement to the surface, confirms the regional evidence that stable, shelf conditions prevailed throughout the Western Cordillera at that time. The apparent absence of Paleozoic strata within the Stewart Complex, although they have been preserved to the west along the Unuk River, to the east at Oweegee Peaks and to the south near Terrace, suggests that pre-Late Triassic uplift and erosion, the Tahltanian Orogeny of Souther (1971), was essentially confined to the Gneiss Complex and the Coast Geanticline (Fig. 9). Early, Late Triassic sedimentation and volcanism locally expressed by the McQuillan Ridge sequence of intercalated volcaniclastics, carbonates, cherts, and thin basaltic and andesitic flows followed the Tahltanian Orogeny. Parts of the Coast Geanticline and Insular Belt remained emergent during the Late Triassic. During this time extensive volcanism was general, but later subsidence with more stable conditions returned during the Norian epoch. Deposition of volcaniclastics, silts, and shales was followed by carbonate deposition well represented by the Sinwa Formation that occurs in parts of the Unuk River area and recognized elsewhere in the Whitehorse Trough by scattered thin carbonate lenses. Souther (1971) suggested that the thinning of the shale and carbonate Sinwa Formation indicated slight emergence of the Stikine Arch. This and accompanying uplift in the Coast Geanticline became more extensive and marked the early evolution of the major trough into the Taku Embayment in the Tulsequah area and the Bowser Basin (Souther, 1971). Extensive

Late Triassic-early Lower Jurassic uplift and deep erosion unroofed Late Triassic plutons and the gneiss complex, and resulted in the deposition on the east slope of the uplift of the thick Lower Jurassic Unuk River strata in the western part of the Bowser Basin, and the Inklin strata in the Tulsequah area. Most of southeastern Alaska was emergent during Early Jurassic time resulting in a broadening of the Late Triassic Coast Geanticline (Fig. 12). In the Insular Belt the Early Triassic was marked by abundant fragmental volcanics.

In the Southwestern Cordillera of British Columbia the development of the Coast Plutonic Complex more or less followed the same pattern as the central and northern section. Baer (1968) has suggested that the first recognizable orogenic cycle in the southern complex included Upper Paleozoic sedimentation and volcanism followed by a paroxysmal phase that included deformation, metamorphism, and synkinematic plutonism ending in a period of uplift and erosion. Campbell (1966) has shown that in the South Central Cordillera, volcanism and sedimentation along the geosyncline essentially paralleled the development of the northern segment. In south central British Columbia, Cache Creek rocks, assumed to include Mississippian to early Triassic strata are strongly deformed, faulted, and overlain by the Late Triassic Nicola and Lower and Middle Jurassic Rossland Groups Campbell (op. cit.) has suggested that these rocks were deposited in rapidly narrowing troughs.

In the Stewart Complex, widespread late Lower Jurassic volcanism and sedimentation, assumed here to represent shallow marine conditions, was followed by post-Toarcian folding and plutonism related to regional compression. This was accompanied by cataclastic deformation, metasomatism, and normal faulting, which was followed by regional uplift and extensive erosion of the Lower Jurassic Unuk River Formation. In the Tulsequah area Souther (1971) included both the Lower Jurassic and Middle Jurassic sediments within the Takwahoni sequence although he admitted it was possible that a break in deposition occurred between Lower and Middle Jurassic time. This break was first recognized by the writer in the Stewart area and has since been mapped by Tipper (1971) in the Smithers area. Baer (1968) suggested that a second orogenic cycle, involving andesitic volcanism, plutonism, and sedimentation in the south central Cordillera and Coast Plutonic Complex, possibly began during Middle Jurassic time; he cited as evidence Middle Jurassic volcanics lying unconformably on crystalline rocks of the first cycle.

Following late Lower Jurassic erosion in the Stewart Complex, the early Middle Jurassic Betty Creek strata was deposited across the depressed surface, filling in trenches and troughs, essentially resurfacing the old highland. The Betty Creek Formation includes volcaniclastics, volcanic flows, and pillow lavas thought to have been largely deposited in a shallow marine environment. Equivalent rocks in the Smithers area include volcanic tuffs and breccias (Tipper, pers. comm.). This unit was not recognized by Souther in the Tulsequah area and it is therefore assumed to be restricted to the Bowser Basin.

Betty Creek sedimentation and volcanism was followed by normal faulting, minor folding, uplift and erosion. Uplift and erosion appear to have been greatest along the northwest edge of the Stewart Complex and restricted to fault blocks. At Anyox, Betty Creek volcanism was followed by a conformable marine sedimentary sequence. The deposition of the Bajocian Salmon River Formation marked a time of depression with extensive fine grained marine sedimentation again filling in troughs along fault controlled older country rocks. Sedimentation was widespread and equivalent rocks have been mapped by Souther (op. cit.) as the upper Takwahoni Formation in the Tulsequah area, and a similar unit has been outlined by Tipper (1971) at Smithers. Granitic clasts in the basal Salmon River Formation indicate the unroofing of Middle Jurassic or older plutons along the Coast Geanticline immediately to the west prior to the major depression and broadening of the basin (Fig. 15).

The Middle Jurassic and Upper Jurassic units within the Stewart Complex are very similar in all respects and have been separated by a granite cobble zone lying below fossiliferous Oxfordian-Kimmeridgian strata. Tipper (pers. comm.) has stated "that this is precisely the situation in Taseko Lakes and Mount Waddington, and has an analogy with Crickmay's stratigraphy in Harrison Lake". It appears to be more than a local feature and probably represents a widespread rapid uplift of the Coast Geanticline. Deposition of the Upper Jurassic Nass Formation in the Western Cordillera was largely restricted to the Bowser Basin although Campbell (1966) has recorded a narrow basin of roughly correlative Fraser deposition along a southerly remnant of the deformed Nechako trough. The Nass and Salmon River Formations exhibit similar complex disharmonious fold structures in part related to gravity tectonics and in part to Tertiary plutonism. Faults are common and the major zones of movement appear to represent revived older structures. Correlatives of the Nass Formation in northeastern British Columbia include the upper Fernie Passage Beds. Province-wide erosion followed Nass sedimentation prior to the deposition of the Hauterivian and Albian Lower Cretaceous Skeena Group. These rocks have not been preserved in the Stewart Complex where uplift and erosion were coupled to the Coast Geanticline uplift.

Tertiary plutons that occur along the margin of the Central Gneiss Belt, and as satellite plutons and dyke swarms east of the margin, followed predominantly northwesterly trends cutting across the northerly trends of the older gneisses, Triassic and Jurassic sediments and volcanics as well as the Mesozoic plutons. Quaternary volcanism has been concentrated along a northerly trending belt that is included by Souther (1971) in a broad Cenozoic tension zone and along a northeasterly zone outlined by the writer (Fig. 1). To the east, extensive Cenozoic volcanism has been largely confined to the margins of the Bowser Basin.

The bulk of the evidence favours the evolution of the Western Cordillera eugeosyncline by continuous plutonism, volcanism, and contemporaneous sedimentation. Early Palezoic evidence of plutonism in the Coast Plutonic Complex indicates that this feature has evolved along the continental margin accompanied by trough and successor basin development along both flanks. Folding as an expression of directed componental stress has played a minor part in the regional tectonics. Block-like uplifts related to faults and sequential vertical tectonics have responded to, and accompanied motion of the major tectonic units.

Unconformities, between major stratigraphic units as well as within any of the units have been developed because of block-movements along well defined faults, developed in response to regional motion. The mainly Mesozoic Stewart Complex has responded to the development of the Coast Geanticline and finally, as a result of Tertiary plutonism, has been essentially fused to the geanticline with the uplift outlined by faults.

A comparison of the tectonic developments of the Western and Eastern Canadian Cordillera shows some similarities such as periodic plutonism and deformation, but the tectonic style as outlined by Wheeler (1966) varies significantly. The Eastern Cordillera has been subjected to polyphase regional metamorphism with a complex pattern developed (Monger and Hutchison, 1971) in direct contrast to the simple Barrovian style of the Western Cordillera. The regional orogenies in the Eastern Cordillera may be compared directly with those outlined by the writer in the Western Cordillera. However, the Eastern Cordillera has developed as a result of combined folding and thrust faulting, with the development of directed folding and the late wholesale movement of a portion into the Rocky Mountains. By contrast, most of the Western Cordillera faulting has been primarily restricted to the formation of relatively small crustal blocks. Current plate tectonic hypothesis suggests that Cenozoic transform faults separate the Pacific and North American plates along the British Columbia coast, and the Denalai Fault System which has been projected to join the Chatham Strait Fault in southeastern Alaska (Richter and Matson, 1971) appears to link with the Fraser-Yukon fault bounding the east margin of the Coast Plutonic Complex. The horizontal and vertical movements on these fault systems are impressive and although extensive uplift along the Fairweather Fault has been demonstrated, the effect on the British Columbia side of the fault is unknown, except for the possible recent faults described by the writer which suggest that vertical uplift is still playing a major role in the evolution of the Stewart Complex.

The evidence presented in this thesis indicates that the Bowser Basin has developed from the older Whitehorse Sub-trough in response to essentially continuous tectonic events marked by recurring cycles of sedimentation, volcanism, plutonism, deformation, uplift and erosion. The Bowser Basin is a structural basin confined within a recognizable regional framework, and in itself the basin comprises a number of major structures. Badgley (1965, p. 463) has pointed out the need to classify a basin tectonically as an aid to understanding the habitat of hydrocarbon deposits, commonly found in structural basins, and to evaluate the potential of these basins.

The writer's study in the Stewart Complex has also shown that most of the known mineral deposits have been localized by unique combinations of structure, lithology, and plutonism.

CHAPTER 5

Economic Geology Studies in the Stewart Complex

Introduction

Mineral exploration in the Stewart Complex started in 1893 when placer miners first prospected the Unuk River and its tributaries. The discovery of bonanza gold-silver ore at Premier, near Stewart, and the successful operation of the mine and smelter at Anyox led to extensive exploration of the area which still continues to-day. Currently, the Granduc copper mine northwest of Stewart, and the B.C. Molybdenum mine near Alice Arm provide the incentive to continued mineral exploration, and to economic geology studies in the Stewart Complex.

Mineral production from the Stewart Complex has included gold, silver, copper, lead, zinc, cadmium, tungsten, molybdenum, iron, arsenic, antimony, and selenium. In terms of productivity, the Stewart Complex ranks second in British Columbia in the total production of gold, silver, and copper. The Silbak Premier mine is second in silver production after the Sullivan mine at Kimberley, and third in gold, after mines in the Bralorne and Rossland camps. Although the Hidden Creek mine at Anyox operated only from 1914 to 1935, it still ranks second in copper production after the Britannia mine near Vancouver. The B.C. Molybdenum mine at Alice Arm is currently the second largest producer of molybdenum in Canada.

Mineral Deposit Distribution in the Western Cordillera

Concepts regarding mineral belt and mineral deposit distribution in the Canadian Cordillera were originally developed during the period 1871 to 1905 by Richardson, Selwyn, Dawson, McConnell, Bauerman, Brock, and others. The general concept developed by the early workers related mineral deposits to two main belts, both separated by the Coast Range Batholith. The westerly zone was called the Pacific belt, and included the Anyox and Britannia deposits. The easterly zone, called the Interior belt, included the Silbak Premier deposit at Stewart, the Dolly Varden at Alice Arm, and small prospects near Terrace and Smithers. This concept led to the general acceptance that copper mineralization was concentrated at the western margin of the batholith, and that gold, silver, and lead were localized near the eastern margin. Schofield (1922) suggested that this apparent distribution was related to the contrasting metamorphic grades found at the batholith's margins, and to the different levels of erosion. He assumed that the western margin represented an unroofed, high grade metamorphic zone, whereas the eastern margin represented a moderate temperature environment. Schofield (1922, p. 68-70) related all mineral deposits in both mineral belts to the major batholithic intrusions which he assumed were all of a Jurassic age.

Buddington and Chapin (1929, p. 356-394) stated, "Throughout southeastern Alaska and the adjoining territory of British Columbia metallization tends to occur in part in localized belts or areas". They suggested a threefold division that differed from the early concept by relegating the Anyox copper deposits to a central Coast Range belt which included all mineral deposits localized in the intrusions. Buddington and Chapin (1929) also accepted the hypothesis that there was a close genetic association between most ores and intrusives. They suggested that there was a strong relationship between magma-type and ore-type, and indicated that Emmon's (1920) classification of ore deposits fitted the mineral distribution in the eastern margin zone, but not in the central zone. These studies, as well as the work by Hanson (1929, 1935) represent the basic, and virtually the only discussions of mineral deposit genesis in the Western Cordillera until the last decade.

Souther, (1966) suggested that copper and molybdenum deposits in northwestern British Columbia are most frequently associated with relatively young syenitic or monzonitic phases of the Coast Range Batholith. He also suggested that the Anyox, Granduc, and other large copper deposits in the Western Cordillera were closely associated with an arcuate belt of Triassic pillow lavas which extended from near Tulsequah, south through the Stikine and Iskut River areas to include the Granduc and Anyox deposits within the Stewart Complex. But, as the writer has previously emphasized, the Granduc ore bodies are localized within a complex Lower Jurassic volcanic-sedimentary sequence, and the Anyox copper deposits are entirely related to Middle Jurassic pillow lavas. Recent discoveries suggest that the mineralization in the Stewart Complex is related to several ages and types of plutons and is not related to the major Tertiary intrusives which comprise the east margin of the Coast Plutonic Complex.

The problems of metallogenesis, which were once so readily explained by relating mineral deposits to the major intrusions forming the Coast Plutonic Complex, and to a single plutonic episode, must now be interpreted on the basis of the new evidence presented here in view of current genetic concepts. The regional patterns of mineral distribution can no longer be related simply to intrusives. Instead, the mineral deposits, and metal distribution, can be variously related to certain plutons, and groups of plutons, to certain structural features, and to distinct lithologic controls. The Stewart Complex represents one of the marginal uplifts of the Mesozoic Bowser Basin where a variety of mineral deposits can be shown to be directly related to certain plutons, distinct structural features, and unique lithologic controls.

Distribution Patterns of Mineral Deposits in the Stewart Complex

The distribution pattern of the mineral deposits in the Stewart Complex (Fig. 22) can be related to several factors. Most of these deposits occur in low-lying areas accessible from the fjords, and streams, and below the snow and ice cover. The blank map areas reflect the presence of barren Middle and Late Jurassic sedimentary strata, and the generally barren Coast Plutonic Complex and satellite plutons. This simple appraisal neglects however, the lithologic, stratigraphic, and structural relationships discussed in the previous chapters. The apparent tendency for the mineral deposits in the Stewart Complex to occur as linear clusters reflects the geological environment which can be determined by detailed studies of the individual mineral deposits. Noble (1963) observed that the closer to a natural scale one approaches, the less one is convinced of the alignment of mineral districts. At a regional scale the several hundred mineral deposits in the Stewart Complex can be represented by a few dots clustered in the Bear River Uplift along the west margin of the Bowser Basin. As a result, the writer holds an opposing view to Noble, that is, the smaller the scale of plotting, and the less detailed the study of ore deposits and the geological controls, the less convincing the concept of mineral belts and provinces becomes. This view has also been taken by Jerome and Cook (1967) as a result of their regional metallogenic studies in the western United States.

As indicated, the mineral belts in the Stewart Complex are apparently restricted to northerly trending elongate clusters. These belts follow the South Unuk River, Cascade Creek, Bear River-American Creek, and Kitsault River lineaments, but the Maple Bay and Anyox belts are apparently unrelated to topographic features. All of these mineral belts include a variety of deposits of different ages, variable mineralogy, and different local geological environments. These mineral belts, or map features, reflect the northerly structural trends described by the writer in Chapter 4, but the metal zoning within each belt is difficult to relate to an overall controlling feature. This apparently random mineral zoning in these belts was discussed by Hanson (1935, p. 35-45). He did not advocate the possibility of mineral zoning in reference to the Portland Canal district but he did link all the mineral deposits to a single source, namely, the Coast Range Batholith.

Distribution Patterns of Major Metals in the Stewart Complex

Although Hanson (1935) dismissed the possibility of local mineral or metal zoning in part of the Stewart Complex, Buddington (1929) related the vein type mineralization in the Hyder district to the Texas Creek pluton and recognized a local zoning of gold, silver, and sulphides to the margins of the pluton. He recognized that the Texas Creek was an older pluton, and also that the younger Hyder pluton, as well as the Coast Range Batholith of Hanson (1929, 1935), was unmineralized and unrelated to the majority of the local mineral deposits. The writer has studied the possibility of metal zoning on both a local and a regional scale, and there now appears to be evidence for both.

It has been demonstrated that for the Stewart Complex, large numbers of deposits tend to occur in linear clusters. These linears or belts appear to reflect topographic lows which in part reflect local structures. However, because of the cover of younger sediments as well as ice and snow, broad scale zoning may expose the overall pattern. Gold, silver, copper, lead, and zinc are the most important metals found in the Stewart Complex. Because of their high value and wide distribution, gold, silver, and copper have been the primary exploration targets, and their abundances have been well documented. The writer has utilized these three metals, as representatives of the various deposits, to separate the Stewart Complex into four simple areas, or cells, dominated by gold, silver, copper, and silver-gold (Fig. 23). In this way, an apparent regional zoning that includes the mineral belts becomes visible, and exposes a broad, previously obscured, regional pattern. The zones thus outlined illustrate the dominance of silver-rich, gold-poor deposits in the Alice Arm district, silver-gold deposits which are localized in the Stewart district between Georgie River and Summit Lake, and a gold-rich, silver-poor district in the Bowser River area. The gold and silver zones are bounded on the west by copper deposits at Anyox, Maple Bay, and Granduc Mountain, which together form a northwesterly trending zone which has been partly transected by the Tertiary Hyder pluton. The easterly boundary of the gold and silver zones is formed by the extensive cover of Middle and Upper Jurassic sediments.

The writer has also defined mineral zones of less abundant metals that lie within the framework of the four main zones. The distribution of arsenic and antimony has previously been shown by the writer to be related to the margins of the Glacier Creek plutons where these bodies have intruded

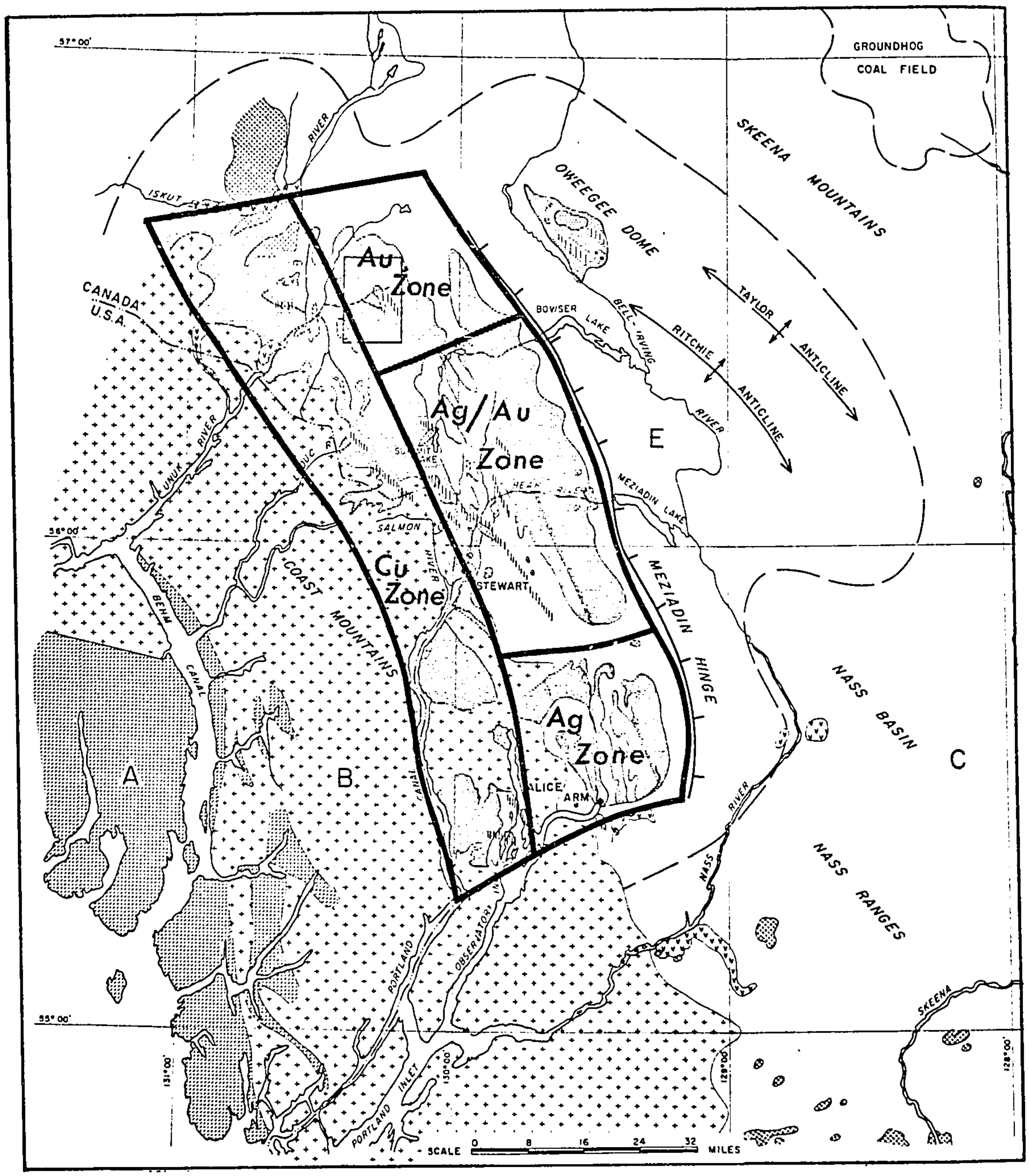

FIG. 23 Metal distribution zone, Stewart Complex.

Middle Jurassic siltstones. Pyrrhotite is localized within the copper zone where it occurs in the massive sulphide deposits and in the vein type copper deposits. Molybdenite is unusual in that it occurs in all four zones where it is associated with a variety of rock types of different ages. The most important molybdenite belt is related to the Tertiary Alice Arm Intrusions that border the eastern margin of the Coast Plutonic Complex between Bear River Pass and the southern limit of the study area. This molybdenite belt is unique in that it can be traced along the margin of the complex from the Yukon, south through British Columbia into the United States. Generally, in respect of metal zoning, the minor metal patterns support the writer's regional metal zoning, a pattern defined by the relative abundance of gold, silver, and copper in the mineral deposits.

The concept of regional and local metal zoning has been discussed often in mineral deposit literature generally for the purpose of providing suggestions for mineral exploration. For the western United States, Lindgren (1933) observed the change in composition of the post-Paleozoic intrusives from dominantly diorite and quartz diorite near the Pacific Coast to alkali-rich plutons in the eastern Rocky Mountains, and suggested this variation coincided with the change in character of the associated mineral deposits. Park (1964) suggested that the complex distribution of ore deposits in California and western Nevada was controlled by zoning related to the Sierra Nevada batholith or to the granitization of heterogenous geosynclinal sediments. At Tonapah, Nevada, Nolan (1935) made use of silver-gold ratios in a systematic local study. His study showed that the silver-gold ratios were high at the margins of a peripheral spherical zone, and low in the center, indicating that silver travelled farther than gold. These examples briefly illustrate how extensively the concept of metal zoning has been applied by various geologists.

The writer has presented evidence for local and regional metal zoning in the Stewart Complex. Field evidence indicates that this distribution is related to mineralization epochs which in turn are related to well defined plutonic, volcanic, and tectonic events (Fig. 24). The large copper deposits concentrated at the western margin of the Stewart Complex in the copper zone represent Late Triassic (Max), Lower Jurassic (Granduc) and Middle Jurassic (Hidden Creek) mineralization. The silver-rich deposits in the Alice Arm district, such as the Torbrit, are virtually gold-free and represent either Late Cretaceous or Tertiary mineralization. At Stewart, the silver-gold deposits range in age from Middle Jurassic to Tertiary with the oldest deposits represented by gold-rich mineralization, such as the Big Missouri and Silbak Premier. The younger silver-rich deposits in the same area are cut by dykes and provide examples transitional between the Silbak Premier and Torbrit type deposits. In the gold zone at the north end of the Stewart Complex the various mineral deposits are mainly confined to Lower Jurassic rocks.

The writer has previously suggested that the Stewart Complex is outlined by high angle normal faults, and that faults have played a major role in determining belts of sedimentation, erosion, and possibly even plutonic intrusion. The result of major faulting has been differential uplift of portions of the Stewart Complex and subsequent erosion which has exposed the oldest country rocks in the Unuk River and Anyox areas. As a result the copper zone deposits at Anyox and Granduc Mountain, and the gold, and gold-silver deposits near Stewart have been exposed. At

PERIOD	EPOCH	TECTONIC EVENT		PLUTONS	VOLCANICS	FORMATIONS	MINERALIZATION
QUATERNARY	RECENT	uplift and erosion faulting		Basalt dykes	Flows		
——1.5 m.y.	TO						
	MIOCENE	?					
TERTIARY	OLIGOCENE	?		Dykes, Sills			vein deposits: silver, lead, zinc
	EOCENE-PALEOCENE	folding and faulting		Hyder pluton, etc. Alice Arm Intrusions		(SUSTUT)	vein deposits: silver, lead, zinc porphyry deposits: molybdenite
—— 64-65 ——							
CRETACEOUS	UPPER	?	?			(SKEENA)	?
	LOWER	? erosion	?	Satellite plutons			vein deposits: silver, lead, zinc
——136——							
JURASSIC	UPPER	erosion and faulting and folding	?	Satellite plutons		NASS	?
	MIDDLE	erosion ± faulting erosion faulting		Texas Creek pluton, etc. Unuk River Intrusions (Satellite plutons)	Rhyolite, and andesitic pillow lavas Andesite and basalt flows, pillow lavas	SALMON RIVER (HAZELTON GROUP) BETTY CREEK (HAZELTON GROUP)	? Silbak Premier deposit: gold, silver Anyox deposits: massive sulphides Mitchell Creek: hydrothermal deposits, chalcopyrite, molybdenite
	LOWER	erosion faulting cataclasis folding	?	Satellite plutons	Andesites, basalts, and rhyolite flows, pillow lavas	UNUK RIVER FORMATION (HAZELTON GROUP)	Granduc deposit: massive sulphide-chalcopyrite, pyrite, pyrrhotite; minor gold-quartz veins
——190-195——							
TRIASSIC	UPPER	erosion faulting folding faulting	?	Satellite plutons	Andesite and basalt flows	TAKLA GROUP	Max deposit: magnetite and chalcopyrite
——225——							
		erosion	?				

FIG. 24 Relationships between plutonism, volcanism, and mineralization, Stewart Complex.

Alice Arm where the country rocks have been depressed and have suffered less erosion, only the young silver-rich gold-poor deposits are presently exposed.

In summary, the writer has defined four broad regional copper, gold, silver, and silver-gold zones which include the northerly trending mineral belts. This indicates that the mineral belts which represent map distribution patterns, are, in the Stewart Complex at least, not representative of regional mineral deposit patterns. The mineral deposits in the Stewart Complex include a variety of types of various ages, which are exposed as a result of faulting, tilting, and erosion. The apparent mineral deposit distribution therefore, merely represents the depth of erosion within various parts of the Stewart Complex. This concept, based on the tectonic evolution of the region, eliminates the need to relate regional metal zoning to hypothetical deep seated magmatic events (Lindgren, 1933) or to granitization of the sediments (Park, 1964) or to the migration of elements in response to a regional thermal gradient (Nolan, 1935). The writer therefore suggests that map distribution patterns, such as mineral belts, must be used with caution and unless detailed geologic studies accompany the analysis of the metal distribution patterns, the interpretations can be misleading or non-informative.

Mineral Deposit Studies

Introduction

The distribution of mineral deposits in the Stewart Complex is shown on Figure 22, and the writer's concept of mineral deposit zoning, in the study area, as based on the apparent age of the mineral deposits, has been presented in the previous section. However, the study of the spatial relationships of the deposits to their wall rocks provides a simple means of separating the hundreds of deposits into workable groups, and will now be presented.

The majority of the mineral deposits in the Unuk River, Stewart, Maple Bay, Anyox, and Alice Arm districts are veins that transect the country rocks. Principal examples of the vein deposits are the Esperanza mine at Alice Arm, and the Prosperity-Porter Idaho mine near Stewart. The Silbak Premier gold-silver deposit near Stewart represents a complex quartz-carbonate-sulphide replacement vein restricted to an altered portion of the Cascade Creek cataclasite zone. Extensive quartz-sulphide fissure veins at Maple Bay are also confined to cataclasites comprising the Maple Bay cataclasite zone. Other vein deposits are localized in granitic bodies such as the Texas Creek pluton, many of the satellite plutons, and members of the various dyke swarms.

Porphyry-type deposits confined to an individual pluton are restricted to the satellite intrusives. The main representative of this class is the B.C. Molybdenum mine at Lime Creek, near Alice Arm. There are at present no known major mineral deposits in the rocks of the Central Gneiss Complex, the Hyder pluton, or in the basalt dykes and flows. Other mineral deposits related to stock-like plutons currently being explored include the nickeliferous gabbro body at Snippaker Creek, and the disseminated replacement copper-molybdenite mineralization related to the syenodiorite complex at Mitchell-Sulphurets Creeks.

Massive sulphide deposits at Granduc Mountain and Anyox represent the largest and most productive deposits in the Stewart Complex. These deposits are confined to volcanic-sedimentary strata which have suffered complex deformation and intrusion. Unlike the vein mineralization, these massive sulphide deposits are largely concordant with the enclosing country rocks and form a distinct class.

The various classes of mineral occurrences and deposits occurring within the study area show a variety of relationships to their wallrocks. Most are fissure veins that cross-cut the country rocks, plutons, and dykes, and few of these have been productive. The unusual, and rare replacement vein, porphyry, and massive sulphide deposits which have been the major metal producers in this area show distinctive wallrock relationships which provide clues to their apparent localization, classification, and to the concepts of mineral deposit formation.

Character and Extent of the Mineral Deposits

The bulk of the mineral deposits in the study area are tabular lenses, pods, and sheets, and stockwork quartz-breccia veins found as fissure fillings in the country rocks and plutons. Gold, silver-gold, and silver bearing sulphide minerals are localized within these tabular quartz-rich bodies as discrete isolated, ĕn echelon, and composite lenticular shoots. The larger vein-type deposits are generally distinguished by replacement features, and are typified by the Torbrit deposit near Alice Arm, and the Silbak Premier deposit near Stewart. Generally, however, a simplicity of form is the major characteristic. The Silbak Premier deposit was once considered (Cooke and Johnston, 1932, p. 39) to represent the typical, vein-type, gold-silver ore deposits of British Columbia. This concept indicated that the bonanza ore mined at Premier before 1930 was typical of these deposits, and that the apparent shallow depths of the ore, as compared to Precambrian gold deposits, was related to topographic features, and partly resulted from secondary enrichment. The writer has presented two frequency distribution diagrams (Figs. 25 and 26) which relate the major Torbrit and Silbak Premier deposits to all the known properties in British Columbia that have recorded gold and silver production. As shown by these diagrams, the Silbak Premier property represents a unique deposit in terms of rank, and cannot be considered typical.

The fissure vein and replacement vein deposits in the Stewart Complex comprise a common group of simple ore and gangue minerals. Wallrock alteration associated with these deposits, is generally simple and cannot be defined as a characteristic of the complex. Secondary enrichment is not significant in any of the deposits, and is generally absent throughout the the Stewart Complex. The ore bodies are typically shallow and appear to be related to surface topography, but this feature is in fact related to the general method of mine development and exploration. The ore bodies at the Silbak Premier represent the maximum extent to which any of the vein deposits have been mined. These ore bodies comprise a series of én echelon lenses which have been developed over a strike length of 5,500 feet and through a vertical range of 2,000 feet. The main ore zone at the Dunwell Mine, north of Stewart (Fig. 22B) consisted of one main shoot 120 feet long, 4 feet wide, and 380 feet deep, lying within a quartz fissure vein having a known length of 1,000 feet and a depth of 550 feet. In general, the ore shoots of other vein deposits in the study area formed a smaller part of the veins.

A frequency distribution of the attitudes of veins and vein systems is shown on Figure 27. This diagram illustrates the distribution pattern for veins in the different country rocks as well as the dominant fracture systems. Northwesterly trends dominate in the Texas Creek and other

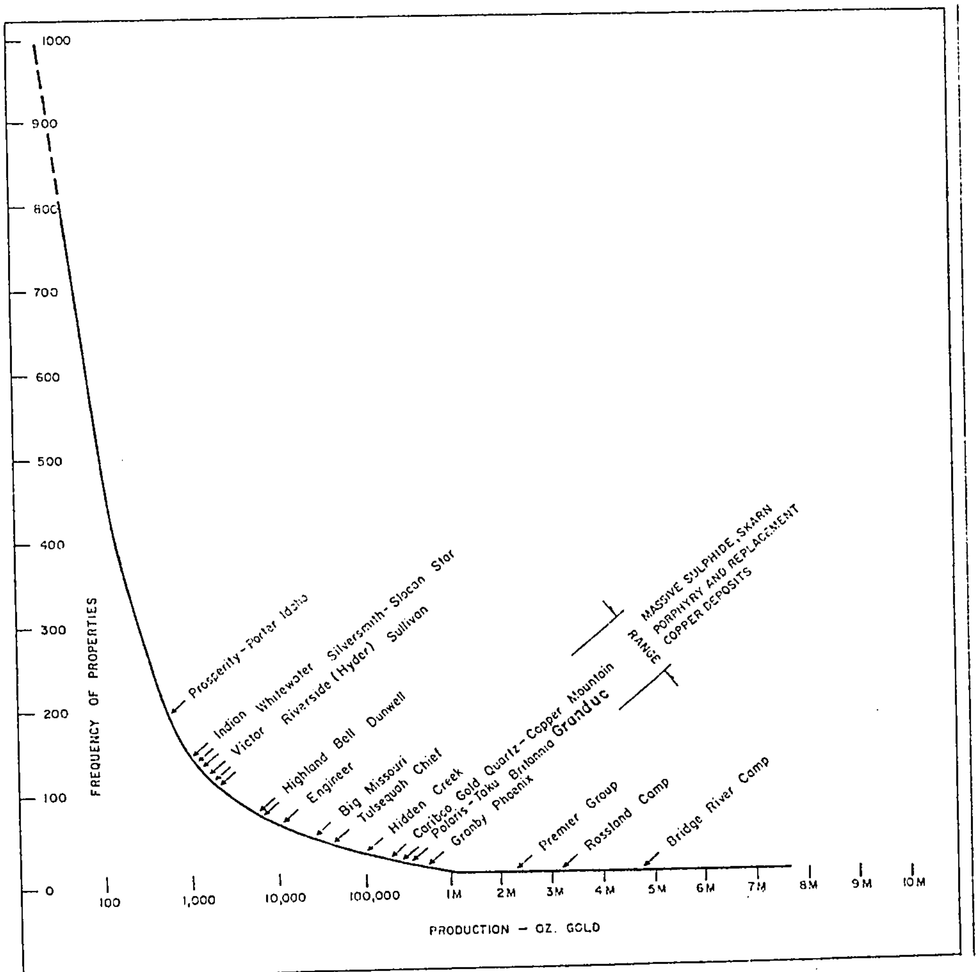

FIG. 25 Frequency distribution, gold deposits, British Columbia.

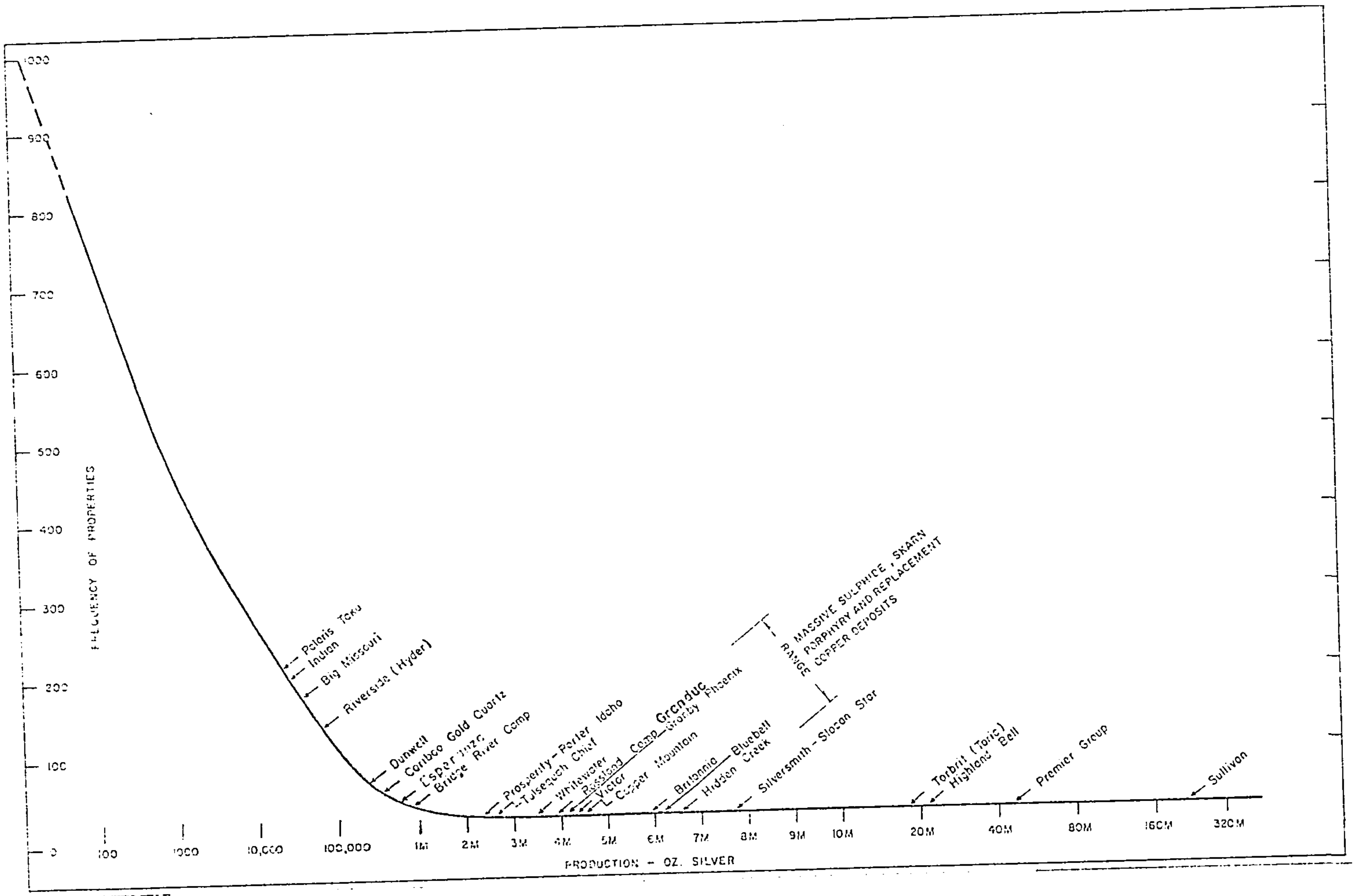

FIG. 26 Frequency distribution, silver deposits, British Columbia.

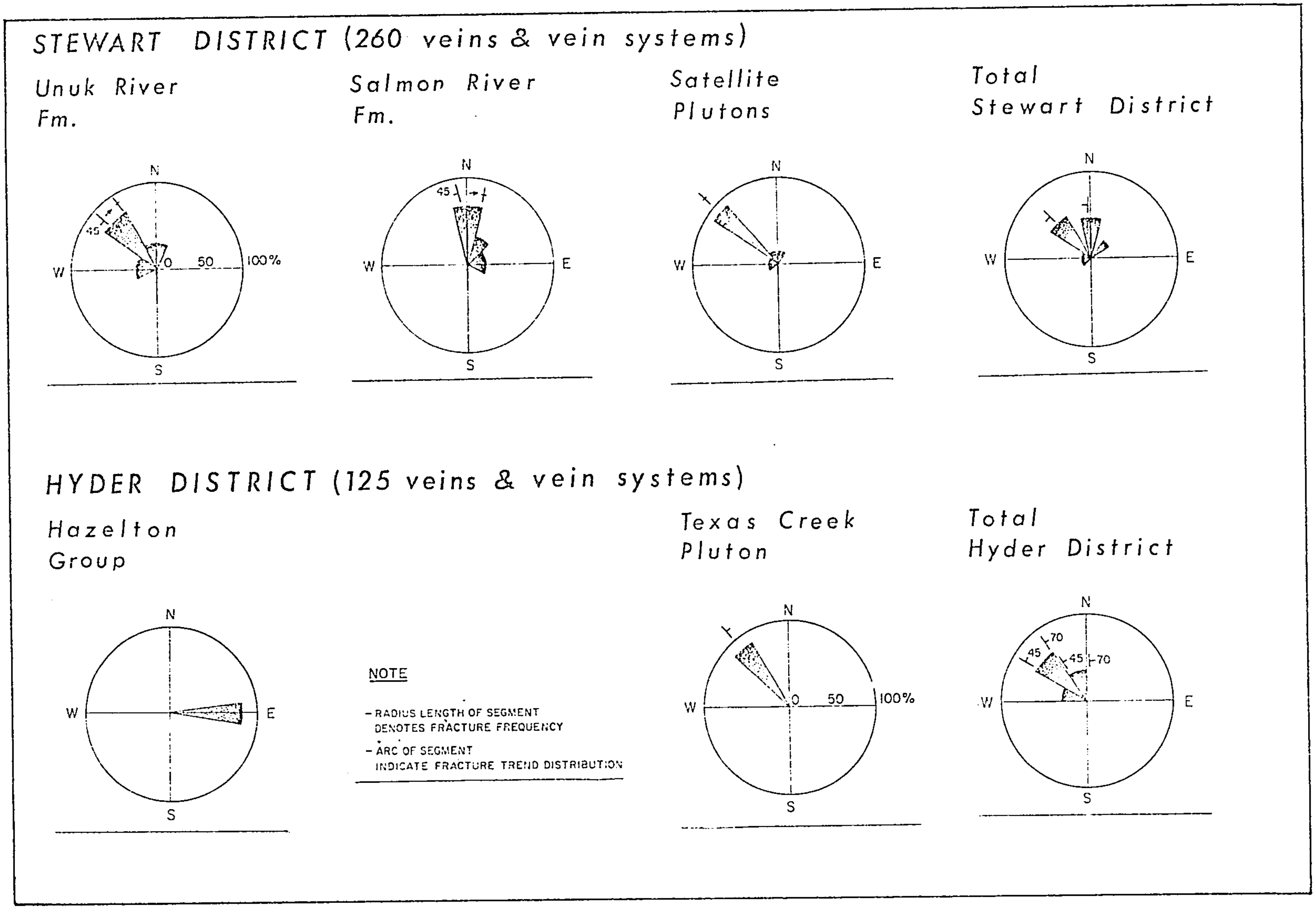

FIG. 27 Frequency distribution diagram, veins and vein systems, Stewart area.

plutons, as well as in the Lower Jurassic country rocks. Northerly trends dominate in Middle Jurassic rocks in the Stewart district whereas in the Hyder district the vein trends are easterly. The bulk of the veins trending northwesterly, northerly and easterly are the generally unproductive fissure type quartz-breccia veins. The unique Silbak Premier deposit includes both northwesterly and northeasterly vein systems of which the latter predominate, and as shown by Figure 27 represent a small fraction of the vein systems in Lower Jurassic rocks. The ore shoots in the Silbak Premier vein system mainly comprise banded massive sulphide lenses, and have caused considerable discussion in the past. In referring to massive sulphide deposits, Gunning (1959, p. 319) suggested that perhaps the puzzling Silbak Premier ore shoots could be placed in the general massive sulphide classification. The writer has studied this property in detail and prefers to characterize the deposit as a replacement vein system. The problem of the Silbak Premier ore deposit will be considered in a later section under the heading "Mineral Deposits".

The major massive sulphide deposits in the Stewart Complex include the Granduc property at Granduc Mountain, and the Hidden Creek, Double Ed, Redwing, and Bonanza properties at Anyox. These have all been studied in detail by the writer, but the massive magnetite-chalcopyrite Max deposit at McQuillan Ridge (Fig. 22A) is not sufficiently known at the present time to merit discussion. The more important deposits, the Hidden Creek, Bonanza, and Granduc will be described in detail in a following section.

Granduc has been termed a sulphide lode deposit by Ney (1966), a stringer lode deposit by Norman and McCue (1966) and a lode deposit by White (1966), and a massive sulphide deposit by Sutherland Brown and others (1971). The discrepancies in the above opinions result from uncertainties as to the actual nature and origin of this deposit. As previously indicated the Granduc ore zones lie within the South Unuk cataclasite zone and are extensively deformed. They can be characterized as flattened lenses and physically compare with the "Kieslagerstätten-type" described from various parts of the world (Vokes, 1969). The full extent of these ore bodies has not yet been determined, but they are presently known to extend over a vertical depth of at least 3,000 feet, with a known length of 5,500 feet, and have a width of up to several hundred feet. Granduc is presently the only known deposit of this type in the Western Cordillera.

The writer's studies have shown that the Anyox deposits are also unique. In the past Hanson, (1935), Nelson, (1948) and others concluded that the Anyox ore bodies represented simple contact metamorphic deposits. These deposits which include the Hidden Creek, Double Ed, Red Wing, and Bonanza properties are actually pipe-like to tabular massive sulphide lenses unrelated to any known intrusives. The Hidden Creek ore bodies represent the largest sulphide masses in the Stewart Complex and compare in size to the ore lenses at Britannia, near Vancouver. Most of the Anyox ore bodies are near vertical lenses that have been traced over a known depth of 1,600 feet, up to 800 feet in strike length and 300 feet in width. The writer has mapped the Anyox deposits in detail and has shown that they are confined to pillow volcanics, and that the old concept of a contact metamorphic origin is invalid. These deposits are described in detail in this thesis for the first time.

Many of the vein and massive sulphide deposits in the Stewart Complex are characterized by mineral banding. In simple fissure vein deposits such as the Dunwell property, the ore exhibits typical ribbon structure.

Ore shoots at Silbak Premier show well defined banding that was previously assumed to represent compositional zoning. Ore bodies at Granduc and Anyox also exhibit sulphide banding. Generally this mineral banding suggests either deformation related to local post-mineral movement, or as in the instance of Granduc, pervasive cataclastic deformation.

Because the features related to porphyry mineral deposits can be fairly easily explained their general character and extent will require less discussion. The simple porphyry-type molybdenite deposit at Lime Creek, near Alice Arm, appears to be typical of porphyry deposits in the Western Cordillera, in that the economic mineralization lies entirely within a portion of a small quartz monzonite stock. Other porphyry deposits include the widespread copper-molybdenum mineralization at Mitchell-Sulphurets creeks. This deposit represents low grade disseminated sulphide mineralization spatially related to differentiated intrusions, and to pervasive quartz-sulphide veining of the country rocks. If this deposit proves economic, it will be considered a porphyry deposit in the mining sense, that is, a deposit denoting extensive, low grade mineralization.

The mineral deposit at Nickel Mountain (Fig. 22A) represents the only known major nickel occurrence in northern British Columbia that is localized in a pipe-like basic pluton. Very little of this mineralized stock-like body is exposed, and current underground exploration has not yet been completed. At present, the evidence suggests that the sulphide minerals are restricted to one edge of the pluton in the upper 1,500 feet of the contact zone with Unuk River siltstones. Other minor nickeliferous deposits have been found in hornfels zones near the contact of the Tertiary plutons and Unuk River strata in the area west of the Unuk River, and near Anyox.

The above brief descriptions of a few significant mineral deposits illustrates the wide variety, character, and size of mineral deposits in the Stewart Complex. As indicated by the mineral inventory maps (Fig. 22) there are hundreds of major deposits in the Stewart Complex. These cannot be treated individually in this study but must be grouped by their major characteristics, in terms of mineral deposit classification.

Classification of Mineral Deposits in the Stewart Complex

Introduction

The first simple grouping of mineral deposits in the study area was instituted by McConnell (1913). His classification included two divisions: 1, veins and fissure zones; 2, replacement deposits; he noted that the two divisions were rarely sharply definable. By the early 1920's most of the mineral deposits in that area had been located and partly developed. Schofield and Hanson (1922), Hanson (1935), Westgate (1921), and Buddington (1929) each produced mineral deposit classifications for parts of the Portland Canal district. These classifications emphasized form, mineral content, and to a lesser extent the physical environment. They generally agreed that all the primary mineral deposits in the area were of a simple hydrothermal origin related to the local intrusions. At the present time, mineral deposit classifications emphasize genetic theories involving total depositional environments.

The writer's detailed studies in the Stewart Complex have revealed the intimate relationships between ore deposits and country rock lithology and structure. The classification of mineral deposits in this area is therefore essentially based upon the relationships of these deposits to their geological environment. The writer's simple classification therefore includes the following major classes of mineral deposits:

I. Vein Deposits

(a) fissure veins

(b) replacement veins

II. Massive Sulphide Deposits

(a) stratiform

(b) concordant

III. Porphyry Deposits

Vein Deposits

Fissure Veins

Vein deposits represent the largest class of mineral deposits in the Stewart Complex and include a variety of discordant tabular epigenetic bodies characterized as dominantly composed of quartz, carbonate, and barite. Many represent simple transgressive units that are clearly fissure filling deposits in which fragmented particles of wallrock form a significant portion of the body. Textures include banding, drusy cavities, and simple comb structures. Alteration is generally not a significant feature, and wallrock replacement is generally insignificant. Many of the simple, massive quartz veins in the Anyox district have been mined over a length of 3,000 feet and to several hundreds of feet in depth, and exhibit no significant evidence for replacement or alteration of the country rock. These deposits generally have low silver values, contained in argentiferous native gold; they rarely contain any sulphides. The majority of these sulphide deficient simple quartz fissure veins are spatially related to the margins of the quartz-rich Tertiary Hyder plutonic mass.

Vein deposits in the Maple Bay section are represented by transgressive, fracture controlled, tabular quartz veins characterized by drusy, finely crystalline quartz in which the open spaces are irregularly filled with interstitial chalcopyrite, pyrrhotite, and minor pyrite which form lenticular ore shoots. These veins have been traced on the surface for over 3,500 feet and are known to extend to depths of over 2,000 feet. The writer has studied these veins in detail and has related the localization of the sulphide ore shoots to dilation features controlled by intersecting fracture sets. This group of veins is entirely confined to fractures within the ultramylonite segments of the Maple Bay cataclasite zone. They have been transected by Tertiary Hyder phase plutons and are probably epigenetic deposits related to the Middle Jurassic Texas Creek plutonic episode.

Fissure veins in the Alice Arm and Stewart districts are characterized by negligible gold content and generally contain a simple group of argentiferous sulphides, and native silver. These fissure veins conform to the regional mineral zone concept previously presented by the writer. The Stewart district veins are generally comparable, but show a greater variety of sulphide minerals, and are commonly characterized by the presence of native silver, rare native gold, and electrum.

Veins localized within the regional gold zone (Fig. 23) are mainly small massive quartz lenses which transect Lower Jurassic country rocks and are generally characterized by the presence of native gold, simple sulphides and a low to negligible silver content.

Replacement Veins

These deposits represent the most productive gold-silver deposits in the Stewart Complex, and include the Torbrit silver mine at Alice Arm and the Silbak Premier mine near Stewart. This type of vein system constitutes less than 5 per cent of all the mineral deposits within the Stewart Complex, but has contributed more than 90 per cent of the total gold, silver, lead, and zinc mined. The Torbrit deposit at Alice Arm is representative of the low gold, replacement vein deposits, and is characterized here as discordant lenses comprising mainly banded quartz, barite, jasper, carbonates, and minor country rock . The ore shoots include simple sulphides and native silver that along with the main vein material has formed by emplacement within fractures and partly by replacement of wallrock during Tertiary time. The principal representative of this class of vein deposit is the Silbak Premier mine. The character, structure, and origin of this unique deposit has been argued for many years, and generally with little evidence. The writer has completely revised the geology of this deposit within the newly defined local and regional geological concepts.

Silbak Premier Mine

The Silbak Premier mineral deposit (Figs. 22A and 28) as well as a large number of small fissure veins, occurs within the boundaries of the Cascade Creek cataclasite zone (Fig. 3). Unlike the fissure vein deposits, the Silbak Premier mineralization has been entirely localized within a metasomatized segment of the Cascade Creek cataclasite zone, adjacent to the margin of the Texas Creek pluton (Fig. 28). During the operating life of the mine it produced in excess of 4.7 million tons of ore containing 1.82 million ounces of gold, 41.2 million ounces of silver,

FIG. 28
GENERAL GEOLOGY
OF THE
SILBAK PREMIER MINES LTD. AREA
SHOWING ORE SHOOT PROJECTIONS

and appreciable copper, lead, zinc, and cadmium. The mine has operated erratically since 1958 and is currently being examined by a major mining company.

The writer has remapped the entire Silbak Premier property at the scale of one inch equals 100 feet, and has mapped the accessible mine workings at one inch equals 20 feet. The study included revising about 400,000 feet of old drill core information, and the integration of the detailed mine and local geology. The country rocks, gangue materials, and ore zones were examined by numerous thin sections and polished sections. This integrated study represents the first time the local and mine geology have been correlated, and has resulted in an entirely new petrologic, structural and genetic concept for the formation and localization of the Silbak Premier ore zones.

Geology of the Silbak Premier Mine

The Silbak Premier ore deposit lies entirely within an altered portion of the Cascade Creek cataclasite zone. Locally, the Lower Jurassic green volcanic conglomerates (Plate 42) and intercalated crystal and lithic tuffs are unconformably overlain by Middle Jurassic sediments, and are intruded by the Texas Creek pluton and numerous dykes (Fig. 28). The writer has previously related formation of the cataclasites to Texas Creek plutonism and subsequent metasomatism. The metasomatic, porphyritic rock in which the replacement veins occur has been called the Premier Porphyry (Plate 43). This porphyritic metasomatic zone has been the site of intense localized fracturing, quartz-carbonate alteration, and the site of widespread localization of sulphide ore shoots. In Figure 28, the principal types of alteration, and the ore shoots have been shown in relation to the generalized surface geology.

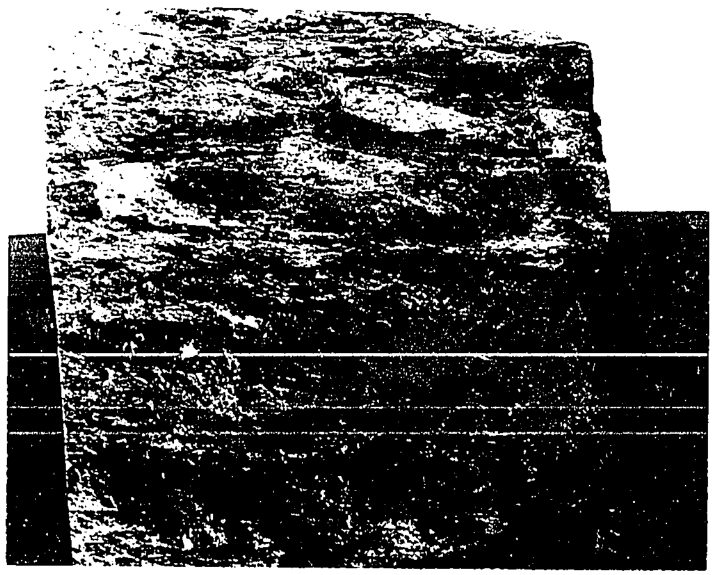

Plate 42. Hand specimen, deformed epiclastic volcanic conglomerate, Premier area.

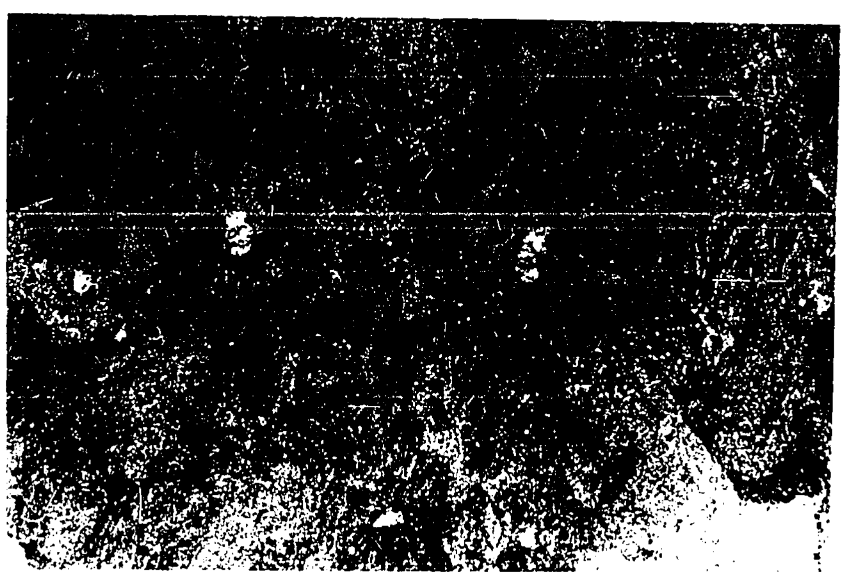

Plate 43. Hand specimen, Premier porphyry, Silbak Premier mine.

Apart from the Premier Porphyry, the nature of the parent country rock has been largely preserved in spite of the incipient dynamic metamorphism, and later metasomatism. Because of the macroscopic character of the country rock, as illustrated in Plate 42, combined with thin section studies, the country rock immediately surrounding the ore zones has been interpreted as part of the local epiclastic volcanic sequence.

In the past, many of the cataclasites in the mine area were interpreted as simple volcanic flows, possibly because of the pseudoporphyritic appearance of the deformed rocks (Plate 44). The deformed character of this rock type is illustrated in Plate 45.

In contrast to the deformed rocks, the Premier Porphyry is a much more distinctive unit in which coarse grained pink orthoclase and medium grained brown hornblende are both conspicuous (Plate 43). In composition it is comparable to the border phase of the nearby Texas Creek pluton, with which it appears to be genetically related. The Premier Porphyry exhibits various stages of alteration related to mineralization. In weakly altered zones the orthoclase porphyroblasts are partly altered to sericite-carbonate along cleavage and fracture planes, and the groundmass has been almost entirely altered to a dense mixture of sericite, carbonate, epidote, and minor chlorite. The plagioclase and hornblende in the rocks are generally represented by pseudomorphs. In more completely altered zones, the orthoclase crystals are visible only as ghost-like pseudomorphs and both plagioclase and hornblende are indistinct. In most of the porphyry, blebs of quartz in the groundmass comprise 5 to 8 per cent of the rock. These grains are typical of the local cataclasites and appear to have survived both metasomatism, and subsequent mineralization-alteration.

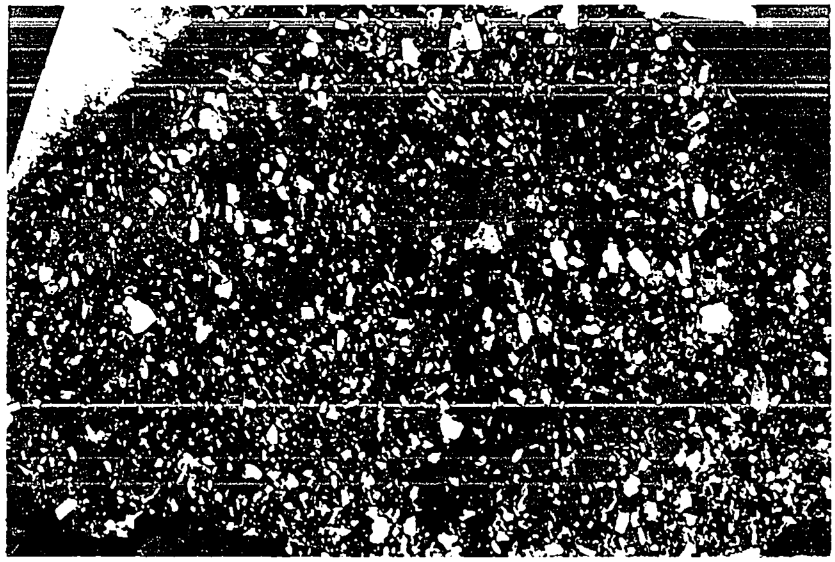

Plate 44. Hand specimen, cataclasite, Cascade Creek cataclasite zone, Premier area.

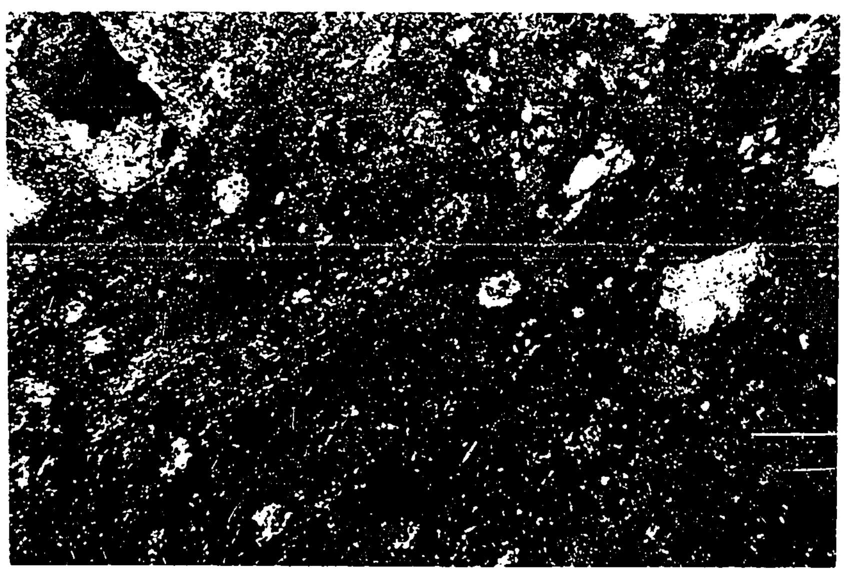

Plate 45. Cataclasite, Cascade Creek cataclasite zone, Silbak Premier mine area.

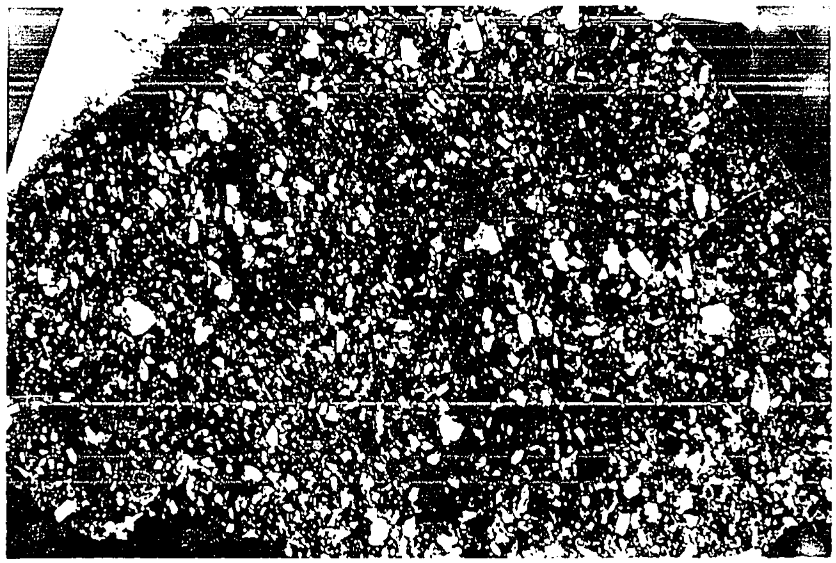

Plate 44. Hand specimen, cataclasite, Cascade Creek cataclasite zone, Premier area.

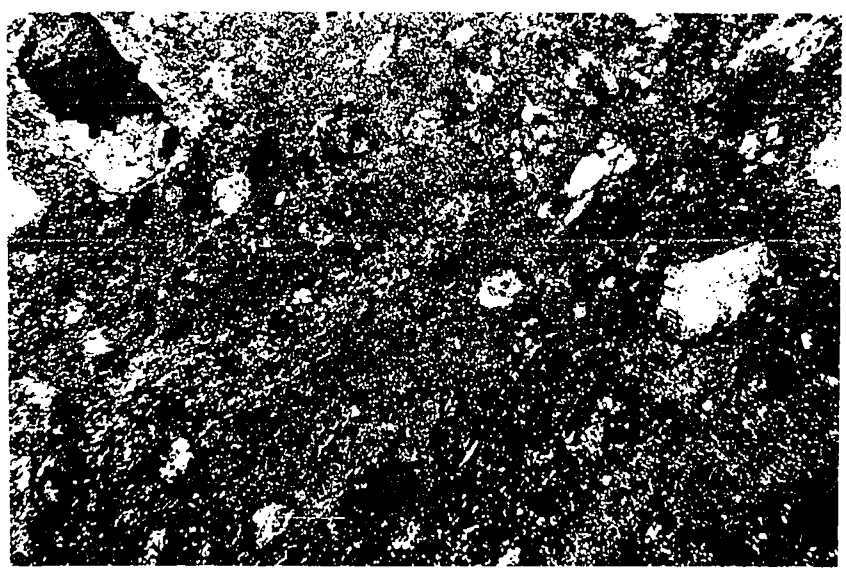

Plate 45. Cataclasite, Cascade Creek cataclasite zone, Silbak Premier mine area.

Secondary quartz is present in most of the porphyry as irregular patches with micro-comb structure. Sphene, and cubic pyrite are present in the porphyry as accessory minerals.

The country rocks immediately adjacent to the Premier Porphyry have been termed greenstones in all the old literature, but as indicated here comprise part of the Cascade Creek cataclasite zone. These rocks have been pervasively altered to fine grained mixtures of equigranular quartz, with sericite, carbonate, epidote, pyrite and minor magnetite. These rocks primarily consist of about 70 per cent quartz, with about 15 per cent sericite, and up to 25 per cent pyrite. Quartz blebs are recognizable in these rocks attesting to their cataclastic character.

The numerous dykes which cut across the Silbak Premier property (Fig. 28) have been described in Chapter 3. The most obvious dykes in the mine area are the large branching Premier swarm members. Most of these dykes swing past the ore zone, but one, the 400 foot wide Main dyke, cuts across the northern ore zone. Lamprophyre dykes are found throughout the mine with the exception of the glory hole area where the large massive sulphide lenses have been localized and where alteration has been most intense.

Structure

The structural geology of the Silbak Premier area has been shown on Figures 3 and 28, and has been described in Chapter 4. Steep, west-dipping, northerly trending Lower Jurassic strata forming part of the west limb of the American Creek Anticline, have been transected at an acute angle by the Cascade Creek cataclasite zone, and are unconformably overlain by Middle Jurassic epiclastic volcanics and siltstones. The elongate, metasomatic Premier Porphyry zone lies within the cataclasite zone and adjacent to the irregular contact of the nearby Texas Creek pluton. The old structural picture of a shallow, west-dipping volcanic sequence with interlayered "Porphyry" has been completely discarded on the basis of the present data.

Incipient foliation developed in most of the country rocks in the Premier area has erroneously been taken in the past as lithologic layering or bedding. The dominant foliation of the property trends northerly and dips 35 degrees to 45 degrees west. In detail however, the trends vary from northwest to northeast and dips increase southerly to near vertical. Rather than intersecting shears, the variations appear to represent rolling flexures reflecting an apparent sinuous contact between the Premier Porphyry and the enveloping wall rocks.

In the mine area, joint sets are well developed in most of the rocks and it appears that the patterns vary from one rock type to another and from dyke to dyke. The Premier Porphyry and ore has a distinctive vertical joint set striking north whereas the less altered cataclasites are typified by a set dipping 45 degrees west and striking north. Dykes in the mine belonging to the same petrologic group also have distinctive joint sets. Joint patterns appear to be useful in the mine area and the Stewart area in general in defining the altered rock types.

In the mine area the dominant joint sets are followed by the dykes and are clearly visible on the air photographs. The northwesterly trend of many of the dyke swarms in the Stewart Complex is also prominent at the mine property. The less conspicuous north 70 degree east trend (Fig. 27) which appears to represent a major ore control feature at the mine, has also been followed by lamprophyre dykes. The Silbak Premier area represents one of the few places in the Stewart district (Fig. 3) where the two intersecting joint sets are marked by extensive intersecting dyke swarms.

Ore Bodies

The distribution of the ore bodies at the Silbak Premier has been shown on Figure 28, and on Figure 29, which represents a longitudinal section of the ore zone, and illustrates the main stope areas.

Mineralization in the Silbak Premier system consists of an extensive replacement vein, quartz zone, enclosing, or partially enclosing a large number of sulphide-rich ore shoots from which the main gold-silver production was derived. Quartz represents the main gangue material and is accompanied by lesser amounts of calcite, and barite, minor adularia, and country rock. The ore shoots contain on an average 20 per cent sulphides, but in the lenses of bonanza ore this amounted to as much as 80 per cent with the rest altered wallrock and quartz-calcite veins. Pyrite is the most abundant sulphide and occurs in most of the sub-ore gangue, and surrounding wallrock as well. The other major sulphides in decreasing order of abundance are sphalerite, galena, chalcopyrite, and pyrrhotite, with small amounts of argentite, tetrahedrite (and freibergite), polybasite, pyrargyrite, stephanite, electrum, native gold, native silver, and rare mercury.

During the early mining period at the mine Dolmage (1920) noted a three fold division of the glory hole ore into the following:

(1) Stephanite-native silver ore in a few small veins (approximately 3,000 ounces silver per ton)

(2) black sulphide ore (500-1,000 ounces silver per ton) and

(3) lower grade siliceous ore.

Since then no other reports of stephanite have been recorded. Electrum has been noted and identified in high-grade and bonanza ore shoots between the surface and 3 level and rarely below (Fig. 29). Native gold apparently has a much more extensive distribution because of its common association with pyrite, but the coarse veinlets found in the bonanza type shoots have a very limited range. Native silver has been identified in most of the ore, but none was seen in drill core from below 6 level. Both mercury and amalgam have been recognized but only in surface bonanza or black sulphide ores. Sphalerite has been found universally in the ores along with galena, chalcopyrite, and tetrahedrite, from surface to the 8 level area. Within the ore shoots however, it does display colour variations and also shows an apparent overall colour change from surface to 8 level. This colour varies from black-brown at the surface to amber at depth and indicates a variable iron content within each shoot as well as over the known vertical range of the deposit. Argentite, the most prominent silver mineral at the mine shows a general decrease in abundance with depth.

An analysis of the stope production records shows a marked decrease in silver at depth. To illustrate this change the silver-gold ratios for various stopes in the main Premier section are plotted in their respective areas on the longitudinal section on Figure 29. The ratios clearly show an apparent planar, semi-circular zonation with silver content decreasing from a high of 112:1, just north of the 110 sub-level projection to lower values to the west, east, and to depth where the value 6:1 predominates.

Another indication of the zoning both along strike and in depth is indicated by the following statistical table where ore production from the four main mine zones has been summarized:

Table (4) Silver-Gold Ratios - Silbak Premier Vein System

Working Area	Silver-Gold Ratio	Copper per cent	Lead per cent	Zinc per cent
B.C. Silver	40:1	0.01	0.5	0.01
Premier	24.5:1	.04	.41	.56
Silbak Premier	17:1	.054	.98	.35
Premier Border	28:1	0.01	4.2	5.00

Various mineralogical studies of the ore have not revealed any anomalous features. Both Burton (1926) and White (1939) found the apparent paragenetic sequence to be normal. Supergene enrichment was thought by the early workers to have been the main process by which the bonanza and high-grade silver shoots were formed, but studies by White (1939), and by the writer indicate that the bulk of the silver minerals are primary. Secondary argentite, wire silver, and minute gold particles are present in vugs in the black sulphide ore as well as in the late vuggy quartz-tetrahedrite-polybasite veins which cut the main sulphide lenses but they are in minor amounts.

In the ore bodies that can now be seen at the mine, the sulphide banding first mentioned by Burton (1926, p. 589) is prominent, and is shown in Plate 46 which illustrates pyritic bonanza ore with altered wall rock cut by sulphides and electrum. The mineral banding reflects a late stage deformation of the relatively soft argentite-galena-sphalerite-rich sections

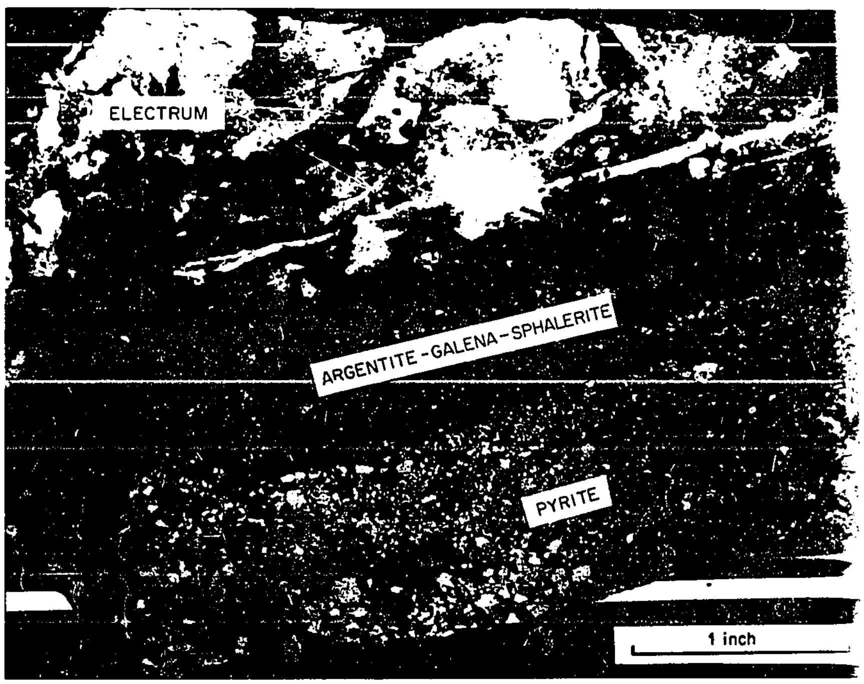

Plate 46. Bonanza ore, Silbak Premier Mine, showing deformation banding.

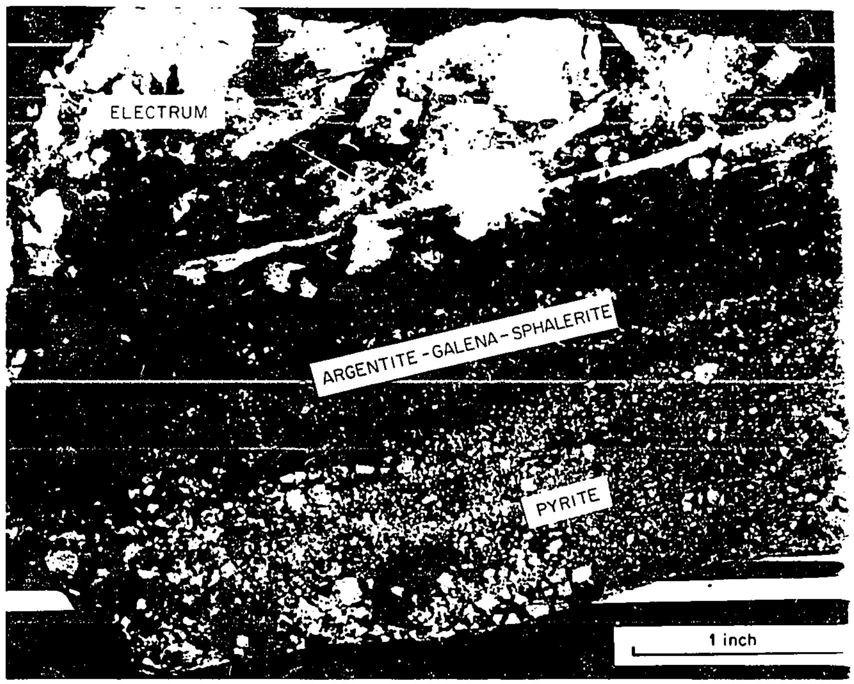

Plate 46. Bonanza ore, Silbak Premier Mine, showing deformation banding.

in which the "hard" pyrite has deformed by fracturing, and the soft sulphide minerals have "flowed" and recrystallized. Within the complex mineral deposit the individual ore shoots are found as isolated or overlapping én echelon, flattened, or pipe-like lenses. These have been illustrated on Figure 28 to show approximate relationships and plunge directions which are uniformly steep to the west. In more detail the individual lenses have a somewhat comb-like appearance with the "back" of the comb marking the parallel to the azimuth of the plunge length and the teeth forming the width. The comb backs trend from 90 degrees to 130 degrees and the teeth are generally oriented in the 70 degree position, which together mark the two prime fracture directions in the host rocks. This can be readily seen in the "ladder vein" section which is still easily accessible.

Genesis of the Silbak Premier Ore

The task of ore genesis is to set out the sequence of major events through which some earlier rock system has been transformed into a later one. The following facts are significant in the present interpretation of the Silbak Premier ore deposit. Spatial relations indicate that this deposit has been localized in metasomatized cataclasites related to the Middle Jurassic Texas Creek pluton. This transformation process, termed ground preparation, by Park and McDiarmid (1964, p. 58-59) tended to make the Silbak Premier zone brittle in respect to the surrounding rocks. Later fracturing in this brittle zone localized the deposition of the vein quartz, carbonate, barite and sulphide.

The writer has studied the metal distribution in the sulphide ore at Silbak Premier with regard to ore genesis. This study has been confined here to the interpretation of the silver-gold ratios which have been calculated from the stope production records. Silver-gold ratios in the Silbak Premier vein system indicate that the deposit is zoned, with gold concentrated in the lower depths, and silver in the upper sections, suggesting a changing ore fluid pH from alkaline to more acid, and also a possible temperature gradient decreasing from depth towards the surface (Fig. 29). The ratio values also support the field evidence that gold was more abundant in the early phases of mineral deposition than in the late phases. It appears likely in view of the apparent mobility of silver that the late silver-rich mineral assemblages were deposited closer to the surface (lower pressure) than the gold-rich assemblages. These results are comparable to those Nolan (1935) obtained at Tonapah, Nevada, that is, they suggest a hydrothermal, telescoped deposit (Borchert, 1951) formed at shallow depth where changes in temperature and pressure are rapid. This type of deposit was originally termed xenothermal by Buddington (1935).

Taylor's (1970) recent experimental studies of phase relations in the silver-iron-sulphur system have shown the importance of the silver sulphidization curve for interpreting Ag-pyrite assemblages. He indicated that the majority of geologists have wrongly concluded that native silver, particularly in Ag-pyrite assemblages, results from the breakdown of silver-bearing minerals (e.g., argentite). Instead, he (op. cit.) suggested that the invarient reaction Argentite (Ag_2S) + monoclinic pyrrhotite (m-po) silver (Ag) + pyrite (py), in the presence of vapor (S), that occurs at 248° C., is important in certain massive sulphides. At the silver-bearing Kidd Creek zinc deposit, in the Timmins, Ontario area, where much of the silver occurs as stringers, veinlets, and blebs in pyrite, the assemblage

Ag+py formed below 248°C, at a sulphur fugacity of less than 10^{-14} atmospheres (Taylor, 1970). The phase relationships in the Ag-Fe-S system, and the above reaction explain the apparent world-wide absence of the assemblage argentite + pyrrhotite in nature. At Silbak Premier, argentite, pyrite, and native silver are concentrated in the near surface, bonanza, massive sulphide lenses, and pyrite and associated native silver extend from surface to a known depth of 1,200 feet. Pyrrhotite is present in minor amounts in the pyrite-galena-sphalerite assemblage in the deep sub-ore sections, but has never been recognized in the upper native silver-argentite-pyrite assemblages. Taylor's (1970) phase diagrams, and mineral assemblage data suggest that the Silbak Premier bonanza massive sulphide ore shoots have formed below 248°C, a figure corresponding to the writer's previous conclusion based upon the silver-gold ratios. The general conclusion is that the Silbak Premier deposit represents a telescoped, low temperature deposit, and that most of the native silver is primary, not secondary as suggested in the old literature.

Indirect evidence by analogy with other comparable silver-gold deposits also suggests a low temperature and pressure of formation for the Silbak Premier ore. Nishiwaki and others (1970, p. 412) have outlined a classification of Neogene silver-gold ores in Japan on the basis of mineral assemblages. The Silbak Premier ores compare to Nishiwaki's (1970, p. 413-415) combined Type-3, argentite ore, and Type-5, high silver sulphosalt ore, as characterized by the Seigoshi deposit. The above authors suggested that the temperature of formation of the combined Type 3-Type 5 deposits was near 200°C and that the depth of formation was as shallow as a few hundred meters. Shilo and others (1970) have indicated that mineral assemblages in silver-gold deposits in the northeast USSR, assumed by the writer to be comparable to the Silbak Premier type, were deposited at temperatures of 230° to 300°C, and at depths of 0.5 to 1.5 km. Shilo and others (1970) suggested that these deposits are related to postmagmatic volcanogenic processes.

The evidence of mineral zoning, metal zoning, mineral assemblages, and the near surface concentration of the bonanza ores at Silbak Premier points to a rapid change in temperature and pressure during the ore forming process, which in part reflects a physical or structural control.

An important structural feature recognized near Premier is the unconformable relationship between the Lower Jurassic rocks and the overlying Middle Jurassic strata. The Cascade Creek cataclasite zone, formed in Lower Jurassic rocks, in which the Silbak Premier deposit occurs, is overlain unconformably by Middle Jurassic sediments. These sediments occur as structural renmants just to the east of Premier at Bear River Ridge, and at Salmon Glacier, just to the west (Fig. 3). Reconstruction of the geological sections (Fig. 4B, EE', and FF') shows the probability of the Middle Jurassic strata overlying the Premier area at a height of about 500 to 1,000 feet. This estimate, plus the fact that the glory hole ore is truncated by the present erosion surface suggests that the bonanza ore once extended above the present level, and has been eroded. Like the ore deposits in Japan and the USSR the Silbak Premier ore has probably also been deposited near the surface.

As indicated, Shilo and others (1970) suggested that certain silver-gold ores in the northeast USSR were genetically related to postmagmatic volcanic processes. The Silbak Premier ores appear to be early

Middle Jurassic in age and related to the adjacent Texas Creek pluton. The Middle Jurassic Monitor Lake rhyolite has also been related to this intrusion in Chapter 3, and diatreme-like breccia zones were also noted near Premier. Spatial, and temporal relations suggest a complex plutonic-volcanic association with the Silbak Premier ore deposits. The red bed strata described near the base of the Middle Jurassic Betty Creek sequence are also spatially related to the mineral deposit and may have been a factor in controlling deposition of the complex ore.

Summary

The detailed study of the Silbak Premier deposit, and the country rocks has resulted in the following basic hypothesis of genesis of the Silbak Premier mineral deposit. Syntectonic deformation which induced destructive deformation along irregular zones now marked by abundant cataclasites was probably accompanied by explosive acid volcanism. Later, during the actual penetration of these zones, the plutons partially granitized limited physically-chemically favourable areas of the wall rocks. Petrographic studies have indicated that in these marginal zones the Texas Creek Granodiorite has significantly lower silica content than the main batholith and this outer zone of dioritic material thus represents an area of chemical depletion. The mobile constituents, possibly including some of the metals released by the granitizing process during an early stage, permeated through the country rocks and migrated along fissures to depositional sites to produce the initial alteration zones. Meteoric waters enriched with iron-rich complexes from the Betty Creek red beds percolated toward the fractured thermal area and mixed with the diffusing mobile materials, and in physically favourable sites assisted in the complex physical-chemical processes which led to the deposition of the oxide-sulphide vein systems. Then a later syndepositional phase(s) of mobilization led to the formation of the now visible mineral deposits in traps in prepared ground. Later dyke swarm intrusions in the same altered horizons have themselves been mineralized by smaller but chemically similar mineral deposits giving a total of at least four very similar successive episodes. Such apparent repetition would be unusual unless the genetic process involved more or less constant factors determined by the total environment.

The concept outlined above, therefore, rejects that of a classical simple hydrothermal fluid ejected by cooling and chemical action, which, in situ, forms complex zoned oxide-carbonate-sulphide masses.

Stratiform Massive Sulphide Deposits

Introduction

Massive sulphide deposits in the Anyox area (Fig. 30) include at least 12 compact mineral lenses comprising principally pyrite, pyrrhotite, and chalcopyrite, with minor sphalerite, as well as gangue minerals which include mainly quartz, calcite, biotite, and sericite. These sulphide-rich lenses are largely confined to volcanic strata and as such can be related to Anderson's (1969, p. 131) category I classification, and are described here as stratiform or bed-like bodies characterized by a low length to width ratio which sets them apart from sedimentary deposits (Dunham, 1971).

In the Anyox area the massive sulphide deposits occur mainly within a volcanic sequence, which is overlain by generally conformable marine sedimentary strata. The major structure is a northerly trending syncline and the sulphide lenses occur near the volcanic-sedimentary contact on both

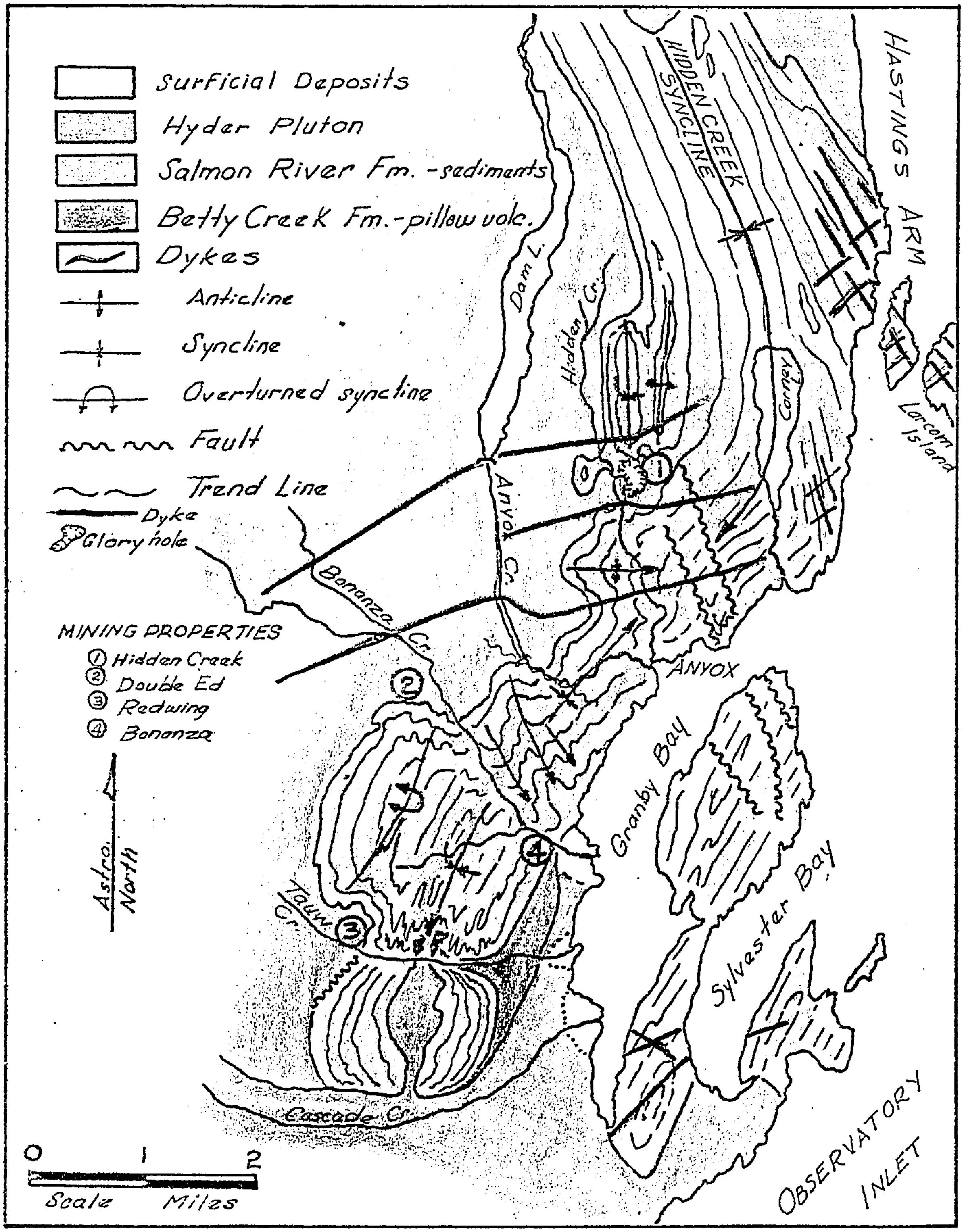

FIG. 30 General geology of the Anyox area, showing mineral properties.

limbs of the Hidden Creek syncline over a known length of six miles. This relationship, and the apparent volcanogenic association of these massive sulphide bodies is described here for the first time. To the writer's knowledge the stratiform massive sulphide deposits at Anyox are the only known occurences of this type in the Canadian Cordillera.

Production Record

Mineral production from the Anyox area has been mainly from the Hidden Creek (and Bonanza) mines (Fig. 30) which operated during the period 1914 to 1935. The total production from these deposits was approximately 24.7 million tons of ore which included 741 million pounds of copper, about 7 million ounces of silver, and 124,000 ounces of gold. Ore from the major Hidden Creek mine averaged 1.5 per cent copper, 0.05 ounces/ton gold, 0.27 ounces/ton silver, and contained less than 0.5 per cent combined lead and zinc. The nearby Bonanza mine, consisting of a single massive sulphide lens, averaged 2.2 per cent copper, 0.03 ounces/ton gold, and 0.39 ounces/ton silver, about one per cent zinc and negligible lead. Selenium was produced at the Anyox smelter as a by-product of the massive sulphide ores.

Geology of the Anyox Area

The main rock types underlying the Anyox area (Figs. 2C, 30) include a thick succession of Middle Jurassic pillow lavas and thin-bedded marine siltstones. These rocks form part of a large pendant that is entirely isolated within the Tertiary Hyder pluton at the eastern margin of the Coast Plutonic Complex. Comparable pillow volcanic-siltstone sequences have also been mapped in other parts of the study area at Treaty Glacier, and Alice Arm, but in these areas the pillow lava units have relatively minor extent compared to the Anyox area, and stratiform massive sulphide deposits appear to be lacking.

The lavas at Anyox which have been correlated homotaxially to the Betty Creek Formation lavas at Treaty Glacier comprise mainly altered green close-packed pillows (Plate 16). In thin section the pillow lava consists of very fine grained felted mass of acicular amphibole, scattered blebs of epidote, and some fine grained fresh biotite. The composition of the lavas is assumed to be andesitic, but the pervasive alteration of these rocks, throughout the area, precludes determination of the original petrography of the flows. The upper 2,000 to 2,500 feet of the pillow lava sequence includes a variety of altered, broken pillow breccias (Plate 17) and pillow breccias which are localized in, and gradational with, close-packed pillow lavas. The pillow breccia zones are the main litholigic feature used to outline the structure of the thick pillow succession. The pillow breccias, and broken pillow breccias form discrete lenses from a few feet to tens of feet thick which are traceable over hundreds of feet. The transition from close-packed pillow to pillow breccia takes place within a few feet, and the vertical limits are marked by sharply conformable contacts. This pillow lava sequence is largely overlain conformably by a thick sequence of thin-bedded marine siltstones homotaxially related to the Middle Jurassic Salmon River Formation.

In the Anyox area the contact between the pillow lavas and the siltstone exhibits a variety of relationships along the length of the Hidden Creek Syncline. In the axial zone, near the south end of the syncline, close-packed pillow lavas are gradational with a 10 to 20 foot thick zone of thinly banded quartzite which in turn is gradational with the overlying calcareous siltstone sequence (Plate 18). Along both limbs of the syncline this contact has been obscured by localized deformation. In the Bonanza Creek area, for example, the contact zone along the western limb is marked by a complex transitional zone consisting of a series of thin carbonate, chert, and siltstone lenses intercalated with the pillow lavas underlying the main siltstone sequence. At the mouth of Bonanza Creek, on the east limb, the pillow lavas underlying the siltstone have been extensively deformed by flattening and have been commonly misidentified as thin-bedded sediments. At Hidden Creek the contact between the pillow lava and the overlying siltstones near the ore bodies is sharp and conformable but has been complexly folded and faulted.

Very generally, the siltstone strata which overlies the pillow lavas includes abundant small limestone concretions, and minor cherty lenses, and is marked by graphite zones. Disseminated, fine grained pyrite and pyrrhotite are ubiquitous within the calcareous siltstones immediately overlying the pillow lavas. These sediments are mainly thinly bedded, buff to black siltstones, with intercalated silty greywackes, calcarenties, and silty argillites. The siltstones are characterized by a blocky to splintery habit, and by reddish surficial weathering. Within the body of the Hidden Creek Trough, the siltstones are moderately fresh and exhibit a typical grey and black striping. Planar banding is the major primary feature in these rocks, although enterolithic-like structures have been used extensively in determining the fold patterns. Foliation is rare in these rocks and is generally limited to the marginal zones along dykes. At the contacts with the Tertiary Hyder pluton the siltstones are indurated and typically display acicular tremolite needles or clumps of needles. Elsewhere, in the trough, altered andalusite and fine grained brown biotite occur as random clusters within the lower 1,000 to 1,500 feet of the siltstone sequence immediately overlying the pillow volcanics. Near the contact with the Hyder pluton, the limestone concretions in the lower part of the siltstone succession have been altered to aggregates of calcite, quartz, epidote and grossularite.

The extensive alteration of the pillow lavas is assumed to represent autometasomatism (Bonatti, 1967), whereas the development of the andalusite in the siltstone sequence is interpreted as indicative of Middle Jurassic low amphibolite grade regional metamorphism. The tremolite hornfels zones are obviously related to Tertiary plutons, and post-date the alteration of the volcanics and older regional metamorphism.

Major geological features in the Anyox area include the Anyox Syncline, and the Hidden Creek structural trough. These major features trend northerly, and exhibit distortion related to simple compressional forces that produced assymetry reflected in the Hidden Creek fold. Shear zones, assumed to be related to the same tectonic event, are primarily localized within the pillow lava sequence along the contact zone south of Bonanza Creek and also along the margins of the massive sulphide deposits.

Detailed structural studies at the Hidden Creek mine have shown that the complexly folded siltstone sequence overlies the massive sulphide bodies forming what has locally been called a structural "nose" in the older literature (Nelson, 1948). This local feature has generally been regarded to represent the major structural control for the localization of the massive sulphide lenses (Fig. 31). Mapping by the writer of the Bonanza, Double Ed, and Redwing properties (Fig. 30) has shown that these deposits lie entirely within the pillow lavas, but that their structural situation in relation to the overlying siltstone is not complicated by folding. The No. 6 ore body at Hidden Creek (Fig. 31) also lies entirely within the pillow lavas and is overlain by relatively undeformed siltstones. The writer has previously indicated that the folding of the Hidden Creek Syncline post-dates massive sulphide deposition and is assumed to be related to Middle Jurassic tectonism. It follows, that on the basis of the writer's regional and local structural evidence that the generally accepted older structural theory of ore control for the massive sulphide deposits in the Anyox area is not acceptable.

Orebodies at the Hidden Creek Mine

The principal orebodies in the Anyox area are those of the Hidden Creek mine and these will be discussed in some detail in view of the writer's new information. The Hidden Creek orebodies are pipe-like to sheet-like lenses of massive sulphides. They consist mainly of pyrite, pyrrhotite, and chalcopyrite with minor arsenopyrite, galena, and magnetite. The gangue minerals are principally quartz, calcite, sericite with minor epidote and garnet. At least 8 separate ore lenses are known of which the largest has a length of at least 1,600 feet, a width of from 800 to 900 feet, and a thickness of up to 300 feet. The dimensions of the smaller lenses are characteristically non-uniform in thickness along their length. All of the lenses at the Hidden Creek mine are nearly vertical, and six major ore lenses have been mined by underground and glory-hole methods. Prior to closing the operation in 1935, novel mining procedures were attempted which resulted in extensive damage to the mine system. Access is now restricted to the surface exposures in the glory-holes, and to limited mine areas; as a result it has not been possible to examine all the orebodies over their known extent.

The orebodies at Hidden Creek mainly lie within the pillow lava sequence at different stratigraphic levels below the siltstone contact. This general relationship is illustrated on the geological plan (Fig. 31) and the composite geological section (Fig. 32). The contact orebodies, Nos. 1, 4, 5, and 6, exhibit complex relationships to the enclosing country rocks, and as indicated by the geological plan and section appear to lie partly within the siltstone. The keel sections as well as the margins of these three lenses are entirely within the altered pillow lavas. But, the upper, complexly deformed segment of the 1-5 ore zone exhibits what has generally been assumed to represent replacement of the thin-bedded siltstones. This siltstone-sulphide contact has been deformed along much of the 1-5 zone, but certain segments, particularly in the No. 5 orebody suggest a continuity of mineral banding in the ore with apparent bedding in the siltstones. The sulphide ore in these segments is irregular and appears to transect the sediments. Elsewhere the apparent replacement of siltstones by the sulphides is a result of localized shearing and sulphide remobilization.

The general mineralogy of these lenses is simple. The footwall zone of the Nos. 1, 4, and 5 orebodies (Fig. 31) comprises a 400 foot thick zone of fine grained granular quartz and sericite, characterized by a vuggy, or spongy texture, with very fine grained framboidal pyrite encrusted within the cavities. In polished sections, this pyrite displays what is assumed to represent radial shrinkage cracks, but is otherwise textureless. The 1, 4, and 5 orebodies themselves, as compared to the footwall zone, consist almost entirely of medium grained, massive pyrite in which chalcopyrite is present as blebs and streaks along discrete fractures. The minor gangue consists of disseminated to lens-like fine grained quartz and calcite.

The number 6 orebody, one of the contact lenses, is marked by well defined inch-scale mineral banding defined by pyrite, pyrrhotite, and quartz-sericite gangue (Plate 47). In this orebody chalcopyrite is also concentrated within the pyrrhotite-rich central zone. In hand specimen the chalcopyrite and pyrrhotite occurs as veinlets and streaks cutting the pyrite gangue banding as an assumed response to late stage deformation.

The narrow footwall of the 2 and 3 orebodies, which are entirely enclosed in the pillow lavas, is uniquely characterized by the presence of very fine grained epidote and grossularite garnet as specks and streaks in the sulphide matrix.

These orebodies comprise principally medium to coarse grained pyrite, pyrrhotite, chalcopyrite, and minor magnetite with minor quartz. In the 2-3 ore zone chalcopyrite is entirely associated with pyrrhotite which is localized within the central part of the ore lenses. The 7 and 8 orebodies, also confined to the pillow lavas, consist almost entirely of granular pyrite, pyrrhotite,disseminated chalcopyrite, and fine grained quartz. These two orebodies have not been completely studied and are known only from exploration drill core data.

Just as the Hidden Creek orebodies are characterized by a relatively simple assemblage of gangue and sulphide minerals, the individual orebodies are characterized by their chemical composition. The chemical compositions of the major orebodies at Hidden Creek have been calculated from the smelter records and are shown in Table 5.

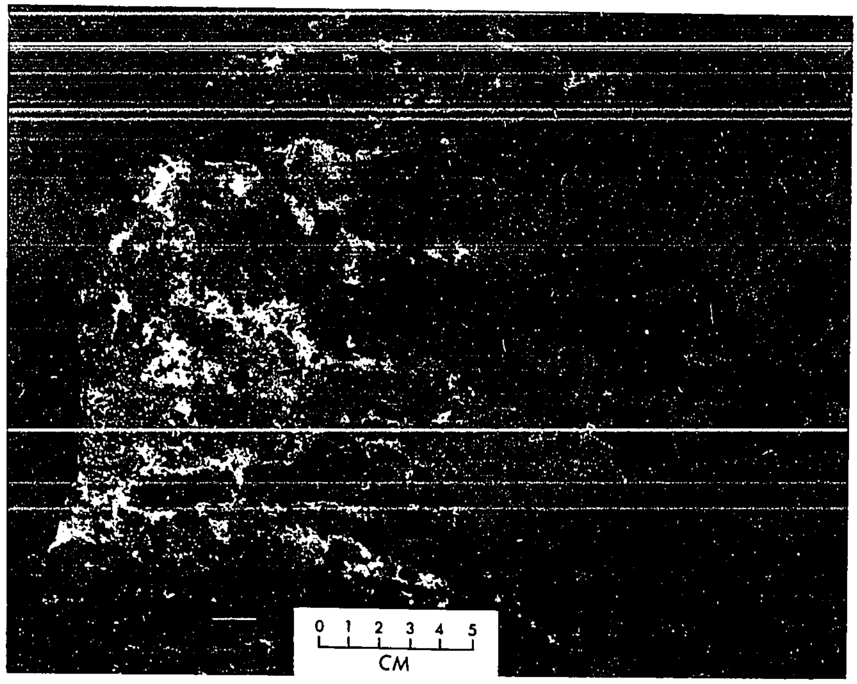

Plate 47. Massive sulphide ore, No. 6 orebody, Hidden Creek Mine, showing mineral banding

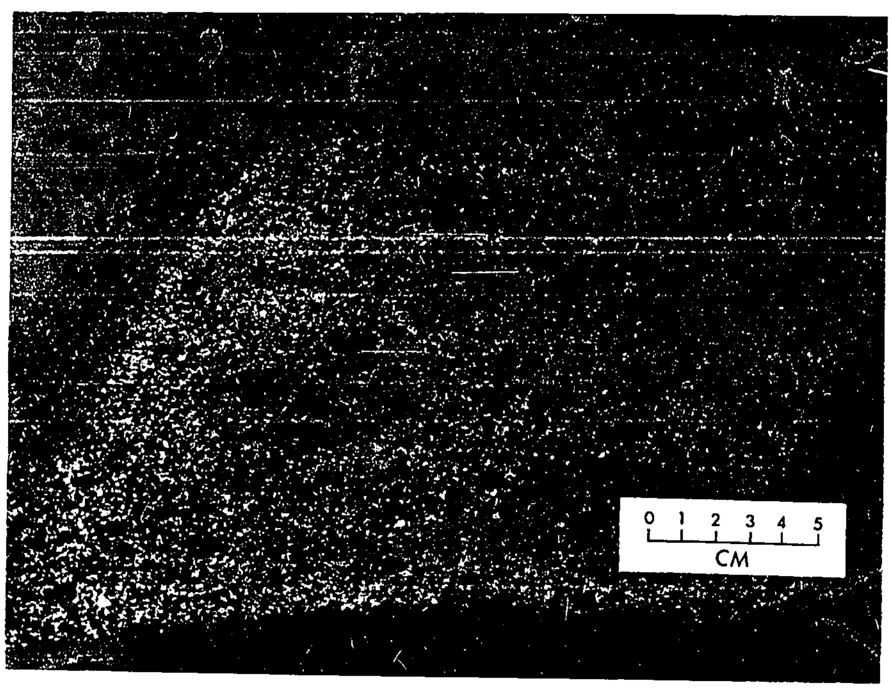

Plate 48. Massive sulphide ore, Bonanza Mine, showing mineral banding

Table 5 Chemical Composition Hidden Creek Orebodies
(Per cent)

Orebody	Cu	SiO_2	Fe	CaO	S	Al_2O_3	MgO
1	2.37	22.4	29.6	4.7	30.0	5.1	1.3
2	2.24	33.2	25.6	3.0	18.0	10.8	4.0
3	1.82	40.8	21.6	1.5	7.9	11.5	6.6
4	1.52	9.2	37.0	9.8	30.5	3.0	0.8
5	3.02	14.8	34.0	5.9	33.3	1.6	0.0

The simple mineralogy of the orebodies is reflected in Table 5. Numbers 2 and 3, as previously mentioned, have a narrow footwall zone marked by the presence of epidote, garnet, and quartz. Numbers 1, 3, and 5 have calcite, quartz, and sericite as the gangue minerals. Pyrite is more abundant in the 1, 4, and 5 massive sulphide lenses, with pyrrhotite conspicuous in the Numbers 2 and 3 lenses.

In summary, the sulphide orebodies at the Hidden Creek mine consist primarily of pyrite, pyrrhotite, and chalcopyrite with minor sphalerite, magnetite, galena, and arsenopyrite. The principal gangue minerals include quartz, calcite, sericite, with some epidote and garnet. The mineral assemblage corresponds to Anderson's (1969) world-wide Class I, and can be characterized as a conformable massive sulphide deposit in the terminology of Dunham (1971).

In more detail, on the basis of the observed mineralogy, mineral zoning, and bulk chemical composition, the individual orebodies can be divided into three distinct groups. These groups include: 1) the contact orebodies, represented by Numbers 1, 4, 5, and 6 orebodies which are primarily pyrite masses with associated pyrrhotite and chalcopyrite, quartz, calcite, and sericite; 2) group 2, includes the 2 and 3 orebodies which lie entirely within the pillow lava sequence, and consist of pyrite, and pyrrhotite, with chalcopyrite entirely confined to the central pyrrhotite zone. The gangue includes calc-silicates, quartz, and minor sericite, but is notably deficient in calcite; 3) includes sub-ore masses such as the number 7 and 8 lenses, which are spatially intermediate between groups 1 and 2, and are relatively deficient in chalcopyrite.

The bulk chemical composition of the Hidden Creek orebodies (Table 5) has been presented to complement the mineralogical variations outlined, and to characterize the deposit. The chemical composition of the individual orebodies also suggests that the lenses in the Hidden Creek deposit are probably co-genetic. This is illustrated in Figure 33, where the major constituents have been plotted in a simple variation diagram.

Alteration in the Hidden Creek mine area

The Hidden Creek orebodies are enveloped in a thin, film-like zone of quartz-sericite schist which varies in thickness from a few feet to several tens of feet where the alteration is gradational with the foot-wall vuggy quartz-framboidal pyrite zone. The pillow volcanics outside the schist zone exhibit the typical amphibole alteration previously described, but apart from local iron staining and weathering show no apparent alteration spatially related to the massive sulphide lenses. Similarly, the overlying siltstones exhibit no significant alteration assemblage characteristically related to the sulphide lenses alone. Locally, silicification, and secondary brown biotite appear to be more prominent near the orebodies than along the non-productive contact in the siltstones, but this may merely reflect rock exposure, regional metamorphism, or personal bias.

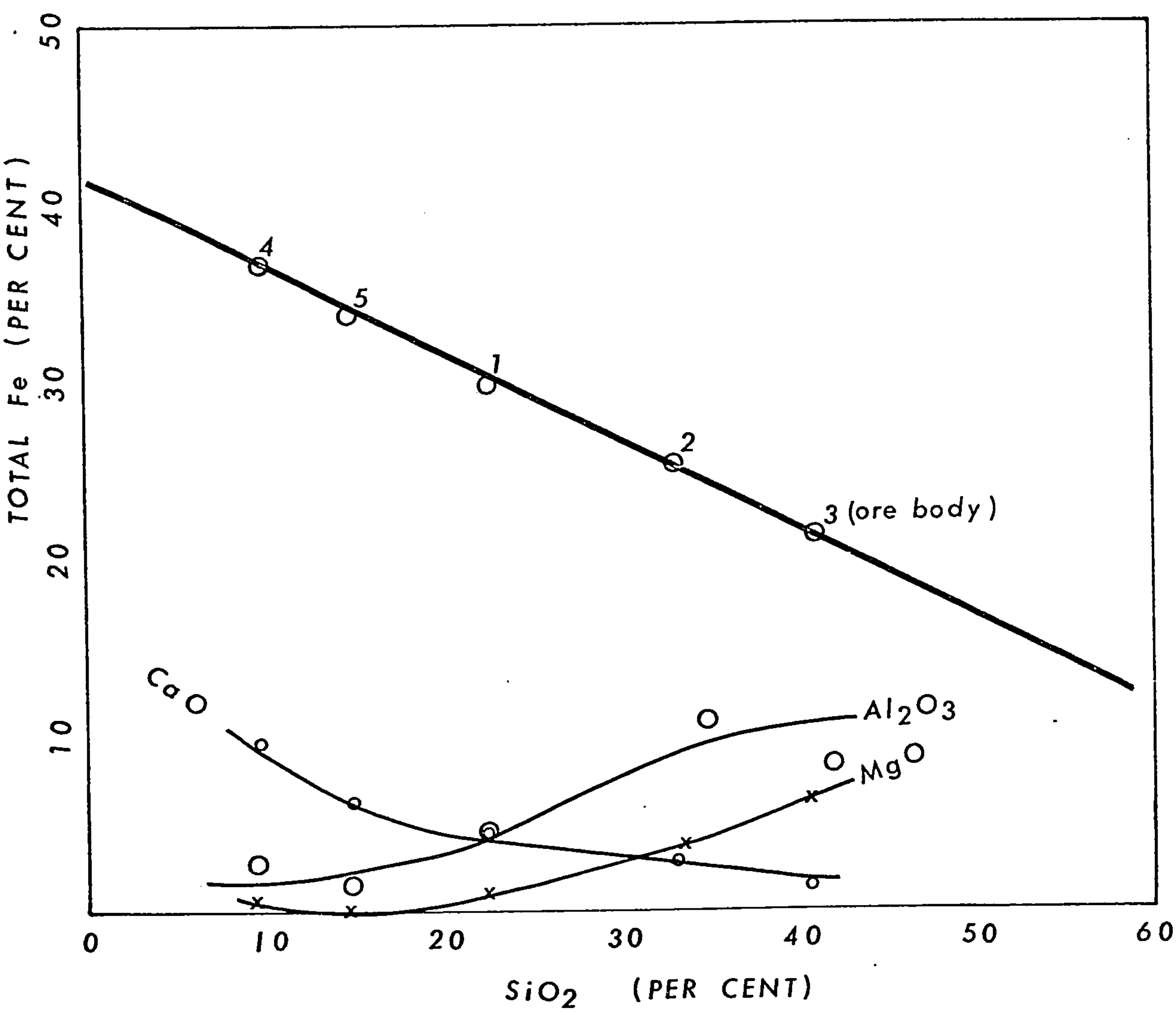

FIG. 33 Variation diagram, chemical composition, Hidden Creek orebodies, Anyox.

Several extensive quartz, carbonate, and magnetite alteration zones have been outlined along the pillow lava-siltstone contact south of the Hidden Creek mine. But, extensive exploration diamond drilling of these areas has not indicated the presence of any massive sulphide, or significant disseminated sulphide mineralization. These zones, like the many barren quartz veins in the Anyox area,are assumed to represent barren Tertiary mineralization.

Other Massive Sulphide Deposits in the Anyox Area

Three other stratiform massive sulphide deposits, namely the Double Ed, Redwing, and Bonanza, are localized near the contact between the pillow lavas and the siltstones south of the Hidden Creek mine. The first two mentioned occur on the west limb of the Hidden Creek Syncline while the Bonanza deposit is the only known occurence on the east limb (Fig. 30). All three deposits are localized within the pillow lavas and are enveloped in a narrow, variably chloritic, quartz biotite schist zone. These deposits are mineralogically similar to the writer's group 1, Hidden Creek orebodies. These deposits are characterized by medium to coarse grained, frequently granular pyrite, streaky pyrrhotite lenses, scattered chalcopyrite, and dark brown sphalerite which outlines the prominent mineral banding in the ore (Plate 48).

The Bonanza deposit consists of a flattened, pipe-like lens, that plunges at a shallow angle to the north below the pillow lava-siltstone contact near the axis of the Hidden Creek Syncline. The known length of this lens is about 2,500 feet; it has a thickness of up to 120 feet, and a width of up to 400 feet. The grade of the mineralization and the mineralogy is comparable to the contact lenses at the Hidden Creek mine. The Bonanza deposit has been cut by several dyke swarms and intruded near the north end by part of the underlying Tertiary intrusive complex.

The Redwing and Double Ed deposits, also localized within chloritic biotite schist envelopes within the pillow lavas, are similar in grade and mineralogy to the Bonanza and Hidden Creek contact deposits. Both the Redwing and Double Ed deposits have been slightly deformed, probably during the regional tectonic episode (Fig. 24). These deposits exhibit flattened pipe-like forms that plunge steeply within the pillow lava sequence, and like all these deposits maintain an essentially parallel spatial relationship to the pillow lava-siltstone contact.

Recent exploration west of the contact has revealed several siliceous massive pyrrhotite-chalcopyrite replacement zones. These are entirely confined to pillow breccia, and broken pillow breccia zones within the close-packed pillow lava sequence. Surface work, and diamond drilling indicate these zones are about 300 feet in diameter, steep, and completely unrelated to any simple fracture system or to plutons.

Genesis of Massive Sulphide Deposits in the Anyox Area

The fact that the stratiform massive sulphide, and sulphide breccia deposits in the Anyox area are associated in every instance with lavas is evidence of a genetic relationship (Dunham, 1971, p. 169). The fact that the length to width ratios of these sulphide lenses are lower than almost all known sedimentary deposits also relates them to the well known deposits of accepted volcanogenic association. Anderson (1969, p. 134) in his study of massive sulphide deposits attempted to show that pyrite could be distinguished as hydrothermal or biogenic on the basis of its selenium content. Pyrite from the Hidden Creek mine has a content of about 1ppm, or less, suggesting on the basis of Anderson's compilation, if not a sedimentary affiliation, probably not a hydrothermal origin. Detailed studies of the ore deposits at Anyox have not revealed the presence of spatially related plutons to which the sulphide deposits can be related, thus completely negating the possibility of a contact metamorphic, or pyrometasomatic origin. The writer has suggested that on the basis of their chemical composition, the sulphide lenses at the Hidden Creek mine were probably formed by a similar process. The lithostructural and mineralogical similarity of the other sulphide deposits in the Anyox area to these Hidden Creek bodies is assumed to indicate a similar genesis, probably volcanogenic, but not excluding hydrothermal processes.

The writer has previously presented a hydrothermal plutonic-volcanic concept for certain vein deposits in the Stewart Complex and has indicated that the bulk of the vein deposits suggest a similarity of process manifested by large amounts of quartz and carbonate gangue as compared to relatively minor sulphide content. A simple calculation based on the Silbak Premier deposit, for example, indicates that the overall ratio of gangue material to sulphide in the vein system is about 700 to 1. Also, a general study of the vein deposits in the Stewart Complex suggests that the minimum gangue to sulphide ratio is greater than 500 to 1. In strong contrast to the hydrothermal vein deposits, the volcanogenic massive sulphide deposits are characterized by a low volume of gangue mineral which at Anyox forms less than half the material in the lenses, or less than a simple 1 to 1 ratio (Table 5).

Comparison of the Anyox deposits to other Massive Sulphide Deposits

The massive sulphide deposits at Anyox appear to form part of a continuous volcanic sequence deposited during the late stages of submarine activity, prior to the onset of regional, shallow marine sedimentation. Amstutz (1971) has suggested, that like x-ray powder patterns for minerals, ore deposits should be compared by analogy before invoking a process. The formation of native sulphur, and iron sulphide deposits associated with the volcanic process has been well documented (Kinkel, 1966), but to date no example of an actively-forming volcanogenic, submarine massive sulphide deposit has been recognized.

Clark (1971), and Hutchinson and Searle (1971) and others, have reviewed the geological setting of the cupriferous massive sulphide deposits of Cyprus. The various workers on the Cyprus massive sulphides have generally concluded that these ore deposits have formed periodically, related to sub-aqueous exhalations or effusions, followed by distinctive iron oxide, silica-rich chemical sedimentation. They have also assumed that the precipitation and accumalation of colloidal sulphide in sea floor depressions occurred in a reducing environment. Hutchinson and Searle (1971) speculated that the water, metals, and sulphur in the volcanic emanations were derived from a mantle source in accord with the character of the Troodos Complex as a whole.

The general relationships of the Anyox massive sulphide deposits including age, size, shape, composition and texture, timing, and in part the sedimentation record correspond closely to the Cyprus deposits. By analogy, the similarity between the extensively altered pillow lavas, the presence of mineralized volcanic breccias, plus the possible colloidal nature of part of the Anyox deposits as expressed by the framboidal pyrite and vuggy quartz zones, suggest a comparable ore forming process.

The writer suggests that on the basis of the geological evidence presented, and the comparability of the Anyox and Cyprus sulphide ore-bodies, that the Anyox massive sulphide deposits formed principally by subaqueous, fumarolic and synvolcanic processes related to Middle Jurassic plutonic-volcanogenic processes (Fig. 24).

In the Anyox area in particular, and the Stewart Complex in general, widespread Tertiary plutonism has erased evidence of any Middle Jurassic pillow lava-ophiolite affiliation, if it ever existed. More importantly, Tertiary plutonism has possibly destroyed, or even recycled, other Anyox type massive sulphide deposits.

Concordant Massive Sulphide Deposits

Introduction

The only known representative of this class of mineral deposit in the area of the Stewart Complex is the Granduc property located at Granduc Mountain 25 miles northeast of Stewart. This large deposit was discovered in 1951 when ablation of the South Leduc Glacier revealed a small area of mineralization at the 3,600 foot elevation (Fig. 6). Published ore reserves indicate 54 million tons of ore with a grade of about 1.55 per cent copper, 0.2 ounces/ton silver, with minor gold, lead, and zinc. The geology of the Granduc deposit which at present represents the largest concordant massive sulphide deposit (Dunham, 1971) in the Canadian Cordillera will be described in some detail.

Geology of the Granduc Deposit

The Granduc ore deposit lies near a conspicuous reentrant in the eastern margin of the Coast Plutonic Complex (Fig. 17). The sulphide lenses comprising the ore deposit are entirely confined to a 400 foot wide zone located near the easterly margin of the South Unuk cataclasite zone. The petrography and structure of this complex cataclasite zone have been previously described in Chapter 3. This deformed zone is locally bounded on the west by northerly trending mixed granodiorite gneisses, previously related to the Central Gneiss Zone, and on the east by variably deformed epiclastic volcanic conglomerates, and indurated, altered pillow volcanics. To the south of Granduc Mountain the country rocks, including the ore bearing cataclasites, have been transected by Tertiary plutons. The country rocks in the mine area have been described in Chapter 3 as part of the Unuk River Formation (Fig. 13). Because the strata in the Granduc Mountain area are deformed, the original nature of the ore bearing strata and enclosing wall rocks is based on the study of the least deformed rock units in the general mine area. Away from the ore lenses, the country rocks include a complex volcanic-sedimentary sequence dated by fossil evidence as Pliensbachian, and referred to in this study as part of the middle member of the Unuk River Formation (Fig. 13).

Thick, extensive, andesitic volcanics east of the Granduc orebodies form part of a northerly trending zone of shallow marine, close-packed pillow lavas intercalated within graphitic siltstones, thin-bedded lithic and crystal tuffs, and volcanic sandstones. This sequence is overlain by a sequence of strata, including the ore zone, which includes mixed strata comprising graphitic siltstones, thin-bedded lenticular gypsiferous limestones, quartz pebble, and quartz cobble conglomerate lenses, banded volcanic tuffs, quartzites, and cherts. The strata north of the ore zone, at North Leduc Glacier, has been intruded by a variety of Lower Jurassic plutons previously described as the Unuk River Intrusions. Several of these small plutons as well as the country rocks have been deformed and form part of the South Unuk cataclasite zone. In addition to cataclasis, the mine area has suffered several periods of later deformation, intrusion, alteration, faulting, and erosion culminating in the Tertiary with Hyder plutonism.

The ore deposit at Granduc Mountain lies along part of a deformed, overturned, west limb of a pre-Middle Jurassic, possibly Aalenian, northerly trending anticlinal fold. The west limb of this fold has been transected at an acute angle by the South Unuk cataclasite zone. In the cataclasite zone, structure at Granduc Mountain is outlined by lenses of deformed, recrystallized limestone, thick, lenticular ultramylonite sheets, and by mineral banding in the mylonites and phyllonites. Both the petrology and structure of this cataclasite zone in the mine area has been described in previous chapters. South of the ore zone, at South Leduc Glacier, the country rocks are weakly deformed, and are represented by thick-bedded, andesitic volcanic conglomerates, with minor fine grained sediments.

Orebodies at Granduc Mountain

All the known ore-grade mineralization at Granduc is confined to a narrow 400 foot wide, vertical zone within the northerly trending South Unuk cataclasite zone. The relationship of the various ore zones within the mylonite-phyllonite sequence is shown on Figure 34. Each ore zone includes several lenses of massive sulphides separated by mainly barren cataclasite or by country rock cut by stockwork-like sulphide stringer zones. Most of the ore is known only from diamond drill core, but certain parts in the upper levels (Fig. 6) have been recently exposed in production development areas prior to mining. These areas have been mapped and studied by the writer as part of a detailed study of the mine. The ore zones have been shown to comprise pancake-like, overlapping, and commonly merging lenses which are known to extend vertically from about 1,500 feet to about 4,000 feet elevation, and extend laterally along the cataclasite zone for at least 4,000 feet. The ore zones have been assigned arbitrary letters, A through F, to partially systematize the confused pattern of massive sulphide lenses (Fig. 34).

The "A" zone lies along the western limit of the mineralized area and extends from depth at the south end to the central mine area. The "B" zone lies at the eastern limits in the central mine area. The "C" zone lies between "A" and "B", and joins "F" zone which extends to the northernmost ore limit. "Ch" zone is the irregular upper part of the main "C" zone. In detail, the individual ore zones consist of massive lenses, irregular streaks and blebs, and veinlets of sulphide which exhibit rapid changes in outline within the mylonite-phyllonite wall rocks. Breccia texture in the massive sulphide, largely represented by rotated blocks of mylonite, as well as abundant evidence of chalcopyrite and pyrrhotite re-mobilization as veins, indicates pervasive sulphide deformation at several periods. As a result of repeated deformation the massive sulphide lenses and orebodies have an irregular, feathery nature and have been called stringer-lodes by the mine geologists (Norman and McCue, 1966).

The Granduc orebodies comprise principally pyrite, chalcopyrite, pyrrhotite, sphalerite, and galena in order of relative abundance. Arseno-pyrite has been identified as a minor mineral in most of the ore zones, and cobaltite identified in the upper part of the "A" zone. Magnetite is a common constituent in both the ore zones and wall rocks, but appears to be more abundant along the western limit of the ore horizon. In the massive sulphide lenses gangue includes blocks of brecciated mylonite-phyllonite country rock, quartz as lenses, stringers and blebs, and moderately abundant recrystallized coarse grained calcite as lenses and stringers.

Each orebody exhibits strong concordance of the massive sulphide lenses to the confining thinly banded wall rocks. The major ore zones (Fig. 34) are comprised of numerous massive sulphide lenses up to several tens of feet thick which extend laterally up to several hundred feet within the confining cataclasites. The wall rocks intercalated with the massive sulphide lenses within each zone include a multitude of concordant millimeter-scale sulphide lenticles as well as a reticulated stockwork of fine sulphide veins and veinlets, mainly consisting of chalcopyrite. These veinlets generally extend outwards from the massive sulphide lenses into and across the country rock for distances of several tens of feet, and have been observed to transect other massive sulphide lenses within the ore zones. Chalcopyrite, and to a lesser extent pyrrhotite, comprising these veinlets are assumed to have been remobilized (Moorkerjee, 1970) by local post-cataclastic deformation. As a result, the essentially barren inter-sulphide wall rock within the ore zone limits can be mined economically.

In the massive sulphide lenses galena and sphalerite appear to be concentrated with quartzose material, and occur as irregular augen throughout the lenses. In contrast to the fine grained pyrite, chalcopyrite, and pyrrhotite in these lenses, the galena and sphalerite are coarse grained, and exhibit little or no evidence of deformation. The galena, sphalerite, and host quartz are also veined by chalcopyrite and pyrrhotite veinlets. Contrary to experimental evidence (J.E. Gill, pers. comm.) chalcopyrite and pyrrhotite appear to have been remobilized in preference to galena. However, the galena and sphalerite may have been buffered in their close association with quartz lenses.

The massive sulphide bodies in all the Granduc ore zones exhibit crude mineral banding, and flow-like structures surrounding the rotated country rock inclusions (Plate 49). The pyrite in the lenses is coarse grained and consists of irregular angular fragments, and forms pods or streaks (Plate 50) surrounded and veined by chalcopyrite and pyrrhotite. Magnetite occurs throughout the ore lenses as segregations marked by complex banding. Both the chalcopyrite and pyrrhotite are fine grained, show re-crystallization and segregation, and generally form the matrix for the angular ore and gangue materials. The protoclastic textures of the ore minerals and gangue indicate that the massive sulphide lenses, like the country rocks, have been subjected to non-uniform, differential deformation. This is expressed by the cataclastic textures, mineral differentiation, and ir-regular mineral recrystallization.

As Stanton (1959, 1960, 1964), and others have suggested, the textures in deformed sulphide ores are not evidence of a normal paragenetic sequence. Instead the textures reflect the intensity of the deformational event as evidenced by the individual characteristics of the minerals, and can commonly be expressed as a crystalloblastic series. In the Granduc ore, as previously indicated, because of unusual conditions, chalcopyrite and pyrrhotite have also been remobilized and recrystallized at a late stage in preference to the normally more mobile galena.

The mobility of chalcopyrite as expressed at Granduc has been an important factor in determining the commercial ore limits. McDonald (1967) has cited experimental and physical evidence for the mobility of chalcopyrite, and the associated preferential enrichment of wall rocks by veining, as a result of differential movement. At Granduc, chalcopyrite and to a lesser extent, pyrrhotite, have veined both country rock and massive sulphide lenses.

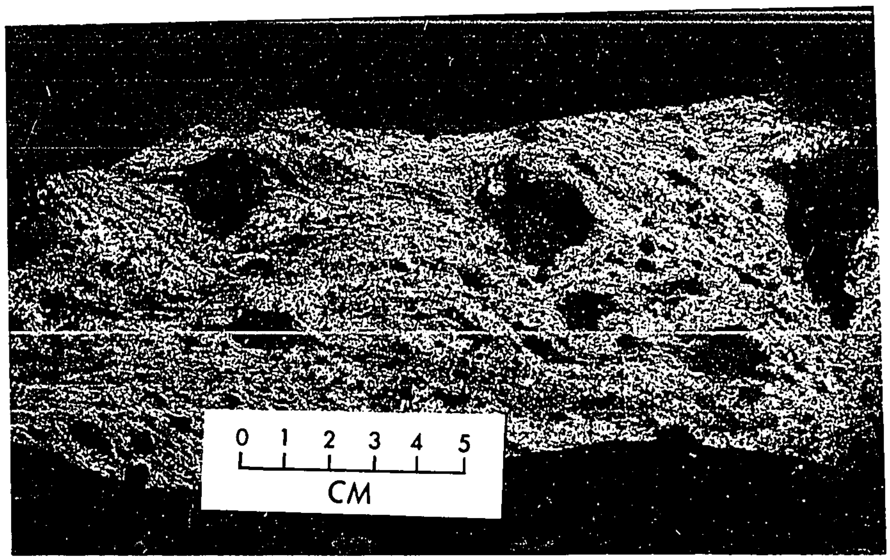

Plate 49. Massive sulphide ore, Granduc Mine, Ch zone, showing rotated country rock inclusions.

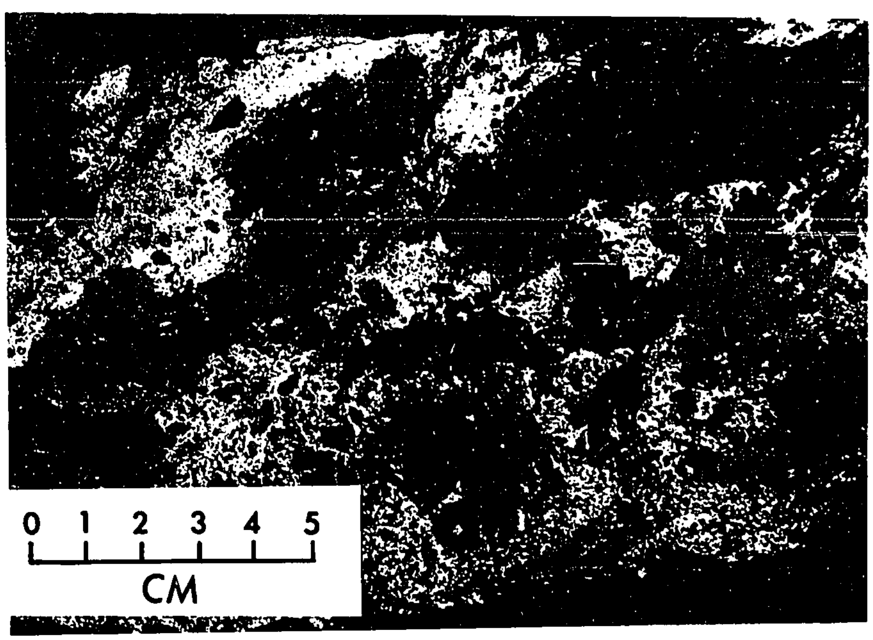

Plate 50. Massive sulphide ore, Granduc Mine, C zone, with fragmented pyrite, and magnetite as streaks.

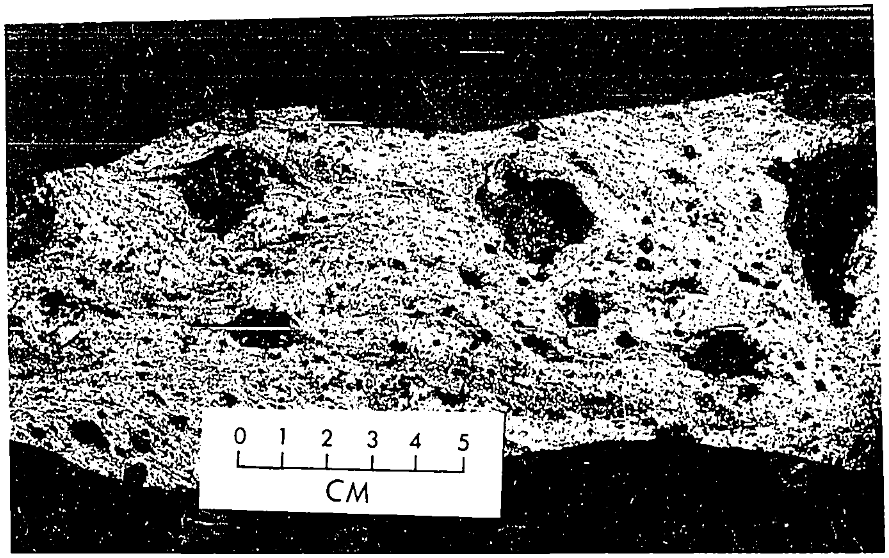

Plate 49. Massive sulphide ore, Granduc Mine, Ch zone, showing rotated country rock inclusions.

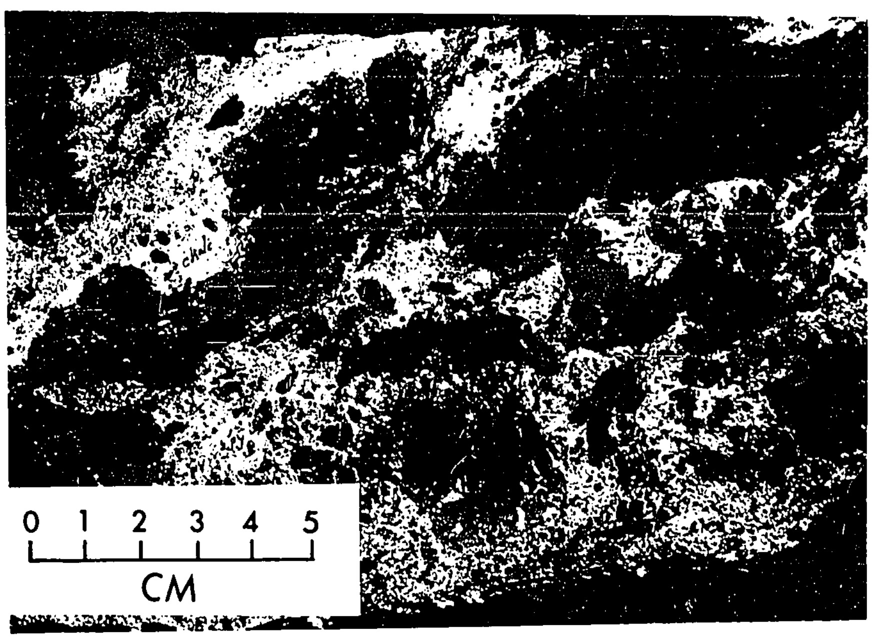

Plate 50. Massive sulphide ore, Granduc Mine, C zone, with fragmented pyrite, and magnetite as streaks.

This evidence indicates that deformation related to the major cataclastic event had ceased, and suggests that sulphide remobilization occurred after local relaxation. The event is assumed to have been related to Tertiary faulting which cuts the ore zones, but could also indicate the presence of a chemically reactive medium and fluid transport as suggested by McDonald (1967, p. 213). The complete lack of alteration in the wall rocks implies the former mechanism and provides evidence for small-scale sulphide remobilization related to deformation.

The evidence of sulphide remobilization at Granduc does not favour Schneiderhohn's (1952) hypothesis for the formation of secondary metamorphic vein deposits, and unlike the sulphide neomagmas that Lawrence (1967) has described at Broken Hill, the Granduc lenses and veins are significantly low in silicate gangue. Lawrence (1967) suggested that the Broken Hill ore was remobilized as a result of high temperature regional metamorphism, partial melting, and the derivation of a flux-charged water vapor phase. At Granduc, limited sulphide remobilization was achieved in the apparent absence of a transport medium in a dry, low temperature environment.

Vokes (1969) has suggested that ores such as the Granduc material, where cataclasis is reflected by breccia healed by the fine grained products of deformed sulphide, are very commonly found in the greenschist facies environment of the Norwegian Caledonides. Composition, particularly the presence of abundant chalcopyrite, appears to partly control mineral textures in massive sulphide deposits deformed under a low grade regime. As a result, the Granduc ores are massive and compact, unlike the sandy, pyritic deposits at Anyox and Cyprus. Vokes (1969, p. 129) has indicated that the pyritic Bleikvassi deposit displays "Durchbewegung" fabric, like the Granduc deposit, where pyrrhotite is an abundant ore constituent.

As Vokes, and many others have pointed out, a banded structure is common to most sulphide ores, and is generally oriented parallel to bedding or country rock stratification, and is an essential characteristic of metamorphosed "kieslagerstätten" ore deposits.

Alteration

There are no apparent macroscopic, or microscopic alteration features related to the massive sulphide lenses in the ore zones at Granduc. Calc-silicate lenses are found within the ore as well as throughout the cataclasite zone at the Granduc property. Tourmaline is found as clasts in the mineralized areas as well as in the footwall phyllonite unit and like the widespread calc-silicate minerals has no direct spatial relationship to the ore. Brecciated remnants of dykes and small plutons have been mapped in segments of the ore horizon, but these appear to be spatially restricted and unrelated to both the ore zones, calc-silicates, and tourmalinized wall rock. The apparent absence of an alteration halo may be a result of cataclastic deformation in the ore horizon, but it may also be construed as evidence of ore genesis.

Ore Genesis

The Granduc ore deposit comprises a series of concordant massive sulphide lenses localized within a complex sequence of volcanic-sedimentary rocks that have been deformed by cataclasis. Norman and McCue (1966) have suggested that the orebodies occur in a folded metasedimentary sequence where they have been formed as a result of mineralizing fluids channeled along a swarm of andesitic dykes. They suggested that the introduction of chalcopyrite was preceded by the formation of abundant magnetite, epidote, actinolite, small amounts of garnet and tourmaline. Also, the presence of biotite in the phyllonites has been interpreted as an alteration halo possibly related to the migrating solutions which have associated with nearby dioritic plutons. Norman and McCue (1966) have classified the Granduc deposit as a pyrometasomatic stringer-lode, while others (Ney, 1966, White, 1966) have referred to it as a sulphide lode, or lode deposit. Because of extensive destructional deformation along the South Unuk cataclasite zone original structures and textures, and relationships between the ore and the country rocks have been obscured. As a result, any genetic interpretation regarding the Granduc orebodies must rely on more indirect evidence than normally presented.

The intimate association of apatite, magnetite, calcite, and calc-silicate minerals in the ore horizon and country rocks suggests an indirect relationship worth investigating. The normal range of apatite in igneous rocks, according to Grobler and Whitfield (1970) is from 0.1 to 1.0 per cent by volume. They indicated that in olivine-apatite-magnetite bands in the Villa Nora deposit, in the Bushveldt Igneous Complex, magnetite averaged 20 per cent, and apatite 22 per cent by volume. Philpotts (1967) has summarized the literature on magnetite-ilmenite-apatite occurrences, and suggested they appear to be restricted to certain alkaline complexes and to the anorthosite suite. He concluded that these minerals were derivatives of fractional crystallization and were formed at minimum temperatures of 850° to 1000° C. Magnetite-apatite deposits are also well known in the Palabora area of northeast Transvaal where they occur as veins and disseminated deposits in pyroxenite, and syenite, and near carbonatite complexes (Schwellnus, 1938; Russel and others 1954; Haughton, 1969). Naldrett and others (1970) have also indicated the widespread occurrence of magnetite-apatite-hypersthene as a cumulus layer within the oxide-rich gabbro in the Sudbury irruptive.

At the Granduc property, the magnetite-apatite-calcite mineral assemblage occurs within the mile wide South Unuk cataclasite zone as thinly banded layers intercalated with calc-silicates, limestone bands up to 20 feet thick, graphitic quartzo-feldsphathic cataclasites, and the massive sulphide lenses. Thin section studies of these rock units show that apatite comprises up to 25 per cent by volume in the calc-silicate layers, and averages about 10 per cent in most of the rocks. Bulk analyses of country rocks outside the ore zone indicate an average composition of about 4.4 per cent total Fe, 2.42 per cent $Ca_3(PO_4)_2$, 0.02 per cent Cu, 0.008 per cent Pb, and 0.005 per cent Zn.

The initial evidence from the Granduc rocks suggests that the magnetite-apatite-calcite zones are random within the local sequence and have not been concentrated as veins related to alkaline, or carbonatite masses, or to basic intrusives. This lack of any specific spatial relationship is assumed to imply the possibility of a sedimentary origin, and concentration of iron-and phosphorous-rich material in close association with organic-rich sediments and carbonates.

In regard to the pyrometasomatic origin of the Granduc ore as postulated by Norman and McCue (1966), Bartholomé (1971) has suggested that, "we should recognize clearly in geology there is nothing which can be called a complete proof - arguments make one theory more probable than another". Bartholomé (1971) outlined eleven points, or geological features, that should be regarded before making the assumption a given skarn-like body results from metasomatic transformation of carbonate rocks - conversely that it resulted from the isochemical transformation of a pre-existing iron-rich rock. The calc-silicates, and massive sulphide ore at Granduc cannot be directly related to either granitic or dioritic intrusive contacts, and because of the extensive cataclastic deformation which has affected the mine area Bartholomé's other nine points cannot be applied.

A hydrothermal origin of formation has been considered for the Granduc mineralization, and has had a few proponents, but again direct evidence appears to be lacking. As previously indicated, Granduc massive sulphide ore, like Anyox ore, has a gangue to sulphide ratio of approximately 1 to 1, even including country rock breccia. Hydrothermal veins in the study area have a minimum gangue to ore ratio of 500 to 1, and the Silbak Premier system which is known in detail has a gangue to sulphide ratio of 700 to 1. The possibility of metamorphic dispersal of the gangue from the sulphide has been entertained by the writer, but this appears to be unlikely for specific reasons. It has been suggested by the writer that the mobility of both sulphide and gangue material is very limited under conditions of a low grade metamorphic environment, and secondly, there are no significant quartz or quartz-carbonate veins in the Granduc area.

Other metamorphic concepts regarding the formation of massive sulphides include Belevstev's (1971) suggestion that metamorphogenic sulphide deposits could form under conditions of regional dynamothermal metamorphism (ultrametamorphism) by migration and concentration. He indicated that the ore minerals would usually be attracted to zones of brecciation, cataclasis, and mylonitization of less compact metamorphic rocks. Boyle (1968) proposed that mobilization, or lateral secretion, during metamorphism,proceeded by diffusion, but he assumed that in general gangue minerals such as quartz, would form a large portion of such deposits.

Regarding the Granduc ore, the absence of a high grade regional metamorphic environment, and of significant gangue associated with the sulphides precludes current lateral migration concepts.

After considering various theories for the origin of massive sulphides, and the evidence available to the writer at Granduc, it is apparent that a volcanogenic-sedimentary concept currently provides the best approach. As Krauskopf (1970) has suggested, most of the world's major ore deposits have been subjected to many proposals of origin, singly or in combination. Krauskopf also noted that the association of massive sulphide deposits with volcanogenic-sedimentary processes eliminates the enrichment stage generally related to hydrothermal and other processes, and also provides a metal source directly in magma. The volcanic-sedimentary sequence in the Granduc area forms part of the middle member of the Unuk River Formation and has been described in detail in Chapter 3, and illustrated on Figure 13. Clues to possible genesis of the Granduc mineralization can be found in the local stratigraphic sequence and in the wall rocks.

Very briefly, the strata in the vicinity of the Granduc deposit comprise a variety of gypsiferous grey limestone lenses, graphitic marine siltstones, volcanic sandstones, lithic and crystal tuffs, cherts, quartz conglomerates, and volcanic conglomerates. This sequence overlies thick shallow water, submarine pillow lavas, rhyolite flows, cherts, and various volcanic sediments. North and south of the Granduc property the complex stratigraphic sequence at the mine grades rapidly into thick epiclastic volcanic conglomerates and intercalated marine sediments. This, in summary, outlines the local lithologic succession.

In Chapter 3, the writer speculated that the strata in which the Granduc massive sulphide lenses occur represents a sequence of shallow water marine, possibly brackish, near shore, or restricted basinal deposits. The original rock assemblage at Granduc is assumed to have included primary calcite, organic matter, iron oxides, gypsum, and phosphate. It appears likely that there was significant acid volcanism active during the deposition of the sedimentary assemblage in the Granduc area.

On the basis of the stability field diagram for iron oxides (Krumbein and Garrels, 1952), the writer assumes that the lithologic assemblage at Granduc was deposited in a restricted, shallow marine environment marked by a low negative Eh, and a pH at or about 7.8. Apparent cyclic deposition in this basin which is evidenced by alternating apatite-magnetite, calc-silicate, limestone, and quartzo-feldspathic lithology, possibly represented fluctuations in the acidity of the basin (Sakamoto, 1950). Periodic incursions of volcanically derived materials are also represented in this basin sequence by the tuffaceous sediments. The massive sulphide lenses at Granduc are present in a 400 foot thick portion of this complex sequence by a series of overlapping lenses separated by originally unmineralized basin sediments. The evidence suggests that these widely separated sulphide layers were formed periodically within this thin zone. The probability that massive sulphide deposits related to volcanic-sedimentary sequences have been generated by related volcanogenic processes has been generally accepted. The evidence at Granduc suggests a related sedimentary-volcanogenic origin possibly analogous to other well known deposits.

Comparison of Granduc with other Deposits

The relatively unmetamorphosed Kuroko-type deposits of Japan (Tatsumi, 1970, and others) provide a ready model for bedded sedimentary sulphides related to submarine volcanic processes (Ohashi, 1962), and formed under conditions of nearly neutral pH and low Eh (Horikoshi, 1965). Sato (1968) concluded that mineralization at the Kosaka mine formed on a rather shallow sea bottom, 100 to 200 meters in depth, where the basin was bounded by a barrier to the open sea, although linked through channels. A comparison of the chalcopyrite-rich sulphide lenses at Granduc to Japanese deposits indicates a similarity to the yellow, massive, cupriferous iron sulphide Oko ores (Matsukuma and Horikoshi, 1970). The Oko ores are apparently transitional between siliceous breccia-ores, and the sphalerite and galena-rich Kuroko ores. This distinction is not as readily made at Granduc, although on the basis of current evidence there is an indication that galena and sphalerite are mainly concentrated in the "A" and "Ch" zones which stratigraphically lie at the top of the ore horizon. The "B" and "F" footwall zones at Granduc, like Kuroko deposits, include a higher proportion of pyrite and siliceous material than the overlying zones. Matsukuma and Korikoshi (1970) have also noted that gypsum deposits which are spatially related to Oko ores have never been found directly adjacent to acidic volcanics, but are generally associated with small lenses of silicified rocks. Apparently, these rocks have commonly been mistaken for rhyolite, but actually represent silicified pyroclastic zones. At Granduc, siliceous ultramylonite lenses which have been previously described are intimately related with the massive sulphide lenses and are comparable in size and extent to the siliceous zones related to Oko ores.

The Granduc ore horizon lies within a sequence marked by abundant graphite and carbonate. As Kajiwara (1970) has noted there are no known occurrences of graphite associated with Kuroko deposits and no carbonate minerals in Kuroko ores. Calcite is a common minor gangue mineral in the Granduc sulphide lenses and graphite is characteristic of the footwall phyllonite country rocks. It appears that although the general ore environment at Granduc compares to certain Kuroko features there are significant variations which imply a somewhat different ore genesis.

Discussion

Dunham (1971) has concluded from his study of base metal sulphide deposits that, other than the pyritic deposits, they have not formed by syngenesis except where hydrothermal or fumarolic activity with the associated enrichment of sea water is in progress, and where biogenic or volcanogenic sulphur is available. Watanabe (1970) has also stressed the physical evidence for the formation of recent iron oxides and iron sulphides in great quantities along the shores of volcanic islands, subaquatic sulphur and iron sulphides in terrestrial volcanic districts, and sulphur with iron sulphides related to subaquatic fumarolic action in lakes near hot springs. Watanabe (1970) suggested that as a result of the development of the syngenetic "volcanic-sedimentary theory", outlined by Niggli and Schneiderhohn, the "kieslager" type in the Sanbagawa metamorphic belt was recognized as being localized within restricted stratigraphic horizons.

Lambert and Bubela (1971) as well as others have studied the various processes leading to the formation of banded sedimentary sulphide ores. In these experiments (Bubela and McDonald, 1969; Lambert and Bubela, (1971) the pH of the suspension was held between 7 and 8, and the aqueous sodium sulphide solution was inoculated with the sulphate-reducing organism <u>Desulfotomaculum</u> nigrificans. As Duncan and Bruynsteyn (1971) and others working in low temperature bacterium enriched systems have emphasized, the sulphate-fixing bacterium requires nutrients in order to promote cell growth. Both nitrogen and phosphorus are essential to organic growth, and to the activity and regeneration of these organisms. Nitrogen is generally available as the NH_4^+ ion, and phosphorus, which supports the primary function of storing and transferring energy, is required as the phosphate.

At Granduc, phosphate is now represented by abundant apatite in both the ore horizon and the country rocks, and appears to have been present in more than adequate amounts to promote bacterial growth, and perpetuate the bacterial sulphate-fixing cycle in the sedimentary-volcanic sequence.

The writer concludes, and speculates, that the concordant Granduc massive sulphide ore represents deformed syngenetic sulphide deposits. These deposits were probably formed in a restricted, shallow marine, sedimentary-volcanic environment where sedimentation was accompanied by hydrothermal or fumarolic enrichment of metal, and where biogenic sulphur was available.

Porphyry Deposits

Porphyry Molybdenum Deposits

Molybdenite ore is currently being mined from the Lime Creek stock south of Alice Arm by the British Columbia Molybdenum Company. Current production is at 6,000 tons per day by open pit methods which produce about 6.1 million pounds of MoS_2 per year. The ore grade is about 0.23 per cent MoS_2 and reserves are estimated at about 40.1 million tons.

The Tertiary Lime Creek quartz monzonite stock, described in Chapter 3, is one of a group termed the Alice Arm Intrusions, all of which bear a close petrological resemblance and all of which have been noted to have molybdenite as an accessory mineral. The Alice Arm Intrusions are part of an extensive belt of Tertiary quartz monzonite stocks that parallel the eastern margin of the Coast Plutonic Belt in British Columbia. Associated plutons are known in the southwestern Yukon Territory, and to the south form a northwesterly trending belt of Montezuman age, differentiated, molbydenite-bearing quartz porphyry stocks in the western United States. G. Pouliot (pers. comm.) has recently studied the producing mines in this belt of Tertiary stocks from Alice Arm to Montana, and has been impressed with their similar petrogenic characteristics. In the Stewart Complex, and northwestern British Columbia the age of these stocks has been determined by potassium argon methods as about 50 to 52 million years, while the Urad stock in Colorado (private reports) has a radiometric age of about 20 million years.

Porphyry Copper - Molybdenum Deposits

These complex deposits are characterized by their large size, complex geological environment, and the presence of both copper and molybdenite mineralization. The major example of a low grade disseminated mineral zone in the Stewart Complex is the Mitchell-Sulphurets property north of the Granduc mine (Fig. 2A). The deposit is a chalcopyrite-pyrite-bornite, and molybdenite replacement feature spatially related to a differentiated syeno-diorite stock and dyke complex. Major features indicating large scale replacement are the alteration haloes of porphyroblastic microcline, pyrite, quartz, and sericite in the country rocks enveloping the stock. The country rocks include preferentially altered and replaced Lower Jurassic volcanic conglomerates, and less altered volcanic breccias and sandstones. Both the mineralized zone and the intrusives have suffered deformation and erosion. The mineralized zone is unconformably overlain by part of the Middle Jurassic Betty Creek Formation which in turn has been faulted, eroded, and is disconformably overlain by the Middle Jurassic Salmon River Formation strata.

The significant features concerning this extensive deposit are the alteration zones. At the present it is assumed that the potash feldspar alteration represents the early widespread hydrothermal alteration phase. Subsequent sericite and quartz alteration was restricted to the northeast margin of the zone where the country rocks have been pervasively altered to a sericitic, quartz stockwork. Meyer and Hemley (1967) have suggested that this common reaction can be represented by the following equation:

$3KAlSi_3O_8 + 2H^+ \longrightarrow KAl_3Si_3O_8(OH)_2 + 2K^+ + 6\ SiO_2$ (1) or quartz can be derived directly:

$3KAlSi_3O_8 + Si(OH)_4 + 12H^+ \longrightarrow 12SiO_2 + 3Al^{3+} + 3K^+ + 12H_2O$ (2)

Quartz appears to have been partially formed by sericitization of K-feldspar and deposited as quartz veins along the east margins of the zone. Extensive, massive quartz emplacement at the north side of Mitchell Glacier suggests a major hydrothermal, possibly primary replacement of the country rocks. Talc schists developed along parts of the eastern hydrothermal aureole appear to have been formed as a result of local deformation related to plutonism.

Metallogenic Epochs in the Stewart Complex

The complexity of the tectonic evolution of the Stewart Complex, as well as the great abundance of mineral deposits in the area, has generally hindered the development of metallogenic concept for the region. The metallogenic epochs presented below are directly applicable to the Stewart Complex but could be adapted to an overall metallogenic hypothesis for the Western Cordillera.

Epoch 1. Upper Triassic - Copper, magnetite

Epoch 2. Lower Jurassic - Copper, molybdenum, gold, silver

Epoch 3. Middle Jurassic - Copper, gold, silver, lead, zinc

Epoch 4. Late Jurassic-Cretaceous - Copper, lead, zinc, gold, silver, antimony, arsenic

Epoch 5. Tertiary - Molybdenum, silver, lead, zinc, tungsten

Epoch 1

One type of mineral deposit characterizes the Upper Triassic mineralization in the Stewart Complex. This is a massive magnetite-chalcopyrite occurrence located on the north side of McQuillan Ridge in the Unuk River area. The Max deposit has not been studied in detail because of poor exposure and limited diamond drill core information. The ore appears to be confined to the anticlinal crest of a folded granular limestone sequence which has been partially intruded and weakly deformed by a Late Triassic quartz diorite intrusion. Physically the Max deposit is a conformable, stratabound massive oxide-sulphide deposit. Speculation by the writer generally suggests that this has been formed by sedimentary-volcanogenic syngenetic processes, rather than by the commonly accepted contact metamorphic process.

Epoch 2

The Lower Jurassic deposits in the Stewart Complex include simple fissure veins which exhibit high gold-low silver ratios, hydrothermal replacement porphyry-type copper-molybdenum deposits, and the conformable cupriferous massive sulphide deposits at Granduc Mountain. Structural and stratigraphic evidence indicates that these various classes of deposits were all formed during the Hettangian to Toarcian stages prior to Aalenian or early Bajocian orogeny.

Epoch 3

Characteristic Middle Jurassic mineral deposits of this epoch include gold-silver fissure veins, vein-replacement mineralization characterized by the Silbak Premier deposits, and stratiform cupriferous pyritic deposits localized in the Anyox area. The simple fissure vein, and transitional vein-replacement deposits are characterized by low silver-gold ratios, and have been correlated with closely related Middle Jurassic granitic intrusion, and acid volcanism.

Epoch 4

These deposits are generally fissure vein, or localized replacement deposits spatially related to the margins of minor intrusions. None of these deposits has produced significant tonnage.

Epoch 5

These deposits are characterized by high silver-low gold fissure and vein-replacement deposits, porphyry deposits, and minor contact skarn deposits. The Torbrit silver mine at Alice Arm is the most productive member of the vein class, and the British Columbia Molybdenum mine at Lime Creek characterizes the Tertiary porphyry deposits. Significantly, there are no known major mineral deposits found in the local Hyder pluton, the large satellitic granitic bodies, or in the gneissic segment of the Coast Plutonic Complex.

Discussion

The metallogenic scheme developed by the writer for the Stewart Complex indicates that the products of mineralization from the Late Triassic to Tertiary periods have an overall similarity as a result of comparable genetic processes, but they are marked by certain distinct features. One feature which readily characterizes the groups of deposits is the silver-gold ratios in the ores. As the writer indicated earlier in this chapter, the Stewart Complex exhibits broad metal zoning (Fig. 23) which can be directly related to metallogenesis. The Upper Triassic and Lower Jurassic vein deposits are recognized by high gold-low silver ratios, the Middle Jurassic vein deposits exhibit low silver-gold ratios of about 30:1, and the younger Jura-Cretaceous and Tertiary deposits are indicated by high silver to gold ratios. At the Torbrit deposit for example, the silver-gold ratio is about 100,000:1, and the Dolly Varden ratio is about 1,400,000:1.

As a general rule, the vein deposits in the Stewart Complex are recognized by the high gangue to sulphide ratio, which at the Silbak Premier was about 700:1, and is even higher in the less productive fissure vein systems. The various massive sulphide deposits are characterized by a low gangue to sulphide ratio of 1:1 or less which appears to be locally indicative of a syngenetic volcanic-sedimentary environment. The gold-silver ratios of the volcanogenic massive sulphide ores range from about 30:1 to 60:1 which is approximately the same as the values calculated for the vein-replacement deposits (e.g., Silbak Premier) related to a plutonic-volcanogenic environment.

The evolution of the Stewart Complex has been characterized by repeated periodic volcanism, sedimentation, plutonism, uplift, and erosion.

Within this orogenic cycle metallogenesis, related to volcanic, sedimentary, and plutonic processes during each major tectonic phase, has combined to produce broad mineral zoning, and a large array of mineral deposits which represent minor phases within the broad evolution of the Stewart Complex, and which have served to characterize this portion of the Western Cordillera.

Contributions to Knowledge

1. Glaciation

Studies presented in this thesis have aided in understanding glacial processes such as ablation, jokulhaup, glacial surges and certain landslide phenomenon in the western Cordillera.

2. Lithology

A large area of the western Canadian Cordillera has been mapped in some detail for the first time. The relationships between Mesozoic volcanism, sedimentation and plutonism, expressed as interrelated pulses has been applied to a concept outlining the development of certain Mesozoic successor basins.

Part of the extensive Coast Plutonic has been studied and its composition as well as its role in local and regional geologic development has been enhanced. The recognition of an extensive satellite pluton belt and the implications in terms of the tectonic concept of the western Cordillera has been presented.

3. Stratigraphy

The problem of the Hazelton Group and its implications in terms of the western Cordillera have been solved for the present. The Takla problem has been placed in a position of lesser confusion.

The Bowser Group has been shown to be an invalid concept and discarded. It has been replaced by defining the Hazelton Group as a succession of recognizable formations.

4. Metamorphic Geology

Four major cataclasite zones have been identified. The role of these zones in terms of tectonism, plutonism and mineralization has been outlined or detailed.

5. Structure

The role of vertical tectonics in the development of a Mesozoic successor basin has been outlined. The timing of tectonic events such as folding, cataclastic deformation, and faulting has been detailed.

6. Economic Geology

a. The position of several hundred mineral deposits, localized within the boundaries of the Stewart Complex, have been studied and related to a metallogenic concept.

b. Metal zoning has been shown to be related to successive epochs of mineralization and is displayed in relation to tectonic development.

c. Major mineral deposits have been restudied or studied for the first time and pre-existing concepts have been shown to be invalid. Massive sulphide deposits such as the Granduc and Anyox, previously considered pyrometasomatic, have been described for the first time as volcanogenic-sedimentary products controlled by distinct geological parameters. The nature of these major deposits has been shown to be somewhat similar to accepted models, but sufficiently different to warrant their classification as models for Mesozoic massive sulphide deposits in the western Canadian Cordillera.

d. The Silbak Premier replacement vein deposit has been represented as a product of Middle Jurassic plutonic-volcanic processes. The localization of this mineralization within a pre-existing catoclasite zone has been demonstrated, and has been described as an unusual telescoped deposit.

e. Six epochs of mineralization have been identified and related to plutonism, plutonic-hydrothermal, plutonic-volcanic, volcanic and volcanic-sedimentary processes. Types and classes of mineralization have been indicated as repetetive, but marked by distinct metal ratios.

Suggestions for Further Work

1. Delineation of plutonic-volcanic episodes in part of the western Canadian Cordillera would be a valuable addition to regional tectonic-mineralalogenic concepts as well as to further definition of regional geochronology. Radiometric age studies on certain materials from the Stewart Complex would be useful to this end.

2. The realization of distinct zones or belts of syenite plutonism in northwestern British Columbia has been recent. These rocks are generally poorly documented in regards to their place in the tectonic plutonic framework and in terms of related mineralization. The problem of the syenites is akin to the greater anorthosite problem but is probably more readily approached.

3. A detailed analysis of the South Unuk cataclasite zone would assist in understanding deformation of inhomogeneous rock masses. At Granduc Mountain the cataclasite zone is well exposed at surface and underground over a large area, and up to 7,000 feet vertically. This situation appears to offer a unique opportunity for detailed structural analysis.

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Appendix I

Stratigraphic Sections

Section 1

Unuk River Formation (Map-unit 12)
Upper Member

Section was measured at Tim Williams Glacier (Unuk River map sheet). It is exposed on the northeast limb of a broad northerly trending anticline. The uppermost beds are unconformably overlain by sedimentary beds of the Salmon River Formation. The lower contact with the middle member of the Unuk River Formation is obscured by permanent ice and snow.

Unit		Thickness (feet) Unit	Total from base
	Salmon River Formation Unconformity		
7	Shale, silty shale and siltstone; monotonous succession, thinly laminated; interbedded with stringers of very fine grained sandstone and silty argillite. Shale comprises 60% of the unit, silty shale 20%, sandstone 15%, and argillite 5%. Sandstone and argillite occur as beds less than 1 foot thick throughout the sequence. Silty shale is olive-green, weathers gray, angular blocky fragments, limonitic stain general. Abundant fossil fragments.	1,200	3,840
6	Graywacke, with intercalated subgraywackes, siltstone and silty argillite; light to medium salt-and-peppery gray, medium grained, medium to light greenish gray, weathers darker gray with limonitic stain. Blocky fragments,fissile argillite weathers to platy blocks. Abundant fossil fragments form coquina within graywacke beds.	120	2,740
5	Andesitic to dacitic lapilli and lithic tuffs, olive-green, maroon, and light gray, well-bedded, locally a foot or two in thickness, mainly lack distinct units. Covered for most part by andesitic debris and shows as isolated outcrops. Bedding down to one half inch in thickness where exposed. Generally siliceous alteration, some pyrite.	210	2,620

4	Volcanic breccia and agglomerate interbedded with tuffaceous graywacke which is medium dark-gray, composed of lithic fragments, mainly andesitic. clasts dark green to gray fine grained amygdaloidal andesite, angular to subrounded, 1/2 inch to 4 inches in diameter, poorly sorted, with obscure bedding, generally appears massive and structureless. Matrix tuffaceous andesite with interbedded fine grained lithic tuffs forming beds locally 1 to 2 feet thick.	1,000	2,410
3	Interbedded tuffaceous graywacke and quartz granule conglomerate. Partly covered, intermittent outcrops, 1/2- to 3 foot beds with flat, regular bedding planes, and no obvious partings; weathers dark gray. Graywacke comprises 75%, pebble conglomerate 25%. Quartz pebble conglomerate prominent near base, very well-sorted having a mean of 1 inch and rarely over 1 1/4 inches or under 3/4 inches across.	410	1,410
2	Interbedded tuffaceous graywacke and quartz pebble conglomerate. Partly covered limonitic stained outcrop, well-bedded, 1/2- to 4 foot beds with flat, regular bedding planes, no obvious partings. Blocky, dark weathering, graywacke 50%, quartz pebble conglomerate, 50%. Pebble conglomerate well sorted, quartz pebbles well-rounded. Fossil fragments locally abundant. Matrix quartz-rich near base, decreasing upward and replaced by medium grained graywacke.	600	1,000
1	Polymictic conglomerate, well rounded boulders and cobbles hornblende granodiorite, with andesitic and basaltic pebbles; thick bedded; sandy dark graywacke as matrix. Coarse grained, thick bedded dark graywacke intercalated within predominantly conglomeratic sequence; 4 to 6 foot beds; gradational into overlying conglomerates. Abundant moderately well preserved fossil fragments.	400	400

Unconformity

Section 2

Unuk River Formation (Map-unit 11, 12)
Middle Member

The composite section was measured in the Twin John Peaks - Mount Madge, and Mount Einar Kvale - Mount George Pearson areas. The succession is partly obscured by permanent ice and snow. These rocks are unconformably overlain by the upper member in the Tim Williams Glacier area as well as by members of the Betty Creek and Salmon River Formations in the Unuk River area. The base of the section is exposed at Twin John Peaks where it unconformably overlies the lower member of the Unuk River Formation.

Unit		Thickness (feet) Unit	Total from base
Unconformity			
13	Interbedded volcanic sandstone, limestone, tuffaceous graywacke, lithic and crystal tuff, quartz pebble conglomerate, chert and rhyolite. The unit is marked by its diversity, and by the discontinuity of the individual members. Volcanic sandstones constitute about 60% of the thickness. Sandstone is typically grayish green, salt-and-pepper appearance in thin to medium beds which often exhibit channeling. Limestone is medium grained, granular white to bluish gray, forming discrete lenses a few inches to tens of feet thick. Tuffs are greenish gray, rarely red or maroon, graded 2- to 10-inch beds, generally andesitic, and intercalated with gray planar bedded tuffaceous graywacke. Chert and rhyolite are thinly banded gray with intercalated quartz sandstone, forming beds 2 inches to several feet thick. Argillaceous siltstone forms thin shaly partings within the various members throughout the unit. Incipient schistosity is general and hornfelses developed adjacent to plutons. Graphite, pyrite, and ankerite are typical alteration minerals, and limonite stain widespread. Fossil fragments rare.	1,000	19,600

12	Gracey Creek limestone member, medium to coarse grained, mottled buff to blue-gray, massive, rare shale partings, no evidence of fossil debris, gray weathering.	600	18,600
11	Volcanic sandstone, andesitic tuff, argillaceous graphitic siltstone, limestone, chert and rhyolite with sandstone comprising up to 40% of this complexly interbedded unit. Limestone as recrystallized, gypsiferous lenses a few inches to several tens of feet thick form up to 30% of the unit. Thinly banded, altered rhyolite and gray chert lenses comprise 20% of the unit. Thinly laminated andesitic crystal and lithic tuff, and dark siltstone form partings throughout the sequence. Deformation has produced incipient schistosity. Most members recrystallized, generally altered and variably hornfelsed. Fossil fragments rare.	2,500	18,000
10	Pillow lava, extensively altered, variably hornfelsed, generally andesitic. Cherty quartz sandstone, siltstone, and limestone as lens-like partings a few inches to several feet thick form less than 10% of this generally massive unit. Generally dark green in colour, weathering medium green.	3,000	15,500
9	Volcanic conglomerate, clasts subangular to subrounded, and comprise 90% andesite, 5% volcanic sandstone, and 5% volcanic siltstone as partings. Massive, medium to light green, weathering dark green. Variably schistose, hornfelsed and marked by irregular mineralization, including scattered magnetite-rich zones.	3,000	12,500
8	Volcanic sandstone, siltstone, conglomerate and some breccia interlayered,in about equal amounts. Light to dark green, massive, locally marked by shaly partings, generally appears structureless. Clasts, and matrix generally andesitic, variably schistose and hornfelsed.	2,000	9,500
7	Pillow lava, variably altered, generally massive, andesitic with rare chert, quartz sandstone and siltstone partings. Dark green, weathers medium green, pillows outlined by altered rims.	3,000	7,500

6	Siltstone, medium olive green to gray brown on surface, mainly thin bedded, weathers to chips, a slope former. Weakly schistose or hornfelsed.	400	4,500
5	Pillow lava, olive-green, weathers medium green, massive, rare chert partings, generally altered, probably andesitic. Hornfelsed and indurated near intrusive contacts.	900	4,100
4	Volcanic conglomerate and graywacke interbedded; conglomerate clasts subangular to subrounded and comprise 90% andesite, 10% graywacke and siltstone. Conglomerate matrix poorly sorted andesite clasts. Medium green, weathering gray to brown. Variably schistose and irregularly altered, and hornfelsed.	1,500	3,200
3	Siltstone, somewhat argillaceous, pencil-weathering, medium olive-gray, weathering light gray, weakly schistose, variably indurated, slope forming unit.	500	1,700
2	Interbedded thinly banded rhyolite, rhyolite breccia, feldspathathic and quartz sandstone, and cherty spherulitic rhyolite. Pink to greenish gray, white weathering; nodular structure well developed in cherty rhyolite, block mosaic typical of breccia lenses; sandstone forms laminations and matrix in spherulitic rhyolite. Rhyolite 80%, with 20% sandstone. Irregular alteration	400	1,200
1	Siltstone, mainly black, thin bedded, with minor irregular beds and lenses of light to medium gray siltstone. Grades upwards into fine-grained graywacke. Generally carbonaceous, variably graphitic, hornfelsed near intrusions. Planar bedding well developed, laminae 1/4 inch to 2 inches marked by colour banding. Fossiliferous at base of unit.		
	Unconformity	800	800

Section 3

Unuk River Formation (Map-unit 12)
Lower Member

Section was measured along the axial zone of a major anticline between Treaty Creek and Jack Glacier, and from West McTagg Glacier to Twin John Peaks. Base of the section is obscured by ice and snow and the section is overlain unconformably by the Middle Member of the Unuk River Formation.

Unit		Thickness (feet) Unit	Total from base
Unconformity			
15	Volcanic conglomerate (70%) with interbedded lithic tuff (30%) form resistant ridge; clasts dominantly greenish gray andesite, angular to subrounded, 1/2 inch to 8 inches across; poorly sorted crudely stratified with erratic augite basalt clasts to 6 inches. Fine grained tuff alternating red/green, planar bedding, channel features prominent	800	28,900
14	Rhyolite, rhyolite breccia, light gray to pink-buff, weathers white; ribbon banding, and pavement mosaic typical; flows banding irregular; forms cliffs.	50	28,100
13	Volcanic conglomerate, volcanic sandstone with 20% siltstone, interbedded with lesser thin augite basalt flows. Clasts dark green, 1/2 inch to 4 inches, andesitic with andesitic clastic matrix. Sandstone, thinly banded red/green, medium grained, planar bedded. Siltstone thinly laminated, colour banded, gray/olive, weathers gray. Basalt dark, weathers green, limonite stain. Fossils.	150	28,050
12	Conglomerate, polymictic; clasts 40% hornblende quartz diorite, well rounded boulders, cobbles, pebbles, basalt cobbles and pebbles 25%, quartz and chert pebbles and cobbles 10%, matrix red sandstone, Poorly sorted, chaotic crossbedding, poorly stratified. Striking red colour, forms craggy spires.	500	27,900
11	Volcanic sandstone, siltstone, and tuff, interbedded; sandstone gray to green, medium grained, indistinct layering; shaly partings; siltstone gray/black, planar bedding, members 1 - 3 feet thick, intercalated with sandstone; tuff red, maroon to green, regular, even 4 inch to 16 inch planar bedding.	900	27,400

10	Volcanic conglomerate, siltstone, interbedded; clasts angular andesite, minor basalt; thin andesite lenses interbedded; siltstone fine grained gray/green, thinly laminated. Conglomerate 70%, siltstone 25%, flows 5%. Limonitic stain, variably pyritic, indurated.	1,700	26,500
9	Rhyolite, ribbon chert; gray to pinkish, white weathering; thinly laminated; irregular pavement breccia in lower member.	200	24,800
8	Siltstone, black/gray, thinly laminated, fissile, pencil-weathering. Forms slope.	300	24,600
7	Graywacke, siltstone, argillite, interbedded; gray/black; some indistinct layering; flaggy weathering siltstone and argillite, blocky graywacke; thin bedded from 1/2 to 10 feet thick with argillite partings.	1,800	24,300
6	Volcanic breccia, sandstone interbedded with lesser amounts of andesitic lava, minor thin basalt lenses; clasts angular, dark green fine grained andesite. 1/2 inch to 2 feet, poorly sorted, crudely stratified, thick beds poorly defined, generally massive appearance; sandstone, green, medium grained, angular, mainly andesite with 10 - 15% augite; lava dark green, black, generally porphyritic, massive, limonite stain.	1,500	22,500
5	Volcanic sandstone, graywacke, and siltstone interbedded; greenish gray; thin alternation of beds throughout unit; clasts mainly andesite; fossil fragments.	1,000	21,000
4	Volcanic breccia, 1/2 inch to 2 feet, angular to subangular clasts, greenish andesite in andesitic matrix; massive, structureless.	1,800	20,000
3	Interbedded monotonous succession volcanic sandstone, siltstone, shale and minor breccia, rare limestone; general gray green aspect; well bedded; 6 inches to tens of feet, rhythmic sequence marked by shaly partings; planar bedding typical, structures rare; fossiliferous at top and base.	15,000	18,200

2	Volcanic conglomerate, sandstone; gradational with overlying sandstone succession; massive appearance, thick bedded, shaly partings; gray green to olive green, brown weathering; blocky, cliff forming; limonite stained, pyritic, altered	1,000	3,200
1	Volcanic flows, breccia, interbedded; massive thick layered porphyritic and amygdaloidal andesitic flows; dark green, gray weathering, limonite stained, pyritic; breccia as intercalations, clasts to 3 feet, andesitic with andesitic matrix.	2,200	2,200

Base of formation not exposed.

Section 4

Betty Creek Formation (Map-unit 13)

Section measured at Betty Creek, on the south side, west of Betty Glacier. The uppermost beds are conformably to disconformably overlain by sedimentary rocks of the Salmon River Formation, and underlain unconformably by units of the upper member of the Unuk River Formation. Part of the succession is obscured by snow and talus

Unit		Thickness (feet) Unit	Total from base
Salmon River Formation Conformity - Disconformity			
4	Interbedded volcanic conglomerate and sandstone; dominantly brick red to maroon, mottled green to gray; clasts entirely greenish to olive green, fine grained to porphyritic andesite, angular to subrounded, 1/2 inch to 4 inches across; poorly sorted, moderately well stratified, crossbedding and oscillation ripples well developed in fine grained members; sandstone forms about 50% of succession, 95% medium grained angular andesite clasts; colouration imparted by iron oxide rich matrix in both conglomerate and sandstone; generally massive in overall aspect.	400	2,700

3	Interbedded volcanic sandstone and conglomerate; dominantly dark olive green to almost black; massive; apparently moderately indurated and variably hornfelsed; bedding indistinct; clasts mainly dark green andesite, with 1/2 to 2 inch angular fragments dominant; sedimentary structures other than planar laminations rare; scattered fossil fragments.	900	2,300
2	Interbedded volcanic sandstone and conglomerate; alternating red and green laminations, bedding planar; crossbedding and oscillation ripples common; clasts 1/2 inch to 4 inches, mainly andesite, up to 10% granitic fragments, thin red shaly partings common; matrix red or green andesite clasts, medium to fine grained; beds 6 inches to 3 feet thick; compact, weakly indurated, ridge forming member; scattered fossil fragments.	1,100	1,400
1	Red volcanic sandstone 80%, conglomerate 20%; massive, beds 3 to 6 feet thick; crossbedding frequent; clasts dominantly dark green andesite, matrix andesitic with abundant oxide which imparts overall colour.	300	300

Appendix II

FOSSIL LOCALITIES

TAKLA GROUP

(Identifications by E.T. Tozer)

Report on Triassic Fossils from the Unuk River Area, Stikine River Map-Area, Cassiar District, Northern British Columbia, submitted by G.W.H. Norman, Newmont Mining Corporation, 1961.

GSC loc. 44414. Elevation 5,000'. West side Harrymel Creek; lat.56°34'N, long.130°37'W.
- Aulacoceras sp.
- Age: Upper Triassic, probably Karnian

GSC loc. 44417. Elevation 4,500'. East slope McQuillan Ridge; lat.56°24'N, long.130°32'W.
- Halobia? sp.
- Age: Triassic, probably Upper Triassic

GSC loc. 44418. Elevation 4,500'. East slope McQuillan Ridge; lat.56°24'N, long.130°32'W.
- Halobia sp.
- Crushed ammonite, indet.
- Age: Upper Triassic

UNUK RIVER FORMATION

GSC loc. 44416. Elevation 5,550'. On ridge 2 miles south of toe of Treaty Glacier; lat.56°36'N, long.130°20'W. (Determination by E.T. Tozer)
- Psiloceras canadense Frebold
- Weyla sp.
- Pleuromya ? sp.
- gastropods
- Age: Hettangian

Field No. 67-F-7. Elevation 5,550'. On ridge 1.8 miles south of toe of Treaty Glacier; lat.56°36'N, long.130°20'W. (Determination by W.R. Danner)
- Indeterminate ammonite
- Weyla sp.
- Indet. gastropod
- Pleuromya sp.
- large pecten
- Lima sp.?
- Entolium sp.?
- Oxytoma sp.?
- Psiloceras canadense
- Horn corals, one form resembles Kraterostrobilos bathys Crickmay
- Age: Lower Jurassic. Collection similar to localities near Ashcroft, B.C.

GSC loc. 44413. Elevation 4,400'. West side Jack Glacier; lat. 56°35'N, long.130°21'W. (Determination by E.T. Tozer)

Weyla sp. indet.
Age: Early Jurassic

GSC loc. 44412. Elevation 4,300'. West side Jack Glacier; lat. 56°37'N, long.130°20'W. (Determination by E.T. Tozer)

Belemnoid fragments indet.
Pecten sp. indet.
Age: Probably Early Jurassic

GSC loc. 86264. Elevation 6,400'. West side of Twin John Peaks; lat.56°33'N, long.130°25'W. (Determination by H. Frebold)

Pelecypods
Weyla sp.
?Cardinia sp. indet.
Age: The genus Weyla is only known from Lower Jurassic beds. Identification of the species would probably enable a more precise age-determination. The material will be sent to Dr. Tipper who is a Weyla expert. At present I am suggesting a Hettangian or Sinemurian age.

GSC loc. 44419. Elevation 6,200'. West side of Twin John Peaks; lat.56°34'N, long.130°25'W. (Determination by H. Frebold)

Poorly preserved ammonites, Arieticeras? in shale.
Weyla sp. and other poorly preserved pelecypods in limestone.
Age: Early Jurassic, probably younger than GSC loc. 44416.

GSC loc. 86265. Elevation 4,400'. Southwest slope of Twin John Peaks; lat.56°31'N, long.130°26'W. (Determination by H. Frebold)

Pelecypods
Very poorly preserved pelecypods
?Weyla sp. (sent to Dr. Tipper)
Age: Probably Early Jurassic

GSC loc. 87061. Elevation 4,765'. East side of small unnamed glacier 4.5 miles south of Treaty Creek (Determination by H. Frebold)

Ammonoids
Dactylioceras sp. (fine ribbed)
Age: Not Cretaceous. The genus Dactylioceras is mainly characteristic of the Toarcian but some species occur already in the upper Pliensbachian (also in British Columbia). As there are no other guide-ammonoids in this collection the exact age cannot be determined at present. Upper Pliensbachian or Toarcian.

GSC loc. 44411. Elevation 5,000'. On ridge 1.5 miles east of King Creek; lat.56°31'N, long.130°42'W. (Determination by H. Frebold)

Belemnoid and pelecypod fragments indet.
Age: Probably Early Jurassic

GSC loc. 86261. Elevation 5,200'. On ridge 1.6 miles east of King Creek; lat.56°31'N, long.130°41'W. (Determination by H. Frebold)

Pelecypods
Numerous but very poorly preserved specimens. No species can be identified
Age: Possibly Middle Jurassic

GSC loc. 86273. Elevation 5,600'. On west ridge of Nickel Mountain; lat.56°44'N, long.130°35'30"W. (Determination by H. Frebold)

Ammonoids
Imprints and flattened specimens of Hildocerataceae in shale. Some specimens somewhat similar to _Haugia_ and related genera but no safe identification of genus can be made. Better material requested.
Age: Possibly Toarcian

BETTY CREEK FORMATION

(Determinations by H. Frebold)

GSC loc. 86263. Elevation 5,700'. North side Mitchell Glacier; lat.56°33'N, long.130°13'W.

Ammonoids
Sonninia sp.
?_Sonninia_ sp. indet.
Subfamily Graphoceratinae Buckman. A few more or less unsatisfactorily preserved specimens somewhat similar to _Graphoceras_

Belemnoids
According to Dr. Jeletzky - undeterminable

Pelecypods
Ostrea sp.
Pleuromya sp.
?_Trigonia_ sp.
Other poorly preserved fragments of pelecypods

Gastropods
Undeterminable

Age: Upper part of lower or middle Bajocian

SALMON RIVER FORMATION

(Determinations by J.A. Jeletzky and H. Frebold)

GSC loc. 69404. Elevation 3,440'. Divide Lake, east shore; lat.56°11'N, long.129°58'W.

> Generically indeterminate representatives of Trigoniidae of a general Jurassic or Cretaceous affinities
> Age and correlation: According to Dr. E.T. Tozer (personal communication) these generically indeterminate trigoniids could hardly be Triassic in age. They must therefore be of a general Jurassic or Cretaceous age. Cannot be dated any closer.

GSC loc. 69405. Elevation 4,300'. On Bear River Ridge, east of Long Lake; lat.56°07'N, long.129°58'W.

> Indeterminate belemnite-like Coleoidea
> Indeterminate pelecypods
> Age and correlation: Presumably Mesozoic. Cannot be dated any closer.

GSC loc. 69403. Elevation 5,000'. West slope of Mount Dillworth; lat. 56°09'N, long. 130°02'W.

> *Cylindroteuthis* (*Cylindroteuthis*?) sp. indet
> *Trigonia* (*Haidaia*?) sp. indet.
> Pelecypods, genus and species indet.
> Solitary corals, genus and species indet.
> Age and correlation: Presumably of the Middle (Bajocian or Bathonian) to early Upper (Callovian to early Oxfordian) Jurassic age but cannot be dated definitively because of extremely poor preservation of all fossils available.

GSC loc. 86260. Elevation 5,200'. West slope Mount Dillworth; lat.56°09' N, long.130°02'30"W.

> Pelecypods
> *Ctenostreon gikshanensis* McLearn (fragment)
> *Trigonia* aff. *T. guhsani* McLearn
> *Pecten* sp. indet.
> Other pelecypods too poorly preserved to warrant safe identification
>
> Belemnoids
> To Dr. Jeletzky
>
> Age: Probably middle Bajocian

GSC loc. 86259. Elevation 4,600'. East side Bruce Glacier; lat. 56°36'N, long.130°17'20"W.

Ammonoids
??Sonninia sp. indet.

Belemnoids
Undeterminable

Pelecypods
Trigonia sp. aff. T. guhsani McLearn
Similar to some of the Trigonias in 86267
?Ctenostreon aff. C. gikshanensis McLearn

Gastropods, indet.

Age: Probably middle Bajocian

GSC loc. 86267. Elevation 4,200'. Between Bruce and Jack Glaciers; lat.56°37'N, long.130°21'W.

Ammonoids
One fragment of a larger ammonoid. Undeterminable.

Belemnoids
According to Dr. Jeletzky - undeterminable

Pelecypods
Trigonia sp. Large specimens. Poorly preserved.

Age: Probably Middle Jurassic

GSC loc. 86268. Elevation 3,500'. On south slope of ridge 1.5 miles northeast of Tom McKay Lake; lat.56°40'N, long. 130°25'W.

Ammonoids
Poorly preserved imprints. Deformed. Undeterminable

Pelecypods
Inoceramus sp. indet.

Age: Jurassic

GSC loc. 86266. Elevation 3,650'. South end Tom McKay Lake; lat.56°36'N, long.130°31'W.

Ammonoids
Squashed and deformed specimens possibly belonging to the genus Kheraiceras Spath. As far as a comparison is possible these fragments seem to be similar to Kheraiceras species from the Smithers area, B.C.
Age: Early Callovian

NASS FORMATION

(Identifications by H. Frebold)

GSC loc. 69406. Elevation 1,600'. At Meziadin Lake, northwest side, along road; lat.56°07'N, long.129°22'W.

Buchia concentrica Sowerby
(?=*Buchia bronni* Rouillier)
large perisphinctid (?) ammonites
(referred to Dr. H. Frebold)
Cylindroteuthis (*Cylindrotheuthis*) sp. indet
Age and correlation: *Buchia concentrica* zone. Upper Oxfordian or Lower Kimmeridgian in terms of the international standard stages. In western British Columbia this zone occurs on the west coast of Vancouver Island in the upper part of Division A of Jeletzky (GSC Paper 50-37), in the lower part of the so called Eldorado Group in Taseko Lakes map-area (920) and in the unnamed Upper Jurassic rocks in Tatlayoko Lakes map-area.

GSC loc. 86269. Snowslide Range, west of Bell-Irving River; lat.56°38'N, long.129°46'W.

Ammonoids
One poor imprint of a small ammonoid. Undeterminable

Belemnoids
To Dr. Jeletzky

Age: Probably Oxfordian

GSC loc. 86270. Snowslide Range, west of Bell-Irving River; lat.56°38'30"N, long.129°46'25"W.

Ammonoids
Subfamily Cardioceratinae Siemiradzki. Small fragments of *Cardioceras*? sensu lato or *Amoeboceras*? sensu lato

Belemnoids
Fragments. To Dr. Jeletzky

Age: Oxfordian

GSC loc. 86271. Snowslide Range, west of Bell-Irving River; lat.56°38'30"N, long.129°45'30"W.

Belemnoids
To Dr. Jeletzky

Pelecypods
Pecten sp.

Age: ?Oxfordian

GSC loc. 86272. Snowslide Range, west of Bell-Irving River; lat.56°39'N, long.129°46'30"W.

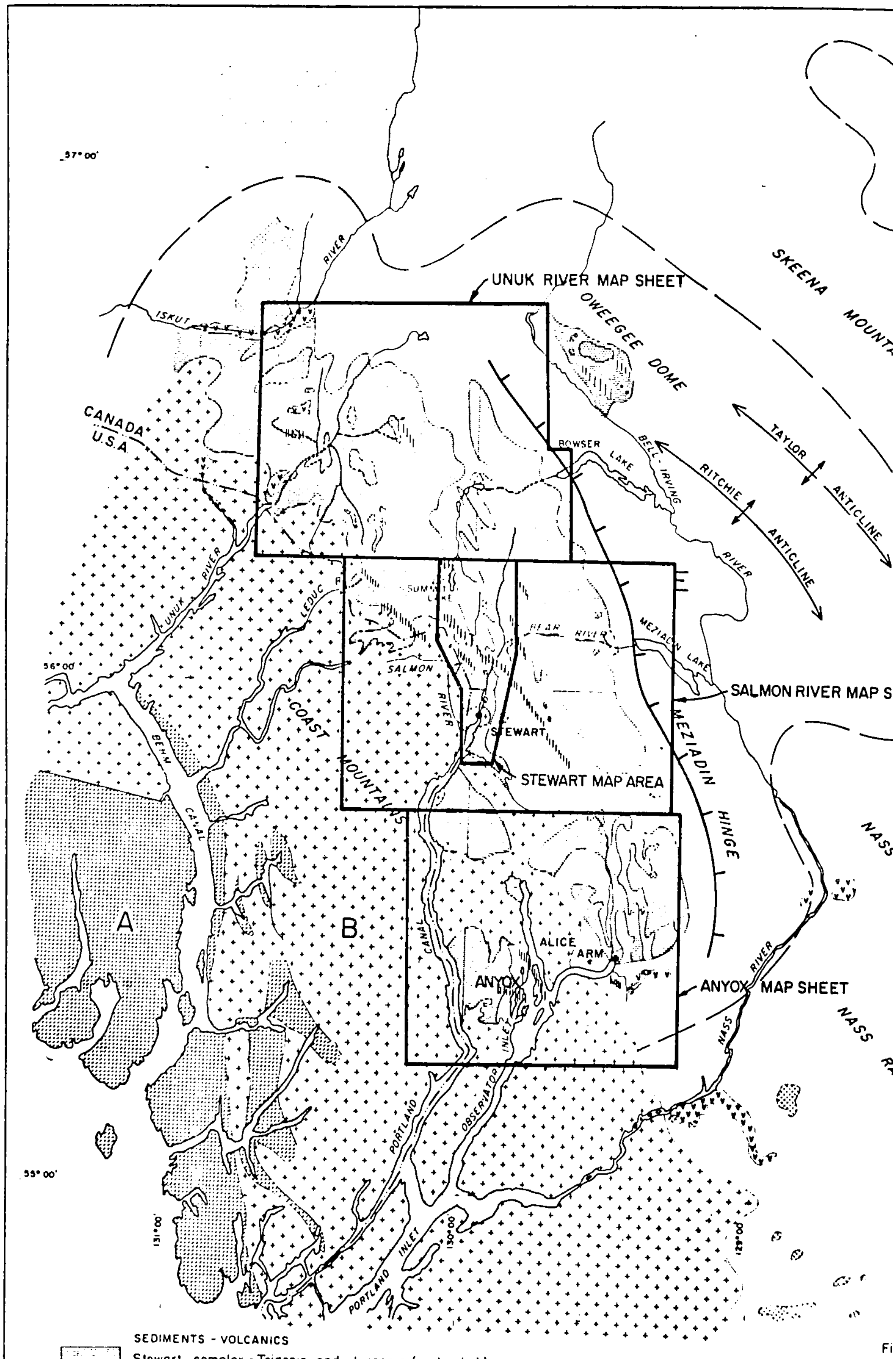
Ammonoids
Subfamily Cardioceratinae Siemiradzki. Very poorly preserved numerous small specimens, probably belonging to the genus Amoeboceras Hyatt, or some of its subgenera. Some specimens resemble also Plasmatoceras Buckman, a subgenus of Cardioceras.
Age: Oxfordian

APPENDIX 3

Development of Mesozoic Terminology in the Portland Canal Area.

The early geological work of McConnell (1913) in the Portland Canal district led to a division of the Hazelton Group into three units: (3) upper argillites, and shales; (2) porphyritic volcanic rocks; and (1) a lower argillite and shale unit. McConnell's subdivisions and the subdivisions of later workers in the Portland Canal section of the Stewart Complex are shown in Table 1. The subdivisions of McConnell (1913), Schofield and Hanson (1922), Hanson (1929), and Buddington (1929) all apply to parts of the Stewart map area (Fig. 1), which has been completely remapped in detail, revised, and re-defined by the writer. All four early workers recognized the superposition of an "argillite" sequence on a volcanic unit, although Buddington did not map it in the Hyder section west of Stewart. McConnell's Nass Formation which he assumed from field relationships to represent the youngest sedimentary unit in the eastern part of the Portland Canal area has been retained in this thesis as a valid term, with considerable revision and refinement by the writer. The Nass Formation mapped in the Salmon River section of the Stewart area, by Schofield and Hanson (1922) and by Hanson (1929) in the Bear River section (Fig. 3) is not equivalent stratigraphically to McConnell's Nass Formation. The writer has shown that these units represent structural remnants of the same unit and the writer has called this unit the Salmon River Formation. The Salmon River Formation devised by Schofield and Hanson (op cit) for extensive conglomerates underlying a thick sedimentary sequence in the Long Lake section does not exist. Detailed work and mapping in that area by the writer (Fig. 3), showed the presence of only minor thin chert pebble conglomerate lenses within the thin bedded sedimentary rocks which are unconformable on older Hazelton members. The writer has therefore reinstated the term Salmon River Formation in the Stewart Complex to replace the Nass Formation of Schofield and Hanson, and Hanson (1929) (Table 1). The Bitter Creek Formation of McConnell and Hanson (1929) was thought to represent an older sedimentary sequence underlying the Bear River Formation which Schofield and Hanson considered as an equivalent to the Porphyrite Group. Later, Hanson (1935, p. 6) suggested that the group of volcanic and sedimentary rocks found throughout the Portland Canal area consisted of only one series of sediments locally divided by large bodies of volcanic rocks. He therefore suggested that this single unit be named the Hazelton Group, but he also indicated that he had not recognized either the top or bottom and did not know what part of the Hazelton Group was represented. Until Map 9-1957 was published by the Geological Survey of Canada, Hanson's (1935) nomenclature was accepted.

On Map 9-1957, Skeena River Area, McConnell's Nass and Bitter Creek formations, Schofield and Hanson's Nass and Salmon River Formations, and Hanson's (1935) Nass Formation were combined to form map unit 12, an Upper Jurassic and Lower Cretaceous unit. The Bear River Formation (Table 1) was shown as map unit 9 a pre-Upper Jurassic volcanic-sedimentary sequence. Later, Duffell and Souther (1964, p. 28) published the proposal that the map unit 12 (Map 9-1957) be named the Bowser Group because of excellent exposures at Bowser Lake and they extended this terminology into the Terrace Map area and subsequently used the term for all surficial marine sedimentary units in the Central Plateau and Mountain Area of British Columbia. As indicated in this current study the term Bowser Group has been shown to be pre-empted. In the Portland Canal these units are now considered part of the revised Hazelton Group and belong to various formations within this group.



SEDIMENTS - VOLCANICS

Stewart complex - Triassic and Jurassic (undivided)

Sustut assemblage - Cretaceous and Tertiary (undivided)

Palaeozoic

Tertiary and recent volcanics

Hazelton Group — Middle and Upper Jurassic

Fi

GEOLOGIC

in c

Northwestern B.C.

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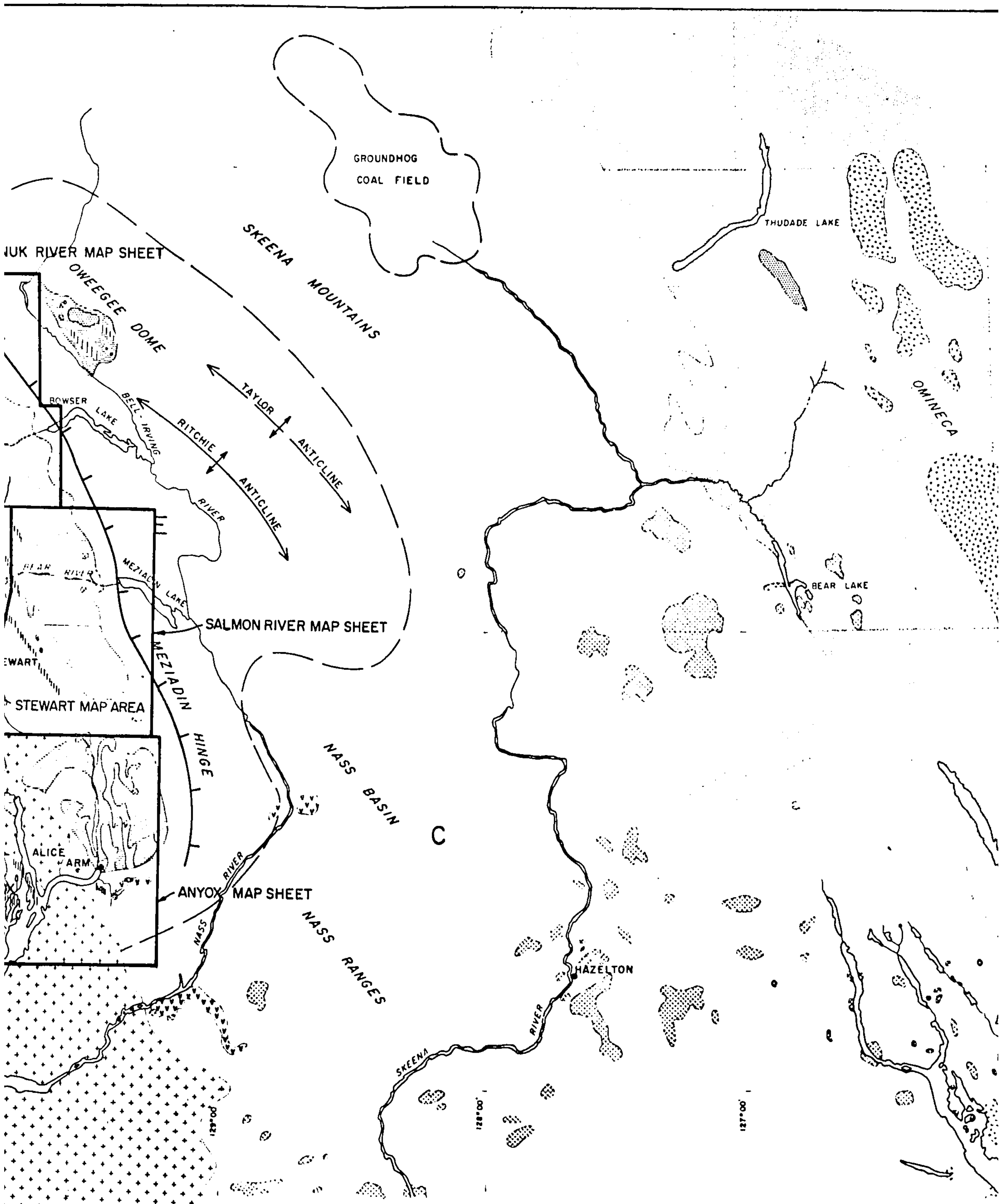


Figure **1**

GEOLOGICAL FEATURES

in a portion of

Northwestern B.C. — Southeastern Alaska

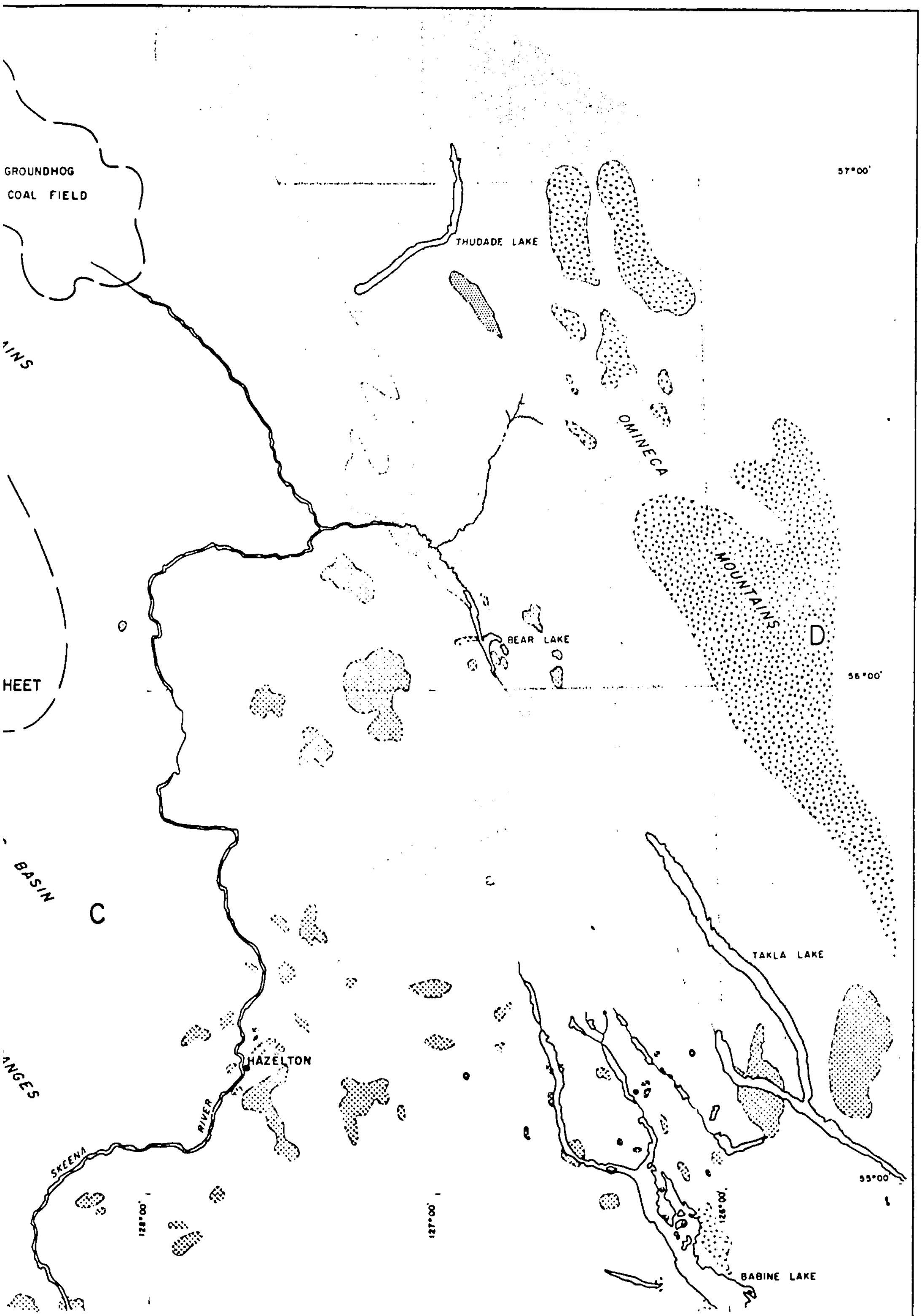
SCALE 0 8 16 24 32 MILES

INTRUSIVES

- Coast Plutonic Complex
- Omineca – Topley – undivided
- Skeena – undivided
- Dyke swarms – undivided

MAJOR FE

- A Wrangell -
- B Coast Pluto
- C Bowser ba
- D Omineca (
- E Bear river
- Wrangell -



gure 1

AL FEATURES

ı portion of

— Southeastern Alaska

16 24 32 MILES

INTRUSIVES

Coast Plutonic Complex

Omineca -Topley - undivided

Skeena - undivided

Dyke swarms - undivided

MAJOR FEATURES

A Wrangell - Revillagigedo belt

B Coast Plutonic belt

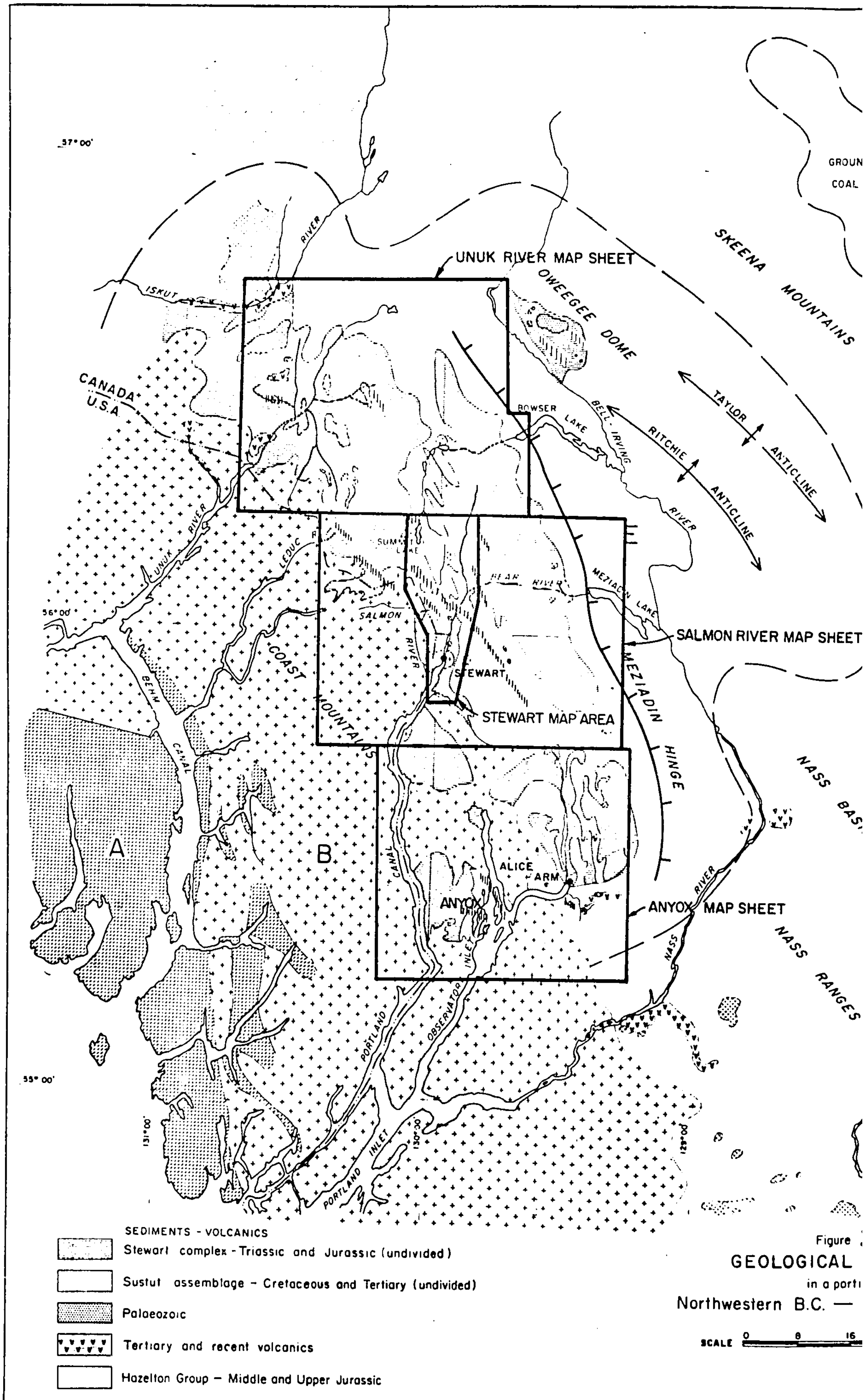
C Bowser basin

D Omineca crystalline belt

E Bear river uplift

Wrangell - Revillagigedo Metamorphics

Fig. 1



Figure

GEOLOGICAL

in a porti

Northwestern B.C. —

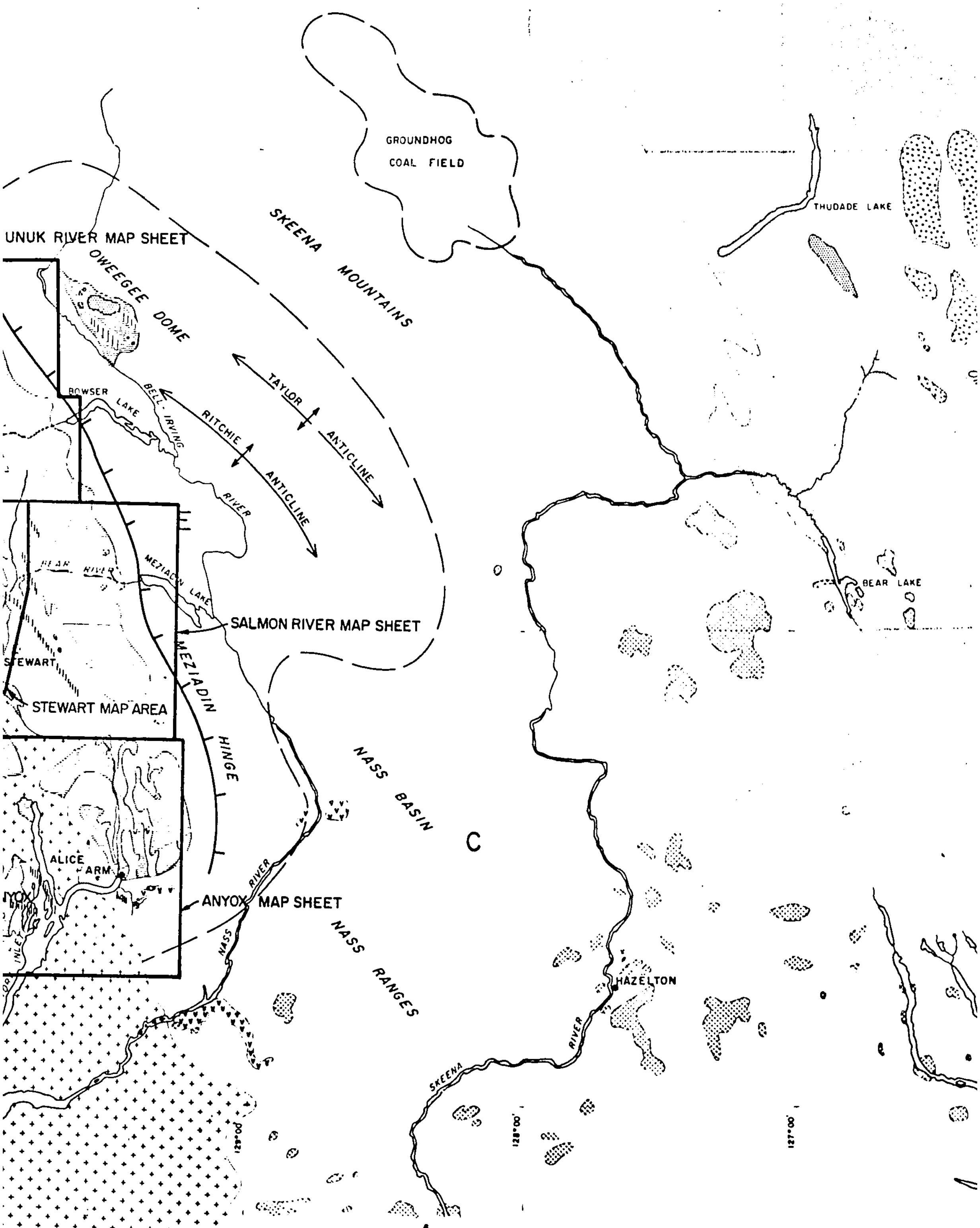


Figure **1**

GEOLOGICAL FEATURES

in a portion of

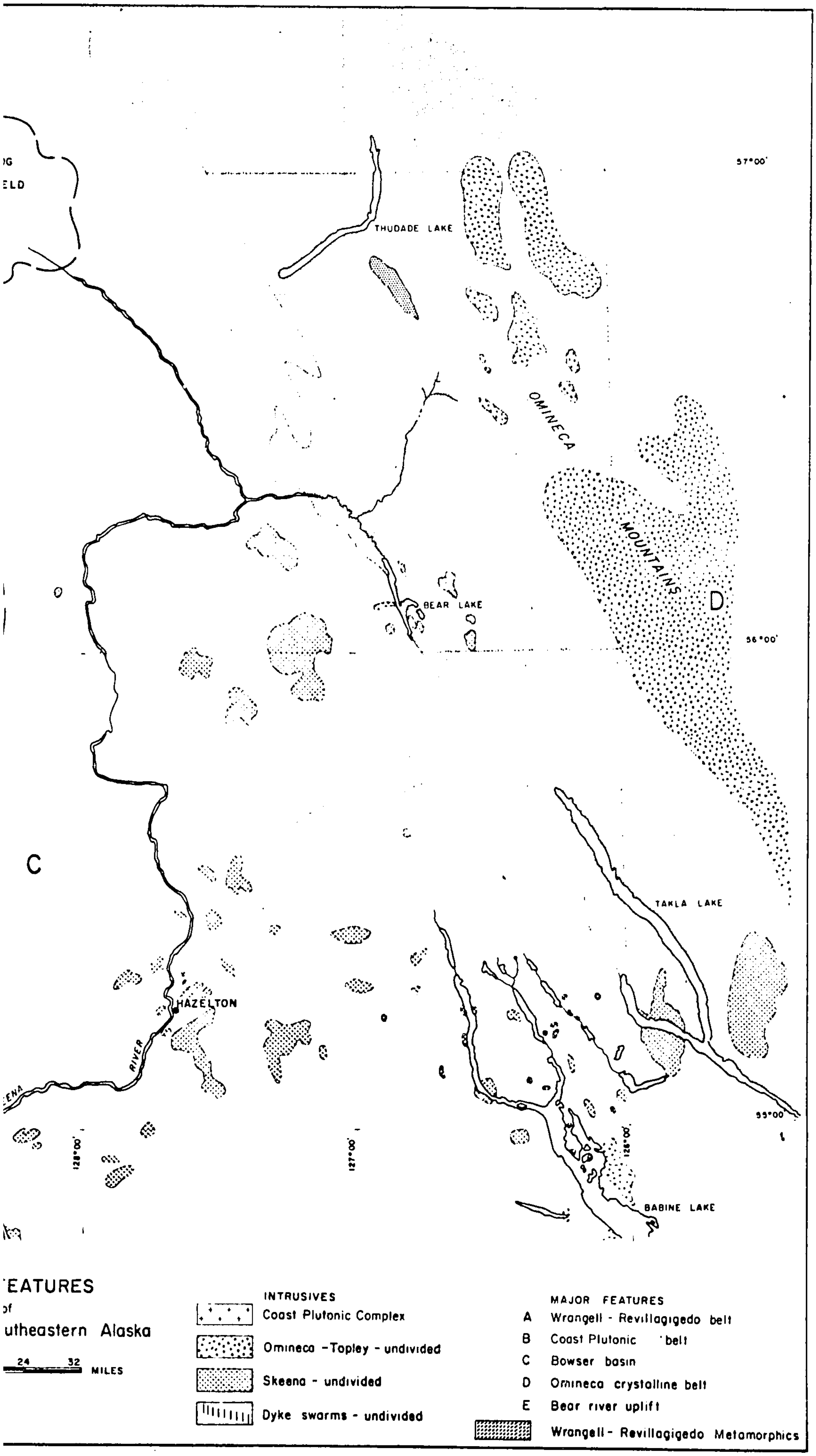
Northwestern B.C. — Southeastern Alaska

SCALE 0 8 16 24 32 MILES

INTRUSIVES

- Coast Plutonic Complex — A
- Omineca – Topley – undivided — B
- Skeena – undivided — C
- Dyke swarms – undivided — D
- E

ded)



THUDADE LAKE
57°00'
OMINECA
MOUNTAINS
D
BEAR LAKE
56°00'
C
TAKLA LAKE
HAZELTON
RIVER
55°00'
128°00'
127°00'
BABINE LAKE
EATURES
of
utheastern Alaska
24 32 MILES
INTRUSIVES
Coast Plutonic Complex
Omineca –Topley - undivided
Skeena - undivided
Dyke swarms - undivided
MAJOR FEATURES
A Wrangell - Revillagigedo belt
B Coast Plutonic 'belt
C Bowser basin
D Omineca crystalline belt
E Bear river uplift
Wrangell - Revillagigedo Metamorphics

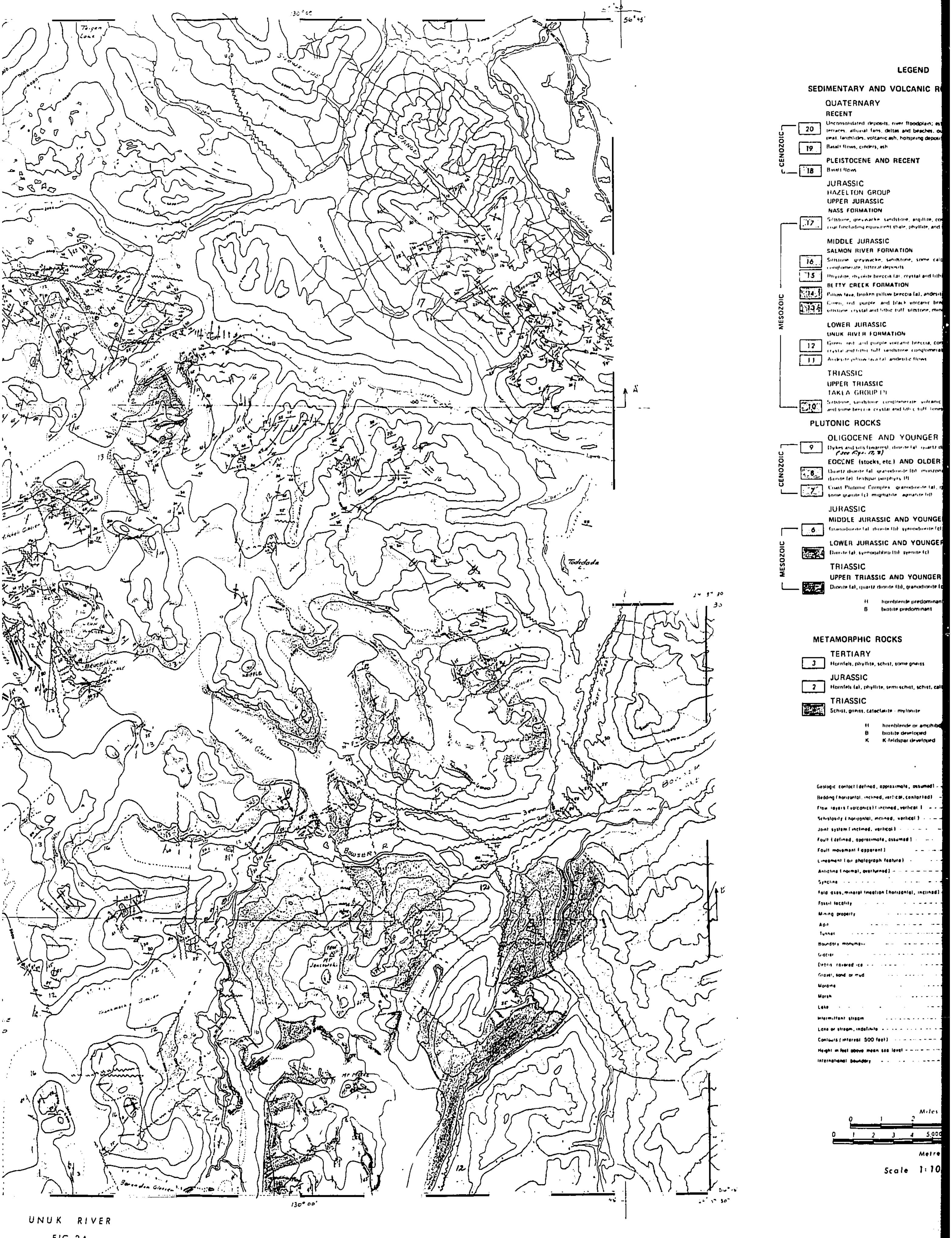
Fig. 1

1 of

Scale 1:100.000

UNUK RIVER

FIG. 2A



UNUK RIVER

FIG. 2A

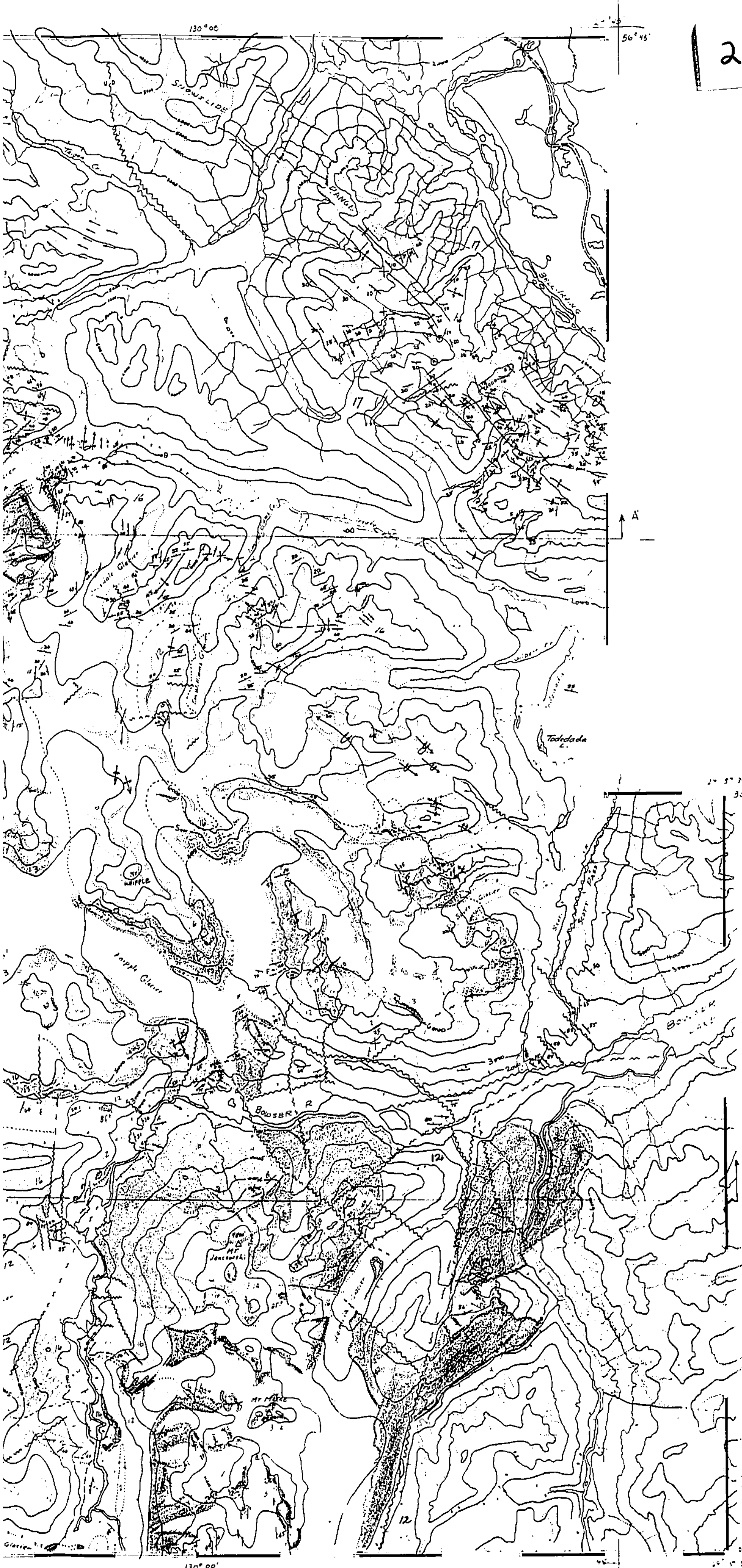
Scale 1:100,000

Miles 2 1 0 1 2 3 4 5

Kilometres 0 1 2 3 4 5 10

UNUK RIVER

FIG. 2A



LEGEND

SEDIMENTARY AND VOLCANIC ROCKS

QUATERNARY

RECENT

CENOZOIC

- **20** Unconsolidated deposits: river floodplain, estuarine deposits, river channel and terraces, alluvial fans, deltas and beaches, outwash, glacial lake sediments, till, peat, landslides, volcanic ash, hotspring deposits
- **19** Basalt flows, cinders, ash

PLEISTOCENE AND RECENT

- **18** Basalt flows

JURASSIC

HAZELTON GROUP

UPPER JURASSIC

NASS FORMATION

MESOZOIC

- **17** Siltstone, greywacke, sandstone, argillite, conglomerate, minor limestone, minor coal (including equivalent shale, phyllite and schist)

MIDDLE JURASSIC

SALMON RIVER FORMATION

- **16** Siltstone, greywacke, sandstone, some calcarenite, minor limestone, argillite, conglomerate, littoral deposits
- **15** Rhyolite, rhyolite breccia (a), crystal and lithic tuff

BETTY CREEK FORMATION

- **14** Pillow lava, broken pillow breccia (a), andesitic and basaltic flows
- **13** Green, red, purple and black volcanic breccia, conglomerate, sandstone, and siltstone, crystal and lithic tuff, siltstone, minor chert and limestone

LOWER JURASSIC

UNUK RIVER FORMATION

- **12** Green, red and purple volcanic breccia, conglomerate, sandstone, and siltstone, crystal and lithic tuff, sandstone, conglomerate, limestone, chert, minor coal
- **11** Andesite pillow lava (a), andesitic flows

TRIASSIC

UPPER TRIASSIC

TAKLA GROUP (?)

- **10** Siltstone, sandstone, conglomerate, volcanic siltstone, sandstone, conglomerate, and some breccia, crystal and lithic tuff, limestone

PLUTONIC ROCKS

OLIGOCENE AND YOUNGER

CENOZOIC

- **9** Dykes and sills (swarms), diorite (a), quartz diorite (b), granodiorite (c), basalt (see Figs. 17, 7)

EOCENE (stocks, etc.) AND OLDER ?

- **8** Quartz diorite (a), granodiorite (b), monzonite (c), quartz monzonite (d), augite diorite (e), feldspar porphyry (f)
- **7** Coast Plutonic Complex: granodiorite (a), quartz diorite (b), quartz monzonite, some granite (c), migmatite, agmatite (d)

JURASSIC

MIDDLE JURASSIC AND YOUNGER ?

MESOZOIC

- **6** Granodiorite (a), diorite (b), syenodiorite (c), monzonite (d), alaskite (e)

LOWER JURASSIC AND YOUNGER ?

- **5** Diorite (a), syenogabbro (b), syenite (c)

TRIASSIC

UPPER TRIASSIC AND YOUNGER ?

- **4** Diorite (a), quartz diorite (b), granodiorite (c)

H hornblende predominant
B biotite predominant

METAMORPHIC ROCKS

TERTIARY

- **3** Hornfels, phyllite, schist, some gneiss

JURASSIC

- **2** Hornfels (a), phyllite, semischist, schist, cataclasite, mylonite

TRIASSIC

- **1** Schist, gneiss, cataclasite, mylonite

H hornblende or amphibole developed
B biotite developed
K K feldspar developed

Geologic contact (defined, approximate, assumed)
Bedding (horizontal, inclined, vertical, contorted)
Flow layers (volcanics) (inclined, vertical)
Schistosity (horizontal, inclined, vertical)
Joint system (inclined, vertical)
Fault (defined, approximate, assumed)
Fault movement (apparent)
Lineament (air photograph feature)
Anticline (normal, overturned)
Syncline
Fold axes, mineral lineation (horizontal, inclined)
Fossil locality
Mining property
Adit
Tunnel
Boundary monument
Glacier
Debris covered ice
Gravel, sand or mud
Moraine
Marsh
Lake
Intermittent stream
Lake or stream, indefinite
Contours (interval 500 feet) — 2000 —
Height in feet above mean sea level ×6548
International boundary

Miles 0 1 2 3 4 5

Metres 0 1 2 3 4 5000 10 000

Scale 1:100,000

FIG. 2A.

1 of 1

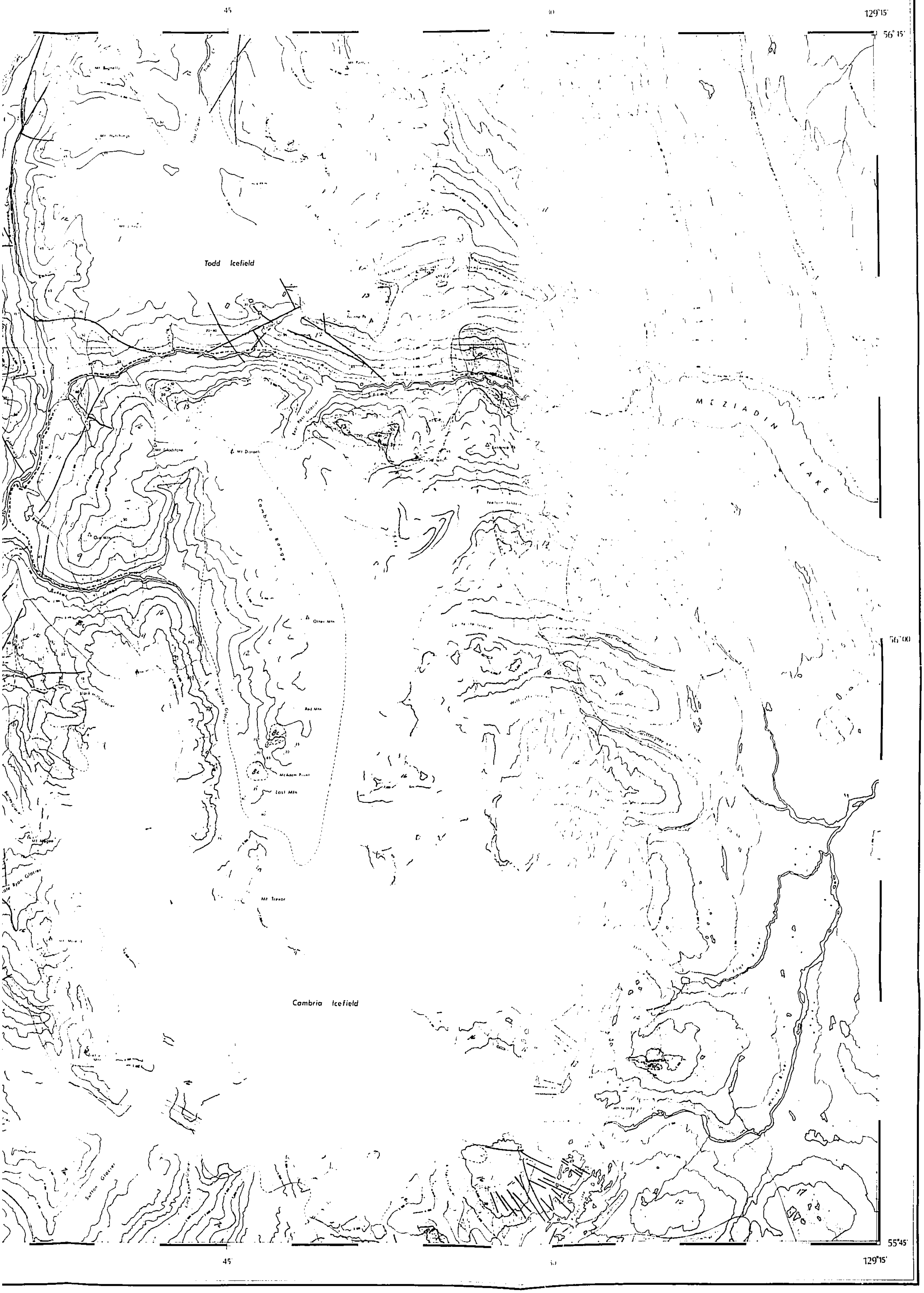
FIG. 2B

SALMON RIVER

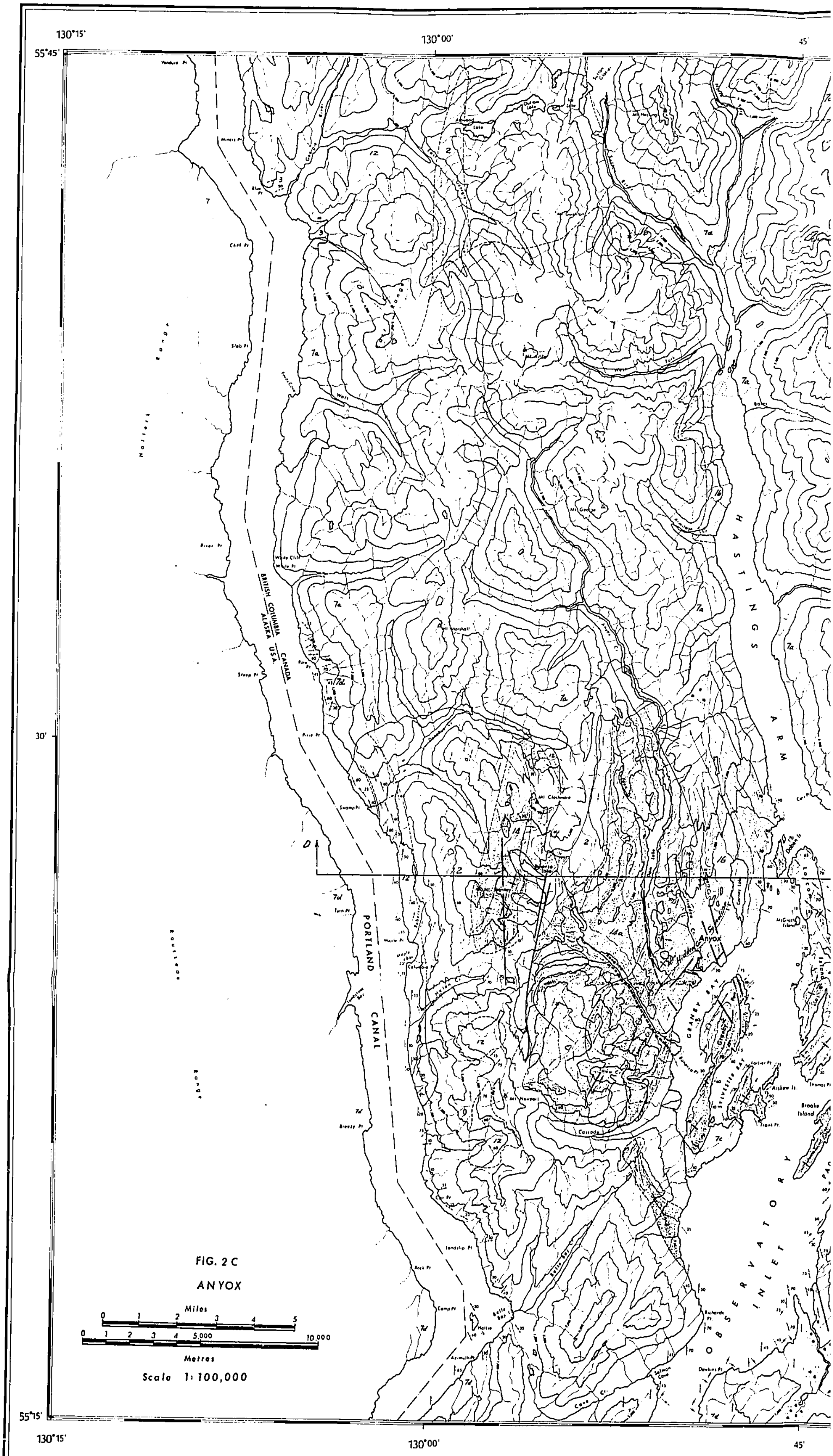
Miles: 0 1 2 3 4 5

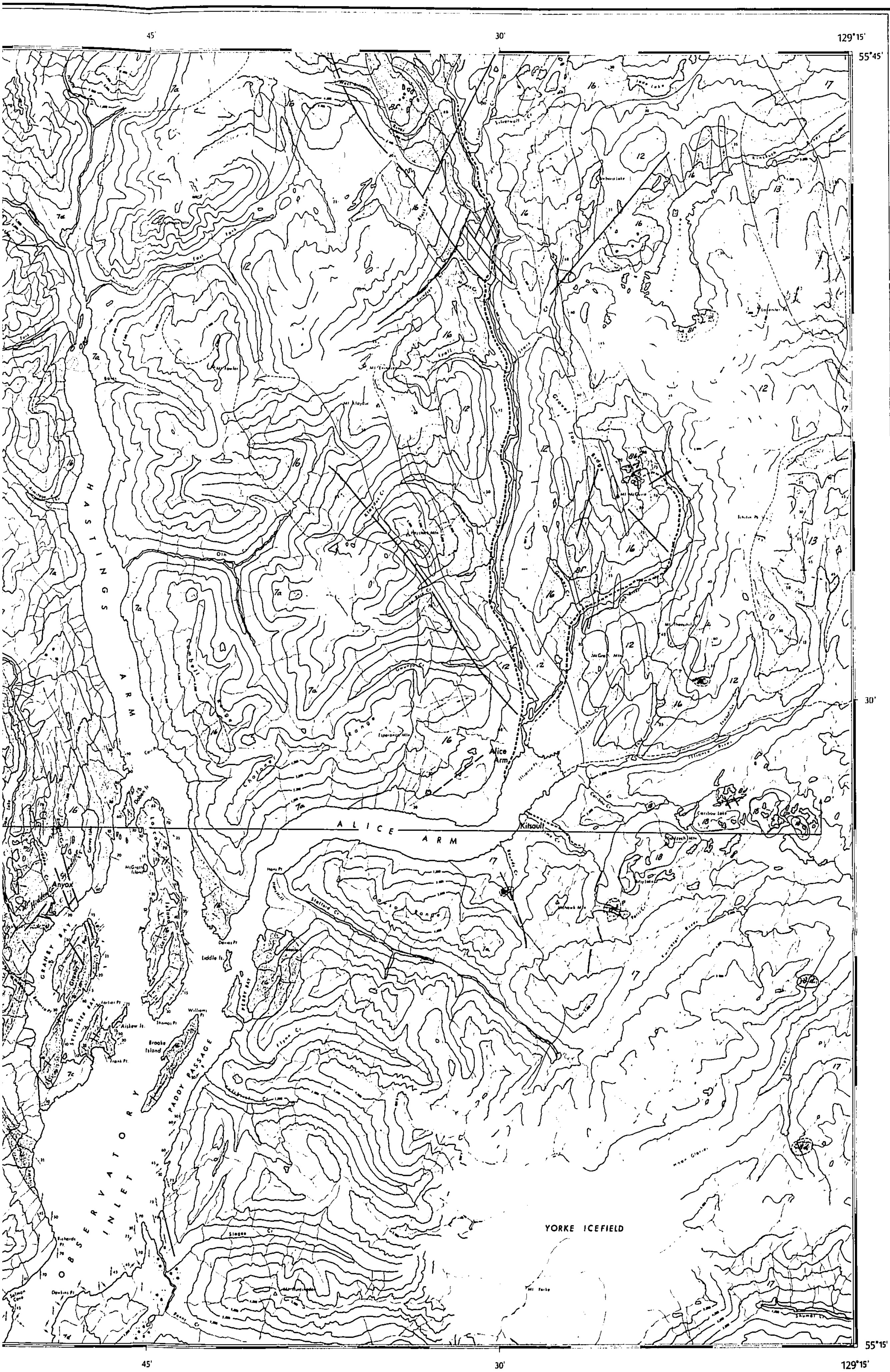
Metres: 0 1 2 3 4 5,000 10,000

Scale 1:100,000


45
50
129°15'
56°15'
Todd Icefield
MEZIADIN LAKE
Cambria Range
56°00'
Cambria Icefield
55°45'
45
50
129°15'

1 of 1


130°15'
130°00'
45'
55°45'
30'
55°15'
HASTINGS ARM
PORTLAND CANAL
OBSERVATORY INLET
GRANBY BAY
BRITISH COLUMBIA CANADA
ALASKA U.S.A.
Anyox
Brooke Island
McGrath Island
Aiskew Is.
Cascade
Halleck Range
Boundary Range
FIG. 2 C
ANYOX
Miles
0 1 2 3 4 5
0 1 2 3 4 5,000 10,000
Metres
Scale 1:100,000



45'
30'
129°15'
55°45'
30'
55°15'
HASTINGS ARM
ALICE ARM
Alice Arm
Kitsault
Anyox
GRANBY BAY
OBSERVATORY INLET
PADDY PASSAGE
PEARSE BAY
Brooke Island
YORKE ICEFIELD
Liddle Is.
Williams Pt.
Dawkins Pt.
Richards Pt.
Salmon Cove
Cariboo Lake
Gravel Top Ridge
Illiance River

LEGEND

SEDIMENTARY AND VOLCANIC ROCKS

PLEISTOCENE AND RECENT

CENOZOIC

- Unconsolidated deposits: River flood plain; estuarine deposits; river channel and stream-cut terraces; alluvial fans, deltas and beaches; outwash, glacial lake sediments

HAZELTON GROUP

MIDDLE JURASSIC

SALMON RIVER FORMATION

MESOZOIC

- B1 — Siltstone, greywacke, argillite, minor chert pebble conglomerate, minor limestone (including equivalent phyllites)
- B2 — Lithic wacke, feldspathic wacke, siltstone, pebble conglomerate (including equivalent phyllites)
- Rhyolite — Rhyolite breccia

BETTY CREEK FORMATION

- Green, red, and buff volcanic sandstone, conglomerate, minor breccia
- Red and black volcanic sandstone, conglomerate, minor breccia
- Red, green, and black volcanic breccia (with purple phases)

LOWER JURASSIC

UNUK RIVER FORMATION

- H1
- H2 — Red and green volcanic conglomerate and sandstone, crystal and lithic tuff
- H3 — Green massive volcanic conglomerate, sandstone, minor breccia with minor intercalated siltstone
- H4 — Red and purple massive volcanic conglomerate, breccia, and sandstone with minor intercalated siltstone
- Green volcanic breccia, with sandstone and conglomerate

PLUTONIC ROCKS

COAST CRYSTALLINE COMPLEX

TERTIARY

CENOZOIC

- bcm — Bitter Creek quartz monzonite, granodiorite
- gcd — Glacier Creek augite diorite (and equivalent)
- sld — Summit Lake gneiss diorite
- bgd — Boundary granodiorite
- hqm — Hyder quartz monzonite (and equivalent)

MIDDLE JURASSIC

MESOZOIC

- tcg — Texas Creek granodiorite (and equivalent)
- H — Hornblende is the predominant mafic mineral
- B — Biotite is the predominant mafic mineral
- Inclusions of country rocks
- h — Metasomatic hornblende
- po — Porphyry phase

METAMORPHIC ROCKS

JURASSIC

HAZELTON EQUIVALENTS

- M1 — Green cataclasites, mylonites, schists
- M2 — Black (bl), purple (pu), red (r), and green (gn) mylonite (predominant colour)
- M3 — Buff and green schists (including phyllonite)

ALTERATION

- P — Pyritization
- S — Silicification
- K — Feldspathization
- h — Metasomatic hornblende prominent

DYKE ROCKS

TERTIARY

CENOZOIC

- Hornblende diorite, quartz diorite (lamprophyre everywhere)
- Diorite, hornblende diorite (mainly Bear Pass area)
- Quartz monzonite, granodiorite and quartz diorite commonly porphyritic (belt of dykes) (mainly Portland Canal dyke swarm)
- Granodiorite porphyry (in Premier area) includes Premier dyke swarm)

- Geologic contact (defined, approximate, assumed)
- Bedding (horizontal, inclined, vertical, contorted)
- Flow layers (volcanics) (inclined, vertical)
- Schistosity (horizontal, inclined, vertical)
- Joint system (inclined, vertical)
- Fault (defined, approximate, assumed)
- Fault movement (apparent)
- Lineament (air photograph feature)
- Anticline (normal, overturned)
- Syncline
- Fold axes, mineral lineation (horizontal, inclined)
- Fossil locality
- Mining property
- Adit
- Tunnel
- Quarry
- Dyke swarms (one line represents 10 to 15 dykes)
- Dyke swarm limit
- Bore hole — BH
- Road, all weather (other)
- Trails
- Tram line
- Bridge
- Building
- Boundary monument
- Glacier
- Debris-covered ice
- Gravel, sand or mud
- Moraine
- Marsh
- Lake
- Intermittent stream
- Lake or stream, indefinite
- Contours (interval 500 feet) — 2000
- Height in feet above mean sea level — 6548
- International boundary
- War memorial
- Ice boundary location (year) — 1957
- Horizontal control point
- Mine waste dump
- Mine glory hole

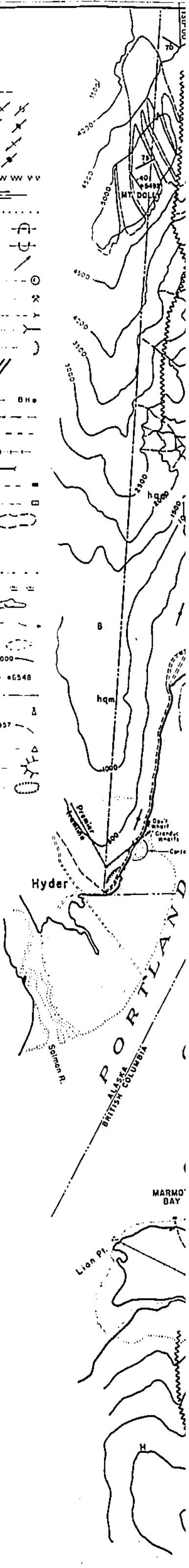


Figure 3

GEOLOGICAL MAP OF THE STEWART AREA

Geology by E.W. Grove, 1964-1965

Scale 0 — 1 Mile

Contour interval 500 feet

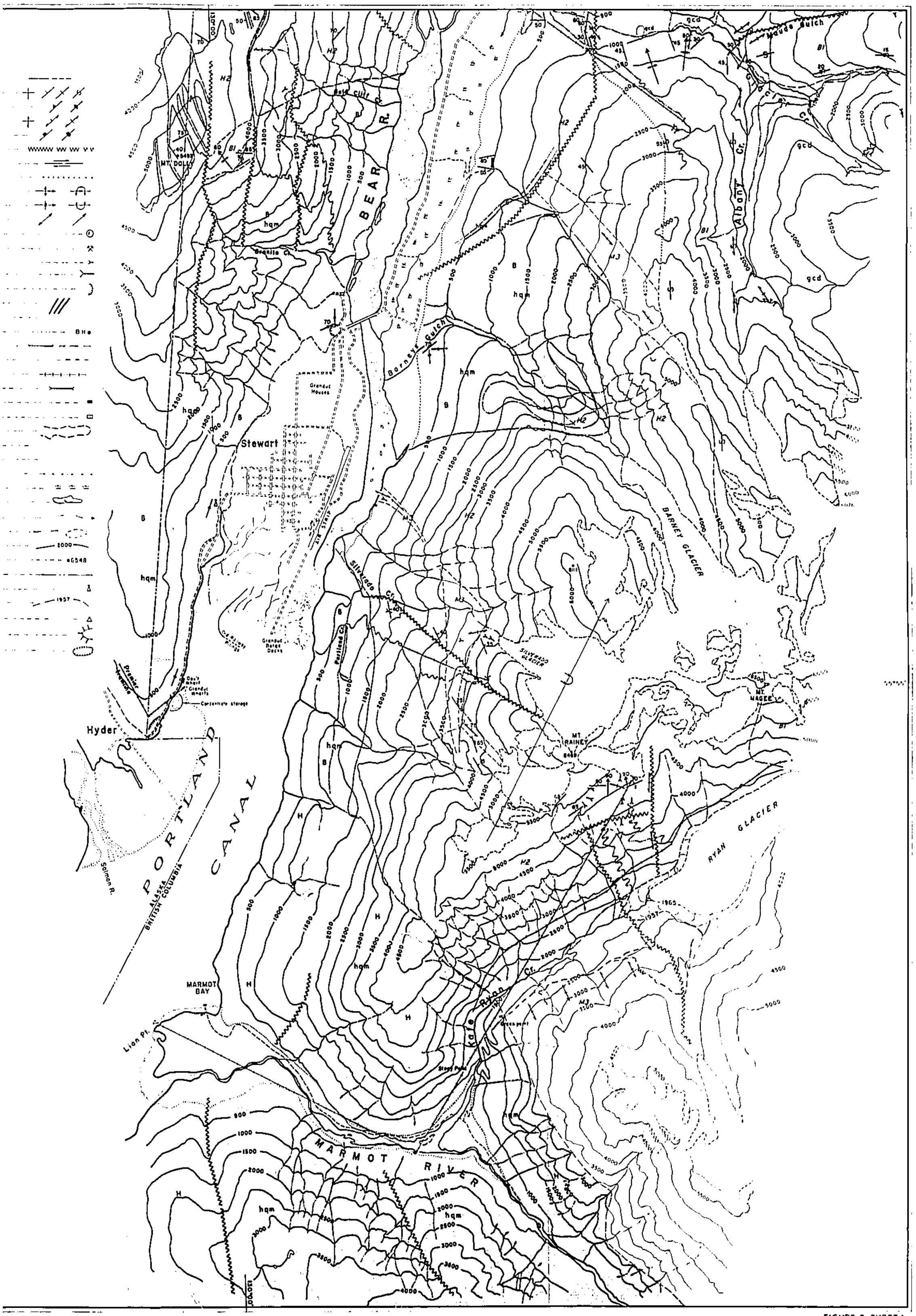
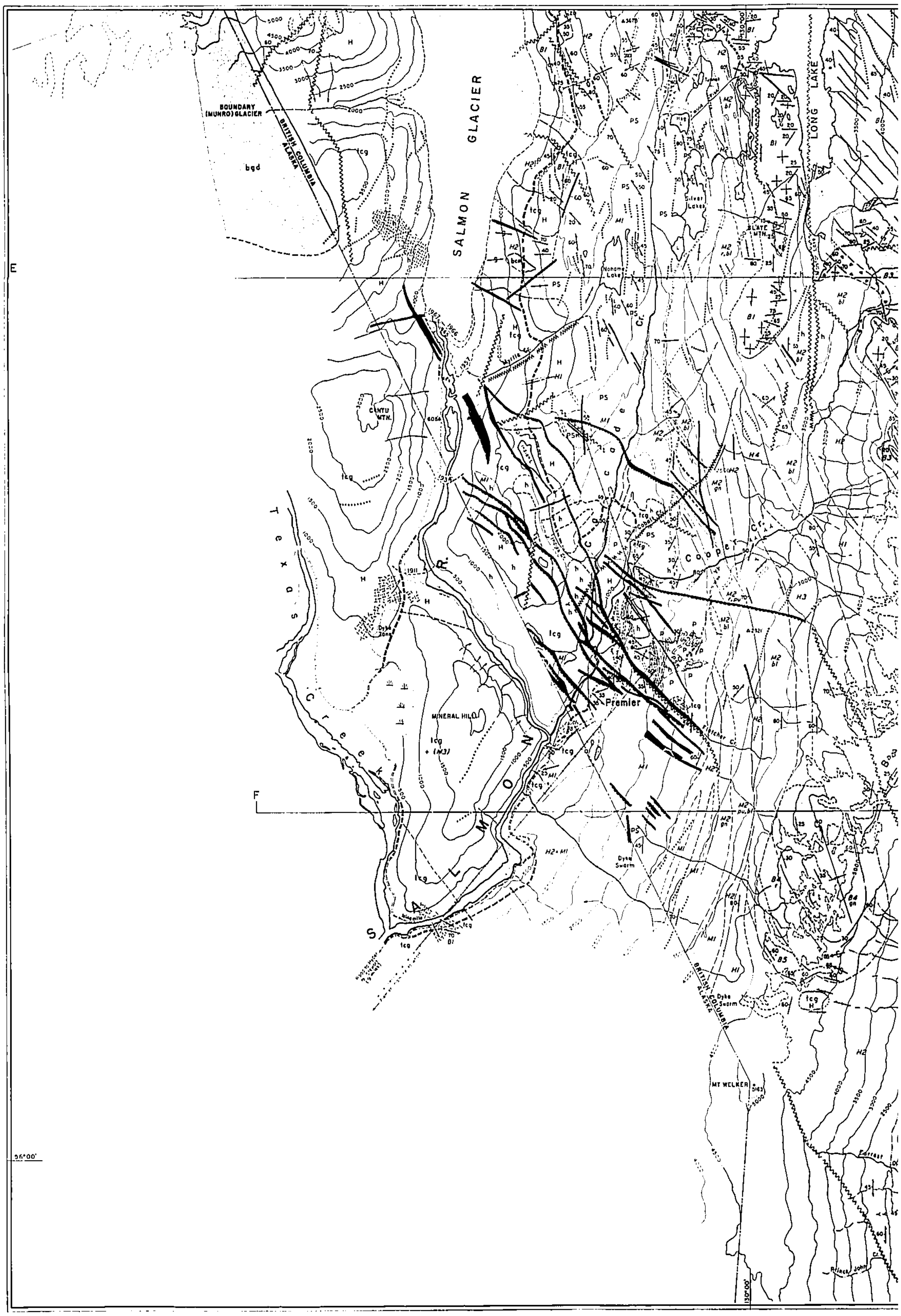


FIGURE 3. SHEET A


SALMON GLACIER
LONG LAKE
BOUNDARY (MUNRO) GLACIER
BRITISH COLUMBIA
ALASKA
CANTU MTN.
Texas Creek
SALMON R.
Premier
MINERAL HILL
Cooper Cr.
Silver Lakes
SLATE MTN.
Dyke Swarm
MT WELKER
E
F
56°00'
130°00'

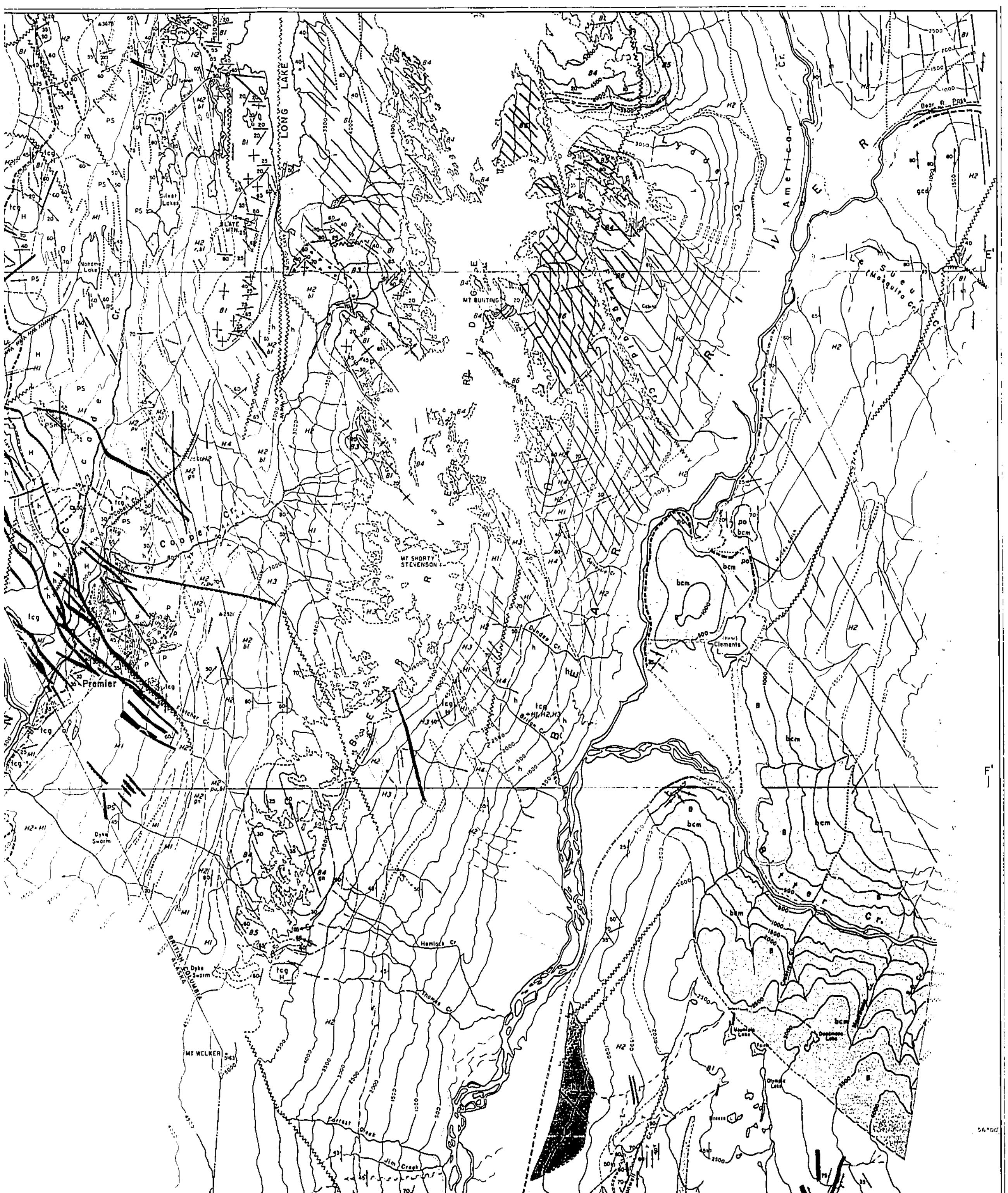


FIGURE 3 SHEET B
FOR LEGEND SEE SHEET A

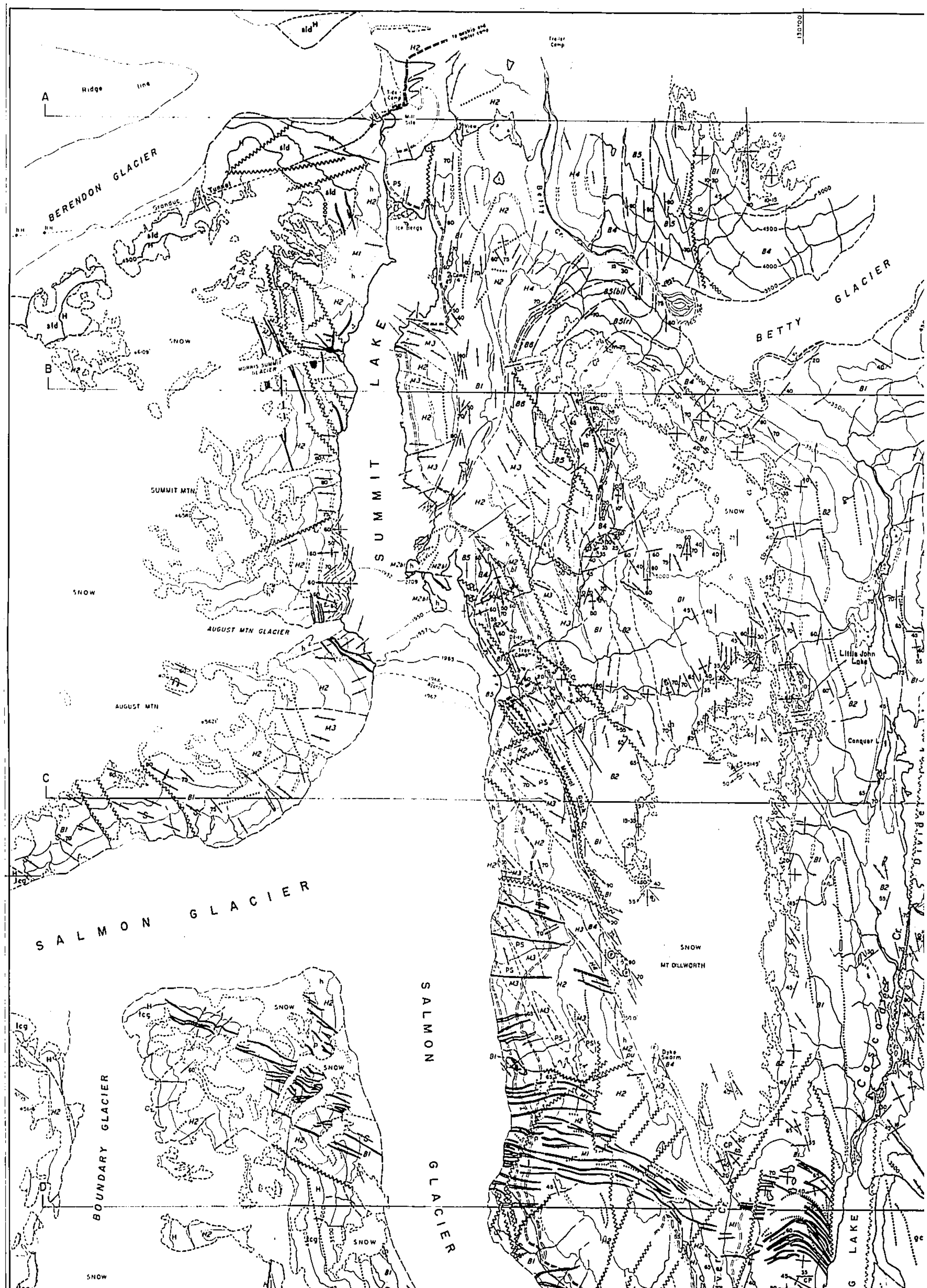

A
B
C
Ridge line
BERENDON GLACIER
Ice Bergs
SUMMIT LAKE
SUMMIT MTN
SNOW
AUGUST MTN GLACIER
AUGUST MTN
BETTY GLACIER
Little John Lake
Conquer L.
SALMON GLACIER
MT DILLWORTH
BOUNDARY GLACIER
LONG LAKE
MT. BAYARD
BRITISH COLUMBIA
ALASKA

FIGURE 3. SHEET C
FOR LEGEND SEE SHEET A

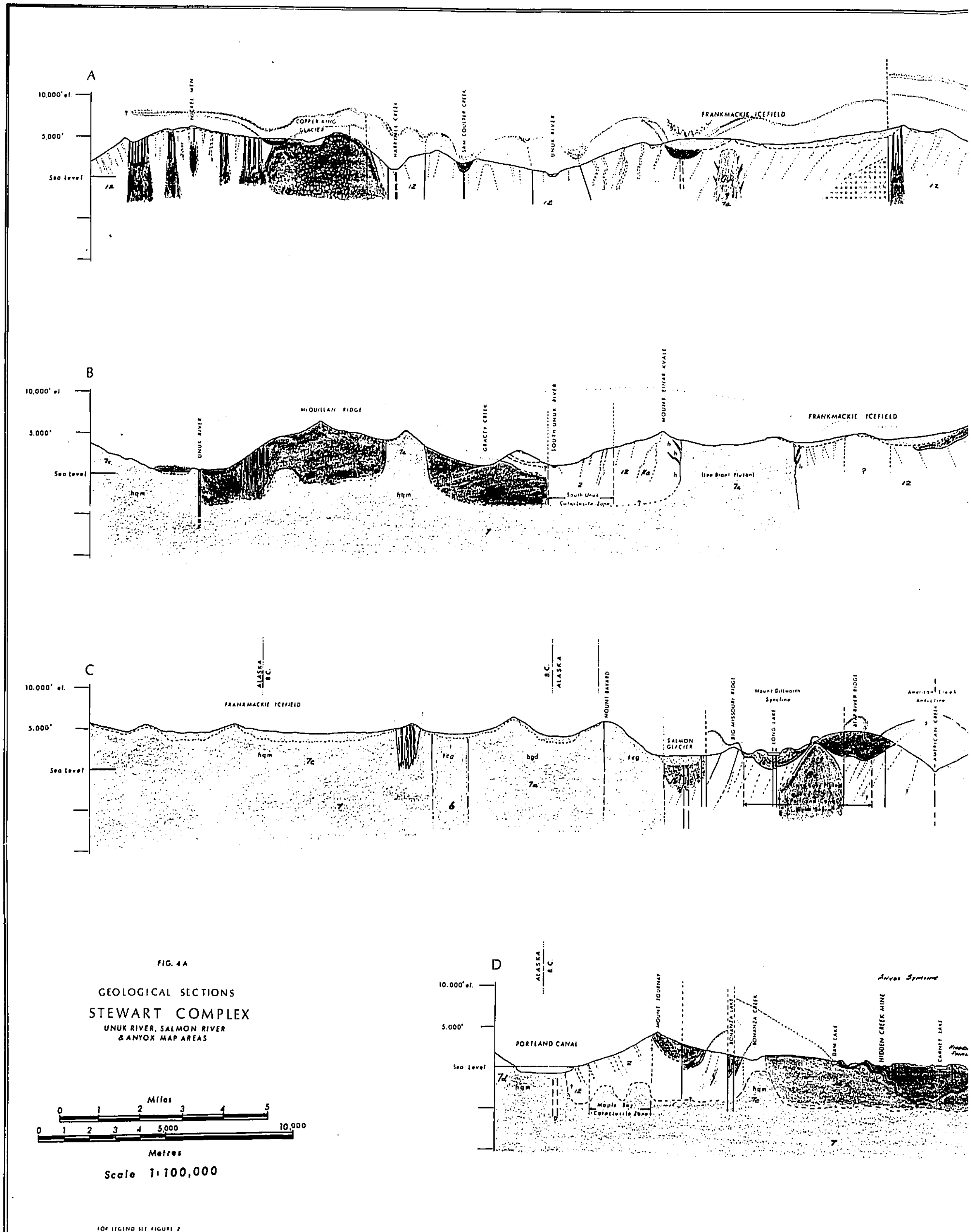


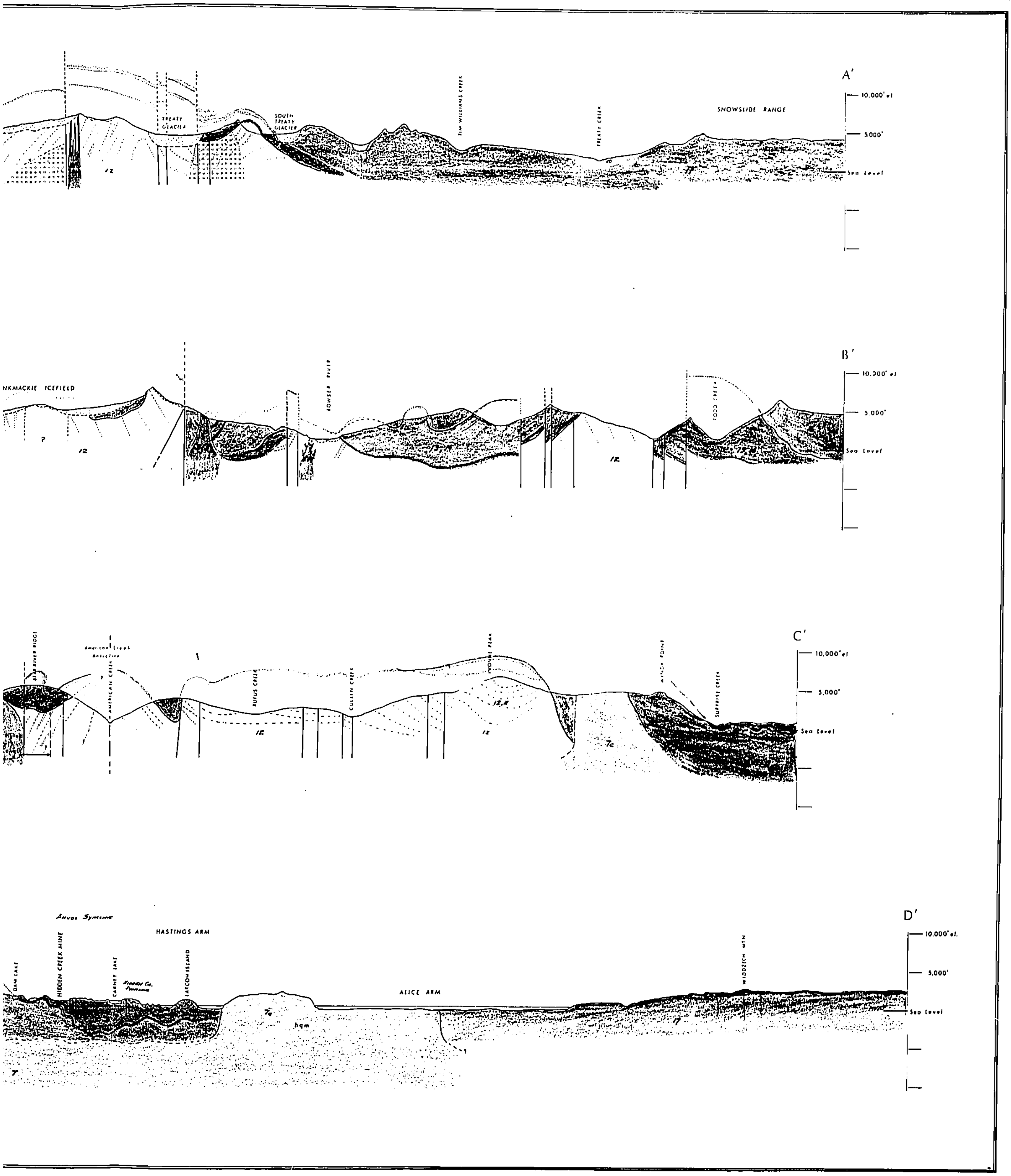
FIG. 4A

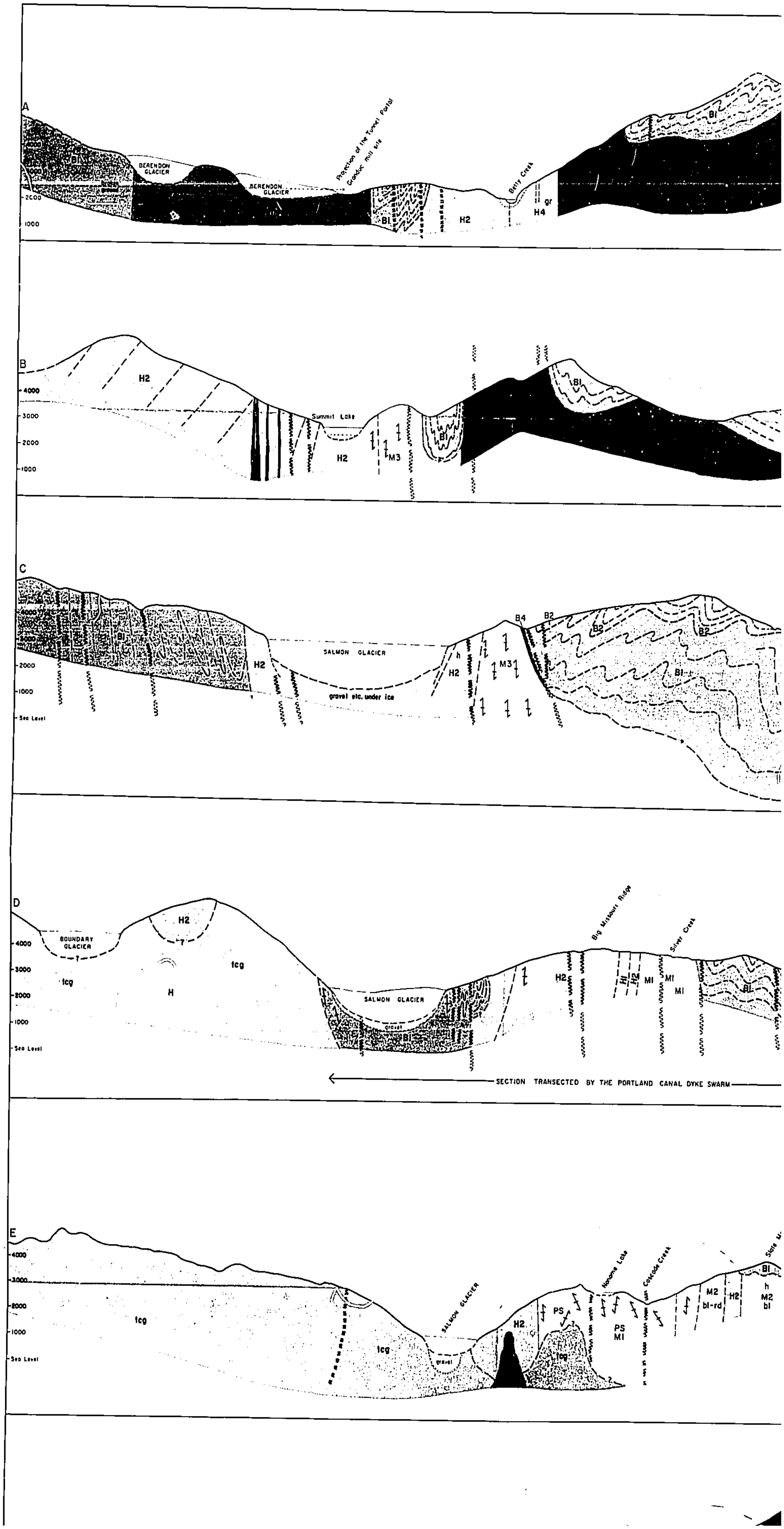
GEOLOGICAL SECTIONS

STEWART COMPLEX

UNUK RIVER, SALMON RIVER & ANYOX MAP AREAS

FOR LEGEND SEE FIGURE 2


A′
10,000′ el
5,000′
Sea Level
TREATY GLACIER
SOUTH TREATY GLACIER
TREATY CREEK
SNOWSLIDE RANGE
B′
NKMACKIE ICEFIELD
BOWSER RIVER
TODD CREEK
C′
AMERICAN CREEK
RUFUS CREEK
CULLEN CREEK
D′
HASTINGS ARM
ALICE ARM
HIDDEN CREEK MINE
CARNEY LAKE
WIDDZECH MTN


A
BERENDON GLACIER
Projection of the Tunnel Portal
Granduc mill site
Betty Creek
Bl
H2
H4
gr
2000
1000
B
H2
Summit Lake
M3
Bl
4000
3000
2000
1000
C
SALMON GLACIER
gravel etc. under ice
B4
B2
H2
M3
h
Bl
4000
2000
1000
Sea Level
D
BOUNDARY GLACIER
H2
tcg
H
SALMON GLACIER
gravel
Big Missouri Ridge
Silver Creek
MI
Bl
4000
3000
2000
1000
Sea Level
SECTION TRANSECTED BY THE PORTLAND CANAL DYKE SWARM
E
tcg
SALMON GLACIER
gravel
H2
PS
MI
Cascade Creek
M2
bl-rd
h
4000
3000
2000
1000
Sea Level

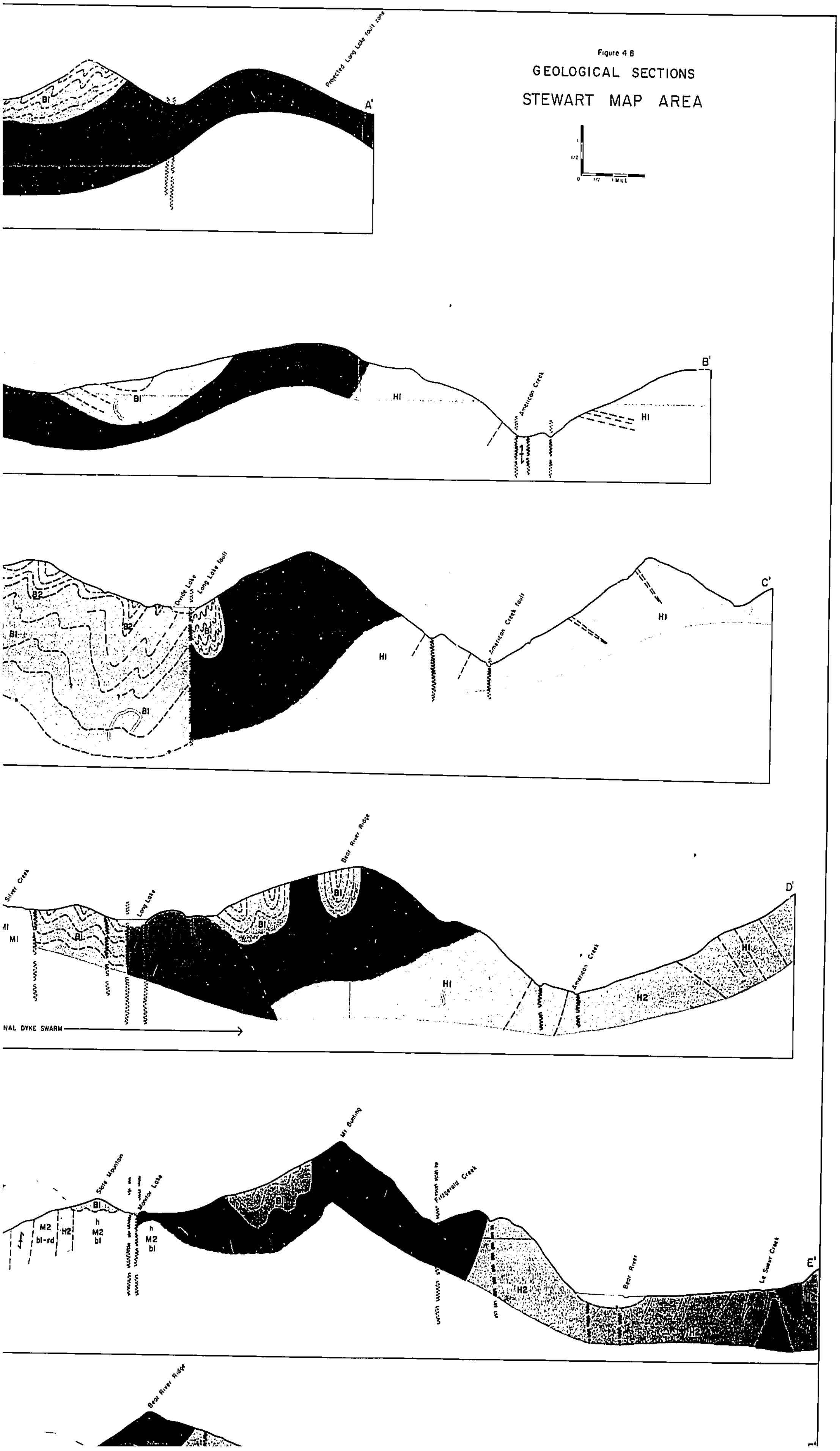
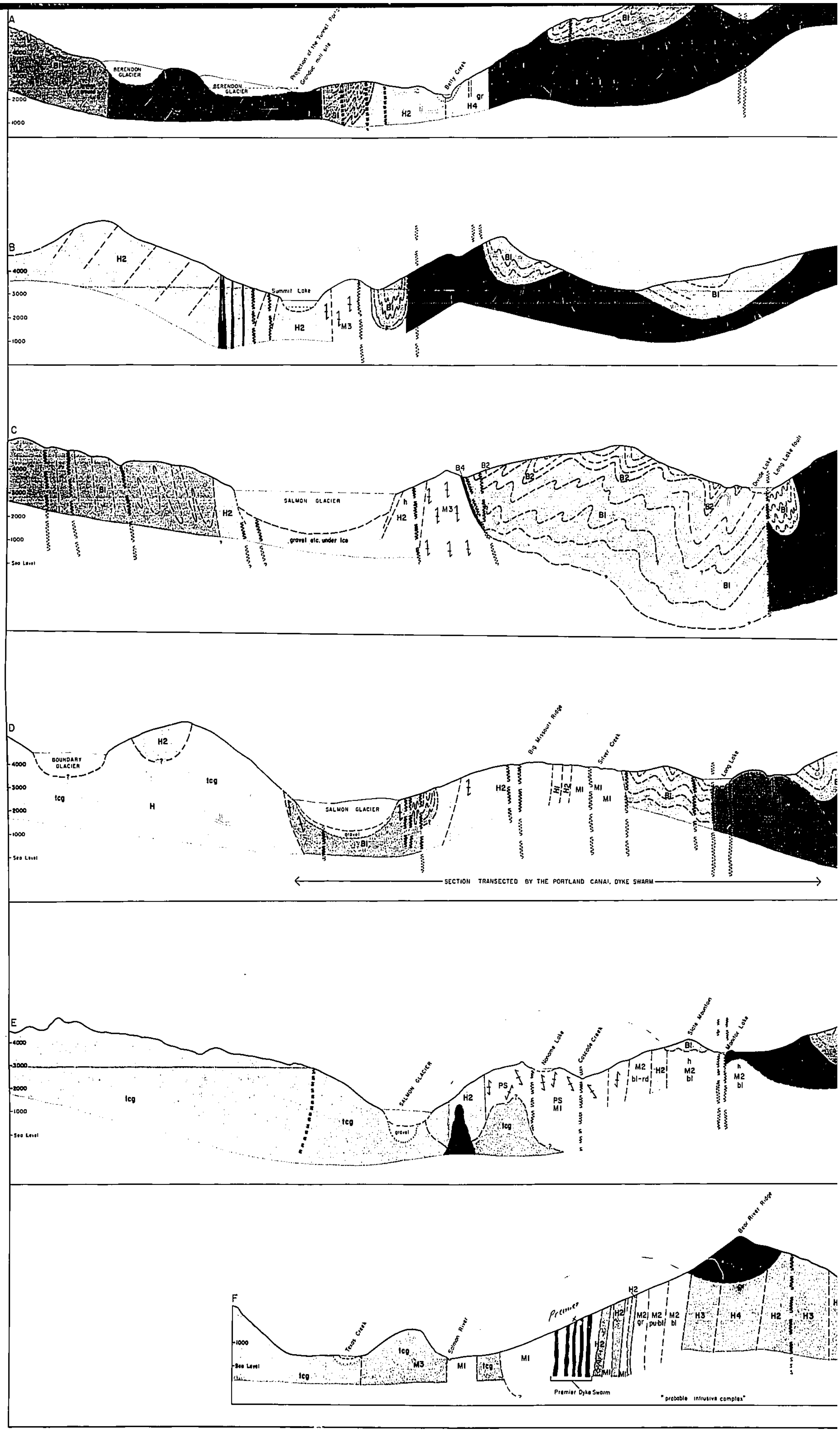
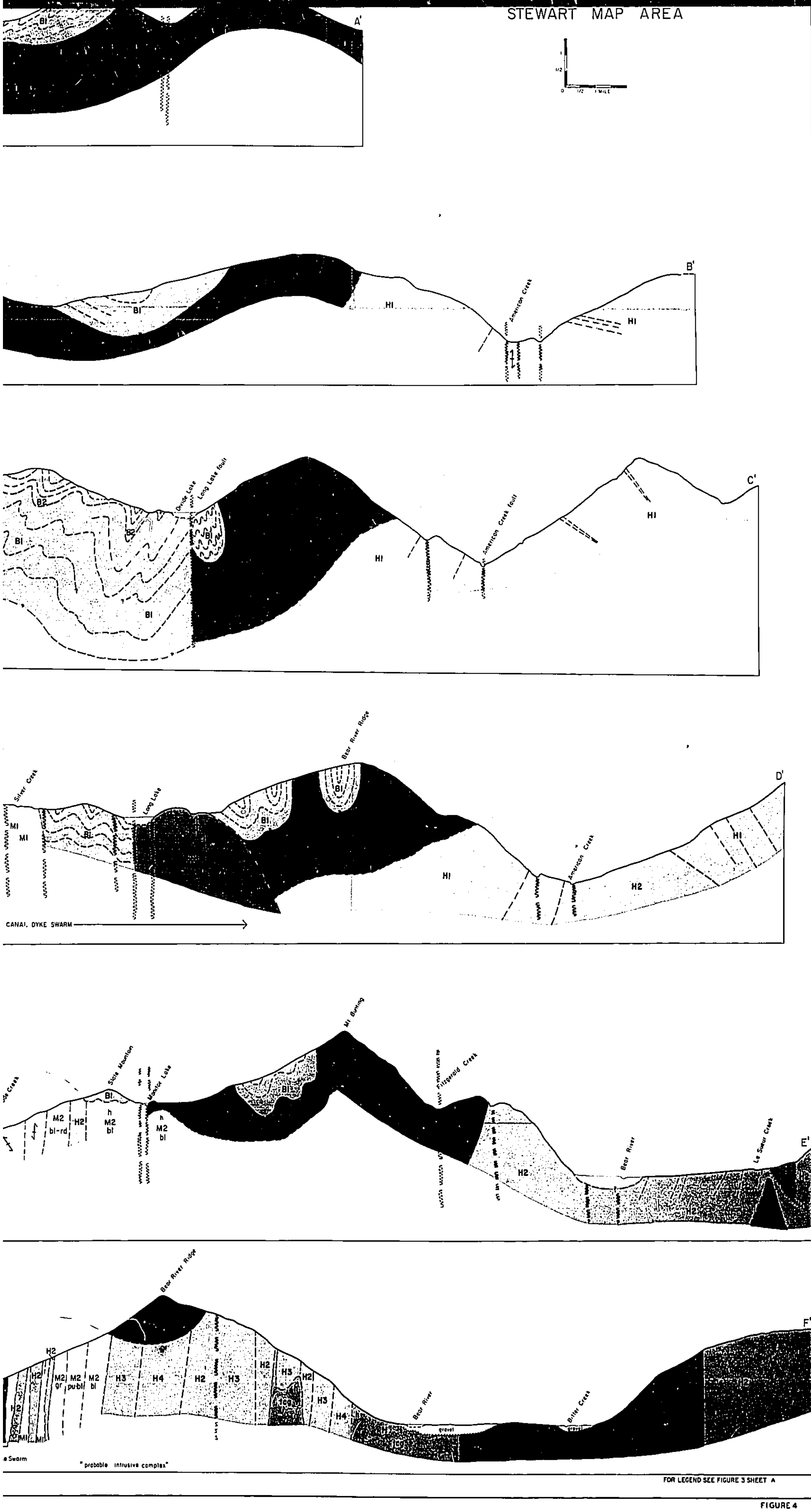


Figure 4 B
GEOLOGICAL SECTIONS
STEWART MAP AREA

2 of 2


A
BERENDON GLACIER
BERENDON GLACIER
Projection of the Tunnel Portal Granduc mill site
Bully Creek
H2
H4
gr
Bl
2000
1000
B
4000
3000
2000
1000
H2
Summit Lake
H2
M3
Bl
Bl
Bl
C
2000
1000
Sea Level
Bl
H2
SALMON GLACIER
gravel etc. under ice
h
H2
M3
B4
B2
B2
B2
Bl
B2
Bl
Bl
Divide Lake
Long Lake fault
D
4000
3000
2000
1000
Sea Level
BOUNDARY GLACIER
H2
tcg
tcg
H
SALMON GLACIER
gravel
Bl
Big Missouri Ridge
H2
Hl
H2
Ml
Ml
Silver Creek
Long Lake
Bl
SECTION TRANSECTED BY THE PORTLAND CANAL DYKE SWARM
E
4000
3000
2000
1000
Sea Level
tcg
tcg
SALMON GLACIER
gravel
H2
PS
tcg
Hanama Lake
Cascade Creek
PS
Ml
M2
bl-rd
H2
Slate Mountain
Bl
h
M2
bl
Monitor Lake
h
M2
bl
F
1000
Sea Level
tcg
Texas Creek
tcg
M3
Salmon River
Ml
tcg
Ml
Premier
Premier Dyke Swarm
H2
H2
M2
gr
M2
pubII
M2
bl
H3
H4
H2
H3
Bear River Ridge
"probable intrusive complex"



STEWART MAP AREA
1/2
1 MILE
A'
B1
B'
H1
American Creek
C'
B2
Divide Lake
Long Lake fault
American Creek fault
D'
Silver Creek
M1
Long Lake
Bear River Ridge
H2
CANAL DYKE SWARM
E'
Slate Mountain
Monitor Lake
Mt Bunting
Fitzgerald Creek
M2
bl-rd
bl
Bear River
Le Sueur Creek
F'
Bear River Ridge
H3
H4
gr
pu-bl
gravel
Bitter Creek
"probable intrusive complex"
FOR LEGEND SEE FIGURE 3 SHEET A

FIGURE 4

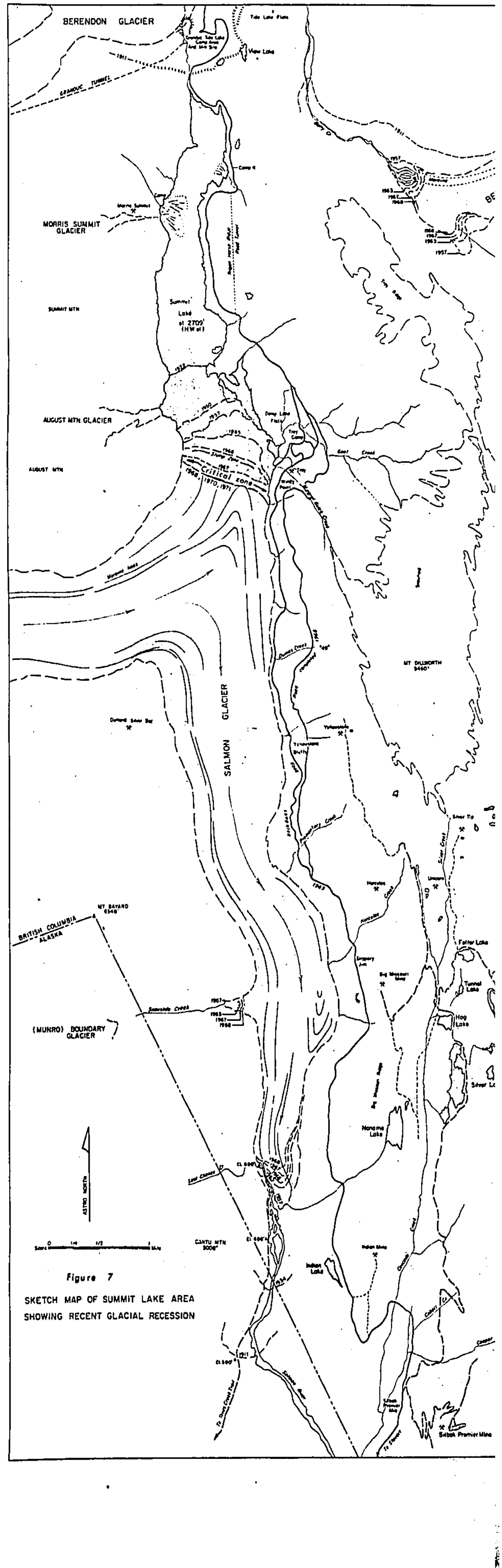
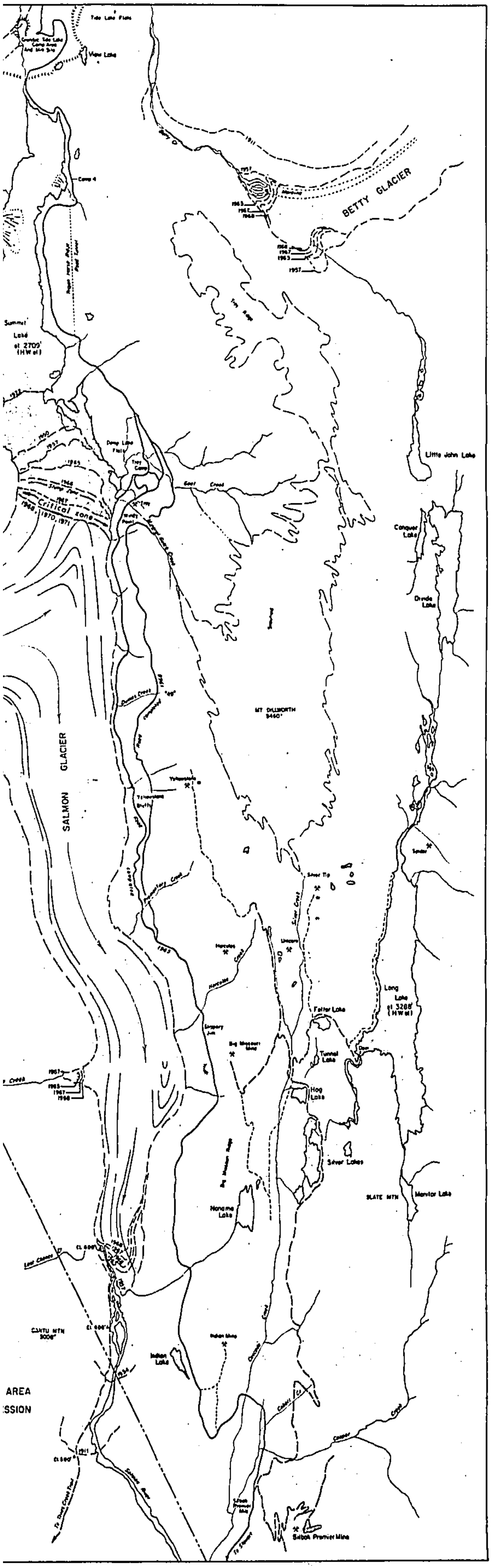


Figure 7

SKETCH MAP OF SUMMIT LAKE AREA SHOWING RECENT GLACIAL RECESSION


BETTY GLACIER
View Lake
Camp 4
Summit Lake el 2709' (HWel)
Critical zone
Little John Lake
Conquer Lake
SALMON GLACIER
MT DILLWORTH 9460'
Long Lake el 3208' (HWel)
Fetter Lake
Tunnel Lake
Hog Lake
Silver Lakes
SLATE MTN
Monitor Lake
Indian Lake
AREA
Silbak Premier Mine

1 of

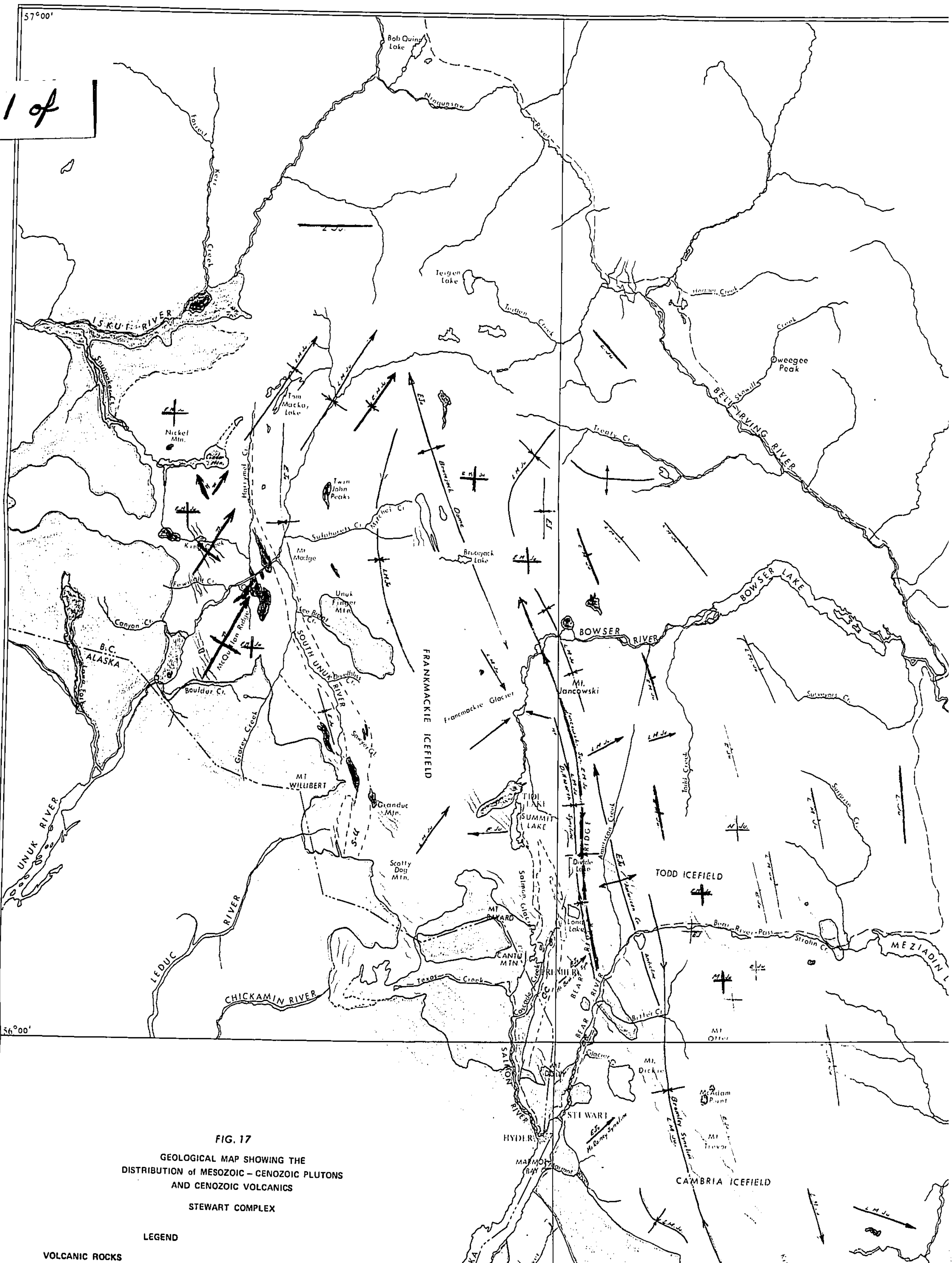


FIG. 17

GEOLOGICAL MAP SHOWING THE DISTRIBUTION of MESOZOIC – CENOZOIC PLUTONS AND CENOZOIC VOLCANICS

STEWART COMPLEX

LEGEND

VOLCANIC ROCKS

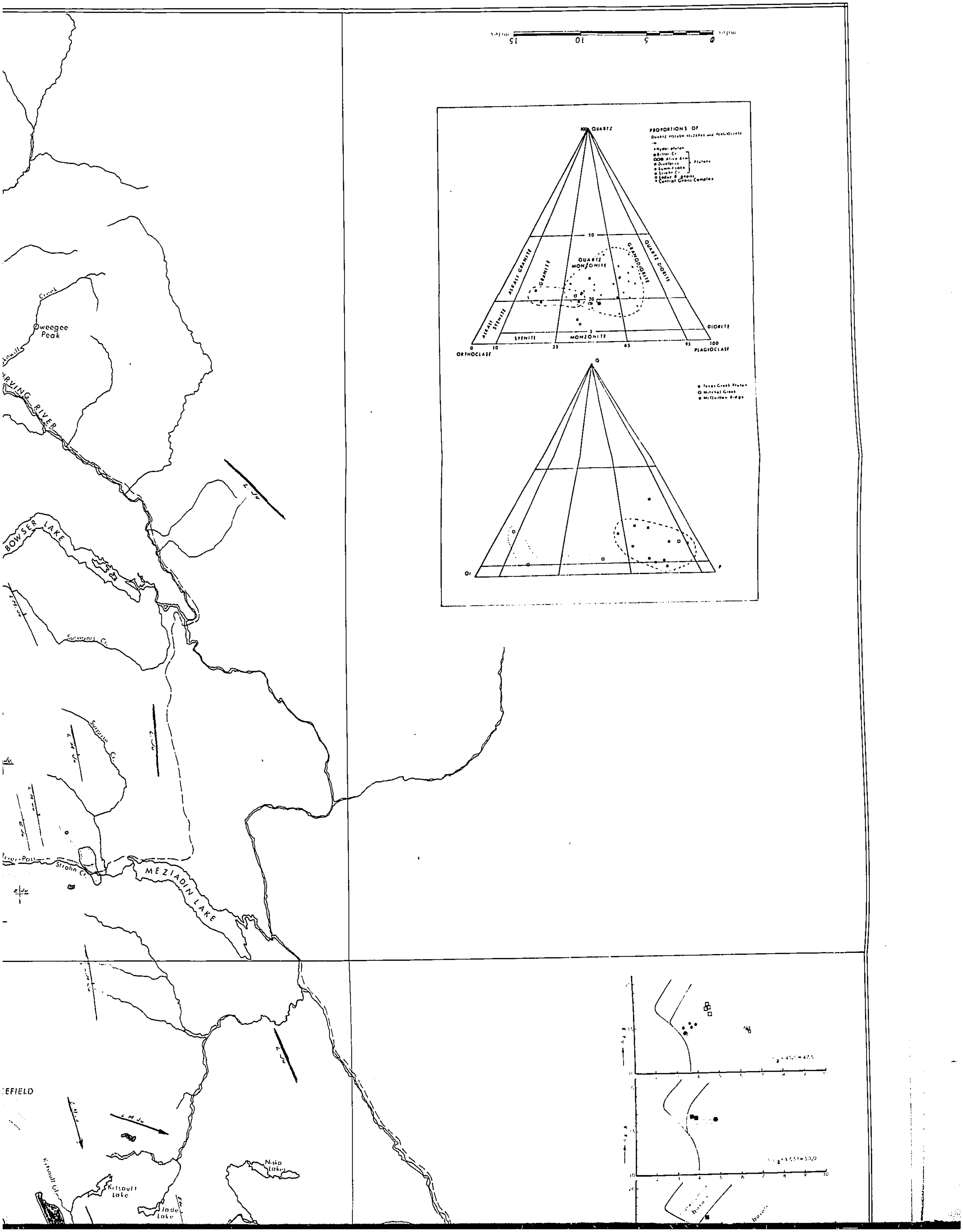
QUATERNARY

Plateau basalts, basalt flows, cinder cones, etc.

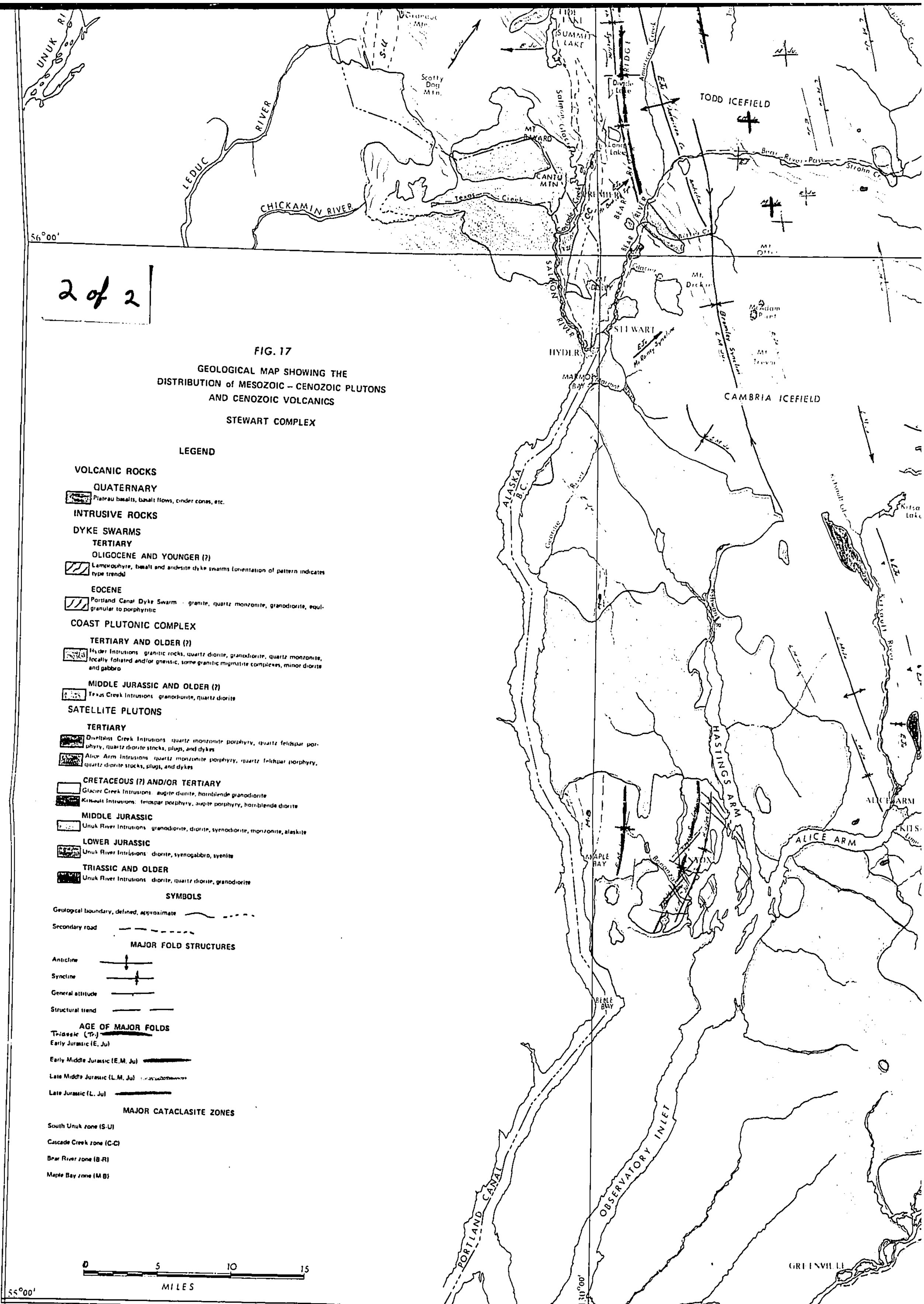
INTRUSIVE ROCKS

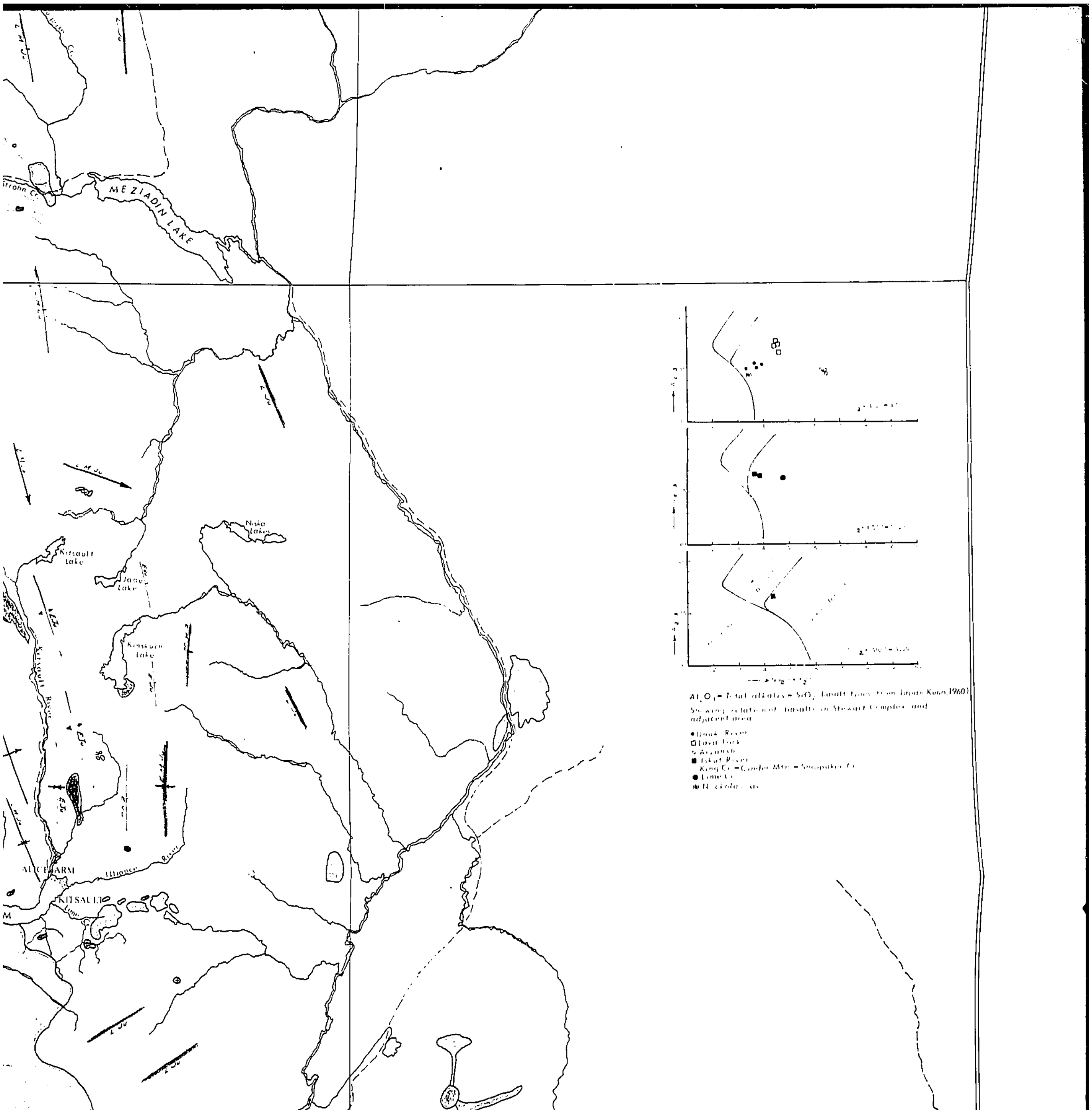
DYKE SWARMS

TERTIARY



Oweegee Peak
IRVING RIVER
BOWSER LAKE
Surveyors Cr.
Strohn Cr.
MEZIADIN LAKE
Kitsault Lake
Jade Lake
PROPORTIONS OF
QUARTZ
ALKALI GRANITE
GRANITE
QUARTZ MONZONITE
GRANODIORITE
QUARTZ DIORITE
ALKALI SYENITE
SYENITE
MONZONITE
DIORITE
ORTHOCLASE
PLAGIOCLASE


2 of 2
FIG. 17
GEOLOGICAL MAP SHOWING THE DISTRIBUTION of MESOZOIC – CENOZOIC PLUTONS AND CENOZOIC VOLCANICS
STEWART COMPLEX
LEGEND
VOLCANIC ROCKS
QUATERNARY
Plateau basalts, basalt flows, cinder cones, etc.
INTRUSIVE ROCKS
DYKE SWARMS
TERTIARY
OLIGOCENE AND YOUNGER (?)
Lamprophyre, basalt and andesite dyke swarms (orientation of pattern indicates type trend)
EOCENE
Portland Canal Dyke Swarm - granite, quartz monzonite, granodiorite, equigranular to porphyritic
COAST PLUTONIC COMPLEX
TERTIARY AND OLDER (?)
Hyder Intrusions granitic rocks, quartz diorite, granodiorite, quartz monzonite, locally foliated and/or gneissic, some granitic migmatite complexes, minor diorite and gabbro
MIDDLE JURASSIC AND OLDER (?)
Texas Creek Intrusions granodiorite, quartz diorite
SATELLITE PLUTONS
TERTIARY
Divelbliss Creek Intrusions quartz monzonite porphyry, quartz feldspar porphyry, quartz diorite stocks, plugs, and dykes
Alice Arm Intrusions quartz monzonite porphyry, quartz feldspar porphyry, quartz diorite stocks, plugs, and dykes
CRETACEOUS (?) AND/OR TERTIARY
Glacier Creek Intrusions: augite diorite, hornblende granodiorite
Kitsault Intrusions: feldspar porphyry, augite porphyry, hornblende diorite
MIDDLE JURASSIC
Unuk River Intrusions granodiorite, diorite, syenodiorite, monzonite, alaskite
LOWER JURASSIC
Unuk River Intrusions: diorite, syenogabbro, syenite
TRIASSIC AND OLDER
Unuk River Intrusions diorite, quartz diorite, granodiorite
SYMBOLS
Geological boundary, defined, approximate
Secondary road
MAJOR FOLD STRUCTURES
Anticline
Syncline
General attitude
Structural trend
AGE OF MAJOR FOLDS
Triassic (Tr.)
Early Jurassic (E. Ju)
Early Middle Jurassic (E.M. Ju)
Late Middle Jurassic (L.M. Ju)
Late Jurassic (L. Ju)
MAJOR CATACLASITE ZONES
South Unuk zone (S-U)
Cascade Creek zone (C-C)
Bear River zone (B-R)
Maple Bay zone (M-B)
0 5 10 15
MILES
56°00'
55°00'
130°00'
UNUK R.
LEDUC RIVER
CHICKAMIN RIVER
SUMMIT LAKE
Scotty Dog Mtn.
MT. BAYARD
CANTU MTN
TODD ICEFIELD
BEAR RIVER
SALMON RIVER
STEWART
HYDER
MARMOT BAY
CAMBRIA ICEFIELD
ALASKA
B.C.
HASTINGS ARM
ALICE ARM
MAPLE BAY
OBSERVATORY INLET
PORTLAND CANAL
GREENVILLE
Fig. 17



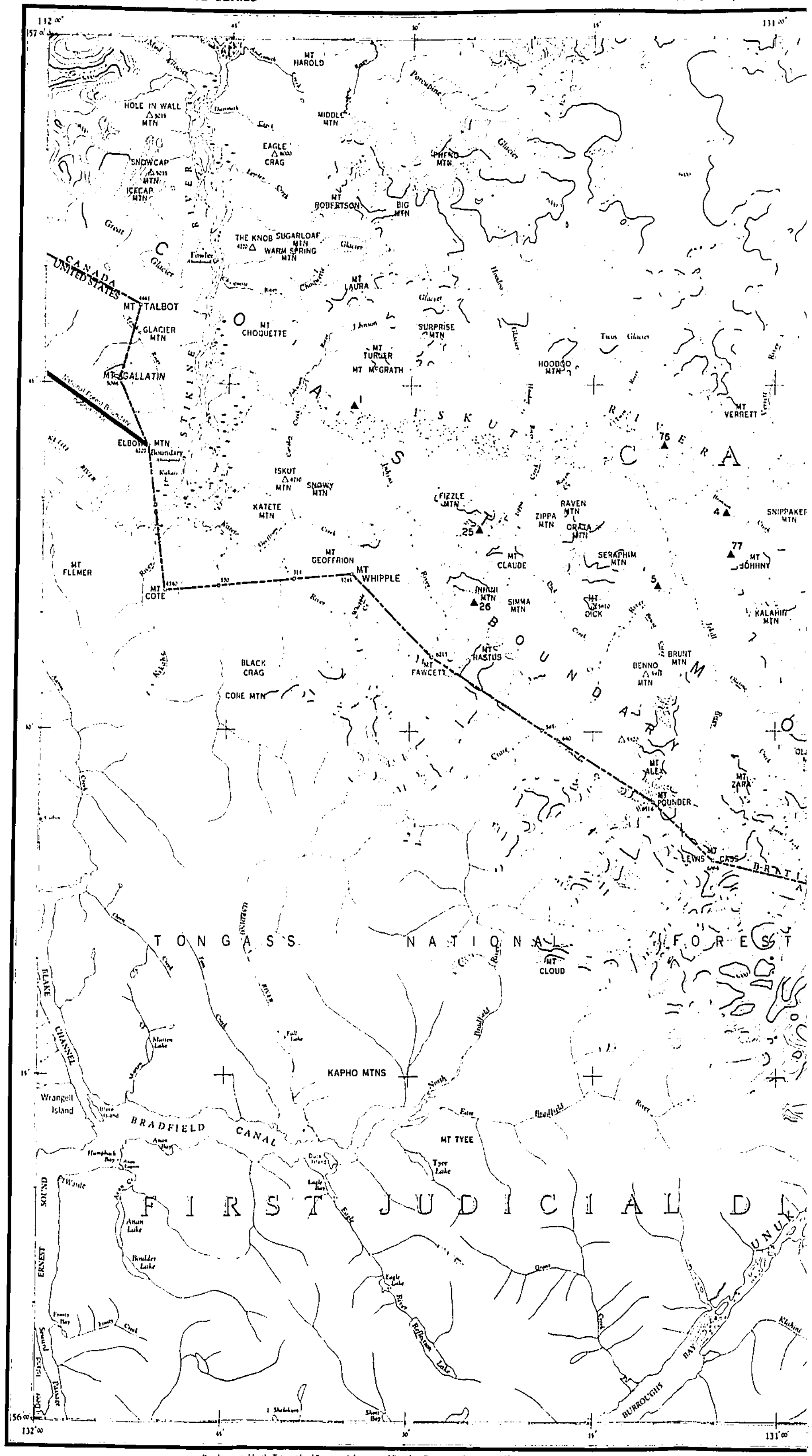
MEZIADIN LAKE
Strohn Cr.
Kitsault Lake
Kitsault River
ALICE ARM
KITSAULT
Illiance River
NASS RIVER
AIYANSH
Lava Lake
KITWANGA
RIVER
CEDARVALE
128°00'

1 of 1

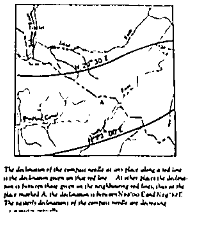
NATIONAL TOPOGRAPHIC SERIES

PRELIMINARY MINERAL

HONOURABLE FRANK RICHTER, MINISTER



THE DECLINATION OF THE COMPASS NEEDLE, 1955



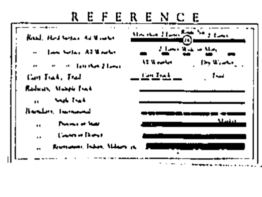
Based on control by the Topographical Survey and International Boundary Commission, Department of Mines and Technical Surveys. Compiled, drawn and printed by the ARMY SURVEY ESTABLISHMENT R.C.E., Department of National Defence, 1953-55. Aerial photography by the R.C.A.F. 1949. Area in Alaska from the Bradfield Canal map of the United States Geological Survey.

ISKUT I

CANADA–UNITED

Scale 1 : 250,0

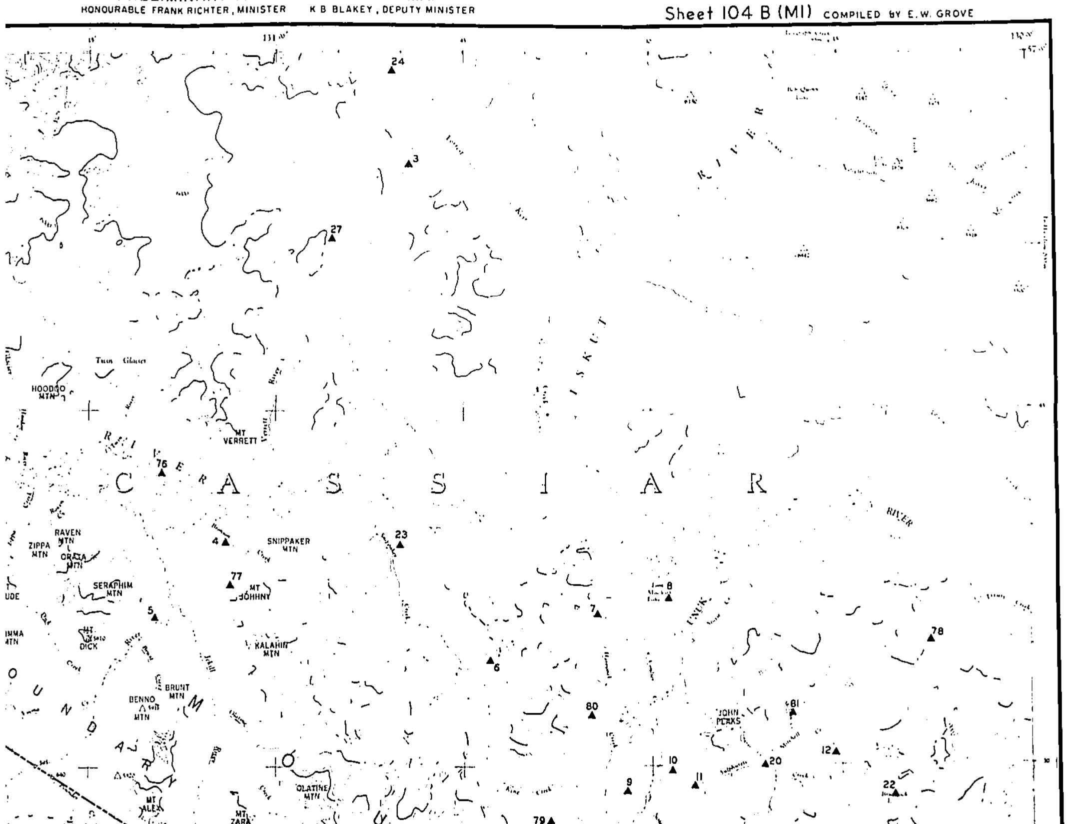
REFERENCE



PRELIMINARY MINERAL INVENTORY MAP

HONOURABLE FRANK RICHTER, MINISTER K B BLAKEY, DEPUTY MINISTER

Sheet 104 B (MI) COMPILED BY E.W. GROVE



ISKUT RIVER

CANADA-UNITED STATES

Scale 1 : 250,000

1 Inch to 4 Miles Approximately

REFERENCE

Sheet 104 B (MI) FIG. 22A

1 of 1

Data compiled from published and unpublished reports.

Accuracy of location

- ● known within a radius of 1,000 feet
- ▲ 1,000 feet to 2 miles
- ■ not known within 2 miles

Location and name subject to revision. Data known to be incomplete.

Copies of this map may be obtained for $1.00 per sheet. Orders for maps should specify the map number and letter, for example 104A-M1. Orders should be addressed, with prepayment, to the

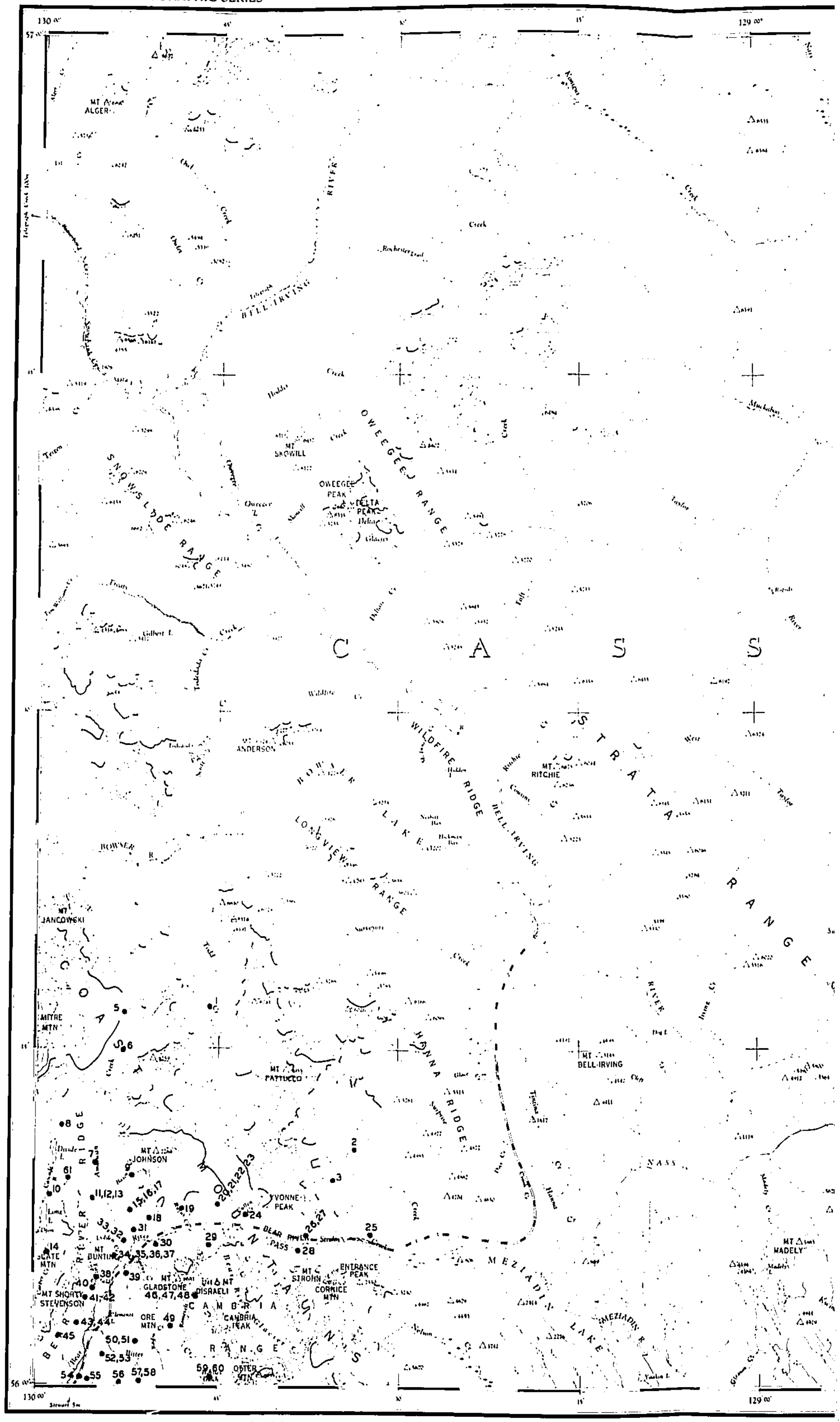
Chief, Mineralogical Branch,
Department of Mines and Petroleum Resources,
Victoria, B.C.

MAP NO	NAME	PROPERTY NO
104A-1	TODD GROUP (Cu)	3223
2	SURPRISE GROUP	3224
3	GOAT GROUP (Ag, Zn, W)	3225
5	NORTH-WESTERN AERIAL PROSPECTORS LTD (Ag, Au)	3226
6	EXCELSIOR PROSPECTING SYNDICATE (Au, Ag)	3227
7	AMERICAN CREEK MINING CO. LTD (Cu, Fe)	3228
8	AMERICAN MINING & MILLING CO. LTD. (BETTY GROUP) (Ag, Pb, Zn)	3229
9	ANACONDA GROUP (Ag, Pb, Zn)	3230
10	SPIDER GROUP (Au, Ag, Pb, Zn)	3231
11	AMERICAN GIRL GROUP (Ag, Pb, Zn)	3232
12	LUCKY JIM GROUP (Ag, Pb, Zn)	3233
13	MOUNTAIN BOY GROUP (Ag, Pb, Zn)	3234
14	MONITOR GROUP (Zn, Pb, Fe)	3235
15	KANSAS GROUP (Ag, Pb, Zn)	3236
16	TERMINUS MINES LTD (Ag, Pb, Zn)	3237
17	VANCOUVER MINES LTD (Fe, Cu)	3238
18	MORNING STAR GROUP (Cu)	3239
19	[illegible] ARGENTA MINES LTD (Cu, Ag)	3240
20	BARITE GOLD MINES LTD (Au)	3241
21	RED TOP (Cu, Ag)	3242
22	BORNITE (Cu, Pb)	3243
23	DIXIA (Pb, Cu)	3244
24	GEORGE ENTERPRISE MINING CO. LTD (Cu)	3245
25	.... (Mo)	3246
26	MONTREAL GROUP (Pb, Zn, Au, Ag)	3247
27	SOUTHERN CROSS GROUP (Cu, Pb, Zn, Ag)	3248
28	BEAR PASS MINING SYNDICATE (Pb, Zn)	3249
29	GEORGE COPPER GROUP (Cu, Fe)	3250
30	BEAR RIVER CANYON MINING CO. LTD (Pb, Zn)	3251
31	PORTLAND [illegible] GROUP (Pb, Zn)	3252
32	GALENA FARM GROUP (Pb)	3253
33	MORNING GROUP (Zn)	3254
34	BIG CASINO MINING CO. LTD (Cu, Pb)	3255
35	INITIAL GROUP (Fe, Cu, Pb)	3256
36	RED CLIFF EXTENSION MINING CO. LTD (Cu, Pb)	3257
37	RED CLIFF MINING CO. LTD. (Cu, Fe, Zn)	3258
38	INDEPENDENCE GOLD MINING CO (Au, Ag, Pb, Zn)	3259
39	RUBY SILVER MINES LTD. (Ag, Pb, Zn)	3260
40	A and T GROUP (Cu, Fe)	3261
41	DALHOUSIE and ROCK OF AGES GROUP (Pb, Zn, Au, Ag)	3262
42	PALMER GROUP (Pb, Zn, Au, Ag)	3263
43	AZTEC GROUP (Cu, Zn)	3264
44	INTERNATIONAL PORTLAND MINING CO. (Pb, Zn, Fe)	3265
45	MC GROUP (Cu, Fe)	3266
46	JUTLAND GROUP (Ag, Pb)	3267
47	LUCKY DOTE GROUP (Ag, Pb, Zn)	3268
48	ST. ELMO GROUP (Ag, Pb)	3269
49	MAYOU GOLD COPPER CO. LTD. (Pb, Cu)	3270
50	LITTLE WONDER GROUP (Ag, Pb, Zn, Cu)	3271
51	ORE MOUNTAIN MINING CO. LTD (Pb)	3272
52	AMERICA'S GIRL GROUP (Cu)	3273
53	GOLD BAR NO. 1 CLAIM (Au)	3274
54	TYEE GROUP (Au)	3275
55	MAYFLOWER GROUP (Pb, Zn)	3276
56	EMPEROR MINES LTD (Pb, Zn, Sb)	3277
57	GOLDIE GROUP (Pb, Ag)	3278
58	SUPERIOR MINES LTD. (Ag)	3279
59	[illegible] GROUP (Pb, Zn, Cu, As, Au, Ag)	3280
60	OLD CHUM GROUP (Pb, Zn, Cu)	3281
61	SILVER CROWN (Pb, Zn, Cu, Ag)	3282

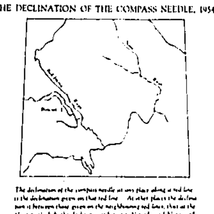
NATIONAL TOPOGRAPHIC SERIES

PRELIMINARY MINERAL INVEN

HONOURABLE FRANK RICHTER, MINISTER   K. B. BLAKE



THE DECLINATION OF THE COMPASS NEEDLE, 1954



The declination of the compass needle at any place along a red line is the declination given on that red line. At other places the declination is between those given on the neighbouring red lines. The annual decrease of the compass needle is decreasing 4 minutes annually.

Surveyed and compiled by the TOPOGRAPHICAL SURVEY, DEPARTMENT OF MINES AND TECHNICAL SURVEYS and the SURVEYS AND MAPPING BRANCH, DEPARTMENT OF LANDS AND FORESTS, BRITISH COLUMBIA. Produced by the ARMY SURVEY ESTABLISHMENT R.C.E.

December 1964 - Additional detail shown by purple overprint may not be positioned as accurately as the original detail.

REFERENCE

Road, Hard Surface, All Weather	
Loose Surface, All Weather	
Less than 2 Lanes	
Cart Track, Trail	
Railway, Multiple Track	
Single Track	
Boundary, International	
Province or State	
County or District	
Reservation, Indian, Military etc.	

BOWSER L.

BRITISH COLUMBIA

Scale 1 : 250,000

1 Inch to 4 Miles Approximately

Miles

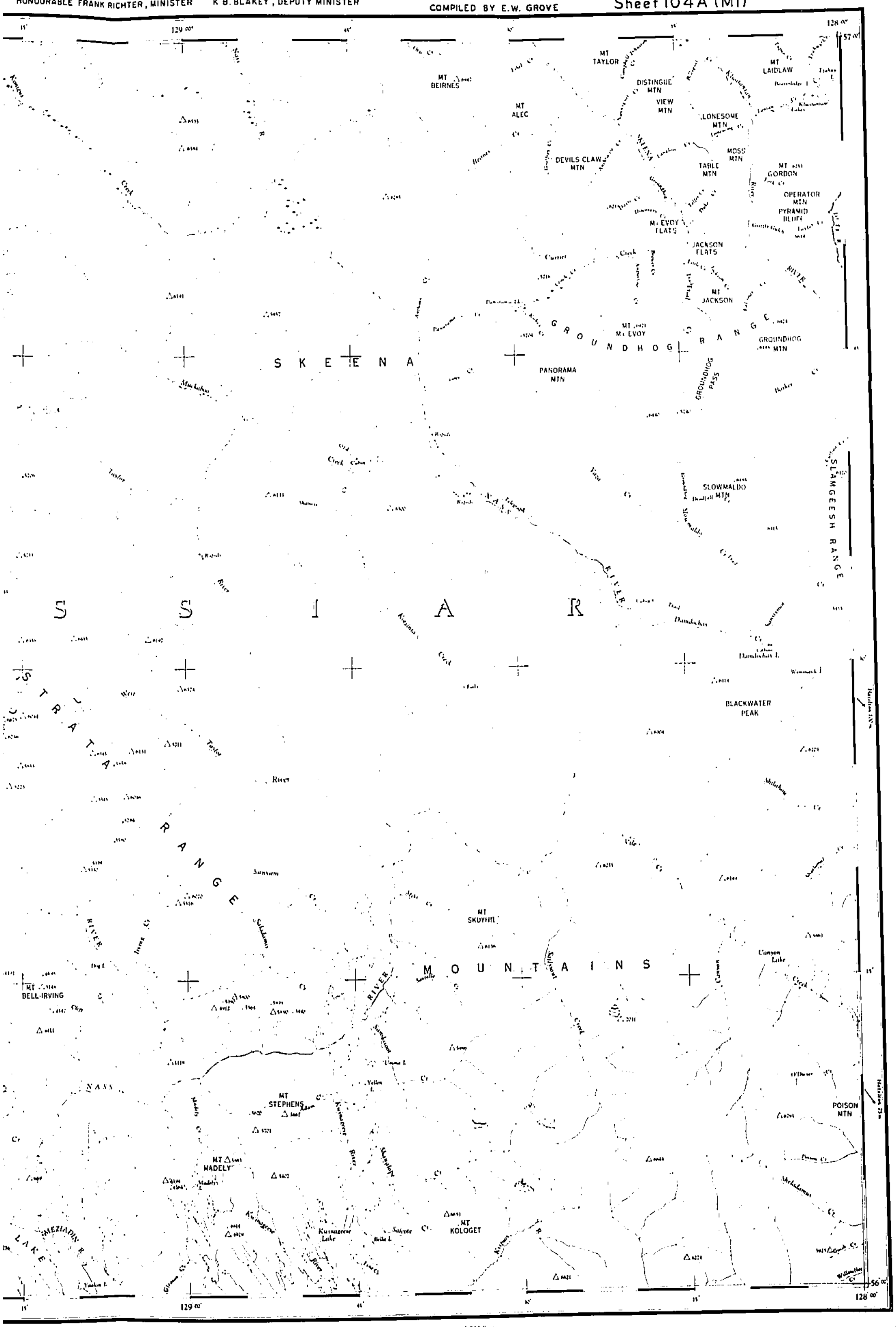
Kilometres

PRELIMINARY MINERAL INVENTORY MAP

HONOURABLE FRANK RICHTER, MINISTER K. B. BLAKEY, DEPUTY MINISTER

COMPILED BY E.W. GROVE

Sheet 104 A (MI)



Contour interval 500 Feet

North American Datum 1927

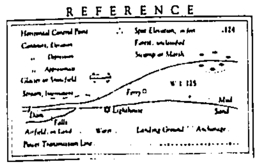
BOWSER LAKE

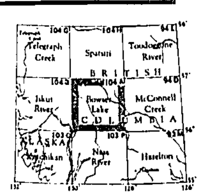
BRITISH COLUMBIA

Scale 1 : 250,000

1 Inch to 4 Miles Approximately

REFERENCE





Sheet 104 A (MI) FIG. 22 B

1 of 1

Data compiled from published and unpublished reports.

Accuracy of location:

- ● known within a radius of 1,000 feet
- ▲ 1,000 feet to 2 miles
- ◉ not known within 2 miles

Location and name subject to revision. Data known to be incomplete.

Copies of this map may be obtained for $1.00 per sheet. Orders for maps should specify the map number and letter, for example, 103P (M1). Orders should be addressed, with prepayment, to the

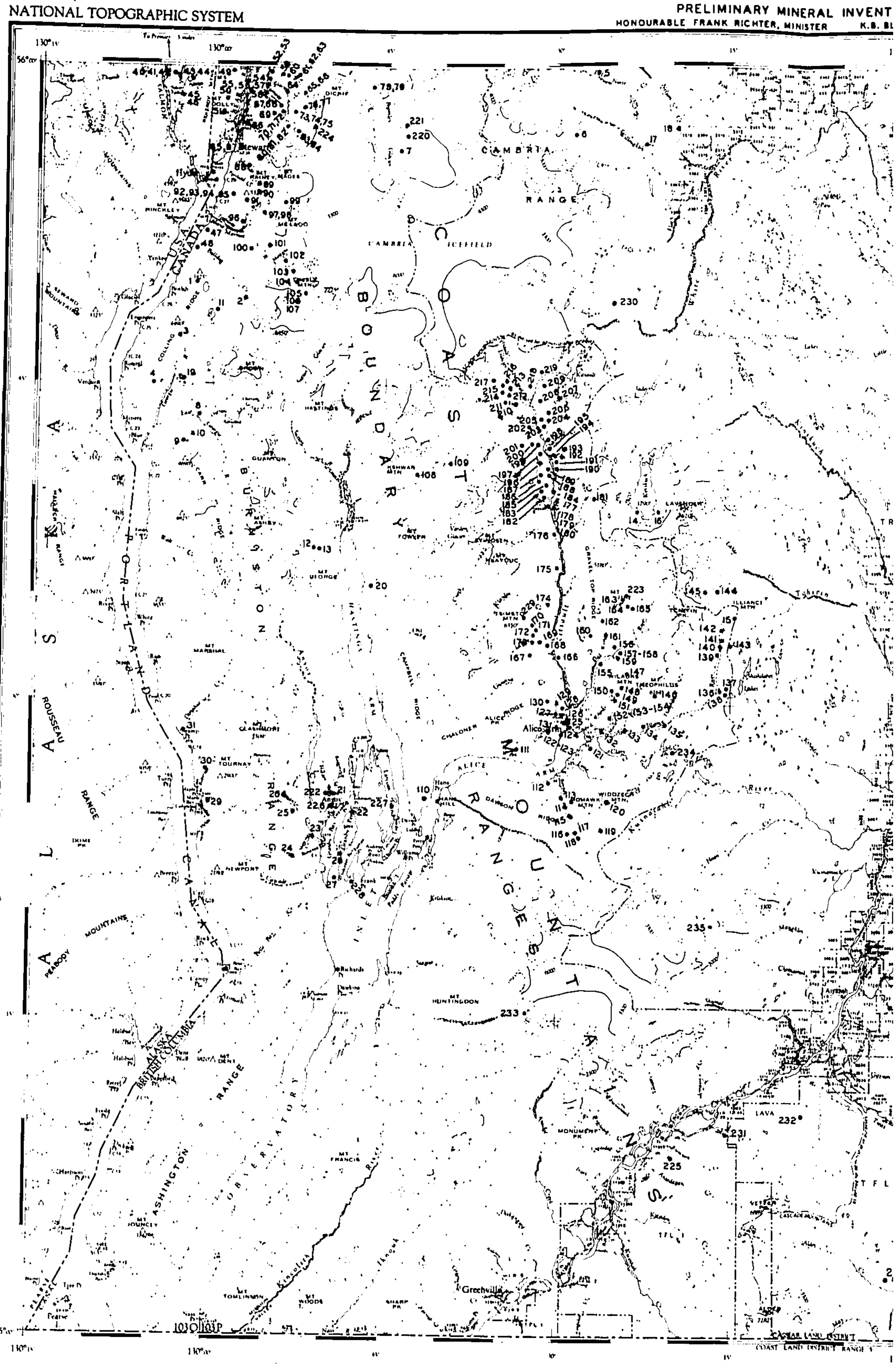
Chief of the Mineralogical Branch,
Department of Mines and Petroleum Resources,
Victoria, B.C.

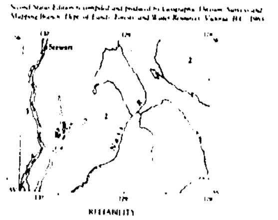
MAP NO		NAME	PROPERTY NO.
103P-	1	B.C. VERDE (Au, Ag, Cu)	1911
	2	MONDAY (Pb, Zn)	1912
	3	GEORGIA RIVER GOLD (Au)	1913
	4	JO (MONTROSE) (Cu)	1914
	5	BULLION (DELNORTE) (Au, Ag, Cu, Zn)	1915
	6	WILLOUGHBY METALS (Au)	1916
	7	E.H.S. (Pb, Zn, Au, Ag)	1917
	8	----- (Au, Pb, Zn)	1918
	9	ALASKAN (Ag, Pb, Zn)	1919
	10	----- (Cu, Pb, Zn)	1920
	11	GLORIA (NORTH COUNTRY MINING) (Au, Ag, Cu, Pb, Zn)	1921
	12	SADDLE (Au, Ag, Pb, Zn)	1922
	13	ELKHORN (Au)	1923
	14	SEABEE (Cu)	1924
	15	MONARCH (Cu)	1925
	16	KINSKUCH (Cu)	1926
	17	WILLOUGHBY CREEK PLACER (Au)	1927
	18	NELSON CREEK PLACER (Au)	1928
	19	I.M. (PEDRO GEORGIA) (Au, Ag, Cu)	1929
	20	MASTODON (Au, Ag, Cu)	1930
	21	HIDDEN CREEK (Cu, Fe, Au, Ag, Zn)	1931
	22	GRANBY POINT (Si, Au, Ag)	1932
	23	BONANZA MINE (Cu, Fe, Au, Ag, Zn)	1933
	24	REDWING (Cu, Fe, Au, Ag, Zn)	1934
	25	DOUBLE ED (Cu, Fe, Zn, Au, Ag)	1935
	26	SAX (EDEN) (Cu, Pb, Zn, Au, Ag)	1936
	27	GOLKEISH (Si, Au, Ag)	1937
	28	GOLD LEAF (Au, Ag)	1938
	29	MAPLE BAY (Cu, Fe)	1939
	30	OUTSIDER (Cu, Au, Ag)	1940
	31	SWAMP POINT (limestone)	1941
	32	BELLE VUE (Cu)	1942
	33	SUNSET (Cu)	1943
	34	MORNING STAR (Au, Ag, Pb, Zn)	1944
	35	ROSALEA (Au, Ag, Pb)	1945
	36	LADDIE (Au, Ag, Zn)	1946
	37	DYNAMITER (Au, Ag, Sb)	1947
	38	WHISKEY CREEK (Au, Ag, Pb, Zn)	1948
	39	MOOSE (Mo)	1949
	40	HOWARD (Pb, Zn)	1950
	41	SIXMILE (Au, Ag, Pb)	1951
	42	LAST SHOT (Au, Ag, Pb, Zn)	1952
	43	BISHOP (Au, Ag)	1953
	44	FISH CREEK (LOWER) (Au, Ag, Pb, Zn, Cu)	1954
	45	MOUNTAIN VIEW (Au, Ag, Pb)	1955
	46	LUCKY BOY EXT. (Au, Ag, Pb, Zn)	1956
	47	EMMA GORDON (Au, Ag, Cu, Pb, Zn)	1957
	48	BIG MIKE (Pb, Zn, Cu)	1958
	49	PRINCE JOHN (Cu, Au)	1959
	50	UNITED EMPIRE (Ag, Pb, Zn)	1960
	51	BAYVIEW (Ag, Pb, Zn)	1961
	52	DUNWELL (Ag, Pb, Zn)	1962
	53	SUNBEAM (Pb, Zn)	1963
	54	GEORGE E (Pb, Zn)	1964
	55	GLACIER CREEK	1965
	56	LITTLE WONDER (Pb, Zn)	1966
	57	O.K. FRACTION (Ag)	1967
	58	PHOENIX (Au, Ag, Pb, Zn)	1968
	59	LAKEVIEW (Ag, Pb, Zn)	1969
	60	NABOB (Cu)	1970
	61	COPPER KING (Au)	1971
	62	RUTH and FRANCIS (Au, Ag, Pb, Zn, Sb)	1972
	63	SILVER BOW (Ag, Pb)	1973
	64	MIMICO (Ag, Pb, Zn)	1974
	65	MORNING STAR (GLACIER CREEK) (Cu)	1975
	66	SUNSHINE (Cu)	1976
	67	BLACK BEAR (Pb, Zn)	1977
	68	PORTLAND CANAL (Au, Ag, Pb, Zn)	1978
	69	MOBILE (Ag, Pb, Zn)	1979
	70	AJAX (Pb, Zn)	1980
	71	ALBANY (Au, Ag, Pb, Zn)	1981
	72	HALLIE (Fe)	1982
	73	COLUMBIA (Ag, Pb)	1983
	74	RUSH-PORTLAND (Ag, Pb)	1984
	75	UNION	1985
	76	L & L (Au, Ag, Pb, Zn)	1986
	77	SILVER KING (Ag, Pb, Zn, Sb)	1987
	78	BLACK BEAR (Fe)	1988
	79	WINDSOR (Au, Ag, Pb, Zn)	1989
	80	BEN BOLT (Ag, Pb, Zn)	1990
	81	CHICAGO	1991
	82	COOK and DOBSON'S CLAIM	1992
	83	BLACK HILLS (Ag, Pb, Zn, Sb, Cu)	1993
	84	EXCELSIOR and EAGLE (Ag, Pb, Zn, Sb)	1994
	85	MOLLIE B (Mo, W, Pb, Zn)	1995
	86	COPPER CLIFF (Au, Ag, Cu)	1996
	87	GOLD ORE (Au, Ag, Pb)	1997
	88	SILVERADO (Au, Ag, Pb, Zn)	1998
	89	PROSPERITY and PORTER IDAHO (Au, Ag, Pb, Zn)	1999
	90	MELVIN (Ag, Pb)	2000
	91	ABERDEEN	2001
	92	COAST SILVER (Pb, Zn, Cu)	2002
	93	MOLLY B (Mo)	2003
	94	RED REEF (Cu)	2004
	95	SILVER BELL (Pb, Zn)	2005
	96	WIRE GOLD (Au)	2006
	97	FRASER (Au, Cu)	2007
	98	NORTH FORK BASIN (Ag, Pb, Zn)	2008
	99	DOMINION (Cu, Pb, Zn)	2009
	100	BI-METALLIC (Au, Ag, Pb, Zn, Cu)	2010
	101	PATRICIA (Au, Cu, Pb, Zn)	2011
	102	MARMOT METALS (Au, Ag, Pb, Zn)	2012
	103	MARMOT ENGINEER (Au, Pb, Zn)	2013
	104	WASHINGTON	2014
	105	HORNET (Au, Ag, Pb, Zn)	2015
	106	HIGH GRADE	2016
	107	PRINCE GEORGE (Cu, Pb, Zn)	2017
	108	VIMY RIDGE (Pb, Zn, Cu)	2018
	109	CARPENTER'S CLAIMS (Cu, Au)	2019
	110	HAYWIRE (Ni, Cu, Co)	2020
	111	TIDEWATER (Mo)	2021
	112	MACY MINE (Si)	2022
	113	ROUNDY CREEK (Mo)	2023
	114	MOHAWK (Ag, Zn)	2024
	115	KEYSTONE-SUNSET (Ag, Pb, Zn)	2025
	116	BASIN (Ag, Pb)	2026
	117	VERONA (Ag, Pb)	2027
	118	SILVER BOW (Ag)	2028
	119	TMS (Ag, Pb)	2029
	120	ALICE (Mo)	2030
	121	BEVERLEY (Cu, Zn)	2031
	122	UTOPIA (Ag, Pb, Zn)	2032
	123	BILLY BARTON (Ag, Pb, Zn)	2033
	124	CARIBOU FRACTION (Ag)	2034
	125	WOLF (Ag)	2035
	126	ESPERANZA (Ag, Cu, Pb, Zn)	2036
	127	ACADIA (Ag, Zn)	2037
	128	LONE MAID (Ag)	2038
	129	ANNA MACK (Ag)	2039
	130	PAYMASTER-ALICE (Ag)	2040
	131	INDEPENDENT (Ag, Pb, Zn)	2041
	132	CASEY (Pb)	2042
	133	THREE MILE	2043
	134	INGRAHAM'S CLAIMS (Ag, Pb)	2044
	135	SILVER LEAF (Ag)	2045
	136	IRON (Au, Ag)	2046
	137	BEAVER EXTENSION (Au)	2047
	138	GOLDEN CREST (Cu)	2048
	139	BELLEVUE (Ag, Pb)	2049
	140	GRAY GOOSE (Ag, Pb, Zn)	2050
	141	SILVER BELL (Ag, Cu)	2051
	142	SILVER BAR (Ag)	2052
	143	SILVER STAR (Ag)	2053
	144	YANKEE BOY (Ag, Pb)	2054
	145	GLACIER, LEFT OVER (Ag, Au, Cu)	2055
	146	HORSESHOE (Cu)	2056
	147	MAC (Zn)	2057
	148	STANDARD (Zn)	2058
	149	BILLY MAC (Zn)	2059
	150	HIGHLAND (Zn)	2060
	151	KENT and MAPLE LEAF (Zn)	2061
	152	ALAMOZA (Zn)	2062
	153	LONE STAR (Zn)	2063
	154	SILVER BELL (Zn)	2064
	155	SAN DIEGO (Cu)	2065
	156	WAR DANCE (Cu, Ag)	2066
	157	SILVER BAR (Zn)	2067
	158	I.X.L. (Zn)	2068
	159	SILVER CHORD (Zn)	2069
	160	RED BLUFF (Cu)	2070
	161	FOX (Cu, Zn)	2071
	162	OBSERVER (Cu, Pb, Zn)	2072
	163	LE ROY (Ag, Pb, Au, Mo)	2073
	164	IDA (Ag, Pb, Zn)	2074
	165	BUTTE (Mo)	2075
	166	RIVERSIDE (Ag, Pb)	2076
	167	B.J. and NEW WORLD (Ag, Pb)	2077
	168	CAPE NOME (Zn)	2078
	169	SILVER STAR (Ag, Pb)	2079
	170	LA ROSE (Ag, Pb)	2080
	171	ST. ELOI (Ag)	2081
	172	SPECULATOR NO. 2 (Ag)	2082
	173	BUNKER HILL (Ag, Pb)	2083
	174	EAGLE	2084
	175	HENDERSON (Ag)	2085
	176	ZORKA (Cu)	2086
	177	CANYON (Ag, Pb)	2087
	178	SILVER KING and EAGLE (Pb, Zn, Ag)	2088
	179	BOULDER (Cu)	2089
	180	REX (Ag, Au)	2090
	181	SILVER BASIN (Ag)	2091

NATIONAL TOPOGRAPHIC SYSTEM

PRELIMINARY MINERAL INVENT

HONOURABLE FRANK RICHTER, MINISTER K.B. BL





REFERENCE

NASS RIVE

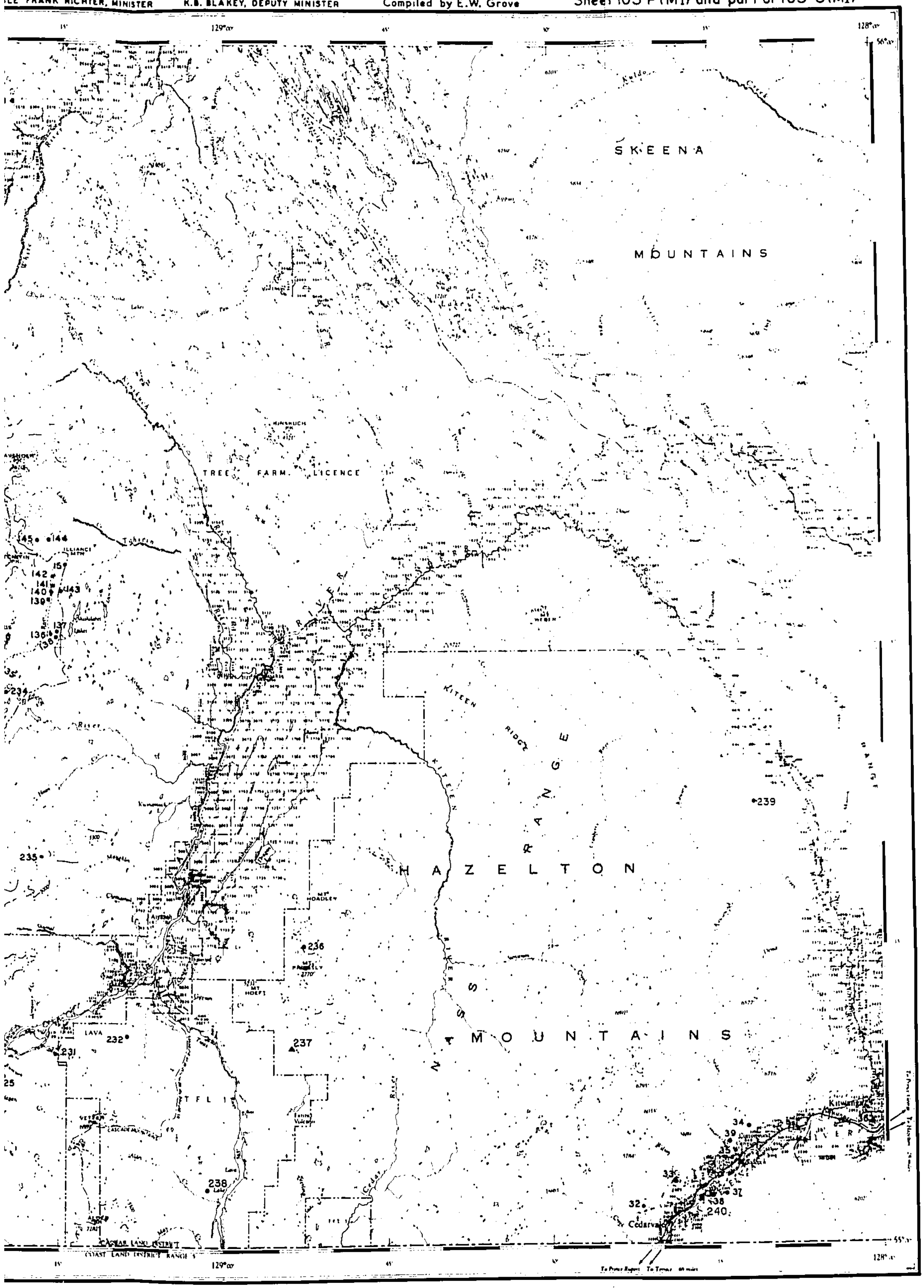
BRITISH COLUMBIA
CASSIAR LAND DISTRICT

Scale 1:250,000 or approximately 1 Inch

Scale of Kilometres

PRELIMINARY MINERAL INVENTORY MAP

ILE FRANK RICHTER, MINISTER K.B. BLAKEY, DEPUTY MINISTER Compiled by E.W. Grove Sheet 103 P(MI) and part of 103 O(MI)



NASS RIVER

BRITISH COLUMBIA

CASSIAR LAND DISTRICT

Scale 1:250,000 or approximately 1 Inch to 4 Miles

Scale of Kilometres

REFERENCE

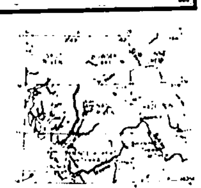
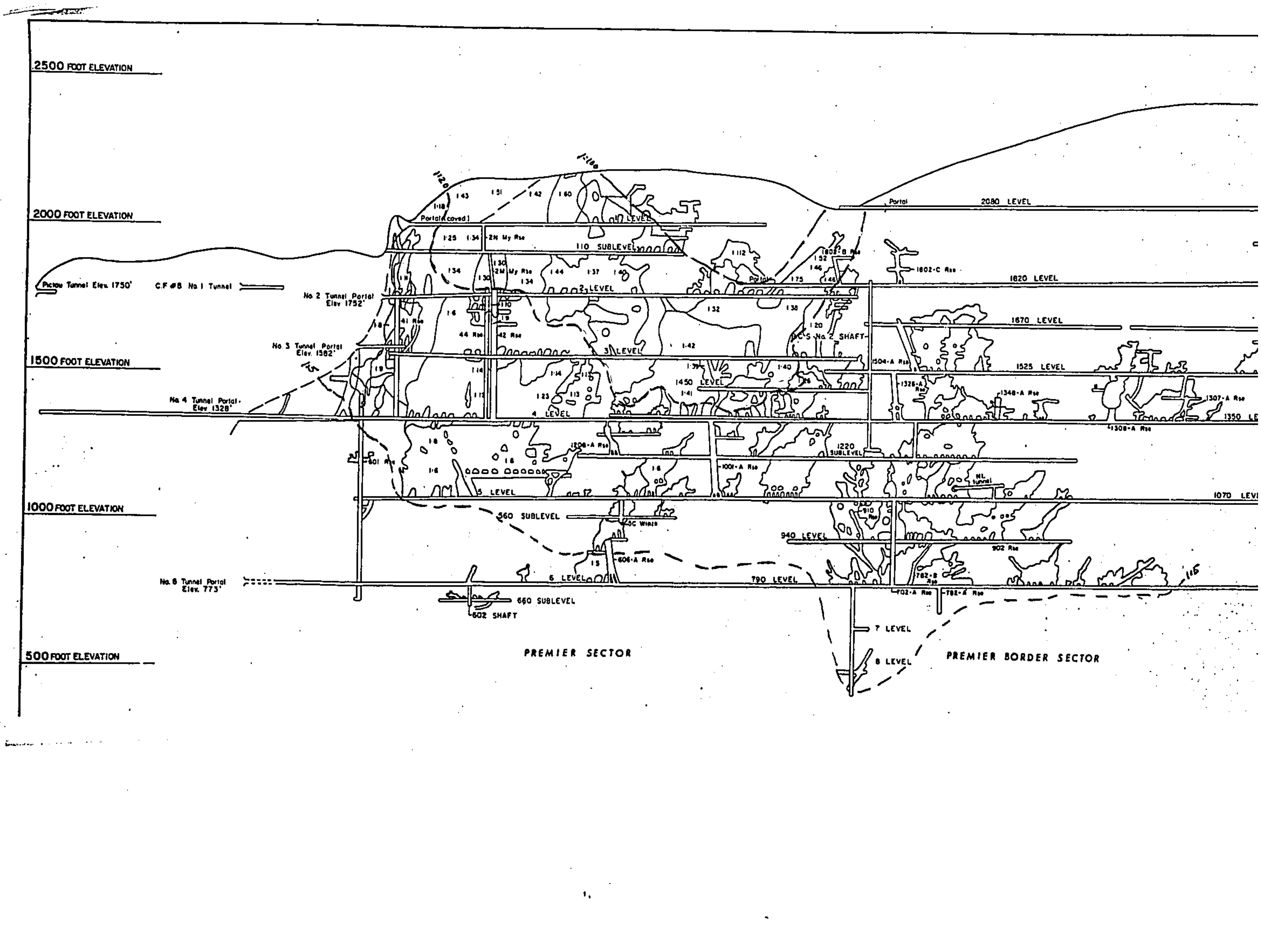


Fig. 22c

103 P(MI)


2500 FOOT ELEVATION
2000 FOOT ELEVATION
1500 FOOT ELEVATION
1000 FOOT ELEVATION
500 FOOT ELEVATION
Pictou Tunnel Elev. 1750'
C.F.#8 No. 1 Tunnel
No. 2 Tunnel Portal Elev. 1752'
No. 3 Tunnel Portal Elev. 1582'
No. 4 Tunnel Portal Elev. 1328'
No. 6 Tunnel Portal Elev. 773'
Portal (caved)
110 SUBLEVEL
2 LEVEL
3 LEVEL
4 LEVEL
5 LEVEL
6 LEVEL
7 LEVEL
8 LEVEL
560 SUBLEVEL
660 SUBLEVEL
602 SHAFT
790 LEVEL
940 LEVEL
1070 LEVEL
1220 SUBLEVEL
1350 LEVEL
1450 LEVEL
1525 LEVEL
1670 LEVEL
1820 LEVEL
2080 LEVEL
Portal
No. 2 SHAFT
PREMIER SECTOR
PREMIER BORDER SECTOR

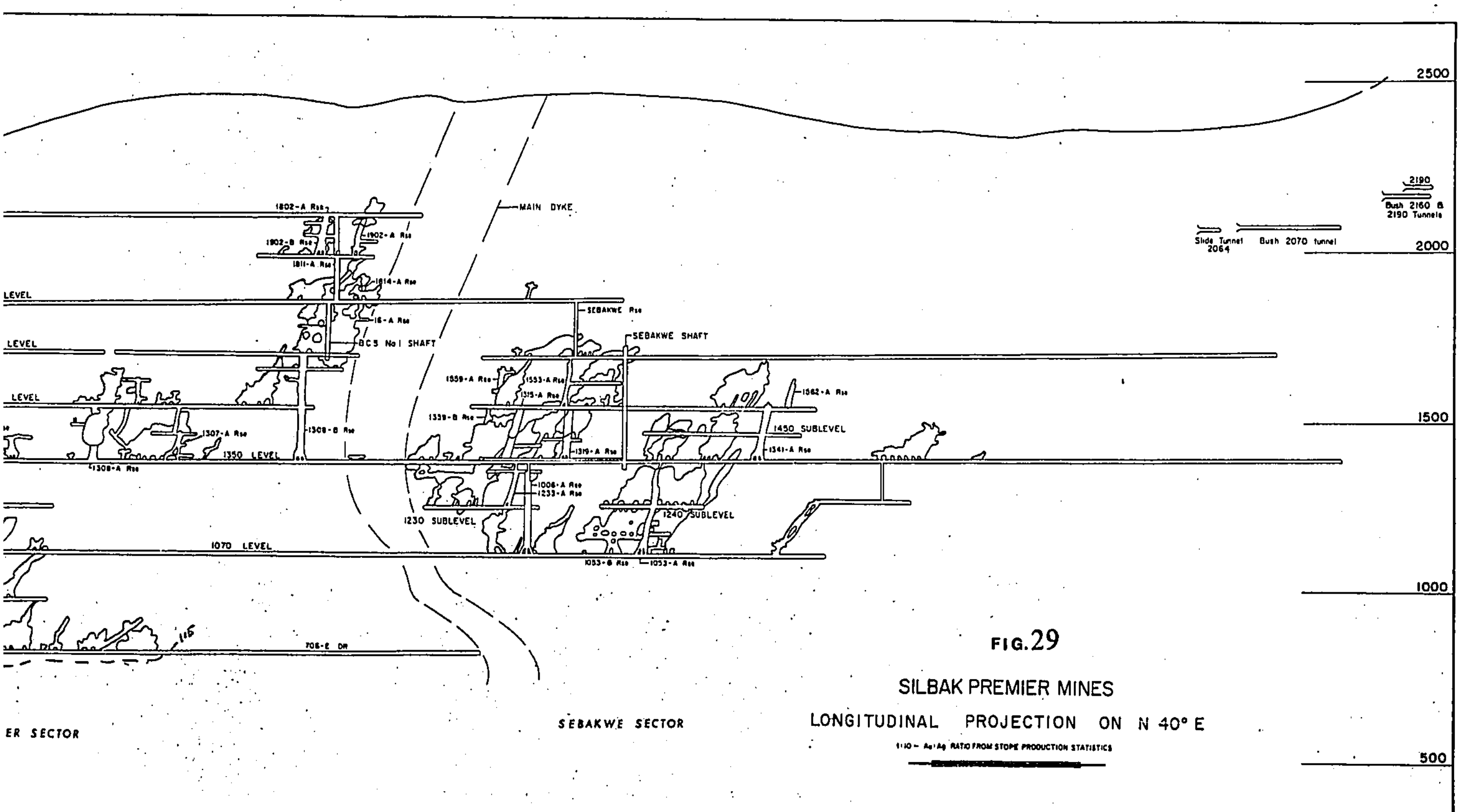
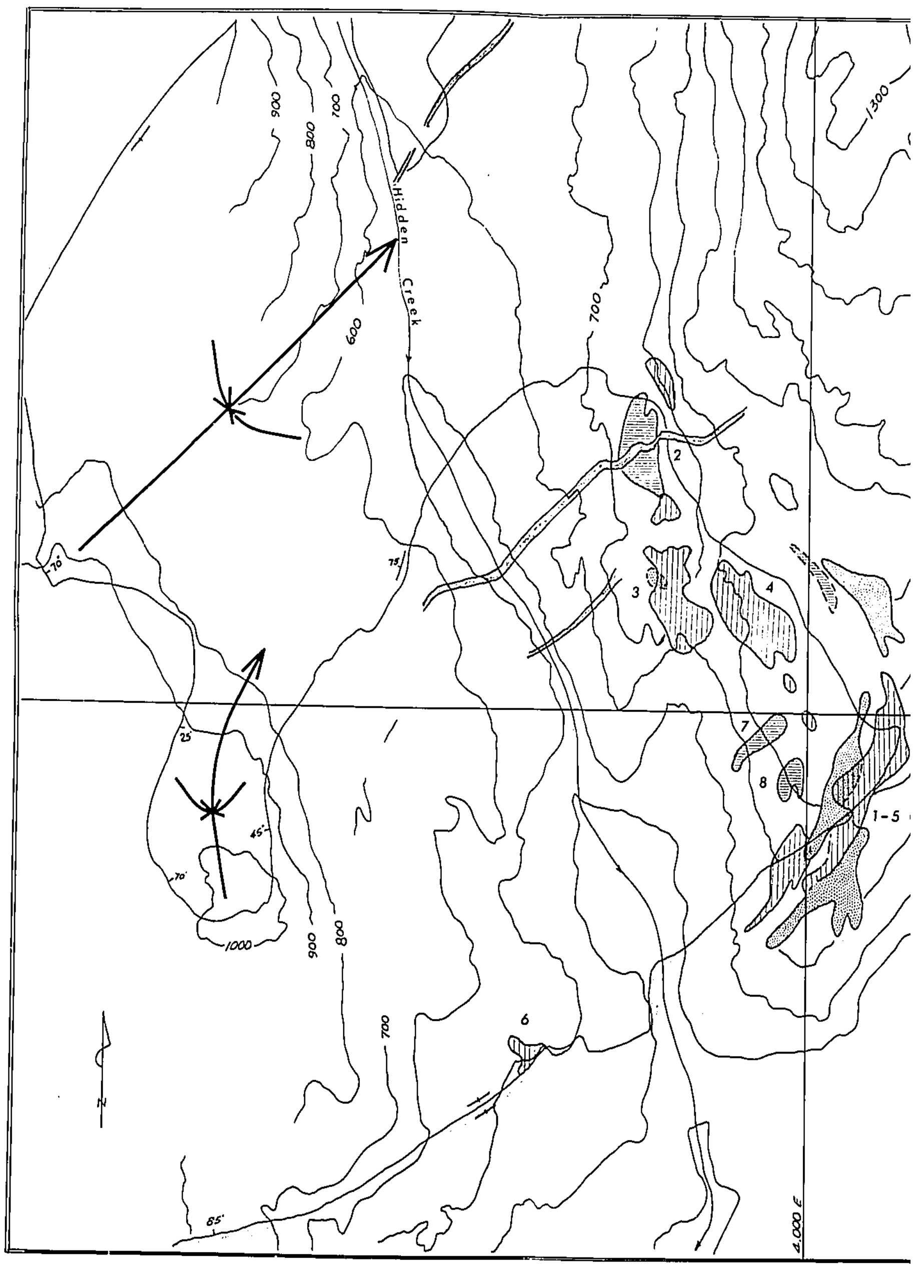


FIG. 29

SILBAK PREMIER MINES

LONGITUDINAL PROJECTION ON N 40° E

1:10 — Au:Ag RATIO FROM STOPE PRODUCTION STATISTICS


Hidden Creek
900
800
700
600
700
1300
70°
75
2
3
4
7
8
1-5
6
25
45°
70°
1000
900
800
700
85°
N
4,000 E

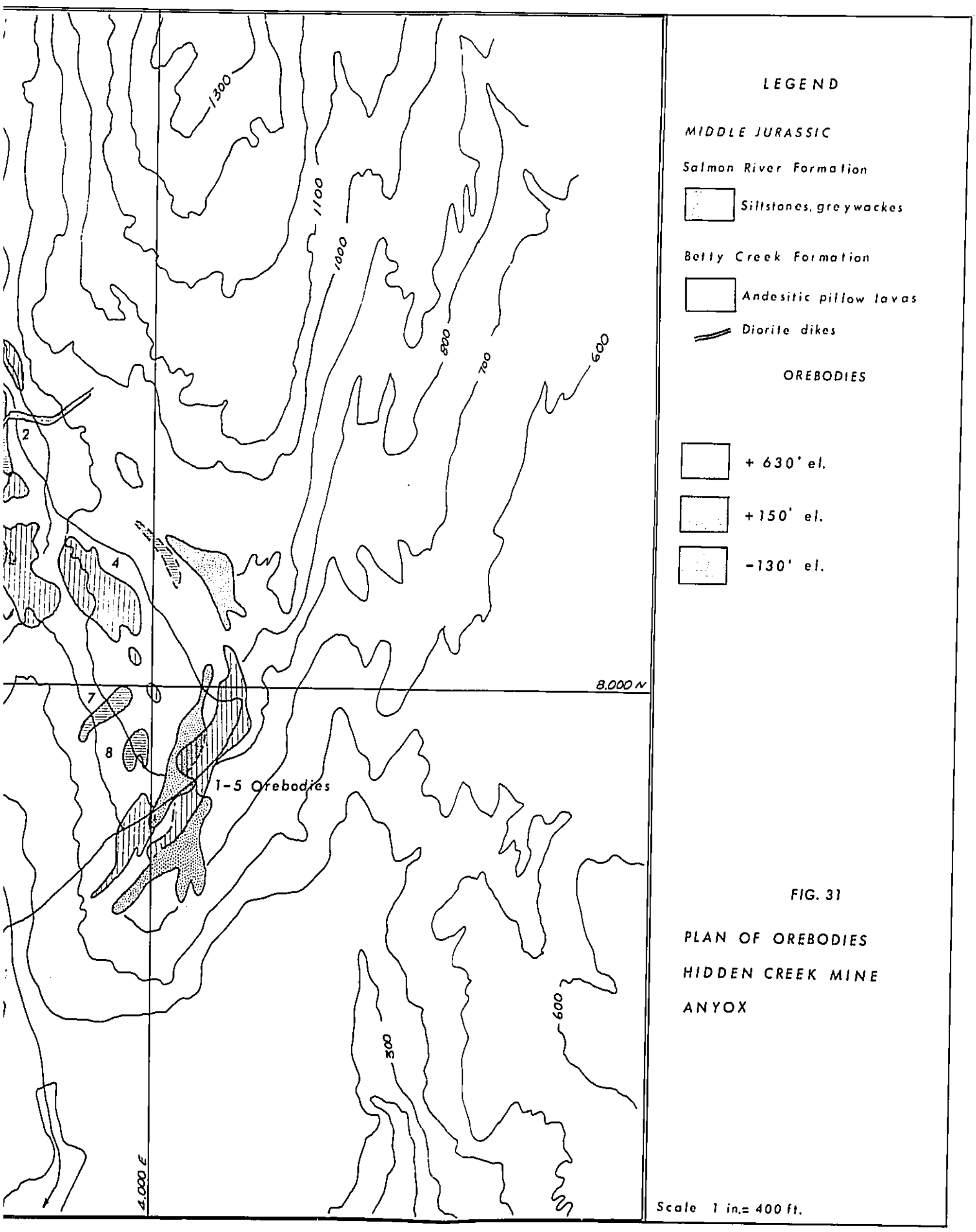
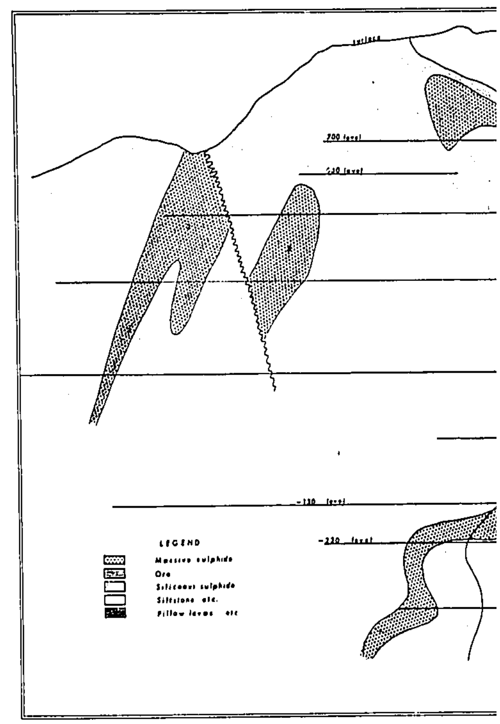


FIG. 31

PLAN OF OREBODIES

HIDDEN CREEK MINE

ANYOX


-130 level
-230 level
LEGEND
Massive sulphide
Ore
Siliceous sulphide
Siltstone etc.
Pillow lavas etc

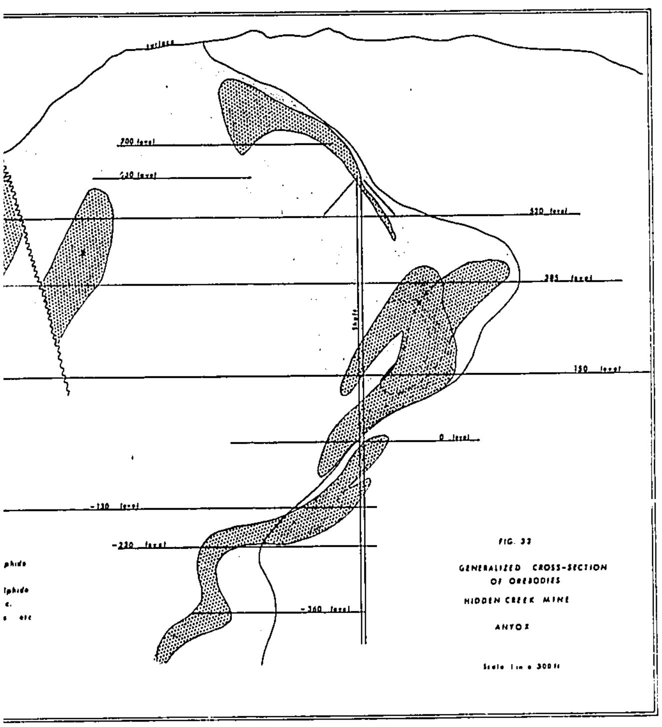


FIG. 33

GENERALIZED CROSS-SECTION
OF OREBODIES

HIDDEN CREEK MINE

ANYOX

Scale 1 in = 300 ft

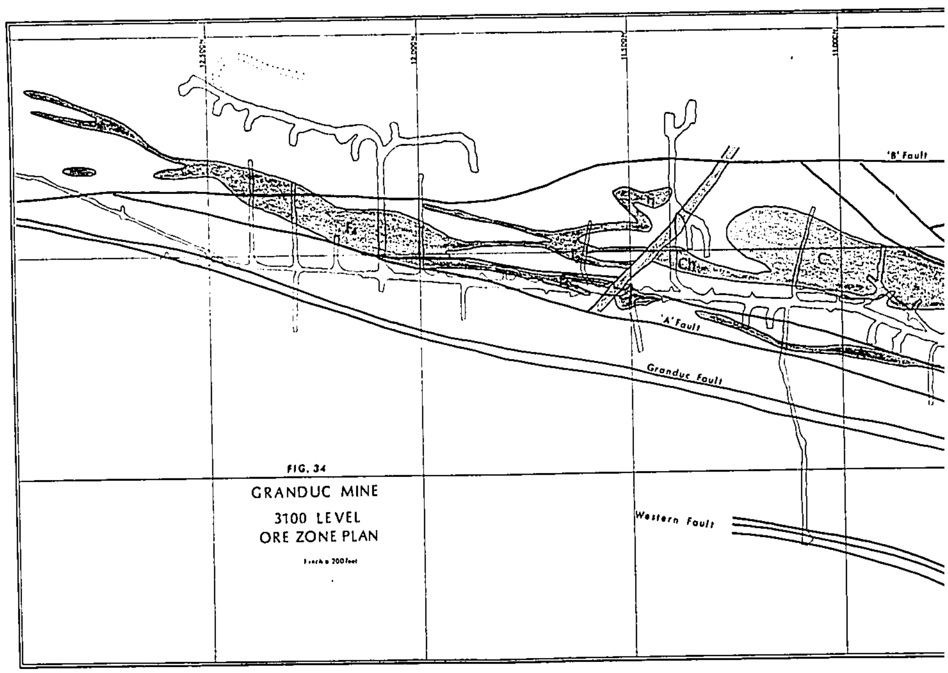
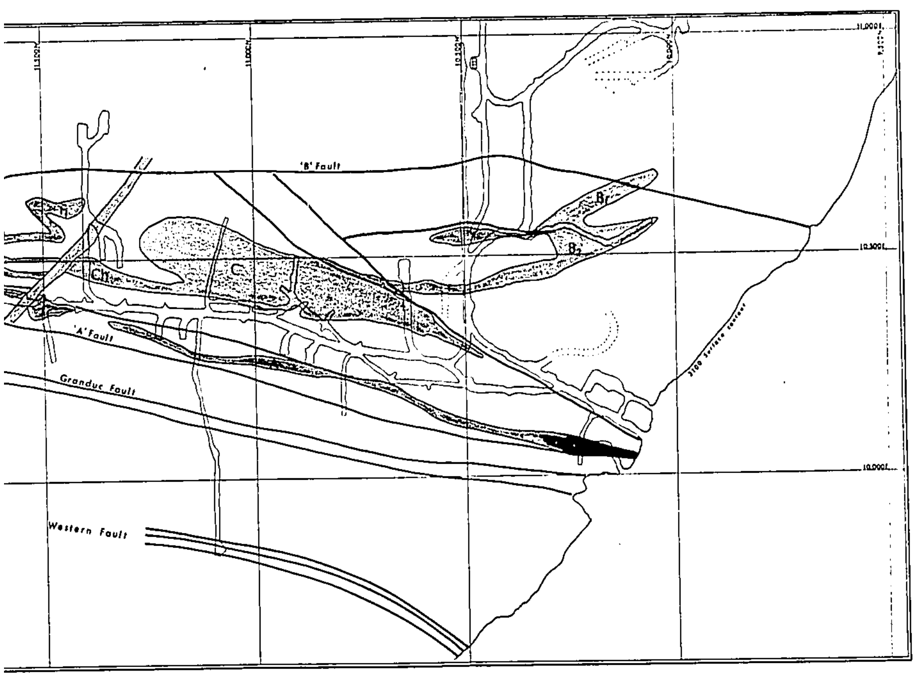


FIG. 34

GRANDUC MINE

3100 LEVEL
ORE ZONE PLAN



11,000N
'B' Fault
'A' Fault
Granduc Fault
Western Fault
2100 Surface contour
10,000N

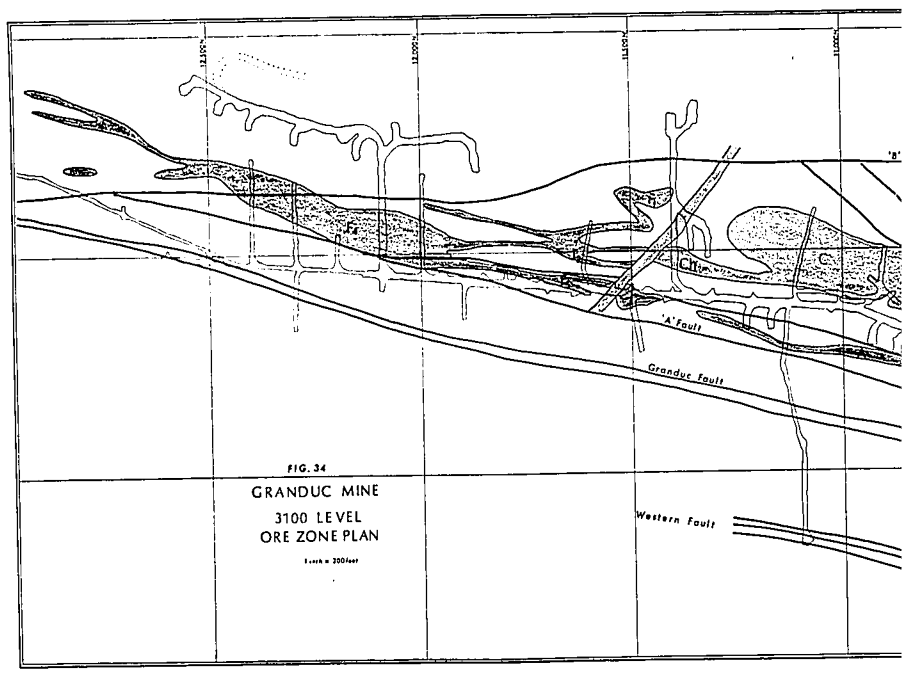
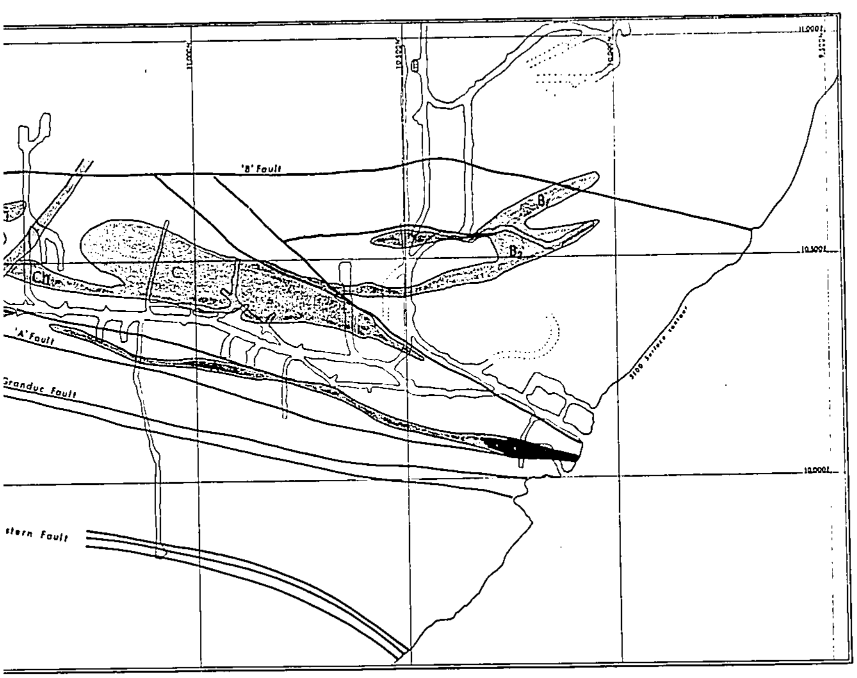


FIG. 34

GRANDUC MINE
3100 LEVEL
ORE ZONE PLAN



11,000 L
10,500 L
10,000 L
'B' Fault
'A' Fault
Granduc Fault
stern Fault
C
Ch
B1
B2