

THE GEOLOGY OF MALARTIC GOLD FIELDS MINE
HALET, QUEBEC

by

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THE GEOLOGY OF MALARTIC GOLD FIELDS MINE

HALET, QUE.

The mine is located 6 miles east of the Town of Malartic, and is about 300 miles northwest of Montreal.

A belt of altered peridotite about 2,500' wide trends southeasterly across the property. An embayment of talc-chlorite rock branches from the Cadillac fault, which forms the north contact of the peridotite, into the peridotite belt in a southeasterly direction. "Diorite" and syenite dykes and lenses intrude the peridotite belt. Two dyke swarms of "diorite" with less abundant syenites located in the talc-chlorite embayments have been fractured and mineralized.

The altered peridotite contains mineral assemblages reflecting metamorphism under greenschist conditions. The later dyke rocks are probably the result of a trondjhemitic differentiation of a normal alkalic calcic magma.

Gold mineralization of ore grade, with pyrite, is concentrated adjacent to quartz veins in "diorite". Similar but weaker concentrations in syenite are not of ore grade. Fractures in the dyke rocks formed the channelways for mineralizing solutions. Deposition of gold and sulphides, mainly pyrite, resulted from the reaction of mineralizing solutions with the hornblende in "diorite". Silica for vein formation was probably derived from alteration of rocks in the vicinity.

A study on the temperature of formation of pyrite and quartz did not lead to decisive conclusions but emphasized the need of special detailed research in this work.

THE GEOLOGY OF MALARTIC GOLD FIELDS MINE
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CHAPTER 1

INTRODUCTION

The mine property of Malartic Gold Fields Limited is about 300 miles northwest of Montreal (see inset map Fig. 1). The property consists of 65 claims (approximately 2700 acres) in Fourniere and Dubuisson townships of the Malartic area, Northwestern Quebec. Malartic Gold Fields is 6 miles east of the Town of Malartic and is included in the Malartic Mining Camp because of similar ores and geology. Within the limits of the town there are four mines: Canadian Malartic; Sladen Malartic; East Malartic, and Barnat Mines.

Purpose and Scope of Thesis:

The purpose of this study was to examine thoroughly the geology of this mine and to determine the causes and controls of gold-bearing orebodies.

This thesis is based on a study of the mine which took place during the summer of 1950 and the year 1951. During this time, the writer was engaged in normal geological work, which included mapping of development drifts, backs of stopes, and raises, as well as logging of drill cores, and locating diamond drill holes. The work was carried out under the direction of Mr. C.K. Wilton, mine geologist, and gave the writer an opportunity to observe the immediate geology of the mine workings to the 1,200 foot level in number 2 mine and to the 1,800 foot level in number 1 mine. In addition to this, a program of surface

exploration by diamond drilling yielded further information on the general geology of the property. There are practically no surface outcrops on the property, consequently smaller-scaled geological maps are based on information derived from diamond drill holes and geological maps of the mine. Studies of fracture patterns are based on the mine geological plans at a scale of 20 feet to the inch. Since orebodies are confined to diorite intrusives, no detailed mapping of fractures was done in syenites, as such work was not called for in the immediate requirements of geological data.

Special studies at the mine included a frequency assay compilation to determine a suitable cut-off grade for the mine, and a program of drilling in diorite dykes to outline low grade zones in ore.

In conjunction with ore examinations, an independent study of the temperature of formation of pyrite and quartz was carried out by the colleagues of Dr. M. Haycock at Ottawa. An attempt is made here to correlate the findings of their report (Graham 1952) with the geological conditions revealed in this study.

Structural and petrological conclusions are based on evidence seen on the property and comparisons with other mines of the Malartic district are made using Eakins' thesis on the Malartic Camp (1952).

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The writer further acknowledges Report M.D. 2872 of the Mineral Dressing and Process Metallurgy Division of the Mines Branch at Ottawa. This study was carried out under the auspices of Dr. M. Haycock by Dr. A.R. Graham on specimens supplied by the writer.

The mine examination was greatly facilitated by the cooperation of mine management, in particular Mr. C.K. Wilton, mine geologist, who has been personally responsible for much of the mapping, and Mr. G.A. Roach, mill superintendent.

Many stimulating and fruitful discussions were held with Dr. A.S. MacLaren of the Geological Survey of Canada and Dr. P.R. Eakins, presently of Cerro de Pasco Corporation.

Previous Work:

The only published report dealing with the mine geology exclusively is that by Halet in 1948. Dr. J.E. Gill worked at intervals on mines in the Malartic district since 1928 and has directed work at Gold Fields since 1949. Halet's early mapping has been revised by Mr. C.K. Wilton, mine geologist since 1947. Smith (1951) published some information on the temperatures of gold deposition in his regional study of mines in northwestern Quebec. Gunning and Ambrose (1940) described the known geology of the property in its early exploration stage. Detailed studies of other mines in the Malartic district include O'Neill's (1934) and Derry's (1939) on the Canadian Malartic Mine; Cormie's (1948) on the East Malartic Mine, and Byers' and Gill's (1948) on the Sladen Malartic Mine.

At Gold Fields, the recent exploration program was planned

by Dr. Gill. It consisted of inclined exploration drilling in arebodies, long drill holes to examine areas between the number 1 and 2 mining areas, and a crosscut southward from the 1,050 foot level station at the number 1 mine to explore the porphyry bodies along the south peridotite contact. Mr. Wilton carried out these programs in conjunction with his normal geological duties and the accumulated geological data form the basis of structural presentations in this thesis.

History of Regional Geological Work:

Early geological reconnaissance in the Cadillac-Malartic area was done from 1912 to 1918 by Bancroft (1913) and Wilson (1913, 1918). From 1925 to 1927 James and Mawdsley (1925) mapped the area in detail and classified stratigraphy according to the Keewatin-Timiskaming concept of the areas to the west. The reported unconformity between the two groups found west of the area could not be found here, and they concluded that the general succession was monoclinial, with rocks becoming progressively younger from north to south. Later investigators retained this subdivision mainly because of their limited field work.

A more intensive study of the area was started in 1937 by Gunning (1937) and continued by Gunning & Ambrose (1940). They outlined a number of definable units of volcanics and sediments which were isoclinally folded into a long, narrow syncline.

Their subdivision was as follows:

younger	Cadillac Group - sediments
↑	Blake River " - volcanics
	Kewagama " - sediments
older	Malartic " - volcanics

The validity of the above grouping rests on the assumption that the belts of volcanics and sediments had not been repeated by appropriate movement along the strike faults of the area. Norman (1943) suggested that repetition by faulting may have occurred and that consequently the dual Archean classification may still be valid for the area.

Mine History:

The first prospectors came into this area in 1923 and worked on what is now the Canadian Malartic Mine. Interest in the area was revived in 1934 after a curtailment of activity and at that time, J.P. Norrie and his associates staked groups of claims eastward along the strike of regional structure, some of which eventually became the East Malartic and Malartic Gold Fields Mines.

Work began on the Gold Fields' property in 1936. Because of the lack of outcrop no geological data were available to direct diamond drilling and the holes were spotted in positions thought to be geologically analogous to those of East Malartic (Halet 1944). This program soon gave way to systematic drilling of the south Blake River Volcanic (peridotite) contact with cross-section drilling planned at one thousand foot intervals.

The fourth hole on the second cross-section across the volcanics cut ore in the vicinity of the number 1 mine shaft. This ore was found after 55,000 feet of drilling and several more thousand feet were drilled before shaft sinking was considered. In 1939, a shaft was sunk and by August of the same year, a 350-ton mill was erected. Production began in December 1939 and was increased to 750 tons when the number 2 mining area was discovered but the difficult war years hindered

further expansion of the operation. In June 1948, a mill was constructed at the number 2 mine to treat ore from that mining area. In the beginning, this mill operated at a rate of 700 tons per day but subsequently was increased to 1,800 tons when development of the number 2 mining area provided the ore.

Notes on Mining:

Gold Fields is the largest straight gold producer in Quebec, milling over one thousand eight hundred tons per day. Presently, all the ore is hoisted up the number 2 shaft and is extracted intermittently from about fifty stopes. Two mining methods are used. For stopes of narrow and intermediate widths, normal cut and fill procedures are in operation and in a few very wide stopes a modified slusher-shrink method is employed. Extensive timbering is required, especially where workings go through talc-chlorite rocks.

The number 2 and number 1 mining areas are being developed for stoping down to the 1,800 foot level. The number 1 shaft has been sunk to the 1,800 foot level where development has intersected additional orebodies.

The mill-heads average .180 oz Au/ton and recovery of gold is 95%. Ore reserves reported at the end of 1951 are 3,545,000 tons or, at the present mining rate, 6 years reserves.

PART 1

REGIONAL AND STRUCTURAL GEOLOGY

CHAPTER 2

REGIONAL GEOLOGY

The northwestern mining area of Quebec, from Rouyn eastward past the Town of Val d'Or, is underlain by rocks of Precambrian age. In this region "Archean" volcanics and sediments are tightly folded into easterly-trending belts, flanked on their north and south sides by large areas of granitic rocks (Fig. 1). Many igneous rocks, ranging in composition from ultrabasic to granitic, intrude these assemblages. The youngest intrusive rocks of the area are diabase dykes that cross the region in a northeasterly direction.

Two main fault structures parallel the trend of the "Archean" rocks. The northernmost, the Destor-Manneville fault has but one mine apparently related genetically to it. To the south, and roughly parallel to it, the Rouyn-Bell River fault extends from Ontario eastward for a short distance past Val d'Or. Most of the mines in northwestern Quebec, including those of the Malartic camp, are located near this fault. From Cadillac Township eastward, the fault is commonly referred to as the Cadillac fault zone.

Regional Geology of the Malartic Mining Camp:

Bedrock along the Malartic Gold belt consists of a series of sedimentary and volcanic rocks belonging to an "Archean" geosynclinal sequence. The formations have been folded, metamorphosed, and intruded by peridotite, diorite, porphyry, and granite. Early in the deformational history of the area, a major strike fault (Cadillac fault zone) was developed and appears to have been the regional control for the formation of gold orebodies of the Malartic area.

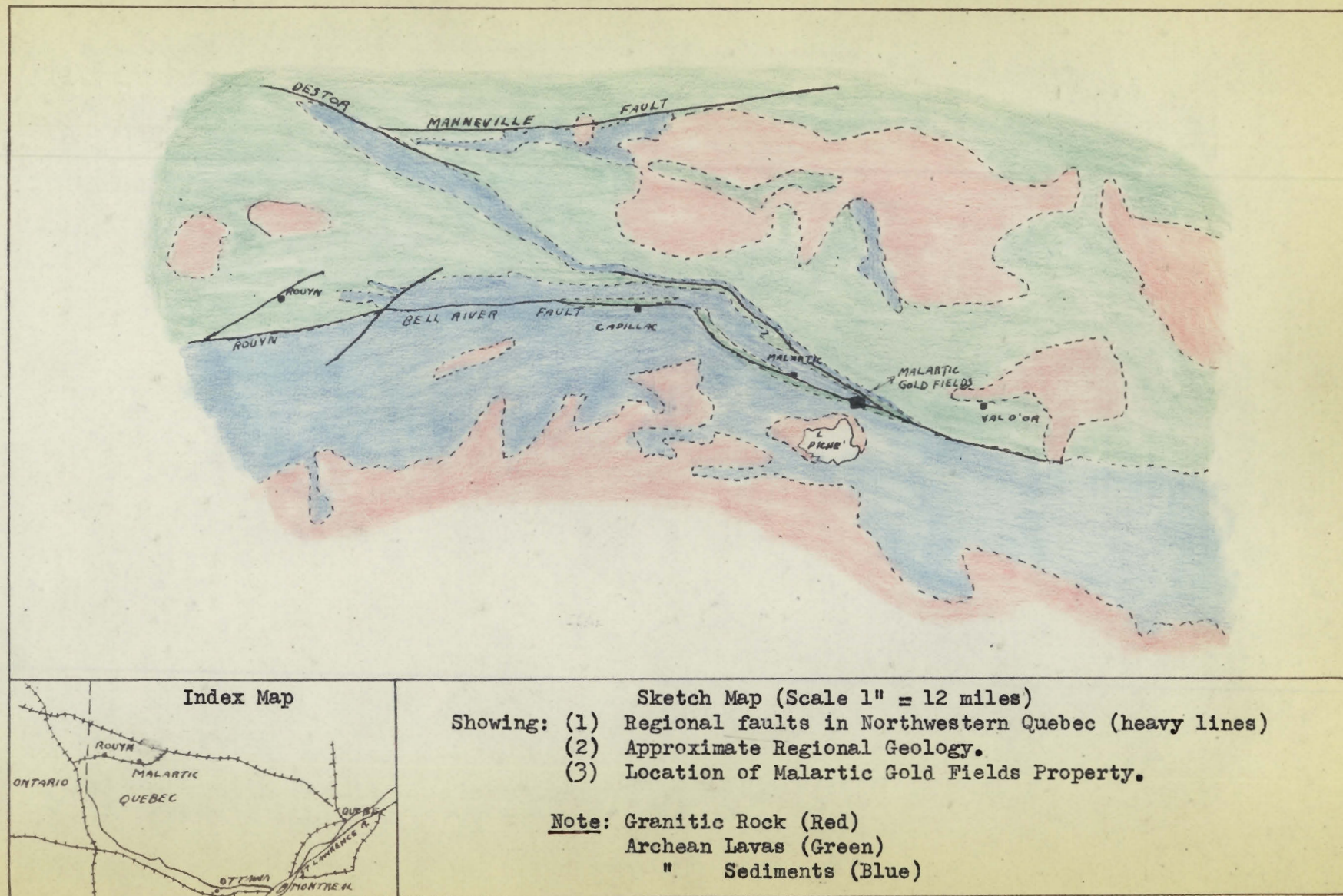


FIG. 1

The main rock types of the district are summarized in the Table below:

Geological Units of the Malartic Gold Belt
(Gunning & Ambrose 1940)

Precambrian

<u>"Archean"</u>	<u>Intrusives</u>	lamprophyre granodiorite albite granite porphyry diorite peridotite
	<u>Sedimentary and Volcanic Rocks</u>	Cadillac Group: greywacke & conglomerate Blake River Group: basic flows and tuff Kewagama Group: greywacke, tuff, & conglomerate Malartic Group: basic lavas & pyroclastics

In 1943, Norman (1943) modified the above stratigraphy by placing the volcanic Malartic Group in the Blake River Group, thus leaving the Kewagama sediments as the oldest group. As nothing new has been added since, Norman's stratigraphy (1943) is retained in the maps showing structural geology of the area (Appendix 2, Figs. A, B).

The Malartic and Blake River volcanic groups are dominantly flow rocks of intermediate composition. Pyroclastics, mainly tuffs, are unevenly interlayered with the lavas. The north belt of Blake River volcanics shown in Figures A & B (Appendix 2) are composed entirely of schistose tuffs on the Malartic Gold Fields property.

The Kewagama and Cadillac sedimentary groups are clastic sediments of the greywacke type containing an appreciable amount of conglomeratic bands. Relatively pure quartzite as well as iron formation are found in only minor amounts.

Of the intrusive igneous rocks indicated in the Table of Formations, peridotite, diorite, and porphyry, are of immediate interest to this study since they are the types of rocks involved in detailed geology of the mine. The closest deep-seated igneous mass approaching batholithic proportions is that found to the south, at Piche Lake (Fig. A, Appendix 2). Regional workers have described this mass as a coarse-grained granodiorite.

Regional structural geology of the Malartic Mining Camp is illustrated on a scale of 2,000 feet to the inch in Appendix 2, Figure A. This map shows the trend of structure for about 12 miles along the Cadillac fault zone. The plan, a compilation by C.K. Wilton, includes the most recent information available and the Malartic Gold Fields property is pictured here in its relation to the other mining properties of the Malartic Camp located west of it.

In this region, the Cadillac fault zone strikes 120° in azimuth and is roughly conformable with the attitudes of surrounding rocks. Near the western termination of the peridotite, the fault crosses to the south contact of the Blake River volcanics going westward. In its extension eastward from the Blake River volcanics, the fault follows the north contact of the peridotite at least into the Dubuisson Gold Fields property. Four thickenings of talc-chlorite rock extend south from the fault zone into the peridotite. From west to east they are found on Sladen, Barnat, Rand, and on the Gold Fields properties.

North of the fault zone a belt of Blake River volcanics, with a southeasterly strike meets the Cadillac fault zone on the Gold Fields property just east of where talc-chlorite schistose embayments in perido-

tite are in contact with the fault. This wedge of volcanics is composed of medium-grained schistose pyroclastics.

A fault on the south peridotite contact that crosses Canadian Malartic, Sladen Malartic, and East Malartic, formerly was thought to continue into Gold Fields ground. Although patches of talc-chlorite schist are found adjacent to porphyry dykes concentrated on the south border of the peridotite at Malartic Gold Fields, they do not form a fault zone but appear to be associated with porphyry intrusions. Moreover, exploration on the East Malartic property has shown that the fault does not continue eastward beyond the property.

The peridotite mass is flanked on the south by the Kewagama sediments and on the north by Cadillac and Kewagama sediments. On the Gold Fields property, the Piche Lake granodiorite is separated from the peridotite to the north by a band of Kewagama sediments.

Intrusives, younger in age than the peridotite, are diorites and porphyries, and of these, the diorites are the older. Porphyry intrusions occur in larger bodies in the vicinity of the Canadian Malartic, Sladen, and East Malartic Mines than at Gold Fields but no definite size distribution can be seen for diorites. Their shapes in the western areas are those of irregular lenticular stocks, while at Gold Fields they are tabular lenses and dykes. In general, porphyry intrusions occupy more surface area than diorites.

All bedrock units have steep to vertical dips. On the Gold Fields property, the Cadillac fault zone as well as the south peridotite contact, dip at about 75° northward.

CHAPTER 3

STRUCTURAL GEOLOGY OF MALARTIC GOLD FIELDS PROPERTY

The geological picture is shown in Appendix 2, Figure B, on a scale of 400 feet to the inch. This map is adapted from Wilton's geological data on the 300 foot mine level and records all possible information that can be projected to that elevation. Mining areas in the vicinity of number 1 and 2 shafts have been mapped in detail while much of the remaining geology is derived from extensive diamond drilling. The "Survey Base Line" shown on this map forms a geometric reference for many of the succeeding illustrations of dykes and fracture systems dealing with the number 2 mining area.

The Table of Formations shown below, lists the rock types locally encountered, the uppermost being the youngest. The petrography of these units described in the following paragraphs contain such generalities as are necessary for an understanding of structural descriptions.

TABLE OF FORMATIONS

Late intrusives	syenite "diorite"	
Altered Peridotite	Talc-chlorite rock "hard massive" peridotite.	schist "soft massive"

Peridotite:

All rocks of this type are derivatives of an ultramafic mass, which, on the property, is elongated toward the southeast. Its

northern contact is marked by the Cadillac fault zone, and its southern contact is with Kewagama sediments.

The "hard massive" type is the least altered variety. In hand specimens it is a dull, massive, dark-bluish-grey, fine- to medium-grained rock composed of variable amounts of dark amphibole, serpentine, chlorite, and minor talc and carbonate. Compared to its "talc-chlorite" derivatives, it is quite hard but can be scratched with a knife.

Talc-chlorite rocks on the other hand, can be deeply grooved with a knife blade and are greasy or slippery. These rocks are dark greenish grey, usually medium-grained, and are composed mainly of talc and chlorite with variable amounts of carbonate. The "soft massive" variety has a non-foliated massive appearance in hand specimens, but the schist shows foliation to a variable degree and grades into the massive variety.

Late Intrusives:

These rocks were introduced along openings developed after the formation of the talc-chlorite rock. The diorites are the older of the two.

"Diorite":

This name has been used to indicate a dark greenish black, pitchy-lustred, medium-grained, dyke rock, composed mainly of amphibole and plagioclase feldspar. The name is in common use throughout the Malartic camp and although inaccurate, it is retained here to avoid confusion. Earlier investigators in the area have been aware of the incorrect usage of the term but were unable to offer a satisfactory substitute.

Syenite:

The syenite bodies range in texture from aphanitic through equigranular medium-grained rocks to porphyritic. Throughout the Malartic Camp, they have been collectively referred to as "feldspar porphyry", or "porphyry", but since some bodies included in the group at Gold Fields are not porphyritic, the name syenite will be substituted hereafter. In color, they range from pinkish grey, light grey, to dark grey. Megascopically, they are seen to be composed of acid plagioclase with very minor quartz, and variable but subordinate amounts of biotite, chlorite, and carbonate.

Structural Geology:

The structural trend on the Gold Fields property is southeast, with the peridotite belt. The peridotite mass is about 2500 feet wide with both contacts dipping steeply north. The Cadillac fault zone forming its north contact is a highly foliated, sinuously-banded, talc-chlorite-carbonate shear zone about 70 feet thick dipping 75° northward. The "hard massive" peridotite contains a complex embayment of talc-chlorite rock branching southeasterly from the fault. The embayment consists of two southeast-trending belts of schist separated by ill-defined masses of "soft massive" peridotite. The "soft massive" bodies are seen only in the embayment area and were not found completely isolated in "hard massive" peridotite. Where seen, the contact between "hard massive" peridotite and the talc-chlorite rocks is marked by a transition zone, up to 5 feet wide in which foliation and sheeting are strongly developed. The color of the rock changes from dark bluish grey to dark green. The attitude of this contact is illustrated in Appendix 2, Figure E, also in

Figure 2, where it is known in relation to the number 2 mining area. Broadly viewed, it is basin-shaped and concaved northward so that the contact dips steeply south in upper levels of the mine and dips northward below the 600 foot level.

The unique structures of the talc-chlorite embayment at Gold Fields compared to roughly similar "thickenings" of the talc-chlorite rock adjoining the Cadillac fault zone, found to the west on the Rand and East Malartic properties, indicates special structural conditions governing its formation. The proximity of the junction of the north wedge of Blake River volcanics and the fault zone, a feature not associated with the "thickenings" to the west, suggests that the Blake River volcanics were partially responsible, at least for the complexities in structures of the embayment. The Blake River volcanic belt may have influenced the formation of embayments in either of the two following ways:

1. During the introduction of ultramafic magma along the Cadillac fault zone, portions of the Blake River volcanics were engulfed and, after consolidation of the magma, formed a structurally weak zone in the peridotite. Subsequent movement along the Cadillac fault zone induced shearing along the inclusions, during which, in an aqueous environment, "hard massive" peridotite was converted to the talc-chlorite rock varieties.

2. No structural weakness was inherited in the peridotite as a result of inclusions, but the rudimentary branching structures of the embayment could be initiated by movement along the Blake River volcanics. Later movements along the Cadillac fault could enlarge the

structures and offset the zone westward from the junction of the Blake River Volcanics and the Cadillac fault.

The former hypothesis lacks positive identification of remnantal volcanic rocks in the embayment areas. One inclusion of agglomerate intersected by a drill hole into "hard massive" peridotite had no shearing associated with it. The somewhat special arrangement of inclusions required to form the primary zones of potential failure is not likely to be maintained in an advancing magma.

Examination of the drill cores which cross the north Blake River volcanics and include the enclosing sedimentary groups, show that the volcanic group consists of sheared pyroclastics with enclosing sediments being relatively massive. The pyroclastics apparently have localized shearing movements and possibly such movements could account for a primitive branching structure into peridotite. The latter hypothesis is also favored because it dispenses with the necessity of having a fortuitous arrangement of inclusions.

"Diorite" bodies, the older of the late intrusives, are more abundant in the embayment areas and so are concentrated close to the Cadillac fault. In the talc-chlorite area, "diorite" occurs as irregular lenses and pipes conforming to the general trend of embayment. In "hard massive" peridotite, they have typical dyke shapes. Collectively, "diorite" dykes appear to be arranged en echelon in a southeasterly direction across the peridotite belt and strike roughly parallel to the trend of the belt.

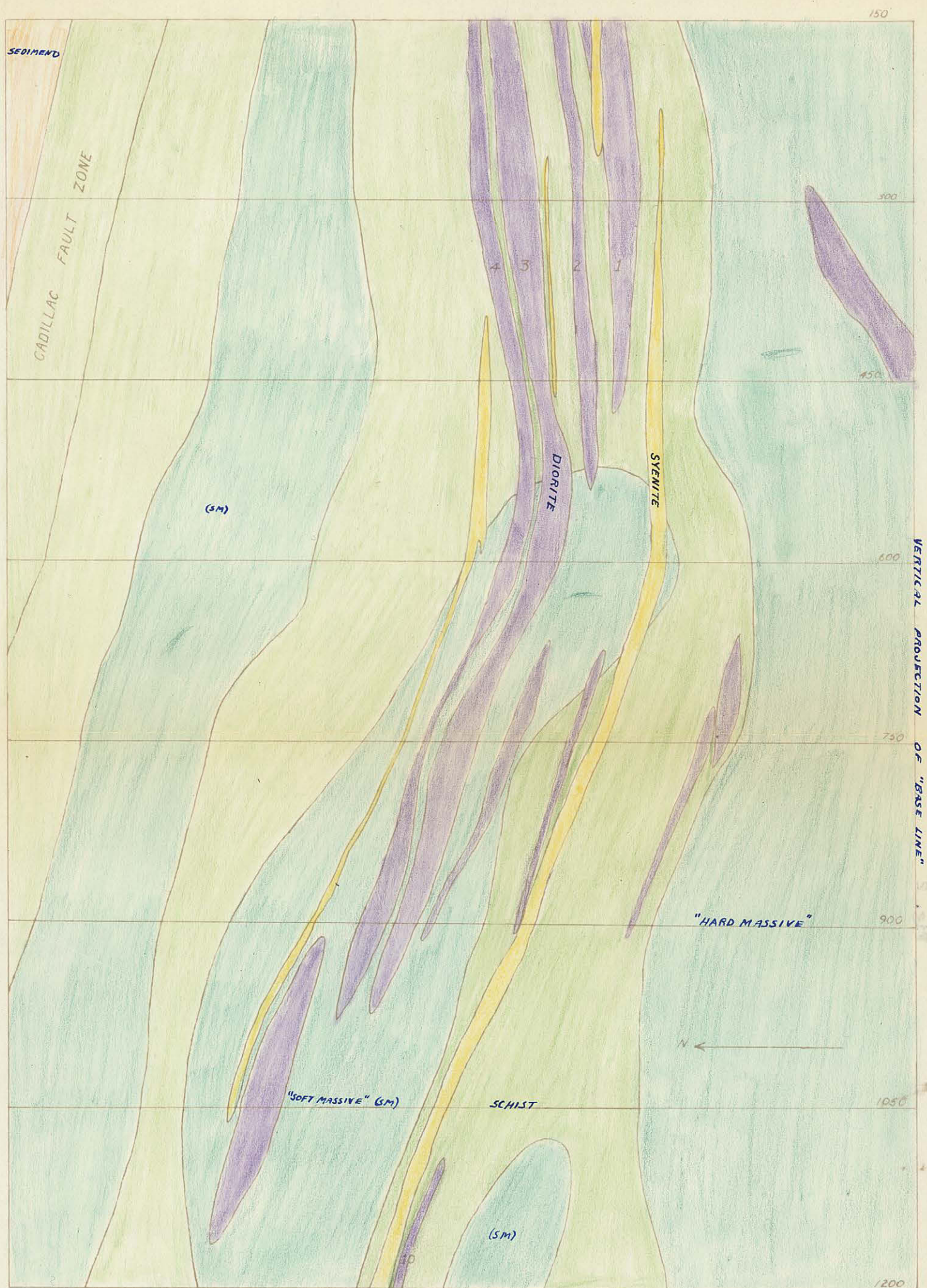
Most of the syenite dykes are concentrated at the south

peridotite contact. They are relatively scarce and smaller within embayment areas. Wherever discordant contacts are found between late intrusives, syenite invariably cuts "diorite". The dykes along the south contact branch eastward from the contact into the peridotite so that their strikes are more easterly than the peridotite contact. Both "diorite" and syenite appear to be confined exclusively to the peridotite belt on the property. The concentration of "diorite" bodies in the northern part of the peridotite belt suggests that structural conditions were favorable for rupture and intrusion in that section, while fracturing, if present along the south contact, presumably did not tap the "diorite" magma chamber. After consolidation of "diorite", stress conditions probably altered so that channelways for syenitic introductions were provided for, mainly along the south contact.

Structural Geology of the Mining Areas:

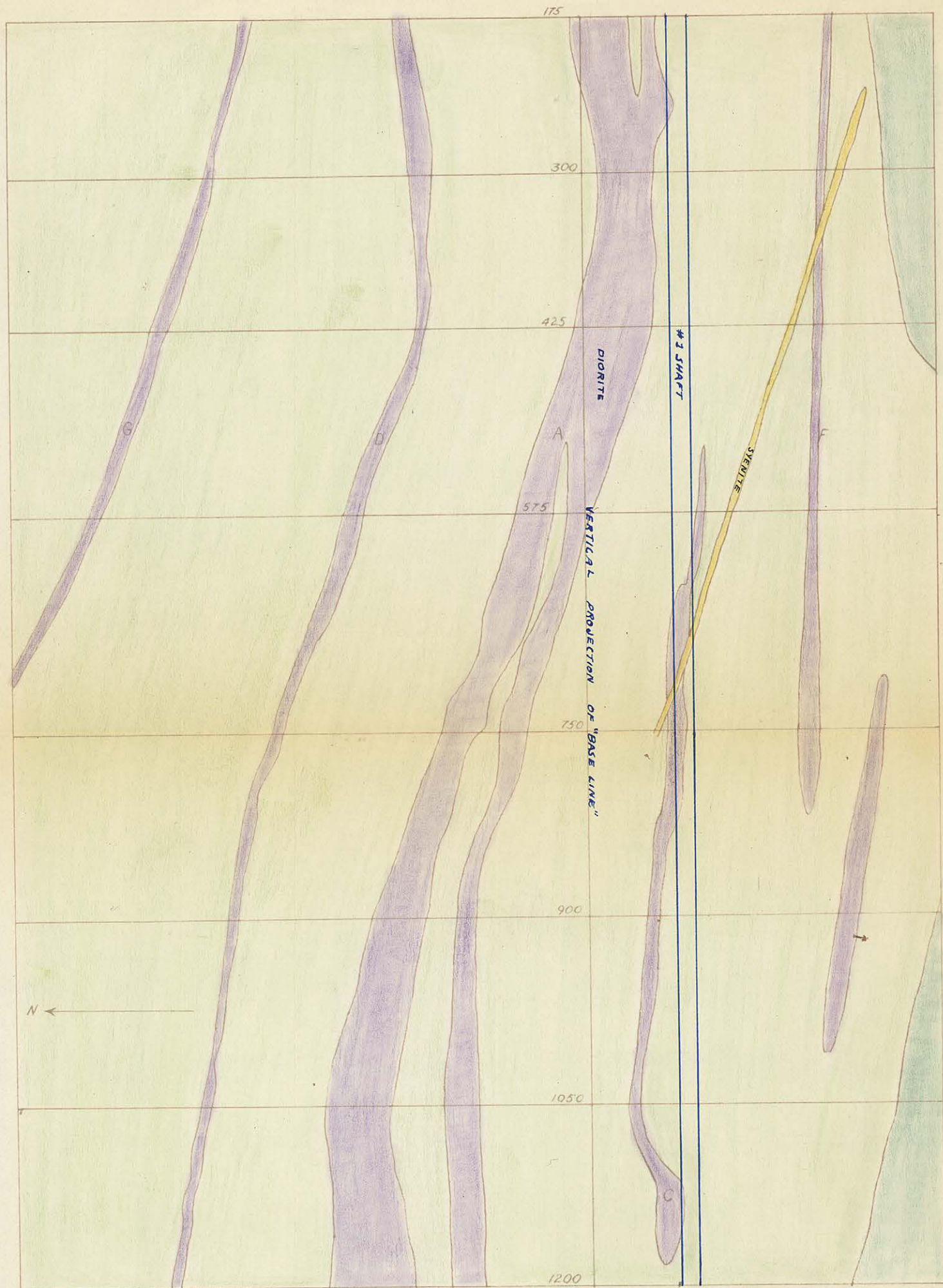
The geology of the mining area is shown in Appendix 2. (Fig. C) at the 1,200 foot mine level on a scale of 100 feet to the inch. Mine workings are omitted for clarity and the color scheme for rock types is the same as used on maps referred to in earlier parts of this thesis.

The structural complexity of the embayment of talc-chlorite rock can be seen in greater detail on this level. The "soft massive" variety of talc-chlorite rock is a large mass separating two schist belts. Numerous small bodies of "soft massive" are also found in the schistose variety but mainly in the northernmost schist belt. The belts maintain their general relationships in depth with the northernmost one being the larger. Comparing the plan on the 200 foot level,



CROSS SECTION 20 THROUGH 2 SHAFT

SCALE 1" = 100'



CROSS SECTION 50 THROUGH I SHAFT

SCALE 1" = 100'

(Fig. B) to that on the 1,200 foot level (Fig. C) the downward expansion of the "soft massive" body appears to be at the expense of the southernmost schist belt (Fig. 2). Structures in the talc-chlorite rocks include steep dipping foliation and sheeted structures, flat cross foliation, flat fractures and dragfolds. Steeply-dipping foliation characteristically separates the schist from the "soft massive" talc-chlorite rock. Sheeted structures parallel the steep foliation and are common to both schist and "soft massive". Probably sheeting was produced as one of the effects of late intrusive emplacement.

Flatly-dipping structures are found near the contacts of late intrusives and are rarely seen elsewhere. Some however, have been observed on both the footwalls and hanging walls of many ore-bearing dykes. In numerous places such fractures are filled with white quartz for a short distance away from the contact. A few of these form the extension of quartz veins that cross dykes, and it seems clear that they originated, at least in part, when the late intrusives were fractured.

Flat foliation has been noted in the hanging walls of "diorite" dykes near drag folds and diapir-like folds at noses of intrusive lenses (Figs. 4A, 4B, 5A, 5B). This foliation could have formed in one of the following ways:

1. Developed by the same forces that produced fracturing in late intrusives.
2. Developed at the time of intrusion as a compressional effect of ascending magma on weak and plastic wall rock.

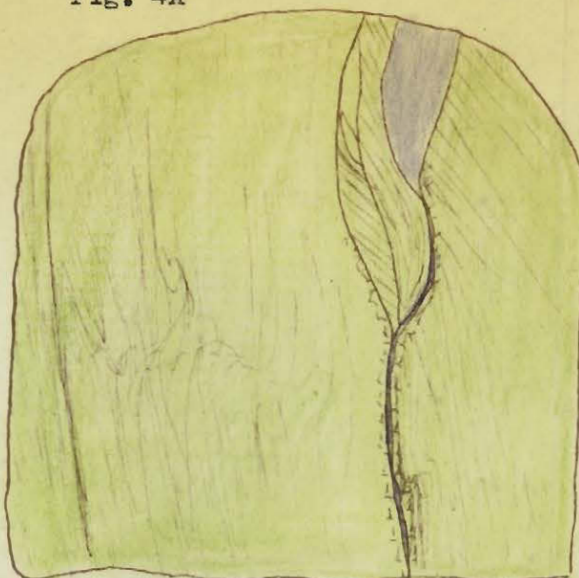
3. The weight of overlying rock produced differential compaction near contacts with flat foliation as a local result.

No positive evidence could be found that indicated a genetic relationship between flat foliation and flat fractures; therefore, the possibility of flat foliation being related to intrusion is not substantiated. Differential compaction appears to be inadequate as a source, because other localities of differential rock strengths, such as the contact of "hard massive" and "soft massive" peridotite, exhibit no corresponding foliation. The second mode of formation therefore, appears to be the most probable.

There are two concentrations of "diorite" dykes in the talc-chlorite embayment, one in each schist belt. Orebodies are confined to these dykes, and for descriptive purposes, dykes grouped around the number 1 shaft are called the number 1 dyke swarm and those north of the number 2 shaft, the number 2 dyke swarm. In the number 1 mining area, ore dykes are lettered for identification while those of the number 2 mining area are numbered.

Orebodies are restricted to dykes and portions of larger dykes where quartz veins and associated pyritic wall rock containing gold are sufficiently numerous to bring the whole mass to ore grade. These dykes range in size from minable widths of about 4 feet up to 90 feet wide and several hundred feet long. The A dyke of the number 1 swarm is the largest dyke of the embayment area, being 900 feet drift length and 85 feet wide on the average. It contains ore at intervals along its

Fig. 4A

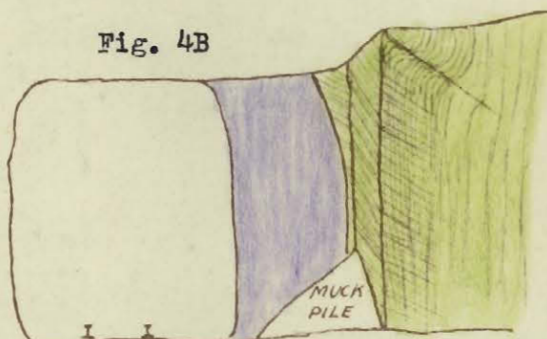


Sketch of face in 12-15-E drift (dimension of face 7'x7')

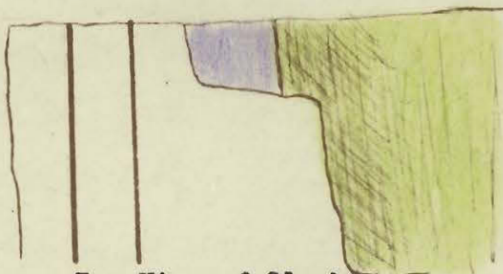
Showing a cross-section of structure

- Note; (1) the lower termination of a "diorite" lense (purple) in talc-chlorite schist (green).
 (2) sheeting structures parallel to the lense.
 (3) contorted foliation in schist.

Fig. 4B



View of Slash facing East



Top View of Slash

Front and Top View of Slash in 10-15-E drift

Showing a cross-section of structure

- Note; (1) increase of vertical foliation near "diorite" contact.
 (2) flat cross foliation.
 (3) dragfold with a short fault sub-parallel to the flat foliation.

Fig. 5A

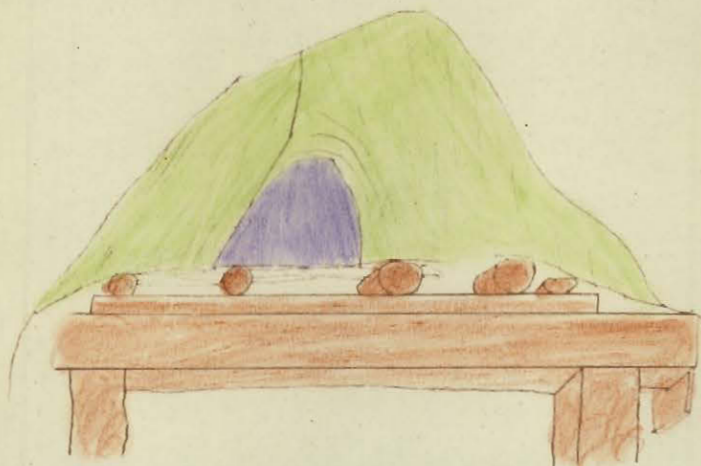
- 21 -



Sketch of face in 4-11-W drift (dimensions of face 7'x7')
Showing a cross-section of structure

- Note: (1) diapir-like foliation around nose of "diorite" lense.
(2) flat cross foliation on hanging wall side.
(3) widely-spaced steep slips.

Fig. 5B



Sketch of a backslash in 7-6-W drift
Showing a cross-section of structure

- Note: (1) foliation around nose of "diorite".
(2) fault plane on hanging wall side.

length where quartz veins with attendant pyrite are numerous. Smaller dykes however, contain a larger proportion of ore with masses of low grade occurring where quartz veins with the pyritic adjacent rock are sparse. The vertical range of orebodies is variable but it is usually found that if fractures persist in dykes in depth, attendant pyrite and gold are also present. Most of the dykes contain ore over their entire vertical range in the mine workings. Illustrations of ore dykes showing low grade zones are shown in Item 2, Appendix 1.

In detail, the two swarms have slight differences. Number 1 swarm occurs completely in schist while in the lower levels, number 2 swarm is in "soft massive" peridotite (Figs. 2 and 3). The A dyke of number 1 swarm is the largest dyke and, smaller, thinner dykes are grouped around it whereas in number 2 swarm, there is no large major dyke. In the latter swarm, the dykes vary greatly in shape and size in depth, especially where they cross from schist to "soft massive" peridotite, while dykes in the number 1 swarm are regular in depth, at least to the 1,200 foot level. Dykes of number 1 swarm dip north and have no pronounced rakes but in number 2 swarm, individual dykes rake steeply eastward. The dips are roughly parallel to that of the north contact of the "hard massive" peridotite. A suggestion of a steep westerly rake to the swarm as a whole is noted hence dykes of the number 2 swarm may have a crude en echelon arrangement.

The shapes of individual "diorite" dykes of the number 2 swarm are shown in the vertically and horizontally-contoured illustrations of Item 2, Appendix 1. The saucer-like concavity of the north contact of the "hard massive" peridotite (Appendix 2, Fig. E) appears

to influence dips of the dykes at corresponding levels. The contact of the "hard massive" peridotite dips steeply southward down to the 600 foot level where it changes and dips northward. "Diorite" dykes 1, 2, 3, 4, 5, and 9 also dip south in upper levels but change to a northerly dip, usually between the 450 foot and 600 foot levels, conforming with the dip of the "hard massive" peridotite contact on corresponding levels (Figs. 2 and 3). Dykes 1 and 2 are concave or saucer-shaped themselves at upper levels and no distinct concavity is seen in these or any other dyke in the lower levels of the mine. Where this feature is observed, the concavity conforms with that of the "hard massive" peridotite contact.

The influence of "soft massive" peridotite on the shape of "diorite" dykes is seen in the contoured illustration of dykes 5 and 6. In passing from schist to "soft massive" peridotite in depth, they change strike, dip and usually rake, the strike changing about 30° counterclockwise. The greatest change however, is in shape and size, the dykes becoming relatively larger in depth below the 600 foot level where they occur in "soft massive" peridotite.

Control of shape by the nature of country rock can again be seen where drifts cut through the horizontal terminations of dykes. In schists these terminations usually split or finger out in thin wedges, (Figs. C and D). Protuberances of "diorite" rarely cut across well-foliated schist but rather cause local contortions in adjacent schist. Terminations in the "soft massive" peridotite are abrupt or rounded and rarely wedge out. Another feature of "diorite" bodies in schist can be seen in dykes 2, 9, 10, and 11 (Item 2, Appendix 1). Each of these dykes have two or more lenses arranged in line of strike. The smaller lenses in the case of dykes 2, 10, and 11 pinch out going upwards. In dyke 11,

these small lenses have been found to join in depth to form a single "diorite" body. The attitudes of other similar lenses in dykes 2 and 10 suggest that they have the same tendency in depth.

The above-discussed effects of the embayment structure on the shapes and distribution of dykes indicate that this structure was developed prior to the introductions of late intrusives. Differences in the strikes of dykes in schist and "soft massive" would indicate that these two units were already structurally effective; however, the talc-chlorite rock had probably undergone additional shearing as a result of "diorite" intrusion. Where terminations of "diorite" bodies have been observed in mine workings, a fault or slip surface extends into talc-chlorite country rock, suggesting that emplacement was controlled by pre-existing fractures. The more tabular aspects of dykes in "hard massive" peridotite seem to indicate the same conclusion. It appears then that the relative weakness of the talc-chlorite rock compared to "hard massive" peridotite restricted the size of openings and hence the size of "diorite" bodies.

Syenite dykes are not as abundant in the embayment area as in the southern sections of the peridotite belt. The larger bodies found here have a more tabular aspect than "diorites" and strike in a more southerly direction and where the dykes are discordant with "diorite" dykes, they invariably cut across latter from left to right. The largest syenite dykes in the embayment areas are confined to schist rather than "soft massive" peridotite. Smaller bodies however, are similar to "diorites" in size, shape, and distribution. The composite plan of dyke 8 (Fig. D) illustrates their various shapes and relationships within the embayment areas.

CHAPTER 4

FRACTURING OF LATE INTRUSIVES

After consolidation of the syenites, the younger of the late intrusives, local stresses produced fracturing in the late intrusive bodies comprising the numbers 1 and 2 dyke swarms, and to a lesser extent, the syenite dykes along the south border of the peridotite belt. The late intrusive dykes in "hard massive" peridotite remained relatively undisturbed. These ruptures are distinguished from fractures of later age by their quartz filling, attitudes, and distribution on the property. The above-noted distribution of fractures indicates that their formation was primarily controlled by the relative strengths of rock units. "Hard massive" peridotite is closer in strength to the late intrusives than to its talc-chlorite derivative. This appears to be the cause of the relatively massive condition of late intrusives found in it. On the other hand, late intrusives in the talc-chlorite embayments behaved, under stress, as brittle bodies in a more plastic medium.

Fractures were the main channelways for mineralizing solutions. In them were emplaced quartz veins with adjacent disseminations of pyrite and gold. The concentration of fractures within a "diorite" was evidently an important control of ore grade. Solutions passing along these fractures reacted with "diorite" wall rock in such a way that pyrite and gold were precipitated and diffused in the rock adjoining fractures. The deposition of these two minerals in syenite bodies adjacent to ore-bearing diorites was not so abundant and therefore, syenites do not contain minable orebodies at Gold Fields. The petrological aspects of mineraliza-

tion are dealt with in a later chapter and the subject considered here is the nature and origin of fractures that form the channelways for mineralization.

Fracture fillings are classified as follows, the youngest being the uppermost:

Carbonate stringers

Tourmaline and molybdenite coated
stringers

Quartz veins	3	grey quartz
	2	glassy quartz
	1	cherty quartz

The relative ages of the fractures indicated are determined by cutting relationships but many other deformational structures, especially in talc-chlorite rock where distinctive fracture fillings were absent, have been identified with the forces producing the features noted in the preceding chapter.

The quartz-filled fractures, contain quartz of three types. The oldest variety is cherty textured quartz ranging in color from white to light grey. It is more abundant in the mines to the west than at Gold Fields, where only a few examples were seen (Eakins 1952). On the 750 foot level of the number 2 mine, a vein of cherty quartz 3 inches wide is cut at right angles by a vein of glassy white quartz. In a few other places, this relationship was found in the number 2 mine but no definite cutting relationships could be seen elsewhere. Eakins noticed identical relationships between cherty and glassy quartz in other Malartic mines. At Gold Fields, glassy white quartz is the predominant variety. This type, later in origin than the cherty quartz, is found in long straight

veins, irregular short gash veins and highly irregular bodies in talc-chlorite rock bordering late intrusives.

Along straight veins, dark grey quartz is seen in white quartz in locations indicating its origin as being related to a mild brecciation of the white quartz (Fig. 9A). Where quartz breccia is recognizable, the matrix invariably is composed of grey quartz. This variety may not be the result of a later quartz introduction because the dark grey color is imparted to the breccia matrix by partial replacement along minute fractures by a sub-microscopically sized, grey, metallic mineral.

Tourmaline stringers as well as those coated with molybdenite are more abundant in syenites than in "diorites". They cross dykes at a large angle and in many places, cut across quartz veins (Figs. 8A, 8B). They are not nearly as abundant as quartz veins, and their discordancies with the latter suggest failure under different stress conditions.

Carbonate stringers cut across the above types as well as quartz veins and are clearly of later age. These stringers may be fractures of jointing nature produced by differential contraction of late intrusives in talc-chlorite rock during regional cooling.

Quartz-filled Fractures:

Quartz-filled fractures were studied in detail in the number 2 mining area, where mining and development activity was more intensive than in the number 1 area during the period of this study. Where comparison of fractures could be made between the two areas, it was seen that general spacial relationships in the number 1 area are analogous to

those of the number 2. Since the grades of gold in syenite were below ore values, no detailed mapping of fractures was carried out in normal mine geological work, hence only qualitative statements on fractures in syenites can be made.

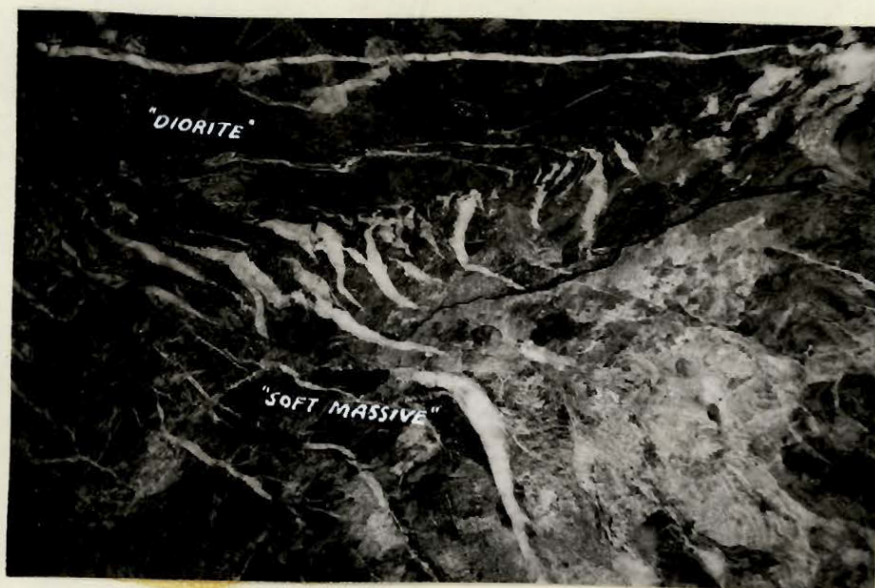
Differences in the nature of fracturing occurring in syenite and in "diorite" indicate that syenite behaved in a more brittle fashion when it failed under stress. Where fractures were seen extending from a "diorite" into an adjoining syenite, a change in attitude was noted. Fractured syenite dykes contained many small reticulated stockworks (Fig. 10A) and vug structures especially near horizontal terminations. Fractured "diorites" rarely exhibited a similar blocky pattern of cracks, and no vugs were found within them. Many large fractures in syenite had small subsidiary fractures along their length but similar types in "diorites" were relatively uncomplicated.

Quartz bodies in talc-chlorite rock are confined to late intrusive contacts, and in places are extensions of quartz veins crossing dykes. Smaller bodies up to 3 feet long are usually curved gash veins that flatten away from the intrusive contact (Figs. 6A, 7A, 7B). Larger bodies extending as far as 5 feet away from the contact are usually located near an irregularity in the dyke contact where fracturing is intense. These bodies contain many talc-chlorite rock inclusions (Fig. 6B). White glassy quartz is the only type found in talc-chlorite rock, grey quartz being completely absent. Some quartz veins that extend into the talc-chlorite rock from intrusives have zones of grey quartz that stop abruptly at the contact. Quartz in talc-chlorite rock contains only traces of gold in a few places.

Two varieties of quartz-filled fractures are found in "diorites". They differ in attitude and character. Straight persistent fractures, are sub-parallel in strike to the dyke in which they occur (Fig. 9A), and dip from 45° to 70° northward, or occasionally steeply southward. The bulk of the mineralization is distributed along diffuse and foliated zones in the altered "diorite" adjacent to the fractures (Fig. 11C). Little displacement parallel to the surface of fractures has been noted but comparisons with flat fractures suggest failure under shearing stress. Considering the surface area involved, a tabular body, such as a "diorite" dyke, has greater shearing resistance in a plane parallel to its strike and dip than at any angle to it. Therefore, the shear fractures, being sub-parallel to the strikes of dykes and with only small angles to their dips, are in planes close to those of maximum shearing resistance of dykes.

Some of the above-described shear fractures are traceable along their drift lengths, into series of irregular small openings with accompanying flattening in attitudes (Fig. 11A). Such flat fractures are characteristically short and jagged and contain many angular inclusions. These appear to be tension fractures. They are not as closely spaced as the steep variety and have no adjoining wall rock alteration or foliation. They are seen as well where shear type fractures cross from "diorite" into talc-chlorite rock. Fractures invariably flatten and become irregular, occasionally as irregular quartz masses, with many inclusions, terminating a short distance from the contact (Figs. 7A, 7B, 6A, 6B). Quartz bodies in the talc-chlorite rock adjacent to intrusive contacts, but not directly connected to fractures in intrusives, are a common contact phenomena (Fig. 6A). The veins have

Fig. 6A



9-6-E drift South Wall #2 mining area
Short gash type tension veins of white quartz in
altered "soft massive" peridotite at the "diorite"
contact.

Note: Drift wall is 20° oblique to the "diorite"
contact which dips toward the viewer.

Fig. 6B



12-2-E drift slash #2 mining area
Large irregular quartz body in "soft massive"
peridotite at "diorite" contact.

Note: Angular and suspended state of "soft massive"
inclusions

Fig. 7A



7-2-E drift slash #2 mining area
 Example of flattening of fractures as they enter "soft
 massive" peridotite
Note: This is the lower portion of a shear type frac-
 ture in "diorite"



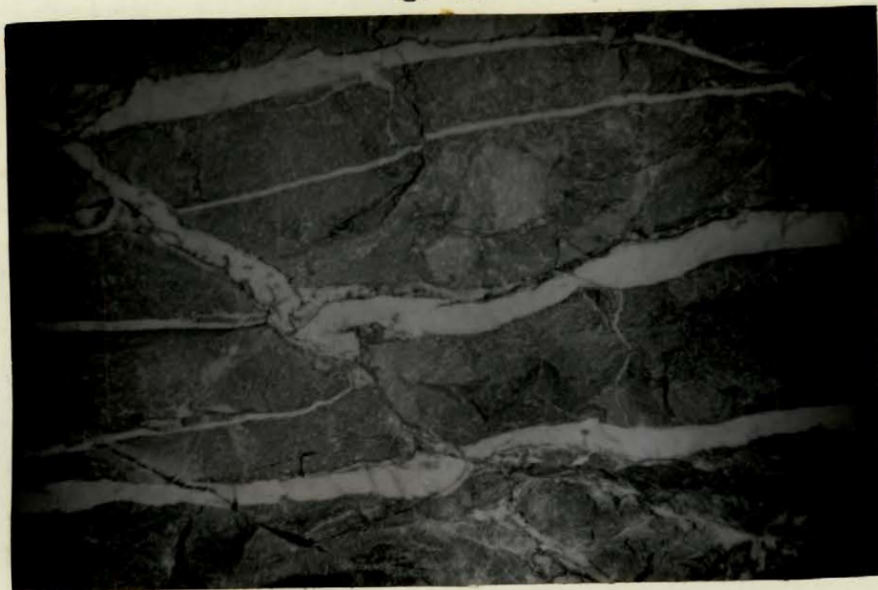
Fig. 7B

9-6-E drift slash
 #2 mining area

Flattening of quartz veins
 as they enter softer wall
 rock on right-hand side.

Note: This is the upper
 part of a shear
 fracture in "diorite"

Fig. 8A



7-8-W drift north wall No. 2 mining area
Quartz veins in syenite with a black tourmaline
stringer cutting the quartz veins.
Note: Bleaching effect along tourmaline stringer

Fig. 8B



7-8-W drift north wall No. 2 mining area
Angular fragments in white quartz vein, not exact-
ly matching

Fig. 9A



9-6-E drift south wall No. 2 mining area
Shear type quartz vein in "diorite" with white and
grey quartz

Note: (1) white quartz fragments in grey.
(2) bleached alteration adjacent to vein.

Fig. 9B



7-8-W drift south wall No. 2 mining area
Amphibolitization along flat quartz vein in
schist in upper right-hand portion is due to develop-
ment of secondary amphibole

Fig. 10A



Hand specimen of fractured syenite showing branching and reticulated fracture patterns

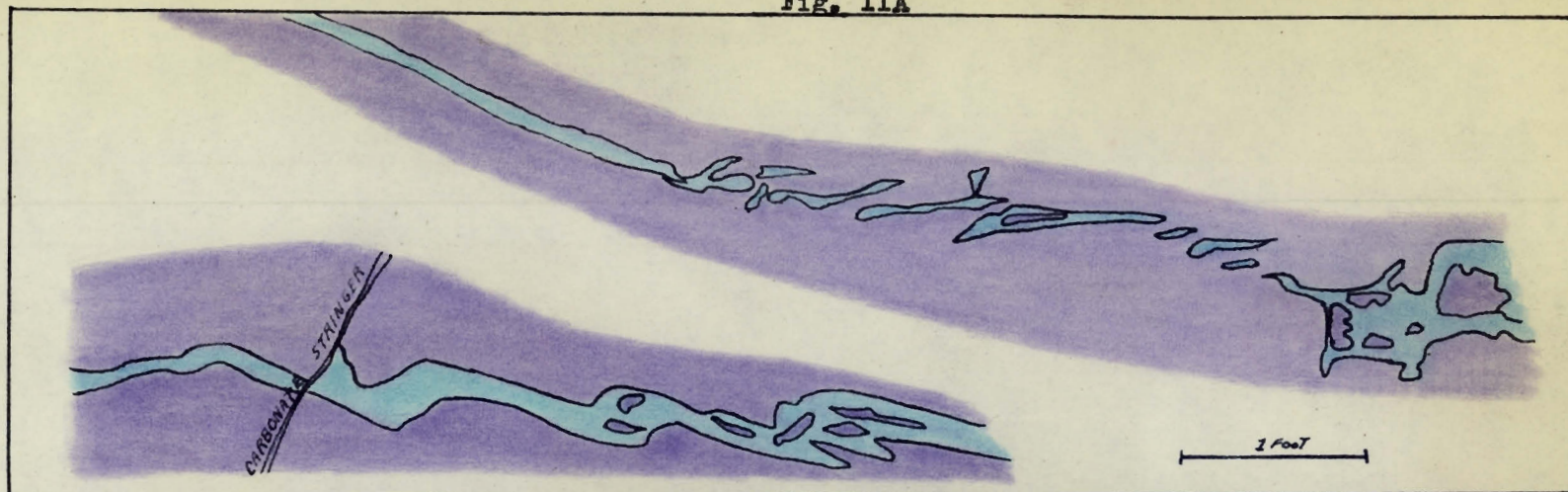
Note: Black cracks are tourmaline stringers

Fig. 10B



Hand specimen showing a syenite chlorite rock contact. Black band contains felted biotite, sparse amphibole and large crystals of tourmaline

Fig. 11A



Sketch 9-11-W drift north wall, showing two fractures.

Uppermost vein is a shear type changing to an echelon tension type vein. Lowermost vein is a typical tension type cut by a carbonate stringer. Note: inclusions of "diorite" in veins, unmatching walls as evidence of replacement.

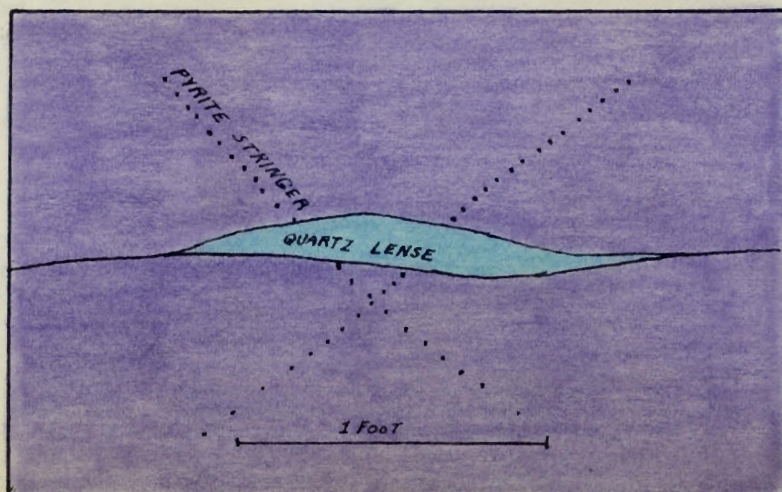


Fig. 11B

Sketch 7-6-E drift south wall
Vein of quartz showing replacement of wall rock
with no displacement of pyrite stringers.

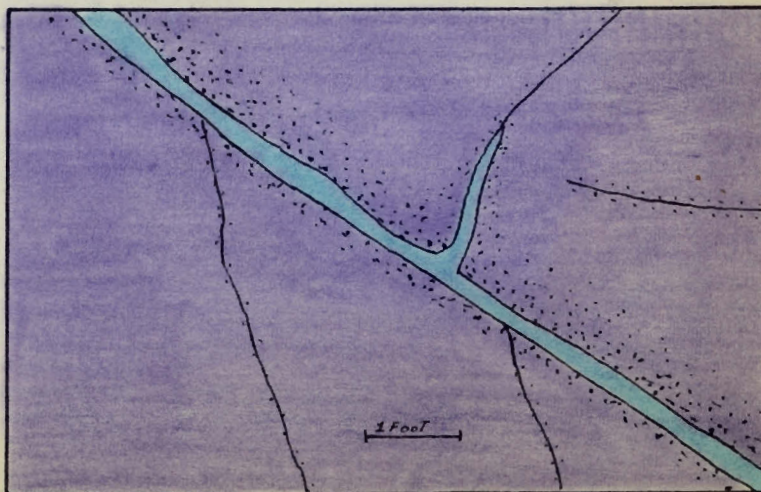


Fig. 11C

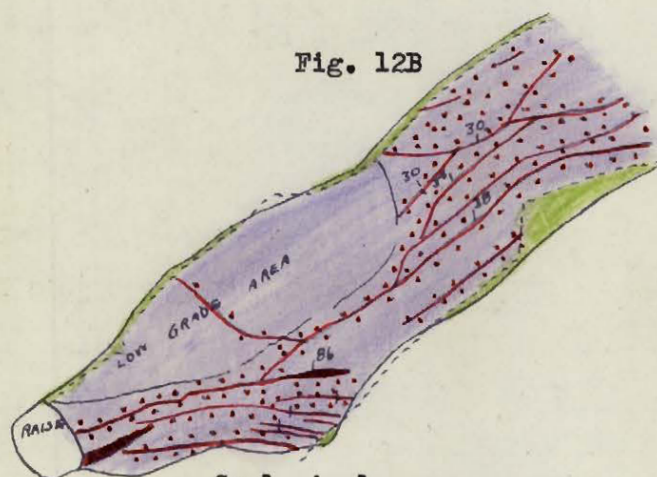
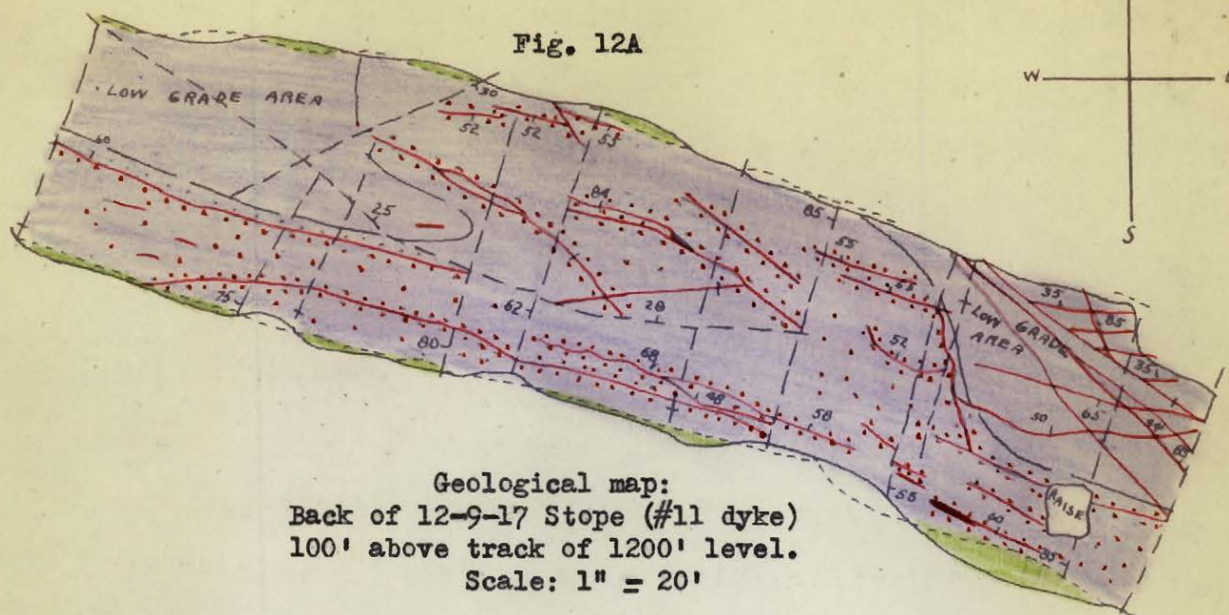
Sketch 9-11-W drift south wall
A shear type vein with altered and pyritized
"diorite" adjacent
Note: sparse pyritization adjacent to cracks.

curved wedge shapes, flattening and pinching out away from the contact. They were mentioned previously in the discussion on structures in talc-chlorite rocks and apparently were produced by the stresses responsible for the fracturing in late intrusives.

Grey quartz is found along shear fractures but only a few examples are seen in tension fractures and none was found in the quartz in talc-chlorite rock. Since grey quartz is related to brecciation and fracturing of white quartz, the above suggests that late fracturing in tension fractures and quartz in talc-chlorite rock was very slight if it occurred at all.

In those sections of "diorite" dykes, where flat or tension type fractures predominate over shear fractures, the zone is not of ore grade. Grade decreases in these zones, not only because of the paucity of associated mineralization but also because the fractures are spaced at greater intervals than those of the shear type. The two plans of the backs of stopes on the following page illustrate the zonal distribution of these fractures (Figs. 12A, 12B).

Low grade zones, and hence zones of predominantly tension type fractures are indicated by the dark grey areas in longitudinal sections of "diorite" dykes in Item 2, Appendix 1. Data for these zones were obtained from inclined diamond drilling parallel to the elongation of dykes, the holes being collared in drift intersections of dykes containing ore (Anderson & Wilton 1953). The drill core obtained from these holes was assayed in 5-foot lengths and the low grade zones were outlined from the grade distribution. Where stope backs were carried through a low grade area, the correspondance of low grade and the lack of shear type fractures



Note:

Quartz veins - in red.
Sulphide - red stipples.
Post quartz fractures: - - - - -
"Diorite" schist contact: - - - - -

and their associated tenor of mineralization was noted. Thus, low grade zones in the illustrations of Appendix 1 roughly outline areas where tensional fractures predominate.

Usually low-grade zones have flat rakes. In dykes 1 and 3 the zones occurring in the upper levels rake west in the saucer-shaped areas of the dykes. In dyke 11, a regular dipping, tabular dyke, they rake consistently westerly. In dykes 5 and 6, the low grade zones are associated with the lower sections of the dykes, where the dykes enter the "soft massive" peridotite.

Statistical Analysis of Fracture Attitudes:

In the number 2 mining area, geological mapping of "diorite" dykes included mapping of quartz filled fractures on a scale of 20' to the inch. Sufficient information exists to construct equal area projections of their attitudes but there was insufficient data to do likewise for the number 1 mining area.

Attitudes of fractures were plotted from geological level plans where dykes were intersected by drifts. An example of this mapping is Figure D, Appendix 2. A dyke therefore, was "sampled" for fracture attitudes at 150' vertical intervals. All dykes examined have at least seven such "samples" as a basis for their projection nets. The dykes studied in this manner are 1, 3, 4, 5, 6, 7, 8, and 11. Normals, or poles to fracture planes are plotted and each contour represents an increase of 1% of fracture attitude concentration. For clarity, every third contour is numbered and for comparison with the illustrations of Item 2, Appendix 1, the "base line" is indicated. The diagrams on pages 40 to 47 inclusive, summarize the study.

Analysis:

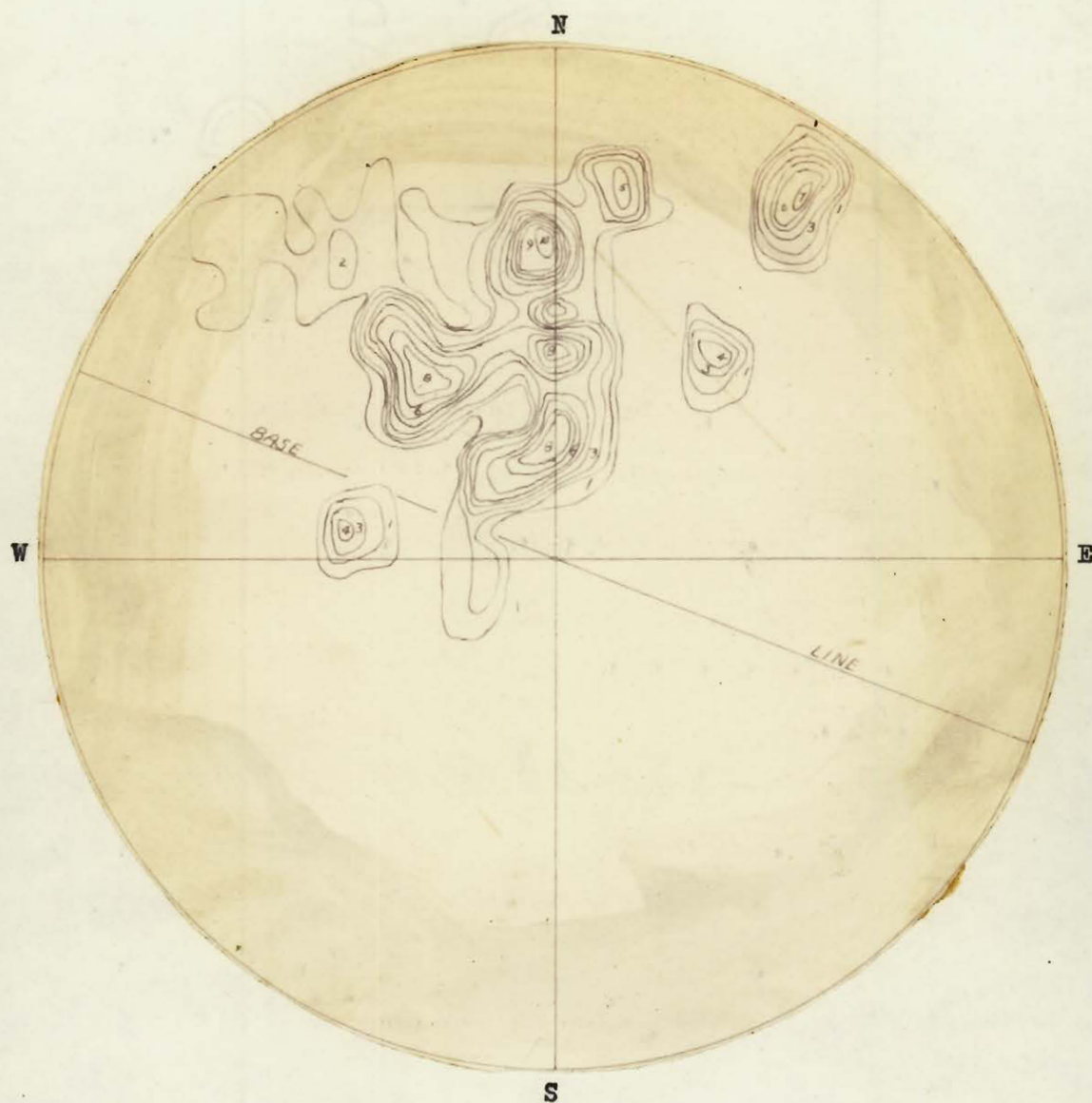
No symmetry other than an approximate axial suggestion is seen in the major concentrations of fracture attitudes. Post quartz fractures are distinguished in dykes 3, 4, 7, 8, and 11 by their steepness and proximity of concentrations to the "base line". Major concentrations of fractures in the northern quadrants contain many peaked areas ranging from 6% to 14% fracture concentration.

Distributions of fracture attitudes do not show steep shear type fractures distinctly separated from tension types but the latter are represented by an extension of contours into low dip sectors which have local increases of concentration of about 4%. This observation is unexpected when contrasted with the zoned distribution of fracture attitudes found in dykes.

The shapes of dykes appear to exert some control on fracture patterns. In dyke 11, a tabular dyke consistent in dip, a strong restricted simple concentration is evident, while in dyke 8 a highly irregular body, concentrations are dispersed with the strike being the greatest attitude variant. Dykes 5 and 6, which appear to twist in depth, exhibit a fairly strong concentration in northern quadrants with a weak girdle tendency in a southwesterly direction.

The above-noted dispositions of fractures in dykes of variable shapes and degrees of complexity indicate that irregularities in dykes have a perceptible effect on their attitudes. The same influence was noted when mapping fractures in dykes where, in the vicinity of constrictions and irregularities, steep fractures diverge markedly in strike. Flat tension fractures however, show no change in these areas. It seems

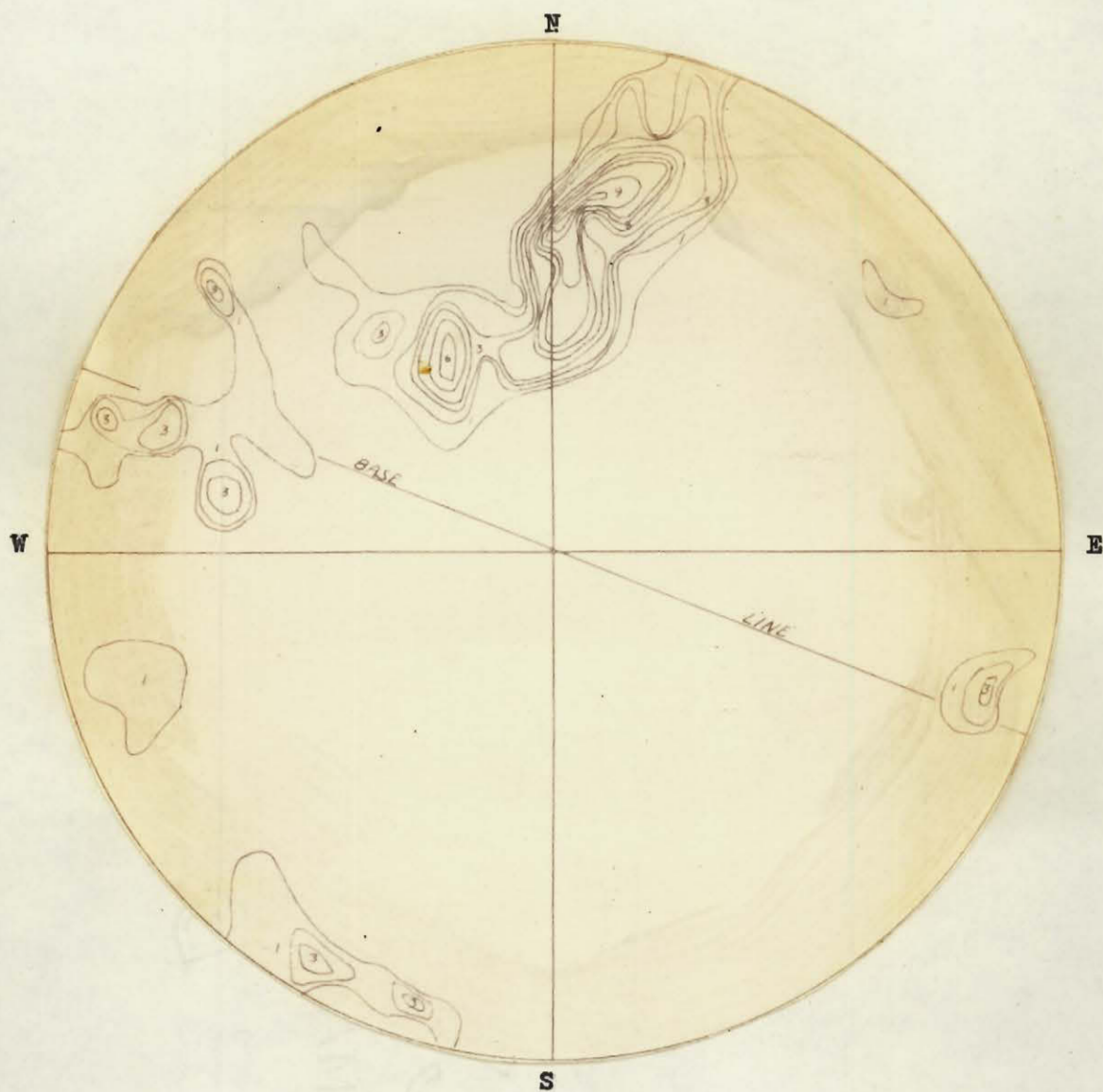
Fig. 13



Equal Area Projection net of
fractures in dyke No. 1.

Based on 79 observations

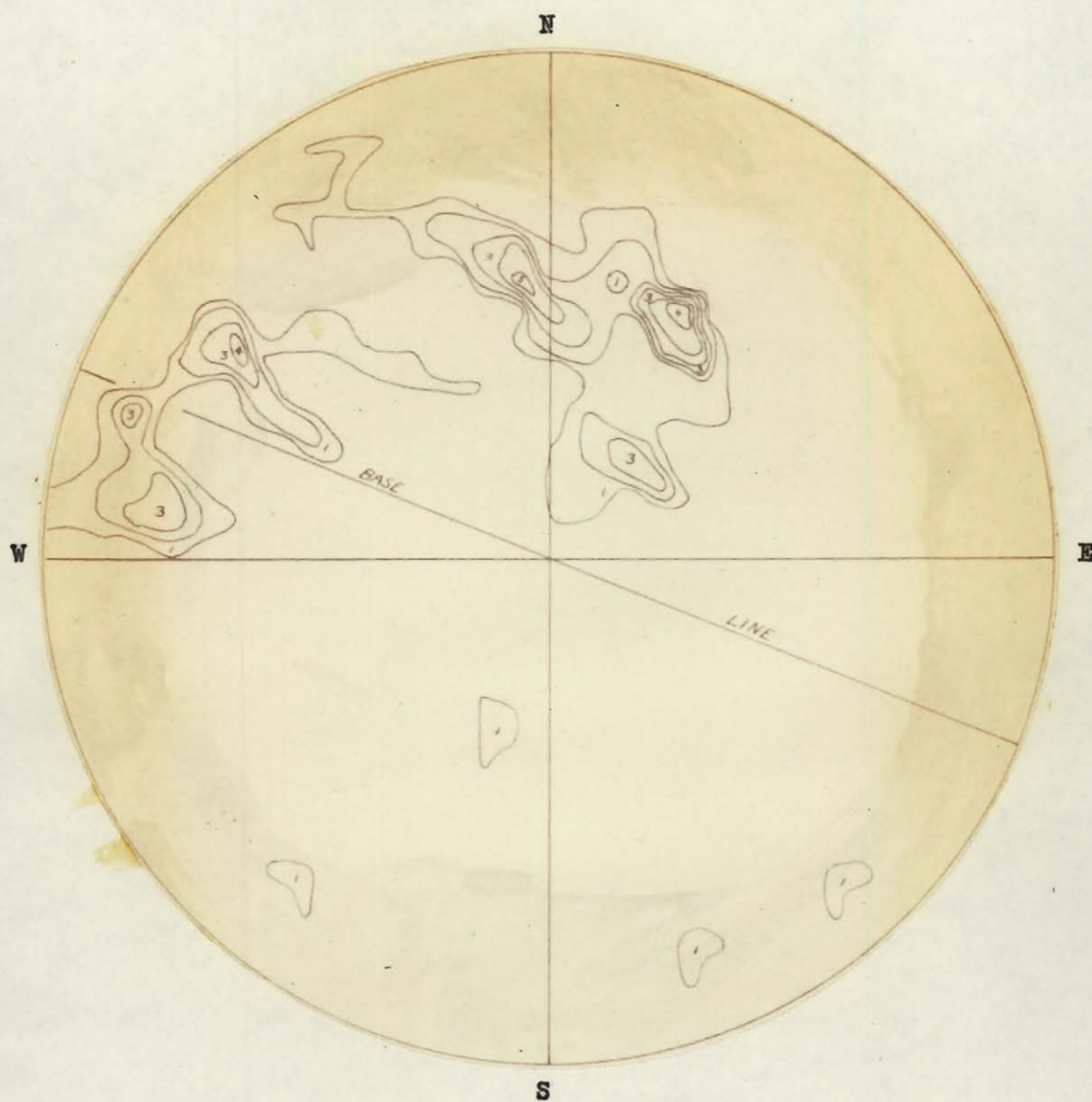
Fig. 13



Equal Area Projection net of
fractures in dyke No. 3.

Based on 63 observations

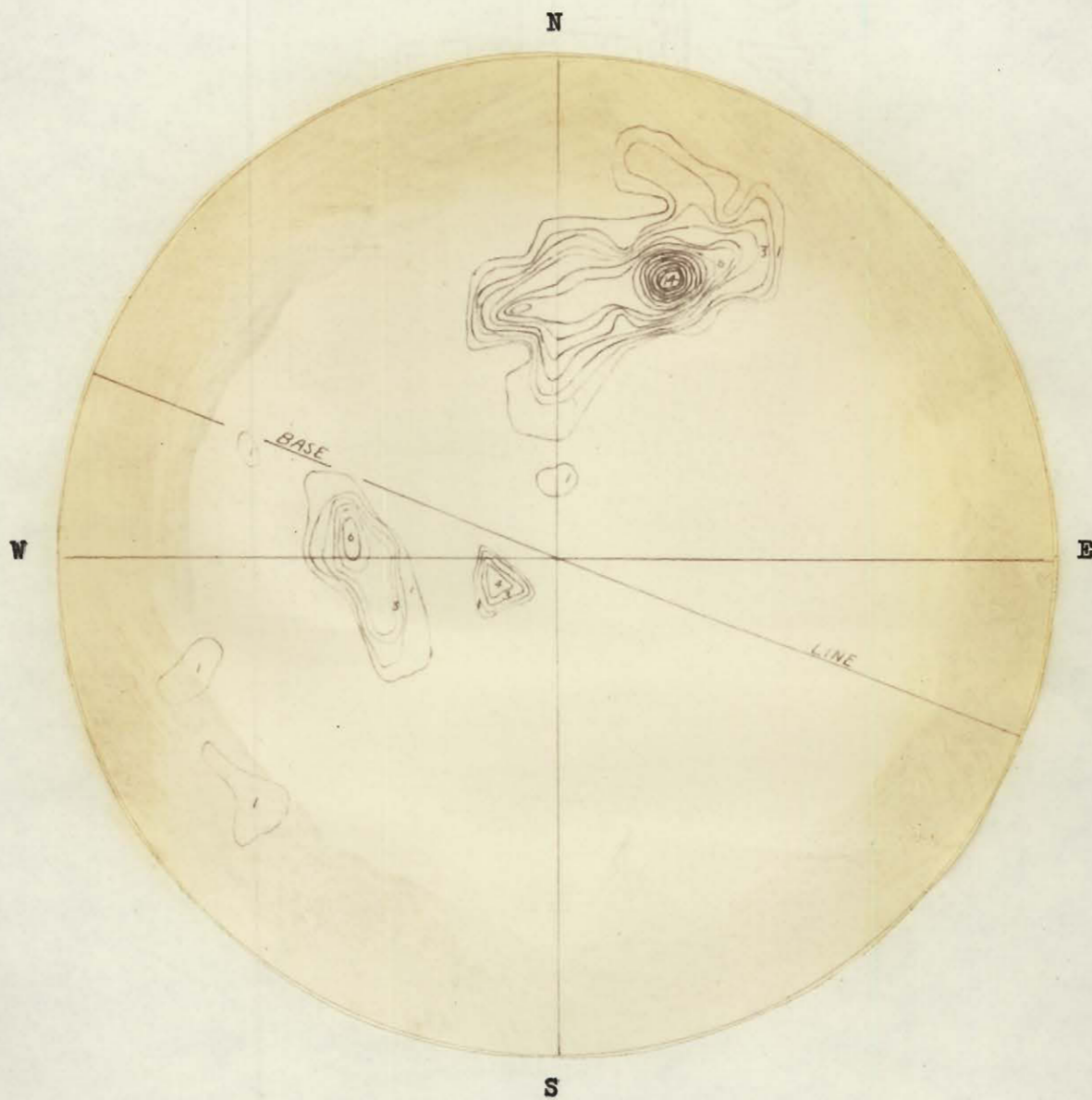
Fig. 13



Equal Area Projection net of
fractures in dyke No. 4.

Based on 56 observations

Fig. 13



Equal Area Projection net of
fractures in dyke No. 5.

Based on 167 observations

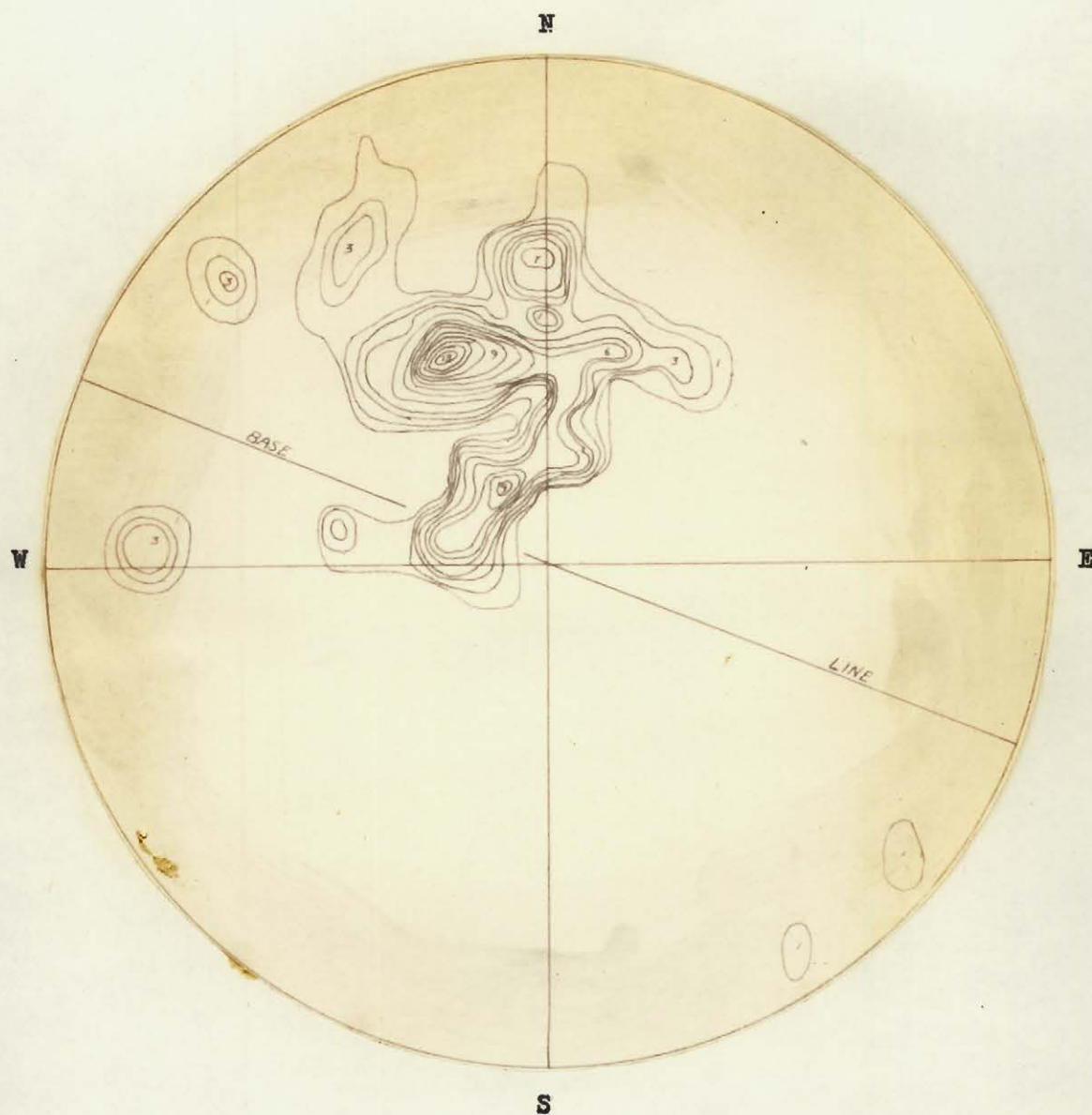
Fig. 13



Equal Area Projection net of
fractures in dyke No. 6.

Based on 154 observations

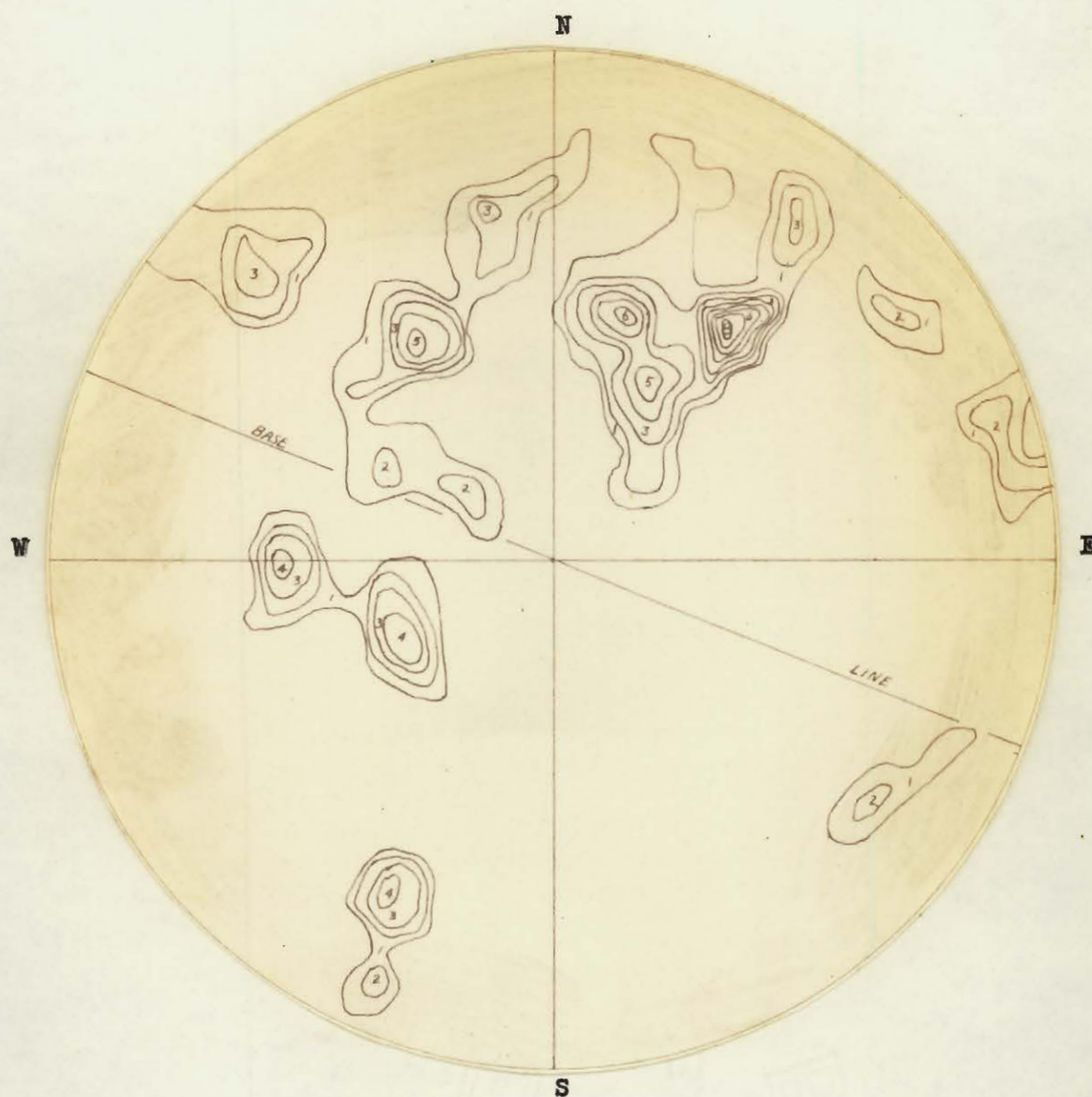
Fig. 13



Equal Area Projection net of
fractures in dyke No. 7.

Based on 101 observations

Fig. 13



Equal Area Projection net of
fractures in dyke No. 8.

Based on 95 observations

Fig. 13



Equal Area Projection net of
fractures in dyke No. 11

Based on 178 observations

clear that minor variations in attitudes, at least, are attributable to irregularities in dykes.

Conclusions:

It was stated previously that shear fractures cross dykes at small angles, and that their planes are those of relatively great shearing resistance compared with planes at greater angles to dykes. It appears therefore, that the responsible stresses were of a unique nature to produce the ruptural effects noted. It is not likely that the theoretical angular relationship between applied stress and resultant planes of greatest shearing stress would be approached under the heterogeneous conditions prevailing. However, the average angle of about 45 degrees between shear and tension fractures suggests that theoretical attitudes of ruptures to the forces causing them may have been approximated at Gold Fields. If this is so, the following conditions appear to be implicit:

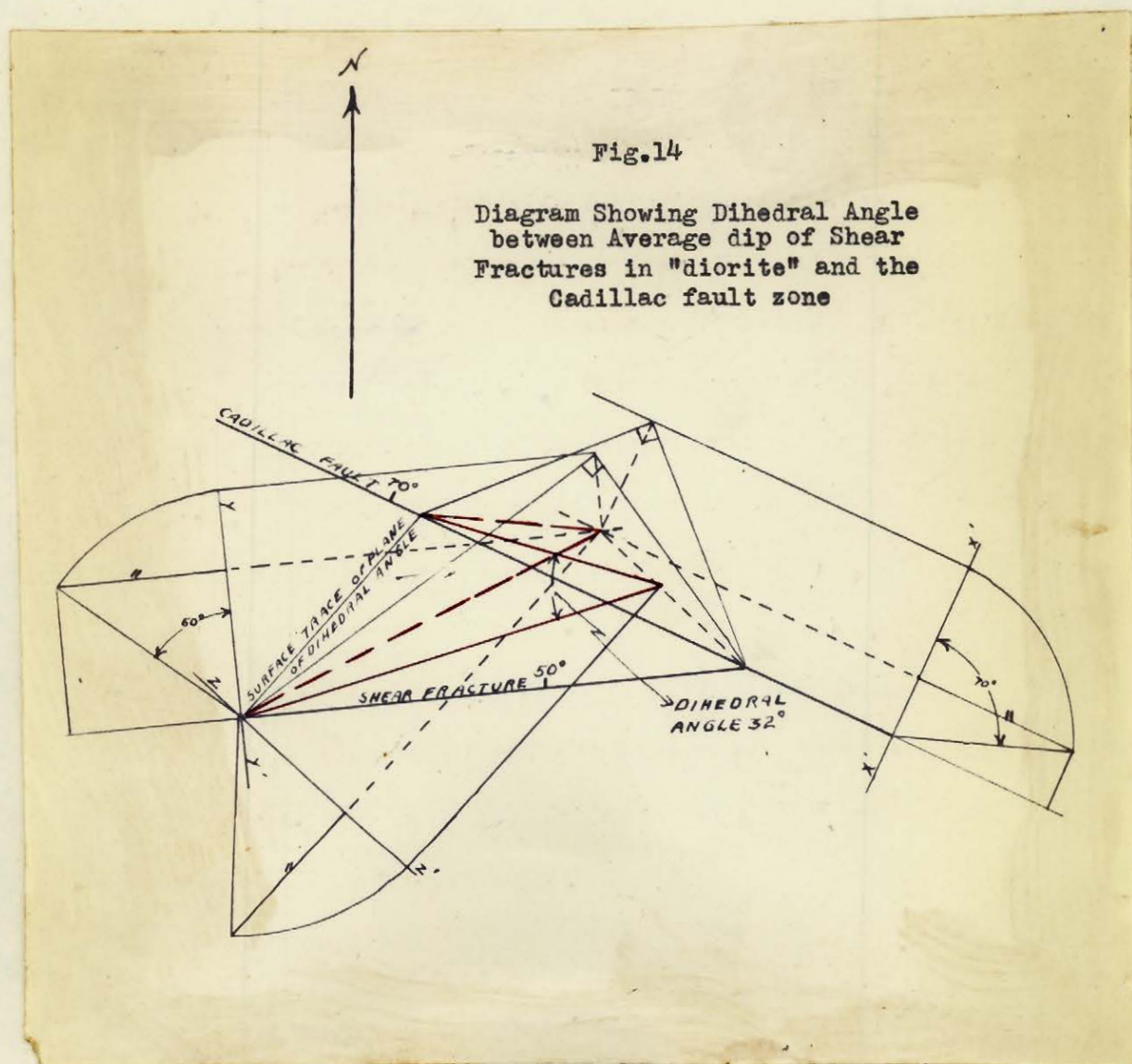
1. Flat tension fractures with dips less than 15° on the average had a reverse sense, and the compressive axis of local stress was flat as well.
2. Strikes of shear fractures suggest that the axis of compression was in a north-south direction.
3. The complexities of dykes affect fractures only to a subordinate extent.

The forces causing rupturing in late intrusive undoubtedly have undergone some rotation in passing through talc-chlorite rock. If the forces were slowly applied, relatively weak talc-chlorite probably would deform plastically, and it is supposed that shears would have appreciable displacements with attendant local contortions in adjacent talc-chlorite rock. Observations on shear fractures show only minor displacements with no related or extensive contortions adjacent, suggesting that rotation had a subordinate role in the rupturing of late intrusives.

If the forces were quickly applied, possibly as a series of shocks, talc-chlorite rock under these conditions would behave more rigidly. Plastic deformation would then be reduced and rotation of applied forces would be minimized. Stress conditions would then be maintained approximately and the resultant fractures may approximate theoretical directions of maximum shearing and tensional stresses, relative to the applied force.

It is assumed that regional stresses would find tectonic expression in movements along the Cadillac fault zone and that ruptural failure of the members in the dyke swarms of the numbers 1 and 2 mining areas are related to the resulting local stresses of these movements. Shear fractures in dykes may be of the fracture cleavage type, developing in the brittle dykes that are enclosed in more plastic talc-chlorite rock adjacent to the Cadillac fault. The geometric relationship would indicate the sense of the movement on the Cadillac fault that caused fracturing in the intrusives. Shear fractures are at an average angle of 30 degrees in strike to the Cadillac fault. The dihedral angle of

32 degrees, as shown in Figure 14, between shears and the Cadillac fault, shows that the required movement on the Cadillac fault had a right-hand normal sense.



PART 2

PETROLOGY OF
MALARTIC GOLD FIELDS PROPERTY

CHAPTER 5

BEDROCK LITHOLOGY OF THE MINING AREA

Introduction:

The types of rock under study in this chapter have been described briefly in the preceding section on structural geology. The Table of Formations shown in that section is reproduced below for convenience and illustrates the rock types encountered in the detailed study of the mine.

TABLE OF FORMATIONS

Precambrian	Late intrusives	syenite "diorite"	
	Altered Peridotite	talc-chlorite rock	schist "Soft Massive" "Hard massive" peridotite

All rocks encountered are intrusive igneous rocks that have undergone alterations of a retrograde nature. Peridotite, the oldest intrusive, was introduced along the pre-existing Cadillac fault zone early in the geosynclinal history of the area. The schistose talc-chlorite derivative was formed later as a result of protracted shearing in an aqueous environment while "soft massive" rock developed under minimum shearing stress. Late intrusive dyke rocks were introduced after the rudimentary structures of the talc-chlorite rock were formed.

The chemical analyses shown in Item 1 (Appendix 1) are incorporated in this study with the permission of the Quebec Department of Mines. Eakins (1952) in his study of the Malartic mining camp showed

gains and losses in rock alterations by using Barth's method of recasting weight percents. In a review of the various methods of comparison, a method devised by Leith & Mead (1915) was adopted for this study. Comparisons between this method and that of Barth's showed serious differences in results between the two. The brief comparative analysis of the two methods in the following paragraphs is thought to be of general value.

Barth's method is based on the conclusion that oxygen anions occupy about 95% of the volume of a rock. His standard cell or basic comparative unit contains 160 oxygens, and in comment on his method he states:

"If we want to compare isovolumetric units, we should compare units containing the same number of oxygens. These considerations, in their first approximation, are restricted to rocks belonging to the same mineral facies."
(1952, p. 82)

The last sentence of this quotation suggests that this method may be unreliable when comparing altered rocks, which have mineral assemblages stable in an environment different from that of the parent rock. The basis of his method is empirical and not related to an intrinsic property of the analysed material.

Leith & Mead, on the other hand, outlined a method of recalculating analyses to show gains and losses of constituent oxides by using an intrinsic rock property, the density. In the analysis of "hard massive" peridotite (Item 1, Appendix 1) the weight of 100 cc of rock would be 293 gms. (density x 100) while the weight of its altered derivative, the "soft massive" peridotite, assuming constant volume,

would be 285 gms. By multiplying the percentages of constituent oxides by the rock density, they can be expressed as grams per unit volume and gains and losses of oxides in transformations can be shown in grams per unit volume. By a further calculation, gains and losses of elements can be expressed in grams per unit volume. The example below illustrates the calculations involved.

	Chemical Analysis 1 "Hard Massive" (Density 2.93)		Chemical Analysis 2 "Soft Massive" (Density 2.85)		Gains and Losses in gms/100 cc
	Wt. %	(gms/100 cc)	Wt. %	(gms/100 cc)	
SiO ₂	43.59	127.7 gms	39.98	113.9	- 13.8 gms SiO ₂
FeO	3.21	9.4 "	6.22	17.7	+ 8.3 " FeO

The above gains and losses shown as elements rather than oxides are as follows:

$$\text{Silicon loss in Gms per 100 cc} = \frac{13.8 \times 28}{32 + 28} = - 6.4 \text{ gms}$$

$$\text{Iron gain in Gms per 10 cc} = \frac{8.3 \times 56}{56 + 16} = + 6.4 \text{ gms}$$

Gains and losses indicated by Barth's method, contrasted with the Leith & Mead method are shown below for the ore type alteration of "diorites".

(Chemical Analyses 5 & 6, Item 1, Appendix 1)

	Leith & Mead (Unit Volume 100 cc)	Barth (Unit cell 160 oxygens)	Ratio
Gains	.3 gms K	1.5 ions K	1:5
	1.4 " C	3.2 " C	1:2.3
	26.0 " S	.3 " Mg	
		.2 " Ca	
Losses	9.5 " Si	3.6 " Si	2.6:1
	.7 " Al		
	.2 " Mg		
	.8 " Ca	2.4 " OH	
	1.3 " Na	.4 " Na	3.2:1

The Table shows a great difference in results of the two methods and also shows some reversals in the elements gained and lost. If the two methods showed the same gain and loss picture, ratios between "grams per 100 cc" and "ions per 160 oxygens" would be constant for all the migratory elements noted. Ratios shown at the right hand side mathematically illustrate the extreme differences in proportionality.

The isovolumetric basis of the Leith & Mead method as well as Barth's will represent transformations insofar as replacement takes place without change in the volume of a rock. In the former method, the assumption of constant volumes is arbitrary, whereas the basis of Barth's calculation is empirical and may have inherent factors affecting its validity as representing equal volumes. Barth acknowledges this weakness when he restricts his method of comparing rock belonging to the same mineral facies. The above examples deal with rocks having mineral assemblages belonging to different facies and it is possible that Barth's method is not applicable under these conditions.

Peridotite

The name peridotite is used here to cover a group of ultra-basic rocks which have undergone alteration of two distinguishable types and ages. These rocks were originally thought to be part of the Blake River volcanic group (Gunning & Ambrose 1940) and were described tentatively as basic flows altered to massive and schistose greenstones. Norman was amongst the first to recognize them as altered ultramafics, although Gunning & Ambrose had mentioned the presence of serpentine dykes previous to his work.

Petrography:

"Hard massive" peridotite is the least altered of this group of rocks and exhibits a remarkable uniformity of texture in hand specimens. The rock is a dull bluish grey in color and is fine- to medium-grained. Compared with its talc-chlorite derivative it is relatively hard to scratch with a knife blade, hence its name. Aside from a reticulated jointing system throughout "hard massive" variety, the rock is structureless.

Talc-chlorite rocks in hand specimen are dark greenish in color and are very soft. They are composed principally of talc and chlorite, with a subordinate and variable amount of carbonate. Where this rock exhibits parallel orientation of platy minerals, it is termed schist but where the megascopic texture appears felted, it is called "soft massive".

No positive megascopic evidence exists to indicate these rocks as being related but it will be seen in the discussion on chemical composition that cogent evidence for this is present in the chemical similarity of the two rocks.

In thin sections, "hard massive" peridotite exhibits a granoblastic texture with grains ranging in size from 0.1 mm to 3 mm (Figs. 15A, 15B). The harder facies are composed of up to 80% hornblende with antigorite, chlorite, and magnetite. No pronounced lineation was found in any of the sections studied. Magnetite ranging in amounts from 5% to 12% of the rock is disposed as very fine dust-like particles and occasionally rod-like, branching aggregations relict after cleavages of older olivine or pyroxene.

"Soft massive" peridotite and schist are mineralogically and chemically similar. Schist averages 65% chlorite; 17% talc; 15% carbonate, and 3% magnetite. In "soft massive" the amount of chlorite occasionally increases to as high as 80% with a noticeable decrease in magnetite. These varieties are quite erratic in grain size but crystals seldom exceed 1.0 mm.

Chemical Composition:

The chemical composition of "hard massive" peridotite approximates the average of 31 analyses of peridotite compiled by Tyrrel (1946). Although the rock is completely altered, positive identification of its origin is indicated by its Cr_2O_3 content. In basalts, Cr_2O_3 content seldom exceeds .1% by weight and averages 0.04% (Guppy 1931). Chemical analyses of all the peridotite varieties show an average of .44% Cr_2O_3 (analyses 1, 2, and 3; Item 1, Appendix 1). Analyses of ultrabasic rocks from other areas and ages exhibit a corresponding quantity of Cr_2O_3 (Guppy 1931).

In passing from "hard massive" to "soft massive" peridotite (analyses 1 and 2) chemical changes are evident but the difference

Fig. 15A



"Hard Massive" Peridotite
(X nicols Mag. x 40)
showing Granoblastic texture

Fig. 15B



"Hard Massive" Peridotite
(Ordinary light - Mag. x 40)
showing finely dispersed magnetite

between "soft massive" and schist are negligible. The values below represent changes of elements expressed in grams per standard volume of 100 cc.

<u>Gains</u>	<u>Losses</u>
.1 gms K	6.4 gms Si
7.3 " C	.7 " Ti
	.5 " Al
	4.7 " Fe (total)
	4.0 " Mg
	1.6 " Ca
	.3 " H

The increase in CO_2 reflects the development of carbonate while decreases of Fe, Mg, Ca, probably is testimony of removal of those elements in carbonated form which are precipitated as carbonates along stringers and joint planes. Also, minerals such as chlorite and talc having the $\text{RO}:\text{SiO}_2$ ratio require less Fe, Mg, and Ca in their composition than higher temperature ferromagnesian silicates which have higher ratios for bases. The loss of 6.4 grams Si is one of the significant effects of the addition of carbonate.

The mineral assemblage of the "hard massive" peridotite, according to Turner (1948), is stable in a doubtful sub-facies between the greenschist and epidote amphibolite facies and the talc-chlorite rocks reflect stability in the greenschist facies. The processes responsible for the characteristics of the "hard massive" peridotite probably were autometamorphic and related to the conditions of ultramafic introduction. The ultramafic magma in being emplaced

along the Cadillac fault and in contact with sediments, probably incorporated appreciable amounts of water which enhanced autometamorphic alteration and hence the development of the actinolite chlorite serpentine mineral assemblage. In an aqueous environment under shearing stress, retrograde metamorphism of the "hard massive" rock results in the formation of talc-chlorite rock.

The Late Intrusives

These intrusives have been introduced into altered peridotite under structural conditions that have been discussed in the preceding section on structure. Two well-defined ages of late introductions are distinguishable both in cutting relationship and in composition. The older, roughly gabbroic in composition, exhibits many anomalous features which are difficult to interpret in postulating an origin for the rock. This rock is here called "diorite". The younger of the late intrusives is a syenite.

All syenite introductions at Gold Fields are later than "diorites". Where discordant igneous contacts between the two are seen, the syenite always cuts the "diorite". The syenites are clearly of igneous origin and show few effects of metamorphism. Mineralization has affected them at Gold Fields where they occur in the ore-bearing areas but grades in gold rarely reach ore values.

"Diorites"

The "diorites" occur as dykes in "hard massive" peridotite and tabular lenses and pipes in the talc-chlorite rocks. The petrographic characters of the rocks in these two environments appear to be different.

Gunning and Ambrose (1940) in mapping the Malartic area experienced great difficulty in distinguishing "diorites" and dioritic phases of andesite flows and they concluded that some "diorites" probably were metasomatic. The structural evidence at Gold Fields points to their origin as being igneous but their petrography does not show igneous textures. Some mineral arrangements however, suggest an original ophitic texture.

Petrography:

"Diorites" located in "hard massive" peridotite are remarkably uniform in character. These rocks, considered to be the freshest of the "diorites", are pitchy lustred, black colored, fine- to medium-grained, equigranular aggregates, composed mainly of dark green amphibole and subordinate feldspar. The freshest "diorites" found in the talc-chlorite areas on the other hand, are dark greenish to dark grey in color and have more feldspar as well as local concentrations of epidote.

In thin sections, all of the fresh types exhibit a peculiar crystalloblastic texture. The black "diorite" has an average grain size of 1.5 mm. and includes the following minerals in its average composition:

Green hornblende	75%
Feldspar	20% and
very fine-grained poikiloblastically	
disposed minor amounts of chlorite,	
epidote and carbonate.	

Hornblende is seen as decussate idiomorphs with ragged and sometimes splintery basal terminations. Their pleochroic formula, x-yellow; y-green; z-greenish blue, with a 2V at about 70°, suggests,

according to Winchell (1946), that they could extend in composition into the sodium-rich side of the hornblende-pargasite series. Spaces between the hornblende crystals are occupied by plagioclase feldspars in the albite-oligoclase range. Saussuritic alteration products prevent accurate optical identification of the original feldspar. Their composition is judged mainly by the amount of alteration products and apparently they are abnormally acid for a gabbroic igneous rock. Minor amounts of sphene, epidote, and magnetite are scattered throughout the rock. This variety of "diorite" is identical with that of East Malartic (Fig. 16).

The least altered "diorite" found enclosed in talc-chlorite rock is similar to that of the Barnet Mine (Eakins 1952). This rock averages 50% hornblende; 37% feldspar; 8% magnetite and ilmenite, and minor epidote, chlorite, and carbonate. In some sections of this variety, ophitic or blastophitic textures are present. Hornblende is less idiomorphic in this type and appears to be partially embayed by feldspar (Fig. 16B). Magnetite and ilmenite are disposed as fine dust-like particles and the older feldspar contains much secondary material. A second generation of albite is evident as well, and usually occurs as clear euhedral crystals along mutual boundaries of hornblende and older feldspar. Carbonate is scattered throughout the rock as subhedral grains of smaller sizes.

Chemical Composition:

No analysis exists for the "diorite" in the "hard massive" peridotite at Gold Fields but the petrographic similarity between it and the East Malartic type indicates that the analysis of the East Malartic "diorite" is representative (Item 1, Analysis 4). The amount of Na seen

Fig. 16A



Fresh "diorite" in "hard massive"
Peridotite at East Malartic
(Ordinary light x 25)

Note: This is an example of the type found at
Gold Fields of similar environment.

Fig. 16B



Fresh "diorite" of the mining area
located in talc-chlorite rock
(Ordinary light x 75)

in the analysis is in excess of the requirements of the albitic feldspar (20%) and the optical character of the hornblende indicates the possibility of hornblende being sodic. Comparing this analysis with the one for the fresh "diorite" of the ore zone at Gold Fields (Item 2, Analysis 5), significant changes in comparative unit volumes of 100 cc are as follows:

<u>Gains</u>	<u>Losses</u>
4.1 grams C	8.6 grams Si
	2.7 " Fe (total)
	6.2 " Mg
	4.3 " Ca

The changes shown above are almost similar to those at East Malartic with the exception of the increase in carbon (Eakins 1952). The unchanged percentage of Na is noteworthy, as an increase in the amount of albitic feldspar is one of the major mineralogic changes. Losses of Fe, Mg, Ca, and Si could be accounted for in a partial breakdown of hornblende crystals with a coincident development of later albite reflecting the redistribution of Na. Fe and Ti released from hornblende and sphene probably goes to form magnetite and ilmenite while some of the Fe, Ca, and Mg may be removed in solution as well as being present in the carbonates. Albitization with a coincident introduction of CO₂ appears to account for the change.

"Diorite" bodies in ore zones and therefore in the talc-chlorite embayment are in close association with syenite, and share many mutual contacts, compared with "diorites" in "hard massive" peridotite. Talc-chlorite rocks in general are more permeable than "hard massive" peridotite. With these comparisons in mind, petrographic and chemical changes in ore zone "diorites" may be affected by the influence of the syenitic magma.

Fugitive constituents of the syenitic magma probably contributed to the alteration where permeability and close association was greater in talc-chlorite rock than in "hard massive" peridotite.

A normative recast of the fresh "diorite" of the Barnat Mine showed that these rocks do not fit into C.I.P.W. classification and that the normative minerals shown below are greatly different from the modal distribution.

Albite	30.93%	Olivine	18.80%
Anorthite	19.46%	Apatite	.34%
Orthoclase	3.05%	Magnetite	6.26%
Nepheline	1.25%	Ilmenite	1.52%
Diopside	20.37%		

Eskola (1935) described similar hornblende albite rocks in Russia as intrusive spillites, that were termed "diorite" and uralite diabase by earlier investigators. The metamorphic aspect of their mineral assemblage is discussed by Turner (1948) who states:

"In conclusion, the metamorphic aspect of the spillite problem may be summarized as follows. Basic igneous rocks, by normal regional metamorphism or by metasomatism under conditions typical of the greenschist facies (muscovite-chlorite sub-facies) give rise to rocks in which albite, epidote, actinolite and chlorite are usually prominent constituents". (p. 125)

The origin of "diorites" is considered at the end of this chapter where genesis of the late intrusive rocks will be discussed. For the present, these rocks are considered to be basic igneous introductions in a "wet" environment that have undergone metasomatism under conditions of the greenschist facies.

Syenites

Syenite bodies occur in positions analogous to those of "diorites" in the peridotite and comprise the last significant igneous introduction on the property. Throughout the Malartic camp, a multitude of names have been applied to them including quartz-albite porphyry, quartz albitite, aplite porphyry, quartz-syenite porphyry, quartz-feldspar porphyry, and quartz monzonite porphyry.

Petrography:

Generally, these rocks are light colored, with grain sizes ranging from that of aphanatic felsites to medium-grained porphyritic rocks. Porphyritic textures with phenocrysts of feldspars are a common feature. In colour, the rocks range from reddish grey to dark grey.

On the property, three varieties are megascopically distinguishable:

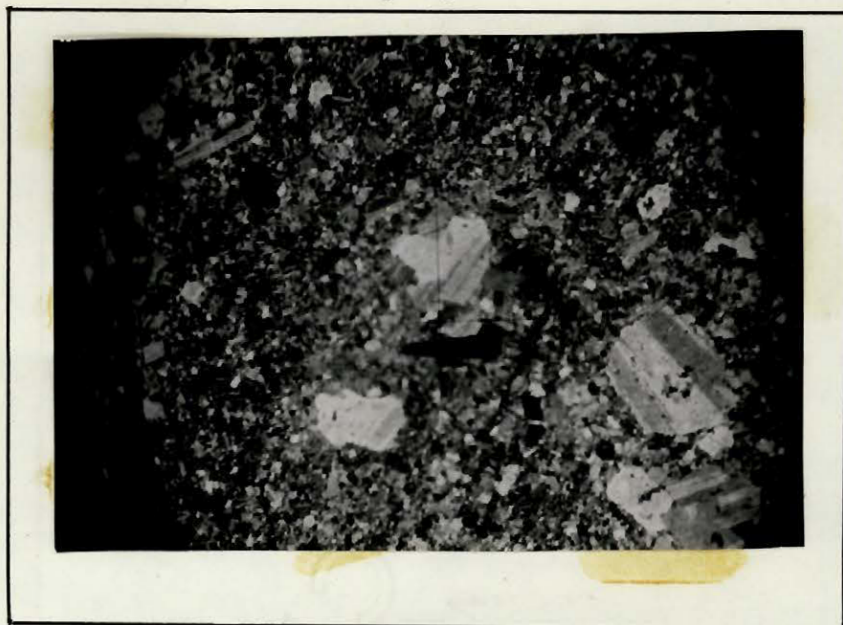
- (1) "Red" porphyry is a medium-grained porphyritic rock with an irregular pinkish to red colour. The reddish hue is due to finely dispersed red hematite. This type is confined largely to the zone along the south peridotite contact.
- (2) Grey porphyry, the most abundant syenite, is found mainly in the mining areas located in the northern sections of the peridotite belt (Fig. 17B).
- (3) Non-porphyritic syenite appears to be identical with the

Fig. 17A



Non-porphyritic fine-grained syenite
(crossed nicols x 25)

Fig. 17B



Porphyritic Syenite
(crossed nicols x 25)

ground mass of the grey porphyry (Fig. 17A). In many cases, the last two varieties are found in the same dyke.

In small thin dykes, porphyritic textures are almost completely absent but in dykes wider than 6 feet on the average, porphyry facies with non-porphyritic margins are common. This fabric distribution is strikingly consistent wherever observed.

Microscopy study of thin sections shows igneous textures. Estimated compositions average 75% albite; 10% biotite; 4% chlorite; 10% carbonate, with minor pyrite sphene and apatite. Fine-grained pyrite is evenly and sparsely disseminated throughout syenites found in the mining area. In porphyritic facies, phenocrysts of albite are greatly variable in size, ranging from slightly larger than groundmass size, up to 3 mm. Crystal outlines are serrated and in many places, phenocrysts are concentrated in clusters. The porphyry groundmass is a fine-grained equigranular, faintly lineated, aggregate, composed of albite, carbonate, biotite, and chlorite.

The non-porphyritic variety is a little coarser-grained than the groundmass of the porphyry but appears to be of the same composition. A trachytoid texture was noted in some thin sections of this variety. Feldspars large enough to be examined optically have a maximum extinction angle of 11° (Michel Levy) and on a few crystals the extinction was seen to be negative, indicating them as albite containing not more than 9% An.

Chemical Composition:

The chemical analysis of this rock (Item 1, Analysis 7) indicates it to be a soda-rich variety of the late acid-intrusives of the

Malartic area (Eakins 1952). In comparing it with analyses compiled by Tyrrel (1946), the analysis approximates those of the syenite clan. The relatively low amount of potash with a high quantity of soda is particularly significant, the ratio being 7.1:1 (Na:K).

Eakins (1952) believes that these rocks were derived from a magma of similar composition and that apart from carbonatization, little alteration has occurred.

The following three hypotheses for the origin of syenites are offered and evaluated:

(1) Textures called porphyritic are actually blastoporphyrictic and developed after consolidation of the acid intrusives, as a result of albitization.

(2) Porphyritic textures are truly igneous and indicate that the rock was emplaced from a magma chamber with phenocrysts already developed.

(3) An igneous introduction with albite phenocrysts developed in place in the more slowly cooling portions of a dyke, from a magma being originally rich in soda.

If the first explanation is valid, metacrysts would be distributed throughout large and small dykes indiscriminately. This however, is not in accord with the observations.

The second hypothesis could explain the presence of phenocrysts but does not adequately account for their distribution. If phenocrysts were present in an advancing magma relatively quick freezing along

borders of thick dykes and throughout thin dykes would include phenocrysts. This feature of borders is consistently absent. Multiple injection along earlier non-porphyrific intrusions may be invoked but it is not indicated, as no evidence of such complexities in dykes exists. Furthermore, phenocrysts that developed in the magma would probably exhibit some primary lineation within a dyke, and lineation of any kind of phenocrysts is not abundant.

The third hypothesis, that of phenocryst development as a result of a magma rich in the critical constituents, appears to explain most satisfactorily the observed conditions. Quick freezing along margins would inhibit crystal growth while slow cooling in the centers of larger dykes could afford opportunity for formations of the observed seriate textures as well as some clusters and the serrated condition of albite phenocrysts.

Genesis of Late Intrusives:

The soda rich nature of the late intrusives indicates that problems of origin of these rocks are probably related to the general ones of the spilite group.

The term spilite was originally proposed by Dewey & Flett (1911) to denote basic pillow lavas rich in soda and associated with other sodic rocks of a wide range in silica content. It was suggested that they are members of a natural family of igneous rocks, the spilite suite, comparable in importance to other rock suites. The characteristic albitization was believed to be a juvenile alteration of rock masses caused by the same agents that produce adinoles and cherts associated with them and was attributed to "pneumatolytic emanations", rich in

water, soda, silica, and probably carbon dioxide.

Many others have studied the problem but with no general agreement as to the origin of spilites. Sundius, for example, after an exhaustive study, concluded that albitization of this type is due to regional metasomatism. In a later study however, he decided that rocks of this type represented an original magmatic suite. A summary of the literature on spilites has been made by Gilully (1935) in his discussions on the keratophyres of Eastern Oregon, and he abridged the divergencies of the many interpretations into three questions:

- (1) Are the spilitic rocks of normal alkali-calcic parentage, or are they derived from an independent magma suite, (spilite suite)?
- (2) Is the soda rich character determined in the magma or is it a product of post magmatic influence?
- (3) Is their mineral composition primary throughout or at least for more siliceous members or is it metasomatic?

As a result of the study, he concluded that spilites are derivations of normal alkali-calcic magma and stated:

"It appears that the suggestion of Daly that the abundant soda of the spilites has been concentrated from an underlying mass of basaltic magma through the action of resurgent water, in conjunction with Goldschmidt's outline of trondjhemitic differentiation, satisfactorily accounts for most of the features of spilitic rocks." (p. 346)

The late intrusives of Malartic Gold Fields have characteristics suggestive of common parentage. Both have similar Na:K ratios and are characteristically rich in soda. Syenites, the acid felsitic type, are consistently younger than "diorites". Osborne (1937) has shown in a variation diagram (made by A.R. Byers) that intrusive rocks of the Quebec-Ontario gold belt are similar to the trondjemite rocks of Norway. The analyses of Gold Fields "diorite" and syenite fit into Byers's variation diagram such that chemical changes in the late intrusives are roughly coincident with those for the district. Goldschmidt (1922) has explained the differentiation of the trondjemite stem as being controlled by a high concentration of water resulting in an early withdrawal of potash and a consequent increase in soda, and that the very low content of dark minerals in the later stages of differentiation (i.e. the syenites) is characteristic.

CHAPTER 6

ORE TYPE ALTERATIONS OF "DIORITES" AND SYENITES AND RELATED VEIN EMBLEMENTS

General Statement:

In the chapter dealing with fractures, it was pointed out that mineralization took place along border zones of fractures in the "diorite" dykes and also in weaker concentrations adjacent to fractures in syenite bodies. The favorable loci for fracturing was in "diorites" and syenites located in the talc-chlorite rock embayment which branches southeasterly from the Cadillac fault zone. Fractures are filled with quartz of variable character. Later alterations include a peculiar development of biotite and a related amphibolitization and probably related to these are veins of tourmaline and molybdenite. The ubiquitous development of carbonate stringers marks the final manifestation of vein formation on the property.

Alterations of "Diorites" and Syenites Associated with Ore:

Alteration adjoining quartz veins in "diorite" produces a color change from the greenish black of the unaltered "diorite", to a brownish grey and a light greenish grey. The more widely spaced fractures exhibit this alteration as diffuse zones bordering their contact (Figs. 9A, 11C) and where fractures are closely spaced, the rock is completely altered. Shear type fractures exhibit this alteration whereas irregular tension type usually has little alteration and associated mineralization. Sulphide minerals are concentrated within these altered zones and the bulk of the gold is associated with them.

Mineralogic changes in "diorite" at the brownish-colored stage

of alteration involve the destruction of hornblende and a partial alteration of feldspars. Newly-formed minerals are biotite, chlorite, epidote, carbonate, magnetite, ilmenite, and sulphides, all of which are found in positions formerly occupied by hornblende. Magnetite and ilmenite occur as fine powdery aggregates of cuneiform shapes suggestive of control by the original hornblendes (Figs. 18A, 19A).

Where the colour of the rock changes from brownish to light greenish grey, a more foliated aspect is noted and chlorite predominates over biotite (Fig. 18B). The feldspars disappear and sericitic types of mica appear, while the magnetite-ilmenite aggregates assume streaked shapes parallel to the foliated platy minerals (Fig. 20B). Concentrations of sulphides show no distinct preference for either stage of alteration, as the stages are gradational. The foliated or schistose type represents the more intensively altered "diorite" and has been subjected to shearing.

The chemical changes involved in the alteration are shown below for a unit volume of 100 cc.

Transformation of Fresh ore zone "diorite"
to ore altered "diorite"
(Analysis 5 & 6, Appendix 1, both from No.6 ore dyke)

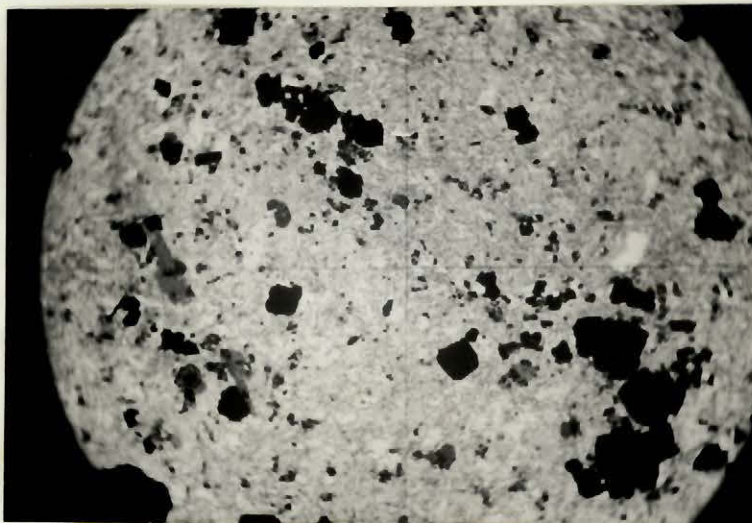
<u>Gain</u>	<u>Loss</u>
3.2 gm K	9.5 gm Si
1.4 " C	.7 " Al
26.0 " S	.2 " Mg
	.8 " Ca
	1.3 " Na

Fig. 18A



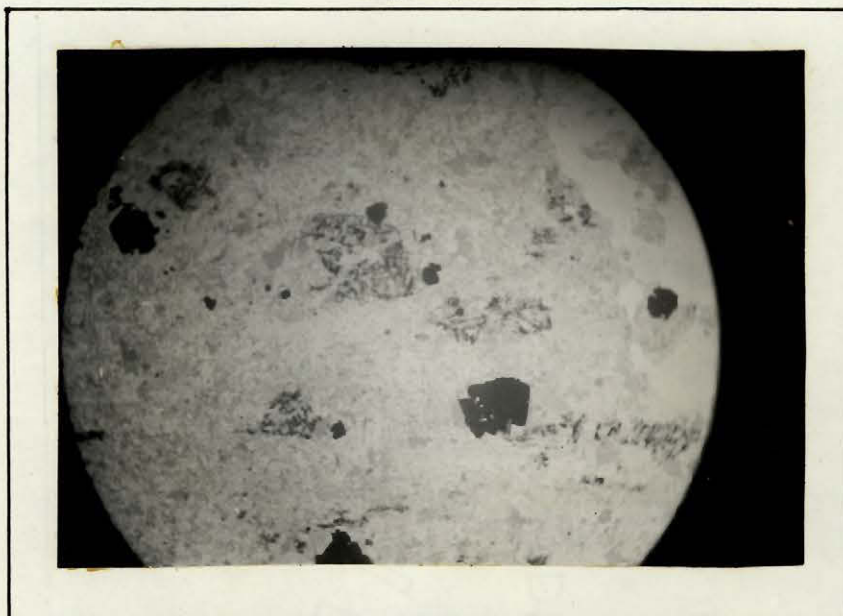
Brownish grey colored ore "diorite"
(ordinary light x 25)
showing cuneiform aggregates of magnetite in
position formerly occupied by hornblende

Fig. 18B



Greenish grey colored ore "diorite"
(ordinary light x 25)
showing development of chlorite, no biotite
and presence of pyrite and
small amounts of magnetite

Fig. 19A



Cunieform aggregates of magnetite in
"diorite" pseudomorphous after hornblende
(ordinary light x 25)

Fig. 19B



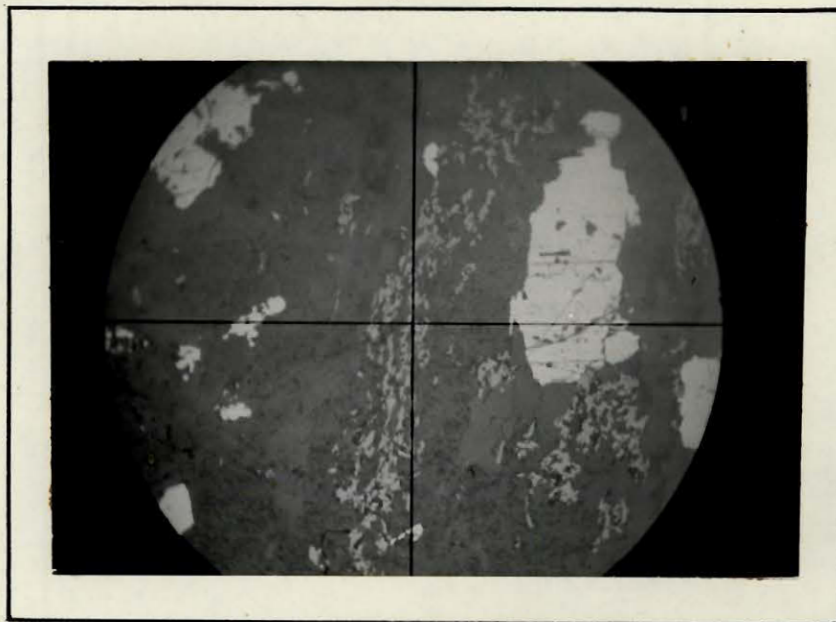
Amphibolitized ore "diorite"
(ordinary light x 25)

Fig. 20A



Ore altered "diorite"
(crossed nicols x 25)
showing the destruction of hornblendes
and some original feldspars

Fig. 20B



Streaked aggregates of magnetite
parallel to foliation.
(reflected light x 40)

The more significant additions are potassium which is mineralogically expressed in biotite, and sulphur which is evidenced by sulphides. The constant amount of total iron indicates that sulphide formation was dependent on a reaction between added sulphur and the iron-bearing minerals of the "diorite". Gold content was not determined in the chemical analyses but is clearly an additive element as well. The silica lost in the breakdown of amphiboles may be a source of vein quartz.

Alterations of syenites are not as profound as those in "diorites". The colour changes from grey to buff adjacent to fractures of all sizes (Figs. 8A, 8B). Concentrations of sulphides adjacent to fractures are weak compared with those in "diorites". The only mineral changes noted are the development of clear euhedral albite, and the alteration of biotite to chlorite. Carbonate is always present partially replacing some feldspar and filling fractures. Changes in texture are slight; some recrystallization has been occasionally noted. The borders of phenocrysts are somewhat corroded and a few crystals of albite are fractured and bent. Eakins (1952) has shown that little chemical change occurs in alteration of syenites in other mines of the Malartic Camp and no evidence of significant change is found at Gold Fields.

The Emplacement of Quartz:

The fractures in syenites and "diorites" which formed channels for mineralizing fluids also were the loci for the emplacement of quartz.

Three types of vein quartz are distinguished at Gold Fields. The oldest, a sugary-textured cherty white quartz, is found in minor amounts and in a few places, the more abundant veins of white glassy quartz cut cherty quartz. The bluish black to grey quartz is found within the

white, colouring it to a variable extent, but with no definite contacts. Some examples of this type appear to form the matrix of brecciated white quartz (Fig. 9A). Microscopy study shows that white glassy quartz occurs as a mosaic of clear interlocking grains. A few groups of crystals have approximately parallel extinctions (Figs. 21A, 22A, 22B). Grey quartz, on the other hand, contains streaked concentrations of submicroscopic grains of a metallic grey mineral (Fig. 21B). The serrated boundaries of grey quartz crystals are similar to some of the crystal boundaries of white glassy quartz (Figs. 21A, 21B). The grey quartz appears to be deformed white quartz containing very finely divided crystals of an unidentified grey metallic mineral.

Quartz seems to have been emplaced mostly by replacement. Several observations indicate that this process has been operative. The best evidence is seen in the abundance of unsupported inclusions, especially those of talc-chlorite rock in quartz. Streaks of pyrite crystals in "diorite" are cut by quartz veins without displacement (Fig. 11B). Again, in "diorite" the walls of veins do not match (Fig. 23A). The large irregular bodies at borders of "diorite" dykes could hardly have been formed by filling alone since the rock is relatively weak and would have caved had there been large voids.

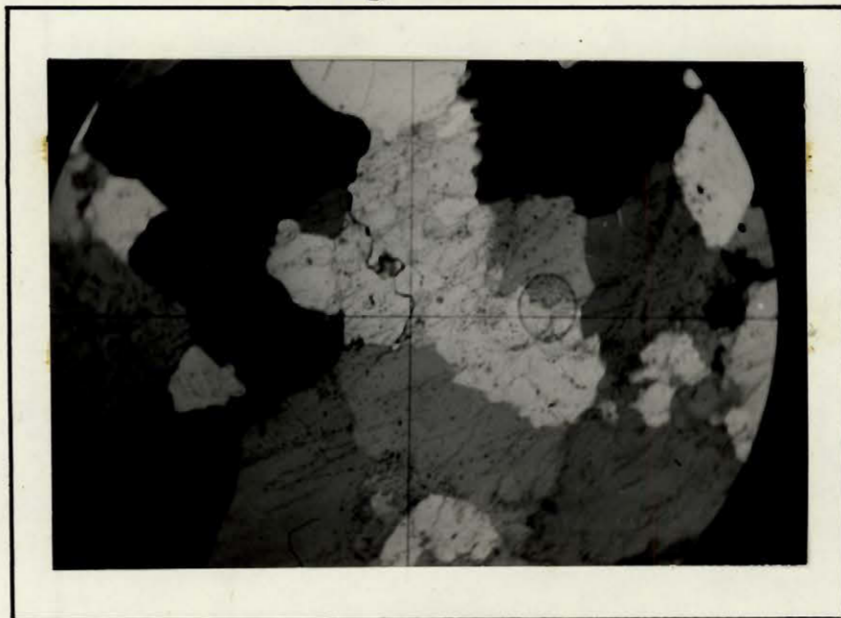
Admittedly there are contrasting evidences. For example, similar inclusions of syenite in quartz are not altered to the same degree (Figs. 8A, 8B) and fragments of talc-chlorite rock are angular and have narrow selvages of steatite with no obvious evidence of replacement (Fig. 23B). Furthermore, gash-like bodies of quartz in talc-chlorite rocks appear to be fissure fillings.

Fig. 21A



White glassy quartz
(crossed nicols x 25)

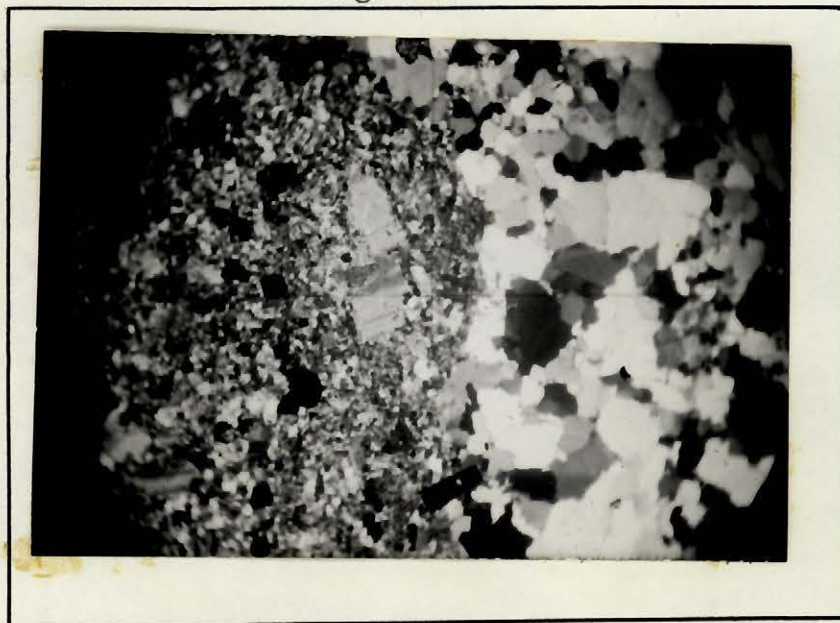
Fig. 21B



Grey quartz
(crossed nicols x 90)

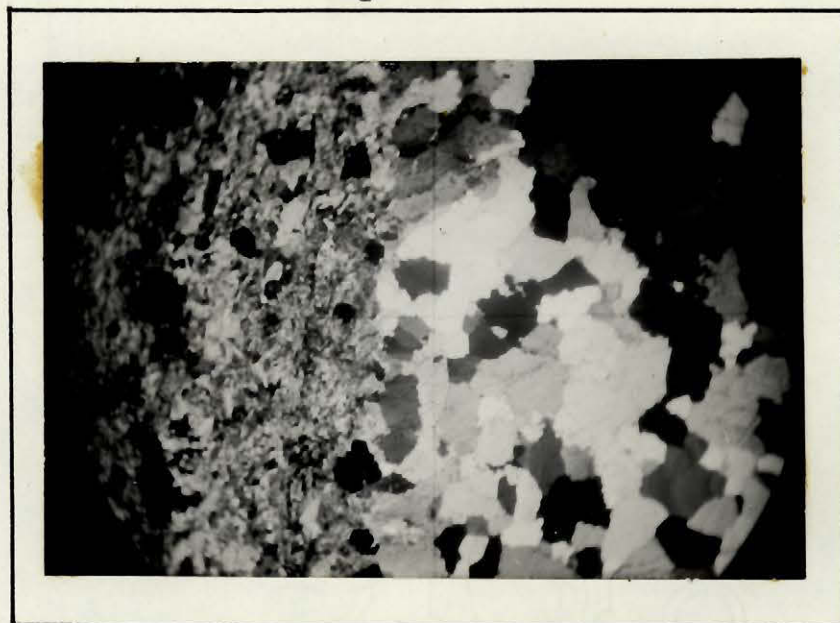
Note sub-microscopic opaque minerals. Also
evidence of deformed grains in lines sub-parallel
to streaks of powdery minerals

Fig. 22A



Contact of white glassy
quartz and syenite
(crossed nicols x 25)

Fig. 22B



Contact of glassy white quartz
and ore "diorite"
(Crossed nicols x 25)
slightly granulated

Further evidence of replacement is found in the structure in quartz bodies. In veins, all gradations were seen between ribbon and book structures, the latter being the more common to quartz bodies in schist. Vein development by successive reopenings, as pointed out by McKinstry (1949), would result in visible differences in successive bands because each would be formed under different conditions. At Gold Fields however, the only evidence of reopening is a mild brecciation characterized by a mottled grey and white colour in brecciated sections and by bands of grey quartz in white quartz.

Silicon for vein formation may have been derived by magmatic differentiation and therefore was an essential as constituent of hydrothermal solutions, or from rock alteration that produced excesses of silicon for resulting mineral assemblages. There was no evidence at Gold Fields that suggested a magmatic origin for silicon. On the other hand, Schmidt (1949) and others have emphasized derivations of silicon from local alteration rather than from a magmatic source, and suggest that magmatically derived silicon is not an essential element in mineralizing solutions.

The retrograde alteration of "hard massive" peridotite to "soft massive" peridotite and the alteration "diorite" adjacent to fractures resulted in excesses of silicon. This excess silicon could have been the source of much of the quartz bodies in late intrusives of the embayment area. In the case of the alteration of peridotite the loss as indicated by recast chemical analyses was 6.4 gms Si per 100 cc of rock and in the alteration of "diorites" the loss was 9.5 gms Si per 100 cc of rock. The excess silicon of the peridotite alteration however, originated before

Fig. 23A



Photograph of hand specimen
showing book structure in quartz veins in "diorite"
Note: Triangular fragment of "diorite" at lower border
of the center vein with no
evidence of displacement

Fig. 23B



Photograph showing mirror sides of a
split hand specimen.
Angular unsupported fragments of
"soft massive" peridotite
in white glassy quartz

late intrusive fracturing and may not have been available for vein formation at the time of fracturing while free silicon produced by alteration along fractures in "diorite" is closely associated in time and space to the vein formation. The excess silicon noted above could have migrated to open fractures and eventually be deposited along the fractures.

On the other hand, there is no direct evidence suggesting that silicon was derived from adjoining wall rock. Quartz veins are equally abundant in the syenite and "diorite" bodies in the talc-chlorite embayment area although chemical changes due to alteration adjacent to the veins are different in both rock types. There is however, the general association of quartz veins and wall rock alteration but this may be due to the concentration of responsible processes at locations of mutual access. Detailed observations of quartz veins do not show a relationship between amount of alteration and amount of quartz. For example, some large veins pinch out along their lengths with no corresponding diminution in wall rock alteration. In some places, branching veins cross altered bands adjacent to the main vein with hardly any increase in alteration and the flat tension veins in "diorite" orebodies have practically no wall rock alteration. If silicon was derived from alteration of "diorite" or general retrograde metamorphism, the above-noted conditions indicate appreciable migration of silica along fractures.

Migration of appreciable quantities of silicon in aqueous solution involves relatively great amounts of water. On the other hand, there is experimental support for transfer of silica in colloidal form which would not require such great quantities of water. In this connection Boydell (1926) states:

"Hydrolysis of silicates, sulphides, and carbonates commonly produce colloidal material and such products may be deposited locally or be removed in solution according to the conditions such as the presence of a precipitant, peptizer, or a protecting agent or solvent, etc." (p. 31).

Kennedy (1950a) has shown by experiments that silica can be moved in relatively great quantities in colloidal form. Frondel's experiments (1938) have indicated that colloidal silica can exist in water in temperature ranges from 25°C to 100°C and probably up to 350°C.

As in practically all Precambrian vein deposits, the evidence for colloidal transfer and deposition of silica is lacking at Gold Fields. Colloidal textures may have been destroyed by a long period of recrystallization at depth. Compared with younger vein deposits at epi and mesothermal depths, where colloidal textures are present, Precambrian deposits were recrystallized during a much longer period and under greater pressures. Presumably then if silica was moved in colloidal state along fractures, the evidences at Gold Fields were destroyed by recrystallization and pressure.

Post-quartz Fractures:

Features discussed under this heading are tourmaline and molybdenite stringers, carbonate stringers and a peculiar development of black biotite bands and amphibolite.

Tourmaline stringers are found mainly in syenite where they occur along fractures which are later than quartz and may possibly be related to the forces that produced the brecciation of white quartz. A few fractures coated with molybdenite are peculiar to syenites as well and

none have been found in "diorites". Large idiomorphs of tourmaline occur along syenite, talc-chlorite rock contacts (Fig. 10B). A thin section of vein tourmaline (Fig. 24A) showed cores of lithium-rich elbaite bordered by iron-rich schorlite. The presence of lithium is indicated by the spectroscope in all types of tourmaline and indicates an alkali-rich variety of derivation from solutions of a pegmatitic nature. Schorlite rims may be the result of a change in the chemical nature of the solutions or local derivation of iron from wall rock.

Biotite, in narrow "sooty" textured bands, locally containing actinolite, is seen in talc-chlorite schist, sub-parallelizing syenite contacts, and in many places, cutting altered "diorite". The bands are composed of fine-grained felted masses of biotite and where they occur as selvages at syenitic contacts, actinolite and tourmaline metacrysts are the usual associates.

In many places actinolite occurs as idiomorphic metacrysts in the schist. Where this occurs, the talc-chlorite rock is bleached to a light greenish grey (Fig. 9B). The bleached rock contains less green chlorite and magnetite than the normal talc-chlorite schist. This suggests that the formation of actinolite impoverished the surrounding rock of iron (Fig. 9B). Elsewhere, in ore zone "diorite", large radiating masses of amphibole occur along, or close to, late fractures. Such amphiboles are occasionally seen bordering quartz veins in "schist" and in the quartz itself.

Spectrographically, banded "sooty" biotite zones show no change in Cr_2O_3 content from the talc-chlorite rock in which it is found and the potassic content of the latter is too low to form biotite, therefore meta-

Fig. 24A



Tourmaline stringer in syenite
(ordinary light x 25)

Note: The section was broken in preparation,
white areas are balsam.

Tourmaline cores are lithium types (elbaite)
rims iron rich (schorlite)

Fig. 24B



Tourmaline in "diorite"
1/4" from syenite contact
(ordinary light x 25)

somatic processes are indicated in biotitization (Eakins 1952). Although these alterations are associated with late intrusives, lack of detailed conformity with contacts rules out the possibility of their origin by contact metamorphism. Also, bands cutting across "diorite" ore show that the development is post ore. The affinity of selvages to syenite contacts rather than "diorite" contacts indicates, presumably, that their origin is related to the syenite. The presence of tourmaline in the alteration suggests as well that they could be related to the development of tourmaline stringers. It is thought that the formation of this biotite and amphibole is related in origin to that of tourmaline and molybdenite and that pegmatitic solutions producing the latter were also responsible for the former.

Carbonate stringers, later than tourmaline cut across all features associated with late intrusives. A combination of density and spectroscopic determinations show them to be dolomitic and ankeritic types. These stringers record the last process of vein emplacement found at Gold Fields. Probably during the waning stages of hydrothermal activity, when temperatures were lower, aqueous solutions containing CO_2 and Fe, Mg, and Ca, cast out of the rock by the ore-forming processes, circulated through available open fractures, and carbonates were precipitated from them. It is also possible that some carbonates stringers developed at shallow depth from meteoric water and do not necessarily represent an igneous manifestation.

CHAPTER 7

MINERALIZATION

In the preceding chapter, alterations and vein formations related to mineralizing processes were discussed and spacial relationships between ore alteration and fractures were emphasized. The detailed aspects of mineralization are considered here and postulates on origin are offered.

Pyrite is by far the most abundant sulphide (90% estimated) and the bulk of the gold is associated with it. Arsenopyrite, pyrrhotite, chalcopyrite, and galena were also found but only in minor amounts. Telluride minerals, though not identified in polished sections were indicated as very small in amount by the presence of tellurium in millhead samples (oral information, G.A. Roach). Oxides are mainly magnetite with a variable and minor amount of ilmenite.

The above-noted mineral associates are disseminated throughout altered "diorite" adjacent to veins such that the construction of a paragenetic sequence cannot be made with any degree of certainty. However, broad age relationships shown below as four stages, appear to be consistent throughout the mine.

Stage (1) Destruction of hornblende in "diorite" with development of biotite, chlorite, sericitic micas, carbonate, magnetite, ilmenite, arsenopyrite, pyrite, and gold.

Stage (2) Precipitation of microscopically visible gold, pyrrhotite, and chalcopyrite.

Stage (3) Emplacement of quartz veins with a continuing deposition and probably a redeposition of gold and pyrite in veins.

Stage (4) Post quartz fracturing with late potash metasomatism and probably a minor introduction of telluride minerals into quartz.

Aside from the fracturing of stage (4) as noted above, no evident fracturing occurred during the deposition of the ore minerals. The mineral constituents are described in the following paragraphs under appropriate mineral headings.

Magnetite and Ilmenite:

The forms and distribution of magnetite and ilmenite in the ore-altered "diorite" have already been described in the preceding chapter on the alteration of "diorites". They are the direct opaque products of the destruction of original hornblende in "diorite". Mutual boundaries of pyrite and magnetite show that most pyrite crystals probably formed slightly later than magnetite (Figs. 26B, 27A).

Arsenopyrite:

Arsenopyrite was found in the north band of the Blake River volcanics as well as in "diorite" but in the former case it is the only sulphide present. In polished sections of the ore "diorite", it was seen as erratically distributed euhedral crystals having diamond-shaped cross

sections. Some crystals were seen straddling streaked aggregates of magnetite and ilmenite, in pyrite crystals, and as grains partially corroded by pyrite (Fig. 26B). The latter observation suggests that arsenopyrite is the older mineral.

Pyrite:

Pyrite is the most ubiquitous sulphide as well as the most abundant. It is found in the following modes:

1. Even but sparse disseminations in syenites.
2. Moderate concentrations adjoining fractures in syenites.
3. Strong concentrations adjacent to fractures in "diorites".
4. Sparse and erratic distributions in quartz veins.
5. Isolated crystals in peridotite usually near late intrusive bodies.

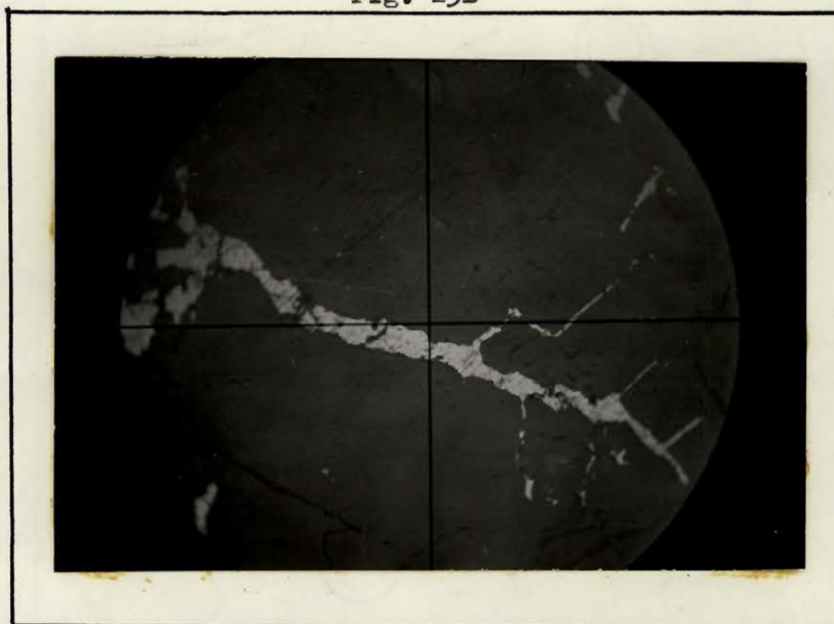
The distribution of pyrite crystals of different sizes show some overall zoning. A barely perceptible coarsening of pyrite appears to be related to increasing depth. Coarser pyrite grains are found near the borders of "diorite" dykes than in the centres. In ore "diorite", grain sizes vary from 1 mm. to 10 mm. and no one size predominates, but in syenites, pyrite is usually of sizes smaller than 3mm. Where quartz veins extend across a dyke and continue for a short distance into enclosing talc-chlorite rock, pyritic wall rock is confined to "diorite" only and stops abruptly at the dyke contact. Some of the pyrite found in unaltered "diorite", with no association with ore altered areas, is usually near a quartz vein. It is not evenly disseminated but occurs as streaks or lines of crystals as though it was formed along minute cracks. Some of these lines are cut by quartz veins (Fig. 11B). Pyrite found in quartz occupies minute fractures

Fig. 25A



Cluster of pyrite crystals in ore "diorite"
(reflected light x 70)
showing silicate mineral nuclei.
Note the general lack of fracturing of pyrite

Fig. 25B



Post quartz pyrite in quartz vein
(reflected light x 70)

Fig. 26A



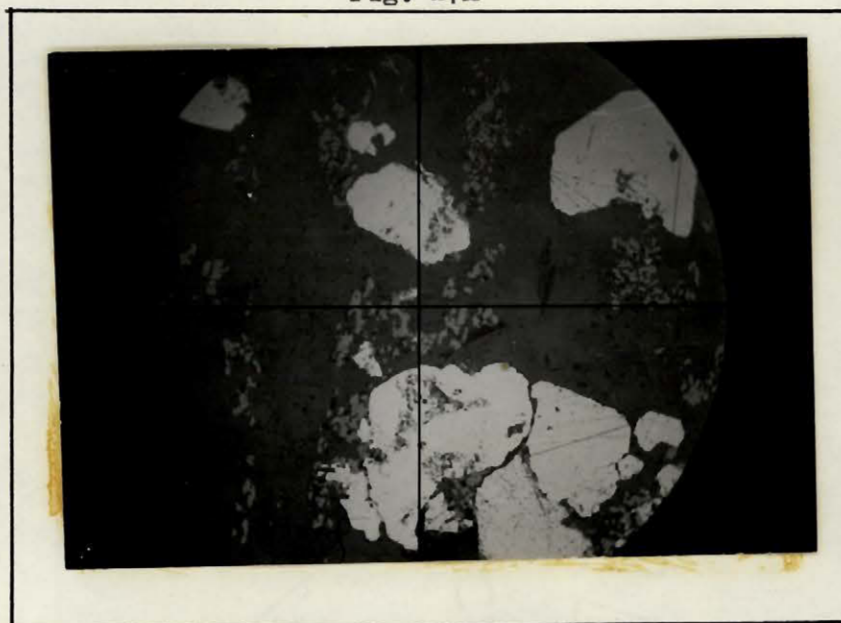
Pyrite along a quartz vein contact
with ore "diorite"
(reflected light x 70)
Note embayment of pyrite by quartz

Fig. 26B



Relationship of Arsenopyrite and Pyrite
(reflected light x 70)

Fig. 27A



Pyrite, Magnetite, and Ilmenite
in ore "diorite"
(reflected light x 70)

Fig. 27B



Relationships of Pyrite,
Pyrrhotite, and Chalcopyrite
(reflected light x 280)

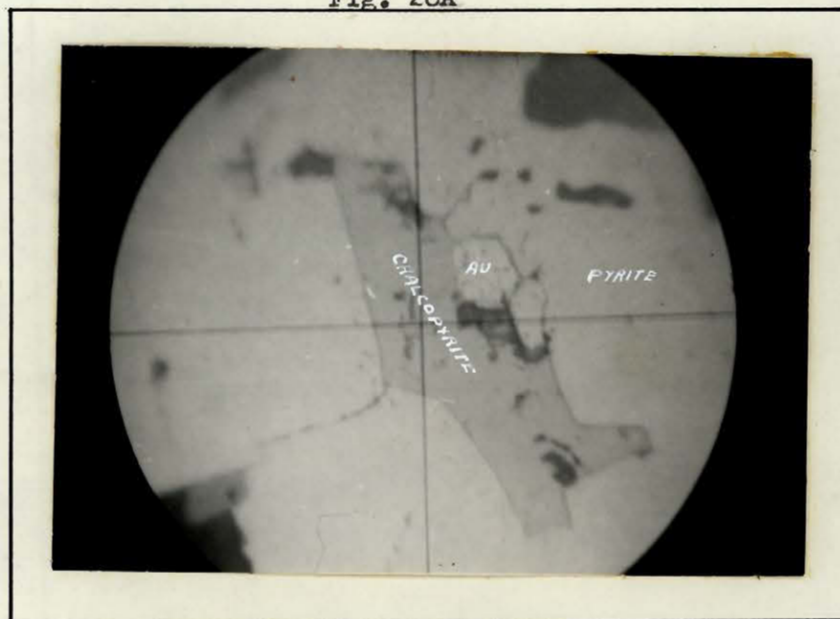
(Fig. 25B). Pyritic "diorite" inclusions in quartz, that show all stages of "digestion" by quartz, are locales for much of the pyrite found in quartz. In one polished section, some pyrite in quartz appears to be replaced by quartz (Fig. 26A). The deposition of pyrite apparently extends slightly beyond the time of vein formation but the bulk of the pyrite was formed probably just prior to quartz deposition. Some pyrite in quartz may have been the result of a redeposition of pyrite on fracture walls.

The pyrite in schist and "soft massive" peridotite is sparsely concentrated near the dyke swarms but has no consistent relationship to particular dykes or fractures. In this environment it crystallizes in euhedral cubes and octahedrons up to 1/2 inch across. Pyrite in "diorite" ore usually exhibits subhedral and anhedral forms, especially if the rock is not strongly schistose. Clusters of pyrite (Fig. 25A) show evidence of mutual interference of crystal development and where isolated crystals occur, subhedral forms predominate (Figs. 19A, 18B, 27A). Many cores of pyrite crystals have included fragments of platy minerals that were probably enclosed during crystal growth (Figs. 25A, 29B).

Almost all pyrite contains gold. Assays on peridotite pyrite, that is, pyrite at the greatest distances from fracture channels, assay .05 ounces per ton in gold. A spectrographic analysis done on other peridotite pyrite showed the presence of As, Co, and Ni but gold was not determined. (A.S. MacLaren, personal information).

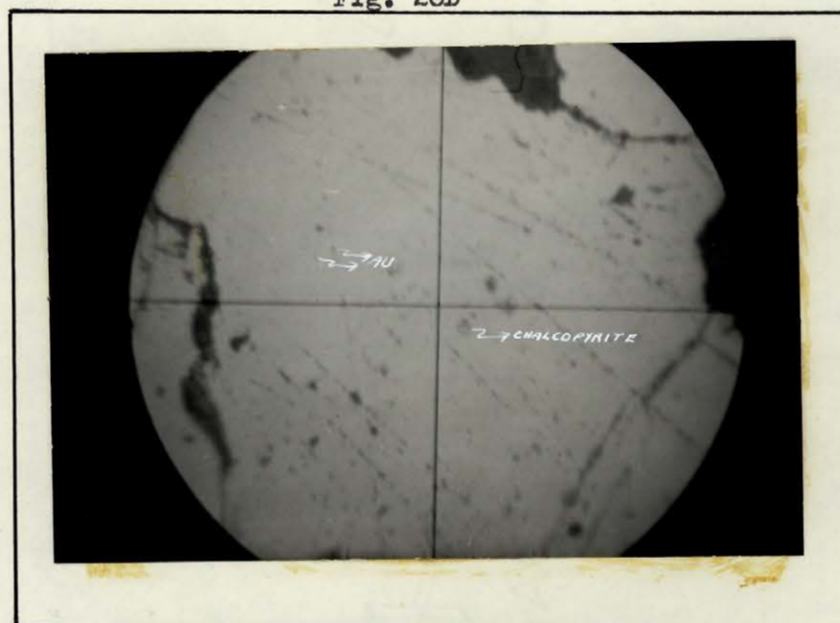
According to mill data, ore-bearing "diorite" with a grade of at least .180 ounces of gold per ton, averages 7 percent sulphides by weight. The close association of gold and pyrite has already been shown

Fig. 28A



Chalcopyrite and gold enclosed in pyrite
(reflected light x 280)

Fig. 28B



Small isolated blebs of chalcopyrite
and gold in pyrite
(reflected light x 280)

in geological observations of the mine and this is corroborated by mill data. Assays on pyrite concentrates from cyclone concentrators in the mill circuit showed that most of the gold is associated with this fraction rather than the siliceous fraction. The iron in pyrite, as indicated by the chemical changes produced by the alterations, was derived from the "diorite" and was not introduced. Eakins (1952) has shown that pyrite can amount to about 25% of the rock when all iron is utilized. Pyrite was rarely seen in greater concentrations and the average is usually much lower.

Pyrrhotite, Chalcopyrite, and Galena:

These minerals occur in minor, erratically distributed amounts in the ore. Where seen in contact with pyrite they appear to have crystallized later (Figs. 27B, 28A). Mill records of an earlier ore study mention the presence of a "tongue" of pentlandite in pyrrhotite and almost all analyses show traces of nickel.

Chalcopyrite occurs as small isolated blebs in pyrite and along mutual pyrite boundaries as well as in close association with pyrrhotite. A few crystals of galena were found as small grains slightly larger than powder-sized magnetite.

Gold:

Like pyrite, gold has ubiquitous distribution within the mining area. It has been observed in the following relationships:

- (1) as micron-sized blebs below .0064 mm. completely enclosed by pyrite grains (Fig. 28B).
- (2) in sizes from .052 to .3 mm. Along mutual boundaries of pyrite (Figs. 29A, 29B).

- (3) associated with chalcopyrite (Fig. 28B).
- (4) as stellated aggregates in quartz veins.

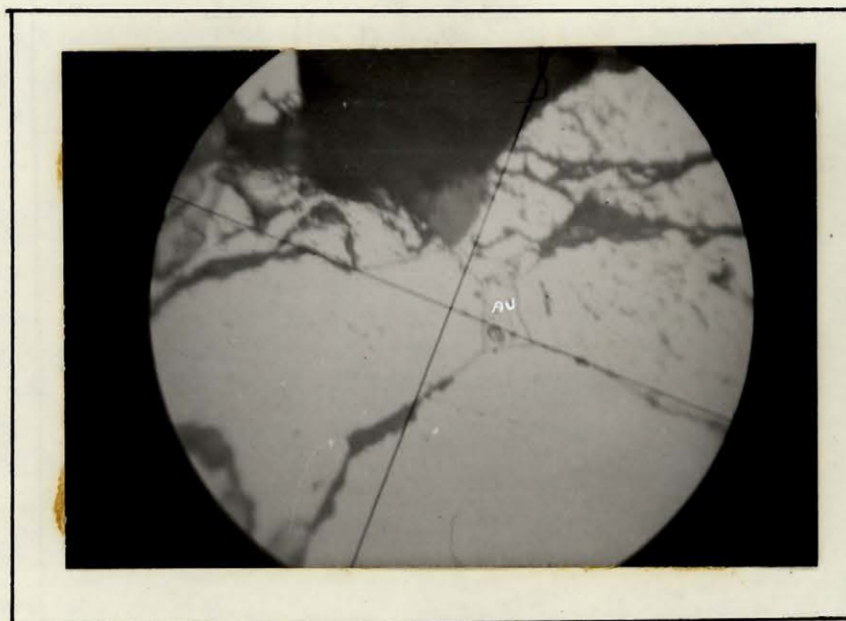
In addition, very finely dispersed gold was indicated in assays on pyrite crystals where visual examination revealed none.

Most of the gold of the early stage is distributed with the pyrite in wall rock. Several assays on pyrite crystals occurring in the talc-chlorite rock averaged .05 oz. Au per ton. There is surprisingly little silver associated with the gold. Assays for silver in gold indicate an average fineness of 983 which is remarkably pure, even for the gold-albite association (Gallagher 1940). Assays of quartz veins gave occasionally, very high values but when considered in bulk, are not of ore grade. Adjacent to such veins in the mineralized wall rock values in gold were much higher, eight selected samples averaging .43 oz. Au per ton.

In sampling the faces of drifts following orebodies, it was common to find that where the face was predominantly of quartz, the grade fell below ore values and where ore altered "diorite", with its associated sulphides was the predominant rock, gold values were of ore grade and sometimes well above.

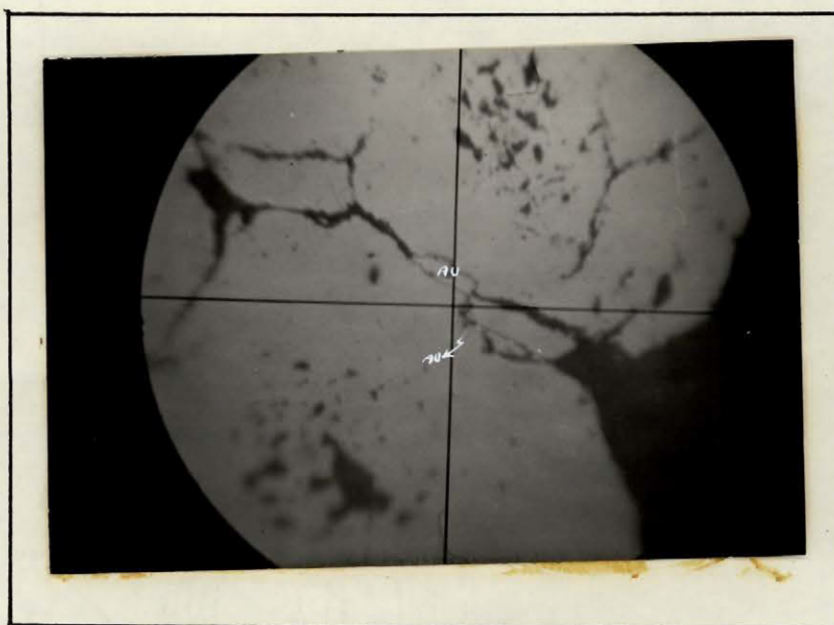
Studies of ore grades at the mine affords a quasi-quantitative picture of the amount of gold found in quartz. A frequency study of assay grades was conducted to establish a suitable cut-off grade for the mine. One phase of the study was done on muck sample assays in the July to December period of 1949 for the No. 2 mine. About 7,000 assays were classified according to value and comprise the basis of the Table below (Fig. 30). Mill grade for this period was .184 oz. per ton. By discard-

Fig. 29A



Gold along mutual contacts of pyrite
(reflected light x 280)

Fig. 29B



Gold along mutual contacts of pyrite
(reflected light x 280)

ing all assays above .70, the mine grade checks the mill fairly closely and subsequent application of this cut-off value vindicated its choice.

The quantitative inference of this cut-off value on the nature of the gold distribution would be quite obscure were it not for the occasional occurrence of visible gold found in quartz. Statistically, for grade estimation purposes, the 4.9% of assays higher than .70 oz. per ton are regarded as erratics. Since the occurrence of visible gold is quite erratic, it appears probable that 4.9% of the gold at Malartic Gold Fields occurs as visible gold erratically distributed in quartz bodies in "diorite" dykes.

FIG. 30

Table Showing % Frequency of Occurrence of Assay Grades

<u>Range in Grade</u>	<u>% Distribution of Frequency</u>	<u>Progressive Cumulative Grade</u>
TR - .09	40%	.045
.10 - .19	23.6%	.082
.20 - .29	13.7%	.111
.30 - .39	8.1%	.133
.40 - .49	4.5%	.149
.50 - .59	3.6%	.164
.60 - .69	2.0%	.174
.70 - .79	1.4%	.182
.80 - .89	0.8%	.188
.90 - .99	0.5%	.192
1.00 - 1.09	1.6%	.203
1.10†	0.6%	.212

Mill data gave some additional information on distribution of gold particle sizes. The percentage extraction curve for different grinding sizes in milling, flattens when grinding is done to 80% minus 200 mesh (74 microns nominally) and under these conditions extraction is 94.5%

complete. With additional diminution in passing through the mill circuit the final distribution in particle sizes, as indicated by sizing analyses of mill tailings (Fig. 31) is as follows:

5.67% of sizes ranging from 149 to 165 microns
 40.48% of sizes ranging from 74 to 40 microns
 53.85% of sizes ranging from 28 to -10 microns

Of the 5.5% gold in tailings, .3% is associated with particle sizes larger than 74 microns (Fig. 31). Since, as mentioned above, 4.9% of the gold in the ore is probably visible gold in quartz, gold may be roughly distributed as follows:

Visible native gold in quartz	4.9%
Gold protected from cyanidation by enclosure in particles smaller than 74 microns	5.2%
Gold not in quartz, but associated with pyrite and that is not protected from cyanidation by particles 74 microns and larger in size	89.9%

The last percentage is admittedly of little value to the study of size distribution. Also, some gold particles less than 74 microns in size would be dissolved by cyanidation because of incomplete protection by enclosure in grains. It is possible that much gold may be dissolved under these conditions from particles less than 74 microns, thus the 5.2% left in tailings would be low for the actual percentage of gold smaller than 74 microns.

The size of gold as indicated by experimentation on tailings by the mill staff at Gold Fields suggests progressive reductions in particle

sizes of gold to colloidal ranges at least. The nature of this research however, was such that it could not be adapted to the needs of this study, in regard to precise quantitative distributions of particle sizes of gold.

Invisible Gold:

Since most of the gold in the mine is in sizes megascopically invisible, discussion on the general aspects of the subject is appropriate. The smallest particles of gold visible under the microscope are in tiny rounded blebs erratically scattered in pyrite (Fig. 28B). It was shown that some gold is more finely divided.

As previously stated, 5.2% is a minimum percentage of the total gold in sizes below 7¹/₄ microns. In a sizing analysis done on mill tailings, it was shown that gold is found in the finest of particles and that the pyrite and gold show the same affinity in detail as in larger-scaled observations. This is illustrated in the Table below:

FIG. 31

Table Showing Size Study of Tailings (April 1951)
(Avg. assay: .010 oz. Au per ton)

<u>Range of Size Microns</u>	<u>% of Tails by weight</u>	<u>% Distribution of gold</u>	<u>Ratio of % of Tails to % gold distribution</u>
149 to 105	5.67%	5.45%	1:1.096
74 to 40	40.48%	64.34%	1:1.59
28 to -10	53.85%	30.23%	1:1.056

The gold distributions above represent gold which has escaped cyanidation in the mill circuit and therefore, was protected mainly by enclosure in sulphides. Coatings by iron oxide, and sulphur ions have been

kept at a minimum in the mill circuit so that these figures are a fair approximation of actual distribution of fine sizes of gold. It demonstrates the possibility of gold occurring in colloidal sizes and possibly in solid solution in pyrite.

It is known that gold of appreciable grades, but invisible to the eye, can be concentrated in pyrite. Pyrite and pyrrhotite containing up to 10 ounces per ton in gold of sub-microscopic sizes have been synthesized by Maslinitzky (1944), indicating that some gold may have been in solid solution. The covalent radius of iron in pyrite is $1.23\text{\AA}$ and is within 15% of the octahedral covalent radius of gold ($1.40\text{\AA}$), indicating gold as a potential guest ion in the pyrite lattice, substituting for iron. The larger size of gold, in a substitutional solid solution would place an expansional stress on the lattice and since the gold ion is close to the maximum of tolerance in size difference, it would seem that very little substitution of gold could take place without a relatively great stress on the lattice. Such stressed lattices would likely be indicated in an anisotropic property of pyrite under reflected light, but pyrite at Gold Fields shows no definite anisotropic properties. Gold in solid solution in pyrite is theoretically possible and is suggested by many experiments but it has never definitely been proven. The author believes that gold in such a state could never be in concentrations of economic grade.

Gold in colloidal state presents other difficulties of economic concentrations. Haycock (1937) in a frequency distribution study of sizes of gold particles in 50 Canadian mines, found that 75% of all visible gold falls within microscopic rather than megascopic sizes. His chart showing the projection of the frequency curve into colloidal and ionic sizes

indicated that gold in colloidal sizes or in solid solution was of little economic importance. The regional finding of Haycock seems to be in keeping with the probable percentage distribution of gold sizes at the mine.

The Ore-forming Process:

During the process of ore formation, materials added included gold, potassium, sulphur, arsenic, and carbon. The hydrous nature of the resulting mineral assemblage indicates an aqueous condition for the mineralizing solutions. The iron of pyrite and silicon for quartz veins appear to be locally derived and are not added materials to the rock. Lindner & Gruner (1938) have shown in experiments, that gold, being transported in solution as the double sulphide $\text{Au}_2\text{S} \cdot \text{Na}_2\text{S}$, can be moved in fairly great quantities, and hydrothermal minerals such as chlorite and serpentine are stable in the solution. Their work also showed that many minerals will alter in these solutions at 300°C . Apparently, as indicated in the ore alterations, the elements for such a compound of gold were present in the mineralizing solution.

Mineralizing solutions containing the above-noted elements, in passing along fracture channels in "diorite", reacted with the wall rock, and the nature of this reaction was responsible for the deposition of gold. Halet (1948) has already suggested a chemical control in ore formation at Gold Fields but did not elucidate. Eakins (1952) noted the breakdown of hornblende in ore alteration but maintained that pyrite developed at the expense of magnetite. His main evidence for this is a decrease in the amount of magnetite where pyrite increased and also a coincident increase in the amount of titanite.

He states:

"It is evident that titanium does not enter into the reaction that formed pyrite from magnetite, since it was shown (p. 120) that magnetite has previously taken titanium into solution. When the magnetite is converted into pyrite, therefore the titanium is thrown out of solution and reappears as titanite".

Eakins also took note of the paradoxical condition of practically no pyrite being present in the talc-chlorite rock where abundant magnetite is also present, but offered no explanation for this. Availability of channelways along late intrusive contacts and associated fractures attest to a structural opportunity for mineralizing fluids to be in contact with talc-chlorite schist. Furthermore, the euhedral shapes of the sparsely-scattered pyrite crystals found in this rock as compared to subhedral shapes in "diorite" suggest a more favorable crystallizing environment in the former rock.

The minerals associated with magnetite in the talc-chlorite rock reflect an environmental condition similar to the biotite, chlorite, carbonate, sericite, associates of magnetite in the ore-altered "diorite". Magnetite appearing as powdery aggregates in ore-altered "diorite" is a by-product of the destruction of hornblende in response to a retrogressive change in environment. If this magnetite would react to form pyrite, the magnetite in talc-chlorite rock should also do so when in contact with mineralizing solutions. It is thought that this selectivity of pyrite habitat reflects a different process of development than the one proposed by Eakins.

Aside from feldspar in "diorite", the greatest modal difference in "diorite" and talc-chlorite rock is hornblende; the mineral that reacts

so definitely with the mineralizing solutions. The iron released by the breakdown of hornblende could be first combined with available sulphur to form pyrite with the excess being taken up in the formation of magnetite. When pyrite is formed, gold in the double sulphide form would be rendered insoluble in proportion to its release from the double sulphide. The primary deposition of gold from double sulphides would tend to concentrate in areas closest to where the destruction of its compound occurred and since pyrite is one of the products of this destruction, fine dispersion and close association with pyrite could be an indication of their being products of the same chemical reaction.

The particles of gold found in the early deposition probably were of colloidal sizes and may have been protected from progressive coagulation by the presence of colloidal silica. Frondel (1938) and Lindner and Gruner (1938) show in experiments that colloidal silica protects colloidal gold from spontaneous coagulation and from electrolytic action, and also that a decrease in temperature also decreases this protective action. A gradual decrease in the temperature of the altered rock could result in gold collecting in microscopically visible particles that are seen enclosed in pyrite or nearby. Complete replacement of pyritic "diorite" inclusions in quartz may also account for the erratic distribution of gold in quartz as well as pyrite. Thus, it would appear that gold distribution in "diorite" reflects a primary concentration while gold in quartz may be a redistribution.

Source of Mineralizing Solutions:

The association of gold deposits with soda-rich intrusives is a commonly noted feature of the Malartic camp mines and is in keeping with a

similar worldwide association of rock types and gold deposits. Characteristic for this association, as indicated by Gallagher (1940), are small amounts of silver and disseminations of simple sulphides. Gallagher found that albitic intrusives usually precede gold mineralization of this type. The alteration effects of the mineralizing solution are more pronounced in "diorite" than in syenite. This may be taken as an indication that the mineralizing solutions are more similar chemically to syenite rather than "diorite". Orebodies at Gold Fields, formed after the syenite introductions may be related to the trondjemite stem. Osborne (1937) believes that the water required in the differentiation of the stem could also be an effective agent in the concentration of metals. If it is correct to relate the mineralization to a trondjemitic type of differentiation, then the solution probably would be the final differentiate of the magma from which syenite was derived.

CHAPTER 8

TEMPERATURE INVESTIGATIONS USING THE PYRITE GEOTHERMOMETER AND QUARTZ DECREPITATOGRAPH

During 1950, 28 specimens were submitted by the writer to Dr. M. Haycock of the Dominion Mines Branch at Ottawa for an independent study on the temperature of formations of minerals, as indicated by the pyrite geothermometer and quartz decrepitatograph. These samples were collected on 8 consecutive levels, from the 150 foot level to the 1,200 foot level of the number 2 mine, and from the 1,800 foot level of the number 1 mine. Additional samples of "hard massive" peridotite containing pyrite were taken in the number 2 mine on succeeding stations down to the 1,200 foot level. Dr. A.R. Graham, a colleague of Dr. Haycock, conducted the investigation and summed up his conclusions in an unpublished paper of that Department (Graham 1952). The table overleaf (Fig. 32) summarizes the results of the study.

In his discussion of results, Graham stated that his lack of knowledge of the geological conditions prevented any spacial interpretation of results. He also emphasized that the extreme scattering of temperatures called for many more samples to determine, with certainty, any temperature zoning. Nevertheless, some broad observations were made. For example, he noted that pyrite in dark grey quartz gave generally low readings while wall rock pyrite gave generally high readings. Decrepitatograph results, while too few to be firmly conclusive, indicate that three general temperatures of crystallization of quartz occurs in the range of the instrument, from 130° to 160°; 290° to 310°; and 380° to 420°.

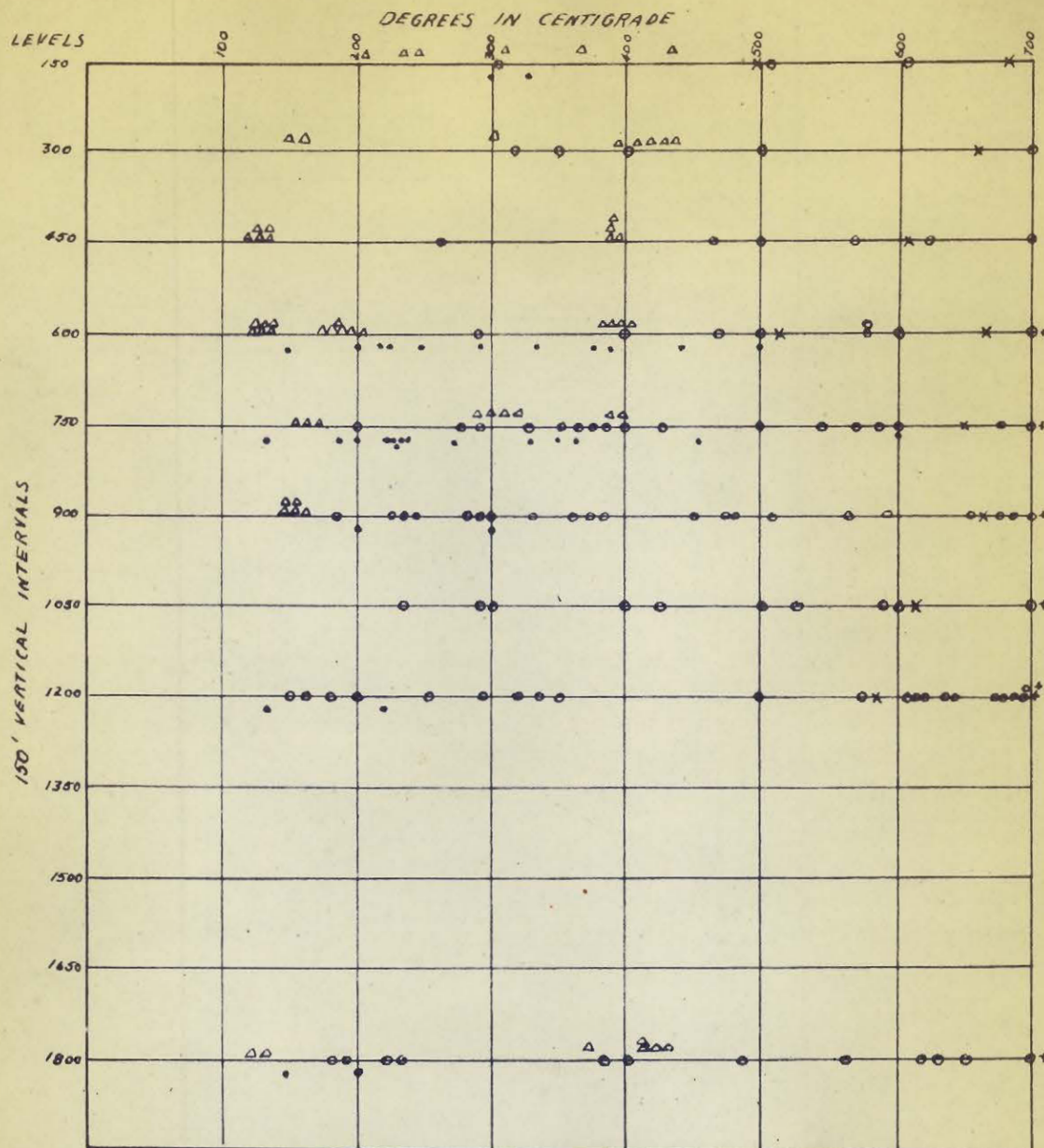


TABLE SUMMARIZING TEMPERATURE STUDY MD. 2872
(Graham 1952)

LEGEND:

Pyrite Geothermometer Temperature Determinations.

- Pyrite in Ore-altered wall rock of Late Intrusives.
- Pyrite in Quartz Veins.
- x Ubiquitous Pyrite at Level Stations in "hard massive" Peridotite.
- △ Quartz Decrepitation Temperature Determinations.

In Figure 32, the general zoning of pyrite temperatures between that occurring in quartz and in wall rock is indicated. No relationship between the three indicated temperatures of quartz and the three observed ages of quartz was found. Petrographic studies indicated that the pyrite in quartz may be slightly earlier and later than quartz deposition and the rough coincidence of temperature readings between quartz and pyrite, may suggest a common temperature range affecting both. The ranges however, are too approximate to be related and thereby attain an indication of pressure conditions. Adjustments for pressure, using Kennedy's charts (1950, p. 540) are given below for depths of rock loads. Kennedy (1950b) measured the P-v-T relations of water over an extended pressure and temperature ranges and based his charts on the new data. Since mineralizing solutions are not composed of pure water, his charts will be in error to the extent that impurities affect the P-v-T relationship.

FIG. 33

TABLE SHOWING ADJUSTMENTS OF
TEMPERATURE FOR PRESSURE

<u>Depth in Miles of rock</u>	<u>Mean of 130-160 145°</u>	<u>Mean of 290-310 300°</u>	<u>Mean of 380-420 400°</u>
1 mile	165	330	Not calculable
2 miles	190	370	" "
3 miles	220	410	" "
4 miles	245	450	" "
5 miles	265	490	" "

It should be emphasized here that decrepitation temperatures approximate the temperature of disappearance of vapor phase in vacuoles at lower temperatures, where a great and speedy increase of pressure occurs when the vapor phase disappears with a small increase in heating. The rate of increase in pressure progressively decreases when the

temperature of disappearance of the vapor phases is in higher ranges so that, when the temperature of formation approaches the critical temperature for the entrapped liquid, the disparity between the former temperature and temperature of decrepitation becomes so great that the relationship between the two is obscured. It will be noted that the intermediate mean temperature of 300° at a depth of 3 miles is greater than the critical temperature of pure water and the mean of 400° is too great to be adjusted for pressure using Kennedy's chart. Stephenson (1952) emphasized the part played by leakage in introducing errors to decrepitation tests and believed that such temperature studies should have coincident optical examinations to evaluate the condition of vacuoles. Any leakage that could plausibly occur in geologic time would seriously affect the validity of temperature determinations by vacuole examination. Leakage would result in higher determined temperatures than at actual formations, and it seems probable that such a source of error may account for the high temperature of 400° .

Pyrite in wall rock has a higher temperature range than that of quartz veins, ranging from 300° to over 700°C . The pyrite occurs in rocks reflecting a range in environment from greenschist to epidote amphibolite. Barth (1952) places the greenschist facies in a temperature range of 100° to 250° with the maximum temperature for the amphibolite facies being 500° , of which no mineral suite is present at Gold Fields. Pyrite in greenschist environment does not contain any mineral associates which would indicate a rise in temperature, at least locally, to the relatively high temperature expressed by the geothermometer. The temperature determinations on pyrite in "hard massive" peridotite are an example of the anomalous condition where pyrite temperatures above 600°C . are found in a rock which reflects a temperature environment below 250°C .

It must be admitted that conditions of the greenschist facies are poorly defined in terms of diagnostic mineral assemblages, but an appreciable rise in temperature, as is indicated in the high pyrite temperature readings above the facies range, should result in the development of related mineral assemblages. Although amphibolite development is found near late intrusives, it can be related to a process later than the formation of pyrite.

In reviewing the theory behind the pyrite geothermometer, as outlined by Smith (1947), it was shown that crystal perfection is a function of the temperature at which it formed. The effect of crystallizing environment was not clarified or evaluated in this paper and under "controlled conditions", Tuttle & Twenhofel (1946) demonstrated the validity of Smith's theories. However, the anomalous observations noted above in the study of Gold Fields pyrite may be taken as an indication that crystallizing environment affects crystal perfection as well as temperature of formation. Euhedral crystals of pyrite in talc-chlorite rock, compared to the subhedral shapes found in late intrusives, show control by environment on crystal outlines and perhaps indicates further that ease of growth in the former habitat results in more perfection in crystal growth, hence the higher temperature indicated on the geothermometer.

It is possible therefore, that distribution of readings on the geothermometer may result not as much from an original thermal gradient at the time of formation as from differences in other environmental conditions.

Such considerations, as outlined above, call for additional

experimentation in pyrite geothermometry with the view in mind of comparing environmental effects on crystal perfection. If a suitable geologic setting is selected and representative samples are tested, it is thought that such a study would be of great value to the general field of temperature study.

Prior to the above study, Smith (1951) in a paper on temperature pressure gradients of the Ontario-Quebec mining regions, incorporated experimental findings at Gold Fields in his regional study. In relating the temperature-pressure gradients to gold deposition, he assumed that:

"Pyrite which was deposited at a low temperature is associated with the gold mineralization in the McIntyre, Kerr-Addison, and Malartic Gold Fields ore".

His results are summarized below:

TEMPERATURE OF FILLING OF
LIQUID INCLUSIONS IN QUARTZ

<u>Depth Below Collar</u>	<u>Decrepitation Temperature °C</u>	<u>Temperature of filling °C</u>
300'	77	57
600'	84	64
600'	105	85
600'	87	67
600'	100	80
1200'	88	68
1200'	85	65
1200'	93	73
1200'	96	76

TEMPERATURE OF DEPOSITION OF
LOW TEMPERATURE PYRITE

<u>Depth Below Collar</u>	<u>Number of Determinations</u>	<u>Average Temperature °C</u>
300'	1	133
1200'	2	126

Smith's temperatures, in the decrepitation tests, are a little more than half of Graham's values for the lowest range in quartz, while the pyrite geothermometer temperatures correspond to the very lowest found by Graham. No obvious explanation is evident for the differences in the decrepitation results, but it may be due to differences in calibration of the instruments; therefore until the instruments are directly compared, a valid comparison between results of these studies would not be possible.

The following observations on the relationships of pyrite, gold, and quartz were seen at Gold Fields:

- (1) The bulk of the gold is with pyrite in wall rock adjoining quartz veins and the pyrite of this habitat gave higher reading than quartz pyrite generally.
- (2) Wall rock mineralization preceded quartz vein formation.
- (3) There is a very minor amount of gold and pyrite in quartz veins which is probably a local redeposition of earlier precipitations that have been dissolved.

Smith's data for Gold Fields appear to represent only a minor amount of the gold present.

PART 3

SUMMARY OF CONCLUSIONS

SUMMARY OF CONCLUSIONS

In reviewing conclusions reached in the foregoing chapters, it is relevant to fit the Gold Fields orebodies into the geological setting for the Malartic camp.

Rock types near the Cadillac fault zone have undergone retrogressive metamorphism in response, generally, to an environment varying between epidote amphibolite and greenschist facies. The early alteration of peridotite was autometamorphic and belongs in an ill-defined sub-facies at the higher temperature end of the greenschist facies. Normal greenschist conditions are indicated where the earlier altered peridotite had undergone retrogressive changes to talc-chlorite rocks. Most of the retrogressive alteration took place before the advent of the late intrusives. Late intrusives, "diorite" and syenite, are soda-rich rocks and are probably members of a trondjemite stem.

The age of fracturing of late intrusives at Gold Fields appears to have been one affecting the Malartic camp in general and the nature of mineralization points to a common source for the whole camp at an unknown depth in the earth's crust. Eakins (1952) distinguishes the ages of mineralization in the region, the older being associated to the cherty or sugary quartz and the younger to white glassy quartz. The abundance of the latter type of quartz at Gold Fields would indicate mineralization as belonging to the younger age for the camp.

Structural control is the prime factor in the formation of the Malartic Gold Fields ore deposits, and the requisite conditions are as follows:

- (1) Proximity to the Cadillac fault zone.
- (2) Great differences in strength of talc-chlorite rock and late intrusive bodies occurring therein.
- (3) Movement on Cadillac fault, probably having a right hand, normal sense.
- (4) Moderate sizes of late intrusive bodies.
- (5) Spacing and type of fracturing in late intrusive bodies.

The source of mineralizing solutions is probably common to that of the late intrusives and related to a trondjhemitic type of differentiation. Fracturing in late intrusives afforded channelways for the mineralizing fluids to come on contact with the host rock. The prime environmental condition for deposition of gold is a decrease in temperature and pressure into ranges suitable for the decomposition of soluble gold compounds on reacting with "dioritic" rocks. Reaction of solutions with the hornblende of "diorites" rendered gold insoluble and the dispersed nature of gold is a feature of primary deposition. Subsequent dissolution and redeposition of gold in quartz veins, as well as in adjacent altered wall rock, resulted in much of the microscopically observable relationships. Gold is only sparsely present in syenite bodies, probably because of the latter's lack of unstable minerals in the mineralizing environment. Deposition of gold here may be due to migration of gold from "dioritic" areas or precipitation as a result of a decrease in the solubility of gold

compounds in the mineralizing solutions with the general decrease in temperature and pressure.

Quartz veins formed by replacement of adjacent rock along fractures and silica were probably derived from rock alterations and may, in part, be a by-product of the mineralization process.

During the period of mineralization, very little movement or deformation occurred, except to mildly brecciate quartz veins and form fractures occupied by tourmaline and molybdenite. These later fractures, with a coincident weak potash metasomatism, form the final identifiable structural and igneous manifestation in the mining areas. Subsequent to this, carbonate-filled fractures and large faults crossing formations on the property and are probably of the nature of joints.

The chapter on pyrite and quartz temperature determinations showed the need for additional experimental research in this field of endeavour and in particular, a research program designed to examine the control of crystal perfection by crystallizing environment.

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APPENDIX I

Item 1

CHEMICAL ANALYSES OF MALARTIC GOLD FIELDS ROCKS (Also one from East Malartic)

These analyses, which were made in the laboratories branch of the Quebec Department of Mines, Quebec, by J.B. Baillot, C. Tousignant, and H. Boileau, are presented here with the permission of the Minister of Mines for the Province. The values for unit volume comparisons are entered to the left of the column of weight percents for each analysis. The calculation is illustrated in Chapter 5 and values in the column represent grams per 100 cc of rock.

- (1) "Hard massive" peridotite - Malartic Gold Fields, No. 2 ore zone,
750' level at north end of No. 2 shaft
station.
- (2) Slightly schistose "soft massive" peridotite -
Malartic Gold Fields No. 2 ore zone,
750' level, main crosscut.
- (3) Talc-chlorite "schist" - Malartic Gold Fields No. 2 ore zone,
main crosscut.
- (4) Unaltered "diorite" - East Malartic Mine, main ore zone,
8th. level, 811 crosscut from No. 3
shaft, in massive peridotite.
- (5) Carbonatized "diorite" - Malartic Gold Fields, No. 2 ore zone,
750' level, 7-6 drift No. 6 ore dyke.
- (6) "Diorite" ore - Malartic Gold Fields, No. 2 ore zone,
750' level, 7-6 drift, No. 6 ore dyke.
- (7) Carbonatized "Grey Porphyry" - Malartic Gold Fields, No. 2 ore zone,
900' level.

ALTERED PERIDOTITE

	1		2		3	
	Wt. %	Grams/ 100 cc	Wt. %	Grams/ 100 cc	Wt. %	Grams/ 100 cc
SiO ₂	43.59	127.7	39.98	113.9	39.38	111.8
TiO ₂	.64	1.8	.27	.7	.32	.9
Al ₂ O ₃	4.82	14.1	5.31	15.1	4.87	13.8
Fe ₂ O ₃	7.48	21.9	2.23	6.3	3.88	11.0
FeO	3.21	9.4	6.22	17.7	5.62	16.0
MnO	.16	.4	.14	.3	.15	.4
MgO	25.64	75.1	24.07	68.6	25.27	71.8
CaO	7.08	20.7	6.47	18.4	5.73	16.2
Na ₂ O	.41	1.2	.02	-	.00	-
K ₂ O	.06	.1	.09	.2	.20	.6
Li ₂ O	.00	-	.00	-	.00	-
P ₂ O ₅	.04	.1	.03	-	.04	.1
H ₂ O _f	5.74	16.8	5.00	14.2	5.34	15.2
H ₂ O-	.17	.5	.16	.4	.15	.4
CO ₂	.22	.6	9.66	27.5	5.54	15.7
S (Total)	.27	.7	.04	.1	.14	.4
Cr ₂ O ₃	.44	1.3	.44	1.2	.51	1.4
V ₂ O ₃	.03	-	.01	-	.01	-
ZrO ₂	.00	-	.00	-	.01	-
BeO	tr	-	tr	-	tr	-
NiO	.13	.3	.13	.4	.23	.6
BaO	.00	-	.00	-	tr	-
SrO	tr	-	tr	-	tr	-
DENSITY	2.93		2.85		2.84	

"DIORITES"

	4		5		6	
	Wt. %	Grams/ 100 cc	Wt. %	Grams/ 100 cc	Wt. %	Grams/ 100 cc
SiO ₂	47.61	149.0	45.81	130.5	38.74	110.0
TiO ₂	1.70	5.3	1.26	3.6	1.32	3.7
Al ₂ O ₃	12.75	40.0	12.67	36.1	12.26	34.8
Fe ₂ O ₃	6.41	20.0	8.33	23.7	12.21	34.7
FeO	8.65	27.0	7.29	20.8	3.81	10.8
MnO	.20	.6	.21	.6	.20	.6
MgO	7.35	23.0	4.47	12.7	4.35	12.3
CaO	8.48	26.5	7.22	20.5	6.82	19.3
Na ₂ O	4.96	15.5	4.57	13.0	3.99	11.3
K ₂ O	.33	1.0	.49	1.4	1.56	4.4
Li ₂ O	.00	-	.00	-	.00	-
P ₂ O ₅	.09	.3	.14	.4	.15	.7
H ₂ O ⁺	1.26	4.0	1.44	4.1	1.14	3.2
H ₂ O ⁻	.12	.4	.13	.4	.12	.3
CO ₂	.17	.5	5.56	15.8	7.42	21.0
S (Total)	.31	1.0	.42	1.2	9.48	27.0
Cr ₂ O ₃	tr	-	tr	-	.00	-
V ₂ O ₃	.03	-	.05	-	.04	-
ZrO ₂	.01	-	.01	-	.03	-
BeO	.00	-	.00	-	.00	-
NiO	tr	-	tr	-	tr	-
BaO	tr	-	tr	-	tr	-
SrO	.00	-	tr	-	tr	-
DENSITY	3.13		2.85		2.84	

SYENITE

7

Weight %

SiO ₂	55.12
TiO ₂	.72
Al ₂ O ₃	16.55
Fe ₂ O ₃	.80
FeO	3.81
MnO	.08
MgO	2.57
CaO	4.99
Na ₂ O	7.75
K ₂ O	1.00
Li ₂ O	.00
P ₂ O ₅	.35
H ₂ O ⁺	1.18
H ₂ O ⁻	.08
CO ₂	4.80
S (Total)	.40
Cr ₂ O ₃	.01
V ₂ O ₃	.01
ZrO ₂	.05
BeO	tr
NiO	tr
BaO	.17
SrO	.09

DENSITY ... 2.75

APPENDIX I

Item 2

VERTICALLY AND HORIZONTALLY CONTOURED ILLUSTRATIONS THE NO. 2 SWARM "DIORITE" DYKES

Explanation:

These illustrations show the general shapes and spacial attitudes of the dykes of No. 2 dyke swarm. The lower portion of each illustration is a horizontal composite outline of the dyke at 150 foot vertical intervals on the scale 1" = 100'. The outlines are coloured in sequential arrangement as in the spectrum. The colours for each level are indicated below:

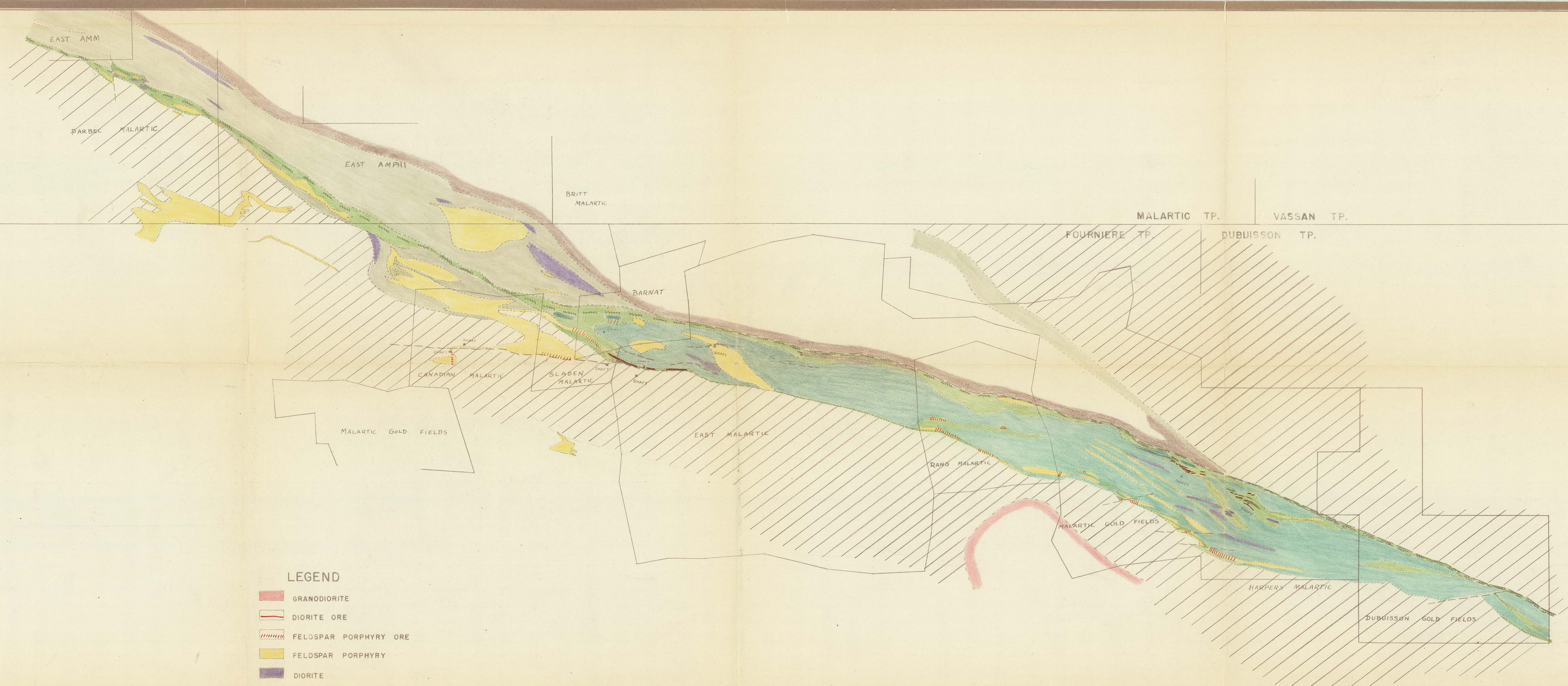
150'		
300'		
450'		
600'		
750'		
900'		
1050'		
1200'		

Above the composites of a dyke is a longitudinal section on which the south contact is contoured. The datum plane for these contours is the downward projection of the Survey Base Line to form a base plane (Fig. C). Contour planes are at 25 foot intervals increasing in footage northwards; therefore an increase in footage indicates a northerly trend while a decrease in footage shows a southerly trend.

Low grade portions of dykes are imposed on longitudinal sections and are coloured in gray. These zones are determined by inclined drilling assay results and stope assay studies.

The base plane is parallel to the bottom margin of the illustration. The short vertical line extending upward from the lower margin, with a number above, is the section line. An examination of the geological plan of the 1,200 foot mine level (Fig. C) will give the reader an impression of the relative position of the dykes.

In the No. 1 dyke, corrections in red represent recent information obtained from Dr. Gill. The value of the illustration is not affected seriously, as the upper portions of the dyke are the sections of most interest.



LEGEND

- GRANODIORITE
- DIORITE ORE
- FELDSPAR PORPHYRY ORE
- FELDSPAR PORPHYRY
- DIORITE
- TALC-CHLORITE SCHIST
- PERIDOTITE
- CADILLAC SEDIMENTS
- KEWAGAMA SEDIMENTS
- BLAKE RIVER VOLCANICS
- FAULT, DEFINED
- FAULT, ASSUMED

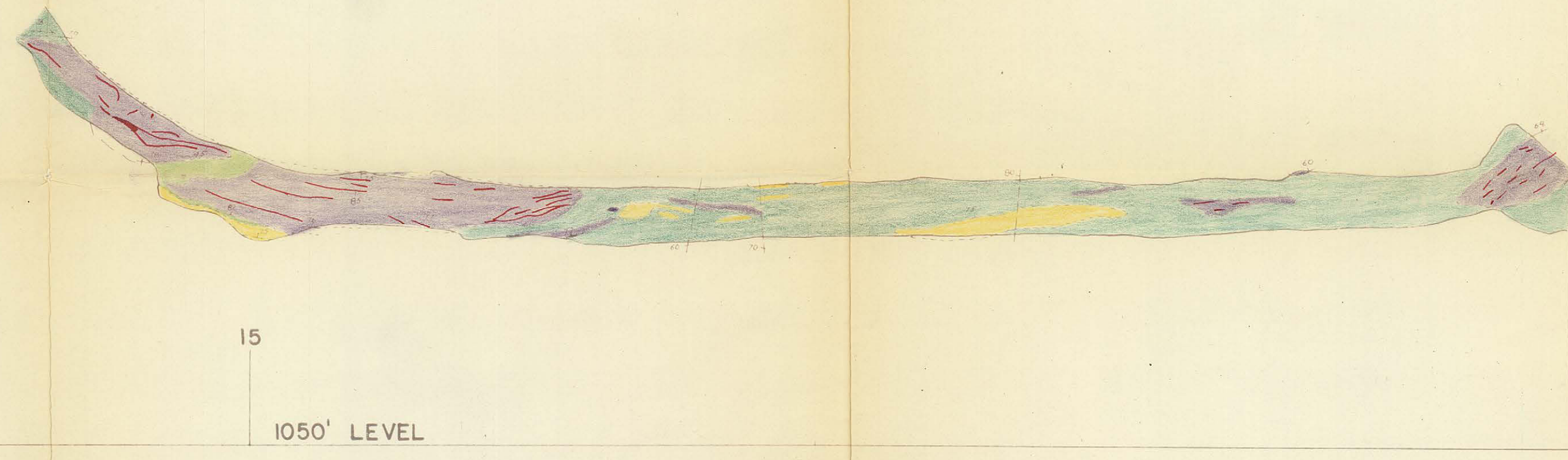
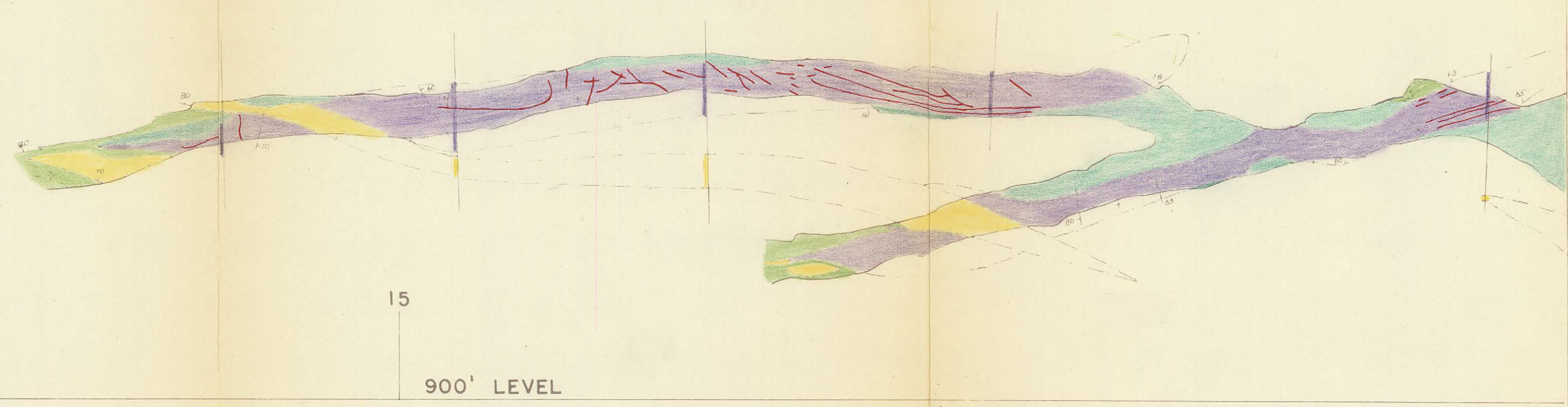
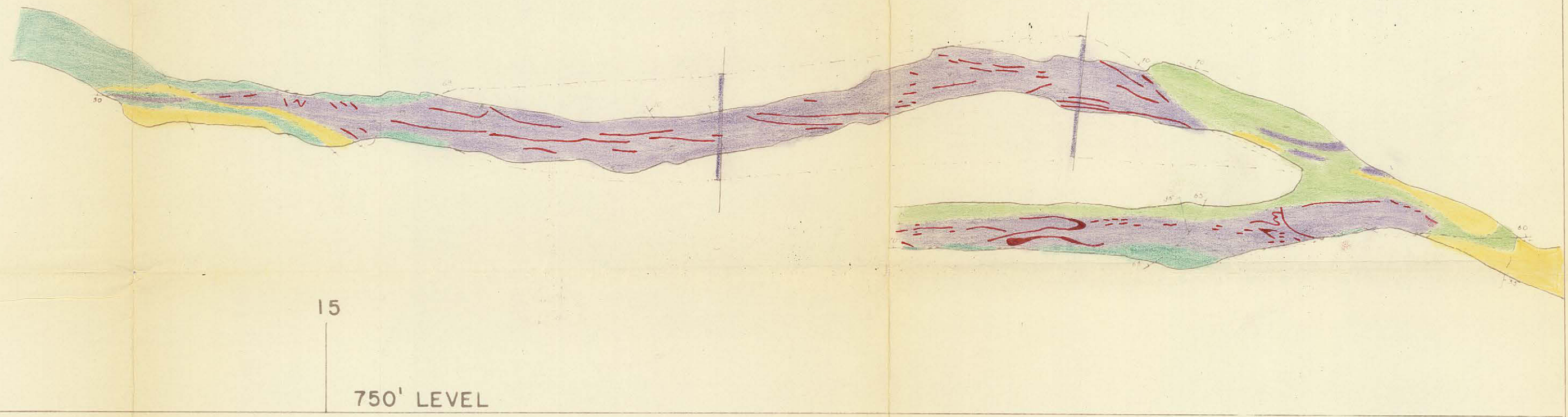
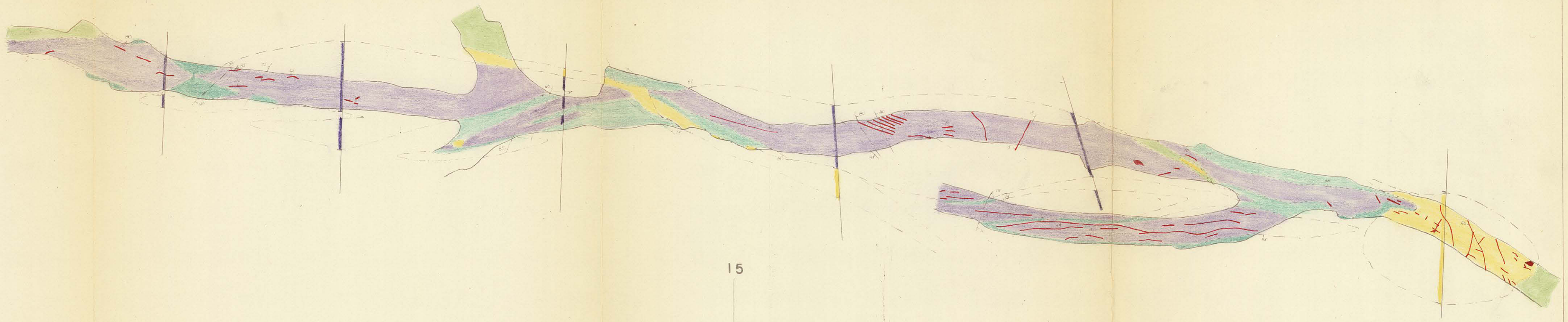
FIGURE A
GEOLOGICAL PLAN
MALARTIC GOLD FIELDS
AND
NEIGHBORING PROPERTIES

SCALE: 1" = 2000'
JUNE/49
REV'D JAN/52
L.K. Wallin



- LEGEND**
- GRANODIORITE
 - ORE DIORITE
 - SYENITE
 - DIORITE
 - TALC-CHLORITE SCHIST
 - PERIDOTITE
 - CADILLAC SEDIMENTS
 - KEWAGAMA SEDIMENTS
 - BLAKE RIVER VOLCANICS

FIGURE B
GEOLOGICAL PLAN AT 300' MINE LEVEL
OF
MALARTIC GOLD FIELDS LIMITED
 SCALE 1" = 400'
 AFTER C.K. WILTON



SYMBOLS

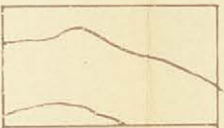
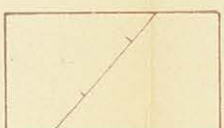
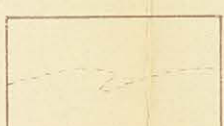
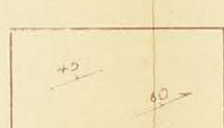
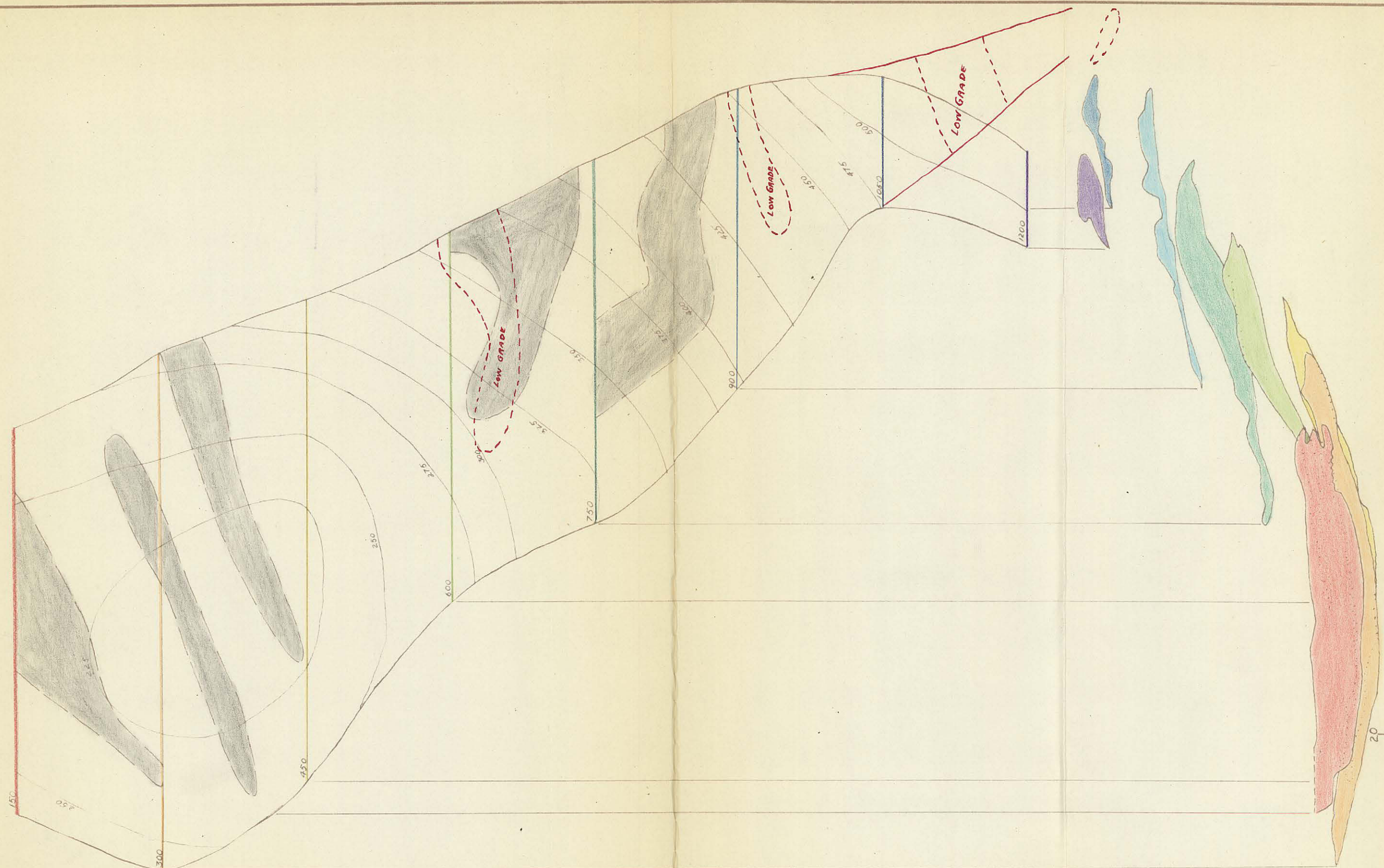
-  DRIFT OUTLINE
-  POST QUARTZ SLIP
-  DRILL HOLE INTERSECTION
-  GEOLOGICAL CONTACT
-  PROBABLE CONTACT
-  QUARTZ VEIN
-  STRIKE AND DIP

FIGURE D
LEVEL PLANS OF THE 8 DYKE

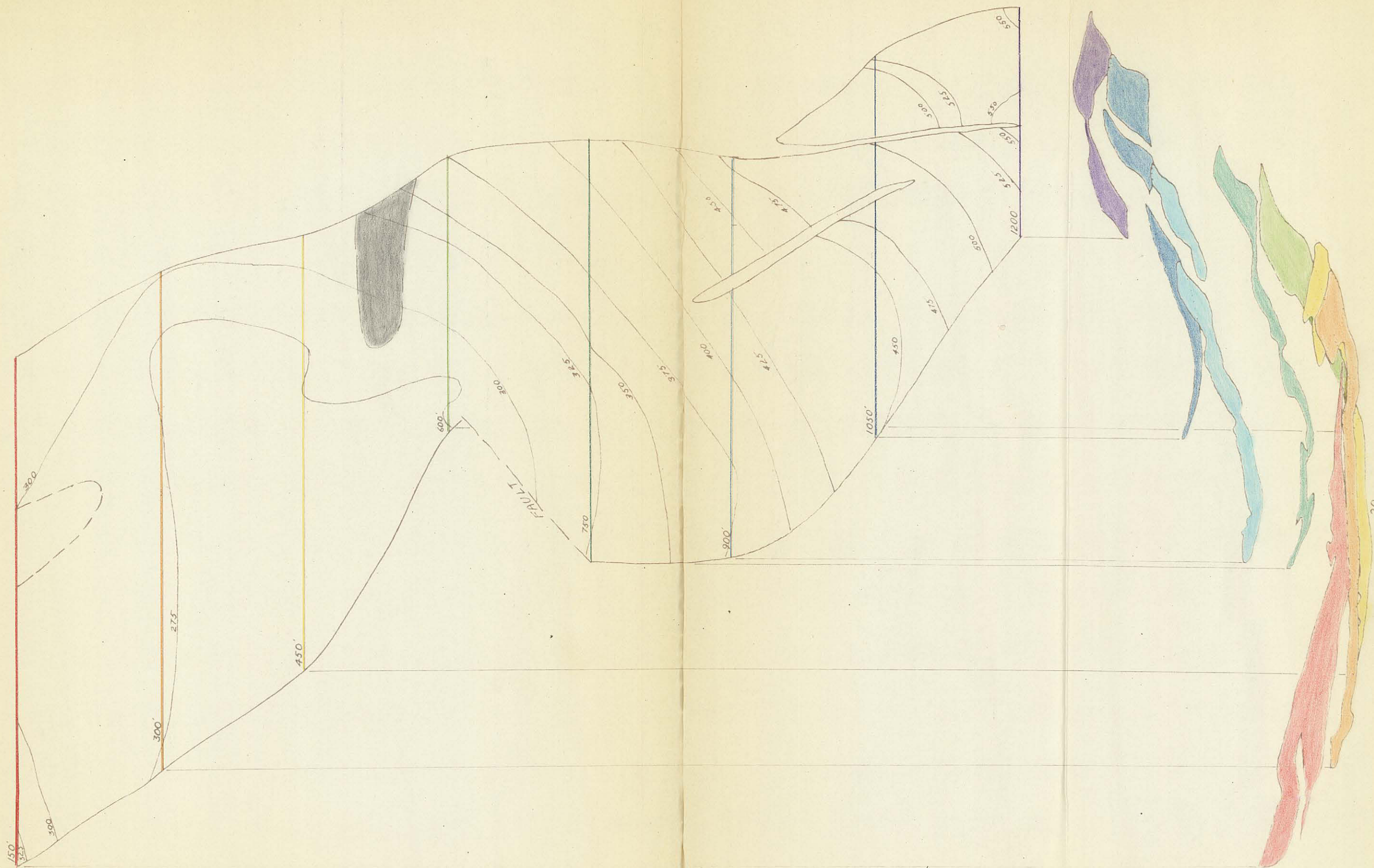
SCALE 1" = 20'



MALARTIC GOLD FIELDS LTD.

#1 DYKE

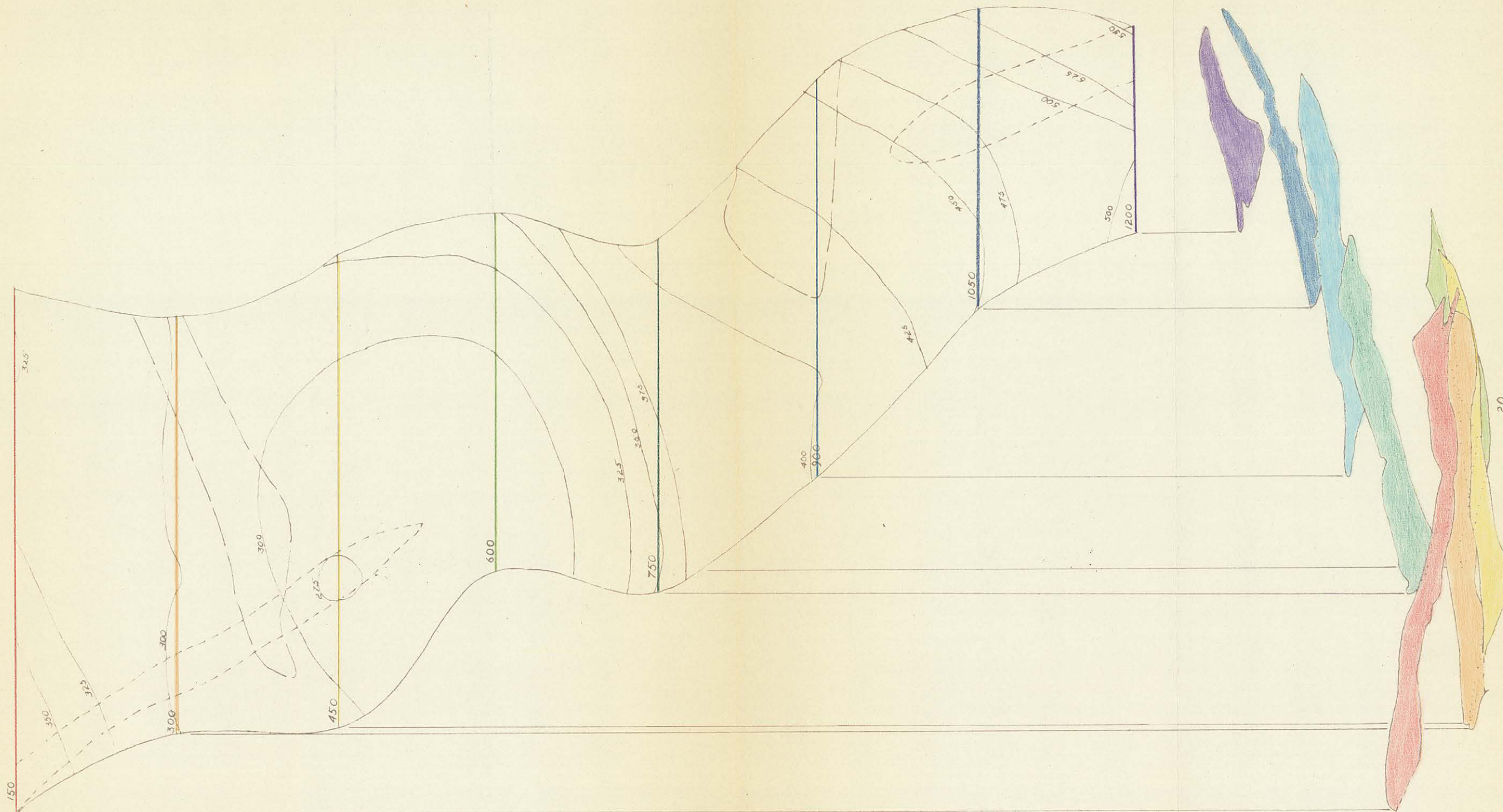
SCALE 1"=100'



MALARTIC GOLD FIELDS LTD.

#2 DYKE

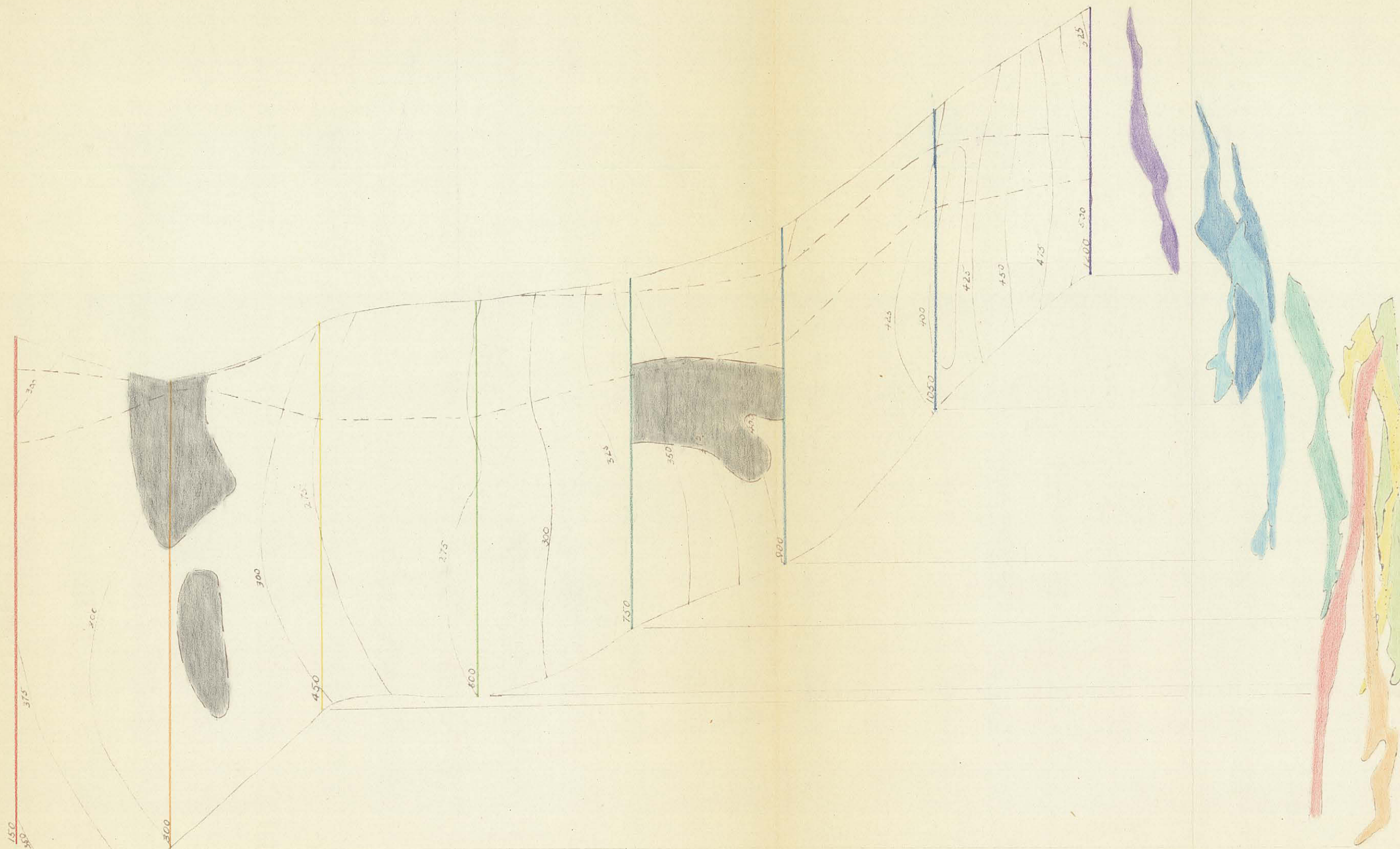
SCALE 1" = 100'



MALARTIC GOLD FIELDS LTD.

#3 DYKE

SCALE 1"=100'



MALARTIC GOLD FIELDS LTD.

4 DYKE

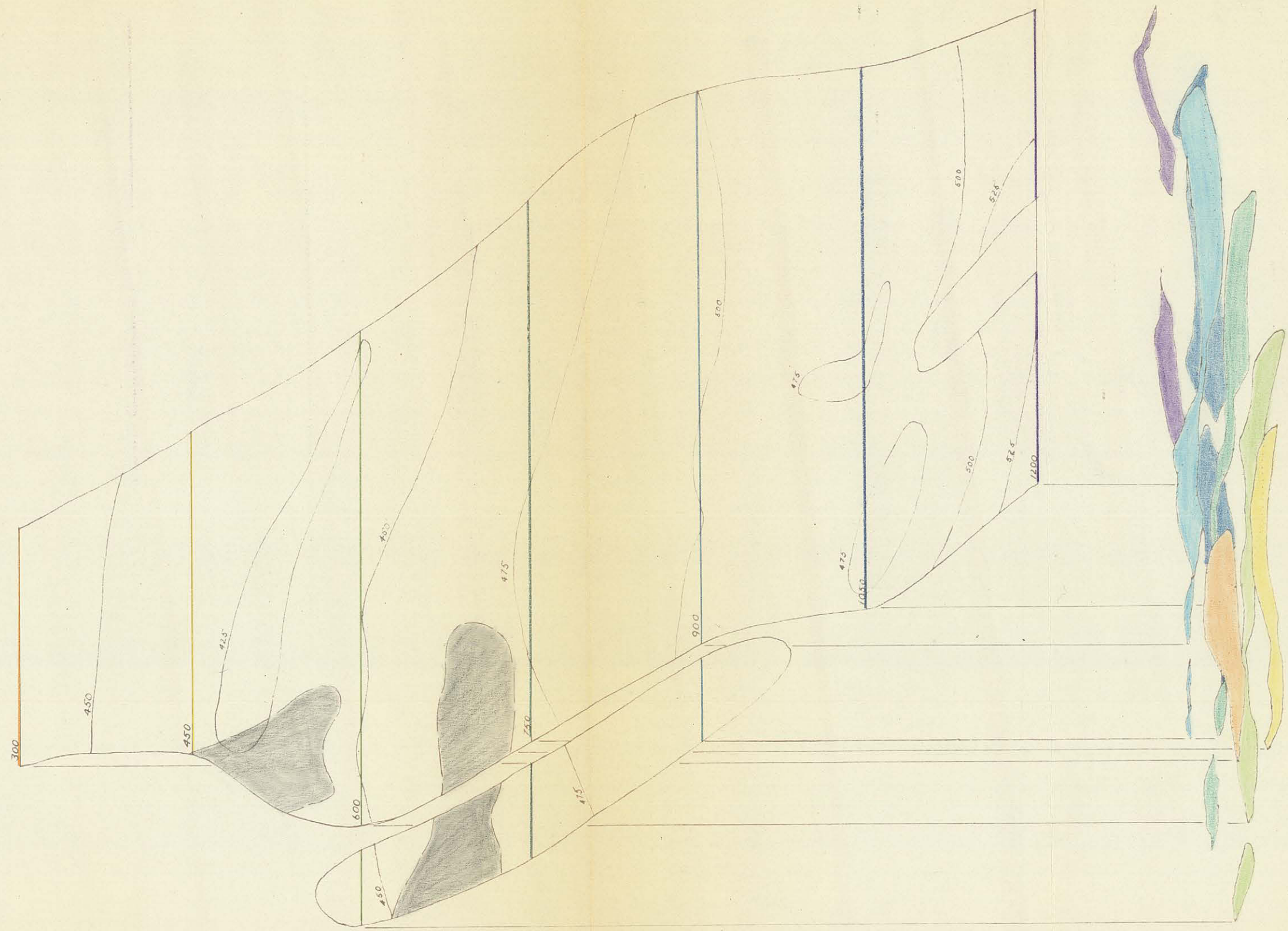
SCALE 1" = 100'



MALARTIC GOLD FIELDS LTD.

5 DYKE

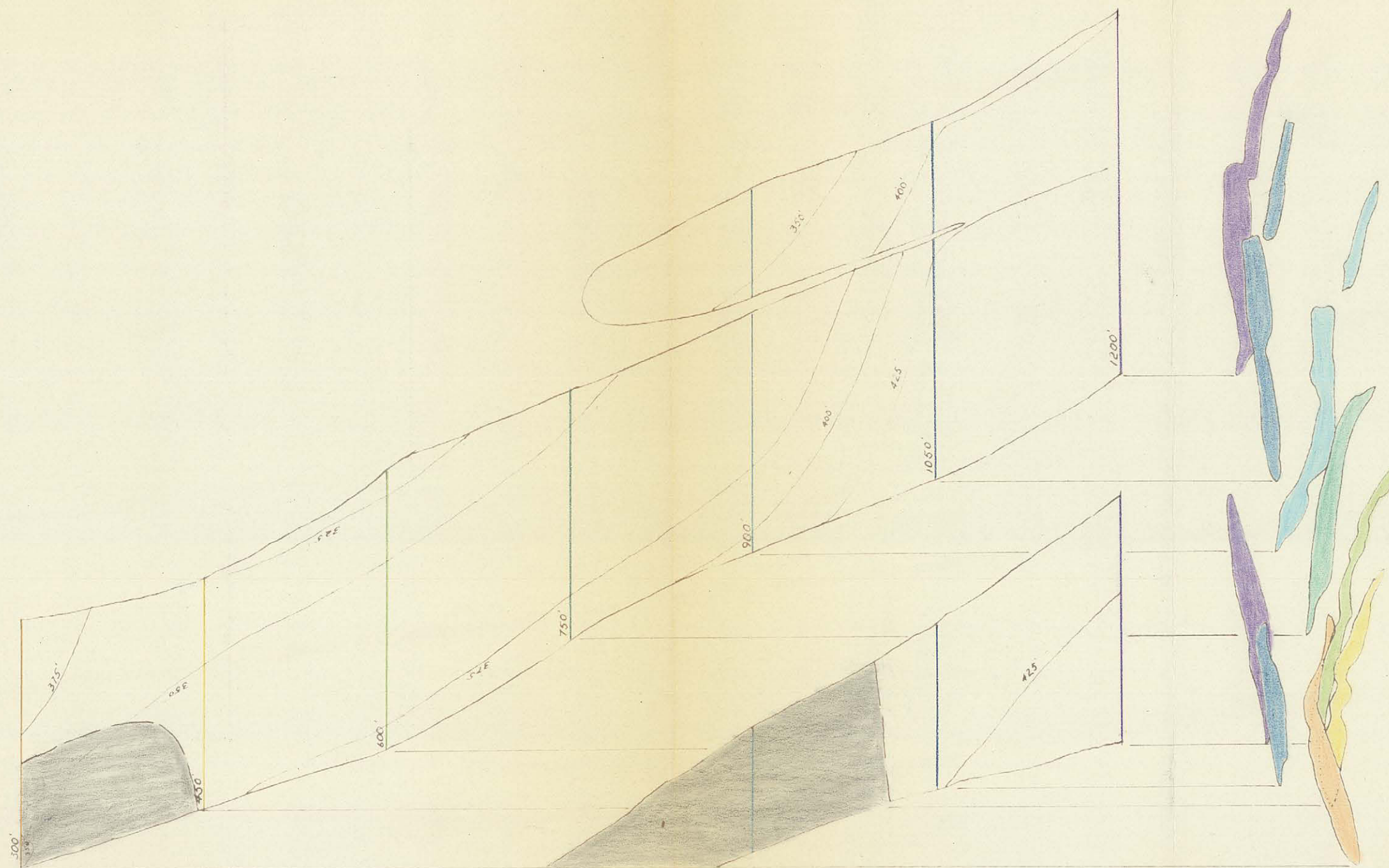
SCALE 1" = 100'



MALARTIC GOLD FIELDS LTD.

#9 DYKE

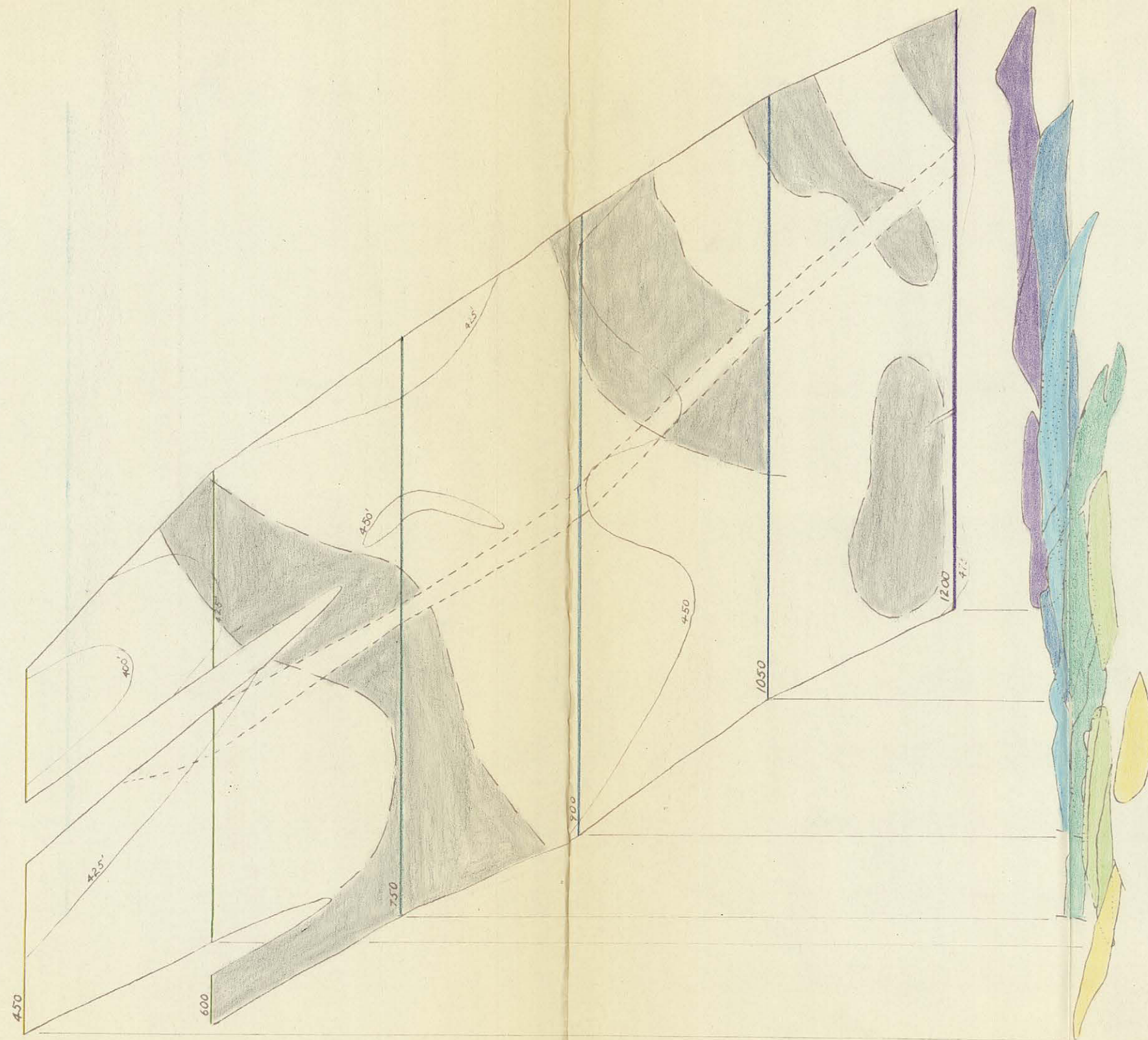
SCALE 1" = 100'



MALARTIC GOLD FIELDS LTD.

10 DYKE

SCALE 1" = 100'



MALARTIC GOLD FIELDS LTD.

11 DYKE

SCALE $1'' \equiv 100'$