ASSIMILATION AND PETROGENESIS

SEPARATION OF ORES FROM MAGMAS

BY
JOHN STANSFIELD

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To Reginald Aldworth Daly
whose writings have inspired
this work

PREFACE

This work deals with the origin of igneous rock types, special attention being paid to the conception of assimilation and the opinions expressed for and against it. Mention of high temperature experiments made by other workers on this and allied topics is made, followed by a detailed account of experiments made by the author. Experimental products obtained by adding known proportions of materials representing sediments, etc., to igneous rocks are described for comparison with natural rocks.

Experiments resulting in the separation of ore minerals from rock melts have yielded important evidence regarding the processes of ore separation from magmas. "Flotation" of sulphides in magmas is illustrated by photomicrographs.

The investigations described herein were commenced in the laboratories of the University of Illinois with the financial aid given through the good offices of Dean A. H. Daniels, of the Graduate School, and with the active support of Professor S. W. Parr, and Dr. M. M. Austin, at that time of the Department of Industrial Chemistry, of Professors A. C. Callen and A. E. Drucker of the Department of Mining Engineering, and of Professor C. W. Parmalee and Dr. A. E. R. Westman of the Department of Ceramics, University of Illinois.

The experiments were continued and microscopic examinations and chemical analyses were carried out at the State School of Mines, Butte, Montana. This was rendered possible by the sympathetic aid freely given by Chancellor M. A. Brannon and ex-President G. W. Craven, and by the analytical work done chiefly by Professor L. J. Hartzell and partly by Assistant Professor C. L. Wilson. The microscopic examinations were continued at the University of Illinois and at Washington University, St. Louis. At St. Louis the work had the sympathetic interest and help of Dean W. E. McCourt.

Dr. W. S. Bayley has very kindly assisted in proof-reading.

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ERRATA

P. 20, last line but one, for **plagiodase** read **plagioclase.**
P. 21, line 3, strike out the second **and.**
P. 22, line 9, for **Molengraaf** read **Molengraaff.**
P. 29, footnote line 4, for **form** read **formed.**
P. 34, line 6, for **nephilinite** read **nephelinite.**
P. 49, for **Molengraaf, A.,** read **Molengraaff, G. A. F.**
P. 55, line 21, for **pryoxenite** read **pyroxenite.**
P. 59, line 10, for **articial** read **artificial;**
line 21, for **nickelferous** read **nickeliferous.**
P. 60, 10th line from bottom, for **microline** read **microcline.**
P 70, 6th line from bottom, strike out , .
P. 88, footnote line 1, insert **1927.**
P. 96, 8th line from bottom, for **Nehpeline** read **Nepheline.**
P. 109, 12th line from bottom, for **andesite** read **andesine.**
P. 111, 7th line from bottom, for **Themolite** read **Tremolite.**
P. 112, 10th line from bottom, for **in** read **is.**
P. 131, 11th line from bottom, for **Granite** read **Granite 1.**
P. 140, **Clino-enstatite-augite rock** should be placed at the head of the page with **peridotite** and **pyroxenite.**
3rd line from bottom, for **Åkermanite** read **Åkermanitic,** and at the end of this sentence add **except those mentioned above.**
P. 146, line 26, for **nickelliferous** read **nickeliferous.**
P. 150, line 11, for **iren** read **iron.**
P. 154, line 15, insert **(471).**
P. 186, 6th line from bottom, for **73, 74** read **74, 75.**
P. 193, for **Molengraff** read **Molengraaff.**
Fig. 10, for **x80** read **x25.**
Fig. 11, strike out **+nicols.**
Figs. 22 and 57, for **syenite** read **syenite a.**
Fig. 48, for **magnesite** read **magnetite.**

PART I

CHAPTER I

INTRODUCTION

Since the beginning of the foundation of the science of geology a number of different views regarding the origin of the rocks we now call "igneous" have been held at different times and by different masters.

Werner, one of the founders of geology, looked upon basalt as a deposit from solution made upon the floor of a hot primordial ocean. It was in the Auvergne district of France that Desmarest first clearly interpreted the origin of basalt in the manner now generally accepted, by the cooling and solidification of molten rock matter poured forth from an opening at the earth's surface, and brought to the surface in liquid form from some distance within the earth's crust.

With the progress of the sciences of geology and mineralogy a large number of minerals have been recognized as forming parts of the earth's crust; and a number of distinctive mineral aggregates (rock types) have been recognized among the igneous rocks, i.e., those which have solidified from fusion. The science of petrology deals with the study of these rock types and their origin. This latter part of the subject—their origin—is still very much open to discussion. The evidence contained within the rocks themselves, visible with the aid of the microscope, is by no means conclusive regarding the broad processes connected with the origin of rock types.

In addition to the detailed studies of the rocks themselves in the field and in the laboratory, experimental work has been carried on during the past century and a quarter in both mineralogy and petrogenesis. But the greater part of this work has been concerned with the formation of certain minerals from pure chemicals and the results have enriched our knowledge of mineralogy and often have given very valuable knowledge of the physico-chemical relations of minerals and melts which have been of incalculable aid in the application of theory to the study of the crystallization of rock magmas.

Experimental work dealing with rock magmas themselves has been less abundant than that dealing with pure mineralogy. Doubtless one cause of this is that the rock magmas are complex "solutions" (accepting the solution view of rock magmas developed by Bunsen, Lagorio, Teall and others), and it is one valuable view-point that the better way to approach a difficult problem is by a thorough comprehension of the simpler problems of an allied type. The Carnegie Institution at Washington has made wonderful strides during the last few decades in the interpretation of many of the problems mentioned.

The experimental work of the past which has dealt specifically with petrogenesis is that of Hall, Watt, Fouqué and Lévy, Vogt, Morozewicz, Doelter, Petrasch and N. L. Bowen. In addition the work of many other investigators has borne upon some of the special points of the problems of petrogenesis.

James Hall (1798) first showed that crystalline rock materials could be obtained by melting basalt in a graphite crucible and allowing it to cool slowly. Fouqué and Lévy later subjected his ingots to microscopic examination and found olivine, labradorite and oxide of iron in them.

Gregory Watt (1804) melted a mass of 700 lbs. of basalt and cooled it during a period extending over 8 days, producing a mass 1.2 metres long, .8 metre wide, and .5 metre thick. The central part of it was crystalline. The chief drawback of these experiments by Hall and Watt was the absence of an adequate method of examination of the products. The microscopic methods of examination had not been developed at that time.

In 1882 Vogt published his "Studier ober Slägger", in Norwegian.[1] This study of the crystallization of industrial slags though dealing with artificial melts uncovered general principles of great importance in the study of igneous rocks.

Vogt gave details of the chemical and mineralogical composition of about 180 slags, and worked out the conditions of chemical composition combined with temperature governing the separation of various minerals from molten slags. The studies of freezing-point curves for multi-component silicate systems have been the direct sequence of Vogt's investigations, which may be regarded as pointing the way for the more recent studies of crystallization conditions of igneous rocks and analogous artificial melts. Vogt recognized the follow-

[1]Vogt, J. H. L., Studier ober Slägger. Christiania. 1882.

ing minerals in slags, and studied the conditions of their formation:

minerals of the olivine group: fayalite, chrysolite, forsterite, monticellite, tephroite, and zinc fayalite;
melilite, gehlenite, åkermanite (the latter named later);
phlogopite, a hexagonal lime silicate, spinels, magnetite, willemite, cuprite, copper and ferrous oxide.

Vogt's later paper treated the same matters in German,[2] and to the list of minerals found in slags he added clino-enstatite (not so named at that time), the plagioclases (oligoclase, labradorite, and anorthite), garnet, corundum, wollastonite, hematite and apatite.

L. Bourgeois (1883) obtained anorthite and monticellite by the fusion of an artificial mixture equivalent in composition to grossularite.[3]

Fouqué and Lévy,[4] in 1882, published the results of an important and comprehensive series of experiments in which mixtures of various rock-forming minerals were melted in platinum crucibles and allowed to stay a little below their fusion temperatures for a period of 48 hours. By this means the following rock-forming minerals were produced by them:

leucite, anorthite, olivine, magnetite and picotite, at the higher temperatures used:
labradorite, oligoclase, pyroxene and enstatite, at the medium temperatures used;
and nepheline, hypersthene, melilite and melanite, at the lower temperatures used.

By melting together requisite amounts of constituent minerals the following rocks were artificially produced:

andesite (from oligoclase and augite);
andesite, with some melilite (from labradorite and augite);
basalt (from basalt glass—olivine + augite + labradorite);
nephelinite (from nepheline and augite);
leucitite (from leucite and augite);
leuco-tephrite (from pure chemicals representing augite + labradorite + leucite);
lherzolite;
meteorites;
ophitic diabase (from anorthite and augite).

[2]Vogt, J. H. L., Mineralbildung in Schmelzmassen. Christiania. 1892.
[3]Bourgeois, L., Annales chim. phys. 29, 1883, p. 458.
[4]Fouqué, F. and Lévy, A. M. Synthèse des minéraux et des roches. Paris. 1882.

In many of these artificial products the ingots were well crystallized and showed abundantly the same structures as volcanic rocks and that the porphyritic structure can be developed in as short a period of crystallization as **two days.**

Morozewicz[4] (1898) published the results of his famous studies of the melts of igneous rocks and artificial mixtures made in clay crucibles placed in openings on the sides of a glass furnace at Warsaw. Forty per cent of the 200 melts were rendered of little value by reason of absorption of some of the materials of the crucibles. The chief results of Morozewicz's studies deal with the crystallization of artificial melts comparable to igneous rocks with added excess of alumina; with the formation of **corundum, spinel, sillimanite, and cordierite,** as well as anorthite, labradorite, augite, olivine, melilite (?åkermanite, because optically +) and enstatite from these melts; and with the chemical relations governing the formation of these minerals.

Melts of igneous rocks alone showed that the same minerals originally present in the rock are not necessarily reproduced after melting; in other words, by varying the physical conditions attending the crystallization of silicate magmas different mineral combinations may be formed.

Another series of Morozewicz's experiments dealt with the formation of nosean, haüyne and sodalite from silicate melts (like certain igneous rocks) with excess of sodium sulphate and sodium chloride.

Morozewicz succeeded in obtaining minute crystals of quartz, biotite and sanidine from a melt of a liparite to which had been added 1 per cent of tungstic acid. Still another important result obtained was the production of glasses of different compositions (more siliceous above and less siliceous below) from a melted granite*. Points of difference between Morozewicz's experiments and mine are that most of his experiments were conducted under atmospheric or oxidizing conditions, while mine have been done under reducing conditions because of the graphite crucibles, and Morozewicz used large quantities of materials (up to as much as 100 lbs. in a single melt) while I have used small amounts (a few grams only).

[4]Morozewicz, J., Tschermak Min. & Pet. Mitth. 18, 1898-9, p. 1.

*In several melts of granite I have noticed the collection of unmelted quartz grains around gas bubbles. The flotation principle acting on these may perhaps enrich the upper part of such a melt in quartz. It is worthy of investigation as to whether or not this result of Morozewicz can be reproduced and if so what is the exact process which causes it.

Morozewicz also made an artificial melilite-basalt from which melilite, augite, plagioclase, olivine, corundum and spinel crystallized.

Bunsen, Brun, Joly, Doelter and others have made many determinations of the melting points of minerals and rocks. In addition Doelter has made studies of the solubilities of minerals in rock melts.[5]

Fouqué (1900) fused augite-andesite and basalt with lime and obtained melilite among the products.[6]

Petrasch (1903) mixed igneous rocks in certain proportions, melted 11 mixes with fluxes and obtained crystalline products, including:

> orthoclase, plagioclase, leucite, magnetite, augite, hornblende?, olivine, nepheline, hematite and tridymite?.[7]

The experimental work of a coterie of workers at Carnegie Institution, Washington, during the last few decades has yielded important results along the lines of the application of physical chemistry to the study of artificial melts yielding rock-forming and other minerals, upon crystallization. These melts have been of pure materials with a limited number of chemical constituents, so that certain definite problems have been studied. The names of Day, Allen, Shephard, Rankin, Sosman, Wright, Merwin, Bowen and Greig stand out in connection with these studies.

In addition to the experimental studies Bowen has contributed general discussions of the broader problems of petrogenesis and has applied thereto the experimental results obtained in his laboratory studies and in those of his colleagues. The important papers of this series, from the point of view of my experiments and their results, are those which appeared in Journal of Geology in 1915 and 1922.[8] The main theme of the former paper is that differentiation of magmas results from the removal of earlier formed crystals by sinking. The later paper (1922) discusses reactions between igneous magmas and inclusions of solid rock matter in them, from the theoretical stand-point. A great many points of interest are brought out in Bowen's treatment which leads him to the opinion that while inclusions may be incorporated in magmas and may add their quota to the materials of the magma, this process goes on only to a limited extent. This opinion is based on the as

[5]Doelter, C., Tschermak Min. & Pet. Mitth. 20, 1901, p. 307.
[6]Fouqué, F., Bull. Soc. Min. 23, 1900, p. 10.
[7]Petrasch, K., Neues Jahrb. B.B. 17, 1903, p. 508.
[8]Bowen, N. L., Jour. Geol. 23, 1915 (Supplement) and 30, 1922, p. 513.

sumption that only a slight amount of superheat in magmas is possible.

It may seem early to some to make any assumption about the degree of superheat possible in magmas. Present knowledge seems to indicate that as magmas approach the surface of the earth oxidation effects may be of sufficient importance to bring about a definite condition of superheat. It is difficult to estimate whether this effect is small and local in significance or large and of more general distribution.

DIVERSITY OF IGNEOUS MAGMAS AND ROCKS

Geological observations have abundantly demonstrated the fact that molten magmas of distinctly different characters have been extruded at the earth's surface at different times in the earth's history, or failing to reach the surface have been intruded into the rocks forming the earth's crust.

Two main views have been advanced to account for the formation of liquid magmas, viz:

1. Still molten portions of original liquid parts of the earth (after the nebular hypothesis) and

2. Portions of the original solid earth which have become liquefied by accession of heat (after the planetesimal hypothesis).

Those who have carried their geological studies back into the realm of the Pre-Cambrian rocks have been brought into contact with an older view that some of the gneisses of the Pre-Cambrian were formed by melting of sediments in situ, the gneissic banding preserving original stratification. While it has been recognized that many of the older gneisses have been formed from igneous rocks by the action of pressure, either before or after consolidation of magmas, there still remains a group of gneisses (para-gneisses) which retain the chemical characteristics of sediments and are regarded as the products of the metamorphism or re-crystallization of sediments. (Included here are cipolins, some garnet, cordierite, and sillimanite-gneisses, some mica schists and micaceous gneisses, and perhaps in some cases certain gneisses* not differing very markedly from granite in mineralogical and chemical composition.)

Werner taught that the deposits from the primordial ocean were deposited upon the original crust of the earth, i.e., the first part to solidify. According to this view the original

*Quirke, T. T., Bull. G. S. A., 38, 1927, pp. 753-770.

earth crust could be reached by a discovery of the oldest rocks of the geological succession, what we would now call the oldest Pre-Cambrian rocks. The more recent teachings of geology would tend to throw doubt upon this and to question whether the earliest formed part of the earth's crust were still preserved in its original form, or even in a metamorphosed form, and be available for examination and study. (The term earth's crust is used here, as in the literature of the day, without the implication that it has been formed by solidification from the liquid state.) It may be that as a result of the oft-repeated intrusion of igneous magmas into the older rocks in Pre-Cambrian times, the rocks which formed the original outer part of the lithosphere have been completely changed from their primordial condition, so as to be no longer available for examination. It may be that the oldest sediments and the oldest igneous rocks of the earth's surface have been melted and incorporated in magmas which have been intruded into the lithosphere or extruded at the surface of the earth in the Pre-Cambrian times of which we have record, and there may possibly have been previous long stretches of time, whose records have been completely destroyed.

The view that the older parts of the Pre-Cambrian rocks may have been re-incorporated in younger magmas of the Pre-Cambrian is not a view which is stressed at the present time, but at least such is a possibility and the mind should be kept open to it.

In addition to this problem of the origin of the oldest visible rocks there are the other fascinating problems of petrogenesis—the origin of distinct rock types, and magmatic differentiation.

ORIGIN OF DISTINCT ROCK TYPES

Original Heterogeneity of Materials—According to the planetesimal hypothesis distinct rock types in separated regions can be accounted for by heterogeneity of the original materials of the earth's body, which, upon being melted at some later times would give rise to magmas of distinctive characters, which might in some cases solidify as peridotites, gabbros, nepheline-syenites, granites, etc., or as their volcanic or hypabyssal equivalents.

Assimilation—Or, if there were a single uniform primordial magma passing through heterogeneous solid materials

in the earth's crust, such a magma might have a good chance of being changed in composition by absorption of more or less of these solid materials and in such a way magmas of distinct types may have risen. This is the kind of suggestion which has been put forward by Daly who has proposed an original primordial basaltic magma from which other magmatic types have been developed by absorption and incorporation of varying amounts of extraneous rocks of different compositions.[9]

Magmatic Differentiation—This question has been discussed theoretically by many writers among whom may be mentioned Rosenbusch, Teall, Iddings, Loewinson-Lessing, Harker, Becker, Daly, Vogt and N. L. Bowen. The two latter workers have made important experimental contributions which, along with the geological facts themselves give the bases for discussion of the question of magmatic differentiation.

All who have studied petrology at all closely will concede the general principle of magmatic differentiation, i.e., that by solidification of a single liquid magma solid portions differing in chemical and mineralogical characters result. This is to be seen clearly in the cases of many single intrusive masses, e.g., Carrock Fell gabbro, Yogo Peak (Montana) syenites, Taberg ilmenitic gabbros, anorthosites of Quebec province, etc.

The wider application of the principle of magmatic differentiation to account for the variation of rock types of "co-magmatic regions" is not clearly demonstrable on the ground, as is the former case, and so while this application of the principle provides abundant food for thought and speculation, a clear and definite conclusion with reference to it cannot be reached.

This drawback should not be allowed to act as a brake upon investigation. Indeed it is probable that by use of this conception and its experimental investigation from all angles very valuable information may be obtained, and indeed, much is already at hand.

FIELD EVIDENCE OF ASSIMILATION

The general heterogeneity of the distribution of the various igneous rock types appears to support the notion that different rock types have resulted from original differences of composition of the earth materials.

Further consideration may suggest that this may not be the whole story, however. There are many examples of

[9]Daly, R. A., Igneous Rocks and their Origin. 1914.

magmas which seem to afford clear field evidence of contamination by assimilation of the surrounding country rocks. The okaite of Oka hills has been cited as an example of such a process, on a restricted scale.[10] The nepheline-syenites of the Haliburton-Bancroft region were considered by Adams and Barlow as an example of the same kind of process on a larger scale.* A number of other examples might be cited, but number is not a specially valuable argument in this case because the citation of many examples of nepheline-syenite or related magmas showing assimilation of sediments does not satisfactorily explain the constant association with the nepheline-syenite magmas of certain minerals among which are rinkite, låvenite, eudialyte, rosenbuschite, mosandrite, astrophyllite, etc.

A survey of the literature shows that the conception of assimilation and syntexis has commended itself to a great many geologists. Among the more prominent names may be mentioned Lyell, Sterry-Hunt, Iddings, Ransome, Bayley, Lawson, Fermor, Holland, Lacroix, Quensel, Tyrrell, Van Hise, Molengraaff and Daly. This list is by no means exhaustive but serves to indicate that assimilation and syntexis have received consideration and acceptance as definite geological processes on many occasions by many geologists.

Some have even gone so far as to consider some magmas as produced by the melting of rocks of the Pre-Cambrian basement. Daly has been the especial champion of assimilation and has pushed this process to the extreme of making it account for all variations of igneous types† by assimilation of certain rocks by a universal parent magma of basaltic character, coupled with differentiation.

The possibility of such a broad scope for the process of assimilation must needs give one pause and lead to a critical examination of the described cases of assimilation. This leads naturally to an enquiry as to how much assimilation of this or that rock material may be possible in magmas of definite types and what would be the resulting products? And also to an enquiry as to whether there exist such products as may be cited in illustration, where they occur, and what volumes they pos-

[10]Stansfield, J., Geol. Mag. 60, 1923, p. 433, & Amer. Jour. Sci., Ser. 5, 11, 1926, p. 396.
*Adams, F. D., and Barlow, A. E., Mem. 6 Can. Geol. Surv., 1910, pp. 232-3, 268-9, 288, 307-8, 332; and Adams, F. D., and Barlow, A. E., Guide Book 2, XII Internat. Geol. Congr., Can. Geol. Surv., 1913, pp. 31, 36, 49, 54, 57, 72-3, 76, 77.
†Not for old Pre-Cambrian acidic rocks, which Daly regards as a differentiate, the basaltic substratum containing the more femic components of this early differentiation. (Personal communication.)

sess? In short, what has been the importance of the assimilation process in nature, so far as evidence is available?

The examples described and cited as illustrating the process of assimilation are so many that it is only practicable to divide them into groups and mention them in that way. A review of the literature suggests the following grouping:

1. Assimilation of siliceous rocks by basaltic or gabbroid magmas.
2. Assimilation of limestone.
3. Assimilation of shale.
4. Reaction between lavas and included rock fragments.
5. Assimilation of igneous rocks.

The first four of these groups will be reviewed. The fifth group will not be considered, partly because of the lack of evidence which would be accepted generally and partly because consideration of this group would enlarge the problem to a much greater breadth than is intended in the experimental program followed and recorded in succeeding pages.

ASSIMILATION OF SILICEOUS ROCKS BY BASALTIC OR GABBROID MAGMAS

The assimilation of siliceous rocks by gabbroid magmas has been described in a number of localities, best known of which are Pigeon Point, Lake Superior; Duluth laccolith; Sudbury sheet; and the Moyie sills.* In these and other similar cases the upper parts of the igneous bodies consist of rocks red in color, with the characters, at least partially, of granophyre, ~~and~~ passing somewhat rapidly into the gabbroid type in the one direction, and either passing insensibly into the surrounding siliceous rocks or enclosing blocks of siliceous rocks in various stages of solution.

This process has been extended by Daly, who would give basaltic magmas the power of dissolving large enough quantities of siliceous rocks beneath the continental masses to yield such large volumes of granite and granodiorite as are exposed along the cores of mountain ranges. The largest one is the

*Bayley, W. S., Bull. 108, U. S. G. S. 1893. Pigeon Point.
Coleman, A. P., Jour. Geol. 1907, p. 759. Sudbury sheet.
Daly, R. A., Mem. 38, Geol. Sur. Canada, 1912, p. 221, etc. Moyie sills.
Calkins, F. C., Bull. 384, U. S. G. S., 1909, p. 49-50. Montana.
Ransome, F. L., Prof. Pap. U. S. G. S. 12, 1903, p. 85. Globe, Arizona.
Collins, W. H., Mem. 95, Geol. Sur. Canada, 1917. Blind River, etc., Ontario.
Bowen, N. L., Jour. Geol. 1910, p. 658 (p. 673). Gowganda, Ont.
Tyrrell, G. W., Geol. Mag. 1909, p. 299 & 359. Scottish dikes of Carboniferous.
Mennell, F. P., Q. J. G. S. 66, 1910, p. 372.
Hatch & Corstorphine, Geol. of S. Africa, 1905, p. 172.
Bain, G. W., Jour. Geol. 33, 1925, p. 509. Sudbury.
Grout, F. F., Jour. Geol. 34, 1926, p. 538. Sudbury. Calculations.
Phemister, J. C., Jour. Geol. 33, 1925, p. 819.

Coast Range batholith of British Columbia, 1200 miles long, up to 100 miles wide and of depth unknown.

According to Daly's theoretical conception the roots of the batholiths should consist of gabbroid rocks. But the impossibility of the exposure of the roots of the batholiths leaves this matter undetermined.

ASSIMILATION OF LIMESTONE

A series of basic rocks forming a border phase to a granite massif at Haute Ariège in the French Pyrenees has been cited by Lacroix as being due to assimilation of limestone by the magma, with consequent basification.[11] The rock types found along the margin vary from the granite of the average magma through diorite to peridotite. The analyses given show a slight increase in CaO percentage but a much more marked increase of MgO percentage over that of the normal granitic type. It may be that dolomite, or even magnesite, may have been assimiliated in this case, or it is possible that some other process in addition to that of assimilation of limestone may have been operative in the production of the results described by Lacroix.

Lacroix has also ascribed to assimilation of limestone the changes in the igneous sequence of the Predazzo complex, from quartz-monzonite, through monzonite, olivine-monzonite to pyroxenite. Lacroix considers the intrusive to have advanced by solution of the limestone. But this mode of advance cannot account for the whole volume of rock intruded, or its composition would be very different from that which exists.

Lacroix records change of hypersthene-andesites of Santorin to labradorites (olivine-free basalts) by assimilation of limestone. It seems that assimilation of shale would be a more likely mode of derivation of basalt from hypersthene-andesite. (See No. 441, p. 81, and No. 452, p. 82.)

Lacroix also has pointed to leuco-tephrites with sanidine at Monte Somma which have become so much basified by the assimilation of limestone as to be no longer recognizable.[12]

A. Bergeat has described contact facies developed in the granodiorite at Concepcion del Oro, Zacatecas, Mexico, as due to assimilation of limestone. Contact metamorphism of limestone country rock is an accompanying feature. The limestone

[11]Lacroix, A., Comptes rendus. 123, 1896, p. 102.
Lacroix, A., Bull. Geol. Carte de la France, 1898, no. 64; and 1900, no. 71.
[12]Lacroix, A., Bull. Geol. Carte de la France, 1898, no. 64; and 1900, no. 71.

is very pure, free from alumina and magnesia, but it contains some silica. As much as 10 per cent of limestone has been absorbed in places. The rock has become a gabbro rich in lime and carrying diopside, garnet, titanite and plagioclase. Another variety occurs consisting of the same minerals but with garnet in great abundance.[13]

Bastin and Hill have described some ore-bearing dikes at the Evergreen Copper Mine in Colorado as showing evidence of having absorbed calcareous materials. Wollastonite is present in the dikes.[14]

The occurrence of okaite at St. Joseph du Lac, Quebec, has been ascribed, by me, to assimilation of Grenville limestone by a magma of unknown type (possibly peridotite). Field evidence and chemical evidence have been advanced in support of this thesis. The chemical analyses show especially well that this rock type and the associated ones are unusually rich in CaO. These considerations and further experimental studies have led me to the conclusion that rock magmas which yield melilite or monticellite upon crystallization have dissolved considerable amounts of limestone.[15]

Assimilation of limestone has been cited by Foye* as a possible major causative factor in the production of nepheline-bearing rocks. He has suggested that the reaction of solution is followed by volatilization or driving out of alkalies from the magma, along with alumina, silica, etc., with the enrichment of certain limited quantities of magma in the alkalies. Daly has supported this view and has attributed nepheline-syenite occurrences to the action of the processes outlined (solution of limestone accompanied by differentiation). He has drawn up a list of occurrences of nepheline-bearing rocks and has attempted to show that they are closely associated with limestones.†

It is to be noted that analyses of nepheline-bearing rocks fail to show enrichment in CaO and that therefore the acceptance of the possibility of the production of nepheline-bearing types in the manner suggested should be suspended until such time as reasonable proof of a sublimation process subsequent to the assimilation of limestone can be shown actually to have been at work in the production of nepheline-bearing rocks.

[13]Bergeat, A., Neues Jahrb. B.B. 28, 1909, p. 421 (p. 455).
[14]Bastin and Hill, Econ. Geol. 6, 1911, p. 465.
[15]Stansfield, J., Geol. Mag. 60, 1923, p. 433.
Stansfield, J., Amer. Jour. Sci., Ser. 5, 11, 1926, p. 396.
*Foye, W. G., Amer. Jour. Sci., Ser. 4, 40, 1915, p. 434.
†Daly, R. A., Bull. G. S. A., 21, 1910, p. 89.

An examination and comparison of rock analyses suggests that nepheline and leucite-bearing rocks are richer in alumina than the more normal rock types, in addition to being richer in Na or K. If such rocks have been derived from magmas of normal types enrichment in alumina and enrichment in alkalies both have to be explained. It is possible that enrichment in alumina may be due to assimilation of clay or shale.

The presence of certain lime-rich silicates in marginal or restricted phases of some igneous rocks may be taken or has been taken as indicative of assimilation of a certain amount of limestone. Such minerals are lime-bearing garnets, sphene, and more rarely wollastonite, diopside, tremolite, vesuvianite, apatite, and epidote.

ASSIMILATION OF SHALE

A number of cases have been described illustrating changes in igneous rocks as a result of assimilation of shale by the magmas. Among the plutonic rocks gabbros and norites are the rock types involved, and among the effusive rocks the andesites illustrate the reaction.

Watt has described a norite intrusion in the Huntly district of Aberdeenshire, Scotland, which has absorbed shale from its surroundings, one variety formed as a result of this reaction being a cordierite-norite.[18]

Winchell has described a cordierite-norite from Snowbank lake, Minnesota, which consists of cordierite, bronzite, biotite and quartz, with staurolite, spinel, epidote and plagioclase as accessories. This variety of norite is due to assimilation of aluminous sediments by a gabbro magma, according to Winchell. It occurs as a border phase of the main gabbro intrusion.[19]

Read has mentioned the occurrence of cordierite in granite as resulting from the assimilation of sediments, and the same author has described the Arnage norite of the Peterhead region of Scotland which is "contaminated" by assimilation of andalusite schist from the country rock. Quartz-gabbro, cordierite-gabbro, norite, and diorite are the main rock types developed in the intrusive sheets. Streaks of granite occur in the cordierite-gabbro. The cordierite-gabbro contains cordierite, spinel and garnet through a zone some hundreds of feet thick.[20]

[18]Watt, W. R., Q. J. G. S. 70, 1914, p. 266.
[19]Winchell, A. N., Amer. Geol. 26, 1900, p. 294.
[20]Read, H. H., Mem. Geol. Sur. Grt. Britain, 1912, expl. sheet 338, p. 38.
Read, H. H., Q. J. G. S. 79, 1923, p. 446.

The gabbro du Pallet in the district of the lower Loire, France, has been described by Lacroix. The country is one of low relief with poor exposures. The gabbro cuts mica schists. The normal type of the rock is a gabbro, generally with olivine. Toward the periphery it changes into a norite with quartz, cordierite and garnet. This change is due to assimilation of the schists by the gabbro magma. The contaminated magma is rich in alumina and poor in lime, so giving chance for the development of cordierite. Hypersthene is present in the cordierite-bearing variety; spinel is abundant; quartz is present in some varieties; staurolite occurs in others; graphite is present; and sillimanite needles are present in some of the cordierite.

Inclusions in the rocks illustrate the various stages in the assimilation of the schists which have been torn off from the surrounding country rock.[21]

Rogers has described the Cortlandt series of New York state as a series of special types: pyroxenite—**norite**—diorite—granite—which have absorbed aluminous sediments. The excess of alumina has partly re-crystallized as corundum or sillimanite. It is suggested that the alumina may have been derived, perhaps, from the Hudson river slates.

Syenite and sodalite-syenite also form members of the series, at the edges. (See map, loc. cit.) Inclusions of schist occur in the igneous rocks, as do also some of limestone and gneiss.[22]

Brammall and Harwood have described part of the Dartmoor granite of south-western England under the caption "giant granite". Parts of this rock contain the following minerals as accessories: almandine garnet, cordierite, andalusite, sillimanite, corundum and spinel. Their presence has been ascribed to assimilation of country rock, much of which is slate.[23]

Hall and du Toit have described the development of new types from norite by the assimilation of quartzite and shale. Accession of a granophyric character is due to the assimilation of quartzite and the development of cordierite-norite (? containing some quartz and very little plagioclase) is due to reaction between norite and shaly matter.[24]

[21]Lacroix, A., Gabbro du Pallet. Bull. Carte Geol. de la France, no. 67, 1898-9, 10, p. 341.
Lacroix, A., Comptes rendus, 109, 1887, p. 870.
Lacroix, A., Bull. Soc. Miner, France. 12, 1889, p. 238.
[22]Rogers, G. S., Ann. N. Y. Acad. Sci. 21, 1911, p. 81.
[23]Brammall and Harwood, Min. Mag. 20, 1923, pp. 39-53.
[24]Hall, A. L. and du Toit, A. L., Trans. Geol. Soc. South Africa, 26, 1923, pp. 82-85.

Assimilation of Shale

A. Bergeat has described in great detail the cordierite-andesite of Lipari. The rock is an andesite carrying biotite, augite and hypersthene, and with younger crystals and grains of cordierite which have separated from the magma. There are also numerous inclusions with andalusite, sillimanite, cordierite, biotite, orthoclase and spinel. Garnet is also present in the andesite.

The andesite is very rich in glass and has strong flow structure. It has porphyritic and resorbed biotite, augite, hypersthene, plagioclase, and very much original cordierite. The latter partly has good crystal form and is partly resorbed, and may have inclusions within it consisting of glass, spinel, sillimanite, zircon, biotite and pyroxene.

Among the inclusions in the rock, which are partly rounded are quartzite, gneiss, and altered slate. The latter inclusions consist chiefly of cordierite, diallage, and spinel; augite is also present, but not so constantly, sillimanite being more important. Andalusite blocks are changed on the outsides to sillimanite, which by reaction with the magma has yielded cordierite, spinel and orthoclase, which have separated from the magma.

Andalusite, garnet, zircon, quartz and part of the biotite and apatite are older and were constituents of the inclusions before the chemical reaction with the magma began, while sillimanite, cordierite, most of the biotite, orthoclase, spinel, corundum and rutile are newly formed as a result of this reaction. Plagioclase is said to have been introduced into the inclusions from the magma.

Corroded red grains of garnet in the andesite are older foreign inclusions, or remnants of inclusions.

Bergeat[25] thinks that the magma has absorbed foreign materials at depth and that the whole rock shows crystallization of this changed magma, all of the products having been formed in this way.

After reading the description I have come to the conclusion that the inclusions are altered foreign matter which has been incorporated in the lava, and that the reaction has gone on in the lava, and not entirely before eruption; and that a considerable part of the cordierite is a product of direct crystallization from the "contaminated" lava. The amount of material assimilated by the lava and incorporated in the

[25]Bergeat, A., Neues Jahrb. B.B. 30, 1910, p. 575.

melt must have been very considerable to yield such an important amount of "primary" cordierite.

Similar inclusions occur in lavas of the Eifel, Cabo di Gata, Asamayama, Mont Dore, Siebenburgen, Santorin, Euganean, Monte Amiata, Campiglia Marritima, Murcia.[26] Primary cordierite is recorded from andesites of Hoyazo (Osann), Asamayama (Hussak), and from the Laacher trachyte (Laspeyres).

Molengraaff[27] has described a rock found in the vicinity of Harrismith, Orange Free State, South Africa, said to be a dike and consisting of cordierite, spinel, augite and glass. It is said to have been produced by the melting of foreign material by a magma and subsequent partial crystallization of the melt. It is suggested the parent material may have been of the nature of melaphyre or diabase. The details of the exact location and relations of the rock to its surroundings were not well known at the time of the description. Further study of these points would seem to be desirable.

OTHER EXAMPLES OF ASSIMILATION

Lacroix[28] has mentioned that the hornblende-andesites of Acrotari have been changed to perlites as a result of the assimilation of granite and cordierite gneiss.

Miller[29] has stated that certain stocks of gabbro in the Adirondack Mountains show evidence of assimilation of basic materials yielding the dark constituents of the gabbros. In other cases assimilation of acid materials has yielded syenite (in some places at the contact). Inclusions are seen in some places, but details of the process are not visible in all stages. Granite, gneiss or syenite have been absorbed.

GENERAL STATEMENTS ON ASSIMILATION

A number of authors have expressed definite views upon the topic of assimilation at different times. Some of the more striking of these will be mentioned.

Michel-Lévy[30] has made the general statement that magmas may attack their containing walls and be profoundly modified. An example of granite changing to diorite at its margins is cited by him in illustration near Puy de Dome, in the

[26]Bergeat, loc. cit., p. 612.
[27]Molengraaff, G. A. F., Neues Jahrb. I. 1894, p. 79.
[28]Lacroix, A., Bull. Carte Geol. de la France, 1898, no. 64.
Lacroix, A., Bull. Carte Geol. de la France, 1900, no. 71.
[29]Miller, W. J., Jour. Geol. 21, 1913, p. 176.
[30]Michel-Lévy, A., Bull. Soc. Geol. France, 3, 24, 1896, p. 123.

Central Plateau of France. Other evidence of a similar nature is mentioned in Brittany, Pyrenees, Saxony, Finland, etc. (Brogger has denied this effect for the Christiania district.)

Loewinson-Lessing[31] has supposed that there are two original or primordial earth magmas (granite and gabbro) from which all others are derived by:

1. Fusion or re-fusion,
2. Assimilation, or
3. Differentiation.

Differentiation is induced by assimilation of sedimentary or igneous matter. The same author thinks that there are no primordial rocks exposed, but that there has been fusion and re-fusion of the basement. Other authors quoted by him regarding fusion of the deeper part of the earth's crust are: Sederholm, Lukaschewitz, Branca, Haug, Suess, Dutton, Schwartz, Delesse and Sterry-Hunt.

Sederholm* has described cases of injection of granitic material into ancient schists of Finland resulting in more or less assimilation of the country rock and interchange of material between it and the magma. The whole has been rendered gneissoid by movement of the pasty mass or by the effect of pressure, giving rise to a "migmatite" or composite gneiss.

Collins[32] has described a granodiorite intrusion in the Onaping map area of Ontario, with petrographical varieties caused chiefly by assimilation. Cubic miles of Pre-Huronian basic schists have been assimilated. Collins states that magmatic assimilation has long been accepted and that quantitative conceptions are needed. He raises the question how much assimilation has there been? According to Collins the part which has disappeared on intrusion has actually been assimilated, changing granite to hornblende-granite and diorite.

Washington[33] has suggested that there is an indication of a general earth magma of the nature of tonalose which has differentiated in every possible direction, yielding the rocks as found. In the production of the various rock types a possible effect of assimilation is mentioned.

Daly[34] has supposed that there is a uniform earth magma of a basaltic nature at some depth beneath the earth's surface

[31]Loewinson-Lessing, F., Geol. Mag. 8, 1911, p. 289.
*Sederholm, J. J. Bull. Geol. Comm. Finlande 23, 1907, p. 110.
[32]Collins, W. H., Mem. 95, Geol. Sur. Canada, 1917.
[33]Washington, H. S., Comptes rendus, Internat. Geol. Congr., Toronto, 1913, p. 235, etc.
[34]Daly, R. A., Igneous Rocks and Their Origin. 1914.

and that all rock types as exposed at the earth's surface have been produced by processes including assimilation and differentiation. Daly has ascribed far greater effectiveness to the processes of assimilation than any other author. The granite batholiths are for him the products of assimilation of siliceous materials by basaltic magma. The nepheline syenites for him have been produced as a result of assimilation of limestone by magmas already far advanced along the way of development from the original basaltic magma.* The detailed statement of the full application of assimilation by Daly is given in his work "Igneous Rocks and their Origin". It is to be noted that the assimilation hypothesis as utilized by Daly will need a considerable amount of revision in the light of experimental results involving actual tests of the results of assimilation of certain definite rock materials by certain definite magmatic types.

Concerning the question of granite batholiths and their origin Professor Daly writes me as follows:

"I have never held that the Pre-Cambrian granites should be explained as the product of assimilation by basaltic magma; rather they seem to be primitive differentiates of the earth's body, the basaltic sub-stratum containing the more femic components of this early differentiation. While formerly I found satisfaction in the hypothesis that Post-Cambrian granites are differentiates from syntectics, I am now suggesting in print that these granites (in the form of very large batholiths) may be due to mere melting of the old Pre-Cambrian granite after large masses of the latter have sunk to considerable depths in the glassy basaltic sub-stratum."

The phase of the assimilation problem mentioned by Daly in his "Igneous rocks and their origin" as abyssal assimilation is not touched upon in the following pages because the aim has been to investigate the amount of assimilation rather than the location of the process. As the answer to this first question is not yet completely elucidated I consider it premature for me to offer any discussion of the question of the locus of assimilation processes.

Foye[35] has supposed that nepheline-syenites are due to gaseous transfer after the solution of limestone by granite.

Bowen[36] has concluded from a theoretical discussion of the topic that solution of sediments in super-heated magmas is

*Daly, R. A., Bull. Geol. Soc. Amer. 21, 1910, p. 89.
[35]Foye, W. G., Amer. Jour. Sci. 40, 1913, p. 413.
[36]Bowen, N. L., Jour. Geol. 1922, p. 513.

not a factor of importance in petrogenesis. Yet at another place he admits that magmas may incorporate considerable amounts of foreign materials.

Both Bowen and Daly[37] have concluded that the anorthosites are produced without assimilation as a result of processes of differentiation solely. Mawdsley's[38] examination of the St. Urbain (Quebec) anorthosites leads him to the conclusion that the problem of the anorthosites is not yet fully elucidated. My view is that anorthosites may possibly illustrate the completion of the process of assimilation of shale or its equivalent. In support of this idea attention may be called to the frequent abundance of garnet in the anorthosites and the occasional presence of sapphirine;* both these minerals are rich in alumina.

Another reaction, opposite in character to assimilation—that of abstraction from a magma of some of its constituents with the formation of different rock types—is illustrated locally at one or two places. Gordon[39] has described the desilication of pegmatites by country rock (especially serpentine) producing therefrom albitites, or even albite + corundum rock (plumasite). The effect of silicification of the wall rock with the formation of biotite and talc can be noticed for a distance of 10 feet from the dikes.

Du Toit[40] has described very similar results in South Africa, dikes in Natal being of the nature of pegmatite where they cut granulite, but becoming plumasite (oligoclase + corundum) where the dike cuts serpentine.

[37]Bowen, N. L., Jour. Geol. 25, 1917, p. 209.
Daly, R. A., Igneous Rocks and their Origin, p. 241, p. 321, etc.
[38]Mawdsley, J. B. Geol. Surv. Canada, Mem. 152. 1927, pp. 31-33.
*Warren, C. H., Amer. Jour. Sci., Ser. 4, 33, 1912, p. 263.
[39]Gordon, S. C., Proc. Acad. Sci. Philadelphia, 73, 1921, p. 169.
[40]Du Toit, A. L., Trans. Geol. Soc. South Africa, 21, 1919, pp. 53-73.

CHAPTER II

REACTIONS BETWEEN MAGMAS AND FOREIGN INCLUSIONS

In addition to the examples discussed above, where a definite effect upon the composition of the magma can be shown to have resulted after assimilation of foreign materials from the country rock, there is another large group of phenomena of slightly less importance but which have a bearing upon the same general question. In many igneous rocks there are inclusions of foreign materials and many of these inclusions show profound changes, including re-crystallization and changes of chemical composition due to the action of the magmas, but there is no apparent parallel effect upon the magmas. The amounts of foreign materials incorporated by the magmas appear to have been too small in these cases to have caused any important chemical or mineralogical changes in the magma or rock.

There often occur in plutonic and hypabyssal rocks fragments of the country rocks, torn off from the reservoir walls or from the basement rocks beneath. These inclusions may be of any kind of rock and often show angularity of outline. The effect of the heat of the magma may be shown by metamorphism—re-crystallization of limestone to marble, sandstone to quartzite, shale to andalusite-, or sillimanite-hornstone, etc. Or there may be indicated addition of materials to the inclusions from the magmas by the development of new minerals in the inclusions, which have derived some of their constituents from the magma, e.g., garnet, vesuvianite, sphene, etc., in limestone; spinel, feldspars and cordierite in shales.

Doubtless these latter changes involve some amount of exchange of materials by which something from the inclusions is added to the magma. But from the appearance of uniformity in the igneous rock such an alteration of composition of the magma escapes detection. The writer considers that such a change undoubtedly takes place but is not detectable in very many cases for two important reasons:

1. The molecular mobility of molten magmas is so great that uniformity of composition is rapidly established and easily maintained by a very active diffusion.

The viscosity which prohibits diffusion appears as the freezing-point of the last mineral to crystallize is approached.

2. The amounts of foreign materials dissolved in many observable cases were probably too small to cause any notable change of composition in the magmas.

Fate of Inclusions—The mechanics of igneous intrusion involve the displacement of large volumes of solid rocks from their former positions in the earth's crust. These are thought to have been either melted (fluxed) by the magma during its advance and in that way to have become incorporated in the magma, or to have been stoped away from the covering of the advancing magma and to have sunk through it. (Daly). Ordinarily the fate of these sunken blocks is left undecided, partly because they are never seen in their sunken positions in actual exposures, and partly because the mere exchange of position of a liquid magma and large loose blocks which come to rest in the lower part of the liquid, perhaps by an establishment of density equilibrium is a possibility which cannot be shown to be a definite and essential part of the mechanics of igneous intrusion.

I hold the view that blocks of rock do not sink very far in fluid magmas. I consider that they will become melted and incorporated in the magma before they have sunk for a distance of one mile. Experimental studies have convinced me of the ease of such incorporation of foreign materials.

There are in many igneous masses inclusions of foreign materials of angular outlines which are therefore considered to be materials broken off from the country rock. But in many cases the included fragments become rounded (e.g., rounded fragments of Pre-Cambrian gneisses seen as inclusions in the nepheline-syenite of Montreal, at Outremont reservoir). Oftentimes difference in mineral composition between included fragments and the igneous rock are not marked and such rounded fragments are often considered as "basic secretions". Doubtless some of them are truly such "basic secretions", but the author considers that many of them are certainly rounded inclusions in process of incorporation in the magma.

Bowen's highly instructive and entertaining discussion of the "behavior of inclusions in magmas" indicates how such inclusions may be expected to be "made over" and gradually changed in mineralogical composition (and therefore also in chemical composition) so as to become more and more like the magma enclosing it, until they eventually become incorporated in it, i.e., become identical with it, rather than become dissolved in it. Such a process must involve transfer of material from the magma to the inclusion and vice versa. This addition to the magma must have its effect in changing the composition thereof. But this change may not be noticeable for the reasons given above.

Bowen, while admitting the possibility of such incorporation of foreign materials in magmas considers that it can only have gone on to a limited extent in nature. I consider that considerable amounts of foreign materials can be incorporated in magmas under natural conditions, but judging from experimental results I conclude that such a process is limited. So far as present results go they seem to indicate that magmas do not often incorporate in themselves as much as one third of their volume of foreign materials and retain the newly added materials in a location close to its original position. If such or even greater amounts of foreign materials are actually incorporated in the magmas they must be rapidly distributed through the magmas by the process of diffusion and so removed from their original positions. Thus the assimilation of one-third of its volume of limestone or shale by any igneous rock of the earth's surface will yield a crystalline product unlike any igneous rocks which are known in any quantity.

Yet the rocks whose places have been taken by the intruded magma have been removed. I would prefer to consider them as incorporated in the magma rather than sunk out of sight. The absence of the specialized types due to assimilation of large proportions of limestone or shale may be explicable:

1. By rapid production of uniformity in the magma by diffusion (especially active under magmatic conditions).

2. The incorporation of large volumes of foreign rock materials, if it takes place would involve the production of an average melt because any large volume of rocks may be re-

garded as including all types in such proportions as to yield an average composition. (Certain dominant regional features may still be recognizable in such averages.)

In many large intrusive bodies there are abundant inclusions (or are they "basic secretions"?), but these constitute only a small portion of the whole volume. Thus there are a great many such "changed inclusions" (or "basic secretions"?) in the Boulder batholith of Montana. An estimate of their volume in places where they are most numerous gives it less than two per cent.

We are forced to conclude that no acceptable account of the fate of the rocks displaced by batholithic intrusions is available. Daly's suggestive theory of their incorporation in basaltic magma with resulting increasing acidity of the upper parts still occupies the more speculative part of the field. But we cannot yet regard it as approaching such establishment as is required for general acceptance.*

With this brief survey of the problem we may now proceed to an examination of evidence of reactions between lavas or magmas and foreign inclusions, which show change of composition of the inclusion, while the complementary change in the magma is so insignificant that it passes unnoticed. The chief evidence along these lines is that collected by Lacroix in his "Enclaves des roches volcaniques" (1893), and in Comptes rendus, 160, 1905, pp. 971-975, by Brauns and Uhlig in Neues Jahrbuch, B.B. 34, 1912, p. 85, and Neues Jahrbuch, B.B. 35, 1913, p. 119 and p. 723; by Harker in the chapter on hybrid rocks in his "Natural History of Igneous Rocks", 1909; and by Thomas in his paper on the diabase sills of the I. of Mull, Q. J. G. S. 78, 1922, p. 227. This evidence has been collected from the various sources mentioned and arranged below under the following heads:

1. Calcareous inclusions,
2. Shaly inclusions,
3. Siliceous inclusions,
4. Inclusions of gneisses and schists,
5. Inclusions of igneous materials.

*The acceptance of the conclusion that magmas have not assimilated as much as 25 per cent of their volumes of foreign rock materials relegates magmatic stoping to the position of a less important major factor of batholithic intrusion. The batholiths thus come to be regarded as occupying large fault spaces sealed as they form during the process of continental sliding as outlined by Daly.** The extensive continental sliding suggested by Wegener is not necessary for the explanation of the emplacement of the batholiths.

**Daly, R. A., Proc. Amer. Phil. Soc., 64, 1925, pp. 283-307.

GENERAL STATEMENT

It is found that an inclusion is more rapidly attacked and destroyed the greater the dis-similarity between its composition and that of the magma. The closer the composition of the two the more nearly will the inclusion be in equilibrium with the magma and the greater are its chances for preservation.

CALCAREOUS INCLUSIONS

Calcareous inclusions in plutonic, hypabyssal or volcanic rocks show effects which are altogether similar to those shown by limestones in contact metamorphic zones. The inclusions in the majority of cases have received addition of silica and in some cases also alumina, or iron, or magnesia, or titanium, or phosphorus, or fluorine. They (inclusions) may have suffered marmorosis or may have had new minerals produced in them, such as diopside, tremolite, forsterite, monticellite, vesuvianite, epidote, plagioclase, scapolite, melilite (humboldtilite), grossularite (or other garnets), sphene, apatite, humite. or chondrodite. Locally, as at Monte Somma, addition of alkalies may have given rise to the development of leucite, nepheline, alkali-feldspars, mica, sanidine or sodalite. At Kaiserstuhl zeolites have been formed.

Sometimes a banded structure is developed as in altered limestone blocks at Monte Somma in which alternating concentric bands of calcite and lime-rich silicates recall the structures of Eozoon canadense and rhythmic precipitates.

SHALY INCLUSIONS

According to **Lacroix** shaly inclusions in basalts are completely fused or fused round the margins. Cordierite and spinel develop from the glass. Pyroxene or anorthite may be present, in addition to cordierite. If alkalies are present feldspar forms instead of cordierite.

In trachytic rocks shaly fragments are sometimes fused at the edges, (Laacher See) and pyroxene microlites develop from the glass.

Santorin and Caucasus andesites have wollastonite round the shale as a new development.

Thomas finds that in the diabase sills of the southern part of the I. of Mull, the shaly inclusions are the largest and most numerous. Xenoliths occur throughout the sill, but chiefly near its edges. Near the edges they are of sandstone, up to

6″ in diameter, and in the central part they are of shale and sandstone up to 2 feet in diameter. The shale is a very pure, highly aluminous fire-clay, very low in Ca, Mg and Fe, with alkalies more prominent, especially soda. The shale may be fused to glass—buchite—in which sillimanite may have formed, with sapphire in the still unmelted part.

Three types of products are formed:

1. Sillimanite-buchites, with or without cordierite.
2. Anorthite-corundum-spinel aggregates (the most common). Little glass is present.
3. Cordierite-spinel-corundum aggregates.

The same xenolith may be more crystalline outside than inside. Its central part may have an outer zone of 2 with a nucleus of 1. The outer zone may be the richest in spinel and there may be a greater proportion of corundum in the inner part of the outer zone. The contact with the igneous material is sharp and the latter shows no effect of assimilation. The earlier formed plagioclase is anorthite and is sometimes connected with resorption of sillimanite. Sometimes there are outer zones of labradorite-oligoclase around the plagioclase crystals.

Cordierite is formed because of addition of MgO by diffusion from the magma. It forms partly at the expense of sillimanite. Cordierite forms with sufficiency of silica, spinel with insufficiency of silica.

Spinel is green and constantly associated with anorthite indicating simultaneous formation. The spinel may not have crystal boundaries. A eutectic relation is suggested. Thomas suggests that spinel is formed by solution of sillimanite. He suggests also that anorthite may break down to yield spinel.

Transfusion of CaO from magma to inclusion gives rise to anorthite,

Transfusion of FeO & MgO from magma to inclusion gives rise to spinel,

Transfusion of FeO, MgO and of SiO_2 from magma to inclusion gives rise to cordierite.

MgO diffuses more slowly than CaO, so spinels crowd the outer zones. Later action of the modified magma gives rise to cordierite, spinel, corundum and acid plagioclase.

Conditions of action—Certain intrusions consist almost entirely of xenoliths. Yet there is no evidence of modification of the magma by assimilation.* Metamorphism was deep-

*Thomas H. H., loc. cit.

seated and due to the action of the magma on the walls of its basin. Gas was prevented from escaping until pressure was relieved, so some of the inclusions are now vesicular. The glass of the sillimanite-buchites melts at 1250°C, so the temperature was higher than that. The presence of tridymite and absence of cristobalite indicates a lower temperature than 1470°C. The metamorphism was completed at the time of the intrusion, the temperature being near 1250° C at the time of intrusion.

SILICEOUS INCLUSIONS

Lacroix finds that the effects are similar no matter what the enclosing magma or rock is. The quartz is etched and fractured and often partly melted. Secondary gas inclusions have been formed. Often there is a rim of augite round the inclusions. Magnetite and spinel often accompany the augite, or rhombic pyroxene develops more readily in inclusions in acid than in basic lavas. Plagioclase forms sometimes from the glass or between the needles of pyroxene. (A fused quartzose inclusion is called "buchite".)

Tridymite is found rarely in the quartz glass (Eifel). Newly formed quartz and cristobalite occur at Laacher See. Quartz and olivine may be present in the same basalt, the former being referred to inclusion. Spinel, pyroxene and cordierite may be formed in basalt glass. Nepheline is recorded round quartz in a basalt without nepheline. The inclusions may be fused to bottle glass.

In trachytoid rocks quartz breaks and liquid inclusions empty themselves and sometimes develop glassy inclusions. If small the inclusion is destroyed and its place is taken by glass with augite crystallites as in the quartz inclusions of basalts, even in rocks poor in augite microlites.

Tridymite is often developed from larger quartzose inclusions.

According to **Thomas** the siliceous inclusions are smaller and fewer than those of shale in the diabases of Mull. Action on the sandstone has produced fringes of tridymite round quartz grains. The tridymite fringes have reverted to quartz. Selective fusion of feldspar is seen. The inclusions are partly melted to glass.

GNEISS AND SCHIST INCLUSIONS

According to **Lacroix** hornblende-andesites of Acrotari are changed to perlites by assimilation of granite and cordierite-gneiss.

Gneiss and Schist Inclusions

Basalts may have inclusions of granulite and gneiss in some localities, sometimes carrying also cordierite, sillimanite, garnet, zircon, etc. Some inclusions have zircon, corundum and diaspore. The changes undergone by the inclusions vary in intensity. Sometimes complete melting has taken place, sometimes partial melting. Most of the inclusions are friable. This is probably due to loss of substance.

Feldspars become broken by intensification of cleavages. They become charged with gas or glass inclusions. Basalt glass may penetrate the outer part of the inclusion and may develop there spinel, hypersthene, sometimes labradorite, with or without basalt glass. (Hypersthene is not characteristic of the main part of the basalts.)

In the compact lavas the inclusions are completely dissolved or leave only remnants of zircon, diaspore, corundum, quartz or feldspar. Quartz grains are often surrounded by radial growths of augite, said to be due to seeding of the solution by foreign matter.

In andesitic and trachytic lavas and tuffs inclusions similar to the above may occur. Feldspars are affected as described above, sometimes they are enlarged. Tridymite is nearly constant, so is spinel and also hypersthene, the two latter within the inclusion itself. Sometimes there is a rim of augite round quartz.

Quartzo-feldspathic inclusions are the most numerous studied by Lacroix. Sometimes they carry minerals not known in the surroundings, e.g., diaspore, corundum, zircon, cordierite. Some of these may be due to the action of heat, others were doubtless originally present in the inclusions. The inclusions of this group are more melted than other types, but also are more glassy, showing a lesser tendency to crystallization.

Biotite and garnet are among the first minerals to melt. The more infusible ones remain.

Biotite yields yellow spinels, often also hypersthene, sometimes sillimanite or cordierite.

Garnet yields hypersthene and green spinel.

Sometimes spherulitic feldspars form. (cf. rhyolite).

Feldspars of two generations may form, and are sometimes variolitic.

Augite forms at the contact between the inclusion and the lava.

Mixture with the lava results in disappearance of augite and olivine and in the formation of more acid feldspars.

Cordierite with spinel sometimes forms inside the inclusions.

Around some inclusions a change is recognizable, e.g., a nephelinite becoming charged with feldspars, a basalt becoming andesitic.

Cavities between lavas and inclusions may have crystals of quartz, feldspar and pyroxene.

Feldspathic (non-quartzose) inclusions—The origin of the feldspathic inclusions is not always easy to determine. They often approach the enclosing rock in composition. The basalts frequently enclose inclusions consisting of plagioclase and hypersthene or augite. Some cases can be definitely ruled out of the consanguinous group, because they show transitions to the other gneissic types.

Sometimes the inclusions are not changed, sometimes they are changed and then always in the same way. Gaseous, glassy or liquid inclusions appear abundantly in all the minerals or in some of them.

Hypersthene and then augite begin to melt at the periphery or along cleavages; microlitic augite and spinel form from them along with glass. Olivine is sometimes formed.

Mica and garnet are changed to a mixture of spinel, hypersthene and brown glass.

In a later stage plagioclase melts and re-crystallizes.

Quartzo-feldspathic inclusions in trachytes and acid andesites—The origin of the inclusions may be difficult to decipher. It is thought that a lower temperature has affected these than the inclusions in basalts. The action of mineralizers seems to have been strong.

One striking fact is the abundance of andalusite and cordierite in the inclusions, where these minerals are unknown in the surrounding rocks. It is thought that they are concentrated by their resistance to the action of heat.

In pegmatite inclusions in trachyte quartz is melted, feldspar has salic feldspar placed on it, or it is re-crystallized as small crystals or radial aggregates. Biotite changes to green spinel, magnetite and a new biotite, surrounded by new feldspar. Sometimes hypersthene and rarely augite develop from biotite.

Two general types of modification are noted:

1. Gradual corrosion of feldspar, which is replaced by a sodic orthoclase of the same orientation. Quartz is more or less completely resorbed. Cordierite and andalusite have new inclusions of glass or spinel. The original structure of the rock is preserved. Sometimes a smaller volume is occupied so that cavities covered with new crystals result. Tridymite, orthoclase, hypersthene, oligoclase, etc., are found in these.

2. New feldspars are granular without relation to the original ones. Schistosity is preserved. Spinel and magnetite and also new biotite develop throughout. Andalusite, kyanite, and sillimanite are changed to spinel and corundum. Also there is formed new sillimanite which is difficult to distinguish from the old. Rutile needles form, probably at the expense of biotite. The abundance of new hypersthene and the rarity of augite in the inclusions may be specially noted, and also the development of hypersthene in the volcanic rock, which may otherwise be free from it.

Quartzo-feldspathic inclusions in haüyne-trachytes seem to indicate the action of a higher temperature than in trachytes as just mentioned. The action of mineralizers is feeble. (Perhaps this is because of shorter time of reaction.) In granite biotite changes to spinel, magnetite and new biotite, sometimes to hypersthene.

Cordierite-gneiss remains unchanged or is changed only a little. Cordierite, garnet and andalusite remain in the glass, alone or accompanied by hypersthene, biotite and feldspar. Lacroix thinks that the cordierite is not a new formation.

In phonolites quartzo-feldspathic inclusions have suffered fusion of feldspar and re-crystallization of sodic orthoclase; mica changes to spinel and sometimes to sillimanite. Aegirine or aegirine-augite is frequent in these inclusions, especially where the magma has penetrated.

Glass is often changed to zeolites.

In haüyne-trachytes—Among granitic inclusions the commonest type has cordierite and garnet. It is changed next to the igneous material to a brownish glass surrounding fragments of the minerals. Minute crystals of pyroxene, spinel and feldspars occur in the glass.

Biotite alone is changed at lower temperatures. Brown glass, spinel and magnetite are formed from it. Hypersthene,

deep green and strongly pleochroic, forms from it, sometimes completely replacing it.

Metamorphic schists often remain intact. Fusion of their edges occurs sometimes, with development of feldspathic veins parallel to the schistosity. Green pyroxene in needles replaces older constituents.

Some inclusions containing cordierite show fusion of the minerals with change of biotite to hypersthene and in one case of cordierite to corundum.

In phonolites and leucitophyres corrosion of feldspar occurs, with later growth on the same. Biotite changes to spinel. New feldspar and aegirine crystals develop. Glass is often zeolitized. Sillimanite in some cases seems to be largely original, with some change to violet spinel, the other spinels being green. Corundum sometimes appears.

In one case sillimanite seems to be formed from biotite, and in another case micro-pegmatite has developed along feldspar cleavages.

Silicate inclusions free from quartz and not consanguinous with the volcanic rock. Diabases are strongly fretted by hypersthene-andesite of Santorin and Krakatoa. Pyroxene is uralitized; epidote and quartz are abundant, the latter often with orthoclase as micro-pegmatite.

Hornblende in more basic inclusions is changed to augite and magnetite at Aden.

Augite is the dominant pyroxene in these inclusions, while hypersthene is in the more quartzose inclusions.

Two types are treated by Lacroix:

1. Ancient granular rocks.
2. Volcanic rocks.

INCLUSIONS AT LAACHER SEE

R. Brauns[2] had already shown (1911) that inclusions thrown out at Laacher See show a series from slate through cordierite rock to sanidinite, indicating clearly a transference of material from the magma into the inclusion. In the place of andalusite pseudomorphs of alkali-feldspar and corundum, and in the place of FeAl garnet pseudomorphs of alkali-feldspar and magnetite indicate transfer of materials.

Remains of garnet, similar to that of the crystalline schists of the region indicate its source.

[2]Neues Jahrb. B.B. 34, 1912, p. 85.

The bombs studied include:

4 bombs with kyanite.

31 bombs with staurolite (including the 4 above).

Two-thirds of these have andalusite, sometimes in two generations. One-third have red garnet, partly resorbed. Also present are sillimanite, alkali-feldspar, cordierite, corundum and spinel.

The series under special investigation are garnet-bearing bombs.

Garnet-bearing bombs are abundant. Bombs with red garnet show all transitions to sanidinites, with all colors and appearances. Bombs with the following have been studied:

Garnet with kyanite	1
Garnet with staurolite	10
Garnet-sillimanite rock	12
Garnet-cordierite rock	60
Garnet in sanidinite	12
Garnet in eclogite	10
Garnet-mica-schist and garnet-phyllite	40

Many more of these could be studied. The eclogite group is very small, however.

More than 100 bombs carry andalusite in fine crystals, with change to corundum or spinel and alkali-feldspar. Many carry sillimanite.

Andalusite is still visible in sanidinites.

Corundum forms from andalusite, sillimanite, staurolite and garnet.

A few scapolite-bearing bombs also occur. Epidote and enstatite occur in a few.

References are given on p. 92 to garnet separated from magmas. The garnets of these schists were present before alteration by the magma.

The bombs examined are poor in lime, rich in alumina. Three groups are recognizable among the garnet rocks:

1. Mica schists.
2. Garnet-cordierite rocks.
3. Sanidinite.

PYRO-METAMORPHISM

Pyro-metamorphism is a new term suggested by Brauns for changes taking place at temperatures lower than the melting points of the minerals, without the action of pressure, but by the action of gas or vapor. There must also be an abstraction of material.

Character of changes—The changes were due to addition of alkalies and abstraction of MgO and FeO. Quartz was removed first then andalusite. Sillimanite went next, garnet last, when alkalization was nearing completion. Micas helped to form cordierite.

The changes took place at depth before eruption, according to Brauns. Alkalies and especially soda have been responsible, but in what combination is unknown.

Friedlander says magmas approach the throat of the volcano as gases and then become white-glowing liquids by condensation, by lowering of pressure and temperature.

Iddings, Sapper, Tschermak, Brun and others have stressed the importance of gases in connection with eruptions.

IGNEOUS INCLUSIONS

Included under this heading would be consanguinous inclusions, whether of closely identical or of distinctly different acidity, as well as rocks of unrelated igneous origin. These two groups may not always be clearly separable, hence no attempt will be made to treat them separately.

Lacroix has examined an extended series of such inclusions. **Trachytes and acid andesites** nearly always have inclusions called "sanidinites," consisting of orthoclase or plagioclase. They are specially abundant in the light colored trachytes. Large crystals of zircon, sphene and sometimes corundum are present.

Often they are mairolitic and cavities between the crystals make the rocks fragile. Good crystals often occur in the cavities. Porphyritic types with melanite and augite are frequent.

The "sanidinites" are regarded as intra-telluric crystallization of the same magma as forms the volcanic phase. Are they segregations or fragmented rocks? The crystals have gaseous inclusions like those in the other inclusions. Some are corroded, with new crystallizations.

The changes are partly due to heat, partly to chemical action of the magma, or of mineralizers. To the latter are due zircons, apatite, sphene, scapolite, and sodalite crystals which are sometimes found. Secondary formation of calcite and quartz takes place frequently in the pores.

Other inclusions consist of plagioclase with ferro-magnesian constituents. They resemble diorites or diabases. Usually they are small and rounded and pass insensibly into the surrounding rock. Corrosion is often only slight; secondary minerals are infrequent. The inclusions are thought to be basic segregations from the magma.

In aegirine-trachytes "sanidinites" analogous to the above occur, with special minerals like låvenite, astrophyllite, etc.; aegirine and arfvedsonite are the pyroxene and hornblende. Sometimes the inclusions are quartzified by subsequent action.

In haüyne-trachytes nosean-sanidinites are common at Laacher See. The amount of nosean varies, and other minerals are present—allanite, pyrrhite, monazite, scapolite, in addition to zircon, sphene, apatite, pyroxene, mica and magnetite.

Lacroix thinks the inclusions are plutonic segregations from the haüyne-trachyte magma. Some of them are partly molten by the action of the volcanic stage. Some have plagioclase with ferro-magnesian minerals, which are segregations from the same magma.

In phonolites and leucitophyres. Nepheline-syenite inclusions occur in the phonolites. They look like rocks torn away. Hornblende is often absent, though present in the volcanic rock. Sometimes låvenite occurs in both. Other minerals present are feldspar, nepheline, haüyne and sodalite. The inclusions are non-drusy and new minerals are not found.

There are two kinds of basic segregations: one is rich in hornblende, with augite, biotite, apatite, rarely sodalite, and olivine. The feldspar is commonly orthoclase, sometimes oligoclase-andesine. They strongly recall the camptonites.

The second type contains apatite, ilmenite, melanite, sphene, pyroxene, biotite, sodalite or haüyne, nepheline and rarely perovskite. Haüyne, garnet or ilmenite vary in being most abundant. When garnet is absent from the volcanic rock it is absent from the inclusions.

In trachytic and leucitic tuffs of Italy—Two groups of inclusions occur:

1. Sanidinites related to sodalite-trachytes and acid leucitic rocks.
2. Crystallizations related to basic leuco-tephrites. (See later, p. 40.)

Sanidinites with haüyne are comparable to haüyne-trachytes. Sodalite replaces haüyne at Somma.

The inclusions are sometimes mairolitic, sometimes porphyritic. Some have leucite in them (Somma). Some show sodalite and orthoclase pseudomorphs after leucite. These have been formed near the surface.

Consanguinous inclusions in basalts—Inclusions more basic than the rock are the most abundant.

In basalts and basic andesites—Two types of inclusions are found:

1. Feldspathic inclusions (approximately similar to the rock).
2. Inclusions more basic than the rock.

Feldspathic inclusions have basaltic hornblende which has crystallized at depth, and augite, plagioclase, apatite and magnetite, with glassy inclusions in all minerals. Hornblende shows resorption very markedly with change to augite and magnetite grains.

Non-feldspathic inclusions are of two types:

1. Nodules with hornblende, augite, etc.
2. Nodules of olivine.

Usually they occur together. Olivine nodules the the most abundant. They are more abundant in lavas than in plutonic rocks. Liquid and glass inclusions are present. Sometimes the inclusions are partly melted.

In nepheline- and leucite-basalts (tephrites and leucotephrites) feldspathic coarse-grained inclusions are not common. They have the structure and composition of teschenite (?essexite) where they are found with sodalite. This occurrence in the case of leucite-basalts recalls Fouqué and Lévy's experiment of melting microline and biotite with the formation of olivine-leucitite. Some of the inclusions are rich in orthoclase and pass to sodalite-sanidinite. Leucite is present in some inclusions, indicating possibility of the formation of leucite at depth. Leucite is easily changed to orthoclase, nepheline and sodalite in the presence of mineralizers.

Some very basic inclusions with little plagioclase also occur.

There are two types of non-feldspathic inclusions, the hornblende and the olivine nodules. The latter occur only in the most basic rocks.

In nephelinite, leucitite, melilite-basalt, augitite, and limburgite:

In leucitite inclusions may consist of leucite + pyroxene + mica, often also orthoclase.

In nephelinite inclusions may consist of nepheline + pyroxene + mica, etc., + sodalite or haüyne. (Cf. ijolite.)

In melilite-basalt inclusions may be like essexite.

Another group of nodules consisting of hornblende, pyroxene, mica and nosean (or haüyne) and also nodules of olivine, occur in all of the above rock types. They are basic segregations from the magma.

Brauns & Uhlig,[3] have described the cancrinite and nepheline-bearing bombs of the Laacher See. Cancrinite in these bombs had previously been widely identified as scapolite.

The bombs consist chiefly of:

	Rare
alkali-feldspar	anorthoclase
cancrinite	nepheline
nosean	augite
lepidomelane	garnet
zircon	sphene
magnetite	apatite
orthite and pyrrhite	calcite
glass	plagioclase

The bombs are porous, friable and easily broken. They are weathered only on the outsides. The internal clouding of cancrinite is due to pyro-metamorphism. The cancrinite most commonly has rounded forms under the microscope. The original cancrinite changes to feldspar, glass and nepheline under the action of high temperature. The nepheline may have glass inclusions. Nepheline may form alone, or nepheline, feldspar and glass. The changes begin inside the crystals, changing them to tubular form, with the central axis changed. Some of the feldspar is primary. It is difficult to distinguish the primary and the newly formed feldspars.

Originally the rocks were nepheline-, nosean-, and cancrinite-syenites, and often show parallel banding as rocks of these types may do. Feldspar was the last mineral to form at depth, and it is thought that it formed there at the expense of nepheline, nosean, and cancrinite. Also, these three are melted and feldspar forms from them at the surface under the

[3]Neues Jahrb. B.B. 35, 1913, p. 119 and p. 723.

high temperature of eruption. (Cancrinite does not occur in volcanic rocks.) It is thought that nosean-phonolite is the volcanic equivalent of cancrinite-syenite. There may be a complete change of inclusions of cancrinite-syenite into sanidinite under the conditions of eruption.

HYBRIDISM

Harker[4] mentions two possibilities in the formation of hybrid rocks:

1. Mixing of magmas.
2. Reactions between magmas and solid rock (solution of rock by magma).

The former idea was first put forward by Bunsen (1851) and again by Durocher (1857) and has been utilized by other authors at different times, e.g., Michel-Lévy (1898) and Loewinson-Lessing (1908).

Harker shows diagrammatically a contrast between the variation diagrams which could be obtained by study of such mixtures of magmas and those obtained by study of actual rock series in petrographical provinces, and hence held to be consanguinous. Harker dismisses this conception rather summarily. He also mentions that existence of the original two magmas has not been explained.

Harker also summarily dismisses the idea of reaction between magmas and rocks because the variation diagrams for such reactions are straight lines instead of the curves found by studying natural consanguinous rock series. He says assimilation is local and limited where the rock and magma are unrelated in origin. He says reaction between consanguinous rocks may give hybridism on a larger scale. He says solution of sediments will produce peculiar rocks and such minerals as are present in metamorphosed sediments. Assimilation has been regarded as the chief cause of diversity in igneous rocks by many geologists. Extensive melting is conceded by Harker and must be postulated for the great primary magma reservoirs at deep levels of the earth's crust. This must tend to uniformity of product. According to Harker it can scarcely be supposed that the rocks melted include any of sedimentary origin.

Sollas has supposed Ordovician strata to have been dissolved in large quantities in the granites of Leinster.

Johnston-Lavis has held the essexites of Gran to be due to absorption of basic sediments by an acid magma. What

[4]Harker, A., chapter on Hybrid Rocks in "Natural History of Igneous Rocks," 1909.

kinds and amounts are not enquired into. The essexites are more basic than the stratified rocks of the district.

Cole, like Daly, thinks of a deep magma of uniform type and that the plutonic rocks we know are contact products and the removal of the previously existing rock makes an intrusion a pseudomorph. Harker's objection to this conception is the great amount of heat required.

Harker thinks there is the best chance for the development of hybridism by successive intrusions, with the earlier rock still hot. Gabbros, norites and eurites are invaded and included by granites in Rum, Skye, Mull and Arran (W. Scotland). When direct evidence of inclusions or veining is lost certain peculiarities remain. The new types are not truly quartz-diorites. The results include streaking out of inclusions as gneissic banding.

Dikes of basalt and later granophyre show reaction affecting both. Stages are shown as follows:

1. Quartz is introduced into the basalt, dark minerals into the granophyre.
2. Basalt is acidified by impregnation. Xenoliths enclose xenocrysts introduced from the granophyre —corroded alkali-feldspar and quartz. The granophyre is more basified. Its feldspars show corrosion of corners.
3. Basalt and xenoliths are more acidified.
4. Xenoliths are totally re-crystallized with andesine instead of labradorite. Introduced xenocrysts have increased in size.
5. Junctions have faded out and identity of the two altered rocks is attained.

Harker's discussion of the fate of cognate xenoliths seems to lead him to no definite conclusions, except that by composition the xenoliths do not fit into variation diagrams and hybridism is not an important factor in petrogenesis.

If complete solution has taken place the process of assimilation is masked. If differences in composition of the two originals, or the amount absorbed is large, "abnormal" varieties of rocks result. Hybrid origin cannot be concealed.

"Marscoite" a local rock of medium acidity is due to reaction of granite and gabbro, producing a product somewhat like quartz-diorite.

The composition of a hybrid rock must not be expected

content of the plagioclase, the Mg content of the pyroxene, and should develop norite from basalt. (loc. cit., p. 550-551.)

It is concluded that assimilation of limestone is not necessary for the production of alkaline rock types (loc. cit., p. 565) but it may help forward an already existing tendency to develop feldspathoids. Bowen concludes that magmas may incorporate in themselves considerable amounts of foreign materials.

MAGMATIC DIFFERENTIATION

Magmatic differentiation may be due to one or to several causes, more probably the latter. The following processes are invoked to account for the results achieved by differentiation:

1. Fractional crystallization.
2. Fractional crystallization accompanied by gravitational settling.

2a. Liquation accompanied by gravitational settling.

3. Limited miscibility.
4. Diffusion.
5. Temperature differences. (Soret principle.)
6. Differences of surface energy.

Fractional crystallization by itself may not be capable of producing any resulting differences of composition in different parts of a magma. But accompanied by **gravitational sinking** important results might be achieved, and doubtless have been achieved in many cases. N. L. Bowen[6] has advanced experimental data in support of the activity of a combination of these two processes in magmatic development. Most workers will be ready to accept these results and to include these processes as among those which have produced magmatic differentiation. But they may not be ready to accept the view that these are the only processes which have had play. It is quite clear that marginal basification cannot be explained solely on the bases of these two processes.

Fractional crystallization accompanied by later earth movement and resulting removal of still liquid portions of magma to other locations, as suggested by Harker, may be another important manner in which differentiation may have resulted.

[6]Bowen, N. L., Jour. Geol. 1915, Supplement.

The experiment of Morozewicz in which liparite magma retained in a molten condition for a considerable time showed marked differences in silica content in upper and lower parts, being more siliceous above, and there possessing a lower density, illustrates the possibility of the action of a process which may be sufficient to account for many of the observed results ascribed to the processes of magmatic differentiation. Unfortunately it is practically impossible to prove whether or not this process has been active in any particular case. It would be worth while to investigate this experiment of Morozewicz with a view to discovery of the processes giving rise to the result obtained.

The **limited miscibility** of sulphide and silicate magmas is conceded by petrologists. As a result there is a separation of a fluid magma into two parts, a silicate part and a sulphide part. It is commonly supposed that this separation takes place as the temperature of the magma falls. Sulphide ore bodies have been explained along these lines. It may be that the separation exists at higher temperatures, also, but that the sulphide particles are dispersed through the silicate magma in what may be called a colloidal suspension, and that as the temperature falls the suspension becomes coagulated, i.e., the sulphide particles become bunched together and may be collected and deposited in separate locations in large enough masses to form ore bodies. The Sudbury sulphide ore-bodies of nickel and copper bearing sulphides are commonly cited as an out-standing example of the separation of sulphide ore-bodies under the control of the principle of limited miscibility of magmas. Segregation by gravitational settling is a process which is usually combined with limited miscibility in this explanation, and Sudbury is the out-standing example which illustrates this case also.

Diffusion has been regarded by some authors as a process capable of giving rise to the transference of material from one part of a magma to another. Some writers consider silicate magmas as too viscous to allow of such transference. But Vogt has shown that some of the silicate magmas are very fluid, and it seems best to consider diffusion as a possibility, if there is an adequate motive force to set the materials moving. The principle of diffusion would be expected to give rise to different results from those produced by gravity. The latter process will concentrate the heavier materials in the

lower part of a magma basin. By diffusion lateral movement may be possible, as well as downward movement, and even also vertical movement upward may be possible. Diffusion acts radially in all directions, under ideal conditions. It may be possible to explain marginal basification by means of diffusion, if an adequate motive power to set the constituents of the magma in motion can be adduced.

Difference of temperature, the so-called Soret principle, has been suggested as a possible cause for setting up of different concentrations of certain mineral matter in a magma basin. Harker[7] and others have discussed this principle and have shown that upon a quantitative basis this principle cannot have had any important effect.

Difference of surface energy is a possible means of setting constituents of a magma in motion relative to each other which is capable of producing important results. As a magma cools it may be that certain constituents become grouped at certain points preparatory to crystallization and that the surface energy at any one point may be different from that at some other point, because of the inherent properties of different materials. If these differences are sufficiently large it may be that they have the power to set the materials in motion and eventually to bring about a difference of relative concentration of various constituents in different parts of the magma basins as a result of the adjustment or partial adjustment of differences of surface energy. Such a transference of material would fall under the heading of diffusion, but in this case the motive force behind the diffusion is recognized as different from those which have been suggested in the past. It is conceived that diffusion actuated by differences of surface energy is capable of acting upon a dispersion of sulphides in a magma, resulting in their transfer to the outer margins of the magma basin, sides and top as well as bottom, where they may be bunched together by coagulation. It will be seen below that results such as these have been obtained in an experimental way in the case of metallic iron and various sulphides and oxides. It is only natural that marginal basification should come to mind in a very similar connection, and we are ready to apply the same explanation to marginal basification involving transference of oxides of iron, etc., toward the margins. Such results have

[7]Harker, A., Natural History of Igneous Rocks 1909, pp. 316-317.

been obtained experimentally, and other experimental results indicate the possibility of assimilation of such segregated oxides, etc., by the magmas near the margins to yield more basic rock types. Thus the disappearance of earlier marginal segregations of magnetite, etc., with the production of basic rock types at the margins offers a rational explanation of the phenomenon of marginal basification, and one which can be substantiated by laboratory results.

Two possibilities suggest themselves in connection with differences of surface energy. It may be that the same substance at two different temperatures may have sufficiently different surface energies for this to form a sufficient motive power for diffusion. Or, it may be that a marked difference in surface energy may exist between those parts of a magma in contact with the walls of the reservoir and the remainder of the magma, and this difference may be sufficient to set certain of the constituents of the magma in motion toward the walls of the reservoir, where they may be concentrated to a more or less marked extent. The case of marginal concentration of metals, sulphides and oxides has been produced experimentally in so many cases that the efficacy of this principle in the case of ore-bodies seems to be definitely established.

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CHAPTER III.

EXPERIMENTS

The possibility of the solution of foreign rock matter by a molten magma to yield a magma of different composition has received notice on many different occasions. The possibility of such assimilation of solid rock from the walls of the magma reservoir or from the rock materials passed through during injection has been given a prominent place in the conceptions of some writers while others have denied the possibility of such extensive assimilation as may be necessary to yield different rock types, whose production has been laid to the workings of the processes of differentiation.

Views on assimilation have been expressed by the following authors, among others:

For	Against
Michel Levy	Rosenbusch
Lacroix	Brögger*
Suess	Vogt
Loewinson-Lessing	Harker
Sederholm	Cross
Daly	Iddings
Barrell	Pirsson
Winchell, N. H.	Washington
Barlow	
Brock	
Collins	
Sollas	
Cole	
Johnston-Lavis	

It is clear that equally weighty opinion is ranged on both sides. This in itself is a sufficient reason for a detailed examination of the question. If the results achieved by experimental investigations indicate that assimilation may have

*More recently Brögger has admitted some assimilation of limestone.

been active in nature the weight of opinion arrayed on the negative side acts as a brake against the too enthusiastic utilization of the assimilation principle in theoretical discussion.

If eventually generally acceptable conclusions may be reached which will lie on a middle ground somewhere between the extreme ideas of these two groups it may be possible for both groups with equal grace to modify their stands on this question.

Bowen[1] has discussed in an able manner some of the theoretical points connected with solution of solid inclusions of foreign matter in magmas and has reached the conclusion that on the whole assimilation does not seem to have played a very important part in the production of igneous rock types.

Clear and unmistakeable field evidence of assimilation is not abundant and a review of such evidence as is available leaves much to be desired regarding a knowledge of the end-products obtainable as a result of assimilation. Daly has suggested assimilation as the main cause of the diversity of rock types. I have found field evidence supported by chemical evidence for the formation of a melilitic rock type (okaite) by assimilation of limestone by a magma.

A natural outcome of such discovery was a thoughtful enquiry into the possibility of extensive assimilation of rock matter by magmas. The assimilation of sedimentary materials would be more likely to yield clearly marked results than the assimilation of igneous materials, the effects of which might not be noticeable in all cases.

A set of experiments was planned in which a chosen series of ten igneous rocks representing common magmatic products ranging from granite at the acid end of the series to peridotite at the ultra-basic end of the series was to be caused to assimilate known amounts of carefully chosen materials representing pure sediments. The three common sedimentary types were represented by a pure calcite from Upper Deer Creek, Montana, a pure kaolin from Woodrow, North Carolina, and a pure glass sand (St. Peter sandstone) from Klondike, Missouri.

All of the raw materials were ground to pass 100 or 150 mesh, and the powdered igneous rock was thoroughly mixed

[1]Bowen, N. L., Jour. Geol. 1922, p. 513.

with the material to be assimilated. The proportions chosen were:

igneous material : material assimilated	1 : 1
	2 : 1
	3 : 1

It was considered that if such mixtures were melted without contamination from other silicates, at temperatures comparable* with magmatic temperatures the results produced may be expected to show definite evidence bearing upon the question of "assimilation", if the products after solidification were sufficiently crystalline. It is doubtless impossible to reproduce magmatic conditions accurately in the laboratory, especially in connection with water content of magmas, and freedom of escape of volatile matters (water, carbon di-oxide, etc.). Therefore such results as are obtained by an experimental investigation of the kind outlined cannot be regarded as a final word on the topic of assimilation, but at the same time must needs be considered in reaching any conclusions in regard to the question.

The proportions used refer to the cold solid before melting. Loss of carbon di-oxide from the calcite and of water from the kaolin will change the proportions of igneous rock to assimilated matter. In the calculation of compositions of the products it can be assumed that the carbonates have lost all of their CO_2 under the conditions of the experiments, and the hydrous minerals have lost all their water of composition during the experiments.

The fine grinding and thorough mixing before melting is thought to give ample opportunity for assimilation and to perform mechanically in a short time a process which may take place more slowly in a magma. The heating of the mixtures took place in electric furnaces or a brick kiln. The temperatures were carried to from 1230° to 1600°C in different cases. The furnace or kiln temperature was not uniform and so the recorded temperatures must be regarded as approximations. An effort was made to melt the mixes at temperatures comparable with magmatic temperatures, and to get a crystalline or partially crystalline product, if possible, which could be compared with igneous rock materials.

In the cases where an electric furnace was used the melts

*Temperatures up to 1600°C have been used with the object of saving time in the production of results.

were kept above 1000°C, 1200°C, 1400°C, 1500°C, or 1600°C, for about four hours and in the cases where the brick kiln was used the temperature of 1230°C, 1400°C, or 1410°C was slowly approached and maintained for two hours. The cooling was as slow as possible in all cases, the results sought being qualitative rather than quantitative. With the electric furnace the melts were completed and cooled again in 24 hours. But with the brick kiln the cooling took about seven days.

The results of the preliminary experiments were so interesting that it was decided to enlarge the scope of the investigations and mixes of igneous rocks with such materials as they might pick up during the act of intrusion were made, with the exception that assimilation of normal igneous rocks was not included in these investigations. The materials used included magnetite, hematite, siderite, dolomite, magnesite, tremolite schist, bauxite, chromite, graphite and various sulphides. Part of the results obtained are discussed separately in Part II, under the title of "Separation of ores from magmas."

GENERAL RESULTS

If these experiments can be regarded as comparable with natural conditions it would seem possible that **assimilation is not difficult of realization,** provided an adequate source of heat is available under magmatic conditions. I offer no argument for or against adequate sources of heat, but hold the opinion that in many cases there is probably enough heat available to allow of the assimilation of considerable proportions of foreign rock matter, probably less than the lowest proportion used in these experiments (25 per cent of the final product). The reader is referred to Bowen's[2] discussion of amounts of heat required for solution of foreign inclusions by a magma, and for a discussion of some of the details of the processes involved.

The results obtained have **not required great lapses of time,** and it may not be necessary to suppose that very great stretches of time are required for the accomplishment of assimilation in magmatic reservoirs.

Assimilation of all the materials used, with the exception of quartz, kaolin, bauxite, chromite, and graphite, has been complete in the short time of a few hours at magmatic tem-

[2]Bowen, N. L., Jour. Geol. 1922, p. 513.

peratures. Assimilation of quartz and chromite has been partial. By assimilation is meant that a uniform melt has been produced and the foreign matter has been completely incorporated with the molten igneous rock material. Crystallization of the melts has not been uniformly obtained. The melts rich in iron, calcium or magnesium have crystallized more or less freely, some of the products rich in lime being wholly crystalline. The products of assimilation of quartz and kaolin have not always crystallized successfully, or have only done so partially, often leaving much desirable information unavailable.

The results of **assimilation of calcite** have been to yield products characterized by melilites, most often of the åkermanite variety (+, medium birefringence), but in some cases of the melilite variety, sensu strictu, (–, low birefringence). These experimental results of the assimilation of calcite support the view expressed by me in connection with the melilitic rock okaite, by Scheumann in connection with the melilitic rocks of the Polzen district of Bohemia, and by Bowen as a generalization resulting from theoretical considerations.[3]

Bowen (loc. cit.) has hesitated to accept assimilation of limestone as a cause of the formation of nepheline-syenite magmas, as suggested by Daly, and my experimental results support Bowen's attitude. I was formerly strongly attracted by Daly's hypothesis (see Geol. Mag. 1923, p. 451-453) and a wish to test that hypothesis and my expressed views regarding okaite were the reasons for the undertaking of these experimental investigations. The results obtained indicate clearly that assimilation of limestone can produce melilitic types. It may be that magmatic differentiation may produce nepheline-bearing types from such limestone syntectics by say sinking of olivine, augite and melilite crystals. The lighter liquid in the upper part of the chamber where such a process was active would probably be like the nepheline-syenites and related types. It is possible that this is capable of experimental proof.

The **assimilation of kaolin** has yielded products which crystallized only partially, leaving much of the melt in the form of glass. In one case (70) that of kimberlite mixed with

[3]Stansfield, J., Geol. Mag. 60, 1923, p. 450.
Stansfield, J., Amer. Jour. Sci. Ser. 5, Vol. 11, 1926, p. 396.
Scheumann, K. H., Centrallbl. fur. Geol. u. Pal. 1922, p. 521.
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kaolin in the proportions 1:1 nearly all of the melt has crystallized. Approximately three-quarters of the whole consists of crystals of cordierite, in short stumpy crystals of hexagonal cross-section. This result is of importance in connection with the origin of rocks rich in cordierite.

The assimilation of kaolin by some melts has led directly to the formation of feldspars.

The **assimilation of quartz** has yielded the least satisfactory results in this set of experiments. The assimilation has not been complete and crystallization has been only partial. Thus these results are inconclusive.

The **assimilation of magnetite** has been partial or complete and the melts have crystallized as augite and glass, or augite, olivine and glass, in varying proportions. The products may be classed with the augitites and limburgites among volcanic rocks. The assimilation of magnetite by magmas varying from granite to peridotite yields magmas of peridotitic type.

The **assimilation of hematite** has been partial or complete, yielding glassy products from the more acid melts, and augitite-pyroxenite types from the more basic melts. From the syenite products comparable with the trachytes or andesites have been obtained.

The **assimilation of siderite** has been complete and the crystallization often good. One of the common products of reaction is metallic iron, which has been formed in amounts up to about 30 per cent in some cases. The crystallization of augite and olivine with remnants of glass suggests the peridotite magmas cooling to limburgites and augitites.

The **assimilation of dolomite** has been complete and crystallization has been partial to complete. The more basic melts have yielded products like those of the peridotite-augitite-limburgite series. The more acid melts have yielded glassy products.

The **assimilation of magnesite** has been complete and crystallization partial to complete. The melts crystallize as products resembling peridotites and limburgites. The formation of colorless augite is a feature of this series.

The **assimilation of tremolite schist** has been complete and crystallization approximately complete, yielding products comparable to the augitite-limburgite-peridotite series.

The **assimilation of bauxite** has been incomplete for the most part, under the experimental conditions and crystallization has been incomplete in most cases, leaving the results inconclusive. Where crystallization has taken place alumina has helped in the formation of feldspar, sometimes by way of spinel, sometimes by way of sillimanite. In other cases alumina-rich silicates of the sillimanite-andalusite series have been formed. These latter products are not comparable with igneous rocks.

Assimilation of chromite has been only slight. Partial assimilation, probably the removal of iron from the chromite, is shown by lighter colored borders of the chromite fragments. The basic feldspathic types have crystallized as limburgites without feldspars, and from the more acid melts some andesitic-trachytic types have been formed. Ferro-chrome or chromiferous iron has been formed and has been transferred to the margins which are often covered with a thin plating of this alloy.

Assimilation of graphite has not taken place and little or no effect upon the crystallization of the silicate melt seems ascribable to its presence.

EFFECTS OF TEMPERATURE

Glassy products have been obtained from the mixes of the magnetite, hematite, siderite, and dolomite series heated to the temperature of 1400°-1410°C. Magnetite and siderite mixes heated to 1230°C have yielded much more crystalline products. In cooling from the higher temperatures the region of the freezing points of the various minerals which might crystallize has probably been passed through rapidly, while at the lower temperature (1230°C) it is probable that the melts were close to their freezing points for a longer time, and crystallization was aided.

In a similar fashion among the sulphides, in experiments conducted at 1410°C, chalcocite, bornite and chalcopyrite appear to have aided crystallization of the silicates while chiefly glassy products have resulted from the pyrite, pyrrhotite, nickeliferous pyrrhotite, galena and zinc blende melts. It may be that the cupriferous mixes were closer to their freezing points at 1410° C than the remainder, which were probably considerably above their freezing points, and passing those temperatures fairly rapidly during the cooling process, failed to crystallize extensively.

With many melts from which augite is the chief mineral to crystallize at 1410°C, olivine has crystallized freely when heated to 1230°C. So a product like augitite may be formed at the higher temperature of crystallization, while from a melt of the same composition a product like limburgite may be formed at the lower temperature of crystallization.

From mixtures containing bauxite plagioclase has been crystallized from syenite and basalt series heated to 1230°C. From the same mixtures heated to 1410°C plagioclase has been formed, but spinel has been formed first and is in process of being incorporated in the plagioclase molecules, by a reaction not completed owing to the too rapid cooling. From the bauxite mixtures most of which gave no crystallization products at 1230°C, a series of alumina-rich silicates have been formed at the temperature of 1410°C. Most of these correspond to sillimanite, and some to andalusite; some of the sillimanites produced artificially are more highly colored and more strongly pleochroic than natural sillimanites. No recognizable mullite has been found in any of the products.

Chromite has a definite effect in aiding the physical processes of ore separation, and of silicate crystallization. The effects on these processes are somewhat different from those of the other materials used.

Magnesite and tremolite-schist mixtures have yielded types similar to the limburgite-peridotite series from all of the rock types from granite to the ultra-basic end of the series. The addition of magnesite to kimberlite has resulted in the formation of garnet from the mixtures, in one case garnet making up approximately 40 per cent of the whole. This case is instructive in comparison with the occurrence of included masses of eclogite (garnet-pyroxene rock) in the kimberlite of the South African diamond pipes.

DETAILS OF EXPERIMENTS AND RESULTS

The igneous rock materials used in these experiments are the following:

I Granite, Hurricane I., Maine. See Dale, T. N., Bull. 738, U. S. G. S., p. 247.

II Granite, Westerly, Rhode I., red variety. See Dale, T. N., Bull. 738, U. S. G. S., pp. 407 & 413.

III Granite, Concord, New Hampshire. See Dale, T. N., Bull. 738, U. S. G. S., p. 199.

IV Syenite, Coe Hill, Ontario. Analyst, L. J. Hartzell.

IVa Syenite, Kaitz bei Dresden, Germany. (Erratic block.) Analyst, L. J. Hartzell.

V Nepheline-cancrinite-syenite, Litchfield, Maine. Analyst, L. G. Eakins. See Bull. G. S. A., III, 1891, p. 241.

VI Hornblende-andesite-porphyrite, Sylvan Pass, Yellowstone National Park. Analyst, L. J. Hartzell.

VII Feldspar basalt, Chaffee County, Colorado. Analyst, L. J. Hartzell.

VIII Basalt, Huerfano County, Colorado. Analyst, L. J. Hartzell.

IX Minette, Las Animas County, Colorado. Analyst, L. J. Hartzell.

X Kimberlite, Murfreesboro, Arkansas. Analyst, R. N. Brackett. See Arkansas Geol. Surv. Ann. Rep. II, 1890, p. 383.

ANALYSES OF MATERIALS USED

The analyses of these rocks follow:

	I	II	III	IV	IVa	V	VI	VII	VIII	IX	X
SiO_2	70.94	73.05	74.47	60.19	52.08	60.39	57.06	54.70	41.22	30.36	38.78
TiO_2											.89
Al_2O_3	15.68	14.53	14.15	21.40	22.70	22.51	20.32	20.35	19.80	19.54	6.85
Fe_2O_3			1.16	1.46	2.57	.42	3.35	4.90	5.79	9.84	8.83
FeO	2.29	2.96	1.21	2.97	5.16	2.26	5.16	5.03	10.54	4.77	1.99
MgO	.19	....	.63	1.00	2.09	.13	2.50	2.05	8.33	5.85	26.34
CaO	1.23	2.06	1.70	2.30	8.10	.32	5.01	6.50	9.60	11.10	3.88
MnO	.13	tr.	....	....	.69	.08	....	tr.	tr.	....	....
Na_2O	3.58	1.72	1.97	4.67	3.55	8.44	3.05	1.86	1.77	1.60	.78
K_2O	5.54	5.39	4.14	5.14	3.00	4.77	3.21	3.57	1.69	2.45	2.56
CO_2			.25			tr.				14.00	.14
S	.05	....	.27	.06		....	....	.04	tr.	.02	....
H_2O	....	.29	.26	....	.15	.57					1.95
Loss & undet.	.37										
Loss on ignition											7.85
	100.00	100.00	100.21	99.19	100.09	99.95	99.66	99.00	98.74	99.53	100.84

A list of the materials ground and mixed with the ground igneous rocks follows, along with their analyses:

XI Calcite, Upper Deer Creek, 7 miles west of Grey Cliff, Sweetgrass County, Montana. Analyst, C. L. Wilson.

XII Kaolin, Woodrow, North Carolina. Analyst, L. J. Hartzell.

XIII Quartz, glass sandstone, Klondike, Missouri. Analyst, C. L. Wilson.

XIV Magnetite, Mineville, N. Y. Analyst, L. J. Hartzell.

Analyses of Materials Used

XV Hematite, Clinton, N. Y. Analyst, L. J. Hartzell.

XVI Bauxite, near Chattanooga, Tenn. Analyst, L. J. Hartzell.

XVII Dolomite, Rochester, N. Y. Analyst, C. L. Wilson.

XVIII Magnesite, Muntodi, Greece. Analyst, C. L. Wilson.

XIX Siderite, Roxbury, Conn. Analyst, L. J. Hartzell.

XX Tremolite schist, Madoc, Ont. Analyst, L. J. Hartzell.

XXI Chromite, Black Lake, Que. Analyst, L. J. Hartzell.

XXII Graphite, artificial. Acheson Graphite Co. Analyst, C. L. Wilson.

XXIII Chalcocite, Butte, Montana. Analyst, L. J. Hartzell.

XXIV Bornite, near Salmon, Idaho. Analyst, L. J. Hartzell.

XXV Chalcopyrite, Globe, Arizona. Analyst, L. J. Hartzell.

XXVI Pyrite, St. Williams, Ontario. Analyst, L. J. Hartzell.

XXVII Pyrrhotite, Haywood County, North Carolina. Analyst, L. J. Hartzell.

XXVIII Nickeliferous pyrrhotite, Worthington, Ontario. Analyst, L. J. Hartzell.

XXIX Galena, near Baxter Springs, Kansas. Analyst, L. J. Hartzell.

XXX Zinc Blende, near Baxter Springs, Kansas. Analyst, L. J. Hartzell.

	XI	XII	XIII	XIV	XV	XVI	XVII	XVIII	XIX	XX	XXI
SiO_2	.43	45.22	99.99	3.60	10.80	2.40	38.69	....	9.20	37.00	7.84
Al_2O_3	.20	40.46	.02	tr.	5.95	66.22	2.05		1.38		7.60
Fe_2O_3		tr.		62.81	81.80			.65	1.49	1.70	
FeO				33.54			.95		48.03		23.70
MgO					tr.	.07	11.27	47.85	3.37	29.04	19.90
CaO	55.58						17.20	.90		10.71	
CO_2	43.69						29.87	50.62	33.85	21.60	
H_2O		14.65				31.30			MnO 2.73	Cr_2O_3	40.95
	99.90	100.33	100.01	99.95	98.55	99.99	100.03	100.02	100.05	100.05	99.99

	XXII		XXIII	XXIV	XXV	XXVI	XXVII	XXVIII	XXIX	XXX
C	98.41	S	20.85	21.63	33.70	49.81	36.51	38.21	13.44	32.68
H	.88	Cu	74.46	56.90	34.42		.35			
H_2O	.08	Fe	1.88	9.18	30.45	43.98	54.06	49.06		.42
Ash	.10	Ni						5.53		
		Pb							86.60	
		Zn								66.70
		CaO						.08		
		MgO						.29		
		Al_2O_3	1.00			.23	1.70	3.51		
		SiO_2	1.69	12.60	1.40	5.94	7.00	2.20		.15
	99.47		99.88	100.31	99.97	99.96	99.62	98.88	100.04	99.95

The composition of the products of the experiments may be calculated from the analyses of the ingredients, combined in the proportions used, assuming in the case of the carbonates and hydrous minerals that CO_2 or H_2O are completely lost under the conditions of the experiments.

PETROGRAPHIC DESCRIPTIONS OF MATERIALS USED

There follow descriptions of the microscopic characters of the rocks ground for use in the experiments.

Granite, Hurricane I., Maine.

The rock is fresh and consists of feldspar with subordinate amounts of quartz with strain shadow, and a green, strongly pleochroic biotite. The latter contains zircons surrounded by pleochroic halos. Oligoclase is present in about equal amount to the remainder of the feldspars. It shows some zonary banding. Microcline is more abundant than orthoclase, and a little micro-perthite is present.

Granite, Westerly, Rhode Island (red variety).

The rock is fresh, and is a two-mica granite. Orthoclase is the prominent feldspar and is slightly sericitized. A little microline is present, and also a little oligoclase, which shows some zonary banding and sericitization. Quartz is prominent. The biotite is greenish-brown in color, and strongly pleochroic. Muscovite is as abundant as the biotite. Magnetite and apatite are accessory minerals and a small amount of calcite is present.

Granite, Concord, New Hampshire.

The rock is fresh and is a two-mica granite. The biotite is prominent, is brown, strongly pleochroic, and has some prominently pleochroic halos around minute included zircons. The muscovite is clear and occurs in large flakes of primary mica, and as included flakes of sericite within feldspar. The feldspars are chiefly orthoclase and microcline, with a small amount of micro-perthite and oligoclase. Quartz is prominent, sometimes shows strain shadow, and has in it abundant included needles. Apatite, magnetite and zircon are accessory, the latter occurring as larger crystals in the other minerals than in the biotite.

Syenite, Coe Hill, Ontario.

The rock is fresh and consists almost entirely of feldspars, chiefly microline and oligoclase, which are commonly intergrown as micro-perthite, or occur as separate individual

grains. Orthoclase, in subordinate amount is associated with the plagioclase in micro-perthite. A green biotite is present in very small amount, being nearly equalled in prominence by a yellowish sphene. Accessory minerals include magnetite, zircon and very little apatite. Calcite is present.

Syenite, Kaitz, bei Dresden, Germany.

The rock consists almost entirely of oligoclase, showing albite and Carlsbad twinning, and a strong tendency to idiomorphic outlines. In addition there is a little augite, partly altered to chlorite, and also a little magnetite.

Nepheline-cancrinite-syenite, Litchfield, Maine.

The rock is fresh and consists predominantly of feldspars, which include albite, orthoclase, microline and micro-perthite. The nepheline occurs in large individuals, which may enclose feldspar crystals. Cancrinite is associated with nepheline, or sometimes with feldspar in a manner indicating that it is a primary crystallization product rather than a secondary decomposition product after nepheline. A strongly pleochroic green mica (lepidomelane) is present in important amount, and large zircon crystals are numerous.

Hornblende-andesite-porphyrite, Sylvan Pass, Yellowstone National Park.

The porphyritic crystals include a light brown to greenish brown, faintly pleochroic hornblende, andesine, a few augite crystals, and magnetite. Secondary epidote is present and apatite occurs.

The groundmass is very fine-grained and consists chiefly of minute laths of andesine with grains of magnetite, augite, secondary epidote and colorless glass.

Feldspar basalt, Chaffee County, Colorado.

Porphyritic crystals include labradorite with zonary banding, augites, and very few brown hornblendes, embedded in a well-crystallized base consisting of labradorite and augite, with some magnetite and bleached biotite. The rock is a highly feldspathie basalt.

Basalt, Huerfano County, Colorado.

Abundant porphyritic crystals of olivine, occasionally altered to serpentine, and less abundant augite are embedded in a crystalline base in which augite and magnetite are most prominent, and olivine and labradorite laths are present in

small amount, a slightly colored glass making up the remainder.

Minette, Las Animas County, Colorado.

A strongly pleochroic brown biotite is the most prominent constituent, as well-crystallized porphyritic crystals, the spaces between which are occupied by laths of orthoclase, sometimes with a fan-like arrangement. Also present are abundant apatite crystals, secondary limonite after magnetite, some magnetite, and very much secondary dolomite.

Kimberlite, Murfreesboro, Arkansas.

Abundant porphyritic crystals of olivine are completely altered to serpentine, and are embedded in a groundmass of brown glass containing abundant small crystals of augite, grains of magnetite, and abundant perovskite. At a few places the ground has a brighter brown color and consists of biotite which encloses the other constituents in the same way as does the glass.

MICROSCOPIC CHARACTERS OF EXPERIMENTAL PRODUCTS

In the following descriptions the proportions of materials named are given, and in parentheses the laboratory number of the specimen and the highest temperature reached in the heating. Where the same proportions of the same materials have been used more than once, in different series of experiments, the descriptions follow each other, except in the case of the bauxite series.

The rock materials alone have been heated and the descriptions of these products are given first. The mixes with the various sulphides crystallize differently, the presence of other materials having a certain effect upon the crystallization of the silicates, so descriptions of these products are included for the sake of the information they give upon that question.

Numerical estimates of the different materials present are included in the descriptions. There is no attempt at accuracy in these estimates. They are offered with the aim of giving the reader some fair idea of the relative importance of the different kinds of crystals formed, or glassy material left uncrystallized. It is thought that such an idea will be of value in studying the problems involved.

Microscopic Characters of Experimental Products

With reference to the following descriptions of the products obtained by melting the rocks and mixtures named it is important to keep in mind that while they are comparable in a general way with volcanic rocks, yet they have been formed under reducing conditions because of the nature of the crucibles—graphite—whereas volcanic rocks are solidified under oxidizing conditions. Instead of dark brown volcanic glasses as in the basic volcanic rocks, the rule in the experimental products is that the glasses are colorless or only slightly colored even if basic in composition. Melts rich in iron have furnished larger or smaller quantities of metallic iron. This is another result of the reducing conditions. The best analogues in nature are the iron-bearing basalts of Ovifak, Greenland, where the iron has been produced as a result of the inclusion of masses of graphitic rock in the basalt.

The crystalline products have been determined by means of optical characters, checked by determinations of refractive indices. The values obtained are given. The numbers of determinations to be made were numerous and in the cases of some of the augite crystals of high refractive indices the fragments of the powders floated on the heavier liquids of higher refractive indices. In such cases the refractive index of augite is recorded as greater than the liquid of highest refractive index in which the fragments sank. The other optical properties of the augite crystals were sufficient for their determination, in very many cases, so that the approximate determination of refractive index for augite does not leave the identification doubtful.

In a few cases it was not possible to make accurate determinations of the refractive indices of some minerals in needle form, because of their intimate association with glass of very different refractive index, in such a manner that it was impossible to get the needles free from glass. In such cases doubt about the determination of the mineral is indicated by the use of the word "probably" or by a (?).

The record of refractive indices is sometimes given as greater or less than that of the oil nearest in refractive index to the one of the mineral in question. Occasionally a refractive index of a mineral is the same as that of one of the oils. The series of oils used differed in refractive indices by .01 in the higher part of the series and by .005 in the lower and medium part of the series. The series used extended from 1.45 to 1.73.

PRODUCTS OF MELTING THE ROCK POWDERS ALONE, AT 1410°C.

Granite, Hurricane I, Maine. (482)

98% colorless glass, with many gas bubbles and flow structure.

2% unmelted quartz crystals, and quartz grains changed to cristobalite, half of each.

Name:—**Glass + quartz + cristobalite**

Granite, Westerly, R. I. (483)

100% colorless glass, with gas bubbles, a few unmelted quartz fragments and quartz grains changed to cristobalite.

Name:—**Glass + quartz + cristobalite**

Granite, Concord, N. H. (484)

95% colorless glass, with many gas bubbles.

5% unmelted quartz fragments.

Name:—**Glass + quartz**

Syenite, Kaitz, bei Dresden, Germany (487)

97% brownish, radially crystallized andesine fibres (*av. 1.550) with radial fibres of augite, (not seen in powder for R.I.*) in small amount, at a few points. Minute opaque globules occur in this part.

3% colorless glass, with minute opaque globules.

*Av. = Average. R. I. = Refractive Index.

Name:—**Andesite**

Nepheline Syenite, Litchfield, Maine. (488)

99% colorless glass, with a few minute opaque globules, showing flow structure, as a result of the movement of abundant gas bubbles.

1% opaque remains of unmelted zircon crystals.

Name:—**Glass**

Andesite Porphyrite, Sylvan Pass, Yellowstone National Park. (489)

100% colorless glass, with some opaque magnetite globules with flow arrangement.

Name:—**Glass**

Feldspar Basalt, Chaffee Co., Colorado. (491)

100% yellowish glass, with some magnetite globules with flow arrangement, and a few microlites of augite.

Name:—**Glass**

Basalt, Huerfano Co., Colorado. (485)

90% needles and cockscombs of augite. (>1.692, <1.710)
10% brownish tinted glass.

Name:—**Augitite**

Minette, Las Animas Co., Colorado. (486)

85% large augite crystals. (av. 1.710)
15% dark brown glass, between the fibres of the crystals.

Name:—**Augitite**

Kimberlite, Murfreesboro, Arkansas. (490)

50% small grains of olivine. (< 1.680)
50% small crystals, and some larger blades of augite, (> 1.692) the whole making a very fine-grained rock, with a thin coating of larger crystals, chiefly grayish, nearly opaque augite, with some long needles and skeleton crystals of olivine.

Name:—**Limburgite** (no glass)

Kimberlite, Murfreesboro, Arkansas. (100) (1379°C)

50% small olivine crystals. (=, < 1.665)
50% very dark brown glass.

Name:—**Limburgite**

IGNEOUS ROCKS AND CALCITE

Granite 1 : Calcite 1 : 1 (401) (1410°C) (See Pl. 1, fig. 1.)

60% of long needles, with radial arrangement, uniaxial, +, birefringence medium, (ϵ 1.615, ω 1.640) åkermanite.
40% brownish glass. Name:—**Åkermanite + glass**

Granite 1 : Calcite 1 : 1 (1) (1470°C)

100% coarsely crystallized åkermanite (uniaxial, +, ϵ > 1.638, ω < 1.638) Name:—**Åkermanite rock**

Granite 1 : Calcite 2 : 1 (402) (1410°C)

90% long radiating needles, or close grids of åkermanite (uniaxial, +, ϵ 1.652, ω 1.640).
10% brownish glass. Name:—**Åkermanite + glass**

Granite 1 : Calcite 2 : 1 (4) (1470°C)

99% colorless glass.
1% crystalline matter, partly opaque, partly clear needles of åkermanite (uniaxial, +, ϵ> 1.638, ω< 1.628) Name:—**Glass + åkermanite**

Granite 1 : Calcite 3 : 1 (403) (1410°C)

97% radial and sheaf-like arrangement of needles of åkermanite (uniaxial, +, with lower birefringence than the above, ϵ 1.650, ω 1.638)

3% brown glass.

Name:—**Åkermanite + little glass**

Granite 1 : Calcite 3 : 1 (7) (1470°C)

97% colorless glass.

3% radiating needles of åkermanite (uniaxial, +, ϵ 1.638, $\omega < 1.638$).

Name:—**Glass + åkermanite**

Granite 2 : Calcite 1 : 1 (404) (1410°C) (much like 401).

65% long needles of åkermanite, with sheaf-like arrangement (uniaxial, +, with medium birefringence, ϵ 1.638, ω 1.628).

35% glass, partly dark, but mostly colorless, with abundant colorless or gray isotropic △ sections and a few octahedra of perovskite, > 2.07.

Name:—**Åkermanite + glass**

Granite 2 : Calcite 1 : 1 (2) (1470°C)

100% coarsely crystallized åkermanite (uniaxial, +, ϵ 1.650, ω 1.628)

Name:—**Åkermanite rock**

Granite 2 : Calcite 2 : 1 (405) (1410°C)

95% long, radiating needles, or close grids of åkermanite (uniaxial, +, with medium birefringence, ϵ 1.650, ω 1.638)

5% brown or colorless glass, between the needles.

Name:—**Åkermanite + glass**

Granite 2 : Calcite 2 : 1 (5) (1470°C)

98% colorless glass.

2% crystalline matter, partly in minute rosettes, or spherulites, partly in larger grids of åkermanite (uniaxial, +, $\epsilon > 1.628$, $\omega < 1.628$).

Name:—**Glass + åkermanite**

Granite 2 : Calcite 3 : 1 (406) (1410°C) (See Pl. 1, fig. 2.)

98% sheaf-like but mostly radial or spherulitic arrangement of åkermanite (uniaxial, +, ϵ 1.638, $\omega > 1.630$)

2% colorless, interstitial glass.

Name:—**Åkermanite + glass**

Granite 2 : Calcite 3 : 1 (8) (1470°C)

98% colorless glass.
2% spherulites and sheaves, at edges, of probably åkermanite (uniaxial, +, refractive index not obtainable).

Name:—**Glass + åkermanite**

Granite 3 : Calcite 1 : 1 (407) (1410°C)

60% long needles of åkermanite with sheaf-like arrangement (uniaxial, +, with medium birefringence, ϵ 1.638, ω 1.628.
40% dark grayish glass.

Name:—**Åkermanite + glass**

Granite 3 : Calcite 1 : 1 (3) (1470°C)

100% coarsely crystallized åkermanite (uniaxial, +, $\epsilon >$ 1.650, ω 1.638)

Name:—**Åkermanite rock**

Granite 3 : Calcite 2 : 1 (408) (1410°C)

98% radial sheaves or compact grids of åkermanite (uniaxial, +, ϵ 1.650, ω 1.638).
2% colorless, interstitial glass.

Name:—**Åkermanite + glass**

Granite 3 : Calcite 2 : 1 (6) (1470°C)

97% colorless glass.
3% spherulites and larger grids at edges of ingot, of åkermanite (uniaxial, +, $\epsilon >$ 1.638, ω 1.638).

Name:—**Glass + åkermanite**

Granite 3 : Calcite 3 : 1 (409) (1410°C)

90% spherulitic and sheaf-like åkermanite (uniaxial, +, with lower birefringence than the varieties richer in lime, $\epsilon >$ 1.638, $\omega <$ 1.638).
10% colorless glass, where crystallization has not extended.

Name:—**Åkermanite + glass**

Granite 3 : Calcite 3 : 1 (9) (1270°C)

99% colorless glass
1% radiating fibres of åkermanite, at edges of ingot (uniaxial, +, ϵ 1.645, ω 1.638).

Name:—**Glass + åkermanite**

Syenite a : Calcite 1 : 1 (416) (1410°C) (See Pl. 9, fig. 17.)
Consists of 70% åkermanite and 30% melilite, the proportions being similar in a fine-grained and in a

coarse-grained part. Iron globules are present in the fine-grained part. In the coarse-grained part the åkermanite crystals occur as dark brown, nearly opaque matter consisting of radiating fibres, uniaxial, +, ϵ 1.650, ω 1.645. The melitite crystals are uniaxial, –, with square basal sections and oblong longitudinal sections, ϵ 1.638, ω 1.650, and occur as large individuals in the coarse-grained part of the rock.

Name:—**Åkermanite - melilite rock**

Syenite : Calcite 1 : 1 (55) (1300°C)

100% colorless glass, with a few colorless åkermanite crystallites (uniaxial, +, ϵ 1.638, ω 1.625).

Name:—**Glass + åkermanite**

Syenite a : Calcite 2 : 1 (417) (1410°C)

99% brownish glass

1% long needles of åkermanite with medium birefringence (uniaxial, +, ϵ 1.638, ω 1.610).

Name:—**Glass + åkermanite**

Syenite : Calcite 2 : 1 (59) (1300°C)

70% colorless glass

30% radiating fibres and grids of åkermanite (uniaxial, +, birefringence medium; the grids do not give a dependable refractive index; some definite needles are present, with $\epsilon > 1.628$, $\omega < 1.628$).

Name:—**Glass + åkermanite**

Syenite a : Calcite 3 : 1 (418) (1410°C) (See Pl. 3, fig. 5.)

100% colorless glass, with myriads of brownish spherulites with fibres of + elongation and straight extinction, probably åkermanite.

Powder from lower edge showed some augite (biaxial, oblique extinction, > 1.680) and åkermanite (uniaxial, +, < 1.638). Powder from upper edge showed glass, or glass + åkermanite rosettes.

Name:—**Glass + åkermanite + augite**

Syenite : Calcite 3 : 1 (63) (1309°C)

50% colorless glass.

50% dark brown crystalline matter, a variety of åkermanite with low to medium birefringence (uniaxial, +, $\epsilon > 1.628$, ω 1.628).

Name:—**Glass + åkermanite**

Nepheline Syenite : Calcite 1 : 1 (419) (1410°C)

90% grids of åkermanite with medium birefringence (uniaxial, +, ϵ 1.638, ω 1.628, color mostly brown).

10% colorless interstitial matter of low birefringence (uniaxial, –, $\epsilon < 1.628$, $\omega > 1.628$). It is melilite.

Name:—**Åkermanite + melilite rock**

Nepheline Syenite : Calcite 1 : 1 (56) (1300°C) (See Pl. 2, fig. 3.)

70% colorless glass.

30% grids of åkermanite (nearly opaque, gray in color, uniaxial, +, $\epsilon > 1.628$, $\omega < 1.628$)

A few colorless cruciform and radiating crystals of åkermanite are present.

Name:—**Glass + åkermanite**

Nepheline Syenite : Calcite 2 : 1 (420) (1410°C) (See Pl. 2, fig. 4.)

70% glass of faint brown tint, with darker brown patches forming borders to clear parts.

30% colorless glass with stars and long needles of åkermanite with medium birefringence (uniaxial, +, ϵ slightly > 1.650, ω 1.650, for both stars and needles).

Name:—**Glass + åkermanite**

Nepheline Syenite : Calcite 2 : 1 (60) (1300°C)

100% colorless glass, with abundant opaque matter, partly as octahedra. A few microlites are arranged like dendrites.

Name:—**Glass**

Nepheline Syenite : Calcite 3 : 1 (421) (1410°C)

100% slightly brownish glass, with many small gas bubbles and opaque specks and some few darker spots of crystalline matter, as needles of negative elongation, ($\epsilon > 1.638$, $\omega < 1.638$), åkermanite.

Name:—**Glass with åkermanite**

Nepheline Syenite : Calcite 3 : 1 (64) (1309°C)

99% colorless glass.

1% tree-like microlites, –, uniaxial, undetermined. (R. I. not obtainable).

Name:—**Glass**

Andesite Porphyrite : Calcite 1 : 1 (422) (1410°C)

100% brownish mineral, much of it with radial arrangement, of high refractive index, medium berefrin-

gence, uniaxial, +, ϵ slightly > 1.619, ω slightly < 1.619, åkermanite. Many gas bubbles are present, some are elliptical due to squeezing.

Name:—**Åkermanite rock**

Andesite Porphyrite : Calcite 1 : 1 (57) (1300°C) (See Pl. 4, fig. 7.)

85% gray grids of a mineral of medium birefringence, –, refractive index not determinable, probably melilite.

15% tetragonal mineral, uniaxial, –, with a square or cruciform cross-section, formed from the grids mentioned, ϵ slightly < 1.628, ω slightly > 1.628. It is melilite.

A little colorless glass is present.

Name:—**Melilite rock?**

Andesite Porphyrite : Calcite 2 : 1 (423) (1410°C) (See Pl. 3, fig. 6.)

50% colorless glass, at centre.

50% stars and grids of åkermanite, partly clear and colorless, partly dirty brown in color, uniaxial, +, ϵ 1.638, ω slightly< 1.628.

Name:—**Åkermanite + glass**

Andesite Porphyrite : Calcite 2 : 1 (61) (1300°C)

99% colorless glass, with minute opaque specks and flow structure.

1% crystalline matter, as minute stars or grids, or collections of needles at the edges of the ingot; uniaxial, +, ϵ slightly > 1.628, ω slightly < 1.628, åkermanite.

Name:—**Glass + åkermanite**

Andesite Porphyrite : Calcite 3 : 1 (424) (1410°C)

98% colorless glass, with many large bubbles at one part.

2% grids and needles near edges, uniaxal, +, ϵ 1.624, ω 1.610, åkermanite. (like 423.)

Name:—**Glass + åkermanite**

Andesite Porphyrite : Calcite 3 : 1 (65) (1309°C)

100% colorless glass, with a few spherules of crystalline matter, of radial fibrous crystals with + elongation, not determined.

Name:—**Glass**

Feldspar Basalt : Calcite 1 : 1 (11) (1470°C) (See Pl. 4, fig. 8.)

90% nearly colorless glass with a few dark, practically opaque needles and many cruciform twins of a mineral of low birefringence, anomalous biaxial character, +, indices slightly < 1.650—åkermanite.

10% radial aggregates of probably åkermanite at margins.

Name:—**Glass + åkermanite**

Feldspar Basalt : Calcite 2 : 1 (14) (1470°C)

99% colorless glass, with abundant minute, opaque needles.

1% colorless needles of åkermanite at one edge, uniaxial, +, $\epsilon > 1.628$, $\omega < 1.628$.

Name:—**Glass + åkermanite**

Feldspar Basalt : Calcite 3 : 1 (17) (1470°C)

100% clear, colorless glass, with many opaque rods, and many opaque minute octahedra.

Name:—Glass

Basalt : Calcite 1 : 1 (410) (1410°C) (See Pl. 8, fig. 15.)

60% augite, practically colorless, with medium birefringence and indices > 1.692.

25% åkermanite, with anomalous biaxial character, +, birefringence very low, and fine peg structure, (ϵ and ω 1.650).

15% glass, some practically opaque, with some yellow perovskite.

Name:—**Åkermanite-augitite**

Basalt : Calcite 1 : 1 (10) (1470°C)

70% chrysolite of high refractive index, due to iron content, extinction straight, birefringence medium, indices > 1.710.

30% åkermanite, with anomalous biaxial character, +, low birefringence, fine peg structure, refractive indices difficult to obtain > 1.650, < 1.660.

A little augite is present as colorless blades.

Name:—**Olivine + åkermanite**

Basalt : Calcite 2:1 (411) (1410°C)

60% åkermanite as long needles with paralled arrangement (skeleton crystals), uniaxial, +, low birefringence, ϵ 1.638, ω 1.628.

40% dark brownish opaque matter between the åkermanite needles. Most of it is glass but some of it is augite with refractive indices > 1.692.

Name:—**Åkermanite-augitite**

Basalt : Calcite 2 : 1 (13) (1470°C) (See Pls. 5 and 6, figs. 9 to 12.

80% grids of large, long, colorless laths of åkermanite, uniaxial, +, low birefringence, ϵ 1.638, ω slightly > 1.628.

20% light drab colored glass, with one large augite crystal, a few microlites of the same, and some small, practically opaque needles, and many minute opaque octahedra.

Name:—**Åkermanite + glass**

Basalt : Calcite 3 : 1 (412) (1410°C)

75% augite, partly colorless, partly brown, in optical continuity, with refractive indices > 1.692.

25% åkermanite, uniaxial, +, low birefringence, ϵ < 1.650, ω slightly > 1.638, partly in laths as it could form between the augites; much of it is practically isotropic. Some colorless to faintly violet isotropic grains of perovskite are present, > 2.07.

Name:—**Augite - åkermanite rock**

Basalt : Calcite 3 : 1 (16) (1470°C) (See Pl. 7, figs 13 and 14.)

75% åkermanite in sets of long needles, uniaxial, +, ϵ > 1.665, ω < 1.665.

25% augite, clear, with high refractive indices (> 1.692), oblique extinction and very little cleavage.

Many minute opaque octahedra of magnetite are present.

Name:—**Åkermanite - augite rock**

Minette : Calcite 1 : 1 (413) (1410°C)

75% brownish chrysolite in rounded grains, extinction straight when the cleavage is visible, biaxial, +, γ 1.710, β > 1.692, α 1.692.

25% colorless chrysolite as long crystals with cross fractures and straight extinction; biaxial, +, γ > 1.710, β > 1.692, α < 1.692.

Name:—**Dunite**

Minette : Calcite 1 : 1 (12) (1470°C)

100% rounded grains of brownish chrysolite, biaxial, +, refractive indices > 1.680.

Name:—**Dunite**

Minette : Calcite 2 : 1 (414) (1410°C)

50% åkermanite, in part very dirty and with inclusions of the next described mineral, so that its optical characters are difficult to obtain; uniaxial, +, with fine peg structure, birefringence low, $\epsilon > 1.638$, ω 1.638. Some are zoned, both inner and outer zones are positive, the outer rims having higher birefringence (richer in lime).

35% åkermanite, with medium birefringence, uniaxial, +, ϵ 1.638, ω slightly < 1.628.

15% augite, biaxial, +, refractive indices > 1.710.

Much yellow to blue perovskite is present as good octahedra (> 2.07).

Name:—**Åkermanite - augite rock**

Minette : Calcite 2 : 1 (15) (1470°C)

A few large, tetragonal, uniaxial, +, crystals with low birefringence are present.

70% base of same materials, but of lower birefringence—åkermanite with refractive indices between 1.665 and 1.670.

30% small grains of augite, with refractive indices $>$ 1.710.

There are many bluish isotropic grains and octahedra of high refractive index—perovskite (> 2.07).

Name:—**Åkermanite-augite rock**

Minette : Calcite 3 : 1 (415) (1410°C)

65% åkermanite, (colorless, uniaxial, +, birefringence low) as long laths, ϵ 1.638, ω slightly < 1.638.

35% interstitial, dark brown, nearly opaque matter; some of it is isotropic but most of it is crystallized to augite, with brown or blue colors and refractive indices > 1.680.

Name:—**Åkermanite-augitite**

Minette: Calcite 3 : 1 (18) (1270°C) (See Pl. 8, fig. 16.)

80% large crystals of åkermanite, uniaxial, +, ϵ 1.665, $\omega < 1.650$.

20% riebeckite, as dark blue to opaque interstitial matter, partly in the form of grids, biaxial, +, extinction angle 8° Z $\wedge$ c, refractive indices between 1.680 and 1.692, pleochroic, X = Y > Z; Z blue, Y and X deep purple.

Name:—**Åkermanite-riebeckite rock**

Kimberlite : Calcite 1 : 1 (425) (1410°C)

80% fine-grained chrysolite of low birefringence, biaxial, +, $2V = 90°$, γ slightly > 1.692, $\beta > 1.680$, $\alpha = 1.680$.

20% nearly opaque dusty matter, unidentifiable.

Name:—**Dunite**

Kimberlite : Calcite 1 : 1 (58) (1300°C)

80% chrysolite of very low birefringence, nearly isotropic, biaxial, +, with refractive indices slightly greater and less than 1.692.

20% grains of a mineral with higher birefringence and oblique extinction, probably augite. The ingot is sintered only, but the minerals present are new. The whole is fine-grained and difficult to determine.

Name:—**Chrysolite + augite**

Kimberlite : Calcite 2 : 1 (426) (1410°C)

50% rounded grains of monticellite of low birefringence, but of higher birefringence than the remainder; biaxial, –, refractive indices between 1.638 and 1.650.

50% base of lower birefringence, but about the same refractive index, uniaxial, +, poikilitic, and with fine peg structure in places, is åkermanite. Some flakes with higher birefringence are also åkermanite. (ϵ 1.650, ω 1.638.)

Globules of iron and green isotropic grains of of perovskite, (> 2.07) are present.

Name:—**Monticellite-åkermanite rock**

Kimberlite : Calcite 2 : 1 (62) (1300°C)

100% small rounded colorless grains of monticellite, of low birefringence, biaxial, –, γ 1.662, β 1.658, α 1.648.

Some yellow grains and gray octahedra of probably perovskite are present (> 2.07).

Name:—**Monticellite rock**

Kimberlite : Calcite 3 : 1 (427) (1410°C)

50% coarse-grained part free from iron gobules, consists of:—

75% åkermanite, clear, uniaxial, +, birefringence medium, $\epsilon < 1.650$, ω 1.638.

25% brownish-violet augite, > 1.692.

50% fine-grained part consists of:—
74% monticellite (with some åkermanite), colorless, biaxial, –, γ slightly > 1.650, β < 1.650, α 1.638. The åkermanite is uniaxial, +, ϵ slightly > 1.638, ω 1.638.
20% colored aggregates of augite, > 1.692.
3% crystals of monticellite, av. 1.650.
3% iron globules.
Name:—**Monticellite + augite + åkermanite**

Kimberlite : Calcite 3 : 1 (66) (1309°C)

50% rounded and rectangular grains of monticellite, biaxial, –, γ 1.665, β 1.655, α 1.648.
50% dark interstitial matter of low birefringence, which is åkermanite, uniaxial, +, 1.638, with more finely grained monticellite, which makes up the greater part of this interstitial matter.
Isotropic yellow grains and some minute gray octahedra of probably perovskite are present, > 2.07.
Name:—**Monticellite + åkermanite**

IGNEOUS ROCKS AND KAOLIN

Granite 1 : Kaolin 1 : 1 (428) (1410°C)

90% dark colored glass, with some clear glass around the unmelted crystals.
10% unmelted crystals, chiefly quartz.
Name:—**Glass + unmelted crystals**

Granite 1 : Kaolin 1 : 1 (19) (1600°C) (See Pl. 10, fig. 19.)

100% nearly colorless glass, with abundant needles of sillimanite, of square cross-section and high refractive index (slightly > 1.660).
Name:—**Glass + sillimanite**

Granite 1 : Kaolin 2 : 1 (429) (1410°C)

85% brown glass, with more clear glass round the unmelted crystals than in 428.
15% unmelted crystals.
Name:—**Glass + unmelted crystals**

Granite 1 : Kaolin 2 : 1 (22) (1600°C)

98% slightly grayish glass, with abundant needles of sillimanite (γ > 1.660, α 1.660) and opaque grains.
2% colorless clear glass.
Name:—**Glass + sillimanite**

Granite 1 : Kaolin 3 : 1 (430) (1410°C)

85% glass, partly brown, partly colorless around the unmelted crystals.

15% unmelted crystals.

Name:—**Glass + unmelted crystals**

Granite 1 : Kaolin 3 : 1 (25) (1600°C)

100% colorless glass, with abundant, minute, opaque specks.

Name:—**Glass**

Granite 2 : Kaolin 1 : 1 (431) (1410°C)

92% brownish glass, with a small amount of colorless glass around crystal fragments.

8% unmelted crystals.

Name:—**Glass + unmelted crystals**

Granite 2 : Kaolin 1 : 1 (20) (1600°C)

100% nearly colorless glass, with abundant colorless needles of sillimanite with refractive indices slightly greater than 1.670.

Name:—**Glass + sillimanite**

Granite 2 : Kaolin 2 : 1 (432) (1410°C)

90% glass, mostly brown; more colorless glass round unmelted crystals than in 431.

10% unmelted crystals.

Name:—**Glass + unmelted crystals**

Granite 2 : Kaolin 2 : 1 (23) (1600°C)

100% colorless glass, with opaque grains, and abundant needles of sillimanite, as in 22 with refractive indices above 1.660.

Name:—**Glass + sillimanite**

Granite 2 : Kaolin 3 : 1 (433) (1410°C)

95% glass, mostly colorless, with some blotchy remnants. Many minute, indeterminable needles (probably sillimanite) are present in this glass.

5% unmelted crystals.

Name:—**Glass + unmelted crystals + sillimanite?**

Granite 2 : Kaolin 3 : 1 (26) (1600°C)

100% colorless glass, with abundant opaque specks.

Name:—**Glass**

Granite 3 : Kaolin 1 : 1 (434) (1410°C)

90% brownish glass.

10% unmelted crystals.

Name:—**Glass + unmelted crystals**

Granite 3 : Kaolin 1 : 1 (21) (1600°C)

100% nearly colorless very vesicular glass, with much opaque or dusty matter, due to undigested kaolin.

Name:—**Glass**

Granite 3 : Kaolin 2 : 1 (435) (1410°C)

90% glass, mostly brown, opaque; some is colorless and clear, around the unmelted crystals.

10% unmelted crystals.

Name:—**Glass + unmelted crystals**

Granite 3 : Kaolin 2 : 1 (24) (1600°C)

100% glass with abundant minute specks. A few needles only of sillimanite have grown from the edge of the ingot, at one side; elongation +, refractive indices between 1.660 and 1.670.

Name:—**Glass + sillimanite**

Granite 3 : Kaolin 3 : 1 (436) (1410°C)

90% glass, half blotchy, opaque, half colorless with many minute indeterminable needles, probably sillimanite.

10% unmelted crystals.

Name:—**Glass + unmelted crystals + sillimanite?**

Granite 3 : Kaolin 3 : 1 (27) (1270°C)

50% colorless glass, with some few indeterminable needles, probably sillimanite.

30% brownish opaque matter, due to incomplete absorption of kaolin.

20% unmelted quartz crystals.

Name:—**Glass + unmelted quartz and kaolin**

Syenite a : Kaolin 1 : 1 (443) (1410°C)

100% brown glass, practically nothing remaining unmelted.

Name:—**Glass**

Syenite : Kaolin 1 : 1 (67) (1309°C)

100% brownish glass, with some opaque spots, and some spots of dark brown color. A few unmelted quartz crystals remain.

Name:—**Glass + unmelted quartz**

Syenite a : Kaolin 2 : 1 (444) (1410°C)

50% radial masses and sheaves of plagioclase needles (andesine, –, average refractive index between 1.550 and 1.557) and orthoclase (refractive index less than 1.528) in a base.

30% brownish to nearly opaque unassimilated matter.
20% grayish glass, enclosing the unassimilated matter.
Name:—**Glass + andesine + kaolin + little orthoclase**

Syenite : Kaolin 2 : 1 (71) (1402°C)

100% glass, partly colorless, partly brownish to opaque, due to incomplete assimilation of kaolin. A few unmelted crystals remain. Many minute needles (indeterminable, probably sillimanite) are present in the colorless glass.
Name:—**Glass + kaolin + sillimanite?**

Syenite a : Kaolin 3 : 1 (445) (1410°C) (See Pl. 11, fig. 22.)

65% grayish base, mostly crystalline, consisting of fibres of orthoclase (< 1.54) with some sillimanite needles (> 1.660).
25% radial felted masses of plagioclase needles (oligoclase-andesine, –, average refractive index between 1.545 and 1.550).
10% brownish, unassimilated matter.
Name:—**Orthoclase + plagioclase + kaolin**

Syenite : Kaolin 3 : 1 (75) (1402°C)

100% colorless glass with some brownish patches due to incomplete assimilation of kaolin, and with some unmelted crystal fragments.
Name:—**Glass + unmelted crystals**

Nepheline Syenite : Kaolin 1 : 1 (446) (1410°C)

100% brown, nearly opaque glass, with very little unmelted matter.
Name:—**Glass**

Nepheline Syenite : Kaolin 1 : 1 (68) (1309°C)

100% brownish glass, with some opaque spots and some spots of dark brown color, and a few unmelted crystals, especially zircons.
Name:—**Glass + unmelted crystals**

Nepheline Syenite : Kaolin 2 : 1 (447) (1410°C)

50% brownish glass, due to incomplete assimilation of kaolin.
50% colorless glass with many minute, indeterminable needles, probably sillimanite, and a few unmelted crystals.
Name:—**Glass + unmelted crystals + sillimanite?**

Nepheline Syenite : Kaolin 2 : 1 (72) (1402°C)

100% glass, partly colorless, partly brownish, with a few unmelted crystals.

Name:—**Glass + unmelted crystals**

Nepheline Syenite : Kaolin 3 : 1 (448) (1410°C)

85% colorless glass with many minute microlites and a few distinct needles of sillimanite (R.I. not obtainable).

15% opaque patches in the above.

Name:—**Glass**

Nepheline Syenite : Kaolin 3 : 1 (76) (1402°C)

100% colorless glass, with brownish patches and unmelted crystal remnants.

Name:—**Glass + unmelted crystals**

Andesite Porphyrite : Kaolin 1 : 1 (449) (1410°C)

100% dark brown, opaque glass.

Name:—**Glass**

Andesite Porphyrite : Kaolin 1 : 1 (69) (1309°C)

100% Brownish glass, with a few unmelted crystal remnants.

Name:—**Glass + unmelted crystals**

Andesite Porphyrite : Kaolin 2 : 1 (450) (1410°C) (See Pl. 10, fig. 20.)

90% nearly colorless glass (refractive index 1.660) with many minute needles of sillimanite with refractive indices greater than 1.660.

10% brownish to opaque patches.

Name:—**Glass + sillimanite**

Andesite Porphyrite : Kaolin 2 : 1 (73) (1402°C)

100% glass, mostly colorless, with some brown patches, and some dusty opaque patches. Many needles of sillimanite (slightly > 1.660) are present in the clear part. A few unmelted crystals remain.

Name:—**Glass + sillimanite + unmelted crystals**

Andesite Porphyrite : Kaolin 3 : 1 (451) (1410°C)

100% colorless glass with many minute opaque specks with flow arrangement. Some long needles of sillimanite (refractive indices > 1.660) radiate from certain points on the edges.

Name:—**Glass + sillimanite**

Andesite Porphyrite : Kaolin 3 : 1 (77) (1402°C)

100% colorless glass, with minute opaque specks in flow arrangement. A few dark brown isotropic patches with indeterminable needles (probably sillimanite) radiating from their peripheries. A few unmelted crystals remain.

Name:—**Glass + sillimanite? + unmelted crystals**

Feldspar Basalt : Kaolin 1 : 1 (29) (1500°C)

50% gray glass with abundant needles of sillimanite (refractive indices > 1.660).

50% opaque matter, due to incomplete assimilation of kaolin.

Name:—**Glass + kaolin + sillimanite**

Feldspar Basalt : Kaolin 2 : 1 (32) (1500°C)

100% colorless glass with abundant opaque specks and a few long needles of sillimanite (with refractive indices greater than 1.660) at the edges.

Name:—**Glass + sillimanite**

Feldspar Basalt : Kaolin 3 : 1 (35) (1500°C)

100% slightly yellowish glass, with some opaque specks near edges.

Name:—**Glass**

Basalt : Kaolin 1 : 1 (437) (1410°C) (See Pl. 11, fig. 21.)

90% mostly clear, colorless glass, partly brownish and crystalline, due to the development of anorthite (–, > 1.572, extinction angle 48°).

10% long, clear needles of sillimanite in the clear glass, and some in the brownish part (average refractive index between 1.665 and 1.670).

Name:—**Glass + sillimanite + anorthite**

Basalt : Kaolin 1 : 1 (28) (1500°C) (See Pl. 9, fig. 18.)

100% colorless glass, with abundant opaque globules. A few long needles of sillimanite (all indices > 1.660) occur at the margins.

Name:—**Glass + sillimanite**

Basalt : Kaolin 2 : 1 (438) (1410°C) (See Pl. 12, fig. 23.)

60% brownish base with felted mass of sillimanite needles, partly without birefringence and showing change to plagioclase.

40% anorthite needles, with the same felted arrangement as the sillimanite. The anorthite is biaxial, –, with average refractive index between 1.572 and 1.600.

Name:—**Anorthite + glass**

Basalt : Kaolin 2 : 1 (31) (1500°C)

100% colorless glass, with abundant opaque specks.

Name:—**Glass**

Basalt : Kaolin 3 : 1 (439) (1410°C)

90% dark brown glass, with indications of long needles of sillimanite.

10% sheaves of anorthite laths (average refractive index > 1.572) developing at the expense of sillimanite, and associated with dark brown glass.

Name:—**Glass + sillimanite + anorthite**

Basalt : Kaolin 3 : 1 (34) (1500°C)

100% colorless glass, with abundant small star-like, indeterminable microlites, with flow arrangement.

Name:—**Glass**

Minette : Kaolin 1 : 1 (440) (1410°C)

50% long laths of anorthite (average refractive index 1.581, extinction angle 50°) with indications of development at the expense of sillimanite needles in sheaves.

50% dark brown glass.

Name:—**Feldspar basalt**

Minette : Kaolin 1 : 1 (30) (1500°C)

98% slightly yellowish glass, with opaque globules with flow arrangement.

2% very dark brown, radiating crystalline matter, probably feldspar after sillimanite.

Name:—**Glass + feldspar?**

Minette : Kaolin 2 : 1 (441) (1410°C)

75% long anorthite (average refractive index slightly > 1.581) or sillimanite needles, with sheaf-like arrangement, the plagioclase developing from the sillimanite.

25% light brownish glass, with many ragged needles with straight extinction and higher birefringence than the feldspar, probably enstatite (average refractive index between 1.600 and 1.660).

Name:—**Basalt, variety**

Minette : Kaolin 2 : 1 (33) (1500°C)

100% grayish glass with abundant indeterminable needles and tree-like microlites.

Name:—**Glass**

Minette : Kaolin 3 : 1 (442) (1410°C)

80% greenish augite, > 1.692.

20% colorless to grayish glass, very vesicular.

Name:—**Augitite, variety**

Minette : Kaolin 3 : 1 (36) (1270°C)

100% slightly yellowish glass with opaque globules.

Name:—**Glass**

Kimberlite : Kaolin 1 : 1 (452) (1410°C)

65% grayish to colorless base, partly colorless glass, partly crystalline, difficult to determine, consisting of anorthite (average refractive index between 1.581 and 1.590, extinction angle 41°).

35% long needles of grayish bronzite (extinction straight, +, refractive indices between 1.680 and 1.692).

Name:—**Bronzite basalt**

Kimberlite : Kaolin 1 : 1 (70) (1309°C) (See Pl. 15, fig. 29.)

75% colorless mineral with rectangular and occasional hexagonal sections, with straight extinction, uniaxial, –, low birefringence (ϵ 1.526, ω 1.531)—cordierite.*

25% dark brown, interstitial matter, partly glass and partly anisotropic, with oblique extinction and refractive indices greater than 1.710—augite.

Name:—**Cordierite + augite + glass**

Kimberlite : Kaolin 2 : 1 (453) (1410°C)

60% long augite needles and skeleton needles (> 1.692).

40% base, partly colorless glass, partly crystalline with development of a herring-bone structure, the beginning of the assemblage of augite (extinction oblique).

Name:—**Augitite, variety**

Kimberlite : Kaolin 2 : 1 (74) 1402°C) (See Pl. 16, fig. 31.)

60% colorless crystals and skeleton crystals of forsterite (biaxial, +, 2V = 90°, refractive indices between 1.660 and 1.665).

40% dark brown, nearly opaque glass.

Name:—**Forsterite + glass**

Kimberlite : Kaolin 3 : 1 (454) (1410°C) (See Pl. 18, fig. 36.)

50% skeleton crystals of augite (γ > 1.692, α < 1.692); some are colored and pleochroic.

*Compare Rankin and Merwin, Amer. Jour. Sci., 45, 1918, p. 317, for uniaxial artificial cordierite.

50% glass, partly colorless, partly dark brown.
A fine-grained part is similar to the above, with chrysolite (refractive indices between 1.680 and 1.692) as small equant grains.

Name:—**Augitite to limburgite**

Kimberlite : Kaolin 3 : 1 (78) (1402°C)

75% very fine-grained augite (> 1.692) with some chrysolite (≦ 1.680 < 1.692).
25% brown glass. Name:—**Limburgite**

IGNEOUS ROCKS AND QUARTZ

Granite 1 : Quartz 1 : 1 (455) (1410°C)

50% colorless glass.
50% unmelted, cracked quartz grains.

Name:—**Glass + unmelted quartz**

Granite 1 : Quartz 1 : 1 (37) (1440°C)

50% quartz grains changed to cristobalite, and a few unchanged quartz grains.
50% grayish glass.

Name:—**Glass + cristobalite + unmelted quartz**

Granite 1: Quartz 2 : 1 (456) (1410°C)

Like 455. Name:—**Glass + unmelted quartz**

Granite 1 : Quartz 2 : 1 (40) (1440°C)

Grayish glass and quartz grains changed to cristobalite (> 1.479, < 1.491).

Name:—**Glass + cristobalite**

Granite 1 : Quartz 3 : 1 (457) (1410°C)

60% colorless glass.
40% unmelted quartz grains, mostly fractured.

Name:—**Glass + unmelted quartz**

Granite 1 : Quartz 3 : 1 (43) (1440°C)

Glass and quartz grains changed to cristobalite.

Name:—**Glass + cristobalite**

Granite 2 : Quartz 1 : 1 (458) (1410°C)

50% colorless glass.
50% unmelted quartz grains, mostly fractured.

Name:—**Glass + unmelted quartz**

Granite 2 : Quartz 1 : 1 (38) (1440°C)

60% grayish glass.
40% quartz grains changed to cristobalite, a few remaining unchanged.

Name:—**Glass + cristobalite**

Granite 2 : Quartz 2 : 1 (459) (1410°C)

70% colorless glass.
30% unmelted quartz grains, many fractured.

Name:—**Glass + unmelted quartz**

Granite 2 : Quartz 2 : 1 (41) (1440°C)

Colorless glass with quartz grains changed to cristobalite.

Name:—**Glass + cristobalite**

Granite 2 : Quartz 3 : 1 (460) (1410°C)

75% colorless glass.
25% unmelted quartz grains, partly fractured.

Name:—**Glass + unmelted quartz**

Granite 2 : Quartz 3 : 1 (44) (1440°C)

Glass with quartz grains changed to cristobalite.

Name:—**Glass + cristobalite**

Granite 3 : Quartz 1 : 1 (461) (1410°C)

50% colorless glass.
50% unmelted quartz grains.

Name:—**Glass + unmelted quartz**

Granite 3 : Quartz 1 : 1 (39) (1440°C)

50% quartz grains changed to cristobalite.
50% grayish glass.

Name:—**Glass + cristobalite**

Granite 3 : Quartz 2 : 1 (462) (1410°C)

66% colorless glass.
34% unmelted quartz grains.

Name:—**Glass + unmelted quartz**

Granite 3 : Quartz 2 : 1 (42) (1440°C)

Glass with quartz grains changed to cristobalite, a few remaining unchanged.

Name:—**Glass + cristobalite + quartz**

Granite 3 : Quartz 3 : 1 (463) (1410°C)

66% colorless glass.
34% unmelted quartz grains, many fractured.

Name:—**Glass + unmelted quartz**

Granite 3 : Quartz 3 : 1 (45) (1270°C)

65% glass.
35% unmelted quartz grains.

Name:—**Glass + unmelted quartz**

Syenite : Quartz 1 : 1 (79) (1249°C)

50% colorless glass with some dark brown patches.
50% unmelted quartz grains.

Name:—**Glass + unmelted quartz**

Syenite a : Quartz 1 : 1 (470) (1410°C)

60% colorless glass.
40% unmelted, fractured quartz grains.

Name:—**Glass + unmelted quartz**

Syenite a : Quartz 2 : 1 (471) (1410°C)

90% colorless glass with flow structure.
10% unmelted fractured quartz grains.

Name:—**Glass + unmelted quartz**

Syenite : Quartz 2 : 1 (83) (1249°C)

66% colorless glass with a few brown patches, and rare radiating, indeterminable crystal needles.
34% unmelted quartz grains.

Name:—**Glass + unmelted quartz**

Syenite a : Quartz 3 : 1 (472) (1410°C)

98% colorless glass, with many minute opaque specks in flow arrangement.
2% unmelted, fractured quartz grains.

Name:—**Glass + unmelted quartz**

Syenite : Quartz 3 : 1 (87) (1379°C)

75% colorless glass, with yellowish streaks.
25% quartz grains changed to cristobalite.

Name:—**Glass + cristobalite**

Nepheline Syenite : Quartz 1 : 1 (473) (1410°C)

100% isotropic matter, mostly glass, but partly quartz grains changed to cristobalite, some still showing small unmelted quartz remnants in them. Some unmelted zircon crystals are present.

Name:—**Glass + cristobalite**

Nepheline Syenite : Quartz 1 : 1 (80) (1249°C)

50% colorless glass.
50% unmelted quartz.

Name:—**Glass + unmelted quartz**

Nepheline Syenite : Quartz 2 : 1 (474) (1410°C)

100% clear, colorless glass, with many gas bubbles and many quartz grains changed to cristobalite, some few with remnants of quartz in them. A few fragments of zircon are present.

Name:—**Glass + cristobalite**

Nepheline Syenite : Quartz 2 : 1 (84) (1249°C)

66% colorless glass.
34% unmelted quartz.

Name:—**Glass + unmelted quartz**

Nepheline Syenite : Quartz 3 : 1 (475) (1410°C)

100% clear, colorless glass, with many gas bubbles, and some quartz grains changed to cristobalite. Many unmelted zircons are present, mostly collected at the surfaces of gas bubbles.

Name:—**Glass + cristobalite**

Nepheline Syenite : Quartz 3 : 1 (88) (1379°C)

75% colorless to gray glass.
25% quartz grains changed to cristobalite.

Name:—**Glass + cristobalite**

Andesite Porphyrite : Quartz 1 : 1 (476) (1410°C)

65% colorless glass, with many colorless microlites.
35% unmelted, fragmented quartz grains.

Name:—**Glass + unmelted quartz**

Andesite Porphyrite : Quartz 1 : 1 (81) (1249°C)

50% gray to colorless glass with some dark brown parts. Some indeterminable fibrous crystalline needles are in it.
50% unmelted quartz grains.

Name:—**Glass + unmelted quartz**

Andesite Porphyrite : Quartz 2 : 1 (477) (1410°C)

85% colorless glass with flow structure shown by minute opaque specks.
15% unmelted, fragmented quartz grains.

Name:—**Glass + unmelted quartz**

Andesite Porphyrite : Quartz 2 : 1 (85) (1249°C)

66% colorless glass, with some dark brown patches.
34% unmelted quartz grains.

Name:—**Glass + unmelted quartz**

Andesite Porphyrite : Quartz 3 : 1 (478) (1410°C)

95% colorless glass, with some flow structure.
5% unmelted quartz grains.

Name:—**Glass + unmelted quartz**

Andesite Porphyrite : Quartz 3 : 1 (89) (1379°C)

90% colorless glass.
10% unmelted quartz and quartz changed to cristobalite.

Name:—**Glass + unmelted quartz + cristobalite**

Feldspar Basalt : Quartz 1 : 1 (47) (1450°C)

65% colorless glass.
35% quartz grains changed to cristobalite, (> 1.479, < 1.491) with some unmelted quartz remnants in the same.

Name:—**Glass + cristobalite**

Feldspar Basalt : Quartz 2 : 1 (50) (1450°C)

95% yellowish glass with abundant opaque specks.
5% quartz grains changed to cristobalite.

Name:—**Glass + cristobalite**

Feldspar Basalt : Quartz 3 : 1 (53) (1450°C)

99.5% yellow glass.
.5% quartz grains changed to cristobalite, often collected round gas bubbles. Very few unmelted quartz remnants are present.

Name:—**Glass + cristobalite**

Basalt : Quartz 1 : 1 (464) (1410°C) (See Pl. 14, fig. 28.)

70% dark brown base, partly glass, partly indeterminable crystalline matter.
20% needles in stars of very low birefringence — tridymite (refractive index not obtainable).
10% unmelted cracked quartz grains.

Name:—**Basaltic glass + tridymite + unmelted quartz**

Basalt : Quartz 1 : 1 (46) (1450°C) (See Pl. 14, fig. 27.)

60% dark brown glass.
30% rosettes and radiating crystals, extending outward from the changed quartz grains, mostly isotropic, some with straight extinction and very low birefringence, average refractive index 1.480, — tridymite.
10% quartz grains changed to cristobalite, with one or two remnants of unchanged quartz.

Name.—**Glass + tridymite + cristobalite**

Basalt : Quartz 2 :1 (465) (1410°C)

100% dark brown matter mostly glass, 80% opaque, 20% translucent. The latter part shows radial crystallization, but is not identifiable.

Name:—**Spherulitic andesitic? glass**

Basalt : Quartz 2 : 1 (49) (1450°C)

95% dark yellow glass.
5% abundant small spherical dark brown patches due to absorption of some of the abundant minute opaque specks, which have flow arrangement, as a result of the movement of gas bubbles, some of which are visible.

Name:—**Glass**

Basalt : Quartz 3 : 1 (466) (1410°C)

100% dark brown to gray spherulitic matter, consisting of needles with the characters of augite (extinction oblique, refractive indices higher than 1.692).

Name:—**Spherulitic augitite**

Basalt : Quartz 3 : 1 (52) (1450°C)

100% yellowish glass, with abundant opaque specks.

Name:—**Glass**

Minette : Quartz 1 : 1 (467) (1410°C) (See Pl. 30,, fig. 60)

75% gray, nearly opaque glass, with tridymite needles (refractive index 1.480) often radiating from quartz grains.

15% unmelted, fractured quartz grains.

10% brownish globules, partly glassy, partly crystalline, within and separate from the gray glass. (See Fig. 60.)

Name:—**Two glasses* + tridymite + unmelted quartz**

Minette : Quartz 1 :1 (48) (1450°C)

85% very dark brown, opaque glass.

10% quartz grains changed to cristobalite.

5% colorless laths of tridymite (refractive index = or < 1.480) associated with the cristobalite.

Name:—**Glass + cristobalite + tridymite**

Minette : Quartz 2 : 1 (468) (1410°C)

80% slightly brownish augite (> 1.692).

20% gray, nearly opaque, isotropic matter.

Name:—**Augitite**

Minette : Quartz 2 : 1 (51) (1450°C)

60% gray glass.

40% darker gray patches through the former, probably augite (> 1.692, extinction oblique).

Name:—**Augitite?**

Minette : Quartz 3 : 1 (469) (1410°C)

60% opaque matter.

40% dark brown matter; where translucent it is spherulitic, probably oligoclase-andesine (1.545).

Name:—**Andesite? variety**

*Compare Grieg, J. W. Amer. Jour. Sci. Ser. 5, 13, 1927, pp. 1 and 133 on immiscibility in silicate melts.
Day, A. L. Ann. Rep. Dir. Geophys. Lab. Year Book 25, 1925-6, pp. 61-62.
Tanton, T. L. Jour. Geol. 33, 1925, pp. 629-641.
Tanton, T. L. Amer. Jour. Sci., Ser. 5, 15, 1928, p. 66.

Minette : Quartz 3 : 1 (54) (1270°C)

50% dark gray glass.
50% darker brown crystalline masses, in radiating fibres, with oblique extinction, possibly augite.

Name:—**Augitite?**

Kimberlite : Quartz 1 : 1 (479) (1410°C)

80% crystalline base most of which is augite of low birefringence, and refractive indices > 1.692.
10% brownish glass.
10% unmelted quartz grains and quartz grains changed to cristobalite.

Name:—**Augitite + unmelted quartz + cristobalite**

Kimberlite : Quartz 1 : 1 (82) (1249°C)

50% unchanged, angular quartz grains.
50% nearly opaque, very fine-grained matter between the quartz grains, mostly isotropic, anisotropic in places, but indeterminable (probably augite).

Name:—**Glass + quartz**

Kimberlite : Quartz 2 : 1 (480) (1410°C)

60% colorless rounded crystals of chrysolite, with refractive indices between 1.680 and 1.692.
27% gray interstitial augite.
11% colorless laths of clino-enstatite.
2% interstitial brown glass. A few unmelted grains of quartz are present.

Name:—**Limburgite**

Kimberlite : Quartz 2 : 1 (86) (1249°C)

50% small crystal grains, possibly clino-enstatite (< 1.650).
30% unaltered, angular quartz grains.
20% dark brown glass.

Name:—**Basalt + quartz**

Kimberlite : Quartz 3 : 1 (481) (1410°C) (See Pl. 17, figs. 33 and 34.)

70% colorless clino-enstatite, much of it with polysynthetic twinning, +; all the refractive indices are close to 1.665.
30% dark gray interstitial needles of augite.

Name:—**Clino-enstatite + Augite**

Kimberlite : Quartz 3 : 1 (90) (1379°C)

99% long crystal fibres, for the most part with straight extinction, but some parts show oblique extinction under high magnifications; refractive indices higher than 1.692 — augite.

1% interstitial, dark brown glass. Name:—**Augitite**

IGNEOUS ROCKS AND MAGNETITE

Granite 1 : Magnetite 1 : 1 (101) (1230°C)

50% brown glass.

50% opaque areas of unidentified needles embedded in glass. Name:—**Glass + crystalline needles**

Granite 1 : Magnetite 1 : 1 (543) (1410°C)

100% very dark brown glass; part is crypto-crystalline, of indeterminable character.

Name:—**Basaltic glass**

Granite 1 : Magnetite 2 : 1 (102) (1230°C)

70% needles of enstatite (+, with refractive indices = and < 1.650) with featherlike attachments.

25% glass, mostly colorless, some dark brown, part with radial crystallization. A few unmelted quartz fragments are in the glass.

5% metallic iron.

Name:—**Enstatite + glass + iron**

Granite 1 : Magnetite 2 : 1 (544) (1410°C)

100% very dark brown glass with some banded structure due to differences of brown color and ? flow structure; very little of the glass suggests crystalline character. Many minute globules of iron are present. Name:—**Glass**

Granite 1 : Magnetite 3 : 1 (103) (1230°C) (See Pl. 24, fig. 48.)

80% yellow to brown glass, with unmelted crystal fragments.

10% needles and larger grids of augite? (characters not determinable).

10% iron.

The lower part of the ingot is glassy; quartz grains are important at the edges.

Grids or needles of augite? occur only near the top.

Name:—**Augitite?**

Granite 1 : Magnetite 3 : 1 (545) (1410°C)

75% opaque assemblages with a tendency to globular shapes and arrangements in bands.
25% dark drab glass.

Name:—**Glass**

Syenite : Magnetite 1 : 1 (110) (1230°C)

33% iron.
34% dark brown glass.
33% enstatite needles (+, $\gamma > 1.650$, α 1.650).

Name:—**Glass + enstatite + iron**

Syenite a : Magnetite 1 : 1 (552) (1410°C)

85% brown radially crystallized, spherulitic matter (orthoclase, < 1.539) with some granules of iron.
15% clear, colorless glass, with small globules of iron.

Name:—**Spherulitic, glassy trachyte**

Syenite : Magnetite 2 : 1 (111) (1230°C)

75% yellow and less colored glass, the latter with many dark needles of augite. (R. I. not obtainable.)
15% dark brown, indeterminable, radially crystalline matter.
10% metallic iron.

Name:—**Glass + iron + augite**

Syenite a : Magnetite 2 : 1 (553) (1410°C)

95% brown, radially crystallized, spherulitic orthoclase (1.539) with granules of iron and gas bubbles between the fibres.
5% glass of lighter color, carrying minute opaque globules with flow arrangement.

Name:—**Spherulitic trachyte**

Syenite : Magnetite 3 : 1 (112) (1230°C)

55% augite needles and grids (> 1.692).
35% brown glass.
10% metallic iron.

Name:—**Augitite**

Syenite a : Magnetite 3 : 1 (554) (1410°C)

85% very dark brown, radially crystallized orthoclase (1.539) with much fine opaque matter and gas bubbles, some of which are elliptical.
15% very dark brown glass, with much fine opaque matter and gas bubbles.

Name:—**Trachyte**

Nepheline Syenite : Magnetite 1 : 1 (113) (1230°C)

35% metallic iron.
45% brown glass, very dark in places.
20% enstatite needles (+, indices between 1.650 and 1.660).

Name:—**Glass + iron + enstatite**

Nepheline Syenite : Magnetite 1 : 1 (555) (1410°C)

100% nearly colorless glass, with many minute opaque globules, often with flow arrangement.

Name:—**Glass**

Nepheline Syenite : Magnetite 2 : 1 (114) (1230°C)

80% brown glass, partly crystallized.
10% bronzite needles (extinction straight, +, average refractive index 1.692).
10% metallic iron.

Name:—**Glass + bronzite + iron**

Nepheline Syenite : Magnetite 2 : 1 (556) (1410°C)

100% colorless glass, with very minute opaque globules, with flow arrangement.

Name:—**Glass**

Nepheline Syenite : Magnetite 3 : 1 (115) (1230°C)

75% dark brown radially crystallized andesine (+, 1.550).
20% very dark brown glass, with some needles of augite (R. I. not obtainable).
5% metallic iron.

Name:—**Andesite variety**

Nepheline Syenite : Magnetite 3 : 1 (557) (1410°C)

100% colorless glass, with very minute opaque globules, with flow arrangement.

Name:—**Glass**

Andesite Porphyrite : Magnetite 1 : 1 (116) (1230°C)

40% metallic iron.
40% dark colored glass.
15% augite needles (R. I. > 1.710).
5% fine grained olivine, in one part (fayalite > 1.710).

Name:—**Limburgite**

Andesite Porphyrite : Magnetite 1 : 1 (558) (1410°C)

100% colorless to slightly brownish glass, with multitudes of very minute opaque globules and rods, and at a few points collections of felted needles of indeterminable matter.

Name:—**Glass**

Andesite Porphyrite : Magnetite 2 : 1 (117) (1230°C)

55% very dark glass, with
15% long needles of augite (> 1.692).
30% metallic iron.

Name:—**Augitite**

Andesite Porphyrite : Magnetite 2 : 1 (559) (1410°C)

100% colorless to slightly brownish glass, with many minute opaque globules and rods, and a few felted masses of indeterminable needles.

Name:—**Glass**

Andesite Porphyrite : Magnetite 3 : 1 (118) (1230°C)

60% very dark glass with inclusions of augite.
25% augite needles (> 1.692).
15% metallic iron.

Name:—**Augitite**

Andesite Porphyrite : Magnetite 3 : 1 (560) (1410°C)

100% colorless glass, with many minute opaque globules, with flow arrangement. The color of the glass is brownish where rich in iron. The flow structure is very striking.

Name:—**Glass**

Basalt : Magnetite 1 : 1 (104) (1230°C)

30% brown glass.
30% fairly large colorless olivines (indices > 1.692).
30% brownish augites, partly asteroid (indices > 1.692).
10% metallic iron.

Name:—**Limburgite**

Basalt : Magnetite 1 : 1 (546) (1410°C)

99% long needles, and cockscombs of augite (> 1.692).
1% dark brown to opaque glass.

Name:—**Augitite**

Basalt : Magnetite 2 : 1 (105) (1230°C)

35% yellowish brown glass.
30% colorless olivines (> 1.692).
30% brownish augites (> 1.692).
5% metallic iron.

Name:—**Limburgite**

Basalt : Magnetite 2 : 1 (547) (1410°C)

70% augite needles (> 1.692) with some cockscomb arrangement.
20% light colored glass.
10% very dark colored glass.

Name:—**Augitite**

Basalt : Magnetite 3 : 1 (106) (1230°C)

45% yellowish glass.
20% olivines (>1.692).
20% augites (> 1.692). The last two constituents are not evenly distributed.
15% metallic iron.

Name:—**Limburgite**

Basalt : Magnetite 3 : 1 (548) (1410°C)

90% augite (> 1.692, some of it shows oblique extinction, much of it shows straight extinction).
10% dark glass. All of the rock is very dark colored and cellular.

Name:—**Augitite**

Minette : Magnetite 1 : 1 (107) (1230°C)

65% fine-grained crystalline matter, probably all augite (>1.680).
35% metallic iron.

Name:—**Augite + iron**

Minette : Magnetite 1 : 1 (549) (1410°C)

100% augite (> 1.692) with fibrous arrangement.

Name:—**Pyroxenite**

Minette : Magnetite 2:1 (108) (1230°C)

70% finely crystalline matter; much is colored and is probably augite; some is colorless and may be olivine; but they are too indefinite for recognition.
30% metallic iron.

Name:—**Peridotite, variety**

Minette : Magnetite 2 : 1 (550) (1410°C)

100% augite (> 1.692) with fibrous structure.

Name:—**Pyroxenite**

Minette : Magnetite 3 : 1 (109) (1230°C)

50% brownish augite (> 1.692).
25% colorless chrysolite (biaxial, +, = and > 1.680).
25% metallic iron.

Name:—**Peridotite**

Minette : Magnetite 3 : 1 (551) (1410°C)

100% slightly brownish augite (> 1.692). A very little dark brown glass is present between the fibres of augite.

Name:—**Augitite or Pyroxenite**

Kimberlite : Magnetite 1 : 1 (119) (1230°C)

60% partly crystalline matter, not clearly determinable, but augite is recognizable and occasionally olivine; some matter seems isotropic, but there is no definite glass.

40% metallic iron. Name:—**Peridotite**

Kimberlite : Magnetite 1 : 1 (561) (1410°C)

50% brownish to opaque augite (> 1.692).

50% chrysolite in smaller crystals than the augite (= < 1.680). Many of them have inclusions of minute opaque particles at their centres.

A small amount of interstitial brown glass is present.

Name:—**Limburgite**

Kimberlite : Magnetite 2 : 1 (120) (1230°C)

Like 119, indeterminate; augite and olivine are recognizable here and there.

25% metallic iron is present. Name:—**Peridotite**

Kimberlite : Magnetite 2 : 1 (562) (1410°C)

65% chrysolite (< 1.692) many with central inclusions of opaque matter.

35% brownish augite (> 1.692) with sheaf-like arrangement.

A minute amount of interstitial, dark brown glass, and much iron are present.

Name:—**Limburgite**

Kimberlite : Magnetite 3 : 1 (121) (1230°C)

Like 119, indeterminate.

Kimberlite : Magnetite 3 : 1 (563) (1410°C)

70% augite (> 1.692) partly nearly colorless, partly reddish brown and slightly pleochroic.

30% chrysolite (< 1.692) some with central inclusions of opaque matter.

Metallic iron is abundant. Name:—**Peridotite**

IGNEOUS ROCKS AND HEMATITE

Granite 1 : Hematite 1 : 1 (227) (1400°C)

66% yellow glass to dark brown glass toward the iron, which is segregated at one edge.

34% metallic iron.

Name:—**Glass + iron**

Granite 1 : Hematite 2 : 1 (228) (1400°C)

100% colorless glass, with a few unmelted crystal remnants, and with minute opaque specks.

Name:—**Glass**

Granite 1 : Hematite 3 : 1 (229) (1400°C)

100% yellowish-brown glass with masses of metallic iron at the edge.

Name:—**Glass + iron**

Syenite a : Hematite 1 : 1 (236) (1410°C)

60% fan-like fibres of augite (> 1.692).

40% interstitial, crypto-crystalline matter of lower refractive index, probably oligoclase (1.539).

Name:—**Augite-trachyte?**

Syenite a : Hematite 2 : 1 (237) (1410°C)

60% interstitial crypto-crystalline matter, probably feldspathic (1.539, oligoclase).

40% fan-like fibres of augite (> 1.692).

Name:—**Augite-trachyte**

Syenite a : Hematite 3 : 1 (238) (1410°C)

50% fan-like fibres of augite (> 1.692).

50% interstitial crypto-crystalline feldspathic matter (slightly > 1.539, oligoclase).

Name:—**Augite-trachyte**

Nepheline Syenite : Hematite 1 : 1 (239) (1410°C)

100% colorless glass, with very minute opaque specks. Fine fibres have begun to grow from the edges. They have no effect on polarized light. Probably they are augites.

Name:—**Glass**

Nepheline Syenite : Hematite 2 : 1 (240) (1410°C)

100% colorless glass with some yellow patches, and many minute opaque specks with flow arrangement.

Name:—**Glass**

Nepheline Syenite : Hematite 3 : 1 (241) (1410°C)

100% colorless glass, with abundant minute, opaque specks with flow arrangement.

Fibrous crystals, too small for identification are present at the margins.

Name:—**Glass**

Andesite Porphyrite : Hematite 1 : 1 (242) (1410°C)

99% colorless glass with abundant minute opaque specks.
1% brownish, crypto-crystalline matter, probably feldspathic, (1.550 andesine) with augite needles at one end.

Name:—**Glass (with augite-andesite)**

Andesite Porphyrite : Hematite 2 : 1 (243) (1410°C)

100% colorless glass, with abundant minute opaque specks, with flow arrangement. Some spherical, nearly opaque, isotropic patches are present.

Name:—**Glass**

Andesite Porphyrite : Hematite 3 : 1 (244) (1410°C)

100% colorless glass, with abundant minute opaque specks, with flow arrangement.

Name:—**Glass**

Basalt : Hematite 1 : 1 (230) (1400°C)

100% augite (> 1.692) as long needles, and partly as cockscombs.

Name:—**Pyroxenite**

Basalt : Hematite 2 : 1 (231) (1400°C)

100% augite (> 1.692) as long needles, and partly as cockscombs.

Name:—**Pyroxenite**

Basalt : Hematite 3 : 1 (232) (1400°C)

100% augite (> 1.692) as long needles and cockscombs.

Name:—**Pyroxenite**

Minette : Hematite 1 : 1 (233) (1400°C)

99% large crystals of augite (>1.692) in parallel fibres.
1% brown glass.

Name:—**Augitite**

Minette : Hematite 2 : 1 (234) (1400°C)

99% large crystals of augite (> 1.692) in parallel fibres
1% brownish glass.

Name:—**Augitite**

Minette : Hematite 3 : 1 (235) (1400°C)

100% large crystals of augite (> 1.692) with a minute amount of interstitial brownish glass.

Name:—**Pyroxenite**

Kimberlite : Hematite 1: 1 (245) (1410°C) (See Pl. 18, fig. 35.)

75% clino-enstatite with polysynthetic twinning, +, average refractive index 1.665.

20% augite (extinction oblique, birefringence medium, indices > 1.692) intergrown with clino-enstatite. The augite is formed later than the clino-enstatite and is grown in crystalline continuity with it.

5% chrysolite (average refractive index 1.680), some crystals with dark centres.

A little interstitial glass is present.

Name:—**Limburgite**

Kimberlite : Hematite 2 : 1 (246) (1410°C)

75% large laths of clino-enstatite (av. 1.665) and many crystals with twinning as in 245.

10% small rounded chrysolite grains (av. 1.692).

5% augite, (> 1.692), formed later than clino-enstatite and grown in crystalline continuity with it.

5% interstitial opaque glass.

5% iron globules.

Name:—**Limburgite**

Kimberlite : Hematite 3 : 1 (247) (1410°C)

45% clino-enstatite (+, av. 1.665); some large crystals are at the margin, some crystals have polysynthetic twinning.

35% chrysolite (av. 1.665), mostly as small grains.

15% globules of iron.

5% augite (> 1.692).

Name:—**Peridotite**

IGNEOUS ROCKS AND SIDERITE

Granite 1 : Siderite 1 : 1 (143) (1230°C)

20% metallic iron distributed throughout.

60% colorless to slightly brownish glass.

15% unmelted crystals.

5% augite needles, in the glass (R. I. not obtained).

Name:—**Glass + iron + augite + unmelted crystals**

Granite 1 : Siderite 2 : 1 (144) (1230°C)

80% needles and grids of enstatite (+, extinction straight, av. 1.665).

15% colorless to brown glass, with a few unmelted crystals.

5% iron, distributed throughout.

Name:—**Enstatite + glass + iron**

Granite 1 : Siderite 3 : 1 (145) (1230°C)

65% yellowish glass with some unmelted crystal remnants.
25% needles and grids of enstatite (extinction straight, av. 1.665).
10% iron, distributed throughout.

Name:—**Glass + enstatite + iron**

Granite 1 : Siderite 1 : 1 (522) (1410°C)

75% yellowish to brownish base, of radially crystallized orthoclase (< 1.539), often with iron as centres of crystallization. Some needles of probably augite are immediately in contact with iron.
15% colorless glass, in the central part.
10% iron, in bunched masses.

Name:—**Spherulitic rhyolite?**

Granite 1 : Siderite 2 : 1 (523) (1410°C)

60% dark brown base of radially crystallized matter (extinction straight, elongation +, av. 1.550).
25% gray glass with abundant needles of enstatite (extinction straight, elongation +, av. < 1.670).
10% lighter brown glass.
5% iron, in the gray glass.

Name:—**Andesite?**

Granite 1 : Siderite 3 : 1 (524) (1410°C)

75% yellow to brown glass.
11% brown to dark brown spherulites and radially crystallized orthoclase (< 1.539).
11% very dark brown blades and grids of enstatite (extinction straight, elongation +, av. < 1.670).
3% iron.

Name:—**Glass + orthoclase + enstatite + iron**

Syenite : Siderite 1 : 1 (152) (1230°C)

60% brown glass, anisotropic in places.
20% iron, distributed throughout.
20% colorless augite laths (> 1.692).

Name:—**Augitite**

Syenite a : Siderite 1 : 1 (531) (1410°C)

95% mostly clear, partly brownish glass, with some iron globules and some minute microlites.
5% ellipsoidal spherulites of orthoclase (< 1.539) with elliptical gas bubbles.

Name:—**Glass + spherulites**

Syenite : Siderite 2 : 1 (153) (1230°C)

50% dark brown to nearly colorless glass.
35% augite needles (R. I. not obtainable).
15% metallic iron, evenly distributed.

Name:—**Augitite**

Syenite a : Siderite 2 : 1 (532) (1410°C)

92% colorless to brownish glass, with many gas bubbles and many globules of iron.
8% radially crystallized oligoclase-andesine (av. 1.543) of brownish color.

Name:—**Glass + spherulites**

Syenite : Siderite 3 : 1 (154) (1230°C) (See Pl. 24, fig. 47).

65% yellow glass.
30% needles and grids of augite (>1.692).
5% iron, as crystallization centres.

Name:—**Augitite**

Syenite a : Siderite 3 : 1 (533) (1410°C)

70% brownish, radially crystallized andesine (av. 1.550) with gas bubbles and opaque globules.
30% colorless glass with gas bubbles and few opaque globules.

Name:—**Andesite, variety**

Nepheline Syenite : Siderite 1 : 1 (155) (1230°C)

57% slightly colored to brown glass.
40% long needles of augite (> 1.692).
3% iron.

Name:—**Augitite, variety**

Nepheline Syenite : Siderite 1 : 1 (534) (1410°C)

100% colorless to chiefly brownish glass with gas bubbles, opaque globules and aggregates of feebly birefringent unidentifiable microlites.

Name:—**Glass**

Nepheline Syenite : Siderite 2 : 1 (156) (1230°C)

45% colorless glass.
45% needles and grids of augite (> 1.692).
10% iron.

Name:—**Augitite**

Nepheline Syenite : Siderite 2 : 1 (535) (1410°C)

90% slightly tinted glass with some gas bubbles, opaque globules and segregated masses of iron.
10% brown spherulitic matter, oligoclase-andesine (1.543), and some unidentified microlites.

Name:—**Glass + spherulites**

Nepheline Syenite : Siderite 3 : 1 (157) (1230°C)

80% colorless glass.
15% iron, distributed throughout.
5% brownish, tree-like growths of augite (R. I. not obtainable).

Name:—**Glass + iron + augite**

Nepheline Syenite : Siderite 3 : 1 (536) (1410°C)

90% brown spherulitic matter, oligoclase-andesine (1.543), with a few opaque globules.
10% colorless glass with a few gas bubbles and opaque globules; there is an indication of the formation of radial needles with the appearance of augite.

Name:—**Andesite, variety**

Andesite Porphyrite : Siderite 1 : 1 (158) (1230°C)

60% opaque and dark brown to colorless glass.
15% needles of augite (>1.680).
25% iron, distributed throughout.

Name:—**Glass + augite + iron**

Andesite Porphyrite : Siderite 1 : 1 (537) (1410°C)

50% brownish glass with some gas bubbles and some needle and tuft-like microlites with straight extinction, probably augite (R. I. not obtainable).
50% darker brown spherulitic matter, probably augite (R. I. not obtainable).

Name:—**Augitite? variety**

Andesite Porphyrite : Siderite 2 : 1 (159) (1230°C)

55% augite needles and feathered needles (> 1.692).
45% brown to clear glass, partly crypto-crystalline and indeterminable.

Name:—**Augitite**

Andesite Porphyrite : Siderite 2 : 1 (538) (1410°C)

100% colorless glass with slightly brownish color near the edges. Some few darker brown parts have the beginning of a radial crystallization of augite. Many gas bubbles occur in the glass and many opaque globulites, often in strings along the paths of bubbles.

Name:—**Glass**

Andesite Porphyrite : Siderite 3 : 1 (160) (1230°C)

70% dark brown base; most of it is anisotropic, with radial arrangement; much of this is probably augite (>1.680).
15% needles of plagioclase (av. 1.550, andesine).
15% iron, distributed throughout.

Name:—**Basalt**

Andesite Porphyrite : Siderite 3 : 1 (539) (1410°C)

100% entirely colorless glass with many gas bubbles and opaque globules, often in strings along the paths of gas bubbles.

Name:—**Glass**

Basalt : Siderite 1 : 1 (146) (1230°C)

60% colorless chrysolites (av. 1.692); some are large.
25% yellow glass, with some nearly opaque tree-like growths of augite and some crystals of augite (> 1.692).
15% iron.

Name:—**Limburgite**

Basalt : Siderite 1 : 1 (525) (1410°C)

80% augite (> 1.692) in long rods, with some cockscomb material.
20% brown glass with greenish tint in places.

Name:—**Augitite**

Basalt : Siderite 2 : 1 (147) (1230°C)

48% yellow glass.
40% colorless chrysolites (av. 1.670).
10% iron.
2% augite (> 1.692) as needles and tree-like growths.

Name:—**Limburgite**

Basalt : Siderite 2 : 1 (526) (1410°C)

80% augite (> 1.692) in long rods with some cockscomb material.
20% brown glass.

Name:—**Augitite**

Basalt : Siderite 3 : 1 (148) (1230°C)

65% yellowish glass.
30% colorless chrysolites (av. 1.670).
3% augite needles (> 1.670) and tree-like growths.
2% iron in bunched patches.

Name:—**Limburgite**

Basalt : Siderite 3 : 1 (527) (1410°C)

50% augite laths (> 1.692) with some cockscomb arrangement.

50% partly colorless glass with small unmelted mineral fragments, partly melted to give brown and green colors.

Name:—**Augitite**

Minette : Siderite 1 : 1 (149) (1230°C)

75% finely crystalline, nearly opaque matter, part of which is certainly augite (>1.692), but no other mineral is recognizable.

25% globules of iron.

Name:—**Peridotite, variety**

Minette : Siderite 1 : 1 (528) (1410°C)

95% augite (> 1.692).

5% opaque glass.

Name:—**Augitite**

Minette : Siderite 2 : 1 (150) (1230°C)

55% brownish augite (> 1.692).

25% metallic iron distributed evenly throughout.

20% colorless chrysolite (av. 1.680) of low birefringence.

Name:—**Peridotite**

Minette : Siderite 2 : 1 (529) (1410°C)

90% augite (> 1.692) with high extinction angle and a little olivine (av. 1.692).

10% brown glass.

Name:—**Augitite**

Minette : Siderite 3 : 1 (151) (1230°C)

55% brownish augite (> 1.692).

20% metallic iron distributed throughout.

25% colorless chrysolite (av. slightly > 1.692), of low birefringence.

Name:—**Peridotite, variety**

Minette : Siderite 3 : 1 (530) (1410°C)

95% augite (> 1.692) in large crystals with high extinction angle.

5% colorless glass with two minute biotite flakes.

Name:—**Augitite**

Kimberlite : Siderite 1 : 1 (161) (1230°C)

55% fine-grained base, probably of both augite and olivine.

25% iron.

20% augite (> 1.692), many crystals recognizable as blades (some twinned) in the fine-grained groundmass. A few chrysolite grains are recognizable (slightly > 1.692).

Name:—**Limburgite**

Kimberlite : Siderite 1 : 1 (540) (1410°C)

97% slightly drab colored augite (> 1.692).

3% chrysolite (av. 1.692), sometimes with dark centres. A small amount of dark drab colored glass is present near the edge.

Name:—**Limburgite**

Kimberlite : Siderite 2 : 1 (162) (1230°C)

80% fine-grained base, probably of augite (> 1.692) and chrysolite (av. 1.692) in which crystals of both are recognizable.

20% iron, distributed throughout.

Name:—**Limburgite**

Kimberlite : Siderite 2 : 1 (541) (1410°C)

62% colorless chrysolite (av. 1.692), many grains having dark centres.

35% slightly brownish augite (> 1.692), in long fibres.

3% iron, between the other minerals.

Name:—**Peridotite**

Kimberlite : Siderite 3 : 1 (163) (1230°C)

75% fine-grained, nearly opaque base, consisting of chrysolite (av. 1.692) and augite (> 1.692).

15% iron.

10% augite in short crystals. Chrysolite is present also.

Name:—**Limburgite**

Kimberlite : Siderite 3 : 1 (542) (1410°C)

70% chrysolite (av. < 1.692).

28% augite (> 1.692).

2% iron globules, distributed throughout.

Name:—**Peridotite**

IGNEOUS ROCKS AND DOLOMITE

Granite 1 : Dolomite 1 : 1 (185) (1400°C)

100% light yellow to dark brown, nearly opaque mass of radial or fan-like crystalline aggregates of refractive index 1.543, whose nature is not clear.

Name:—**Andesite?**

Granite 1 : Dolomite 2 : 1 (186) (1400°C)

99% colorless glass.

1% brownish crystalline patches, assemblages of augite dendrites. A few iron globules are present, attached to gas bubbles in some cases.

Name:—**Glass**

Granite 1 : Dolomite 3 : 1 (187) (1400°C)

100% colorless glass with minute opaque specks with some flow arrangement.

Name:—**Glass**

Syenite : Dolomite 1 : 1 (194) (1400°C)

97% light yellow to dark brown, nearly opaque radial or fan-like crystalline aggregates, refractive index 1.545, probably oligoclase-andesine.

3% yellowish glass.

Name:—**Andesite?**

Syenite : Dolomite 2 : 1 (195) (1400°C)

99% colorless glass with streaks of minute opaque globules with flow arrangement.

1% brown patches of crystalline matter, dendritic and radial assemblages with oblique extinction, refractive index 1.539 (oligoclase?).

Name:—**Glass**

Syenite : Dolomite 3 : 1 (196) (1400°C)

100% clear, colorless glass, with streaks of opaque specks.

Name:—**Glass**

Nepheline Syenite : Dolomite 1 : 1 (197) (1400°C)

97% colorless glass.

3% brown crystalline part, at the edges, with refractive index 1.545 (?oligoclase-andesine?).

Name:—**Glass**

Nepheline Syenite : Dolomite 2 : 1 (198) (1400°C)

99% colorless glass, with abundant opaque specks with flow arrangement.

1% crystalline matter.

Name:—**Glass**

Nepheline Syenite : Dolomite 3 : 1 (199) (1400°C)

100% colorless glass with minute opaque specks with some flow arrangement.

Name:—**Glass**

Andesite Porphyrite : Dolomite 1 : 1 (200) (1400°C)

100% nearly opaque crystallized matter, partly radial, or fan-like, behaving partly like aggregates of augite and augite needles (> 1.692, extinction oblique) embedded in glass.

Name:—**Augitite**

Andesite Porphyrite : Dolomite 2 : 1 (201) (1400°C)

95% colorless glass with opaque specks and flow arrangement.

5% crystalline matter, dark brown, with characters of dendrites of augite, except refractive index (between 1.550 and 1.557) which may be that of the glass, the association of the fibres with the glass being very close.

Name:—**Glass + augite? dendrites**

Andesite Porphyrite : Dolomite 3 : 1 (202) (1400°C)

97% colorless glass with flow arrangement of minute opaque specks.

3% crystalline matter, brown augite? dendrites (index between 1.550 and 1.557).

Name:—**Glass + augite? dendrites**

NOTE—In Nos. 185-202 all the crystalline matter consists of radial fibres of positive elongation. The fibre bundles and glass are very intimately associated and give refractive index values characteristic of plagioclase feldspar. But it is not certain that these are not augite fibres. Better crystallization would give more information.

Basalt : Dolomite 1 : 1 (188) (1400°C)

96% large crystals of long needles of augite (> 1.692).

3% chrysolite (< 1.692).

1% dark brown glass.

Name:—**Limburgite**

Basalt : Dolomite 2 : 1 (189) (1400°C)

98% large and well crystallized, slightly colored augites (> 1.692); chrysolite (av. 1.692) is present.

2% dark brown to colorless glass.

Name:—**Augitite**

Basalt : Dolomite 3 : 1 (190) (1400°C)

99% large, well crystallized, slightly colored augites (> 1.692).
1% colorless glass. Chrysolite is present (av. 1.692).

Name:—**Augitite**

Minette : Dolomite 1 : 1 (191) (1400°C)

98% large, well-crystallized augites (>1.692).
2% dark brown glass.

Name:—**Augitite**

Minette : Dolomite 2 : 1 (192) (1400°C)

99% augite (> 1.692), large and very well crystallized.
1% brown or drab glass.

Name:—**Augitite**

Minette : Dolomite 3 : 1 (193) (1400°C)

100% large, well crystallized augites (> 1.692).

Name:—**Pyroxenite**

Kimberlite : Dolomite 1 : 1 (203) (1400°C)

80% large crystals of augite (> 1.680).
18% minute grains of chrysolite (av. 1.680).
2% iron globules.

Name:—**Peridotite**

Kimberlite : Dolomite 2 : 1 (204) (1400°C)

73% large crystals of augite (> 1.692).
20% minute chrysolite grains (av. 1.680).
5% brown glass.
2% iron globules.

Name:—**Limburgite**

Kimberlite : Dolomite 3 : 1 (205) (1400°C) (See Pl. 22, fig. 43.)

68% large crystals of colorless augite (> 1.680).
25% small grains of chrysolite (av. 1.680).
5% brown glass.
2% large iron globules.

Name:—**Limburgite**

IGNEOUS ROCKS AND MAGNESITE

Granite 1 : Magnesite 1 : 1 (164) (1400°C)

75% small, colorless, equant grains of augite (birefringence low, indices between 1.692 and 1.710).
15% colorless glass.
10% unmelted feldspars.

Name:—**Augite + glass + unmelted feldspars**

Granite 1 : Magnesite 2 : 1 (165) (1400°C)

60% colorless glass, with some long needles of augite (> 1.692).
35% small rounded crystals of chrysolite? (indices between 1.680 and 1.692).
5% unmelted feldspars.

Name:—**Peridotite, variety**

Granite 1 : Magnesite 3 : 1 (166) (1400°C) (See Pl. 20, fig. 40.)

60% colorless glass.
20% small rounded crystals of augite (extinction oblique, indices > 1.692).
20% long needles of augite (av. 1.692).

Name:—**Augitite, variety**

Syenite : Magnesite 1 : 1 (173) (1400°C)

90% colorless equant crystal grains of augite (extinction oblique, indices > 1.710).
10% colorless glass. Some few unmelted feldspars are present, and a few octahedra of spinel in clear patches of glass.

Name:—**Augitite, variety**

Syenite : Magnesite 2 : 1 (174) (1400°C)

55% small equant crystal grains of augite (extinction oblique, indices between 1.692 and 1.710).
45% colorless glass. A few large globules of iron are present.

Name:—**Augitite, variety**

Syenite : Magnesite 3 : 1 (175) (1400°C) (See Pl. 21, fig. 41.)

55% colorless glass with a few long colorless needles of augite (+, oblique extinction, indices > 1.710).
45% small equant grains of augite (av. 1.710). A few large globules of iron are present.

Name:—**Augitite, variety**

Nepheline Syenite : Magnesite 1 : 1 (176) (1400°C)

80% small equant crystal grains of augite (extinction oblique, av. 1.710).
15% unmelted feldspars.
5% colorless or light brownish glass. A few minute spinel octahedra are present in areas of clear glass.

Name:—**Augitite, variety**

Nepheline Syenite : Magnesite 2 : 1 (177) (1400°C)

50% small equant crystal grains of augite (extinction oblique, α 1.692, $\gamma > 1.710$).
45% colorless glass.
5% unmelted feldspar crystals.

Name:—**Augitite, variety**

Nepheline Syenite : Magnesite 3 : 1 (178) (1400°C)

60% colorless glass with many long needles of colorless augite (extinction oblique, indices between 1.680 and 1.692).
40% small equant crystal grains of augite (extinction oblique, indices > 1.692).

Name:—**Augitite, variety**

Andesite Porphyrite : Magnesite 1 : 1 (179) (1400°C)

80% colorless equant augite grains (extinction oblique, average index 1.710).
20% grayish masses, probably augite; some clearer patches consist of augite needles. A minute amount of colorless glass is present. A few spinel octahedra are present in clear patches of glass.

Name:—**Augitite, variety**

Andesite Porphyrite : Magnesite 2 : 1 (180) (1400°C)

50% small equant grains of augite with good crystal outlines (extinction oblique, average index 1.710).
50% colorless to brownish base; the colorless part is glass, the brownish part consists of laths of plagioclase (–, variolitic and twinned, average index between 1.557 and 1.563; andesine-labradorite in composition; the index corresponds with labradorite, but labradorite is +).

Name:—**Basalt**

Andesite Porphyrite : Magnesite 3 : 1 (181) (1400°C) (See Pl. 20, fig. 39.)

55% colorless glass.
25% small equant augite grains, segregated (> 1.692).
20% long needles and grids of augite (> 1.692). A brown patch of anisotropic base seems to consist of radial augites.

Name:—**Augitite**

Basalt : Magnesite 1 : 1 (167) (1400°C)

Both olivine and augite are recognizable. The olivine is forsterite (average index slightly > 1.660). The index of the augite was not obtained.

100% groundmass of fine grain; much of it has low birefringence and may be a mixture of some augite with predominant olivine; possibly some other minerals may be present.

Name:—**Limburgite?**

Basalt : Magnesite 2 : 1 (168) (1400°C)

70% colorless forsterite grains, with opaque centres (av. 1.670).

25% slightly colored augites (> 1.692):

5% colorless to dark colored glass. A few large iron globules are present.

Name:—**Limburgite**

Basalt : Magnesite 3 : 1 (169) (1400°C)

50% colored augites (> 1.692) and dark glass passing into augite.

40% olivines with large black centres (av. slightly < 1.670).

10% colorless to brownish glass.

Name:—**Limburgite**

Minette : Magnesite 1 : 1 (170) (1400°C)

70% forsterite (index av. 1.650).

15% augite (> 1.692).

10% colorless spinel (index approximately 1.710).

5% opaque matter.

Name:—**Peridotite**

Minette : Magnesite 2 : 1 (171) (1400°C) (See Pl. 15, fig. 30.)

50% colorless forsterite (av. 1.650).

45% slightly colored augite (> 1.692).

5% iron globules. A dark colored isotropic mineral is garnet (much > 1.710, < 2.07). Green isotropic octahedra of lower refractive index than the last is spinel (slightly > 1.710).

Name:—**Peridotite**

Minette : Magnesite 3 : 1 (172) (1400°C)

85% violet augites (>1.692). A few are highly colored, strongly pleochroic laths, deep greenish-blue to deep violet; a variety of pyroxene.

10% colorless olivines (av. slightly < 1.660).

5% iron globules.

Name:—**Peridotite**

Kimberlite : Magnesite 1 : 1 (182) (1400°C)

60% colorless, fine-grained chrysolite (av. 1.680) with opaque inclusions.

40% slightly grayish garnet (> 1.73, < 2.08). There is a little colored matter which is nearly isotropic.

Name:—**Olivine-garnet rock**

Kimberlite : Magnesite 2 : 1 (183) (1400°C)

90% fine-grained olivine (av. slightly < 1.660).

5% opaque matter.

5% grayish matter; no other mineral is recognizable.

Name:—**Dunite**

Kimberlite : Magnesite 3 : 1 (184) (1400°C)

60% small rounded grains of olivine, (av. 1.670).

30% brownish augite, difficult to determine (> 1.680).

10% opaque matter.

Name:—**Peridotite**

IGNEOUS ROCKS AND TREMOLITE SCHIST

Granite 1 : Tremolite Schist 1 : 1 (206) (1400°C)

100% crystalline, in aggregates of long needles of augite (extinction oblique, > 1.692, birefringence low). Needles of different orientation overlap.

Name:—**Pyroxenite**

Granite 1 : Tremolite Schist 2 : 1 (207) (1400°C)

95% grids of augite (extinction straight, index much lower than 1.692, but this is probably due to association with glass) grown to needles of augite (> 1.692) in one place.

5% colorless, interstitial glass. A little interstitial brown matter is not isotropic.

Name:—**Augitite**

Granite 1 : Tremolite Schist 3 : 1 (208) (1400°C)

50% augite grids (biaxial, +, commonly straight extinction, but occasionally oblique, index not obtainable because of close association with glass).

50% colorless glass, enclosing augite grids and between the fibres of the grids.

Name:—**Augitite**

Syenite a : Tremolite Schist 1 : 1 (215) (1400°C) (See Pl. 23, fig. 46.)

85% long needles of augite (av. 1.710) with feathery areas of the same between them.

15% fine-grained augite (extinction oblique, > 1.680), with segregation of iron.

Name:—**Pyroxenite**

Syenite a : Tremolite Schist 2 : 1 (216) (1400°C)

95% augite (> 1.692) in needles, with feathery areas of the same between them. (The refractive index is difficult to obtain because of the glass.)

5% colorless glass.

Name:—**Augitite**

Syenite a : Tremolite Schist 3 : 1 (217) (1400°C)

75% augite needles and feathers (> 1.692). The refractive index is difficult to determine because of the glass.

25% clear, colorless glass.

Name:—**Augitite**

Nepheline Syenite : Tremolite Schist 1 : 1 (218) (1400°C) (See Pl. 21, fig. 42.)

55% colorless glass.

45% colorless augites, as long needles, skeleton crystals, and small equant grains, also as aggregates of needles in brown patches (indices between 1.692 and 1.710).

Name:—**Glass + augite**

Nepheline Syenite : Tremolite Schist 2 : 1 (219) (1400°C)

80% colorless glass, with crystallization of augites in certain patches.

20% colorless augite needles (> 1.692; the refractive index is very difficult to determine).

Name:—**Glass + augite**

Nepheline Syenite : Tremolite Schist 3 : 1 (220) (1400°C)

65% slightly brownish base, probably consisting of augites, not completely assembled.

20% augite grids.

10% colorless glass.

5% long augite needles (> 1.692, index difficult to obtain).

Name:—**Augitite**

Andesite Porphyrite : Tremolite Schist 1 : 1 (221) (1400°C)

60% long augite needles (+, indices between 1.692 and 1.710) with augite feathers and a little colorless glass between them.

40% finer grained augite needles, rounded grains of forsterite (indices < 1.665, 2V = 90°) and iron globules, concentrated.

Name:—**Augitite**

Andesite Porphyrite : Tremolite Schist 2 : 1 (222) (1400°C)

98% grids of augite (> 1.692, difficult to determine) and many long bundles of needles of augite.

2% colorless glass.

Name:—**Augitite**

Andesite Porphyrite : Tremolite Schist 3 : 1 (223) (1400°C)

90% brownish crystalline base of radial or fan-like aggregates of augite needles (> 1.692); in some parts the augite grids are more definite than in others. A little colorless, interstitial glass is present in places.

10% colorless glass.

Name:—**Augitite**

Basalt : Tremolite Schist 1 : 1 (209) (1400°C)

70% augite, mostly colorless, some slightly colored (> 1.692).

20% colorless, fine-grained chrysolite (av. 1.680).

10% iron globules. A minute amount of colored glass is present.

The upper half of the ingot is all augite; the lower half is fine-grained and includes some chrysolite.

Name:—**Peridotite**

Basalt : Tremolite Schist 2 : 1 (210) (1400°C) (See Pl. 23, fig. 45.)

80% large augite crystals, colorless, or nearly so (> 1.692).

18% colorless, equant grains of chrysolite (indices between 1.680 and 1.692).

2% colorless or slightly brown glass. Spherical globules of iron are present.

Name:—**Limburgite**

Basalt : Tremolite Schist 3 : 1 (211) (1400°C)

90% augite (> 1.692).

10% chrysolite with dark centres (indices between 1.680 and 1.692). A small amount of colorless glass is present, and also spherical globules of iron.

Name:—**Limburgite**

Minette : Tremolite Schist 1 : 1 (212) (1400°C)

75% augite (av. 1.680). Coarse augites occur on one side; the remainder consists of large augites and small chrysolites.

25% chrysolite (av. 1.680), with abundant (3%) globules of iron.

Name:—**Peridotite**

Minette : Tremolite Schist 2 : 1 (213) (1400°C)

50% coarse augites (> 1.692).

50% finer-grained augites and ?olivines (1.692) with segregation of large iron globules.

Name:—**Peridotite**

Minette : Tremolite Schist 3 : 1 (214) (1400°C)

90% coarsely crystalline augite (extinction oblique, av. 1.680).

10% colorless forsterite (av. 1.660, $2V = 90°$). There is a segregation of iron in the last part to crystallize.

Name:—**Peridotite**

Kimberlite : Tremolite Schist 1 : 1 (224) (1400°C)

87% large crystals of augite (> 1.692), poikilitic to olivines.

10% small rounded grains of olivine (av. slightly > 1.670), enclosed in augite, or interstitial.

3% iron globules. A very small amount of a dark brown glass is present, interstitially.

Name:—**Limburgite**

Kimberlite : Tremolite Schist 2 : 1 (225) (1400°C)

77% augite (> 1.692).

20% olivine (av. 1.670).

3% iron globules.

Name:—**Peridotite**

Kimberlite : Tremolite Schist 3 : 1 (226) (1400°C)

70% augite (> 1.692).

29% olivine (av. 1.670).

1% iron.

Name:—**Peridotite**

IGNEOUS ROCKS AND BAUXITE

Granite 1 : Bauxite 1 : 1, 2 : 1, 3 : 1. (122) (123) (124) (1230°C)

These consist of isotropic matter and unmelted crystals. Much of the isotropic matter is opaque. The reaction is not completed, the temperature having been too low.

Syenite : Bauxite 1 : 1 (131) (1230°C)

All is isotropic, except a few unmelted crystals. Part (10%) is colorless, part (90%) is opaque, with clear brown isotropic edges.

Syenite : Bauxite 2 : 1 (132) (1230°C)

Like 131. 40% is colorless, 60% dark brown to opaque. A few minute laths of labradorite (1.563) occur in either base.

Name:—**Glass + labradorite**

Syenite : Bauxite 3 : 1 (133) (1230°C)

Like 132, but more (60%) colorless glass; where rich in bauxite the glass is brown. Labradorite laths (1.563) have crystallized from both the brown and clear glass. The reaction and crystallization are incomplete.

Name:—**Glass + labradorite**

Nepheline Syenite : Bauxite 1 : 1 (134) (1230°C)

20% colorless and 80% dark brown glass, the latter being rich in bauxite. A few unmelted crystals remain. Reaction and crystallization are not complete. There are some needles in the colorless glass (extinction straight, elongation +, birefringence medium, perhaps sillimanite?). A few spinel octahedra are present in the colorless glass.

Name:—**Glass + sillimanite? + spinel**

Nepheline Syenite : Bauxite 2 : 1 (135) (1230°C)

40% colorless and 60% dark brown glass, with a few unmelted crystal remnants. Some small needles with medium birefringence and straight extinction occur in the colorless glass and possibly are sillimanite, but are too small for identification.

Name:—**Glass**

Nepheline Syenite : Bauxite 3 : 1 (136) (1230°C)

Like 135, but with more (60%) of the colorless glass.

Name:—**Glass**

Andesite Porphyrite : Bauxite 1 : 1 (137) (1230°C)

Dark colored isotropic matter, with a few unmelted crystal remnants. Reaction and crystallization are incomplete.

Name:—**Glass**

Andesite Porphyrite : Bauxite 2 : 1 (138) (1230°C)

Like 137, but with more (50%) of a less darkly colored glass, with a little crystalline matter developed. It is plagioclase (> 1.560, < 1.572 extinction angle 28°, labradorite).

Name:—**Glass + labradorite**

Andesite Porphyrite : Bauxite 3 : 1 (139) (1230°C)

50% colorless to dark brown glass, with new crystals on a minute scale, some of which are labradorite (1.563).

35% opaque unassimilated bauxitic matter.

15% unmelted crystals.

Name:—**Glass + unmelted constituents + labradorite**

Basalt : Bauxite 1 : 1 (125) (1230°C)

Nearly all is isotropic. No assimilation has taken place.

Basalt : Bauxite 2 : 1 (126) (1230°C)

90% dark colored glass, with much opaque matter, probably bauxite. A few crystals of olivine remain unmelted.

10% base of lighter color to colorless. Part of the base is crystalline and is plagioclase (index 1.572, bytownite) with brown, pleochroic needles, with oblique extinction (35°), > 1.710, hornblende?

Name:—**Glass + bytownite + hornblende?**

Basalt : Bauxite 3 : 1 (127) (1230°C)

45% labradorite laths (biaxial, +, extinction angle 40°, 1.563).

25% augite (> 1.680).

25% isotropic glass and opaque unassimilated bauxite, with some violet spinel.

5% Minute octahedra of magnetite.

Minute grains and larger masses of spinel form a step between bauxite and plagioclase.

Name:—**Basalt**

Minette : Bauxite 1 : 1 (128) (1230°C)

Opaque, non-coherent.

Minette : Bauxite 2 : 1 (129) (1230°C)

Like 128.

Minette : Bauxite 3 : 1 (130) (1230°C)

85% opaque matter, unassimilated bauxite, with isotropic material.

15% finely crystalline matter, both augite (> 1.692) and labradorite (1.563, extinction angle 34°) are present with glass.

Name:—**Basalt**

Kimberlite : Bauxite 1 : 1 (140) (1230°C)

75% opaque isotropic matter.

25% crystalline matter, indeterminable, with aggregate polarization and medium birefringence.

Kimberlite : Bauxite 2 : 1 (141) (1230°C)

50% opaque, isotropic matter.

50% crystalline matter with aggregate polarization, as in 140.

Kimberlite : Bauxite 3 : 1 (142) (1230°C)

25% opaque, isotropic matter.

75% crystalline matter, with aggregate polarization as in 140 and 141.

Granite 1 : Bauxite 1 : 1 (501) (1410°C)

50% light brownish glass with fine needles of the next mineral.

22% laths of sillimanite with square cross-sections (1.670, pleochroic X and Y pink, Z green).

25% dark, opaque matter, which is the remains of bauxite.

3% colorless glass produced by melting of quartz, with some unmelted quartz remnants inside.

Name:—**Glass + bauxite + sillimanite**

Granite 1 : Bauxite 2 : 1 (502) (1410°C)

75% clear, colorless glass (with many minute sillimanite needles) becoming brownish where assimilation of bauxite is proceeding.

25% opaque matter which is the remains of unassimilated bauxite. There are some remnants of unmelted quartz in the colorless glass and some nests of sillimanite crystals (indices > 1.670) here and there.

Name:—**Glass + bauxite + sillimanite**

Granite 1 : Bauxite 3 : 1 (503) (1410°C)

Like 502, but with more (80%) clear glass, and only little brownish glass. A few nests of sillimanite crystals and many fine needles of the same are present (the refractive index is unobtainable by reason of the glass).

Name:—**Glass + sillimanite**

Syenite a : Bauxite 1 : 1 (510) (1410°C)

60% opaque, indeterminable base.

40% labradorite laths (1.563), nearly opaque, being crowded with spinel grains.

5% of the whole consists of clear areas with plagioclase laths (nearly free from spinel), some nearly colorless glass, and deep greenish-blue needles, feebly pleochroic, with no birefringence. This mineral remains undetermined. Similar needles occur through the nearly opaque base. They may be a variety of sillimanite.

Name:—**Glass + labradorite + sillimanite?**

Syenite a : Bauxite 2 : 1 (511) (1410°C)

50% labradorite laths (1.563), well crystallized and clearer than in 510, but still crowded with spinel grains.

50% mostly opaque base, at a few places transparent, isotropic, with slightly brownish tint.

Practically opaque, dark blue rods are abundant in the base and a few occur in the labradorite. These are undetermined, possibly they are a variety of sillimanite.

Name:—**Labradorite + glass + sillimanite?**

Syenite a : Bauxite 3 : 1 (512). (1410°C)

65% labradorite laths (1.563), mostly clear and well formed, but many are crowded with spinel grains.

35% opaque to brownish transparent glass. Long, practically black needles are abundant in the base, not so much so in the plagioclase. (?variety of sillimanite?)

Name:—**Labradorite + glass + sillimanite?**

Nepheline Syenite : Bauxite 1 : 1 (513) (1410°C)

100% opaque, indeterminable matter.

Nepheline Syenite : Bauxite 2 : 1 (514) (1410°C)

50% opaque, indeterminable matter.

50% colorless glass, with many minute spinel inclusions, some with hexagonal, diamond shaped etc., outlines, cross-sections of octahedra, and refractive index > 1.710.

Name:—**Glass + spinel**

Nepheline Syenite : Bauxite 3 : 1 (515) (1410°C)

65% colorless glass, with some needles of crystalline matter, possibly sillimanite, and many small spinel crystals (> 1.710).

35% opaque, undigested matter.

Name:—**Glass**

Andesite Porphyrite : Bauxite 1 : 1 (516) (1410°C)

100% indeterminable matter.

Andesite Porphyrite : Bauxite 2 : 1 (517) (1410°C)

50% labradorite laths (1.563, or slightly less), with a tendency to variolitic arrangement, and clouded with spinel grains.

50% base, mostly opaque, some brownish and isotropic. Many opaque needles are present, especially in the base, but also in the labradorite laths (?a variety of sillimanite).

Name:—**Labradorite + base + sillimanite?**

Andesite Porphyrite : Bauxite 3 : 1 (518) (1410°C) (See Pl. 13, fig. 25.)

Similar to 517, with a greater tendency to variolitic arrangement of plagioclase (labradorite-bytownite, slightly < 1.572). The glass is clearer and brown. A few sheaves of sillimanite are present (index of sillimanite not obtainable). The plagioclase seems to be developed from the sillimanite and has no spinel inclusions.

Name:—**Plagioclase + glass + sillimanite**

Basalt : Bauxite 1 : 1 (504) (1410°C)

50% large labradorite laths (1.563), much clouded by small spinels (index between 1.71 and 1.73).

50% opaque, non-birefringent base, mostly unassimilated bauxite. Many long needles of a dark green (practically black) unidentified mineral (?a variety of sillimanite?) are present in the base.

Name:—**Labradorite + base + sillimanite?**

Basalt : Bauxite 2 : 1 (505) (1410°C) (See Pl. 13, fig. 26.)

50% labradorite forms (1.563), crowded with spinel grains and octahedra (> 1.71).

48% brownish interstitial matter, with some opaque needles. Some of these are greenish, with no effect on polarized light. The base is mostly isotropic, but partly consists of a brown mineral in needles with low birefringence, straight extinction, pleochroic (Z brown, > Y fainter brown, > X very faint brown), biaxial, + elongation, 1.650. The opaque, greenish and brown needles may be different varieties of amphibole?

2% iron globules.

Name:—**Labradorite + base + amphibole?**

Basalt : Bauxite 3 : 1 (506) (1410°C) (See Pl. 12, fig. 24.)

33% long labradorite laths (1.563), partly with variolitic arrangement.

34% consisting half of sillimanite needles, strongly colored and pleochroic (indices beteen 1.65 and 1.67), and half of spinel as irregular, colorless grains (> 1.71).

33% straw colored glass.

Name:—**Labradorite + sillimanite + spinel + glass**

Minette : Bauxite 1 : 1 (507) (1410°C)

80% sheaves and big bundles of andalusite?, strongly pleochroic Z>Y>X, X pink, Y and Z blue), elongation –, extinction straight, > 1.650.

15% base, some isotropic, some anistropic, but undetermined. Colorless spinel is present. Ghosts of laths of feldspar? are seen.

5% iron globules.

Name:—**Andalusite? + base**

Minette : Bauxite 2 : 1 (508) (1410°C)

50% long bytownite laths (–, 1.572), crowded with spinel grains.

50% consisting of many long laths of opaque and pleochroic bluish needles embedded in an isotropic base, which is crowded with spinel grains and growing hornblendes. The pleochroism of the latter is X>Y >Z, X and Y green, Z pink; the extinction is oblique, X-c 20°, elongation –, indices between 1.650 and 1.670; the mineral is probably hornblende. The

bright blue needles have pleochroism X>Y >Z, X and Y strong blue, Z pink, colorless or violet, extinction straight, elongation +, indices slightly > 1.650; they are sillimanite.

Name:—**Plagioclase + hornblende + sillimanite + glass**

Minette : Bauxite 3 : 1 (509) (1410°C)

70% augite needles, with bluish color, sheaf-like arrangement, or in big bundles, with oblique extinction, X-c 30°, biaxial, +, pleochroic X>Y>Z, X bluish, Y and Z faint pink, indices > 1.710.

20% labradorite laths (1.563).

10% either augite or material not completely crystallized.

Name:—**Basalt**

Kimberlite : Bauxite 1 : 1 (519) (1410°C)

100% isotropic matter, 8-10% of this is clear and is spinel (some octahedra are seen). The remainder is chiefly indeterminable, but includes some green pleochroic rods of aegirine-augite? (extinction oblique, indices > 1.680).

Indeterminable

Kimberlite : Bauxite 2 : 1 (520) (1410°C)

60% dark colored to opaque base, isotropic, sprinkled with iron, and opaque rods, greenish under intense light. The base is probably chiefly spinel, with some needles of sillimanite.

40% colorless mineral, with medium birefringence, straight extinction, biaxial, –, average index 1.650 — monticellite, with minute included spinels.

Name:—**Monticellite + base**

Kimberlite : Bauxite 3 : 1 (521) (1410°C)

63% small equant grains of monticellite, (biaxial, –, indices 1.650 and slightly greater).

35% nearly opaque base of greenish to pink color; the greenish part is spinel, the pinkish part consists of feebly birefringent fibres occasionally pleochroic, but not distinctly so, Z>Y>X, Z bluish, Y bluish, X brownish, elongation +, biaxial, +, extinction straight, index not obtainable, probably augite?

2% opaque rods, undetermined; a little green spinel is present at the edge in clear crystals larger than the grains mentioned above.

A small amount at one edge is coarse-grained and consists of:—

75% brown to blue needles, feebly birefringent, elongation +, extinction oblique (42°), pleochroic Z > Y > X, Z and Y blue or green, X pink, > 1.710, probably augite.

25% long, clear monticellite crystals (biaxial, –, 1.650).

Name:—**Monticellite + augite with monticellite + spinel + augite?**

IGNEOUS ROCKS AND CHROMITE

Granite 1 : Chromite 1 : 1 (290) (1410°C) (See Pl. 19, fig. 37.)

50% chromite, lighter colored at the margins.

50% colorless glass, with about 15% of the whole as long needles of bronzite (extinction straight, elongation +, indices between 1.680 and 1.692). Minute chromite octahedra are abundant in the glass, as a new crystallization.

Name:—**Chromite + bronzite + glass**

Granite 1 : Chromite 2 : 1 (291) (1410°C)

45% crystalline matter, biaxial, extinction straight, elongation +, birefringence higher than that of feldspar, average index 1.650 —— enstatite.

30% colorless glass, with some fairly large octahedra of chromite. These octahedra are new crystals.

25% chromite grains whose color is lighter than it was originally.

Name:—**Enstatite + glass + chromite**

Granite 1 : Chromite 3 : 1 (292) (1410°C)

55% colorless glass, with some newly formed chromite octahedra.

30% crystalline matter, as in 291 —— enstatite (+, average index 1.665).

15% chromite, with lighter color than the original one. Some long opaque needles are present.

Name:—**Glass + enstatite + chromite**

Syenite a : Chromite 1 : 1 (299) (1410°C)

50% chromite.

25% augite (> 1.692).

24% colorless glass.

1% iron globules.

Name:—**Chromite + augite + glass**

Syenite a : Chromite 2 : 1 (300) (1400°C)

64% glass, enclosing one-third of its volume of augite needles (> 1.692).
30% chromite.
6% colorless glass, with needles.

Name:—**Glass + chromite + augite**

Syenite a : Chromite 3 : 1 (301) (1410°C)

35% colorless glass; some of it is crypto-crystalline (orthoclase?).
30% brown base, with spherulitic arrangement of orthoclase.
25% chromite grains, lighter colored at the margins.
10% many tree-like growths of possibly enstatite? (indices of orthoclase? and enstatite? not obtainable.)

Name:—**Trachyte with chromite**

Nepheline Syenite : Chromite 1 : 1 (302) (1410°C)

50% chromite in angular grains, darker in color than in 301.
35% glass of brownish tint.
15% colorless prismatic crystals of augite (> 1.692) in a glassy base.

Name:—**Chromite + glass + augite**

Nepheline Syenite : Chromite 2 : 1 (303) (1410°C)

70% colorless or brownish glass, part of which is devitrified, by the assemblage of augite needles in preliminary crystallization.
20% chromite; also some minute, new octahedra of the same occur in the base.
10% long needles of augite (> 1.692) with branches set obliquely.

Name—**Glass + chromite + augite**

Nepheline Syenite : Chromite 3 : 1 (304) (1410°C)

This is like 303 in every respect, except relative proportion of chromite.
15% chromite. Many new, minute octahedra of chromite are present.
10% augite needles.
75% base, 10% of the whole base is isotropic, the remainder is changed to augite, (index not well seen, probably > 1.692).

Name:—**Augite + chromite + glass**

Andesite Porphyrite : Chromite 1 : 1 (305) (1410°C)

50% chromite, lighter colored than the original chromite.
30% clear, colorless glass.
20% clear, colorless augite (extinction oblique, av. 1.692).

Name:—**Chromite + glass + augite**

Andesite Porphyrite : Chromite 2 : 1 (306) (1410°C)

50% glass.
34% chromite.
16% augite outlines not so clear as in 305, (extinction oblique, > 1.692); 306 is very similar to 305.

Name:—**Chromite + glass + augite**

Andesite Porphyrite : Chromite 3 : 1 (307) (1410°C)

40% augite needles (> 1.692).
35% glass.
25% chromite, lighter colored than the original chromite.

Name:—**Augite + glass + chromite**

Basalt : Chromite 1 : 1 (293) (1410°C)

50% dark colored chromite.
28% augites (> 1.692); some are slightly violet in color.
20% chrysolite (α 1.680, γ 1.692), fine, clear, and larger than is usual in these experiments.
2% slightly colored to colorless glass.

Name:—**Chromite-limburgite**

Basalt : Chromite 2 : 1 (294) 1410°C) (See Pl. 16, fig. 32.)

40% augite (> 1.692).
30% chromite.
26% chrysolite, large and clear, (+, extinction straight, 2V=90°, av. 1.680).
4% dark brown glass.

Name:—**Chromite-limburgite**

Basalt : Chromite 3 : 1 (295) (1410°C) (See Pl. 19, fig. 38.)

55% slightly colored augite (> 1.692).
25% large, clear chrysolites, also some long needles of the same (elongation +, av. 1.680).
20% brown glass. The chromite has mostly dissolved, and some new, large octahedra of chromite have formed.

Name:—**Limburgite**

Minette : Chromite 1 : 1 (296) (1410°C)

50% chromite.
45% augite (> 1.692).
5% chrysolite (av. 1.692) and dark brown glass.

Name:—**Chromite-limburgite**

Minette : Chromite 2 : 1 (297) (1410°C)

78% greenish, chromiferous augite (> 1.692).
10% dark colored, partly dissolved chromite.
10% clear, colorless chrysolite (av. 1.680).
2% glass.

Name:—**Chromite-limburgite**

Minette : Chromite 3 : 1 (298) (1410°C) (See Pl. 22, fig. 44.)

80% green, chromiferous augite (> 1.692).
18% long needles of colorless chrysolite (+, extinction straight, indices between 1.670 and 1.680).
2% glass.

Name:—**Limburgite**

Kimberlite : Chromite 1 : 1 (308) (1410°C)

50% chromite, lighter colored than the original, some grains with lighter colored margins.
50% chrysolite (av. 1.692) and augite (> 1.692) in very fine grains. The augite is clear, colorless and difficult to distinguish; it is in much smaller amount than the chrysolite. A considerable amount of iron is present as globules.

Name:—**Chromite-limburgite** (no glass)

Kimberlite : Chromite 2 : 1 (309) (1410°C)

66% chrysolite (indices between 1.692 and 1.710) and augite (> 1.710) in very fine grains; the augite is slightly colored, and in some parts is nearly as prominent in amount as the chrysolite.
34% chromite.

Name:—**Chromite-limburgite** (no glass)

Kimberlite : Chromite 3 : 1 (310) (1410°C)

80% fine-grained chrysolite (av. 1.692) and augite (> 1.710), the chrysolite being more abundant than the augite.
20% chromite.

Name:—**Chromite-limburgite** (no glass)

IGNEOUS ROCKS AND GRAPHITE

Granite 1 : Graphite 3 : 1 (332) (1410°C)

85% colorless glass, with
15% unmelted quartz grains; graphite dust is scattered through the whole.

Name:—**Glass + unmelted quartz + graphite**

Syenite a : Graphite 3 : 1 (335) (1410°C)

50% glass with graphite

50% crystalline part, without graphite, grayish in color; part is augite in sheaves (> 1.692), part is feldspar?

Name:—**Augite trachyte?**

Nepheline Syenite : Graphite 3 : 1 (1410°C)

100% glass with graphite; many fine needles are present in the glass.

Name:—**Glass + graphite**

Andesite Porphyrite : Graphite 3 : 1 (337) (1410°C)

100% glass, with many minute black inclusions arranged with flow structure.

Name:—**Glass**

Basalt : Graphite 3 : 1 (333) (1410°C)

60% augitite free from graphite, except in round blebs; half consists of augite laths (> 1.710), half of dark brown glass.

40% graphitic glass.

Name:—**Augite + glass + graphite**

Minette : Graphite 3 : 1 (334) (1410°C)

85% fine, big crystals of augite (av. 1.710).

15% dark brown or colorless glass; part has some needles in it which appear to be augite. Graphite is absent except at the edge of the specimen. A few iron globules are present.

Name:—**Augitite**

Kimberlite : Graphite 3 : 1 (338) (1410°C)

Much graphite is present.

Some mineral fragments are present in places; other parts may have some clear glass, but none can be definitely established.

Indeterminate

IGNEOUS ROCKS AND CHALCOCITE

Granite 1 : Chalcocite 3 : 1 (339) (1410°C)

84% glass with flow structure due to many very minute opaque specks.

15% unmelted crystalline matter.

1% large globules of chalcocite, with native copper patches at the edges.

Name:—**Glass + unmelted crystals + little chalcocite**

Syenite a : Chalcocite 3 : 1 (342) (1410°C)

60% clear glass, with myriads of minute opaque specks, and some chalcocite globules of larger size.

40% spherulitic crystallization of oligoclase (1.539), brownish in color. Chalcocite globules are present, with an edge of native copper on some.

Name:—**Andesitic glass**

Nepheline Syenite : Chalcocite 3 : 1 (343) (1410°C) (See Pl. 26, fig. 52.)

100% clear glass, with minute opaque inclusions, flow structure and many large globules of chalcocite, mostly attached to gas bubbles, and some with a touch of native copper at the edges.

Name:—**Glass with chalcocite**

Andesite Porphyrite : Chalcocite 3 : 1 (344) (1410°C)

100% clear glass, with minute opaque inclusions and some flow structure. A few large globules of chalcocite are present, most of them with a fleck of native copper at the edge.

Name:—**Glass**

Basalt : Chalcocite 3 : 1 (340) (1410°C)

95% mostly augite needles and cockscombs (> 1.710), with some glass; no sulphide is present at all.

5% dark brown or very light brown glass.

Name:—**Augitite**

Minette : Chalcocite 3 : 1 (341) (1410°C)

97% augite (> 1.710).

3% dark brown glass. No sulphides are present.

Name:—**Augitite**

Kimberlite : Chalcocite 3 : 1 (345) (1410°C)

75% clino-enstatite ($\leqq 1.650$, < 1.655) and chrysolite (indices greater than 1.670); the former is in greater amount, some is very fine-grained.

25% abundant large globules of chalcocite, many flecked with native copper, and most of them have their shapes controlled by gas bubbles to which they are attached.

Nearly opaque glass is present in very small amount.

Name:—**Limburgite, variety + chalcocite**

IGNEOUS ROCKS AND BORNITE

Granite 1 : Bornite 3 : 1 (346) (1410°C)

75% colorless glass, with unmelted quartz remnants, which are often cracked.

25% chalcocite globules of graded sizes, mostly large. Many of them are attached to gas bubbles. Native copper is seen on some, and some have a little bornite with the chalcocite.

Name:—**Glass + chalcocite + unmelted crystals**

Syenite a : Bornite 3 : 1 (349) (1410°C)

50% colorless glass with some minute opaque globules in streaks.

50% brownish, radially arranged oligoclase (1.539) with some streaks of minute globules.

One or two larger globules of chalcocite with specks of native copper are present in the colorless glass. Some globules of bornite with chalcocite and one of bornite are present.

Name:—**Glassy andesite + bornite + chalcocite**

Nepheline Syenite : Bornite 3 : 1 (350) 1410°C) (See Pl. 27, fig. 53.)

75% clear glass, with much minute opaque matter, showing flow structure very well.

25% chalcocite globules, many with shapes changed by gas bubbles to which they are attached. Native copper occurs on some of them.

Name:—**Glass + chalcocite**

Andesite Porphyrite : Bornite 3 : 1 (351) (1410°C)

100% colorless glass, with a little opaque matter as very minute globules, with some flow arrangement. A few large globules of chalcocite, with flecks of native copper are present, some of which have their shapes controlled by gas bubbles.

Name:—**Glass + chalcocite**

Basalt : Bornite 3 : 1 (347) (1410°C)

90% augite needles (> 1.710), radial in some places, and some as cockscombs are present.

10% dark brown glass. No sulphides are present.

Name:—**Augitite**

Minette : Bornite 3 : 1 (348) (1410°C)

90% augite (> 1.710).

10% or more of dark brown glass. The ore mineral has separated out.

Name:—**Augitite**

Kimberlite : Bornite 3 : 1 (352) (1410°C)

50% finely granular base, probably mostly clino-enstatite, or colored olivine; at any rate not clear, like the larger olivines.

25% clino-enstatite (indices between 1.650 and 1.660) and chrysolite (av. 1.670) in about equal amounts.

25% chalcocite globules of large size, flecked with native copper, some with shapes controlled by gas bubbles.

Name:—**Limburgite + chalcocite**

IGNEOUS ROCKS AND CHALCOPYRITE

Granite 1 : Chalcopyrite 3 : 1 (353) (1410°C) (See Pl. 25, fig. 49.)

75% colorless glass, with some unmelted crystals remaining.

25% large and graded sizes of globules of chalcocite (with occasional chalcopyrite and native copper). The shapes of some of the globules are controlled by gas bubbles.

Name:—**Glass + chalcocite**

Syenite a : Chalcopyrite 3 : 1 (356) (1410°C)

80% brownish base of oligoclase needles (1.539) with sheaf-like arrangement, and some needles of augite.

20% colorless to brownish glass; some minute opaque globules with flow arrangement are present.

Name:—**Trachyte + glass**

Nepheline Syenite : Chalcopyrite 3 : 1 (357) (1410°C) (See Pl. 27, fig. 54.)

95% colorless glass, with abundant minute opaque specks, and fine flow structure due to movement of gas bubbles.

5% globules of graded sizes, some quite large, of chalcocite, with some chalcopyrite and native copper, with shapes controlled by gas bubbles.

Name:—**Glass + chalcocite**

Andesite Porphyrite : Chalcopyrite 3 : 1 (358) (1410°C)

99% colorless glass with myriad minute opaque specks, and very marked flow structure.

1% sulphide globules. Some few large globules of bornite or bornite with chalcocite occur, and one big mass of chalcopyrite with bornite and a little chalcocite is present at the edge.

Name:—**Glass + bornite + chalcocite (+chalcopyrite)**

Basalt : Chalcopyrite 3 : 1 (354) (1410°C)

90% augite needles (> 1.710) with radial and cockscomb arrangement.
8% very dark brown, nearly opaque; probably glass.
2% colorless interstitial glass.

Name:—**Augitite**

Minette : Chalcopyrite 3 : 1 (355) (1410°C)

50% fine crystals of augite (> 1.710).
50% opaque, in places very dark brown glass. No sulphides are present.

Name:—**Augitite**

Kimberlite : Chalcopyrite 3 : 1 (359) (1410°C)

75% augite (> 1.710) and chrysolite (av. 1.692) in about equal proportions; sometimes the augite is a little more prominent in amount. A little brown glass is present.
25% large bornite globules, or bornite and chalcocite, and occasionally pyrrhotite; some globules have shapes controlled by gas bubbles.

Name:—**Limburgite + bornite + chalcocite**

IGNEOUS ROCKS AND PYRITE

Granite 1 : Pyrite 3 : 1 (360) (1410°C) (See Pl. 25, fig. 50.)

75% slightly gray glass, with some unmelted crystal remnants.
25% pyrrhotite globules of graded sizes, some large; their shapes are controlled by gas bubbles in part; the glass is cracked around some of them because of differences of coefficients of expansion.

Name:—**Glass + pyrrhotite**

Syenite a : Pyrite 3 : 1 (363) (1410°C) (See Pl. 29, fig. 57.)

100% colorless glass with very many minute opaque specks, and many large gas bubbles, giving rise to swirling and flow structure.

Name:—**Glass**

Nepheline Syenite : Pyrite 3 : 1 (364) (1410°C)

90% slightly grayish glass.
10% pyrrhotite globules of graded sizes; some few are large.

Name:—**Glass + pyrrhotite**

Andesite Porphyrite : Pyrite 3 : 1 (365) (1410°C)

100% colorless glass, with myriads of minute opaque specks and some large gas bubbles, giving rise to flow arrangement. Only a few globules of pyrrhotite are present.

Name:—**Glass**

Basalt : Pyrite 3 : 1 (361) (1410°C)

90% augite (> 1.680).

10% very dark gray glass. The sulphides have separated out.

Name:—**Augitite**

Minette : Pyrite 3 : 1 (362) (1410°C)

100% very dark brown, vesicular glass, practically opaque in places, anisotropic in spots, due to crystallization of augite. No sulphides are present.

The powdered material from the top of the ingot contains much of both chrysolite (av. 1.680) and augite (> 1.710).

Name:—**Glass + augite + olivine**

Kimberlite : Pyrite 3 : 1 (366) (1410°C)

87% augite (> 1.692) and chrysolite (indices between 1.680 and 1.692), the chrysolite being more abundant in parts.

10% nearly black glass.

3% pyrrhotite globules.

Name:—**Limburgite + pyrrhotite**

IGNEOUS ROCKS AND PYRRHOTITE

Granite: Pyrrhotite 3 : 1 (367) (1410°C) (See Pl. 26, fig. 51.)

75% slightly grayish glass, with unmelted crystal remnants.

25% pyrrhotite globules of graded sizes, mostly large, with shapes modified by gas bubbles.

Name:—**Glass + pyrrhotite**

Syenite a : Pyrrhotite 3 : 1 (370) (1410°C)

100% colorless glass with abundant minute opaque specks and some large gas bubbles which have produced swirling or flow structure.

Name:—**Glass**

Nepheline Syenite : Pyrrhotite 3 : 1 (371) (1410°C) (See Pl. 28, fig. 56.)

92% grayish glass, with some flow structure shown by minute opaque inclusions.

8% globules of pyrrhotite of graded sizes; there is some indication of their movement by the flow arrangement and by a clearing of the globules from one space.*

Name:—**Glass**

Andesite Porphyrite : Pyrrhotite 3 : 1 (372) (1410°C)

100% colorless glass with many minute opaque specks and gas bubbles giving rise to flow structure. Only a few pyrrhotite globules are present.

Name:—**Glass**

Basalt : Pyrrhotite 3 : 1 (368) (1410°C)

100% nearly opaque very vesicular glass, with some slight crystallization to augite; no sulphides are present.

Name:—**Glass + augite**

Minette : Pyrrhotite 3 : 1 (369) (1410°C)

100% dark brown to opaque very vesicular glass, partly crystallized to augite in places; no sulphides are present.

Name:—**Glass + augite**

Kimberlite : Pyrrhotite 3 : 1 (373) (1410°C)

75% chrysolite (av. 1.680) and augite (> 1.710) in about equal proportions, or perhaps with slight predominance of chrysolite. A little nearly opaque glass is present.

25% large pyrrhotite globules, some with shapes modified by gas bubbles.

Name:—**Limburgite + pyrrhotite**

IGNEOUS ROCKS AND NICKELIFEROUS PYRRHOTITE

Granite 1 : Nickeliferous Pyrrhotite 3 : 1 (374) (1410°C)

75% grayish, clear glass, with unmelted crystal remnants.

25% nickeliferous pyrrhotite globules of graded sizes, but mostly large ones; the bronze color of the globules is a little lighter and brighter than that of pyrrhotite, and occasionally a crystal face is present.

Name:—**Glass + nickeliferous pyrrhotite**

*The movement in segregation shown in fig. 56 is toward the side of the ingot. The figure has been turned through 90 degrees to make it fit in the page. The pyrrhotite mass seen in the figure is at the side of the ingot.

Syenite a : Nickeliferous Pyrrhotite 3 : 1 (377) (1410°C)

100% colorless glass, with some large gas bubbles and myriads of minute, opaque specks, with swirled flow arrangement. At one edge is a little brown to dark gray radially crystallized matter, perhaps incipient augite.

Name:—**Glass**

Nepheline Syenite : Nickeliferous Pyrrhotite 3 : 1 (378) (1410°C)

95% slightly brownish glass, with some few minute specks.

5% nickeliferous pyrrhotite globules of graded sizes, mostly large.

Name:—**Glass + nickeliferous pyrrhotite**

Andesite Porphyrite : Nickeliferous Pyrrhotite 3 : 1 (379) (1410°C) (See Pl. 29, fig. 58.)

100% colorless glass, with myriads of minute opaque specks, with wonderful swirling effects, due to movements of gas bubbles. There is no separation of sulphide globules of any size.

Name:—**Glass**

Basalt : Nickeliferous Pyrrhotite 3 : 1 (375) (1410°C)

100% nearly opaque glass, with very little crystallization of augite. No separation of sulphides is noticeable.

Name:—**Glass**

Minette: Nickeliferous Pyrrhotite 3 : 1 (376) (1410°C)

100% very vesicular, dark brown to opaque glass, partly crystalline in spots, but indeterminable. Irregularly shaped masses of nickeliferous pyrrhotite are present near one edge.

Name:—**Glass + nickeliferous pyrrhotite**

Kimberlite : Nickeliferous Pyrrhotite 3 : 1 (380) (1410°C) (See Pl. 28, fig. 55.)

50% chiefly chrysolite (av. 1.680) with subordinate opaque glass, crystallized to augite (> 1.710) in places. No sulphides are present.

50% chiefly augite, with subordinate chrysolite, and say 10% large globules of nickeliferous pyrrhotite. A little pyrrhotite is seen in some of the globules.

Name:—**Limburgite + nickeliferous pyrrhotite**

IGNEOUS ROCKS AND GALENA

Granite 1 : Galena 3 : 1 (381) (1410°C)

97% colorless glass with unmelted crystal fragments and minute opaque specks.

3% globules of lead sulphide, of graded sizes and steel gray color; some are attached to gas bubbles.

Name:—**Glass + lead sulphide**

Syenite a : Galena 3 : 1 (384) (1410°C)

100% colorless glass, with some small brownish patches, with radial feldspars. There are abundant, minute opaque specks with well marked flow arrangement. A few steel gray globules of lead sulphide are present.

Name:—**Glass**

Nepheline Syenite : Galena 3 : 1 (385) (1410°C)

98% colorless glass, with minute opaque specks in flow arrangement, due to movement of gas bubbles and

2% lead sulphide globules, which have a light steel gray color.

Name:—**Glass + lead sulphide**

Andesite Porphyrite : Galena 3 : 1 (386) (1410°C) (See Pl. 30, fig. 59.)

100% colorless glass, with very many minute opaque specks with flow arrangement. Some few gas bubbles are present and a few globules of lead sulphide of graded sizes and steel gray color, some of iron, and some lead sulphide globules with a coat of iron.

Name:—**Glass**

Basalt : Galena 3 : 1 (382) (1410°C)

100% very dark colored, vesicular glass, with partial crystallization to herring-bones of augite (> 1.710) and chrysolite (av. 1.680), which seem to be present almost throughout. No sulphides are present.

Name:—**Limburgite (glassy)**

Minette : Galena 3 : 1 (383) (1410°C)

70% augite crystals (> 1.710).

30% very vesicular, nearly opaque glass. No sulphides are present.

Name:—**Augitite**

Kimberlite : Galena 3 : 1 (387) (1410°C)

50% chrysolite (av. slightly > 1.680).

50% augite (> 1.710). The proportions of the two constituents vary in different parts. One or two steel gray globules of lead sulphide are present, and also a little iron.

Name:—**Peridotite**

IGNEOUS ROCKS AND ZINC BLENDE

Granite 1 : Zinc Blende 3 : 1 (388) (1410°C)

75% colorless glass, with unmelted crystals of quartz and feldspar.

25% dark brown zinc blende, evenly scattered, but in irregular shaped masses.

Name:—**Glass + zinc blende + unmelted crystals**

Syenite a : Zinc Blende 3 : 1 (391) (1410°C)

100% colorless glass, with very many minute opaque specks, and very pronounced flow structure. Some nearly opaque edges show a slight indication of radial crystallization (indeterminable). A pyrrhotite mass at one margin has dark colored zinc blende associated with it.

Name:—**Glass**

Nepheline Syenite : Zinc Blende 3 : 1 (392) (1410°C)

75% colorless glass, with some minute crystals of zinc blende.

25% zinc blende as large, irregular nearly opaque crystalline growths. Some very large vesicles are present.

Name:—**Glass + zinc blende**

Andesite Porphyrite : Zinc Blende 3 : 1 (393) (1410°C)

100% colorless glass, with abundant minute opaque specks, showing striking flow structure. Crystallization in radial fashion occurs at one edge, the material being nearly opaque (probably incipient augite).

Name:—**Glass**

Basalt : Zinc Blende 3 : 1 (389) (1410°C)

Most of this is opaque and indeterminable. Part has crystallized as augite (> 1.710). No zinc blende is recognizable. Some of the opaque matter may be zinc blende.

Name:—**Augitite?**

Minette : Zinc Blende 3 : 1 (390) (1410°C)

50% minute laths of augite (much > 1.710) make up most of the specimen, with

25% glass

25% zinc blende, crystallized as dark-colored tree-like forms.

Name:—**Augitite + zinc blende**

Kimberlite : Zinc Blende 3 : 1 (394) (1410°C)

75% chrysolite (av. 1.692) with a few long needles and long crystals of augite (> 1.710).

25% dark brown to light brown to nearly colorless glass, carrying much opaque, dendritic zinc blende.

Name:—**Limburgite + zinc blende**

Note.—Movement of zinc blende is not so clearly marked as in the case of the other sulphides. When pyrrhotite is present the zinc blende seems to move with it. The mode of accumulation in its details is not clearly shown.

SUMMARY AND CONCLUSIONS*

An experimental investigation has been made to find out what would be the characters of the products of assimilation by igneous magmas of sedimentary materials and other rock materials (not average igneous types), such as may be encountered by magmas during the processes of intrusion.

Intimate association of the igneous material and the material to be assimilated was achieved by means of fine grinding and mechanical mixing. This was followed by melting at temperatures comparable to magmatic temperatures, those used varying from 1230°C to 1600°C. The heating was performed by means of electric furnace or brick kiln. Cooling, in the former case, was rapid, the whole experiment being completed in 24 hours. Only eight melts could be accommodated at one time in the electric furnace used. In the later experiments a brick kiln was used, which allowed of the melting of larger numbers of mixes at one time, and the cooling was much slower, in the effort to aid crystallization. The proportions of the materials used in the experiments were:—igneous : assimilated material 1:1, 2:1, 3:1.

Microscopic examination of the products has shown that assimilation, as indicated by the formation of a uniform melt, is easily and quickly attained in the cases of the addition of

*See also pp. 53 to 56.

calcite, magnetite, hematite, siderite, impure dolomite, magnesite, and tremolite schist. Assimilation is not achieved so easily or completely in the cases of quartz, kaolin, chromite, bauxite, and graphite, at the temperatures used. Possibly assimilation of quartz, kaolin, chromite, and bauxite may be accomplished more slowly, and at higher temperatures.

The results obtained point to the formation of melilitic types by assimilation of calcite. Åkermanite (optically +) is the dominant variety of melilite formed with excess of calcite, as used in the experiments, but in some cases melilite (optically –) was formed. Monticellite and riebeckite have been formed from some types after the assimilation of calcite.

Assimilation of kaolin by peridotite has yielded a type rich in cordierite, in one case, and a basalt in another case. Assimilation of kaolin has yielded increase of basicity of feldspars in some cases.

Assimilation of quartz has been incomplete and has yielded inconclusive results.

Assimilation of magnetite, hematite, siderite, impure dolomite, magnesite, and tremolite schist has yielded magmas rich in iron, calcium or magnesium, from which augite and in some cases olivine have crystallized, leaving a varying proportion of glass. These products are comparable to the augitites and limburgites.

Assimilation of bauxite by the more basic and even acid magmas has given rise to the formation of plagioclase, which was to be expected, perhaps. In other cases some new aluminous silicates or aluminates have been formed (spinel, sillimanite, etc.) giving rise to products unlike any igneous materials. Assimilation of bauxite by a magma under natural conditions is improbable and therefore non-correspondence of the artificial products with natural rocks is to be expected.

The general results of the experiments agree with the possibility of assimilation of sedimentary and other materials by igneous magmas, provided an adequate source of heat is available. The products obtained in the experiments are similar in a general way to natural occurrences, except in the cases of assimilation of chromite and bauxite. This statement needs modification in the case of assimilation of large proportions of calcite, which has yielded åkermanite, a mineral which does not occur in natural igneous rocks. The case of the assimilation of calcite appears to indicate that while assimilation by natural magmas may take place, it is doubtful if assimilation

of such large proportions as the equivalent of 25 per cent of the body of the magma has taken place in nature. Bowen has put forward considerations which point to the possibility of assimilation of rock materials by magmas to a restricted extent. The experimental results support this view of the possibility of restricted powers of assimilation of foreign rock matter by magmas. It is suggested that perhaps 10 or 15 per cent may be the limit of the amount of foreign rock matter which has been assimilated by natural magmas. This is a tentative suggestion which must be discarded if not supported by experimental results in the future.

The assimilation hypothesis of Daly regarding the origin of many igneous rock types is seen to be supported in a general way by the results of the experiments described above. Assimilation of limestone has been found to yield melilitic rocks. There is no direct evidence bearing upon the formation of nepheline-bearing types. It is always possible that removal of crystals rich in lime, iron and magnesium by sinking from a magma which has assimilated limestone may leave a desilicated magma rich in alumina and alkalies, and it is quite easily possible that this may have been one of the important processes in the genesis of nepheline-syenites and related rock types.

New minerals (not in the parent rock materials) formed in the experiments, with the mode of their formation, include: **åkermanite, melilite, monticellite, riebeckite and perovskite,** formed by assimilation of calcite; **cordierite, plagioclase, sillimanite and spinel** by assimilation of kaolin; **plagioclase, sillimanite and spinel,** by assimilation of bauxite; **augite, olivine and garnet** by assimilation of magnesite; **augite** and **olivine** by assimilation of tremolite schist; **bronzite, enstatite and olivine** by assimilation of iron-bearing minerals; **enstatite and clino-enstatite** by assimilation of quartz.*

The formation of melitite in three cases (syenite a, nepheline-syenite, and andesite porphyrite : calcite 1 : 1 series), which under other conditions have yielded åkermanite may be taken as an indication that the constant formation of åkermanite in the melts may not actually be such an important distinction from the natural melilitic rocks as it appears to be at first sight. It may be that under certain conditions differing from those of the experiments that many of the melts including assimilated calcite may yield melilite instead of åkerma-

*For a list of the minerals formed in the experiments and the materials from which they were formed see the appendix, pp. 184-187.

nite. It may be that under oxidizing conditions ferric iron may be available and optically negative melilite may be formed.

Rock types reproduced experimentally include:—

Rhyolite? from granite + siderite.

Trachyte from syenite + magnetite; syenite + hematite; syenite + chromite; syenite + graphite; syenite + chalcopyrite.

Andesite from syenite alone; syenite + chalcocite or bornite.

Augitite from basalt and minette alone; basalt and minette + graphite, chalcocite, bornite, chalcopyrite, or zinc blende; basalt + pyrite; minette + galena.

Limburgite from kimberlite alone; kimberlite + chalcocite, bornite, chalcopyrite, pyrite, pyrrhotite, nickeliferous pyrrhotite, or zinc blende.

Rock types formed experimentally after more or less assimilation include:—

Andesite from basalt and minette + quartz (?); nepheline-syenite + magnetite; andesite-porphyrite + hematite; syenite and nepheline-syenite + siderite; syenite + dolomite.

Basalt from minette + kaolin; kimberlite + quartz (?); granite + magnetite (?); andesite-porphyrite + siderite; andesite-porphyrite + magnesite; basalt and minette + bauxite.

Bronzite-basalt from kimberlite + kaolin.

Augitite from basalt and minette + calcite*; minette and kimberlite + kaolin; basalt, minette and kimberlite + quartz; granite, syenite, andesite-porphyrite, basalt and minette + magnetite; minette + hematite; syenite, nepheline-syenite, andesite-porphyrite, basalt and minette + siderite; andesite-porphyrite, basalt and minette + dolomite; granite, syenite, nepheline-syenite and andesite-porphyrite + magnesite*; granite, syenite, nepheline-syenite and andesite-porphyrite + tremolite schist*.

Limburgite from kimberlite + kaolin; andesite-porphyrite, basalt and kimberlite + magnetite; basalt and kimberlite + siderite; basalt and kimberlite + dolomite; basalt + magnesite; basalt and kimberlite + tremolite schist; basalt, minette and kimberlite + chromite.

Dunite from minette and kimberlite + calcite; kimberlite + magnesite.

*These products are more like contact metamorphic rocks than igneous rocks.

Peridotite from minette and kimberlite + magnetite; kimberlite + hematite; minette and kimberlite + siderite; kimberlite + dolomite; granite*, minette and kimberlite + magnesite; basalt, minette and kimberlite + tremolite schist; kimberlite + galena.

Pyroxenite from minette + magnetite; basalt and minette + hematite; granite and syenite + tremolite schist.

Melilite rock from andesite-porphyrite + calcite. This product recalls okaite or uncompahgrite. ‡

Åkermanite-melilite rock from syenite and nepheline-syenite + calcite. This recalls okaite or uncompahgrite.‡

Olivine-garnet rock (comparable to eclogite) from kimberlite + magnesite.

Monticellite-åkermanite rock from kimberlite + calcite. This recalls the monticellite-alnoites.‡

Monticellite-åkermanite-augite rock from kimberlite + calcite. This recalls monticellite-alnoites.‡

Åkermanite-augite rock from basalt and minette + calcite. This recalls melilite-basalts.‡

Åkermanite-olivine rock from basalt + calcite. This recalls the melilite-basalts.‡

The following types formed experimentally from the constituents named more closely simulate products of contact metamorphism than igneous rocks. The åkermanite-riebeckite rock has no counterpart among natural rocks. **

Cordierite rich rock from kimberlite + kaolin.

Åkermanite rock from granite and andesite-porphyrite + calcite.

Åkermanite-riebeckite rock from minette + calcite.

Monticellite rock from kimberlite + calcite.

Åkermanite types from granite, syenite, nepheline-syenite, andesite-porphyrite, basalt, minette and kimberlite + calcite,

Clino-enstatite-augite rock from kimberlite + quartz.

*These products are more like contact metamorphic rocks than igneous rocks.

**The specimens with åkermanite are not strictly analogous to natural rocks since åkermanite is a very uncommon natural mineral. Some of the specimens may be compared, however, to rocks containing gehlenite, humboldtilite or velardenite.

‡These comparisons involve the idea that the formation of åkermanite is due to the reducing conditions of the experiments, and that melilite may be formed instead of åkermanite under oxidizing conditions.

Part II.

SEPARATION OF ORES FROM MAGMAS

In the study of the modes of ocurrence of ores it has been concluded that in many cases the ores have originated by separation from a magma of which they originally formed a part. After their separation from the magmas they have passed through various vicissitudes and have finally come to rest in veins, stockworks, replacement deposits, contact deposits, etc., a variety of mode of occurrence which serves to mask the details of the process of separation from the magma. Thus the connection between ores and parent magma is not always demonstrable. But often one striking feature of the distribution of the ores is location at or not far distant from the margin of an igneous mass. Sometimes the ore-bodies are found near the base of the intrusive rock, as a result of gravitational settling. In other cases they are found along the lateral borders or even along the upper contacts of the intrusive body. These latter occurrences cannot be explained by gravitational settling.

The marginal concentration of ores is a general process which does not depend upon the kind of ore mineral and is illustrated by deposits of magnetite, hematite and many sulphides, including pyrite, pyrrhotite, pentlandite, chalcopyrite, zinc blende, galena, etc. In so far as an attempt to explain marginal concentration of ores has been made it has been ascribed to magmatic differentiation.

In connection with the series of experiments dealing with "assimilation and petrogenesis", described in the foregoing pages, ground igneous rock materials and materials representing sediments and other rocks have been melted together, after grinding to pass 100 mesh, and after thorough mixing in the proportions igneous : sedimentary, etc. 1:1, 2:1, 3:1.

If we may call these experimental melts magmas it is found that many of the magmas, either before or after assimilation of other rocks, illustrate the processes of magmatic differentiation in a very striking manner. The minerals which

were present in the original rock powders were evenly distributed by grinding and mixing. Some of the minerals were reduced to metal which segregated in many cases to the sides and base of the ingot where it collected in the form of hemi-spherical globules, occupying, in many cases, pores formed by expansion of gases. This result is more prominent in some cases than others, but in some it is so striking that it is surprising that such a result has not been obtained before. It is a result of the first importance in connection with the formation of ore-deposits, and in connection with the general principle of magmatic segregation or differentiation. In many cases the metal globules are more important in amount at the base of the ingot than at the sides. In other cases the distribution of metal in base and sides of the ingot is more uniform. In still other cases there are globules on the upper surfaces of the ingots. That is to say, in some cases gravity seems to play a definite part in the segregation of the metal, while in other cases it plays a small part in the segregation, only. A more important general principle, in the latter case, appears to be that the metal segregates at the surfaces of the ingots, base, sides, and in some cases the top.

The cause of this result is doubtless connected with surface tension and its variations in different parts of the molten mass, especially at its contact with the walls of the containing reservoir.

PROCESSES OF SEPARATION OF ORES FROM MAGMAS

The igneous magma is intruded either as

1. a homogeneous liquid which later separates into two parts—a silicate magma and a sulphide or oxide magma (this is Vogt's idea of the process),

or 2. in the form of a suspensoid system in which liquid silicate (with some dissolved sulphide or oxide) is the dispersing medium, and the excess of sulphide or oxide over the amount soluble at any given temperature is the dispersed liquid phase.

It does not matter, practically, which of the two conceptions of the original condition is correct, because even if originally homogeneous owing to complete mutual solution of silicate and sulphide or oxide at high temperatures, the liquid separates into two parts on cooling. According to Vogt the sulphide separates in increasing amount with falling tempera-

ture because of the smaller solubility of sulphide in silicate melt at lower temperatures. After the separation of the melt into two parts both are still liquid.

My conception of the state of the magma is that it is a colloidal emulsion of sulphide or oxide globules dispersed in silicate fluid. It may be that the globules have a different size from those of colloidal suspensions at normal temperatures. The view is advanced, here, that at the temperatures of 1000°C to 1300°C the sizes of particles of a dispersed phase may be different from the sizes of particles of a dispersed phase at ordinary temperatures, (larger or smaller than 5 to 500 μ μ) and yet may be able to behave in a similar manner to that of a dispersed system of the sizes mentioned, at ordinary temperatures.

The course of the evolution of the sulphide-silicate or oxide-silicate emulsion is extremely interesting, at any rate from the point of view of its results—the formation of ore-bodies. If the cooling of the magma is rapid the whole solidifies and the sulphides or oxides are sporadically but fairly evenly distributed throughout the rock mass.

If the cooling is slower a separation of the two liquids may take place with a segregation of the sulphides or oxides into ore-bodies, a result which has often been produced in nature, but generally the segregation has not been complete and there is still a certain amount of sulphide or oxide distributed through the rock mass. The forces which may be involved in the segregation of sulphides, oxides or metals into ore-bodies are:—

1. Gravity a. Sinking
   b. Flotation
2. Temperature differences (Soret principle)
3. Differences of surface energy
4. Cohesion.

The globules of the dispersed phase are in constant motion (Brownian movement) and as a result of this motion there is a tendency to even distribution of the globules within the liquid. But the force of gravity tends to collect the globules in the lower part of the magma. These two forces act differently and seeing that the effect of either is never completely established, there is never a complete separation of the ore and silicate liquids. But the other forces mentioned also have play in the processes of separation.

If gases are liberated during the magmatic evolution they

will tend to rise upward toward the roof of the reservoir. In so moving gas bubbles may become attached to small ore globules, which may be carried upward, in much the same manner as in the flotation processes of ore dressing. Coalescence of such floated ore globules may give rise to ore-bodies at the upper contacts of igneous masses. Cases illustrating that such a process may actually occur in a molten magma have been found in the experimental melts and are illustrated in figs. 49 to 56.

By reason of temperature differences a concentration of the ores toward the cooler parts of the magma reservoir will tend to be established (Soret principle). But it has been shown by Harker* that the amount of this effect is very small.

The effect of surface tension in bringing about movement of ores in a magma has not been considered previously. The surface tension at the surface of the ore globules will have a certain average value which may be different from the value of the surface tension between the walls of the reservoir and the magma. If the latter is lower than the former the globules of the suspensoid which are close to the reservoir walls will tend to move toward it and eventually (theoretically) to join themselves to it, with a resulting diminution of free surface energy. The completion of this process may not be perfected in every case. As a result of the action of the force due to differences of surface energy in different parts of the magma, movements of the ore globules will take place through the dispersing medium, toward the region where the surface energy is lower. This type of movement is called diffusion and as a result of it there will be an increase of the proportion of the ore globules in the marginal parts of the reservoir, i. e. at the base, sides, and sometimes even the roof.

If the force of cohesion (a force of chemical nature) is sufficient to overcome the force of surface tension at the surfaces of two globules which come together for a short time, as a result of their constant motion, the globules will coalesce (compare the coalescence of mercury globules after breaking). So that after the ore globules have been brought to the margins of the reservoir by the forces of surface energy or of gravity coalescence takes place and volumes of liquid or oxide of varying sizes are collected within the magma or at the wall of the reservoir. With the fall of temperature in the simple

*Harker, A. Natural History of Igneous Rocks, 1909, pp. 316-7.

case they will solidify as ore-bodies at the lower contact, or along the sides or even top of the intrusion as **marginal deposits.**

If earth-movements complicate the process of solidification part of the sulphides or oxides may be injected into the surrounding country rocks in the form of veins of sulphides or oxides, as so-called **"off-set deposits."**

Most of the cases outlined can be illustrated by the details of the Sudbury sulphide ore-deposits. The incompleteness of the separation of sulphides from silicates is shown by the general distribution of sulphides through the norite. The stages in the coalescence of the sulphide globules to clots of varying sizes are shown by the sulphide masses in the norite near its margin and near the ore-bodies. The insufficiency of the force of gravity to account for all of the marginal deposits is shown by the location of some of the ore-bodies (and also some of those of Norway) at lateral margins, or contacts, which are vertical or highly tilted, and which cannot be shown, in all cases, to have been originally the base of the reservoir which has since been tilted up.

EXPERIMENTS

In the experimental melts mentioned above there were small amounts of iron formed by reduction of the iron-bearing minerals. Larger amounts of iron have been formed when iron ores have been mixed with the igneous materials. In a large proportion of the cases tried there has been accumulation of the metal formed at the peripheries of the ingots. The greater amount of the metal is generally to be found in the base of the solidified ingot. But there is clear evidence in all cases of separation that gravity is not the only force moving the metal to the bounding surfaces. This evidence is that some of the globules are found at the sides of the ingots, and in some cases at their tops. At the sides and bases of the ingots the metal has collected in the form of hemi-spherical masses, the flat sides being against the sides of the crucibles.

These experiments have shown that the diffusion of the metal through the silicate magma is rapid. The results achieved were obtained within 24 hours and the time of active movement extended over only a few hours, say 4 or 5 hours, at most. The completeness of the separation in this short time is quite striking and although the distance of movement is small (the ingots have a diameter of 3/4") yet the speed of the separation seems to be greater than that commonly assumed

by writers on the topic of magmatic differentiation. It is often remarked that given sufficient time much can be accomplished by small forces, and it is the practice to postulate unlimited time for the completion of the reactions in magmas. On the contrary, it may be emphasized that important effects can be achieved as a result of gravitative separation, and separation by differences of surface energy within a comparatively short time. It may be that the large sulphide masses of the sulphide ore-bodies may have been accumulated within a comparatively short time, say within a day or two during which the conditions were satisfactory for such accumulation; and it may be that in connection with the formation of ore deposits formed at depth the notion will grow upon us that the period of formation has been quite brief, though this may not be so closely demonstrable as in the case of certain ore-bodies formed at shallow depths.*

The common and rather loose way of calling into play the effect of unlimited time may not be necessary for the explanation and elucidation of the processes of formation of ore deposits.

After the results mentioned above had been obtained a series of melts were made of the igneous materials chosen, mixed with various sulphides in the proportions igneous rock : sulphide 3:1, using chalcocite, bornite, chalcopyrite, pyrite, pyrrhotite, nickeliferous pyrrhotite, galena and zinc blende. It was expected that these experiments would offer additional evidence regarding the processes of separation of sulphides from magmas. It was found that the same principles as mentioned above were illustrated by the separation of the sulphides mentioned from the magmas. Details of the results are given below. The copper-bearing minerals separating often show the effect of the graphite of the crucible, in the formation of a small amount of native copper. When chalcopyrite was included in the mixes it was rarely reproduced, after heating. Upon cooling it was found to have been changed to bornite or chalcocite. Bornite in the original mineral was most often changed to chalcocite. These results indicate that in dry melts chalcocite is more stable than bornite at high temperatures, and bornite is more stable than chalcopyrite at high temperatures. The series is chalcocite—bornite—chal-

*Lindgren, Mineral Deposits, 2nd Edition, 1919, p. 476.

copyrite in order of stability with reducing temperature. It may be that the presence of one or other of these minerals in primary segregations from magmas may be indicative of certain temperature conditions at the time of their formation, chalcopyrite being indicative of a lower temperature of formation and chalcocite of a higher temperature of formation.

DETAILS OF EXPERIMENTAL RESULTS

The materials used in the experiments were a series of rocks chosen to represent the more important magmatic types from granite to peridotite, a set of minerals or sediments chosen to represent the sedimentary minerals or common mineral masses that might be caught up by a magma during the act of intrusion. These materials often yielded by reduction a small proportion of metallic iron, and after noting the results obtained in the separation of this iron a set of the common sulphide minerals was chosen for a further series of experiments.

The names, localities, chemical analyses, and descriptions of the materials used are given on pages 57 to 62.

RESULTS OBTAINED BY MIXING AND MELTING IGNEOUS ROCKS WITH SEDIMENTS, ETC.

In the following record of the results in connection with gravitative separation, or separation at the walls, top and over the bases of the ingots abbreviation of the rock and mineral names are used for convenience. These are such as need no explanation, with the exception that in the case of the granites Gr. 1 refers to Hurricane I. granite; Gr. 2 to Westerly granite; and Gr. 3 to Concord granite; An. refers to the hornblende-andesite-porphyrite from Sylvan Pass, Yellowstone National Park; Mag = magnetite, FeBas = feldspar-basalt, Tr. Sch. = tremolite schist and Ni-Pyrr = nickeliferous pyrrhotite. The laboratory numbers and highest temperatures reached in the heatings are recorded in parentheses. The proportions of the materials are given immediately after the abbreviations indicating the materials in the mixes.

Gr. 1 : Calc. 1 : 1 (401) (1410°C) Small globules of magnetite are present over nearly all of the base.

Gr. 1 : Calc. 2 : 1 (402) (1410°C) Small globules of magnetite are present over nearly all of the base and very few minute specks of iron, inside.

Gr. 1 : Calc. 3 : 1 (403) (1410°C) A few small scattered globules of magnetite are present in the base and very few minute specks of iron inside.

Gr. 2 : Calc. 1 : 1 (404) (1410°C) A few small scattered globules of magnetite are present in the base.

Gr. 2 : Calc. 2 : 1 (405) (1410°C) A few small scattered globules of magnetite are present in the base.

Gr. 2 : Calc. 3 : 1 (406) (1410°C) A few small scattered globules of magnetite are present in the base and sides.

Gr. 3 : Calc. 1 : 1 (407) (1410°C) Magnetite globules are scattered over the base.

Gr. 3 : Calc. 2 : 1 (408) (1410°C) Magnetite globules are scattered over the base and sides.

Gr. 3 : Calc. 3 : 1 (409) (1410°C) Magnetite globules are scattered over the base and a few globules of iron inside.

Sy. a : Calc. 1 : 1 (416) (1410°C) The base is magnetic due to a mass of minute iron globules inside, near the centre of the base. Also there are magnetite globules on the outside.

Sy. a : Calc. 2 : 1 (417) (1410°C) One large globule of iron is present half-way up on the side.

Sy. a : Calc. 3 : 1 (418) (1410°C) Globules of magnetite are scattered over the base and some on the sides, half-way up. One iron bead, diam. 1/8″, occurs inside.

NeSy. : Calc. 1 : 1 (419) (1410°C) One large globule of magnetite occurs near the top of the side.

NeSy. : Calc. 2 : 1 (420) (1410°) One large magnetite globule is present near the top of the side.

NeSy. : Calc. 3 : 1 (421) (1410°C) Minute globules of magnetite occur in the base, and some of iron inside.

An. : Calc. 1 : 1 (422) (1410°C) Small black iron oxide globules occur on the base; one large globule at the top of the side has a black oxide outer coat.

An. : Calc. 2 : 1 (423) (1410°C) Small iron globules (with black oxide outside) occur on the base, especially near the centre. A few are present high on the sides, and one large one at the top of the side. A few globules of iron are present inside, near the base.

An. : Calc. 3 : 1 (424) (1410°C) Iron oxide globules are scattered on the base but the largest ones are at the top of the sides. One mass of iron inside, diam. 1/8″, has a black coating.

Bas. : Calc. 1 : 1 (410) (1410°C)

Bas. : Calc. 2 : 1 (411) (1410°) Iron globules (with black oxide coating) protrude from the base near the centre.

Many fairly large ones occur at the top of the edge. An iron mass is present at the centre of the base and the edge of the top. (The latter has a black coating of oxide.)

Bas. : Calc. 3 : 1 (412) (1410°C) A few globules of iron (with black oxide coating) protrude from the base near the centre. Several, and one very large, are present at the top of the sides.

Min. : Calc. 1 : 1 (413) (1410°C) Abundant small specks of iron are present throughout, inside.

Min. : Calc. 2 : 1 (414) (1410°C) Small iron globules (with black oxide coating) protrude from the base; one large one is present on the side, and several at the top of the sides.

Min. : Calc. 3 : 1 (415) (1410°C) Small iron globules with black oxide coating protrude from the base; larger ones occur at the top of the side. Inside, small iron masses are present at the centre of the base, and upper inside near the edge.

Kim. : Calc. 1 : 1 (425) (1410°C)

Kim. : Calc. 2 : 1 (426) (1410°C).. Many minute specks of iron are present throughout, inside.

Kim. : Calc. 3 : 1 (427) (1410°C) Many minute specks of iron occur throughout the lower fine-grained half. The upper coarsely crystallized half is nearly free from them. There is a thin plating of metallic iron on the base.

Gr. 1. : Calc. 1 : 1 (1) (1470°C) Ferro-silicon globules are present in the base and sides, and are more abundant in the base than the sides.

Gr. 1 : Calc. 2 : 1 (4) (1470°C) A few ferro-silicon globules occur in the base, with fewer on the sides. A few very minute ferro-silicon globules occur throughout.

Gr. 1 : Calc. 3 : 1 (7) (1470°C) A few small ferro-silicon globules are in the base.

Gr. 2 : Calc. 1 : 1 (2) (1470°C) A few ferro-silicon globules are on the sides and base, and are about evenly distributed.

Gr. 2 : Calc. 2 : 1 (5) (1470°C) A few large ferro-silicon globules occur on the base, and fewer on the sides. A few minute globules occur throughout, inside, being more common near the base.

Gr. 2 : Calc. 3 : 1 (8) (1470°C) A few small ferro-silicon globules are on the base and the lower part of the sides. A very few minute ferro-silicon globules occur throughout, inside, and are more common near the base.

Gr. 3 : Calc. 1 : 1 (3) (1470°C) A few ferro-silicon globules occur in the base.

Gr. 3 : Calc. 2 : 1 (6) (1470°C) Some ferro-silicon globules occur on the lower part of the base. A few very minute globules of ferro-silicon occur throughout, inside, being more common near the base.

Gr. 3 : Calc. 3 : 1 (9) (1270°C) Minute iron specks occur on the base, and on the top near the side.

Sy. : Calc. 1 : 1 (55) (1300°C) A very few iron globules occur on the base and at the top of the sides.

Sy. : Calc. 2 : 1 (59) (1300°C) A few minute iron specks occur on the base; one large one is at the top of the side; two small ones are near the top, inside.

Sy. : Calc. 3 : 1 (63) (1309°C) Some iron occurs on the top.

NeSy. : Calc. 1 : 1 (56) (1300°C) A very few iron globules occur on the base and top of the sides.

NeSy. : Calc. 2 : 1 (60) (1300°C) A few small iron specks occur near the lowest point of the base. Also metallic iron, diam. 1/4″, occurs on top at centre.

NeSy. : Calc. 3 : 1 (64) (1309°C) Some iron is present at the centre of the top.

An. : Calc. 1 : 1 (57) (1300°C) A few medium sized iron globules occur on the sides.

An. : Calc. 2 : 1 (61) (1300°C) Medium sized iron globules are abundant on the sides, with fewer on the base. A very few minute ones are inside.

An. : Calc. 3 : 1 (65) (1309°C) Iron globules are all over the sides and base.

FeBas. : Calc. 1 : 1 (11) (1470°C) Iron globules are well sprinkled over the sides and base.

FeBas. : Calc. 2 : 1 (14) (1470°C) Small iron specks are on the sides.

FeBas. : Calc. 3 : 1 (17) (1470°C) Some small specks of iron are on the sides.

Bas. : Calc. 1 : 1 (10) (1470°C) Medium sized iron globules are all over the sides and base and some are on the top.

Bas. : Calc. 2 : 1 (13) (1470°C) Medium sized iron globules are well distributed over the sides and base.

Bas. : Calc. 3 : 1 (16) (1470°C) Iron coating nearly covers the sides and base.

Min. : Calc. 1 : 1 (12) (1470°C)

Min. : Calc. 2 : 1 (15) (1470°C) Medium sized iron globules are on the sides and base. A few large ones are present at the top of the sides.

Min. : Calc. 3 : 1 (18) (1270°C) Large globules of iron are well spread over the sides and base; some large ones are at the top of the sides.

Kim. : Calc. 1 : 1 (58) (1300°C)

Kim. : Calc. 2 : 1 (62) (1300°C) Minute iron specks are distributed throughout, inside.

Kim. : Calc. 3 : 1 (66) (1309°C) A little iron has separated on the sides and base. Inside, some minute iron specks are near one upper side.

Gr. 1 : Koal. 1 : 1 (428) (1410°C)

Gr. 1 : Kaol. 2 : 1 (429) (1410°C) Some very minute iron specks are inside.

Gr. 1 : Kaol 3 : 1 (430) (1410°C) Some very minute iron specks are inside.

Gr. 2 : Kaol 1 : 1 (431) (1410°C)

Gr. 2 : Kaol. 2 : 1 (432) (1410°C) Some very minute iron specks are inside.

Gr. 2 : Kaol. 3 : 1 (433) (1410°C)

Gr. 3 : Kaol. 1 : 1 (434) (1410°C)

Gr. 3 : Kaol. 2 : 1 (435) (1410°C) Very few, minute iron specks are inside.

Gr. 3 : Kaol. 3 :1 (436) (1410°C)

Sy. a : Kaol. 1 : 1 (443) (1410°C)

Sy. a : Kaol 2 : 1 (444) (1410°C) Many small globules of iron occur throughout, inside.

Sy. a : Kaol 3 : 1 (445) (1410°C) A few iron globules (with black oxide coating) are on top, and specks of iron are inside, chiefly in the lower part.

NeSy. : Kaol. 1 : 1 (446) (1410°C)

NeSy. : Kaol. 2 : 1 (447) (1410°C)

NeSy. : Kaol. 3 : 1 (448) (1410°C)

An. : Kaol. 1 : 1 (449) (1410°C)

An. : Kaol. 2 : 1 (450) (1410°C) A few small globules of iron are on the base and inside.

An. : Kaol. 3 : 1 (451) (1410°C) A cavity at the top centre has one bright iron globule at its side. A few minute iron globules occur near the base, inside.

Bas. : Kaol. 1 : 1 (437) (1410°C) At centre top is a cavity with several iron globules round its margin. A few iron globules are present inside, chiefly near the base or sides.

Bas. : Kaol. 2 : 1 (438) (1410°C) One large mass of iron is at centre of the base; on top many medium sized globules of iron, with very thin oxide coating, protrude.

Bas. : Kaol. 3 : 1 (439) (1410°C) Many large globules of iron (black oxide coated) are round the top of the sides; also some smaller are on the base. (There is more oxide than metallic iron.)

Min. : Kaol 1 : 1 (440) (1410°C) One large iron and many small iron oxide globules are on the top; the large one is near the side. (A black shell of oxide has peeled off the large globule.)

Min. : Kaol. 2 : 1 (441) (1410°C) Small masses of iron (black oxide coated) protrude from the top and base, and larger ones from the top of the edges.

Min. : Kaol. 3 : 1 (442) (1410°C) One large mass of iron is at centre of the base; many medium sized ones are at the bottom of the sides, and many smaller are on the base. Black oxide coats them.

Kim. : Kaol. 1 : 1 (452) (1410°C) Many scattered globules of iron (black oxide coated) occur over the base; a few (also black oxide coated) are near the centre of the top.

Kim. : Kaol 2 : 1 (453) (1410°C) Many small iron masses (black oxide coated) occur over the base; some occur at the sides. Inside, iron globules are on the base and top.

Kim. : Kaol 3 : 1 (454) (1410°C) Inside, minute iron specks occur in the lower part, chiefly near the base.

Gr. 1 : Kaol. 1 : 1 (19) (1600°C)

Gr. 1: Kaol. 2 : 1 (22) (1600°C) Minute ferro-silicon specks occur evenly over the sides and base.

Gr. 1 : Kaol. 3 : 1 (25) (1600°C) A large ferro-silicon globule is on top, and minute ones on the side; the base is absent. Very few minute specks of iron are inside.

Gr. 2 : Kaol 1 : 1 (20) (1600°C)

Gr. 2 : Kaol. 2 : 1 (23) (1600°C) Minute specks of ferro-silicon occur evenly over the sides and base.

Gr. 2 : Kaol. 3 : 1 (26) (1600°C) Minute specks of ferro-silicon occur evenly over the sides and base.

Gr. 3 : Kaol. 1 : 1 (21) (1600°C)

Gr. 3 : Kaol. 2 : 1 (24) (1600°C) Minute specks of ferro-silicon occur over the upper part of the sides; one is seen on top.

Gr. 3 : Kaol. 3 : 1 (27) (1270°C)

Sy. : Kaol. 1 : 1 (67) (1309°C)

Sy. : Kaol. 2 : 1 (71) (1402°C)

Sy. : Kaol. 3 : 1 (75) (1402°C) A very little ferro-silicon occurs at the top.

NeSy. : Kaol. 1 : 1 (68) (1309°C)

NeSy. : Kaol. 2 : 1 (72) (1402°C)

NeSy. : Kaol. 3 : 1 (76) (1402°C)

An. : Kaol. 1 : 1 (69) (1309°C)

An. : Kaol. 2 : 1 (73) (1402°C) A little iron is on the top. One or two specks are on the side. One is inside, at the upper left centre.

An. : Kaol. 3 : 1 (77) (1402°C) Ferro-silicon globules occur on the top only.

FeBas. : Kaol. 1 : 1 (29) (1500°C)

FeBas. : Kaol. 2 : 1 (32) (1500°C) Minute ferro-silicon specks are on the sides and base, and larger globules are on the top.

FeBas. : Kaol. 3 : 1 (35) (1500°C) Minute iron specks occur over the sides, base and most of the top The larger globules are near the edge.

Bas. : Kaol. 1 : 1 (28) (1500°C) Iron globules are fairly evenly distributed over the top, sides and base. The largest ones are at the top of the sides.

Bas. : Kaol 2 : 1 (31) (1500°C) Large iron globules are about evenly spread over the sides and base. Many small ones are on the top.

Bas. : Kaol. 3 : 1 (34) (1500°C) Large iron globules occur over the sides and base; some small ones are on the top.

Min. : Kaol. 1 : 1 (30) (1500°C) Iron globules (carrying some sulphur) are fairly evenly spread over the top, sides and base; some of them are large.

Min. : Kaol 2 : 1 (33) (1500°C) Iron globules are on the sides and base.

Min. : Kaol. 3 : 1 (36) (1270°C) Medium sized iron globules occur all over the sides and base; some very small ones are on the top, and a few minute ones are inside.

Kim. : Kaol. 1 : 1 (70) (1309°C)

Kim. : Kaol. 2 : 1 (74) (1402°C) A few minute iron specks occur on the sides and base, and more occur on the top.

Kim. : Kaol. 3 : 1 (78) (1402°C) Very minute iron specks are on the sides, base and top.

Gr. 1 : Qtz. 1 : 1 (455) (1410°C)

Gr. 1 : Qtz. 2 : 1 (456) (1410°C) A very few minute iron specks occur throughout, inside.

Gr. 1 : Qtz. 3 : 1 (457) (1410°C) A very few minute iron specks occur throughout, inside.

Gr. 2 : Qtz. 1 : 1 (458) (1410°C) A very few minute iron specks occur throughout, inside.

Gr. 2 : Qtz. 2 : 1 (459) (1410°C)

Gr. 2 : Qtz. 3 : 1 (460) (1410°C)

Gr. 3 : Qtz. 1 : 1 (461) (1410°C)

Gr. 3 : Qtz. 2 : 1 (462) (1410°C)

Gr. 3 : Qtz. 3 : 1 (463) (1410°C) Minute ferro-silicon specks are scattered in the sides and base.

Sy. a : Qtz. 1 : 1 (470) (1410°C) Minute iron specks occur in the lower part, inside.

(471) **Sy. a : Qtz. 2 : 1 (1410°C)** Minute iron specks occur in the lower part, and upper part inside.

Sy. a : Qtz. 3 : 1 (472) (1410°C) Many minute iron globules are on the top.

NeSy. : Qtz. 1 : 1 (473) (1410°C)

NeSy. : Qtz. 2 : 1 (474) (1410°C)

NeSy. : Qtz. 3 : 1 (475) (1410°C)

An. : Qtz. 1 : 1 (476) (1410°C) Some few minute iron specks are inside.

An. : Qtz. 2 : 1 (477) (1410°C) Minute iron specks are inside, chiefly in the lower part, and also at the top.

An. : Qtz. 3 : 1 (478) (1410°C) At centre of the top is a large silicate globule having a different appearance from the rest. It has many small iron globules on its surface.

Bas. : Qtz. 1 : 1 (464) (1410°C) Many minute iron specks occur over nearly all of the base and sides; iron globules (with black coating of oxide) occur at the top of the edges, and some are inside.

Bas. : Qtz. 2 : 1 (465) (1410°C) Iron globules occur here and there on the base, sides, and at the top of the sides. The latter are coated with black oxide.

Bas. : Qtz. 3 : 1 (466) (1410°C) Iron (black coated) occurs over nearly all of the base and sides; also globules are on the top, and some inside.

Min. : Qtz. 1 : 1 (467) (1410°C) A little iron (black oxide coated) occurs chiefly on the sides and near the top of the sides. Minute specks of iron are inside.

Min. : Qtz. 2 : 1 (468) (1410°C) Minute globules of iron (covered by black oxide) are scattered on both sides and base. Minute globules of iron occur inside.

Min. : Qtz. 3 : 1 (469) (1410°C) Iron occurs on the base, sides and top, the largest globules (coated with black oxide) being near the top of the sides. Inside, minute iron specks are present throughout.

Kim. : Qtz. 1 : 1 (479) (1410°C) Inside, a few minute iron specks are uniformly distributed.

Kim. : Qtz. 2 : 1 (480) (1410°C) Minute iron globules occur throughout, inside and partial plating with iron occurs on the base and sides.

Kim. : Qtz. 3 : 1 (481) (1410°C) Minute iron globules occur throughout, inside.

Gr. 1 : Qtz. 1 : 1 (37) (1440°C)

Gr. 1 : Qtz. 2 : 1 (40) (1440°C) A few minute ferro-silicon specks are on the sides and base.

Gr. 1 : Qtz. 3 : 1 (43) (1440°C)

Gr. 2 : Qtz. 1 : 1 (38) (1440°C)

Gr. 2 : Qtz. 2 : 1 (41) (1440°C)

Gr. 2 : Qtz. 3 : 1 (44) (1440°C) Minute ferro-silicon specks are on the sides and base.

Gr. 3 : Qtz. 1 : 1 (39) (1440°C)

Gr. 3 : Qtz. 2 : 1 (42) (1440°C)

Gr. 3 : Qtz. 3 : 1 (45) (1270°C)

Sy. : Qtz. 1 : 1 (79) (1249°C)

Sy. : Qtz. 2 : 1 (83) (1249°C) Very few iron specks are on the base.

Sy. : Qtz. 3 : 1 (87) (1379°C) Minute ferro-silicon specks are on the base, sides and especially at the centre of the top. A few specks of iron are inside.

NeSy. : Qtz. 1 : 1 (80) (1249°C)

NeSy. : Qtz. 2 : 1 (84) (1249°C)

NeSy. : Qtz. 3 : 1 (88) (1370°C)

An. : Qtz. 1 : 1 (81) (1249°C)

An. : Qtz. 2 : 1 (85) (1249°C) A few minute specks of iron are in the sides and base.

An. : Qtz. 3 : 1 (89) (1379°C).. Minute iron and ferro-silicon specks are on the sides and top.

FeBas. : Qtz. 1 : 1 (47) (1450°C) A few minute ferro-silicon specks are in the sides and base.

FeBas. : Qtz. 2 : 1 (50) (1450°C) A few minute ferro-silicon specks are on the sides, top and fewer are on the base.

FeBas. : Qtz. 3 : 1 (53) (1450°C) Iron and ferro-silicon globules are on the sides and one of iron is on the top.

Bas. : Qtz. 1 : 1 (46) (1450°C)

Bas. : Qtz. 2 : 1 (49) (1450°C) Small iron and ferro-silicon globules occur evenly over the sides and base; one large one is near the top of the side; the largest one is at the bottom of the side. Some very minute iron specks occur throughout, inside.

Bas. : Qtz. 3 : 1 (52) (1450°C) Large iron globules are on the sides and base, and small ones are on the top; minute ones occur throughout, inside.

Min. : Qtz. 1 : 1 (48) (1450°C) A few ferro-silicon specks occur on the top.

Min. : Qtz. 2 : 1 (51) (1450°C) Iron and ferro-silicon globules are on the top, sides and base. Some minute ones of iron occur throughout, inside.

Min. : Qtz. 3 : 1 (54) (1270°C) Medium sized iron and ferro-silicon globules are well distributed over the sides and base; a few are on the top.

Kim. : Qtz. 1 : 1 (82) (1249°C)

Kim. : Qtz. 2 : 1 (86) (1249°C)

Kim. : Qtz. 3 : 1 (90) (1379°C) Iron and ferro-silicon globules are on the sides and base, and one is on top; a few minute ones are inside.

Gr. 1 : Mag. 1 : 1 (101) (1230°C) The ingot is in fragments, is strongly magnetic, and contains much metallic iron and magnetite.

Gr. 1 : Mag. 2 : 1 (102) (1230°C) Metallic iron is present throughout, inside. The ingot is porous and is oxidized at the outside.

Gr. 1 : Mag. 3 : 1 (103) (1230°C) Abundant minute iron specks occur inside, and are least abundant near the top. The ingot is oxidized at the outside.

Sy. : Mag. 1 : 1 (110) (1230°C) The ingot is very porous, magnetic, with much metallic iron throughout, and is oxidized at the surface.

Sy. : Mag. 2 : 1 (111) (1230°C) The ingot is very porous and light, magnetic, partly due to metallic iron, but mainly due to magnetite on the surfaces.

Sy. : Mag. 3 : 1 (112) (1230°C) The ingot is very porous and light, magnetic, with much metallic iron in the outer part, and is oxidized at the surfaces.

NeSy. : Mag. 1 : 1 (113) (1230°C) This is a very irregular ingot, with no base. Magnetic globules, oxidized at the

surfaces, occur at the sides and metallic iron is present throughout.

NeSy. : Mag. 2 : 1 (114) (1230°C) The ingot is very light, porous and is magnetic; metallic iron is not seen. Many small magnetite particles occur on the surfaces.

NeSy. : Mag. 3 : 1 (115) (1230°C) The ingot is mushroom shaped, with a large pore inside. The base is magnetic; metallic iron is not seen. Magnetite is present on the surface. The ores are concentrated near the base.

An. : Mag. 1 : 1 (116) (1230°C) The ingot has magnetic top, bottom and sides. Metallic iron occurs throughout, inside, and is oxidized at the surfaces.

An. : Mag. 2 : 1 (117) (1230°C) The ingot is very porous and is magnetic at all sides. Metallic iron is present throughout, and is oxidized at the surfaces.

An. : Mag. 3 : 1 (118) (1230°C) The ingot is magnetic; metallic iron is present throughout, and is oxidized at the surfaces.

Bas. : Mag. 1 : 1 (104) (1230°C) Many iron globules (with very thin oxide coat) occur in the base, at the sides and on the top; the largest one is at the centre of the base.

Bas. : Mag. 2 : 1 (105) (1230°C) Many iron globules are present; the largest ones are on the base, off centre, and at one side; others are round the sides and on the top. Some are unevenly distributed inside.

Bas. : Mag. 3 : 1 (106) (1230°C) Globules of iron occur near the sides of the base; they are larger and more numerous round the sides. Iron is unevenly distributed inside.

Min. : Mag. 1 : 1 (107) (1230°C)

Min. : Mag. 2 : 1 (108) (1230°C) Very many minute iron globules are evenly distributed, inside.

Min. : Mag. 3 : 1 (109) (1230°C) Very many minute iron globules are evenly distributed, inside.

Kim. : Mag. 1 : 1 (119) (1230°C) The ingot is magnetic on all sides; it is sintered not molten; metallic iron is not present.

Kim. : Mag. 2 : 1 (120) (1230°C) The ingot is magnetic on all sides; it is sintered not molten; metallic iron is not present.

Kim. : Mag. 3 : 1 (121) (1230°C) The ingot is magnetic on all sides; it is sintered not molten; metallic iron is not present.

Gr. 1 : Mag. 1 : 1 (543) (1410°C) Some globules of iron (black oxide coated) are on the top, sides and base. One large iron mass (coated at base with black oxide) is at the lower centre; a few small ones are inside and one is at the top.

Gr. 1 : Mag. 2 : 1 (544) (1410°C) Crowds of minute black iron oxide globules are at one side, and on the base, near one side. One big globule of iron is present.

Gr. 1 : Mag. 3 : 1 (545) (1410°C) A mass of magnetite is inside, at the centre of the base.

Sy. a : Mag. 1 : 1 (552) (1410°C) A large mass of iron is at the centre of the base, with many octahedra of magnetite on its outside.

Sy. a : Mag. 2 : 1 (553) (1410°C) Iron globules (with coating of black oxide) occur on the base, and sides, and small ones occur on the top. Two large masses are at opposite sides of the base. A few small scattered iron globules occur inside.

Sy. a : Mag. 3 : 1 (554) (1410°C) A large mass of iron is at the centre of the base; others (black oxide coated) are on the base, and sides, and minute ones are on the top.

NeSy. : Mag. 1 : 1 (555) (1410°C) A large mass of iron with thick black oxide coating is at the edge. Three oxide coated iron globules are on the base.

NeSy. : Mag. 2 : 1 (556) (1410°C) A large mass of iron (black oxide coated) with magnetite crystals is at the centre of the base; a few other oxide-coated iron globules are on the base.

NeSy. : Mag. 3 : 1 (557) (1410°C) A large mass of iron (black oxide coated) is at the centre of the base and similar globules occur over the rest of the base.

An. : Mag. 1 : 1 (558) (1410°C) Separation of silicate and iron (part with a thick magnetite coating) into two nearly equal parts, one at the side of the other, has taken place.

An. : Mag. 2 : 1 (559) (1410°C) Two large iron masses (black oxide coated) are at opposite sides; one smaller is at the centre of the base, and some small globules are on the base, and minute ones of iron are inside.

An. : Mag. 3 : 1 (560) (1410°C) One large iron mass (black oxide coated) is at the side; others smaller are on the base and edge; minute ones are on the top and inside.

Bas. : Mag. 1 : 1 (546) (1410°C) One big mass of iron with thick outside coating of magnetite is at the centre of the base.

Bas. : Mag. 2 : 1 (547) (1410°C) This is similar to the

last, with some big magnetite-coated iron globules at the edge of the base, and many minute ones of iron, throughout inside.

Bas. : Mag. 3 : 1 (548) (1410°C) This is similar to 546, with medium sized globules of iron at the top of the sides, and small oxide coated ones over the rest of the base and sides. A few minute globules of iron are inside.

Min. : Mag. 1 : 1 (549) (1410°C) A large mass of iron is at the centre of the base. Small masses of iron are at the top and bottom of the sides, one of each. All have outer coatings of magnetite.

Min. : Mag. 2 : 1 (550) (1410°C) This is similar to 548, but most of the medium sized globules are at the bottom of the sides. One medium sized mass of iron is just above the large central mass.

Min. : Mag. 3 : 1 (551) (1410°C) This is similar to 550. Inside, one large iron globule is at the lower corner, and one is a little above the large mass at the centre of the base.

Kim. : Mag. 1 : 1 (561) (1410°C) Iron masses are distinct on the base, but on the sides and top run together and cover nearly all. Inside, iron is abundant in the outer part all round, with a central part free. Magnetite coats the iron outside, with some magnetite crystals.

Kim. : Mag. 2 : 1 (562) (1410°C) Iron globules coated with black oxide (with magnetite crystals) protrude from the base, sides and top; they are smaller on top. Inside, the central part has abundant iron specks, the margin being free from them.

Kim. : Mag. 3 : 1 (563) (1410°C) Masses of black oxide coated iron are in the base and sides, and smaller ones are on the top. Many minute iron specks are inside and one large mass is at the centre of the base.

Gr. 1 : Baux. 3 : 1 (124) (1230°C) Minute specks of iron occur throughout.

Bas. : Baux. 2 : 1 (126) (1230°C) Minute specks of iron occur throughout.

Bas. : Baux. 3 : 1 (127) (1230°C) A few specks of iron occur on the margins of cavities at the edges of the ingot.

Min. : Baux. 3 : 1 (130) (1230°C) Minute specks of iron occur throughout.

An. : Baux. 3 : 1 (139) (1230°C) A few minute iron specks are inside.

Kim. : Baux. 3 : 1 (142) (1230°C) A few minute iron specks are inside.

Gr. 1 : Baux. 1 : 1 (501) (1410°C)
Gr. 1 : Baux. 2 : 1 (502) (1410°C)
Gr. 1 : Baux. 3 : 1 (503) (1410°C)
Sy. a : Baux. 1 : 1 (510) (1410°C) Minute specks of iron occur throughout, inside.
Sy. a : Baux. 2 : 1 (511) (1410°C) Minute specks of iron occur throughout, inside.
Sy. a : Baux. 3 : 1 (512) (1410°C) Minute specks of iron occur throughout, inside, especially below, and some oxide-coated iron globules are on the top.
NeSy. : Baux. 1 : 1 (513) (1410°C)
NeSy. : Baux. 2 : 1 (514) (1410°C)
NeSy. : Baux. 3 : 1 (515) (1410°C)
An. : Baux. 1 : 1 (516) (1410°C) Minute specks of iron occur throughout, inside.
An. : Baux. 2 : 1 (517) (1410°C) Minute specks of iron occur throughout, inside.
An. : Baux. 3 : 1 (518) (1410°C) Some iron globules (oxide coated) are on the top; some are inside, especially in the lower part.
Bas. : Baux. 1 : 1 (504) (1410°C) The base is slightly magnetic. Small iron specks occur throughout.
Bas. : Baux. 2 : 1 (505) (1410°C) Iron specks occur throughout, inside; the largest ones being at the top, are black oxide coated outside.
Bas. : Baux. 3 : 1 (506) (1410°C) Iron globules (black oxide coated) occur in the base, sides and top; the largest ones are at the top of the sides; a few of iron are present inside, in the upper part.
Magnetite coats most of the surfaces indicating marginal concentration of oxide. Some crystals are on the top.
Min. : Baux. 1 : 1 (507) (1410°C) Many minute iron specks occur throughout, inside.
Min. : Baux. 2 : 1 (508) (1410°C) Many minute iron specks occur throughout, inside, especially in the lower part. One large globule (black oxide coated) is on the top.
Min. : Baux. 3 : 1 (509) (1410°C) Iron globules (black oxide coated) occur; one at the centre of the base is the largest; others are on the top, but most of them are at the top of the sides. A few very minute ones occur inside.
Kim. : Baux. 1 : 1 (519) (1410°C) Minute iron specks occur throughout, inside.

Kim. : Baux. 2 : 1 (520) (1410°C) Minute iron specks occur throughout, inside.

Kim. : Baux. 3 : 1 (521) (1410°C) Minute iron specks occur throughout, inside.

Gr. 1 : Sid. 1 : 1 (143) (1230°C) The ingot is magnetic at the top, bottom and sides. Abundant metallic iron is present throughout.

Gr. 1 : Sid. 2 : 1 (144) (1230°C) The ingot is magnetic at the top, bottom and sides. Abundant metallic iron is present throughout.

Gr. 1 : Sid. 3 : 1 (145) (1230°C) The ingot is magnetic at the top, bottom and sides; a little iron occurs inside.

Sy. : Sid. 1 : 1 (152) (1230°C) The ingot is magnetic at the top, bottom and sides; metallic iron occurs throughout inside.

Sy. : Sid. 2 : 1 (153) (1230°C) The ingot is magnetic at the top, bottom and sides; metallic iron occurs throughout inside.

Sy. : Sid. 3 : 1 (154) (1230°C) The ingot is magnetic at the top, bottom and sides; metallic iron occurs throughout inside.

NeSy. : Sid. 1 : 1 (155) (1230°C) The ingot is magnetic at the top, bottom and sides; it is very porous. Iron is not detected. Magnetite is concentrated at the surfaces.

NeSy. : Sid. 2 : 1 (156) (1230°C) The ingot is magnetic at the top, bottom and sides; metallic iron occurs throughout, inside, and is oxidized outside.

NeSy. : Sid. 3 : 1 (157) (1230°C) The ingot is magnetic at the top, bottom and sides; metallic iron occurs throughout, inside, and is oxidized outside.

An. : Sid. 1 : 1 (158) (1230°C) The ingot is magnetic at at the top, bottom and sides; metallic iron occurs throughout, inside, and is oxidized outside.

An. : Sid. 2 : 1 (159) (1230°C) The ingot is magnetic at the top, bottom and sides, most strongly on the top, most weakly on the base. Metallic iron occurs here and there, inside, and magnetite at the surfaces.

An. : Sid. 3 : 1 (160) (1230°C) The ingot is magnetic at the top, bottom and sides; iron occurs throughout inside.

Bas. : Sid. 1 : 1 (146) (1230°C) Large globules of iron occur in the base and on the sides; iron is irregularly distributed throughout.

Bas. : Sid. 2 : 1 (147) (1230°C) Large iron globules occur in the base and sides; the largest ones are at the side of the top; some iron globules are present, inside.

Bas. : Sid. 3 : 1 (148) (1230°C) Many small iron globules are in the base and at the sides; one large one is at the side.

Min. : Sid. 1 : 1 (149) (1230°C) The ingot is slightly magnetic; metallic iron is evenly distributed throughout.

Min. : Sid. 2 : 1 (150) (1230°C) The ingot is slightly magnetic, metallic iron is evenly distributed throughout.

Min. : Sid. 3 : 1 (151) (1230°C) The ingot is magnetic at the top, bottom and sides; some minute iron specks are on the sides, and occur evenly throughout, inside.

Kim. : Sid. 1 : 1 (161) (1230°C) The ingot is magnetic at the top, bottom and sides; minute iron specks occur inside, most abundantly near the top.

Kim. : Sid. 2 : 1 (162) (1230°C) The ingot is magnetic at the top, bottom and sides; metallic iron occurs throughout, inside.

Kim. : Sid. 3 : 1 (163) (1230°C) The ingot is magnetic at the top, bottom and sides, most strongly on the top, most weakly on the base. Iron globules occur throughout, inside, most abundantly near the top.

Gr. 1 : Sid. 1 : 1 (522) (1410°C) Conspicuous black oxide coated iron globules occur on the base, sides and top; that at the centre of the base is the largest. Iron is present through the central part of the ingot.

Gr. 1 : Sid. 2 : 1 (523) (1410°C) A few small iron globules are on the top. Iron is prominent in the upper central part, inside.

Gr. 1 : Sid. 3 : 1 (524) (1410°C) A few small iron globules are at the top of the sides; an uneven shaped mass of iron is inside.

Sy. a : Sid. 1 : 1 (531) (1410°C) A large mass of iron extends from the centre to the side of the base; others (oxide coated) are small at the top of the sides, over the base, and minute ones are on the top.

Sy. a : Sid. 2 : 1 (532) (1410°C) Iron globules (oxide coated) occur over the base, and one large one (black oxide coated) is at the side.

Sy. a : Sid. 3 : 1 (533) (1410°C) Black coated iron globules occur over the base and sides, and a few minute ones are on the top.

NeSy. : Sid. 1 : 1 (534) (1410°C) Black oxide coated globules of iron occur over the base and top; one large one is at the side.

NeSy. : Sid. 2 : 1 (535) (1410°C) Iron globules (oxide coated) occur over the base, sides and top; and irregular masses of iron occur in the upper central part, inside.

NeSy. : Sid. 3 : 1 (536) (1410°C) Minute oxide coated iron globules occur over the base and sides. The top is strongly magnetic; some large iron globules are present on it. Metallic iron is present near the top, inside.

An. : Sid. 1 : 1 (537) (1410°C) Iron globules, black oxide coated outside, are present over the base; some minute ones are on the top; the largest one is at the edge; the one at the centre of the base is fairly large.

An. : Sid. 2 : 1 (538) (1410°C) Black oxide coated iron globules occur over the base, and some minute ones are on the top; one large one is at the edge; a few iron globules are present inside.

An. : Sid. 3 : 1 (539) (1410°C) Black oxide coated iron globules occur over the base, and some minute ones are on the top; one large one is at the edge; a few iron globules are present inside.

Bas. : Sid. 1 : 1 (525) (1410°C) Iron globules occur in the base and sides; two large ones are at the top of the side. The globules are black oxide coated.

Bas. : Sid. 2 : 1 (526) (1410°C) Black oxide coated iron globules occur in the base and sides; the largest ones are at the top of the sides.

Bas. : Sid. 3 : 1 (527) (1410°C) Black oxide coated iron globules occur in the base and sides; the largest ones are at the top of the sides.

Min. : Sid. 1 : 1 (528) (1410°C) A large mass of very hard steel (the lower part black oxide* coated) is at the centre of the base. Small globules of black oxide coated iron occur on the base and sides.

Min. : Sid. 2 : 1 (529) (1410°C) A large mass of very hard steel (the lower part black oxide* coated) is at the centre of the base. Small globules of black oxide coated iron occur on the base and sides.

Min. : Sid. 3 : 1 (530) (1410°C) A large mass of iron (black oxide coated) occurs near the centre of the base; other small ones are present in the base and sides.

*With some magnetite crystals.

Kim. : Sid. 1 : 1 (540) (1410°C) Large black oxide coated iron globules are present over the base, and there is one on the top. A large gas cavity is present inside.

Kim. : Sid. 2 : 1 (541) (1410°C) Black oxide coated iron globules occur over the base, sides and top.

Kim. : Sid. 3 : 1 (542) (1410°C) This is similar to the last. Large iron globules occur at the top of the sides, one at the centre of the base, and one at the side of the base. Many small iron globules occur throughout, inside.

Gr. 1 : Magnes. 1 : 1 (164) (1400°C) A few specks of iron are present inside.

Gr. 1 : Magnes. 2 : 1 (165) (1400°C) A few specks of iron are present inside.

Gr. 1 : Magnes. 3 : 1 (166) (1400°C) A few specks of iron are present inside.

Sy. : Magnes. 1 : 1 (173) (1400°C) Minute globules of iron occur throughout, inside.

Sy. : Magnes. 2 : 1 (174) (1400°C) Some minute globules of iron occur throughout, inside.

Sy. : Magnes. 3 : 1 (175) (1400°C) Very few globules of iron are present inside.

NeSy. : Magnes. 1 : 1 (176) (1400°C) Very few globules of iron are present inside.

NeSy. : Magnes. 2 : 1 (177) (1440°C) Some minute iron globules are present inside.

NeSy. : Magnes. 3 : 1 (178) (1400°C) A few minute iron globules are present inside.

An. : Magnes. 1 : 1 (179) (1400°C) Minute iron globules occur inside.

An. : Magnes. 2 : 1 (180) (1400°C) Minute iron globules occur inside.

An. : Magnes. 3 : 1 (181) (1400°C) Minute iron globules are present inside, in the lower half. One large globule is near the top of the side.

Bas. : Magnes. 1 : 1 (167) (1400°C) A few specks of iron are present inside.

Bas. : Magnes. 2 : 1 (168) (1400°C) Many globules of black oxide coated iron occur on the base, sides and top, most abundantly on the top. Fewer minute ones are distributed throughout.

Bas. : Magnes. 3 : 1 (169) (1400°C) Many iron globules (thinly coated with black oxide) occur on the base, sides and top, more abundantly on the top than the base, most

abundantly round the top of the sides. Very few are present inside.

Min. : Magnes. 1 : 1 (170) (1400°C) Metallic iron is present in minute globules throughout, inside, most abundantly near the top.

Min. : Magnes. 2 : 1 (171) (1400°C) Abundant specks of iron occur throughout, inside.

Min. : Magnes. 3 : 1 (172) (1400°C)

Kim. : Magnes. 1 : 1 (182) (1400°C)

Kim. : Magnes. 2: 1 (183) (1400°C) Abundant minute iron globules are present throughout, inside.

Kim. : Magnes. 3 : 1 (184) (1400°C) Many minute iron globules are present throughout, inside.

Gr. 1 : Dol. 1 : 1 (185) (1400°C) The base is slightly magnetic, due to a globule of iron. A few globules of iron are present, inside.

Gr. 1 : Dol. 2 : 1 (186) (1400°C) Many iron globules are present, on the top only, outside. A few are present inside, mostly in the lower part.

Gr. 1 : Dol. 3 : 1 (187) (1400°C) Two or three small oxide-coated iron globules occur on the top; very few are present inside.

Sy. : Dol. 1 : 1 (193) (1400°C) Iron globules (with thin oxide coating outside) occur in base, sides and top of sides, chiefly near the centre of the base.

Sy. : Dol. 2 : 1 (195) (1400°C) Few globules of iron (with thin oxide coating outside) occur on the base and at the top of the sides; very few minute ones are present inside.

Sy. : Dol. 3 : 1 (196) (1400°C) One large iron globule (with thin oxide coating outside) is present at the top of the side; some small ones are on the top and a few minute ones, inside.

NeSy. : Dol. 1 : 1 (197) (1400°C) Iron globules (with thin oxide coating outside) occur in the base; a few are at the sides and at the top of the sides. Minute specks of iron are present in a dark central part, inside.

NeSy. : Dol. 2 : 1 (198) (1400°C) One iron globule (with a thin coating of oxide) occurs at the edge; some minute ones are inside.

NeSy. : Dol. 3 : 1 (199) (1400°C) A few minute specks of iron are present inside, especially near the top.

An. : Dol. 1 : 1 (200) (1400°C) Many iron globules occur on the base and sides.

An. : Dol. 2 : 1 (201) (1400°C) Iron globules are present in the base, but mostly at the sides of the base.

An. : Dol. 3 : 1 (202) (1400°C) Iron globules (with thin oxide coat) occur near the centre of the base and at the top of the sides.

Bas. : Dol. 1 : 1 (188) (1400°C) Many iron globules are present in the base; many also are round the top of the sides, not elsewhere.

Bas. : Dol. 2 : 1 (189) (1400°C) Iron globules are in the base and sides, especially at the centre of the base and top of the sides.

Bas. : Dol. 3 : 1 (190) (1400°C) Iron globules occur in the base and sides, and at the top of the sides.

Min. : Dol. 1 : 1 (191) (1400°C) Iron globules (with thin oxide coat) occur in the base and sides, especially at the top of the sides.

Min. : Dol. 2 : 1 (192) (1400°C) Iron globules occur in the base and sides, especially at the top of the sides,.

Min. : Dol. 3 : 1 (193) (1400°C) Iron globules (with thin oxide coat) occur in the base and sides, especially at the top of the sides.

Kim. : Dol. 1 : 1 (203) (1400°C) Abundant, minute iron specks are present inside, in the lower, fine-grained half.

Kim. : Dol. 2 : 1 (204) (1400°) Abundant, minute iron specks occur throughout, inside.

Kim. : Dol. 3 : 1 (205) (1400°C) Abundant, minute iron specks occur throughout, inside.

Gr. 1 : Tr. Sch. 1 : 1 (206) (1400°C) A few iron globules (with thin oxide coat) occur on the base and edge of the base.

Gr. 1 : Tr. Sch. 2 : 1 (207) (1400°C) Globules of iron are present on the base and top; very few minute ones are inside.

Gr. 1 : Tr. Sch. 3 : 1 (208) (1400°C) Some globules of iron occur inside, on the top and on the base.

Sy. a : Tr. Sch. 1 : 1 (215) (1400°C) Many small globules of iron occur in the base, and in the lower central part, inside.

Sy. a : Tr. Sch. 2 : 1 (216) (1400°C) Many small iron globules are present in the base, and at the edge of the base, also on the sides where the sides are presnt.

Sy. a : Tr. Sch. 3 : 1 (217) (1400°C) Many large iron globules are present in the base and also on the sides.

NeSy. : Tr. Sch. 1 : 1 (218) (1400°C) Many small globules of iron occur in the base, and a few inside.

NeSy. : Tr. Sch. 2 : 1 (219) (1400°C) Many small globules of iron occur in the base, sides and top, and a few inside.

NeSy. : Tr. Sch. 3 : 1 (220) (1400°C) Some iron globules occur round the top of the edges, some small ones are present on the top, and a few inside.

An. : Tr. Sch. 1 : 1 (221) (1400°C) Many small iron globules are present in the base and sides; inside, they are abundant in the lower one-fourth.

An. : Tr. Sch. 2 : 1 (222) (1400°C) Much iron is present all over the base, especially toward the centre.

An. : Tr. Sch. 3 : 1 (223) (1400°C) Many iron globules occur in the base, especially toward the centre, also at the edge and top of the edges.

Bas. : Tr. Sch. 1 : 1 (209) (1400°C) Oxide-coated iron globules occur at the top of the sides. Inside, abundant small iron globules are present in the lower fine-grained part.

Bas. : Tr. Sch. 2 : 1 (210) (1400°C) Iron globules (with thin oxide coat outside) occur at the top of the sides and all over the base. Iron globules are present inside, chiefly near the lower centre.

Bas. : Tr. Sch. 3 : 1 (211) (1400°C) Many large iron globules (with thin oxide coat outside) occur all over the base and at the top of the sides. Iron is present near the lower centre, inside, as minute globules.

Min. : Tr. Sch. 1 : 1 (212) (1400°C) Some small iron globules occur in the base. Iron is prominent in the lower fine-grained part, inside.

Min. : Tr. Sch. 2 : 1 (213) (1400°C) Iron globules occur in the base. Some iron is in the lower part, inside.

Min. : Tr. Sch. 3 : 1 (214) (1400°C) Large, protruding iron globules occur in the base. Iron is prominent in the lower central part, inside.

Kim. : Tr. Sch. 1 : 1 (224) (1400°C) Small iron globules are distributed throughout, inside.

Kim. : Tr. Sch. 2 : 1 (225) (1400°C) Small iron globules are distributed throughout, inside.

Kim. : Tr. Sch. 3 : 1 (226) (1400°C) Small iron globules occur on the top and base. Iron is present throughout inside.

Gr. 1 : Hem. 1 : 1 (227) (1400°C) The top and base are magnetic and very porous. Iron is abundant in a certain zone, inside.

Gr. 1 : Hem. 2 : 1 (228) (1400°C) Many small iron glob-

ules occur on the top and base. Iron is present throughout, inside, but especially at the edges of gas cavities.

Gr. 1 : Hem. 3 : 1 (229) (1400°C) The ingot is porous and magnetic at the top only; iron masses occur near the top centre, inside.

Sy. a : Hem. 1 : 1 (236) (1410°C) Many small oxide coated iron globules are at the base and on the top; one very large globule (also with oxide coat) is at the side; some small ones are inside.

Sy.a : Hem. 2 : 1 (237) (1410°C) Many small (oxide coated) iron globules are at the base and on the top; one very large one (with oxide coat) is at the side; some are inside in the lower part.

Sy. a : Hem. 3 : 1 (238) (1410°C) One large, black oxide coated iron mass is at the side, some are on the base, especially near the centre; also small ones are on the top. Inside, a few iron globules, and one large one occur in the lower part.

NeSy. : Hem. 1 : 1 (239) (1410°C) Many oxide coated iron globules are on the base and sides. Inside a large central mass is rich in iron.

NeSy. : Hem. 2 : 1 (240) (1410°C) The ingot is magnetic at top and bottom, especially the top. Small iron globules (with thin oxide coating) are visible in the base and sides. A central mass has an iron rich rim.

NeSy. : Hem. 3 : 1 (241) (1410°C) The ingot is magnetic top and bottom, especially at the top. The central part inside is rich in iron.

An. : Hem. 1 : 1 (242) (1410°C) A large black oxide coated mass of very hard steel is at the side; one small one is on the opposite side, at the top. Small globules. are present on the base and top. One large iron globule is inside, at one edge.

An. : Hem. 2 : 1 (243) (1410°C) This is similar to the last. A few small iron globules are inside.

An. : Hem. 3 : 1 (244) (1410°C) This is similar to the last; a few iron globules are on the top and inside, especially in the lower part.

Bas. : Hem. 1 : 1 (230) (1400°C) A big iron globule is at the centre of the base, some are at the edges of the base, and many smaller ones occur over the base.

Bas. : Hem. 2 : 1 (231) (1400°C) Large iron globules are at the edges of the base and many smaller ones occur over the base.

Bas. : Hem. 3 : 1 (232) (1400°C) Large iron globules are at the edges of the base and many smaller ones occur over the base.

Min. : Hem. 1 : 1 (233) (1400°C) Iron globules occur in the base; the largest one is at the centre; there are other large ones at the edge of the base. A little black oxide is present on some of them.

Min. : Hem. 1 : 1 (234) (1400°C) ..Iron globules occur in the base; the largest one is at the centre; there are other large ones at the edge of the base.

Min. : Hem. 2 : 1 (234) (1400°C) Iron globules occur in the base; the largest one is at the centre; there are other large ones at the edge of the base. A little black oxide is present on some of them.

Kim. : Hem. 1 : 1 (245) (1410°C) A large iron mass is present at the side, one small one is on the other side at the top. Small oxide coated iron globules occur on the base and top. A large iron mass inside, has a hard black oxide coating.

Kim. : Hem. 2 : 1 (246) (1410°C) Iron masses (black oxide coated) occur on the top and bottom and one large one (also oxide coated) is inside.

Kim. : Hem. 3 : 1 (247) (1410°C) The ingot is magnetic at the top, bottom and sides. Iron globules are present on all; those on top have an oxide coating. Inside, iron is abundant, especially in the lower part.

***Gr. 1 : Chrom. 1 : 1 (290) (1410°C)** A thin plating of iron and some ferro-chrome is present on parts of the base and sides. Some specks of iron are inside.

Gr. 1 : Chrom. 2 : 1 (291) (1410°C) Small iron and ferro-chrome globules are present on the top, and a few of iron are in the base and inside and also a few of ferro-chrome are inside.

Gr. 1 : Chrom. 3 : 1 (292) (1410°C) Ferro-chrome and a few iron globules are in the base and a few globules of iron are inside.

Sy. a : Chrom. 1 : 1 (229) (1410°C) Most of the sides and base, except the lowest part are plated with ferro-chrome with crystalline structure. Some iron specks are inside.

Sy. a : Chrom. 2 : 1 (300) (1410°C) Some of the sides and base, except the lowest point, are plated with ferro-chrome. Specks of iron are well distributed, inside.

Sy. a : Chrom. 3 : 1 (301) (1410°C) Some ferro-chrome

*The metal coating the ingots in the chromite series is ferro-chrome. It is less magnetic than iron, does not react with $CuSO_4$, and gives a chromium bead.

globules occur in the base, near the edge, and at the top of the edges; a few of iron are inside.

NeSy. : Chrom. 1 : 1 (302) (1410°C) A few globules of iron are inside.

NeSy. : Chrom. 2 : 1 (303) (1410°C) A few globules of iron are inside, and a few are on the top.

NeSy. : Chrom. 3 : 1 (304) (1410°C) Very few globules of iron occur inside.

An. : Chrom. 1 : 1 (305) (1410°C) Ferro-chrome plates the base and sides. Iron globules occur inside, chiefly across the middle.

An. : Chrom. 2 : 1 (306) (1410°C) Ferro-chrome occurs in the base and sides, as globules; iron globules are inside.

An. : Chrom. 3 : 1 (307) (1410°C) Ferro-chrome globules are on the top, sides and some are on the base; a few small ones of iron are inside, chiefly in the lower half.

Bas. : Chrom. 1 : 1 (293) (1410°C) Ferro-chrome plates the sides and base, except the lowest point. A few iron globules are present inside.

Bas. : Chrom. 2 : 1 (294) (1410°C) Ferro-chrome plates the sides and base, except the lowest point. A few iron globules are present inside.

Bas. : Chrom. 3 : 1 (295) (1410°C) Ferro-chrome plates the sides and base, except the lowest point. A few iron globules are present inside.

Min. : Chrom. 1 : 1 (296) (1410°C) Ferro-chrome plates the sides and base, except the lowest point. A few iron globules are present inside.

Min. : Chrom. 2 : 1 (297) (1410°C) Most of the sides and base, except the lowest point are plated with ferro-chrome with crystalline structure. A few globules of iron are present, inside.

Min. : Chrom. 3 : 1 (298) (1410°C) Most of the sides and base, except the lowest point are plated with ferro-chrome with crystalline structure. A few globules of iron are present, inside.

Kim. : Chrom. 1 : 1 (308) (1410°C) Ferro-chrome plates the sides and base; small iron globules are on the top and some small ones are inside, especially in the upper half.

Kim. : Chrom. 2 : 1 (309) (1410°C) The sides, base and top are plated with ferro-chrome; some iron globules are present inside.

Kim. : Chrom. 3 : 1 (310) (1410°C) The sides, base and

top are plated with brittle non-magnetic ferro-chrome. Small globules of iron are distributed throughout, inside; large ones are near the top.

Gr. 1 : Graph. 3 : 1 (332) (1410°C) The silicate part is vermicular around graphite powder.

Sy. a : Graph. 3 : 1 (335) (1410°C) The silicate part is vermicular around graphite powder.

NeSy. : Graph. 3 : 1 (336) (1410°C) The silicate part is vermicular around graphite powder.

An. : Graph. 3 : 1 (337) (1410°C) The silicate part is vermicular around graphite powder.

Bas. : Graph. 3 : 1 (333) (1410°C) The silicate part is vermicular around graphite powder.

Min. : Graph. 3 : 1 (334) (1410°C) The silicate part is vermicular around graphite powder.

Kim. : Graph. 3 : 1 (338) (1410°C) The silicate part is vermicular around graphite powder.

RESULTS OBTAINED BY MIXING SULPHIDES WITH IGNEOUS ROCKS

In this series of experiments the igneous rock materials and sulphides were mixed in the proportion of 3 : 1, and they were heated to a maximum temperature of 1410°C. The results noticed are given below.

Gr. 1 : Chalcoc. 3 : 1 (339) (1410°C) A large chalcocite mass is at the centre of the base and one is inside; some small ones are at the sides; also native copper is seen on the base and sides. Globules of copper and chalcocite are on the top.

Sy. a : Chalcoc. 3 : 1 (342) (1410°C) A large mass of iron and chalcocite and some native copper is at the centre of the base. Two large and several small chalcocite masses are at the top of the sides, and some are inside; some small ones are on the top. The whole ingot is cracked, the cracks running through the sulphide-iron mass.

NeSy. : Chalcoc. 3 : 1 (343) (1410°C) Many chalcocite and native copper globules are on the base, top and sides, and a few are inside. The largest ones are on the top.

An. : Chalcoc. 3 : 1 (344) (1410°C) Four large buttons of chalcocite (all strongly magnetic) with a little native copper are at the sides of the base and one is at the centre of base. On the top are small chalcocite globules and a cavity with many small wires of native copper.

Bas. : Chalcoc. 3 : 1 (340) (1410°C) A large mass of chalcocite with some streaks of native copper in it is at the centre of the base. A few globules of native copper and chalcocite globules are at the edges of the base. Inside, iron-chalcocite masses are near the centre of the base; one is large and has native copper at the side of it. The sulphide mass is cracked and it has in it a globule of copper below with one of iron above it.

Min. : Chalcoc. 3 : 1 (341) (1410°C) A hard steel button with chalcocite around and above it, and native copper below it, is at centre of the base. Also some steel globules are on the sides and some of chalcocite are over the base and part of the sides.

Kim. : Chalcoc. 3 : 1 (345) (1410°C) Chalcocite occurs in the base, sides and top, and throughout, inside. Native copper is seen in the base and sides. One large globule of native copper has one of iron above it.

Gr. 1 : Born. 3 : 1 (346) (1410°C) Chalcocite in small globules occurs on the top, sides, and base and throughout, inside. A little native copper is on the base and more is on the sides.

Sy. a : Born. 3 : 1 (349) (1410°C) A large globule of iron with bornite and chalcocite occurs at the centre of the base, and several large globules of chalcocite with native copper are at the top of the sides.. The sulphide globules show cracking.

NeSy. : Born. 3 : 1 (350) (1410°C) A little chalcocite and native copper is on the sides. At the top centre is a cavity with chalcocite on the bottom and native copper wires from several points on its sides. Inside, a large chalcocite globule is just below the one at the top centre, and many small globules of chalcocite are in the lower part of the ingot.

An. : Born. 3 : 1 (351) (1410°C) Chalcocite globules, with some native copper are present; the largest one is at the centre of the base; other small ones are on the base and sides the largest one of them being at the top of the side. The chalcocite is black and soft, but magnetic, so it is ferriferous.

Bas. : Born. 3 : 1 (347) (1410°C) A button of bornite, with iron and native copper is at the centre of the base. Chalcocite and copper are present near the top of the side, at one place. Cracks run through the whole.

Min. : Born. 3 : 1 (348) (1410°C) Globules and plating of bornite, chalcocite and native copper are on the base. A

little bornite and native copper are on the sides. Cracks run through the whole. A large button at the centre of the base has a central mass of iron surrounded by chalcocite, bornite and native copper.

Kim. : Born. 3 : 1 (352) (1410°C) Chalcocite globules and some native copper are on the base, sides and most of the top, and many are inside.

Gr. 1 : Chalcop. 3 : 1 (353) (1410°C) Some chalcocite globules are on the sides and top, and throughout, inside.

Sy. a : Chalcop. 3 : 1 (356) (1410°C) Four large magnetic masses of chalcocite with iron and some bornite and chalcopyrite are at the sides. Fractures are present.

NeSy. : Chalcop. 3 : 1 (357) (1410°C) The ingot is broken by bursting, due to a magnetic bornite mass in the centre of the ingot. Other masses of chalcopyrite with bornite are on the sides and base; the largest one is in the centre of the base; some native copper wires occur in cavities with the bornite.

An. : Chalcop. 3 : 1 (358) (1410°C) A coating of chalcocite and a little bornite is on the base and sides; one large mass of magnetic chalcocite is at the side of the base, and has native iron through it.

Bas. : Chalcop 3 : 1 (354) (1410°C) Bornite with a little chalcocite and native copper and a mass of iron inside it is at the centre of the base; a little chalcocite as small globules is on the sides.

Min. : Chalcop. 3 : 1 (355) (1410°C) A chalcocite mass is on the base, with a mass of iron inside it. Chalcocite is on the sides and small globules of the same are throughout, inside.

Kim. : Chalcop 3 : 1 (359) (1410°C) A coating of bornite and chalcocite is on the base, sides and top. Magnetic bornite is on the base, and chalcocite is on the sides, top and throughout. An iron mass is in the lower central mass of bornite.

Gr. 1 : Pyr. 3 : 1 (360) (1410°C) Minute globules of iron occur all over the base and sides, and inside.

Sy. a : Pyr. 3 : 1 (363) (1410°C) A large mass of pyrrhotite is at the centre of the base.

NeSy. : Pyr. 3 : 1 (364) (1410°C) A few medium sized globules are in the base, a few larger ones are on the sides, and one larger still on top. Some are iron, and some are magnetic sulphides of iron. There is one mass of pyrrhotite inside,

near the corner of the base. The ingot is cracked through the middle.

An. : Pyr. 3 : 1 (365) (1410°C) Pyrrhotite covers most of the base.

Bas. : Pyr. 3 : 1 (361) (1410°C) A large mass partly iron and partly magnetic sulphide of iron extends from the centre of the base to one edge of the base.

Min. : Pyr. 3 : 1 (362) (1410°C) A large mass of iron extends from the centre of the base to one edge of the base.

Kim. : Pyr. 3 : 1 (366) (1410°C) Magnetic sulphide of iron covers most of the base, there is some on the sides, and very little on top. There are some globules of the same in a central porous part, which is a gas chimney from the sulphide mass at the centre of the base.

Gr. 1 : Pyrr. 3 : 1 (367) (1410°C) Many globules of iron are inside, especially near the base.

Sy. a : Pyrr. 3 : 1 (370) (1410°C) Magnetic sulphide of iron is nearly all over the base. Metallic iron is on the sides and at the top of the sides.

NeSy. : Pyrr. 3 : 1 (371) (1410°C) The ingot is burst, due to a pyrrhotite ball, inside.

An. : Pyrr. 3 : 1 (372) (1410°C) A large pyrrhotite mass is at the centre of the base; some smaller ones of black iron are on the sides.

Bas. : Pyrr. 3 : 1 (368) (1410°C) The ingot is magnetic over the base and lower part of the sides due to iron and magnetic sulphide of iron.

Min. : Pyrr. 3 : 1 (369) (1410°C) The ingot is magnetic all over the base. It has a central mass of metallic iron with magnetic iron sulphide around it.

Kim. : Pyrr. 3 : 1 (373) (1410°C) The ingot is magnetic at the base and top. The inside shows magnetic sulphide of iron, especially at the upper end near one side; it also shows some specks of iron.

Gr. 1 : Ni-Pyrr. 3 : 1 (374) (1410°C) The base and sides are coated with nickeliferous iron sulphide (?); globules of the same are on the top, and throughout, inside.

Sy. a : Ni-Pyrr. 3 : 1 (377) (1410°C) A large mass of magnetic sulphide of iron is at the base; others of nickeliferous iron (not reacting with Cu SO_4) are at the top of the sides.

NeSy. : Ni-Pyrr. 3 : 1 (378) (1410°C) A large mass of

magnetic sulphide of iron near the centre of the base caused bursting of the ingot. Smaller iron masses are on the sides and inside.

An. : Ni-Pyrr. 3 : 1 (379) (1410°C) A large very slightly magnetic sulphide mass is on the base; some small ones are on the side.

Bas. : Ni-Pyrr. 3 : 1 (375) (1410°C) Iron is on the base; the sides are coated with iron; globules of the same are on the top, and a large mass is at the top of the side.

Min. : Ni-Pyrr. 3 : 1 (376) (1410°C) Iron is coating the base, sides and part of the top. Large iron globules are inside at the top, on one side.

Kim. : Ni-Pyrr. 3 : 1 (380) (1410°C) The base, sides and top are magnetic. A large mass of iron with a little pyrrhotite is at the centre of the base. The ingot is cracked. A gas chimney extends upward from the mass on the base; some specks of iron are carried up through this chimney.

Gr. 1 : Gal. 3 : 1 (381) (1410°C)

Sy.a : Gal. 3 : 1 (384) (1410°C) Many large lead sulphide globules occur at the tops of the sides.

NeSy. : Gal. 3 : 1 (385) (1410°C) Small globules of lead sulphide occur almost throughout, inside, but mostly in the lower part.

An. : Gal. 3 : 1 (386) (1410°C) Magnetic iron globules are at the top of the sides, only. Lead sulphide has not separated.

Bas. : Gal. 3 : 1 (382) (1410°C) One large iron globule is at the top of the side. The base has a hard metallic cover of iron. Lead sulphide has not separated.

Min. : Gal. 3 : 1 (383) (1410°C) Five large lead sulphide globules, with thin black magnetic covers project from the top. A mass of lead sulphide is irregularly distributed through the silicate collected at the centre of the base.

Kim. : Gal. 3 : 1 (387) (1410°C) One body of lead sulphide and iron is on the side. Many minute specks of iron occur throughout, inside.

Gr. 1 : ZnB. 3 : 1 (388) (1410°C)

Sy. a : ZnB. 3 : 1 (391) (1410°C) The base has a metallic appearance; at the centre of the base is a mass of strongly magnetic spongy iron sulphide.

NeSy. : ZnB. 3 : 1 (392) (1410°C)

An. : ZnB. 3 : 1 (393) (1410°)

Bas. : ZnB. 3 : 1 (389) (1410°C) Magnetic iron sulphide is in the base.

Min. : ZnB. 3 : 1 (390) (1410°C) The inside shows metallic iron at the centre of the base and along one side of the base.

Kim. : ZnB. 3 : 1 (394) (1410°C) A mass of magnetic iron sulphide is at the centre of the base, and at part of the edge of the base. The base has a metallic lustre.

RÉSUMÉ OF RESULTS OF SEPARATION OF ORES FROM EXPERIMENTAL MELTS

Calcite Mixes (1410°C)

Iron has separated from these mixes. There has been segregation of the iron at the surfaces of the ingots with the kimberlite melts, one basalt and one minette melt; segregation has been chiefly by sinking from granite melts and one nepheline-syenite melt; by sinking and in other directions from syenite, andesite-porphyrite, basalt and minette melts; and chiefly in other directions than by sinking from two nepheline-syenite melts.

Calcite Mixes (1470°—1270°C)

Iron has separated from all these melts. Segregation has been mainly by sinking from granite melts; by sinking and in other directions from granite, syenite, feldspar-basalt, basalt, minette and kimberlite melts; and chiefly in other directions than by sinking from andesite-porphyrite and feldspar-basalt melts.

Kaolin Mixes (1410°C)

Iron has separated from some of these mixes, but there is not a very marked tendency toward separation from these mixes, perhaps because of the high viscosity of the melts. Segregation has taken place from one syenite, one andesite-porphyrite, from basalt, minette and kimberlite melts. While sinking is the dominant process of segregation in these cases, lateral and upward movement to the sides and top are illustrated.

Kaolin Mixes (1600°—1270°C)

Practically no ore mineral separation has taken place from the syenite and nepheline-syenite melts. Segregation has been by sinking and in other directions from granite, feldspar-basalt, basalt, minette and kimberlite melts. It has been

chiefly in other directions than by sinking from one syenite, two andesite-porphyrite, and from feldspar-basalt melts.

Quartz Mixes (1410°C)

Iron has segregated from one granite, two syenite, one andesite-porphyrite, and all the basalt and minette melts. There has been no separation from most of the granite, one syenite, the nepheline-syenite, two andesite-porphyrite, and the kimberlite melts. Segregation has been by sinking and in other directions from one granite (out of nine), one syenite, the basalt and minette melts; chiefly in other directions than by sinking from one syenite and one andesite-porphyrite melts.

Quartz Mixes (1440°—1249°C)

There has been no ore mineral segregation from most of the granite, from one syenite, the nepheline-syenite and two kimberlite melts. Segregation has been chiefly by sinking from one syenite melt; by sinking and in other directions from two granite, one syenite, the andesite-porphyrite, feldspar-basalt, basalt, minette and one kimberlite melts; chiefly in other directions than by sinking from two feldspar-basalt melts.

Magnetite Mixes (1230°C)

Much magnetite is absorbed by granite and syenite melts, some by minette, nepheline-syenite and kimberlite melts; much magnetite is not absorbed by andesite-porphyrite and basalt melts.

The magnetite not absorbed or reduced to iron has segregated as follows:—in all directions from andesite-porphyrite and kimberlite melts; by sinking and in other directions from one nepheline-syenite and the basalt melts; chiefly by sinking from one nepheline-syenite melt; and chiefly in other directions than by sinking from minette melts.

There has been very vigorous reaction with increase in volume and porosity with granite, syenite, nepheline-syenite and andesite-porphyrite melts.

Magnetite Mixes (1410°C)

No segregation took place from one granite melt; segregation was chiefly by sinking from syenite, nepheline-syenite, basalt and minette melts; in all directions from kimberlite melts; by sinking and in other directions from granite, syenite, nepheline-syenite, basalt and minette melts; chiefly in other directions than by sinking from andesite-porphyrite melts.

Bauxite Mixes (1230°C)

There have been no segregations of ore minerals from any of the bauxite mixes heated to this temperature. Most of them were only partially melted, so that very little or no opportunity for movement of the ores has occurred.

Bauxite Mixes (1410°C)

There has been no ore mineral segregation from granite, two syenite, the nepheline-syenite, two andesite-porphyrite, one basalt, one minette and two kimberlite melts. Segregation has been chiefly by sinking from one basalt, and from one kimberlite melt; in all directions from one minette melt; by sinking and in other directions from one syenite, one andesite-porphyrite and one minette melt, and chiefly in other directions than by sinking from one basalt melt.

Siderite Mixes (1230°C)

In all the melts siderite has been reduced to metallic iron which has separated from the melts at the boundary surfaces, the sides and top as well as the base.

Siderite Mixes (1410°C)

Siderite has been reduced to metallic iron, which has segregated chiefly by sinking from syenite and minette melts; by sinking and in other directions from granite, syenite, nepheline-syenite, andesite-porphyrite, basalt, minette and kimberlite melts; and chiefly in other directions than by sinking from basalt melts.

Magnesite Mixes (1400°C)

There has been reduction of iron minerals to the metallic state, without segregation from granite, syenite, nepheline-syenite, andesite-porphyrite and kimberlite melts. There has been segregation by sinking and also in other directions from two basalt and one minette melts; and chiefly in other directions than by sinking from one minette melt.

Dolomite Mixes (1400°C)

There has been reduction of iron to the metallic state. There has been no segregation of iron from one nepheline-syenite and from the kimberlite melts; segregation has been chiefly by sinking from one granite melt; by sinking and in other directions from the syenite, two nepheline-syenite, the andesite-porphyrite, basalt and minette melts; and chiefly in other directions than by sinking from two granite melts.

Tremolite Schist Mixes (1400°C)

There has been reduction of iron to the metallic state without segregation from the granite and kimberlite melts, but there has been segregation from the remainder of the melts. Segregation has been chiefly by sinking from one syenite, one nepheline-syenite, one andesite-porphyrite, one basalt and two minette melts; by sinking and in other directions from two syenite, one nepheline-syenite, two andesite-porphyrite, two basalt, and one minette melt; and chiefly in other directions than by sinking from one nepheline-syenite melt.

Hematite Mixes (1400°—1410°C)

There has been reduction to metallic iron, which has segregated chiefly by sinking from the basalt and minette melts; by sinking and in other directions from two granite, the syenite, nepheline-syenite, andesite-porphyrite, basalt and kimberlite melts; and chiefly in other directions than by sinking from one granite, and the andesite-porphyrite melts.

Chromite Mixes (1410°C)

Separation of metallic iron or ferro-chrome as a plating of the outside of the ingot (base, sides and top in some cases) took place with all the melts, except the nepheline-syenite ones, from which there was no clear segregation.

Graphite Mixes (1410°C)

No separation of ore minerals was noticed with these melts.

Chalcocite Mixes (1410°C)

The main tendency is separation of the chalcocite by sinking. There is some reduction to native copper, by the action of the graphite of the crucible. There is separation of the sulphide in other directions (to the sides or top or to both), from the granite, syenite, nepheline-syenite, andesite-porphyrite, minette, kimberlite, and some of the basalt melts. One of the syenite ingots is cracked (342) and cracks are present in the sulphides segregated from basalt and minette melts.

Bornite Mixes (1410°C)

The bornite has been changed to chalcocite for the most part. There is little segregation of chalcocite from the granite melts; it is to all sides, and there is reduction to native copper seen on the sides and base.

The main tendency is to separation by sinking from the syenite, andesite-porphyrite, basalt, and minette melts. The

main segregation is not in the base in the case of the nepheline-syenite melts. There is segregation in other directions than by sinking from the syenite, andesite-porphyrite, basalt, minette and kimberlite melts.

Cracks occur through the whole ingot with basalt and minette melts, and in the sulphides with the syenite melts.

Chalcopyrite Mixes (1410°C)

Segregation of ore minerals is chiefly by sinking from the basalt and minette melts. Segregation in other directions occurs from the nepheline-syenite, andesite-porphyrite, basalt, minette and kimberlite melts. The segregation is chiefly in other directions from granite and syenite melts. At high temperatures chalcopyrite is not stable and changes to bornite, and bornite changes to chalcocite, which is the most stable of the three at high temperatures. Bornite is formed from the syenite, nepheline-syenite, andesite-porphyrite, basalt, minette, and kimberlite melts. Chalcocite has formed from all melts except the nepheline-syenite one. Chalcopyrite has been reproduced in small amount from the syenite and nepheline-syenite melts.

Cracks have been formed in the ingots of syenite, nepheline-syenite and minette melts. One of the nepheline-syenite ingots has burst.

Pyrite Mixes (1410°C)

Segregation has been chiefly by sinking from syenite, nepheline-syenite, andesite-porphyrite, basalt, minette and kimberlite melts; and has been in other directions from granite, nepheline-syenite and kimberlite melts. At high temperatures pyrite gives way to pyrrhotite which has been formed from all the melts except the granite melts.

Cracks occur in the nepheline-syenite ingots.

Pyrrhotite Mixes (1410°C)

Ore mineral segregation has been chiefly by sinking from syenite, andesite-porphyrite, basalt, minette, and kimberlite melts; it has been in other directions from syenite, andesite-porphyrite, and kimberlite melts; and chiefly in other directions from granite melts (though small in amount).

Cracks have developed in a nepheline-syenite ingot, due to a ball of pyrrhotite inside the ingot.

Nickeliferous Pyrrhotite (1410°C)

Ore mineral separation has been chiefly by sinking from syenite, nepheline-syenite and andesite-porphyrite melts; and it has been in other directions also from the melts of all the varieties.

Cracks have developed in nepheline-syenite and kimberlite ingots.

Galena Mixes (1410°C)

There has been no separation of lead sulphide from the granite and nepheline-syenite melts. The segregation of sulphides has been chiefly in other directions than by sinking from the syenite, andesite-porphyrite, basalt, minette and kimberlite melts. It is important to note that the high density of lead sulphide has not always been effective in bringing about sinking.

Zinc Blende Mixes (1410°C)

There has been no visible separation of ore minerals from granite and nepheline-syenite melts. Separation has been chiefly by sinking from syenite, andesite-porphyrite, basalt, minette and kimberlite melts; and also in other directions from minette melts. The ore mineral separating is not necessarily zinc blende.

CONCLUSIONS

From a consideration of the results of experimental melts of rock materials containing a certain amount of metals, sulphides or oxide ores, evenly distributed, it is concluded that the separation of metals, sulphides or oxides from magmas may take place rapidly if the conditions are suitable for the separation. Thus ore-bodies may have been formed in comparatively **short periods of time.**

It is found that sinking under the action of gravity is an important factor in the separation of metals, sulphides or oxides from magmas, but in addition it is found that the metals, sulphides or oxides show a very definite tendency to collect at the lateral, lower, and sometimes upper margins of the melts. This is considered to result from differences of surface energy between metal, sulphide or oxide globules colloidally suspended in silicate melt, and the boundaries of the reservoir enclosing the melt. Differences of surface tension result in the collection of globules at or near the walls having lower surface

tension values. Reduction of free surface energy, and the chemical force of cohesion aid in the coalescence of the globules to form masses of varying sizes, including the larger masses known as ore-bodies.

The action of gas bubbles in carrying upward metal, sulphide, or oxide globules may result in the accumulation of ores at the upper contact of an intrusive body, by the process of "flotation."* It may be that the existence of any ore bodies of igneous origin at all near the earth's surface is ultimately due to the efficacy of this process of "flotation."

The principle of marginal accumulation of certain magmatic products may be applied to account for "marginal basification" of igneous rock masses. By collection of the earlier separated globules at the reservoir walls, as a result of surface tension differences, and by subsequent reaction between these materials and the still liquid magma the globules or crystals formed from them may be completely dissolved giving rise to varieties of igneous rock more basic than the average for the intrusion. The experiments dealing with "assimilation and petrogenesis" have shown how the assimilation of crystals like magnetite, or materials rich in magnesium or calcium may be complete within a short time at magmatic temperatures, provided an adequate source of heat is available. Assimilation of such materials results in the production of basic types of igneous rocks.

Differences of coefficients of expansion of separated ore minerals and silicates of the solidified magma may result in unequal contraction of ore and rock, with fracturing of the rock materials. Such fractures may form paths for the movement of still liquid parts of the magma or ores, and hence may be sealed later as veins. This may have been an important cause of the formation of vein-fractures in many places.†

The effect of temperature in controlling the products of magmatic consolidation is clear. Pyrrhotite takes the place of pyrite at high temperatures. Chalcopyrite gives way to bornite and bornite to chalcocite at high temperatures, so that with decreasing temperatures the mineral series successively deposited may be chalcocite first, succeeded by bornite, and then by chalcopyrite. Chalcocite is found to be stable at high temperatures and is to be regarded as a "high temperature

*On flotation of ores in magmas see also Goodchild, W. H., Mining Mag. 1918.
†See Goodchild, W. H., loc. cit.

mineral'' as well as a ''low temperature mineral'' characteristic of secondary enrichment.

The heavy sulphides show a general tendency toward separation by sinking. But all of them show some separation in other directions. The high density of lead sulphide might well have been expected to cause it to sink easily, but it shows a dominant tendency to movement upward rather than downward, in separation from the experimental magmas.

APPENDIX

ALPHABETICAL LIST OF MINERALS FORMED IN THE EXPERIMENTS, WITH THE MATERIALS FROM WHICH THEY WERE FORMED

Aegirine-Augite from kimberlite + bauxite (p. **121**).

Åkermanite from granite, syenite, nepheline-syenite, andesite-porphyrite, feldspar-basalt, basalt, minette and kimberlite + calcite (pp. **65-75**).

Andalusite from minette + bauxite (p. **120**).

Andesine from syenite alone (p. **64**) and from nepheline-syenite + magnetite (p. **92**); andesite-porphyrite + hematite (p. **97**); syenite (p. **100**) and andesite-porphyrite (p. **102**) + siderite.

Anorthite from basalt (p. **80**), minette (p. **81**), and kimberlite (p. **82**) + kaolin.

Augite from syenite (p. **64**), basalt (pp. **64,65**), minette (p. **65**) and kimberlite (p. **65**) alone; from basalt (pp. **71, 72**), minette (p. **73**) and kimberlite (pp. **74, 75**) + calcite; minette (p. **82**) and kimberlite (pp. **82, 83**) + kaolin; basalt (p. **88**), minette (pp. **88, 89**) and kimberlite (pp. **89, 90**) + quartz; granite? (p. **90**), syenite (p. **91**) nepheline-syenite (p. **92**), andesite-porphyrite (pp. **92, 93**), basalt (pp. **93, 94**), minette (p. **94**) and kimberlite (p. **95**) + magnetite; syenite (p. **96**), basalt (p. **97**), minette (p. **97**) and kimberlite (p. **98**) + hematite; granite (pp. **98, 99**), syenite (pp. **99, 100**), nepheline-syenite (pp. **100, 101**), andesite-porphyrite (pp. **101, 102**), basalt (pp. **102, 103**), minette (p. **103**) and kimberlite (p. **104**) + siderite; granite (p. **105**), andesite-porphyrite (p. **106**), basalt (pp. **106, 107**), minette (p. **107**) and kimberlite (p. **107**) + dolomite; granite (pp. **107, 108**), syenite (p. **108**), nepheline-syenite (pp. **108, 109**), andesite-porphyrite (p. **109**) basalt (p. **110**), minette (p. **110**) and kimberlite (p. **111**) + magnesite; granite (p. **111**), syenite (p. **112**), nepheline-syenite (p. **112**), andesite-porphyrite (p. **113**), basalt (pp. **113, 114**) minette (p. **114**) and kimberlite (p. **114**) + tremolite schist; basalt (p. **116**), minette (pp.

117, 121) and kimberlite (pp. **121, 122**) + bauxite; syenite (pp. **122, 123**), nepheline-syenite (p. **123**), andesite-porphyrite (p. **124**), basalt (p. **124**), minette (pp. **124, 125**), and kimberlite (p. **125**) + chromite; syenite (p. **126**), basalt (p. **126**) and minette (p. **126**) + graphite; basalt (p. **127**) and minette (p. **127**) + chalcocite; basalt (p. **128**) and minette (p. **128**) + bornite; syenite (p. **129**) basalt (p. **130**), minette (p. **130**) and kimberlite (p. **130**) + chalcopyrite; basalt (p. **131**) minette (p. **131**) and kimberlite (p. **131**) + pyrite; basalt (p. **132**), minette (p. **132**) and kimberlite (p. **132**) + pyrrhotite; basalt (p. **133**) and kimberlite (p. **133**) + nickeliferous pyrrhotite; basalt (p. **134**), minette (p. **134**) and kimberlite (p. **135**) + galena; basalt (p. **135**), minette (p. **136**) and kimberlite (p. **136**) + zinc blende.

Bronzite from kimberlite + kaolin (p. **82**); granite + chromite (p. **122.**)

Bytownite from basalt (p. **116**) and minette (p. **120**) + bauxite.

Clino-enstatite from kimberlite + quartz (p. **89**); kimberlite + hematite (p. **98**); kimberlite + chalcocite (p. **127**); kimberlite + bornite (p. **129**).

Chrysolite from kimberlite alone (p. **65**); from basalt (p. **71**), minette (p. **72**) and kimberlite (p. **74**) + calcite; kimberlite + kaolin (p. **83**); kimberlite + quartz (p. **89**); basalt (pp. **93, 94**), minette (p. **94**) and kimberlite (p. **95**) + magnetite; kimberlite + hematite (p. **98**); basalt (p. **102**), minette (p. **103**) and kimberlite (p. **104**) + siderite; basalt (pp. **106, 107**) and kimberlite (p. **107**) + dolomite; granite? (p. **108**), basalt (p. **110**), minette (p. **110**) and kimberlite (p. **111**) + magnesite; basalt (pp. **113, 114**), minette (p. **114**) and kimberlite (p. **114**) + tremolite schist; basalt (p. **124**), minette (pp. **124, 125**) and kimberlite (p. **125**) + chromite; kimberlite + chalcocite (p. **127**); kimberlite + bornite (p. **129**); kimberlite + chalcopyrite (p. **130**) kimberlite + pyrite (p. **131**); kimberlite + pyrrhotite (p. **132**); kimberlite + nickeliferous pyrrhotite (p. **133**); kimberlite + galena (p. **135**); kimberlite + zinc blende (p. **136**).

Cordierite from kimberlite + kaolin (p. **82**).

Cristobalite from granite alone (p. **64**); from granite (pp. **83, 84**), syenite (p. **85**), nepheline-syenite (pp. **85, 86**), andesite-porphyrite (p. **86**), feldspar-basalt (pp. **86, 87**), basalt (p. **87**), minette (p. **88**) and kimberlite (p. **89**) + quartz.

Enstatite from minette + kaolin (p. **81**); granite (p. **90**),

syenite (p. **91**) and nepheline-syenite (p. **92**) + magnetite; granite + siderite (pp. **98, 99**); granite (p. **122**) and syenite? (p. **123**) + chromite.

Fayalite from andesite-porphyrite + magnetite (p. **92**).

Forsterite from kimberlite + kaolin (p. **82**); basalt (p. **110**) and minette (p. **110**) + magnesite; andesite-porphyrite (p. **113**) and minette (p. **114**) + tremolite schist.

Garnet from minette (p. **110**) and kimberlite (p. **111**) + magnesite.

Hornblende from basalt (p. **116**) and minette (pp. **120, 121**) + bauxite.

Labradorite from syenite (pp. **115, 118**), andesite-porphyrite (pp. **116, 119**), basalt (pp. **116, 119, 120**) and minette (pp. **117, 120, 121**) + bauxite.

Labradorite-Bytownite from andesite-porphyrite + bauxite (p. **119**).

Melilite from syenite (pp. **67, 68**), nepheline-syenite (p. **69**) and andesite-porphyrite (p. **70**) + calcite.

Monticellite from kimberlite + calcite (pp. **74, 75**); kimberlite + bauxite (pp. **121, 122**).

Oligoclase from syenite + hematite (p. **96**); syenite + dolomite (p. **105**); syenite + chalcocite (p. **127**); syenite + bornite (p. **128**); syenite + chalcopyrite (p. **129**).

Oligoclase-Andesine from syenite (p. **100**) and nepheline-syenite (pp. **100, 101**) + siderite; syenite + kaolin (p. **78**); minette + quartz? (p. **88**); syenite (p. **105**) and nepheline-syenite (p. **105**) + dolomite.

Olivine from kimberlite alone (p. **65**); basalt + calcite (p. **71**); andesite-porphyrite (p. **92**) and basalt (pp. **93, 94**) + magnetite; basalt (p. **110**), minette (p. **110**) and kimberlite (p. **111**) + magnesite; minette (p. **114**) and kimberlite (p. **114**) + tremolite schist. Also see chrysolite, fayalite, forsterite and monticellite.

Orthoclase from syenite + kaolin (p. **77**); syenite + magnetite (p. **91**); granite (p. **99**) and syenite (p. **99**) + siderite; syenite + chromite? (p. **123**).

Perovskite from granite (p. **66**), basalt (pp. **71, 72**), minette (p. **73**) and kimberlite (pp. **74, 75**) + calcite.

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Riebeckite from minette + calcite (p. **73**).

Sillimanite from granite (pp. **75, 76, 77**), syenite? (p. **78**), nepheline-syenite? (p. **78**), andesite-porphyrite (pp. **79, 80**), feldspar-basalt (p. **80**), basalt (pp. **80, 81**) and minette (p. **81**) + kaolin; granite (pp. **117, 118**), syenite? (p. **118**),

nepheline-syenite (pp. **115, 119**), andesite-porphyrite (p. **119**), basalt (p. **120**), minette (p. **121**) and kimberlite (p. **121**) + bauxite.

Spinel from syenite (p. **108**), nepheline-syenite (p. **108**), andesite-porphyrite (p. **109**) and minette (p. **110**) + magnesite; syenite (p. **118**), nepheline-syenite (pp. **115, 119**), andesite-porphyrite (p. **119**), basalt (pp. **116, 119, 120**), minette (p. **120**) and kimberlite (pp. **121, 122**) + bauxite.

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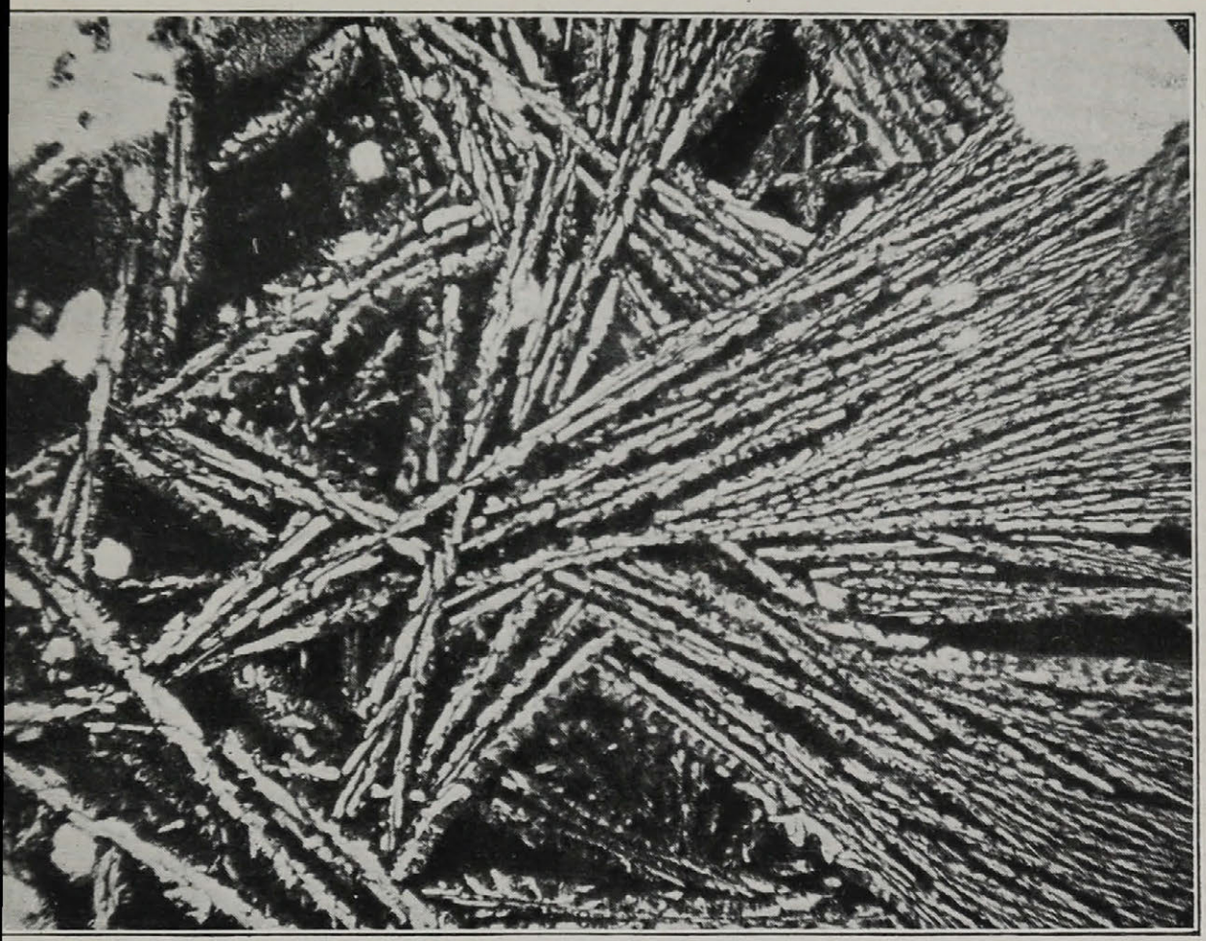

Fig. 1
Åkermanite and brownish glass. Granite 1 : Calcite 1 : 1 (401)
(1410° C) x 25. See p. 65

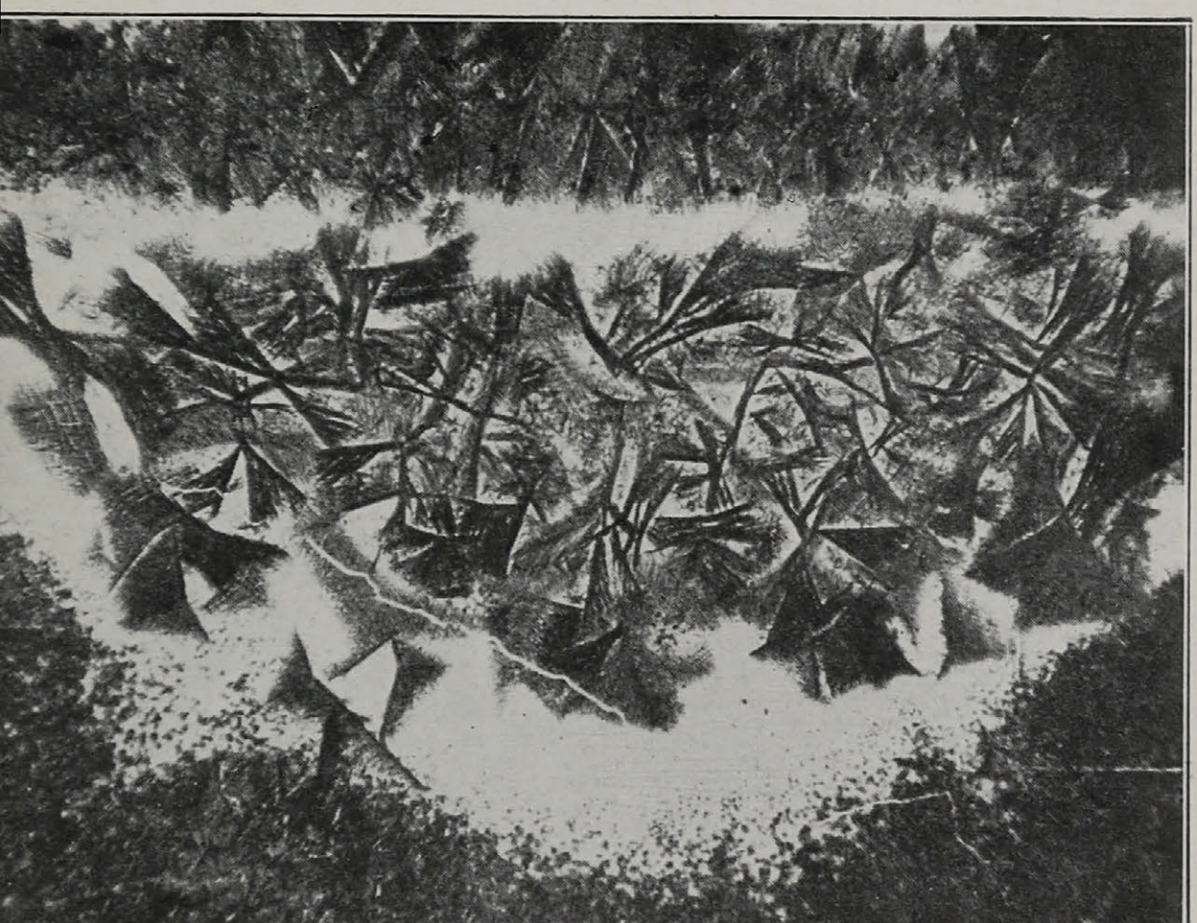

Fig. 2
Åkermanite sheaves in glass. Granite 2 : Calcite 3 : 1 (406)
(1410° C) x80. See p. 66

Plate No. 2

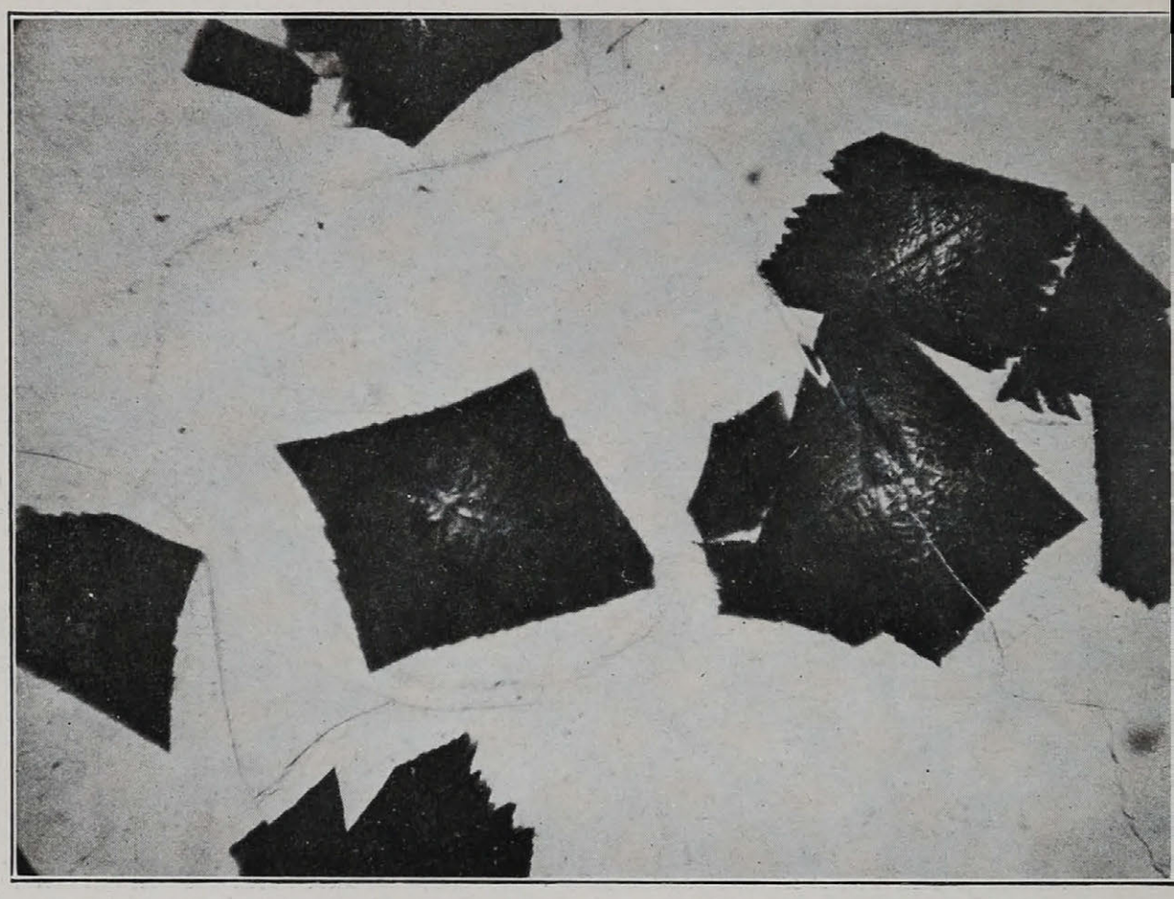

Fig. 3
Glass with åkermanite grids. Neph. Sy. : Calcite 1 : 1 (56)
(1300° C) x25. See p. 69

Fig. 4
Åkermanite and glass. Neph. Sy. : Calcite 2 : 1 (420)
(1410° C) + nicols, x80. See p. 69

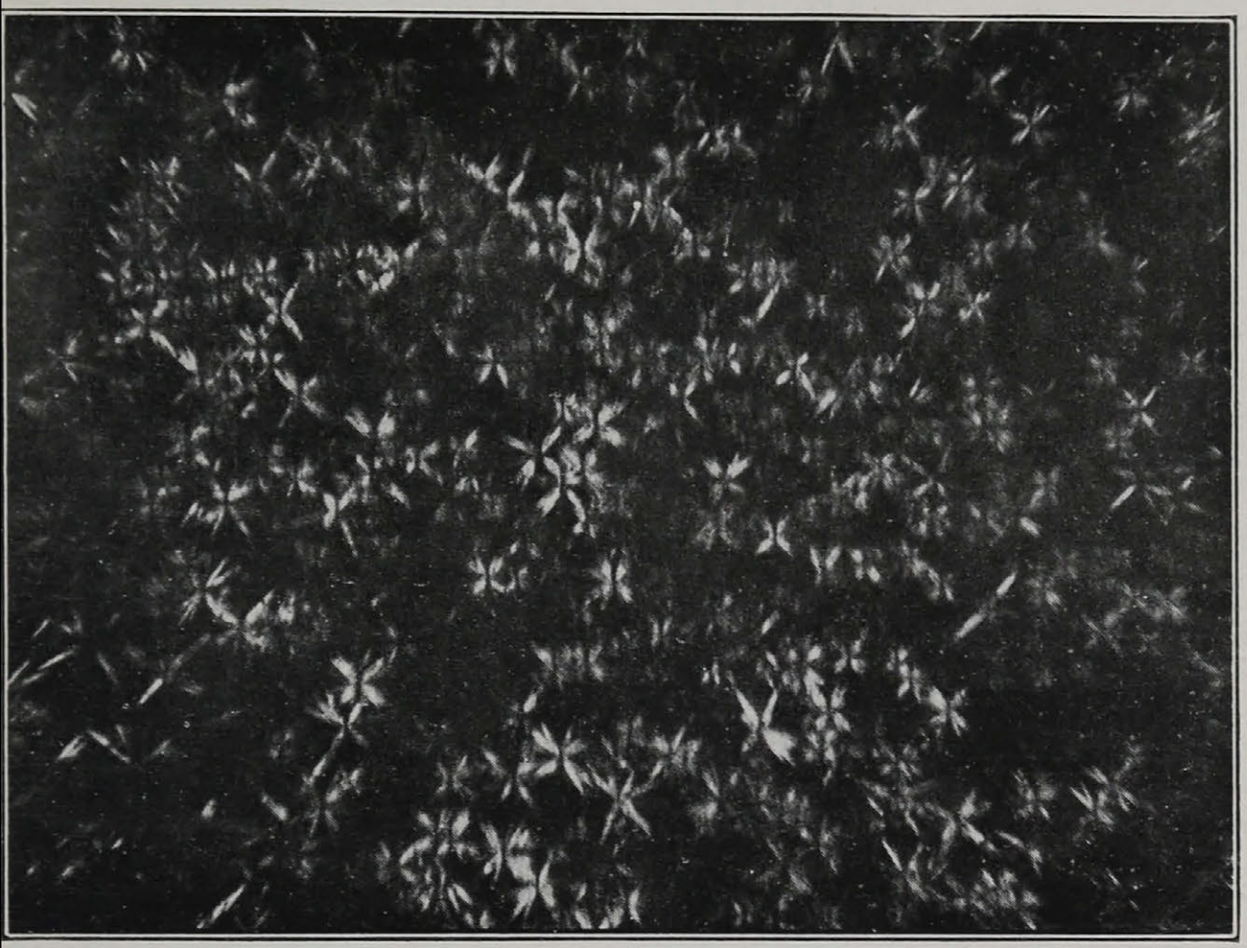

Fig. 5
Åkermanite and glass. Syenite a : Calcite 3 : 1 (418)
(1410° C) + nicols, x80. See p. 68

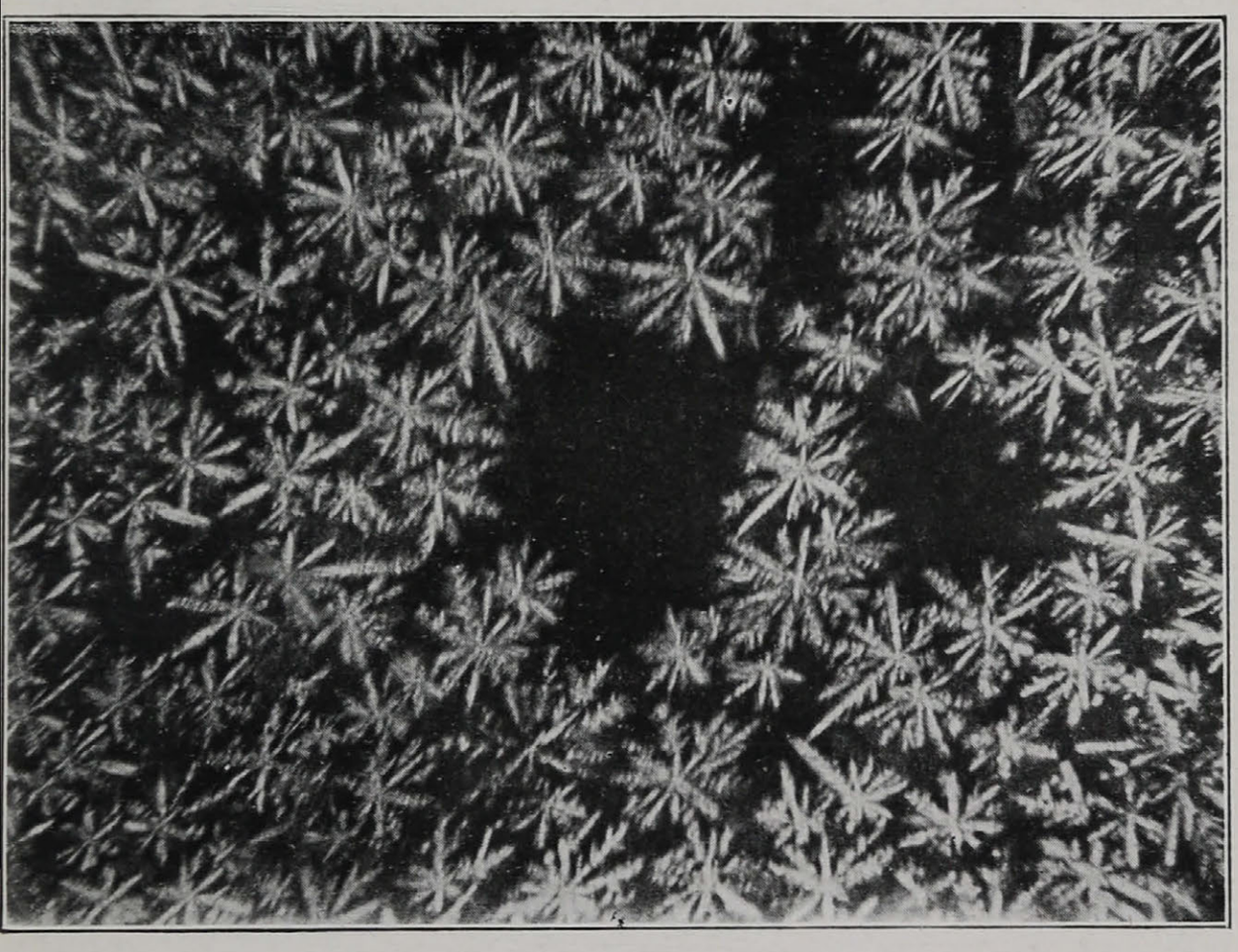

Fig. 6
Åkermanite and glass. Andesite porphyrite : Calcite 2 : 1 (423)
(1410° C) + nicols, x80. See p. 70

Plate No. 4

Fig. 7
Melilite crystals and skeleton crystals in gray melilite?
Andesite porphyrite : Calcite 1 :1 (57)
(1300° C) x25. See p. 70

Fig. 8
Åkermanite and glass. The large mass has medium birefringence; the cruciform twins have low birefringence. Feldspar basalt : Calcite 1 :1 (11) (1470° C) + nicols, x25. See p. 71

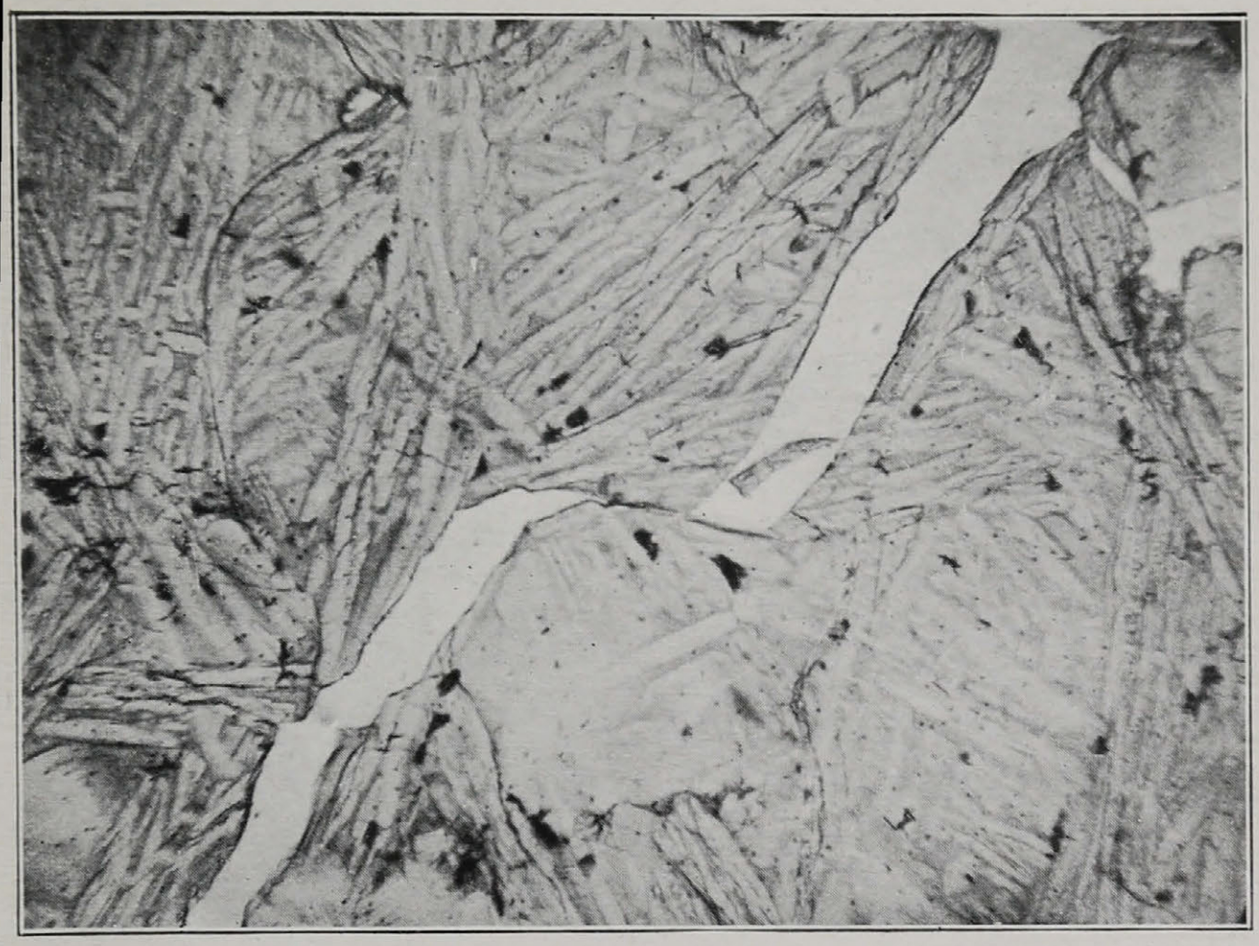

Fig. 9
Åkermanite. Basalt : Calcite 2 : 1 (13)
(1470° C) x25. See p. 72

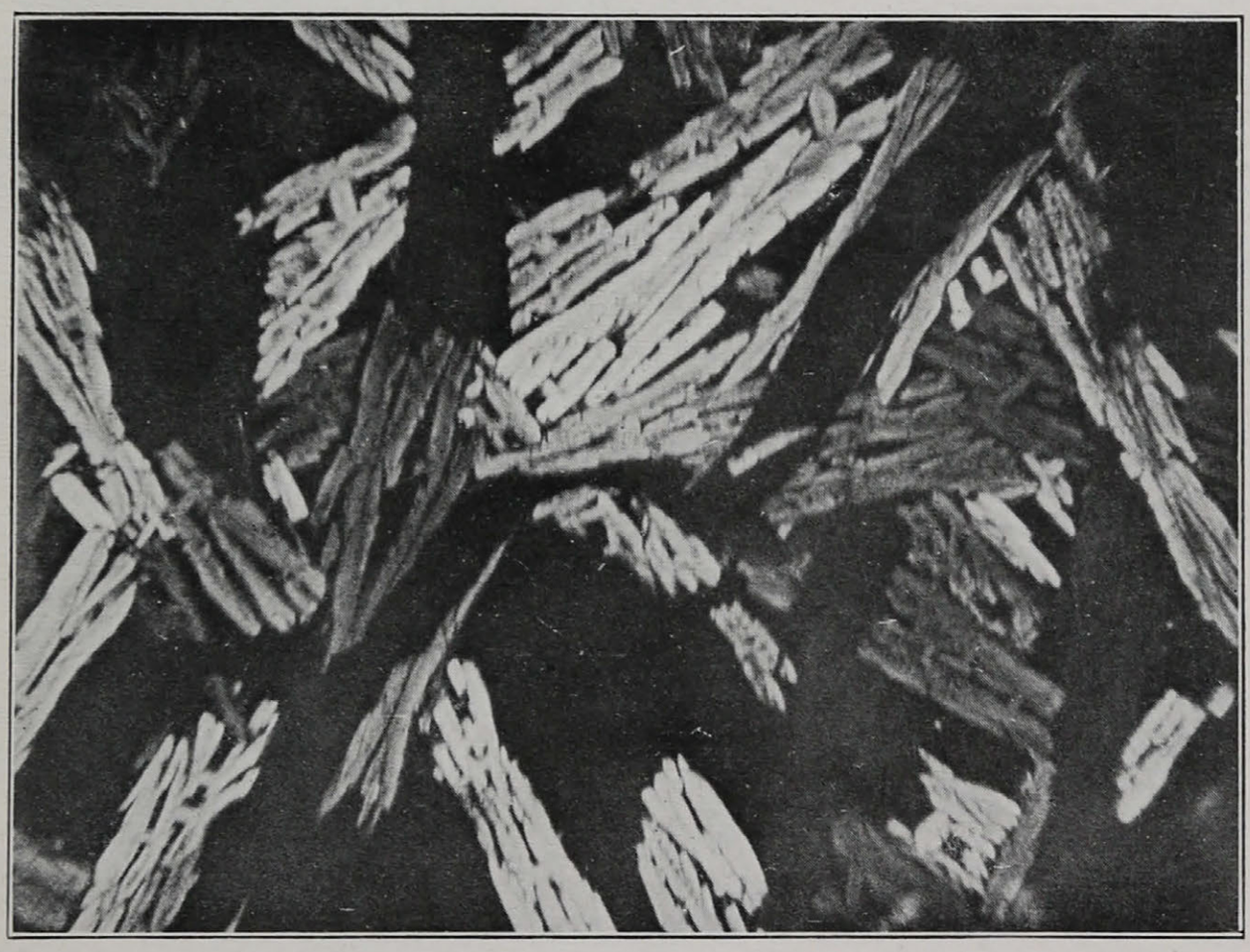

Fig. 10
Åkermanite. Same field as fig. 9. Basalt : Calcite 2 : 1 (13)
(1470° C) + nicols, x89. See p. 72

Plate No. 6

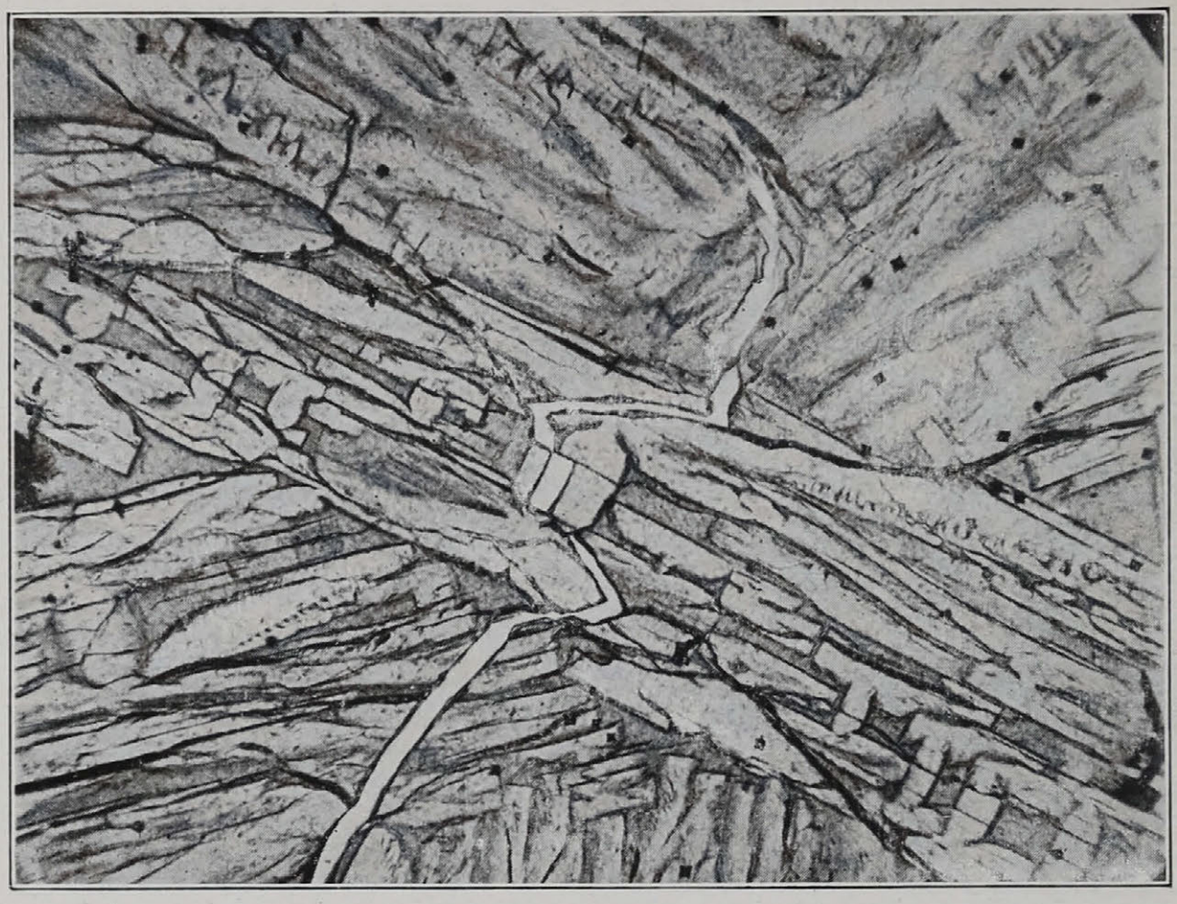

Fig. 11
Åkermanite and octahedra of magnetite. Basalt : Calcite 2 : 1 (13) (1470° C) + nicols, x80. See p. 72

Fig. 12
Åkermanite. Same field as fig. 11. Basalt : Calcite 2 : 1 (13) (1470° C) + nicols, x80. See p. 72

Fig. 13
Åkermanite with augite, iron globules and minute opaque octahedra. Basalt : Calcite 3 : 1 (16) (1470° C) x80. See p. 72

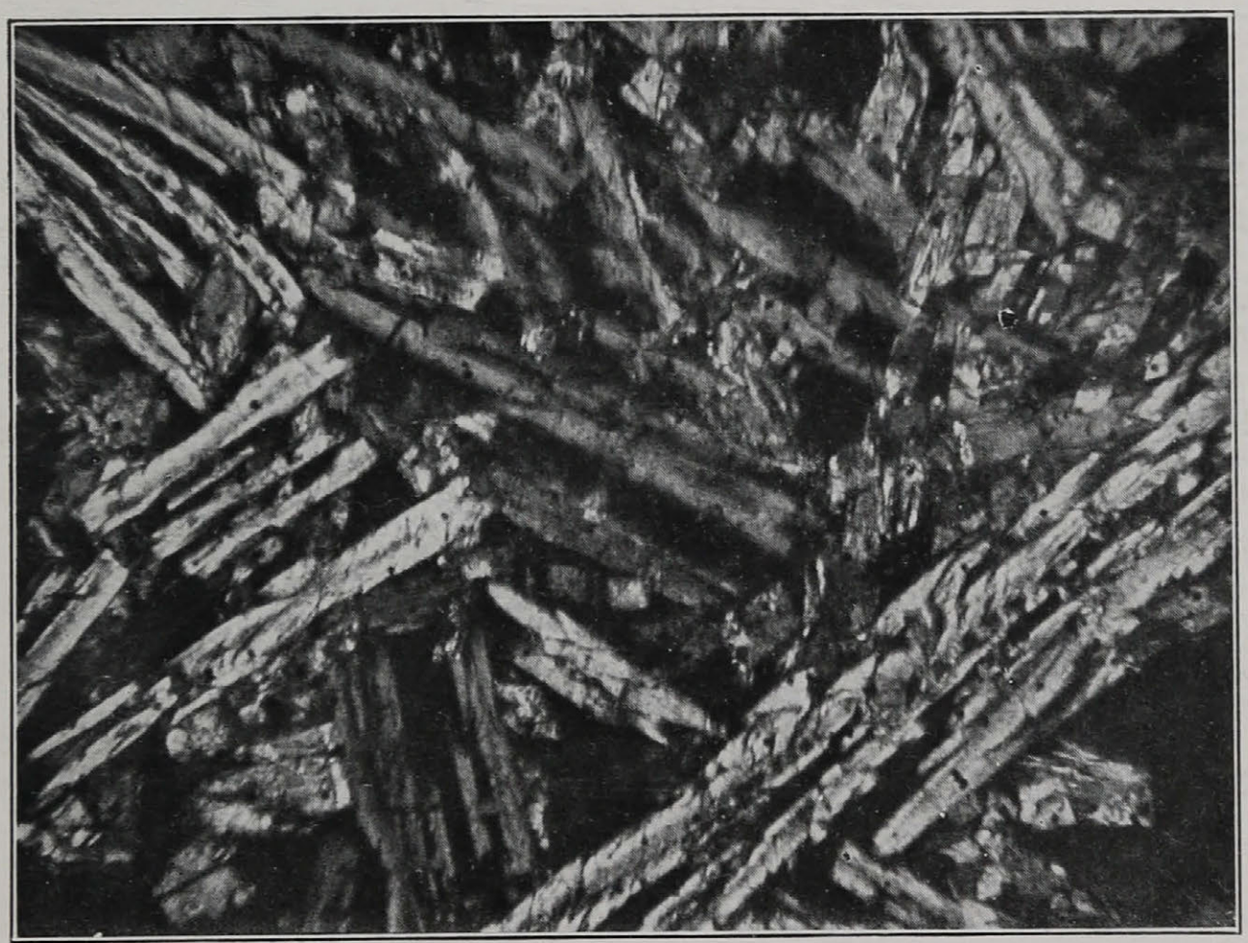

Fig. 14
Åkermanite with augite, iron globules and minute opaque octahedra. Same field as fig. 13. Basalt : Calcite 3 : 1 (16) (1470° C) + nicols, x80. See p. 72.

Plate No. 8

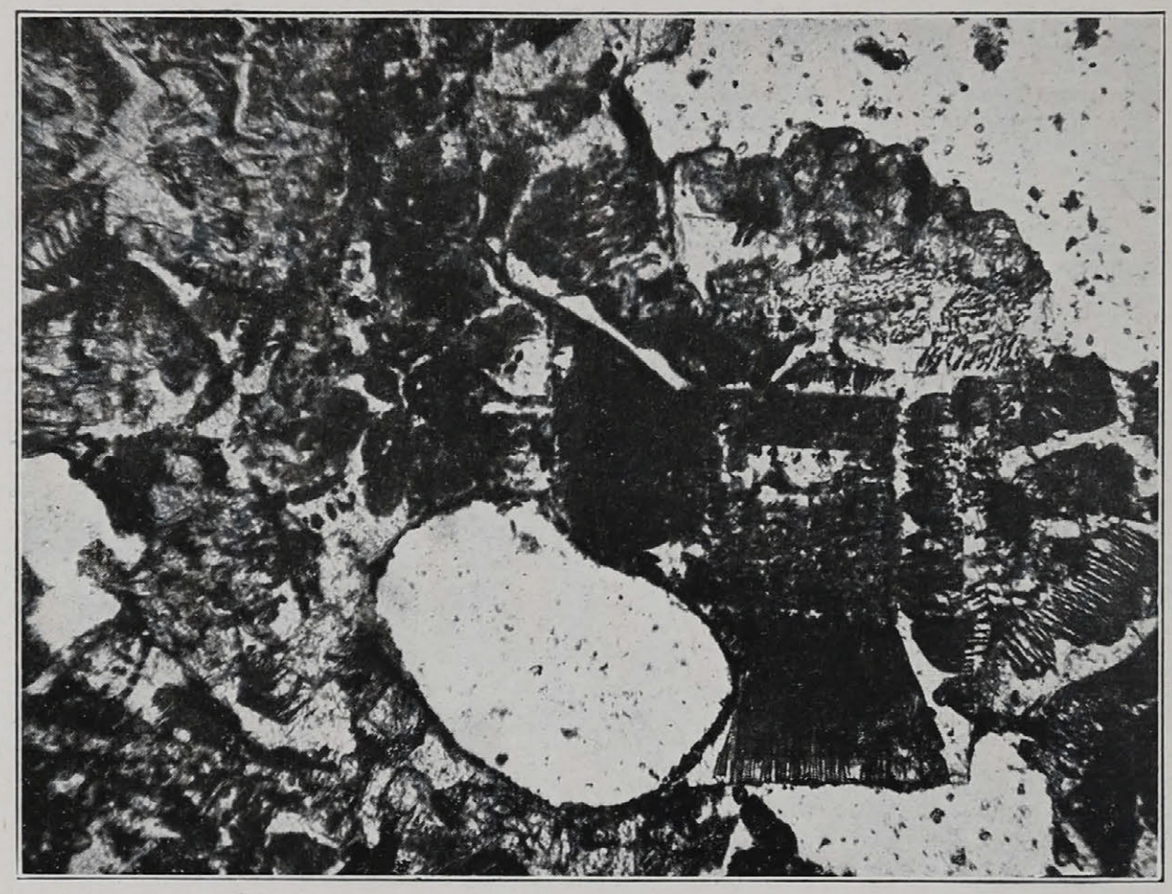

Fig. 15
Åkermanite, with peg structure in outer zone. Basalt : Calcite 1 : 1 (410) (1410° C) x80. See p. 71.

Fig. 16
Åkermanite and riebeckite. Minette : Calcite 3 : 1 (18) (1270° C) x25. See p. 73

Fig. 17
Melilite crystals and fine grained aggregates of melilite and åkermanite. Syenite a : Calcite 1 : 1 (416) (1410° C) x25. See p. 67

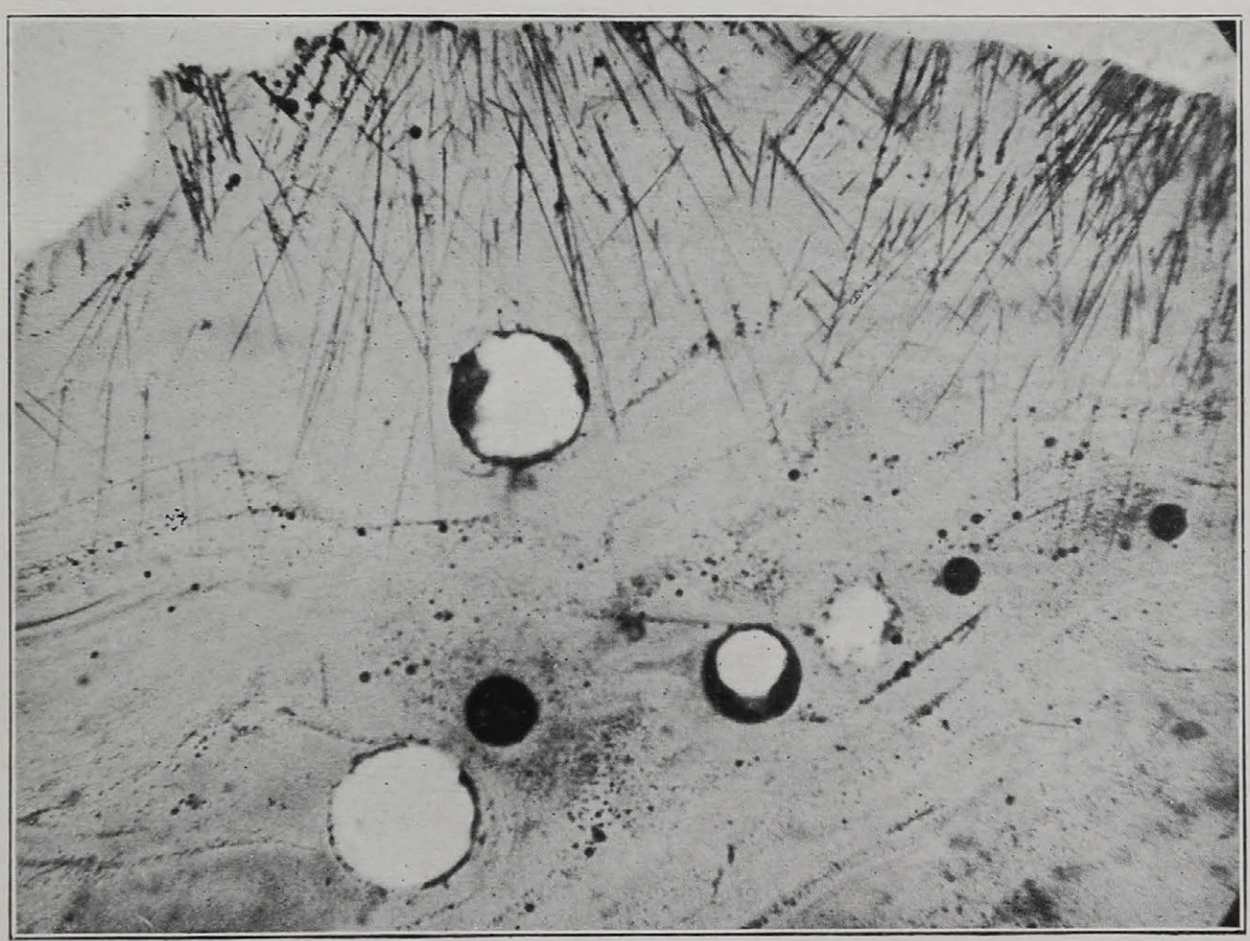

Fig. 18
Glass with needles of sillimanite developed from the edge. Basalt : Kaolin 1 : 1 (28) (1500° C) x25. See p. 80

Plate No. 10

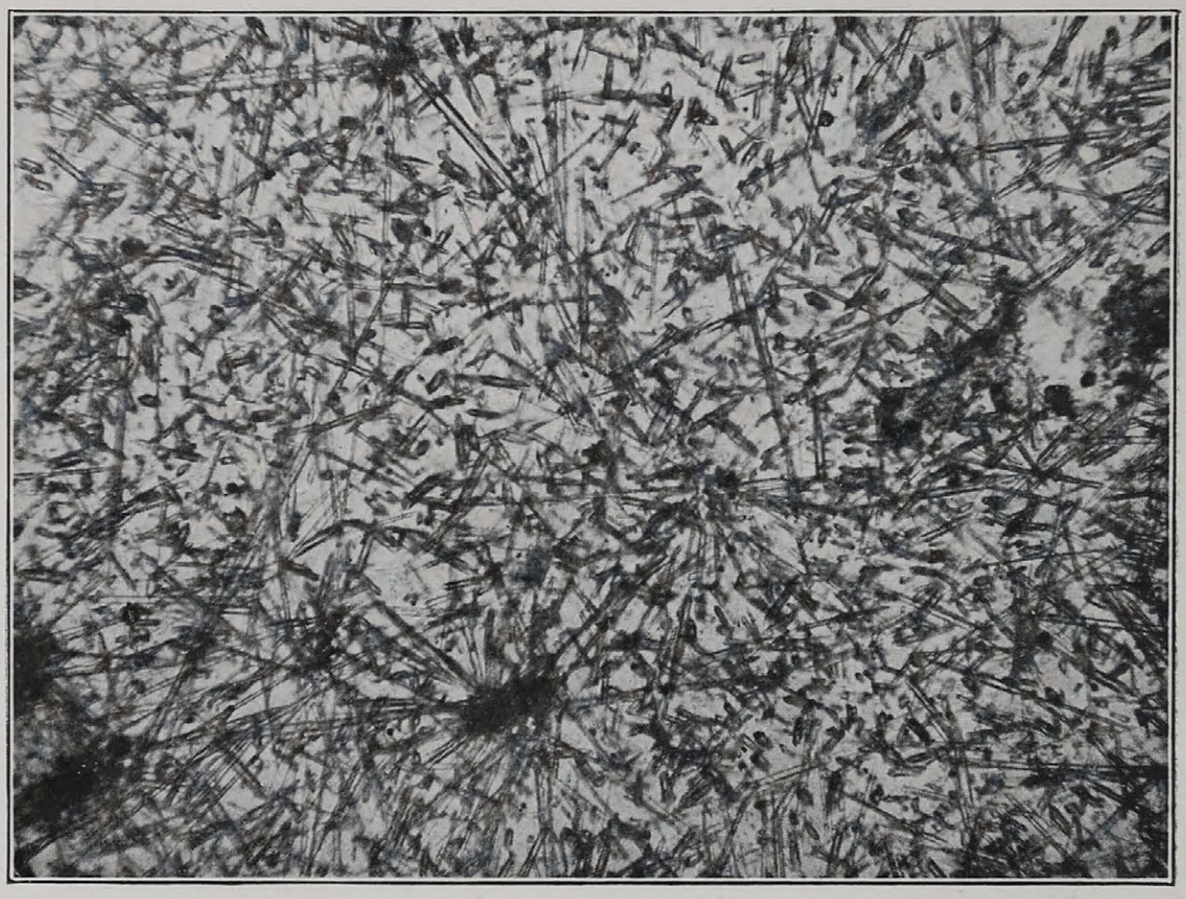

Fig. 19
Glass with sillimanite. Granite 1 : Kaolin 1 : 1 (19)
(1600° C) x80. See p. 75

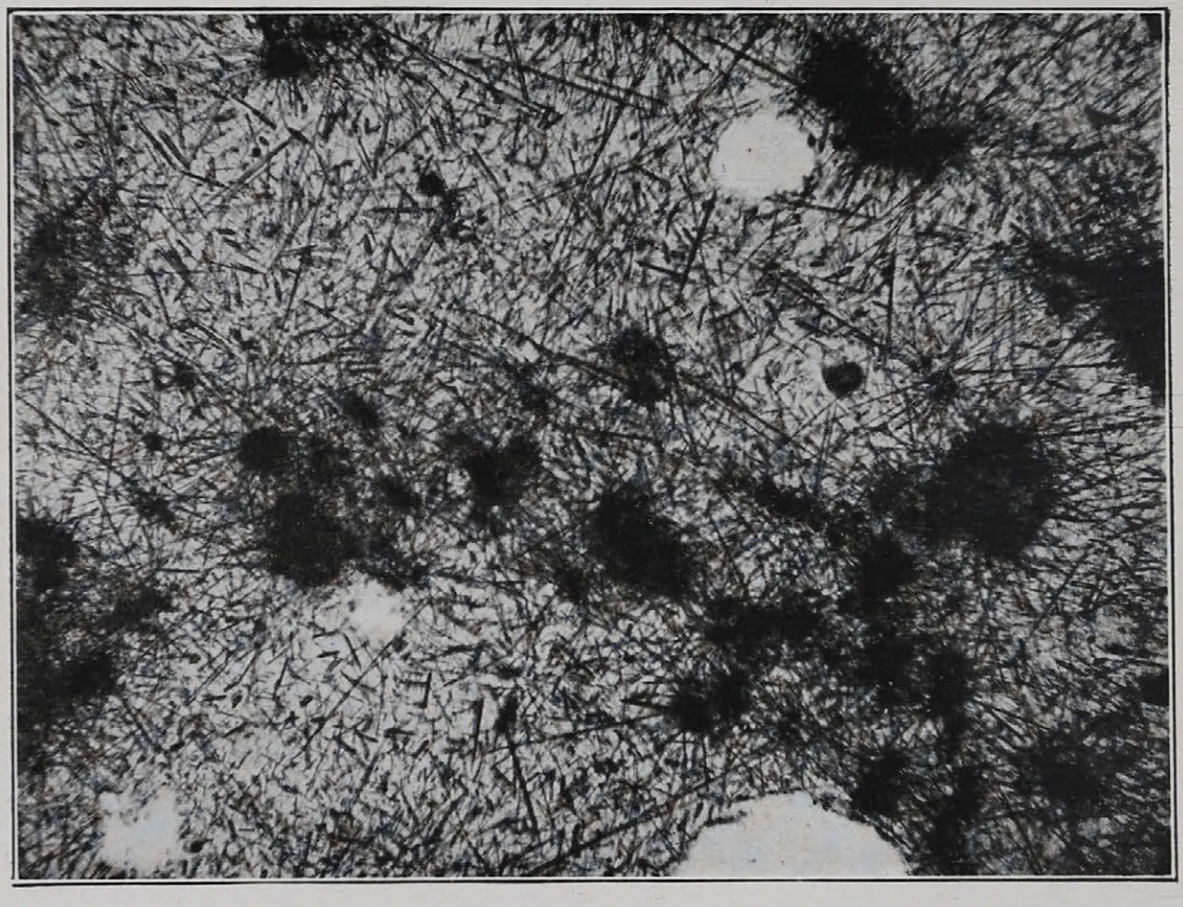

Fig. 20
Glass with sillimanite and unassimilated kaolin.
Andesite-porphyrite : Kaolin 2 : 1 (450) (1410° C) x80. See p. 79

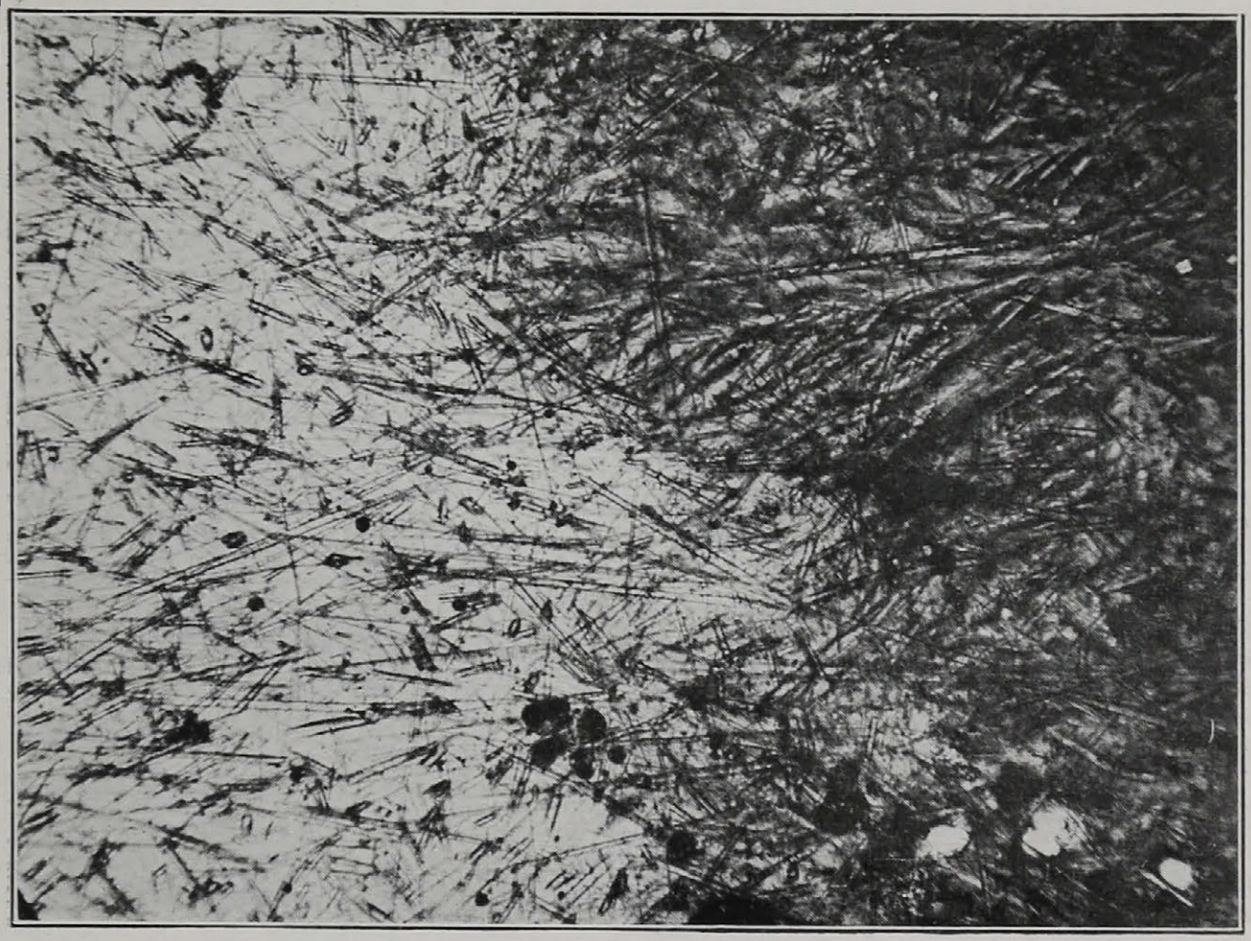

Fig. 21
Clear glass + sillimanite and anorthite + sillimanite.
Basalt : Kaolin 1 : 1 (437) (1410° C) x80. See p. 80

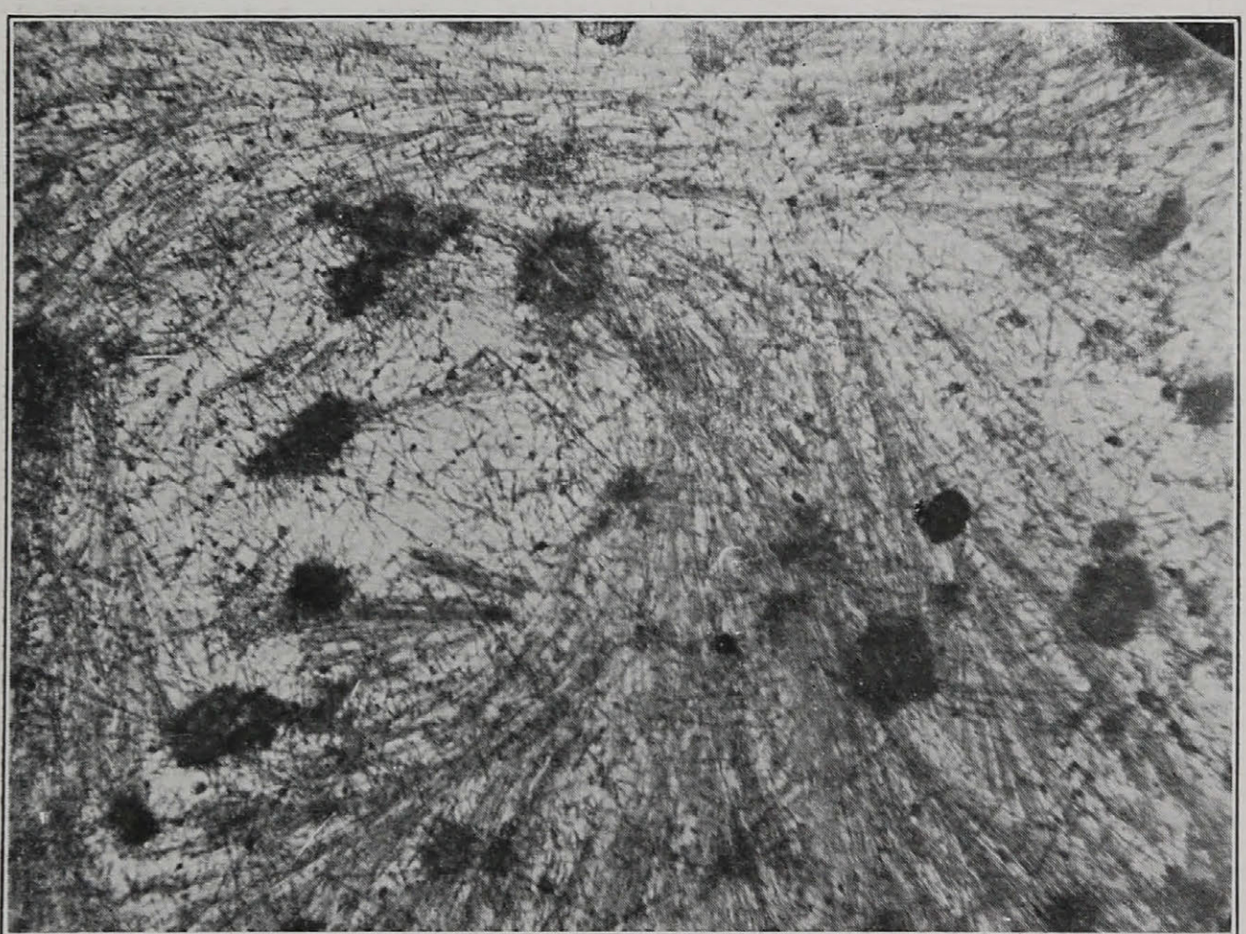

Fig. 22
Plagioclase and sillimanite needles. Syenite : Kaolin 3 : 1 (445)
(1410° C) x80. See p. 78

Plate No. 12

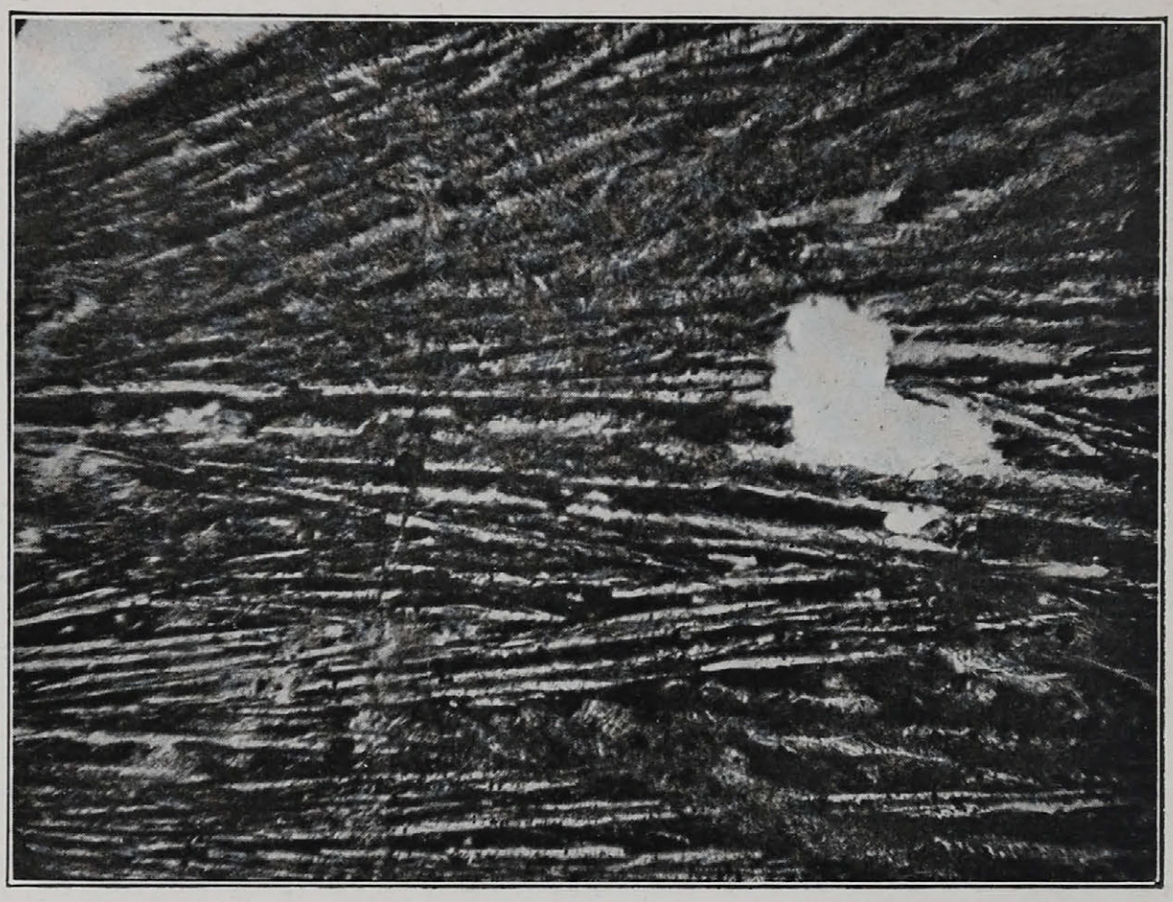

Fig. 23
Anorthite needles developed from sillimanite. Basalt : Kaolin 2 : 1
(438) (1410° C) x80. See p. 80

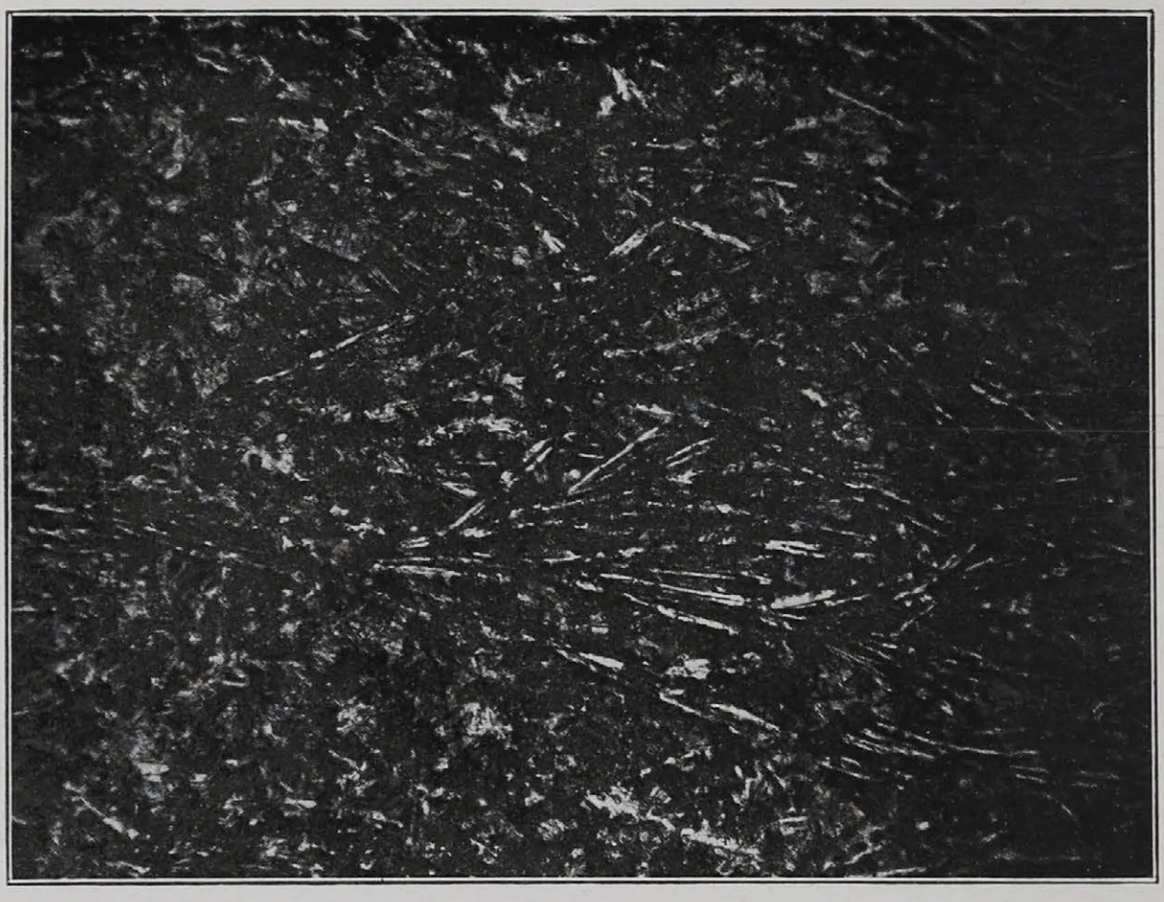

Fig. 24
Variolitic arrangement of plagioclase laths. Basalt : Bauxite 3 : 1
(506) (1410° C) x80. See p. 120

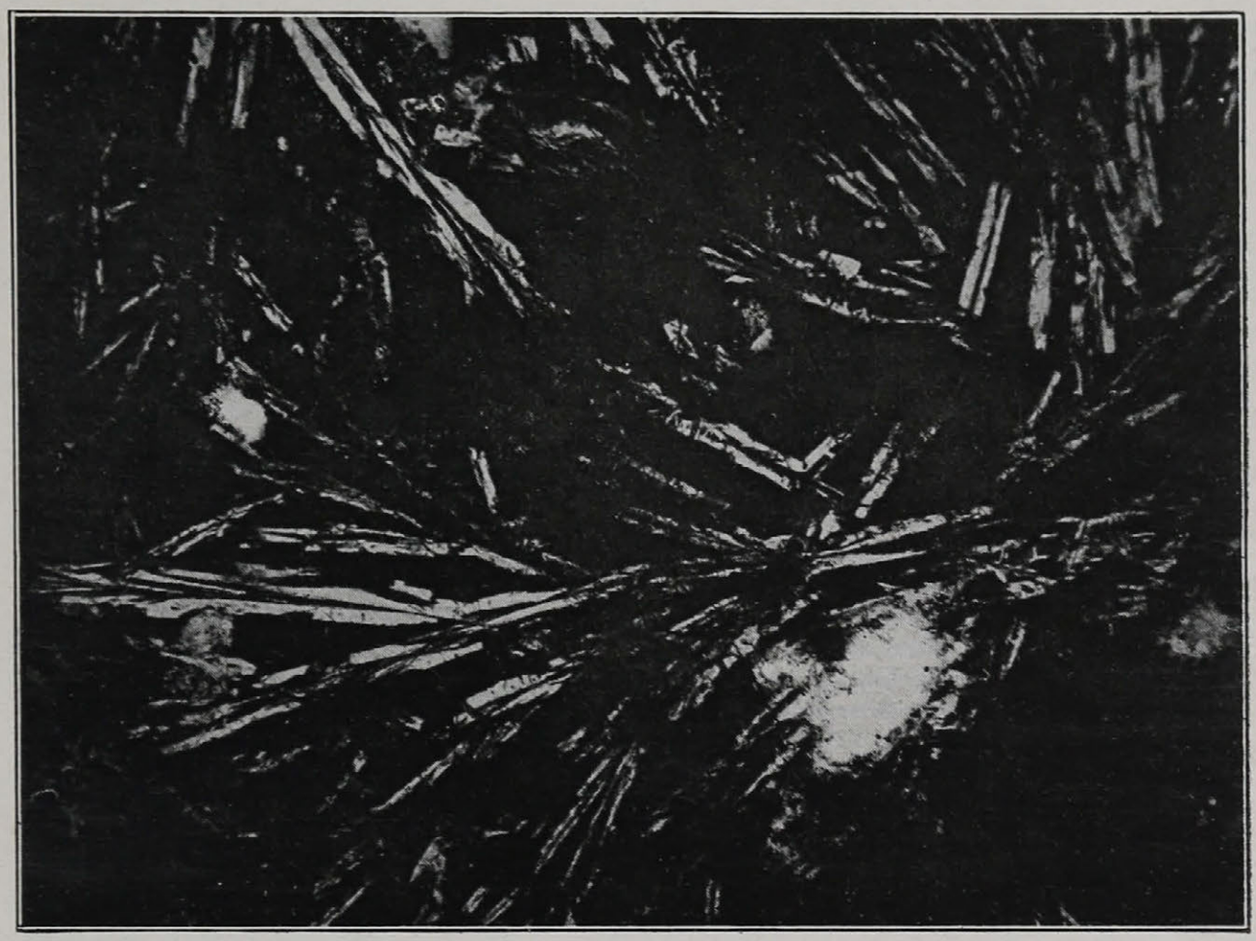

Fig. 25
Labradorite-bytownite laths (after sillimanite) with variolitic tendency + brown glass. Andesite porphyrite : Bauxite 3 : 1 (518) (1410° C) x80. See p. 119

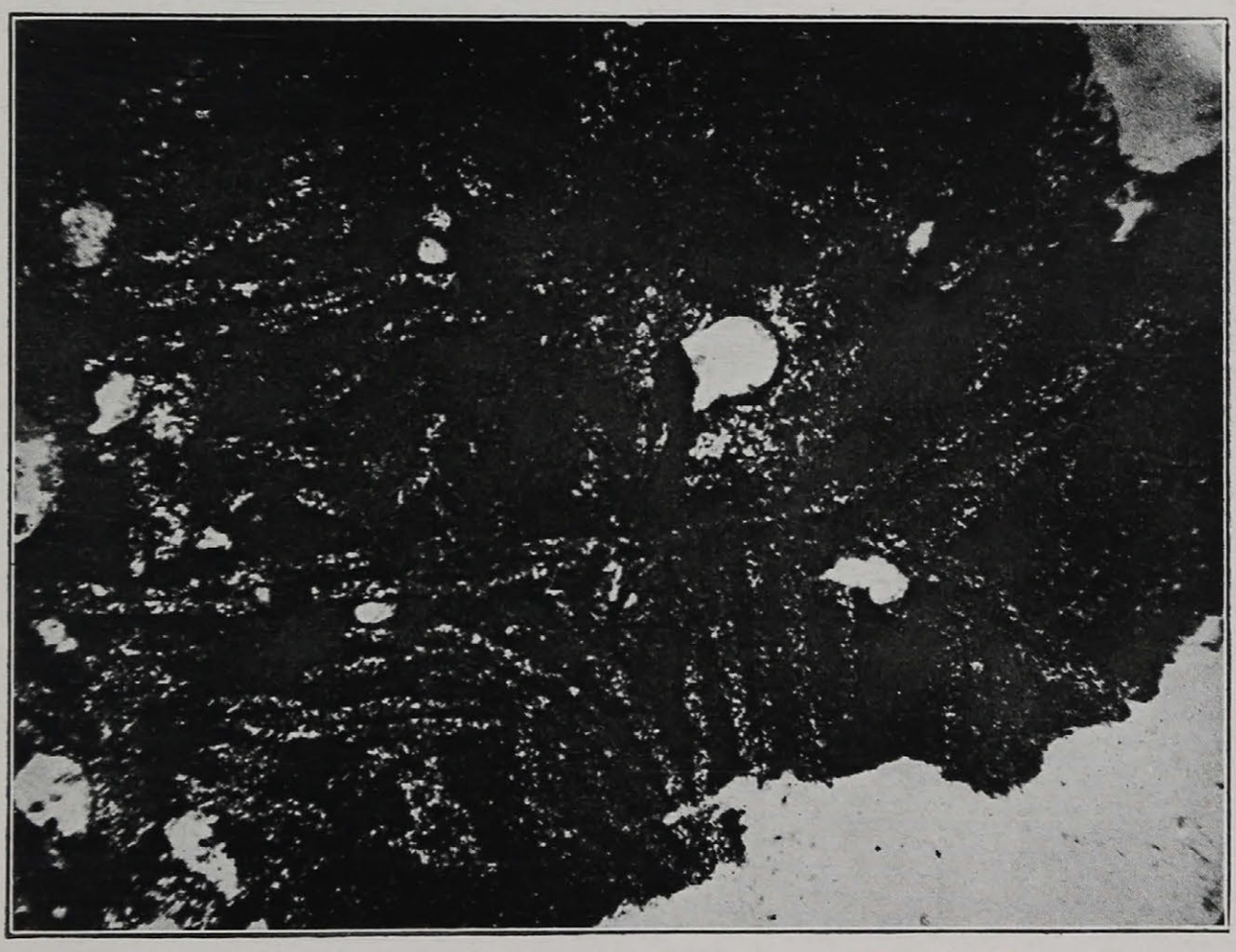

Fig. 26
Opaque base (glass, etc.) with labradorite laths crowded with spinel grains. Basalt : Bauxite 2 : 1 (505) (1410° C) x25. See p. 120

Plate No. 14

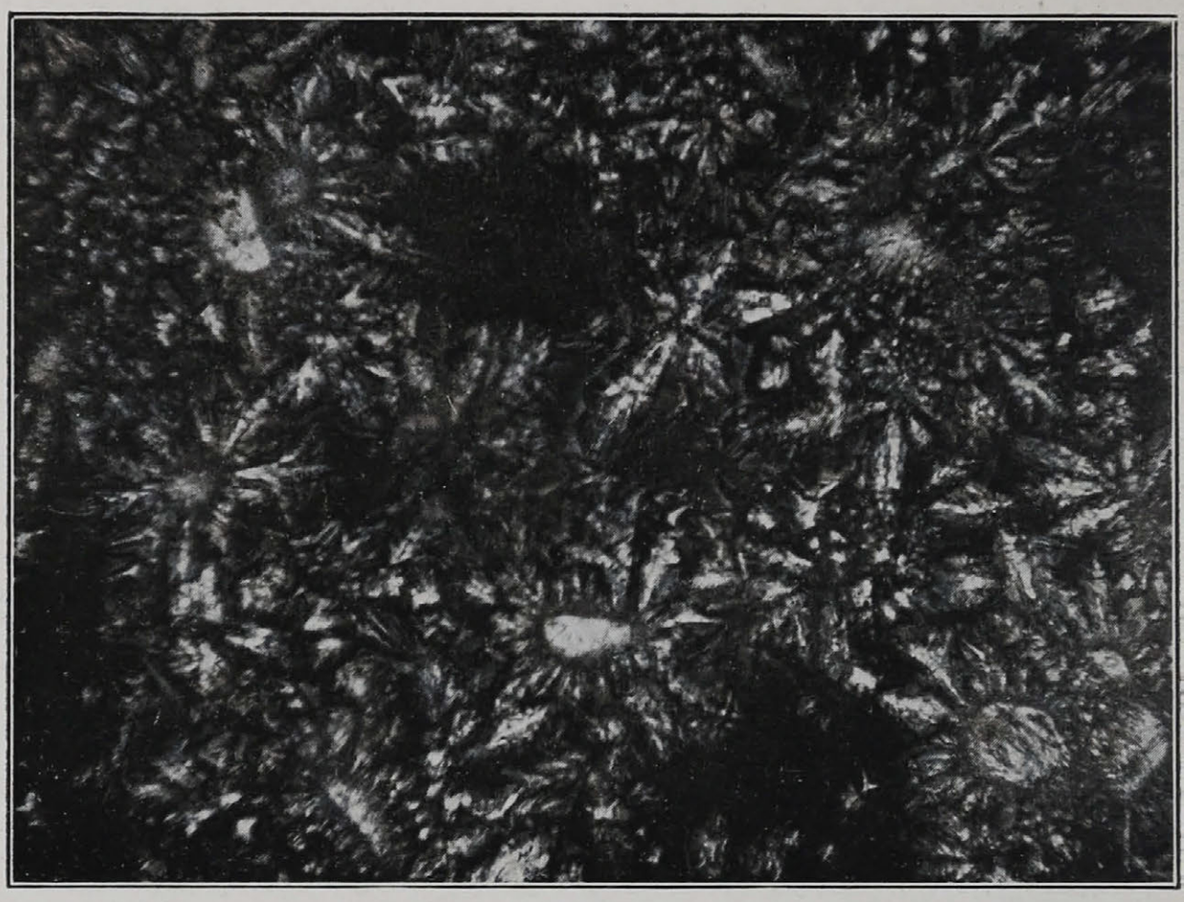

Fig. 27
Brown glass and rounded quartz grains with tridymite rosettes.
Basalt : Quartz 1 : 1 (46) (1450° C) x80. See p. 87

Fig. 28
Dark brown glass and rounded quartz grains with tridymite rosettes.
Basalt : Quartz 1 : 1 (464) (1410° C) x80. See p. 87

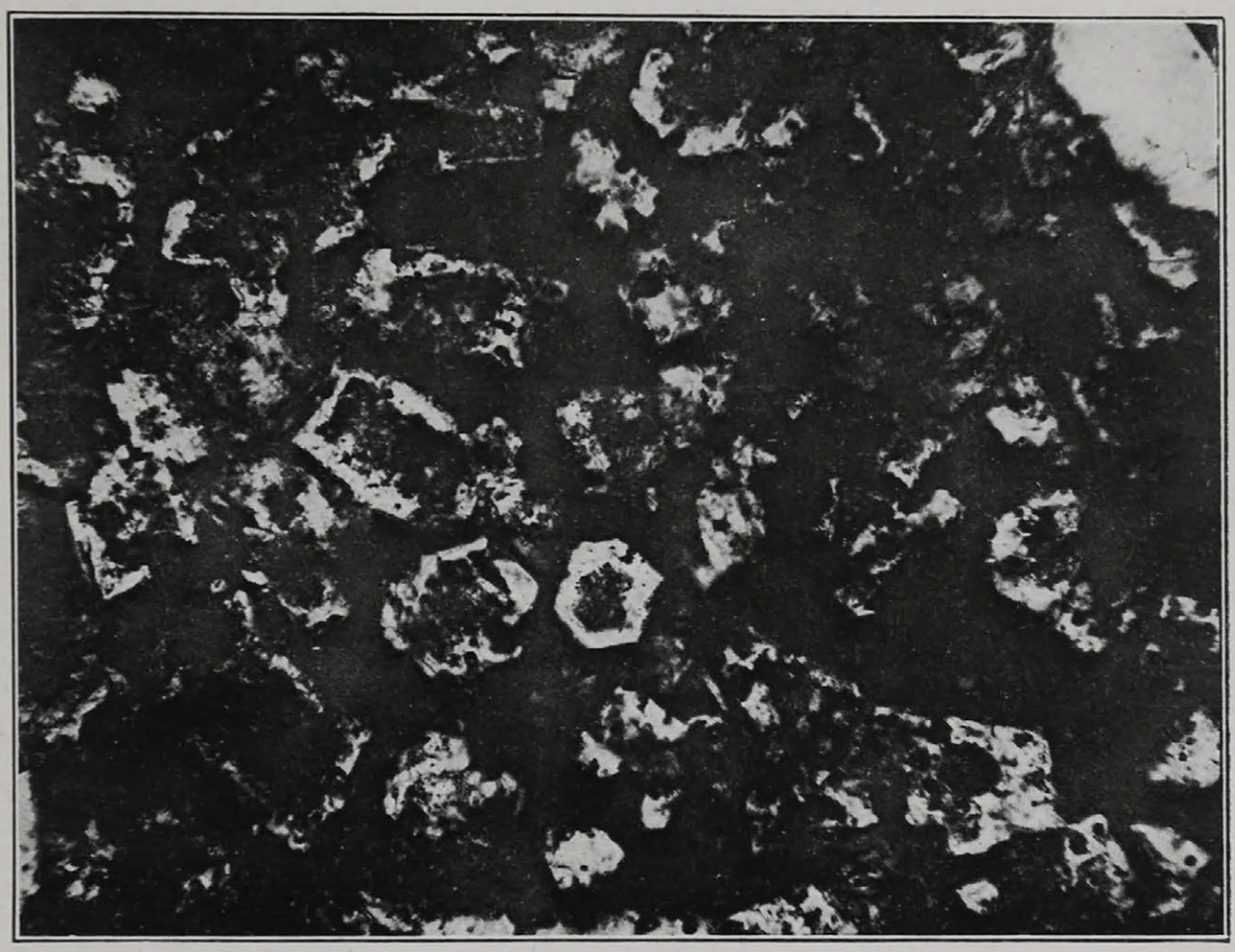

Fig. 29
Glass + cordierite. Kimberlite : Kaolin 1 : 1 (70)
(1309° C) x80. See p. 82

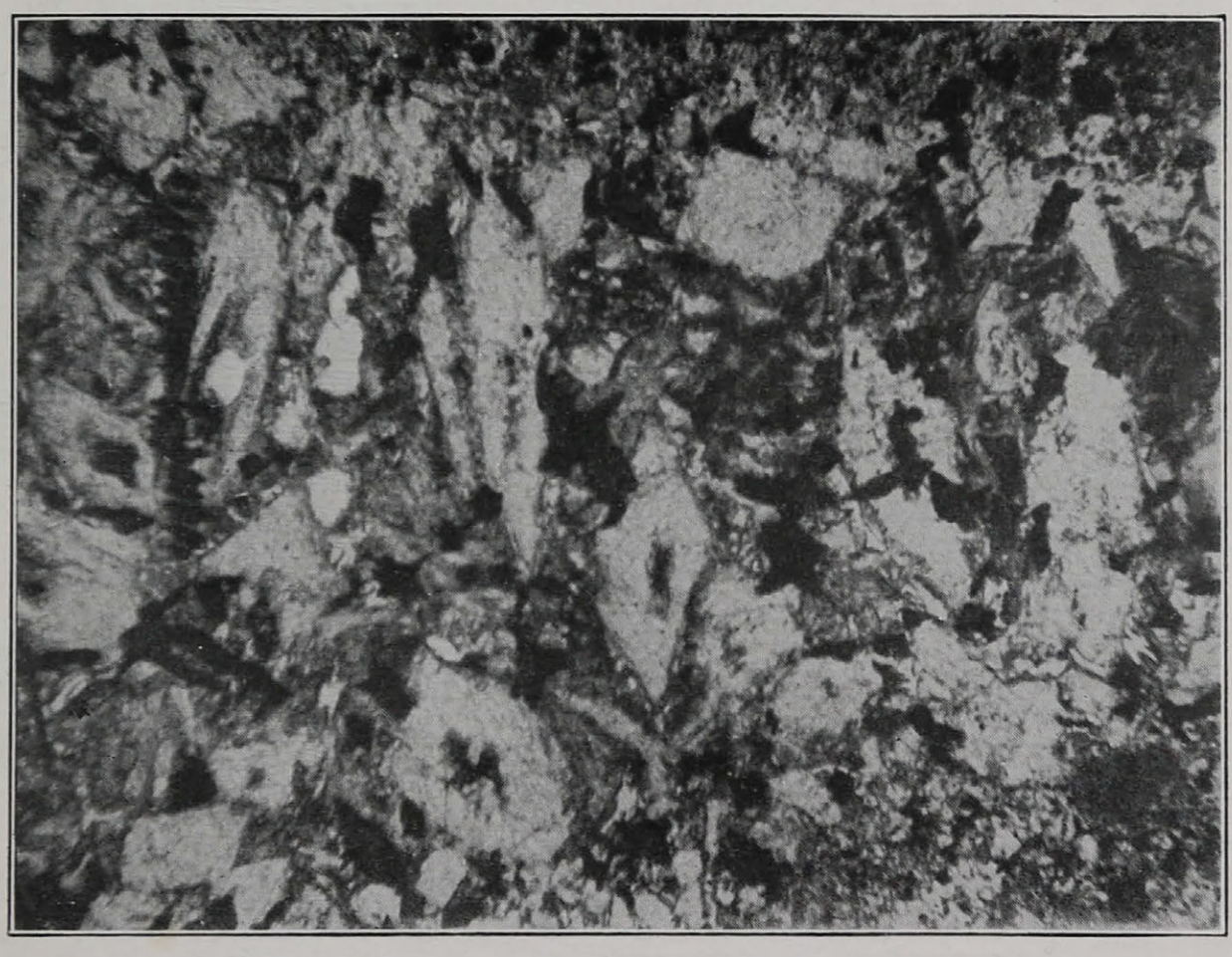

Fig. 30
Forsterite, augite, garnet and spinel. Minette : Magnesite 2 : 1 (171)
(1400° C) x80. See p. 110

Plate No. 16

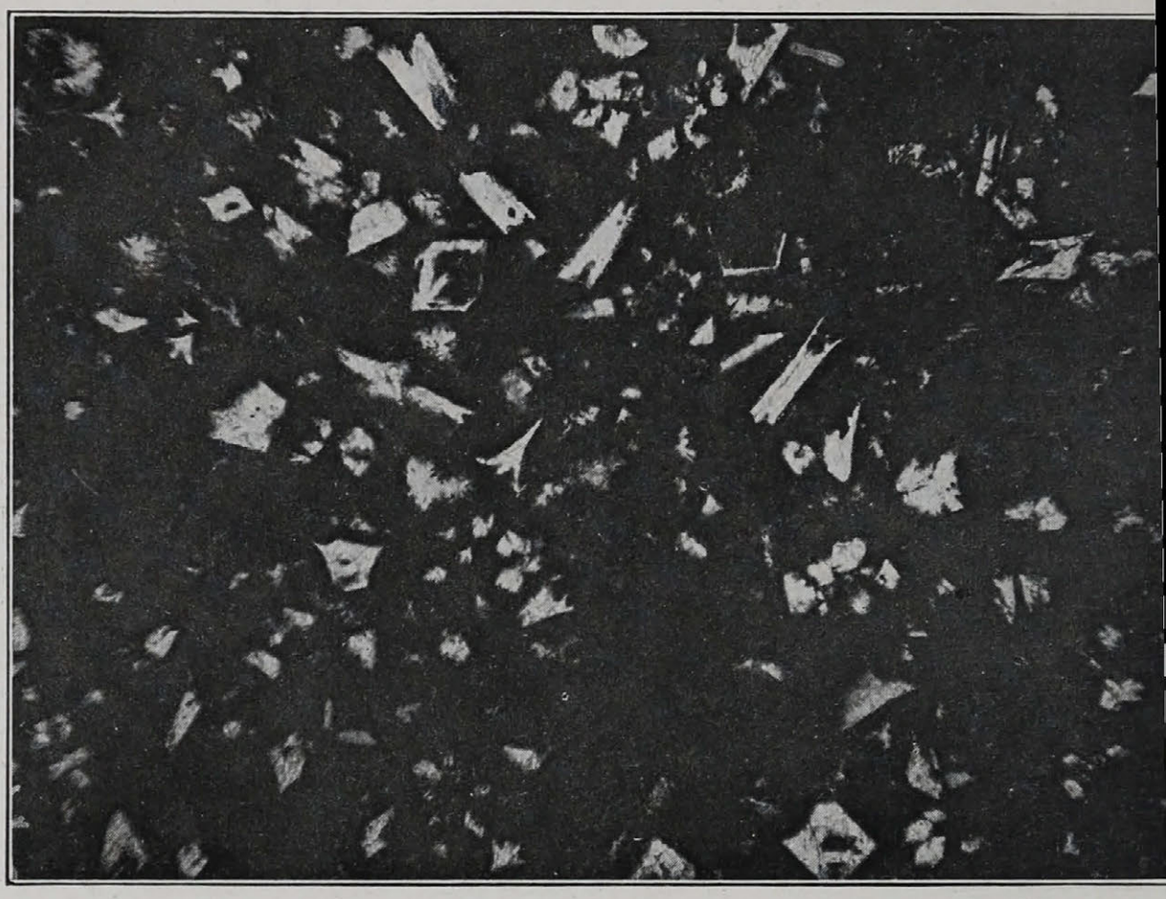

Fig. 31
Glass with forsterite crystals and skeleton crystals.
Kimberlite : Kaolin 2 : 1 (74) (1402° C) x80. See p. 82

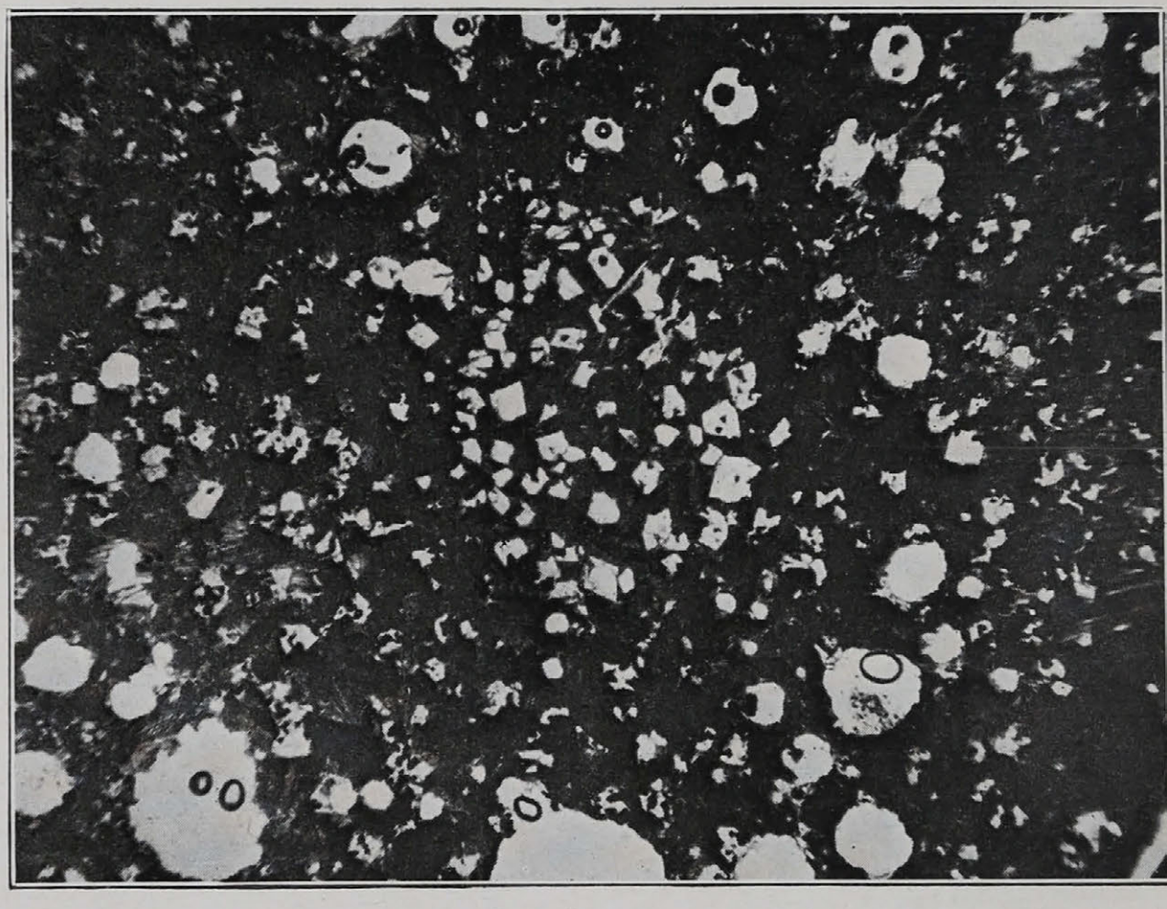

Fig. 32
Transparent olivine crystals associated with augite and chromite.
Basalt : Chromite 2 : 1 (294) (1410° C) x25. See p. 124

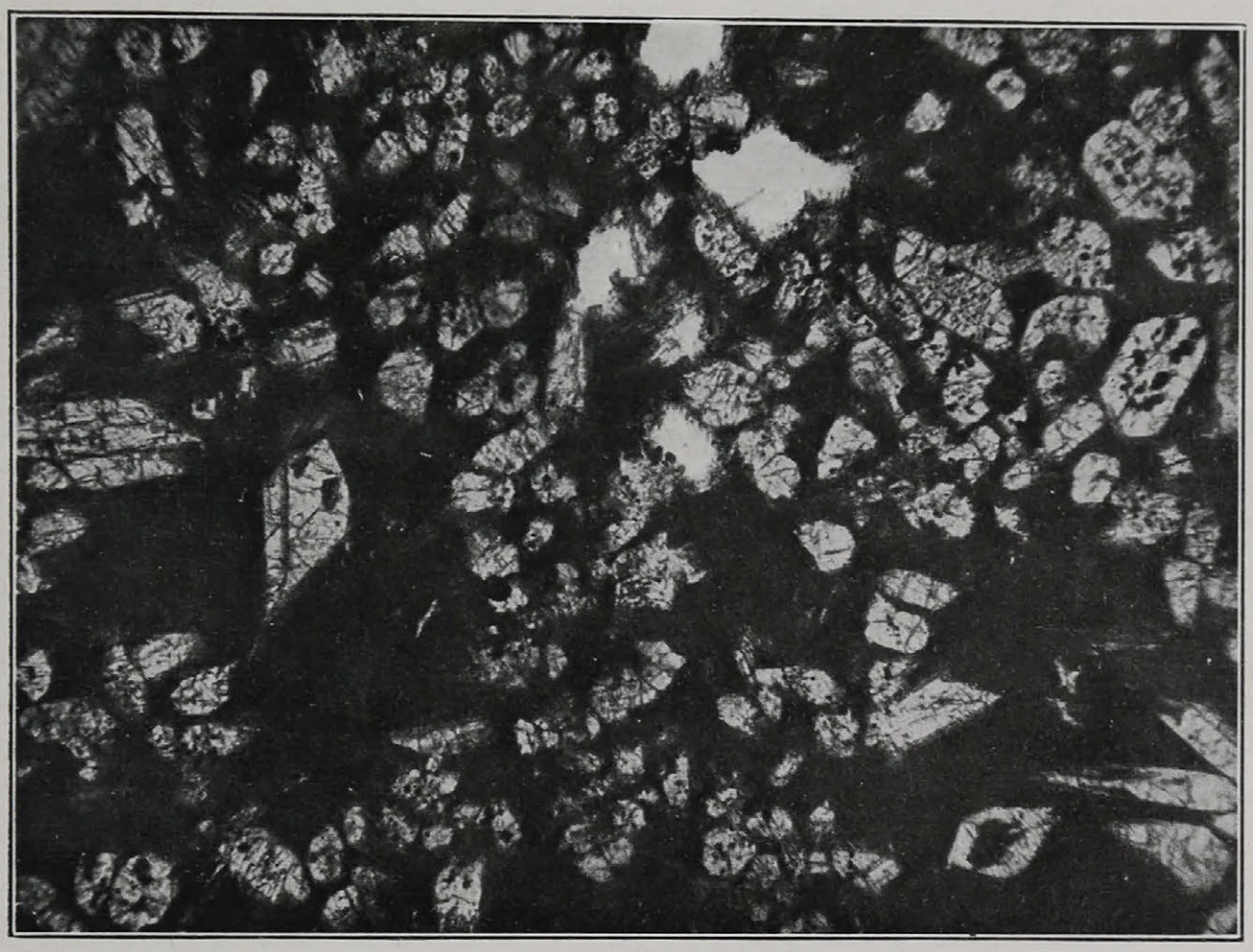

Fig. 33
Transparent clino-enstatite with augite (unilluminated).
Kimberlite : Quartz 3 : 1 (481) (1410° C) x80. See p. 89

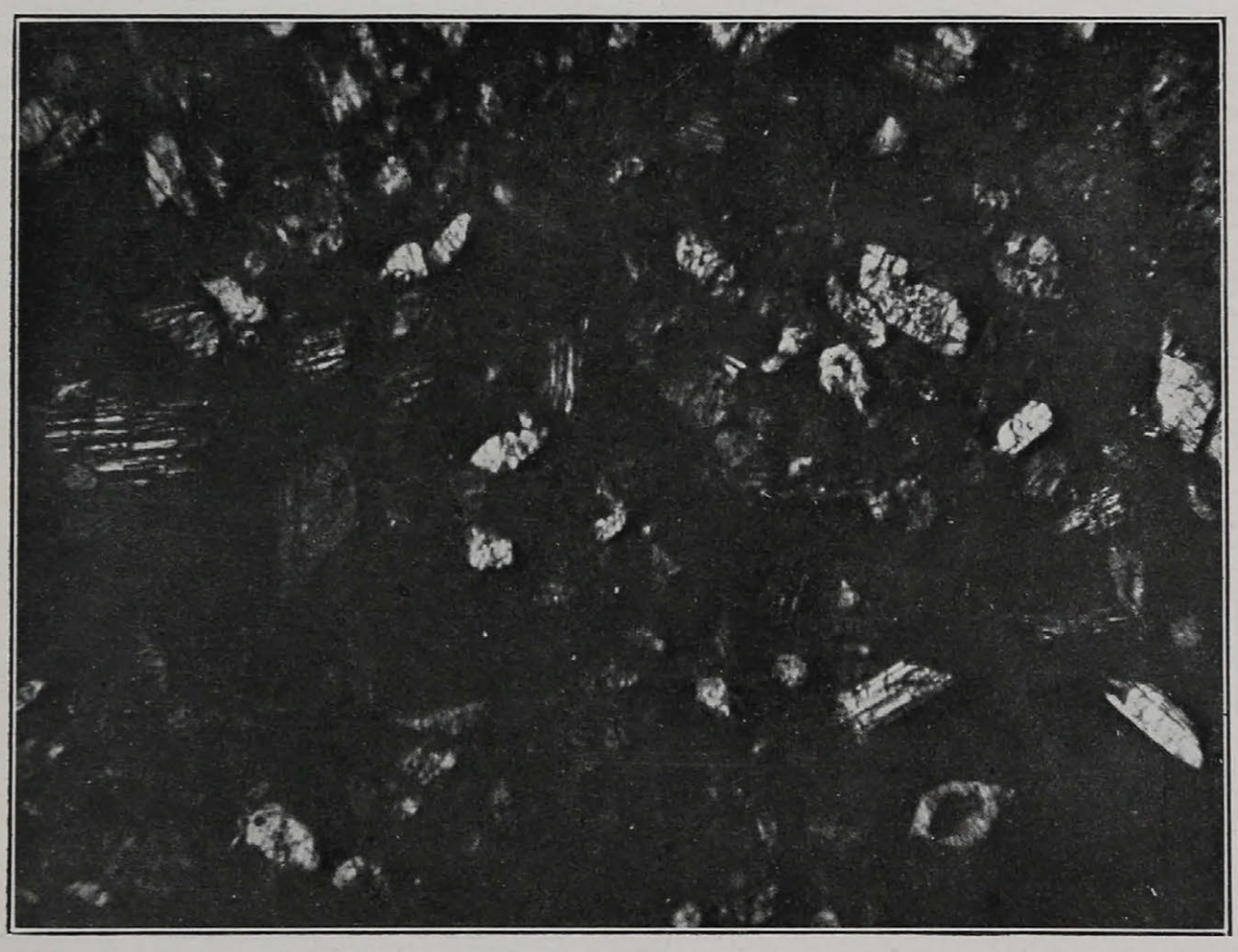

Fig. 34
Clino-enstatite showing poly-synthetic twinning. Same field as fig. 33
Kimberlite : Quartz 3 : 1 (481) (1410° C) + nicols, x80. See p. 89

Plate No. 18

Fig. 35
Clino-enstatite with augite in crystalline continuity at the outsides
the crystals. The small clear grains, some with dark centres, a
chrysolite. Kimberlite : Hematite 1 : 1 (245) (1410° C) x80. See p.

Fig. 36
Skeleton crystals of augite with dark brown glass.
Kimberlite : Kaolin 3 : 1 (454) (1410° C) x25. See p. 82

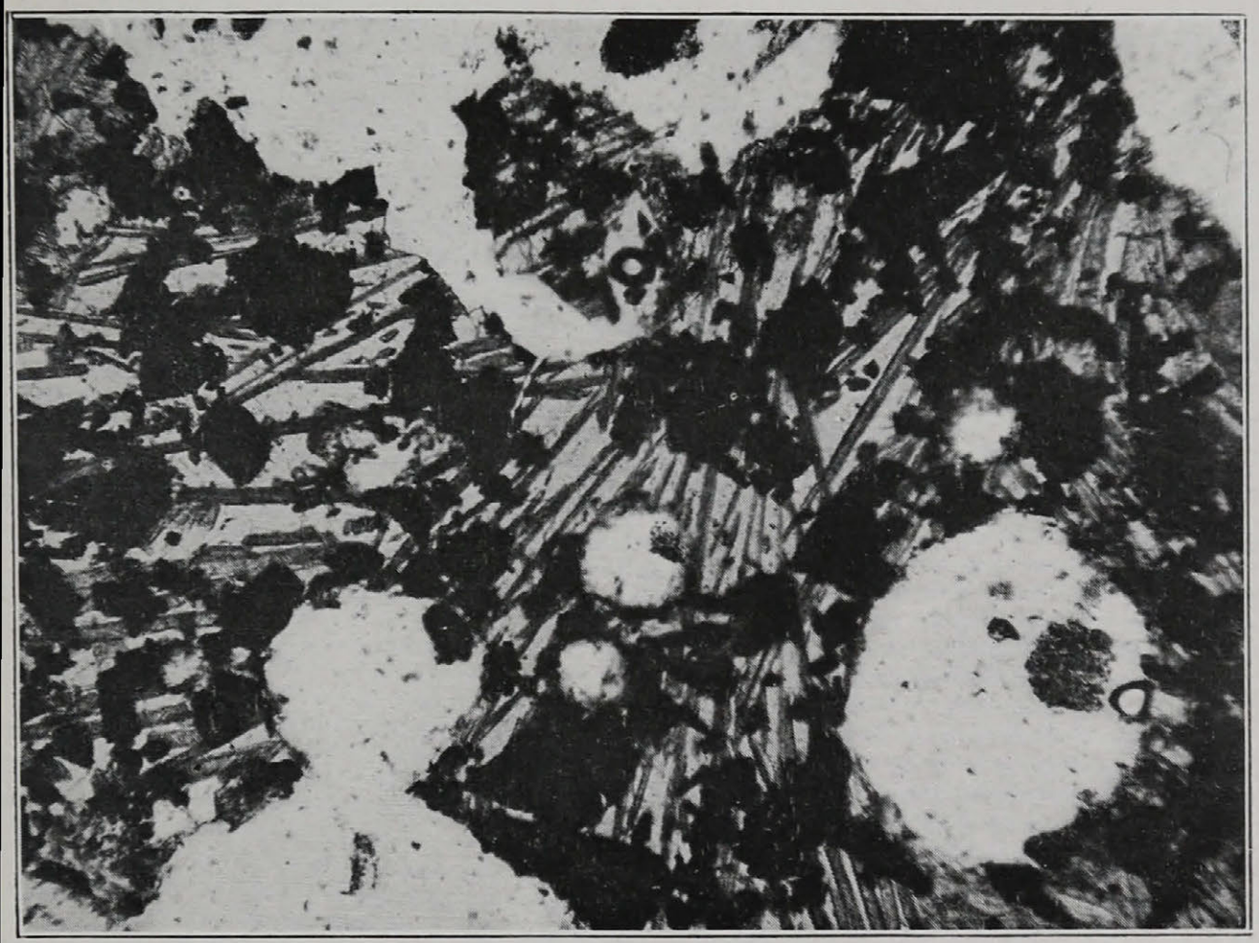

Fig. 37
Colorless glass, chromite (opaque) and needles of bronzite.
Granite 1 : Chromite 1 : 1 (290) (1410° C) x80. See p. 122

Fig. 38
Clear olivine, and augite with brown glass. Some new octahedra of chromite are present. Basalt : Chromite 3 : 1 (295) (1410° C) x80.
See p. 124

Plate No. 20

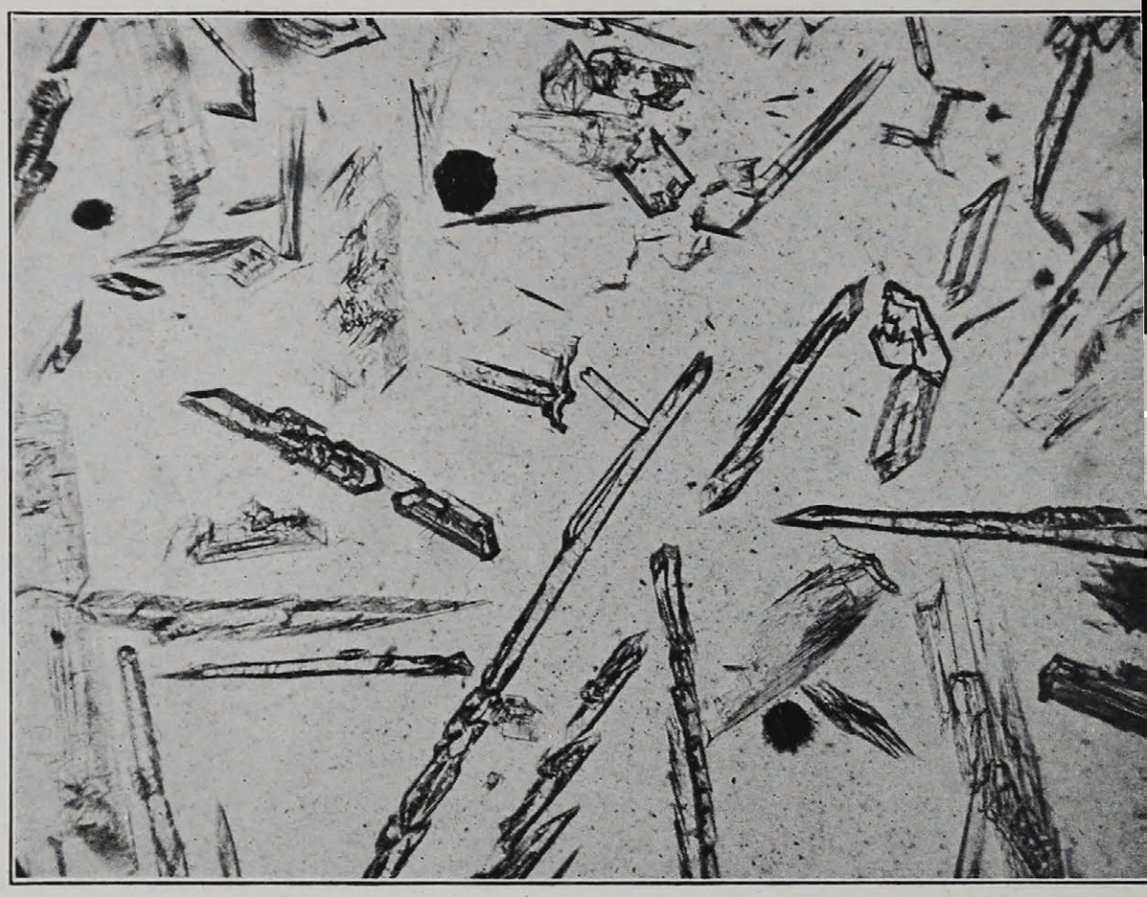

Fig. 39
Colorless glass and augite needles. Andesite porphyrite : Magnesit
3 : 1 (181) (1400° C) x80. See p. 109

Fig. 40
Colorless glass with needles and equant grains of augite.
Granite 1 : Magnesite 3 : 1 (166) (1400° C) x80. See p. 108

Fig. 41
Colorless glass with needles and grains of augite.
Syenite : Magnesite 3 : 1 (175) (1400° C) x80. See p. 108

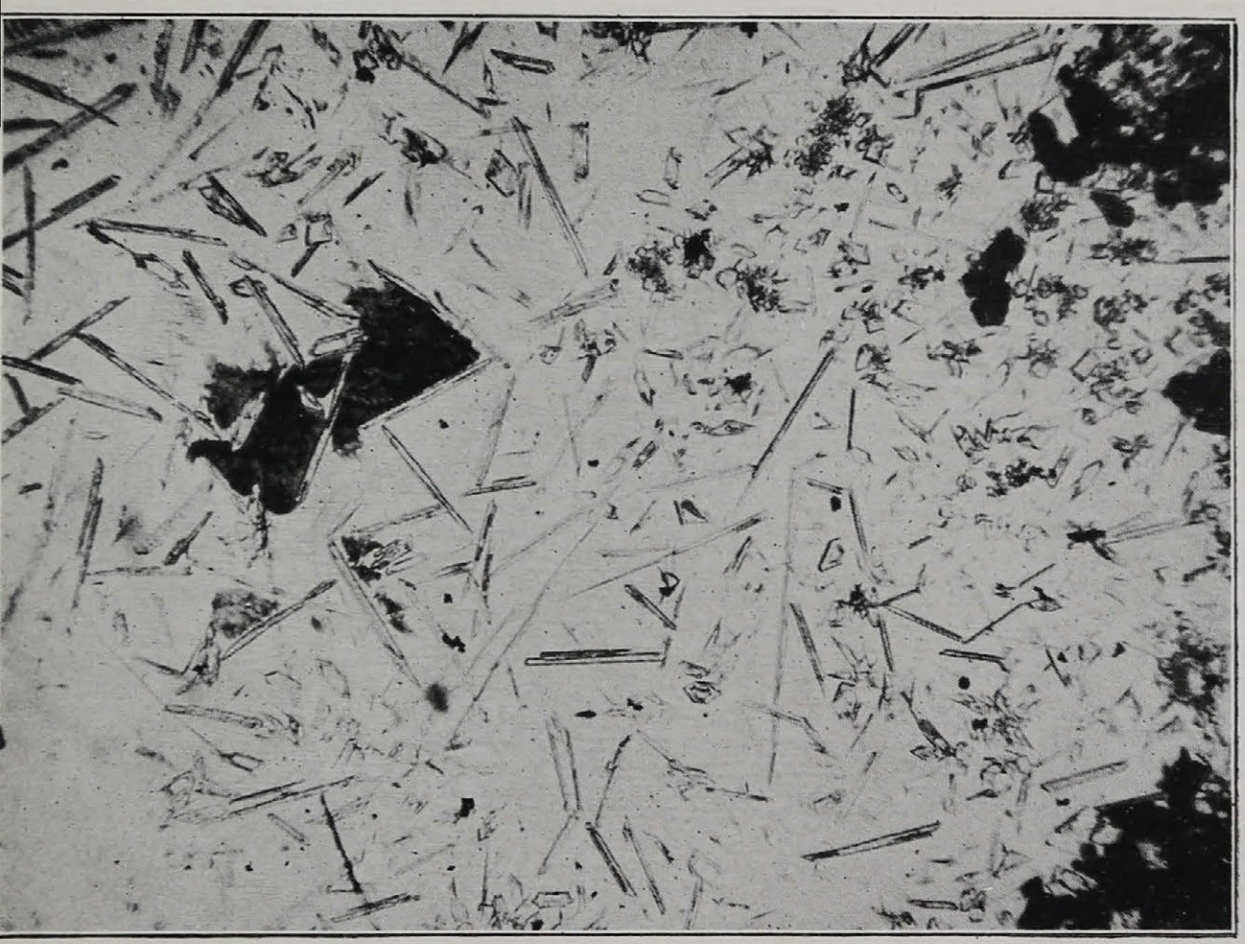

Fig. 42
Colorless glass with augite needles and equant grains.
Nepheline-syenite : Tremolite schist 1 : 1 (218) (1400° C) x25.
See p. 112

Plate No. 22

Fig. 43
Augite, small crystals of chrysolite, some with dark centres, and brow
glass. Kimberlite : Dolomite 3 : 1 (205) (1400° C) x80. See p. 10

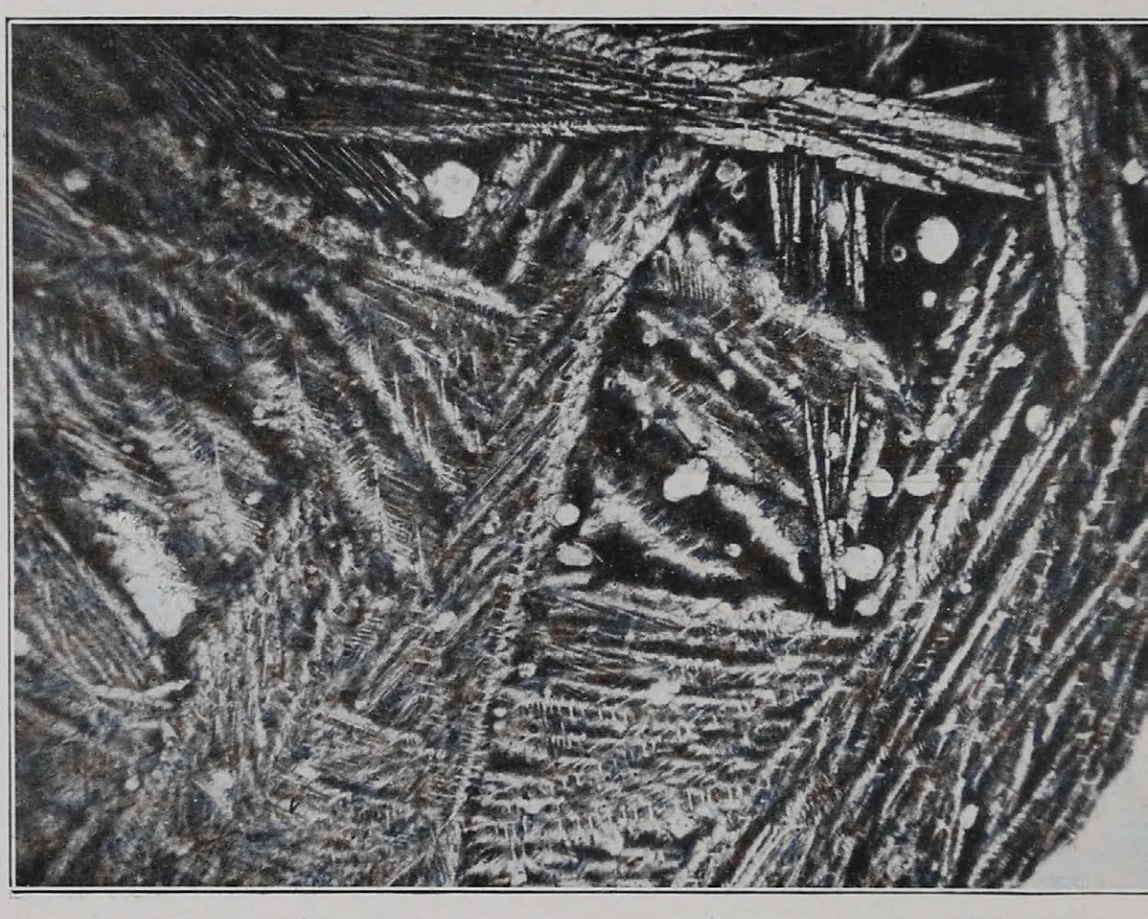

Fig. 44
Chromiferous augite needles with featherlike attachments. Olivi
needles at top. Minette : Chromite 3 : 1 (298) (1410° C) x25.
See p. 125

Fig. 45
Augite crystals and small crystals of chrysolite (clear, some with dark centres). Basalt : Tremolite schist 2 : 1 (210) (1400° C) x25.
See p. 113

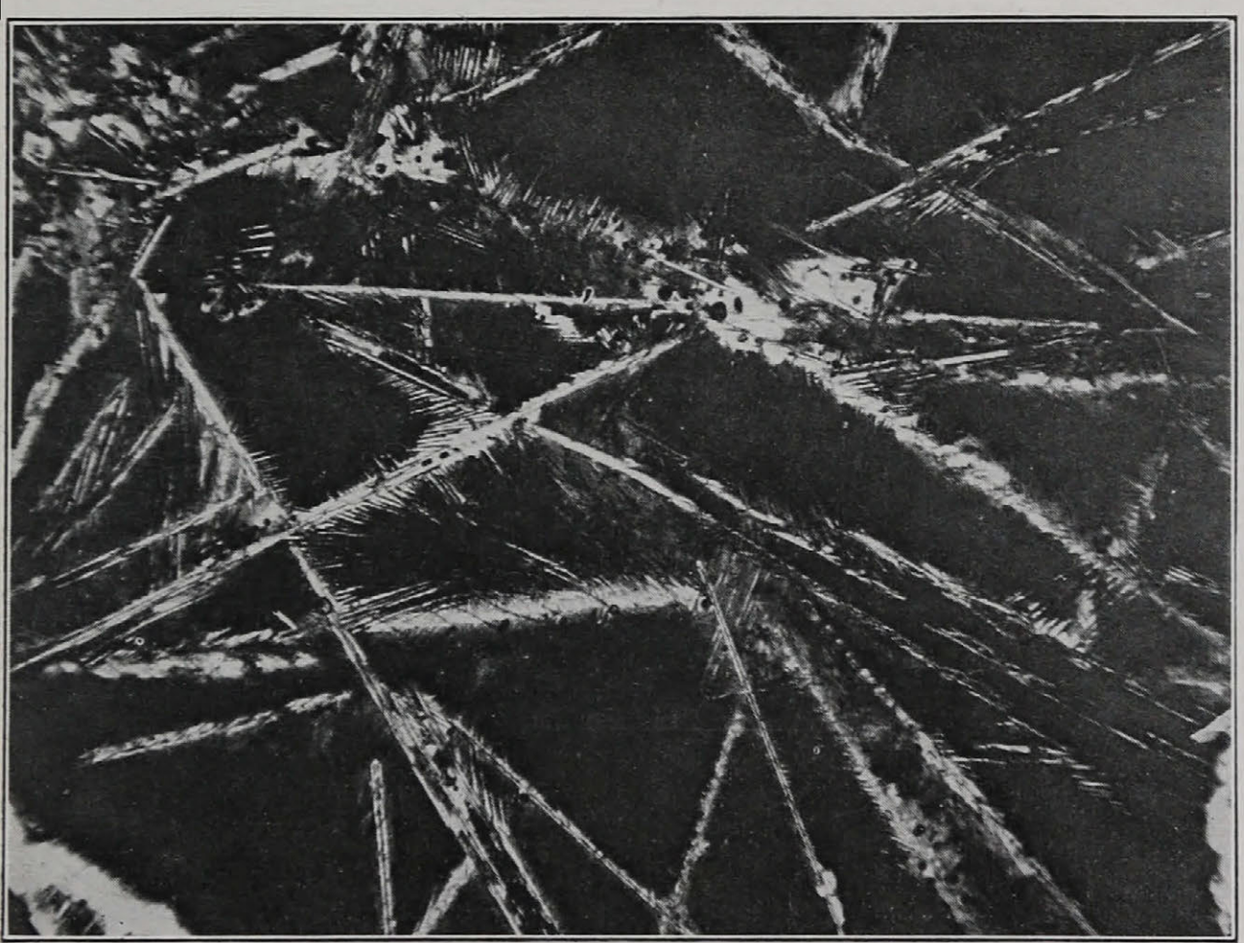

Fig. 46
Long needles of augite with feathery attachments.
Syenite a : Tremolite schist 1 : 1 (215) (1400° C) x25. See p. 112

Plate No. 24

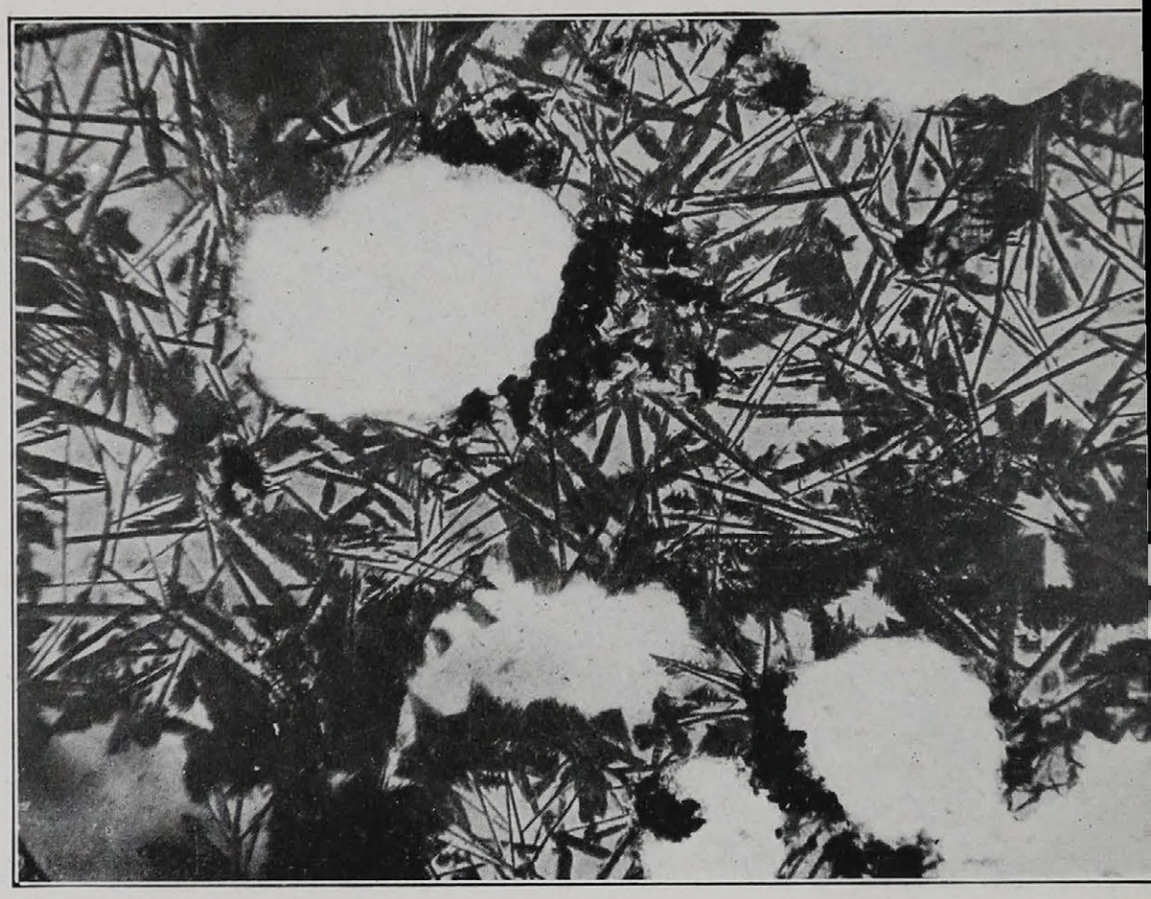

Fig. 47
Glass with metallic iron and augite needles and grids.
Syenite : Siderite 3 : 1 (154) (1230° C) x80. See p. 100

Fig. 48
Glass with metallic iron and augite needles and grids.
Granite 1 : Magnesite 3 : 1 (103) (1230° C) x80. See p. 90

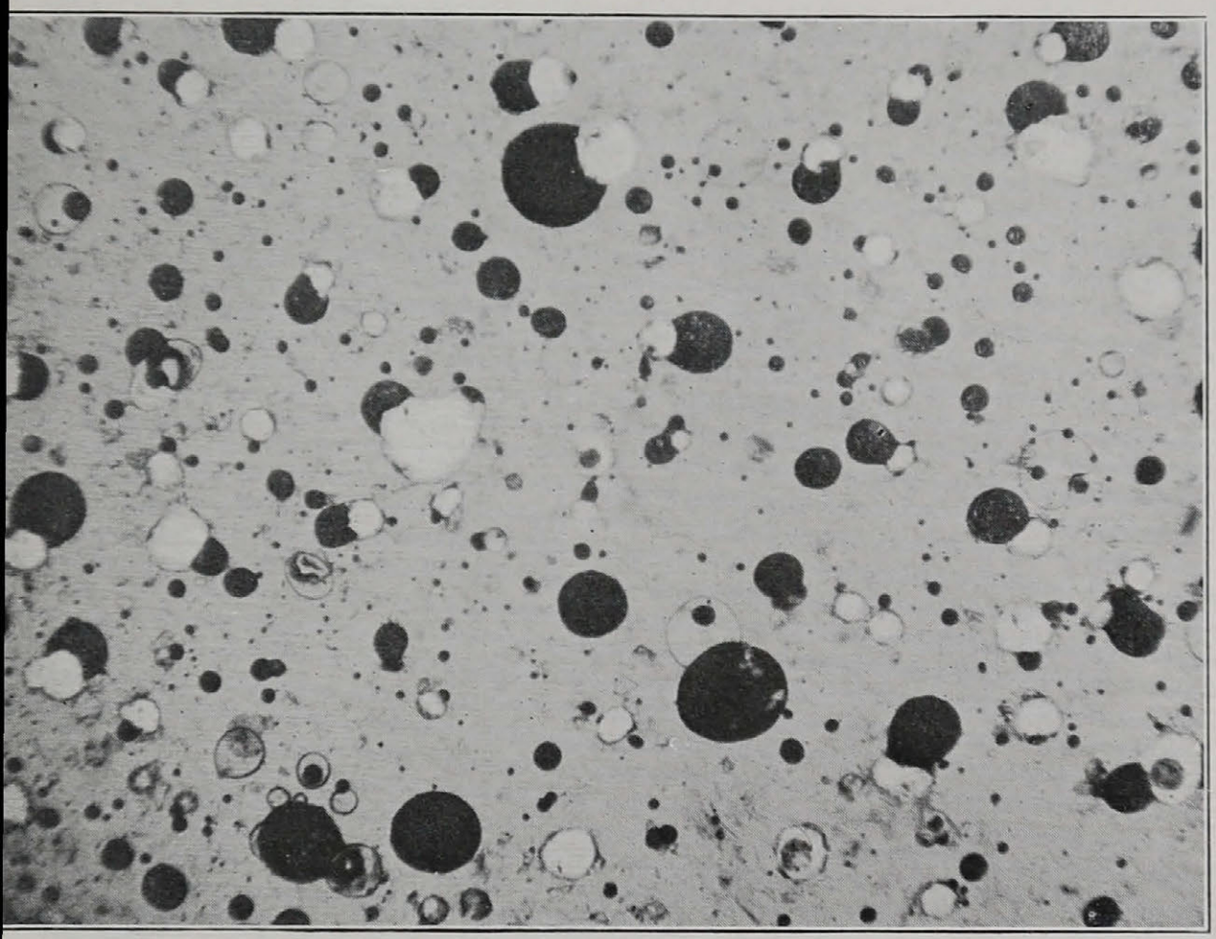

Fig. 49
Glass with gas bubbles and chalcocite globules of graded sizes. Some of the latter are attached to gas bubbles.
Granite 1 : Chalcopyrite 3 : 1 (353) (1410° C) x25. See p. 129

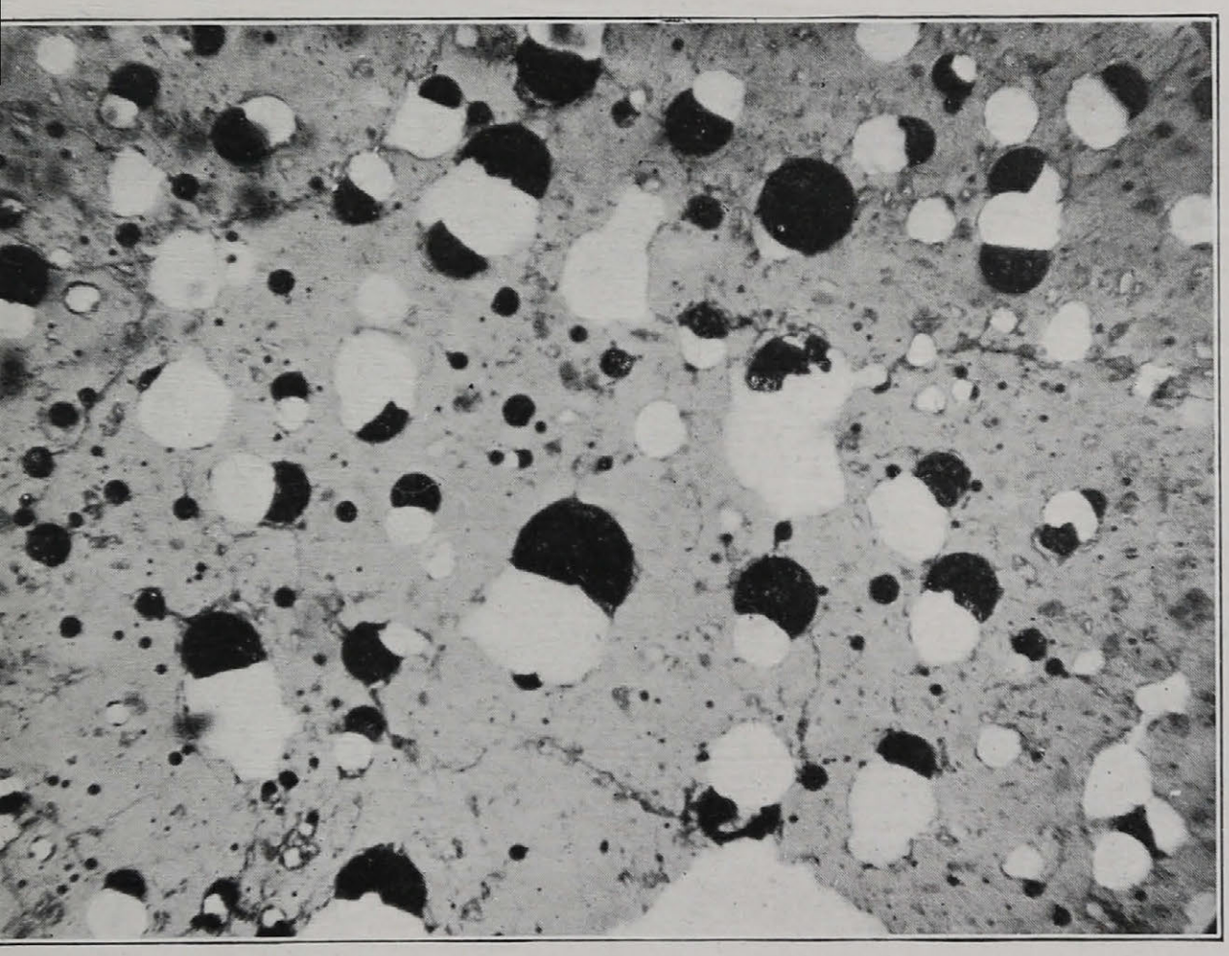

Fig. 50
Glass with gas bubbles and pyrrhotite globules of graded sizes.
Granite : Pyrite 3 : 1 (360) (1410° C) x25. See p. 130

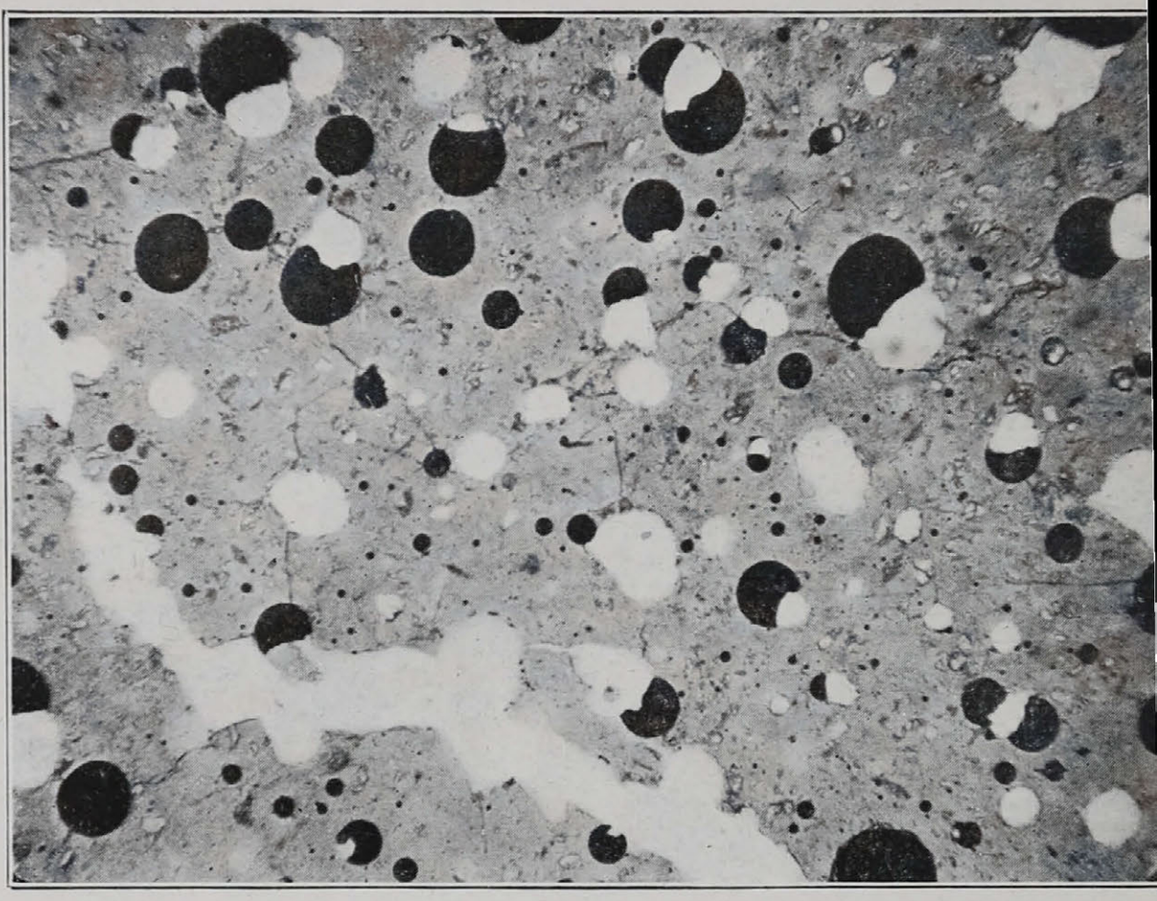

Fig. 51
Glass with unmelted quartz fragments, gas bubbles and pyrrhotite globules of graded sizes.
Granite 1: Pyrrhotite 3 : 1 (367) (1410° C) x25. See p. 131

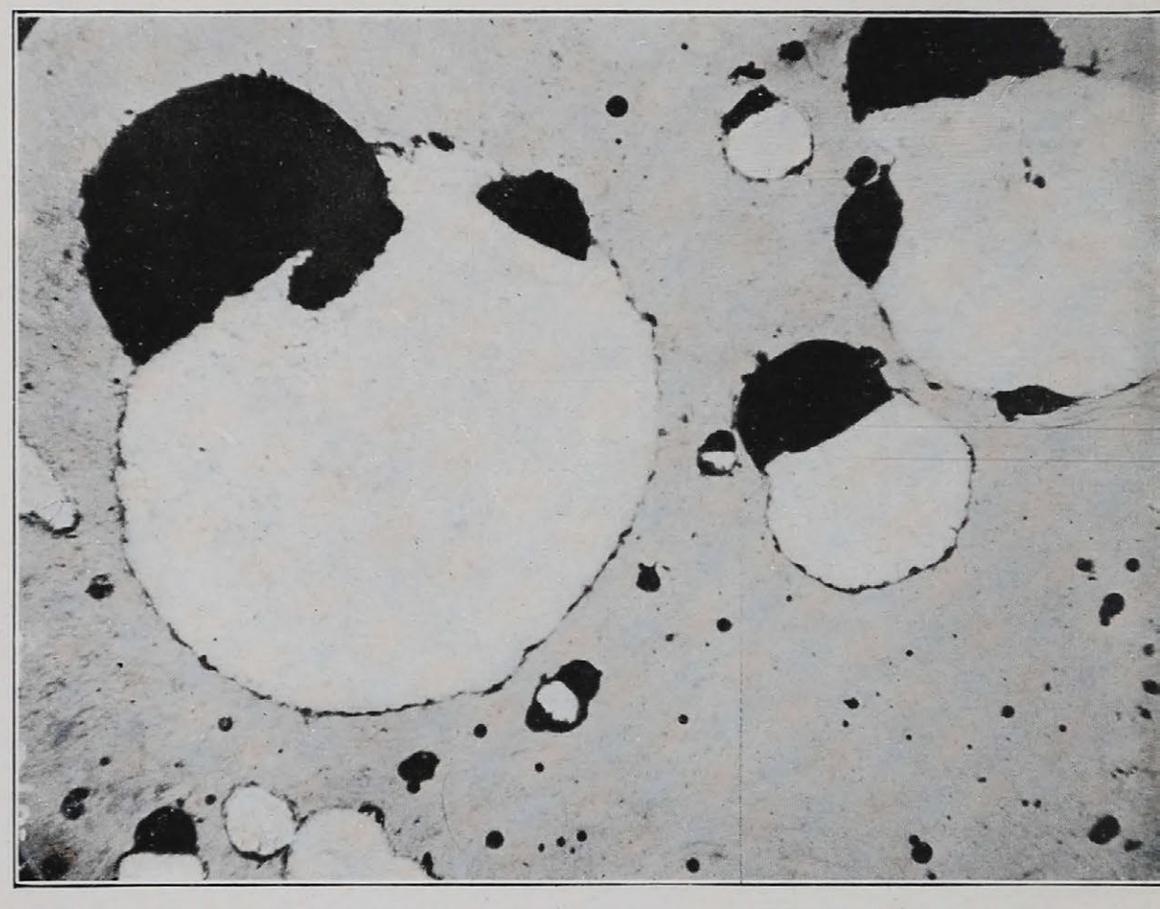

Fig. 52
Glass with chalcocite globules attached to gas bubbles.
Nepheline-syenite : Chalcocite 3 : 1 (343) (1410°C) x25. See p. 127

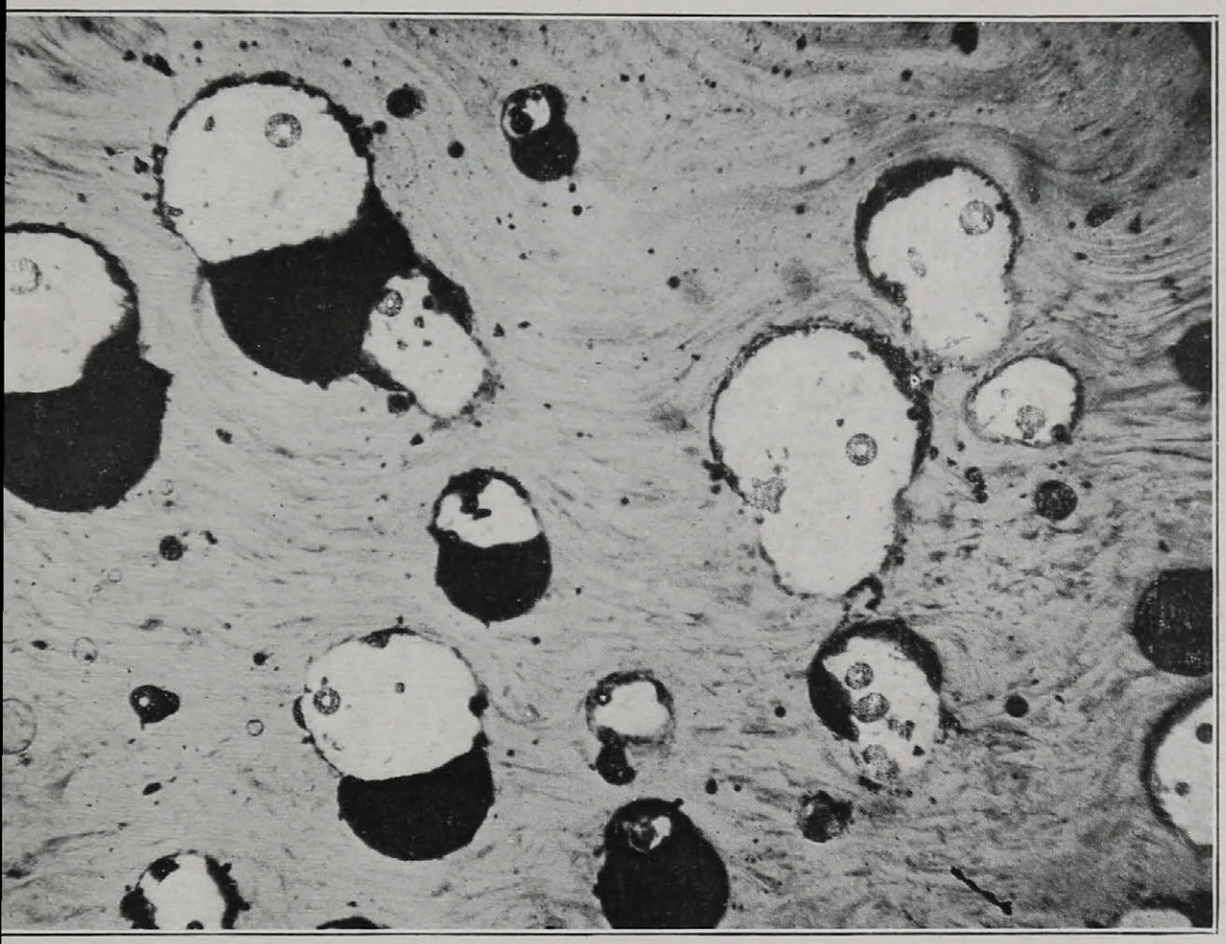

Fig. 53
Glass with chalcocite globules attached to gas bubbles. Flow structure is due to movement of gas bubbles and chalcocite globules.
Nepheline-syenite : Bornite 3 : 1 (350) (1410° C) x25. See p. 128

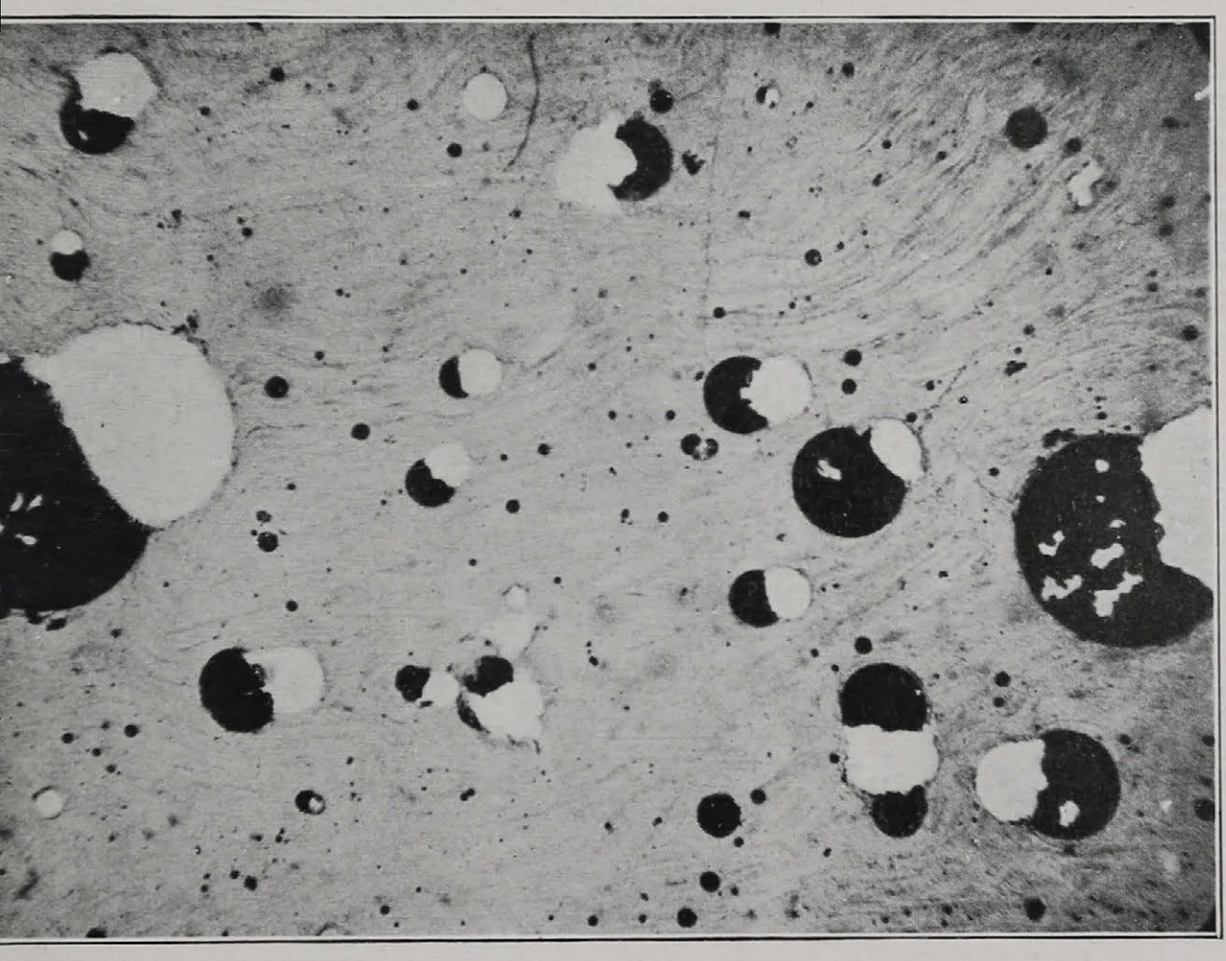

Fig. 54
Glass with gas bubbles and chalcocite globules. Flow structure is due to movement of gas bubbles and chalcocite globules.
Nepheline-syenite : Chalcopyrite 3 : 1 (357) (1410° C). See p. 129

Plate No. 28

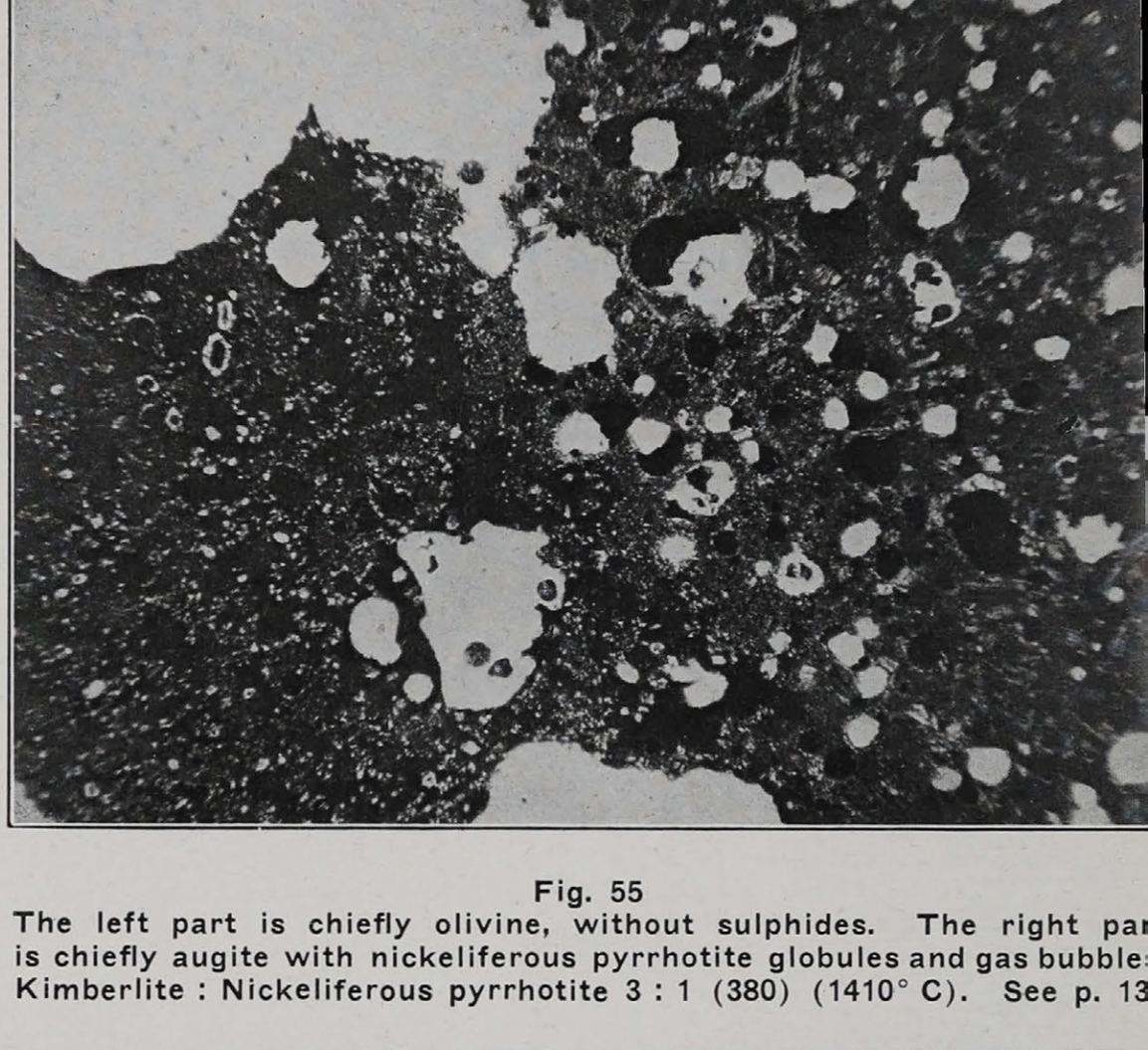

Fig. 55
The left part is chiefly olivine, without sulphides. The right par
is chiefly augite with nickeliferous pyrrhotite globules and gas bubble
Kimberlite : Nickeliferous pyrrhotite 3 : 1 (380) (1410° C). See p. 13

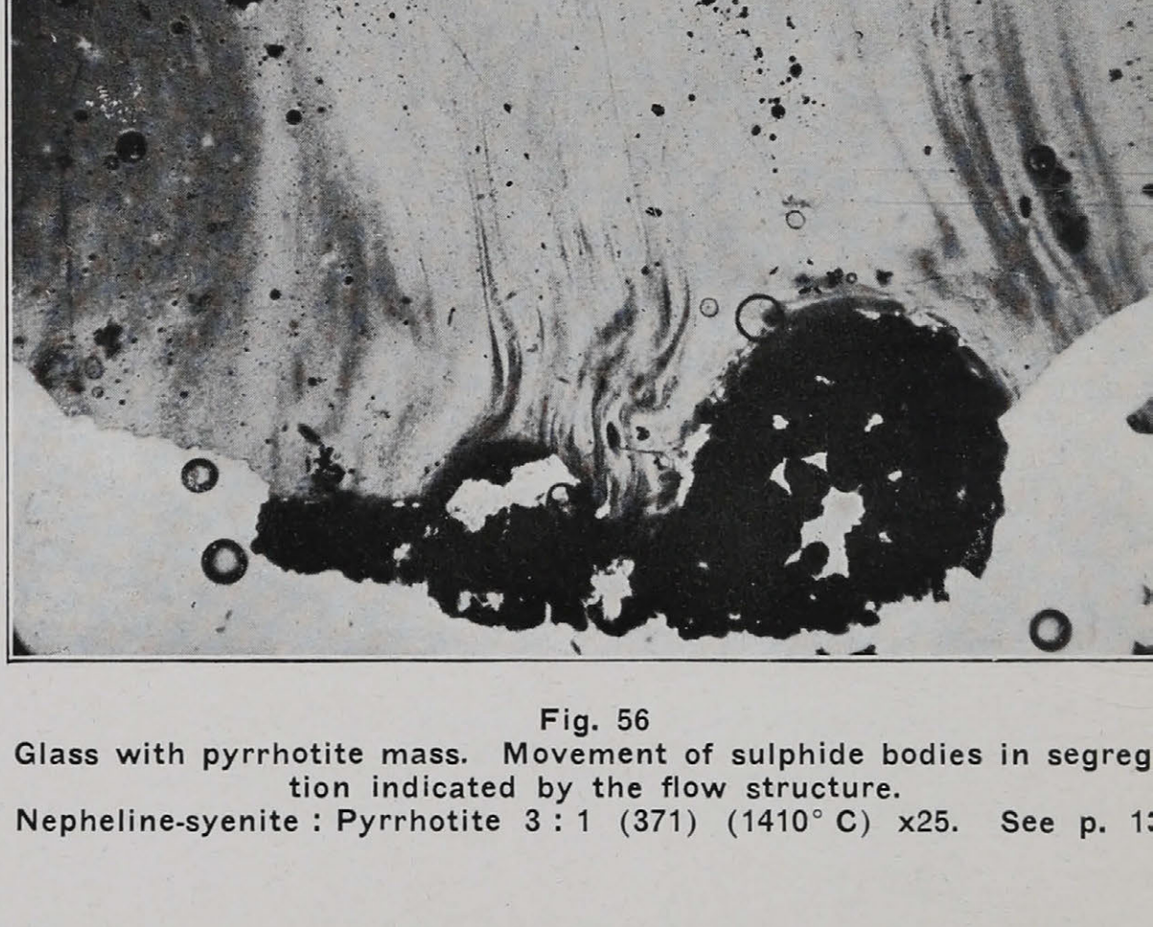

Fig. 56
Glass with pyrrhotite mass. Movement of sulphide bodies in segreg
tion indicated by the flow structure.
Nepheline-syenite : Pyrrhotite 3 : 1 (371) (1410° C) x25. See p. 1

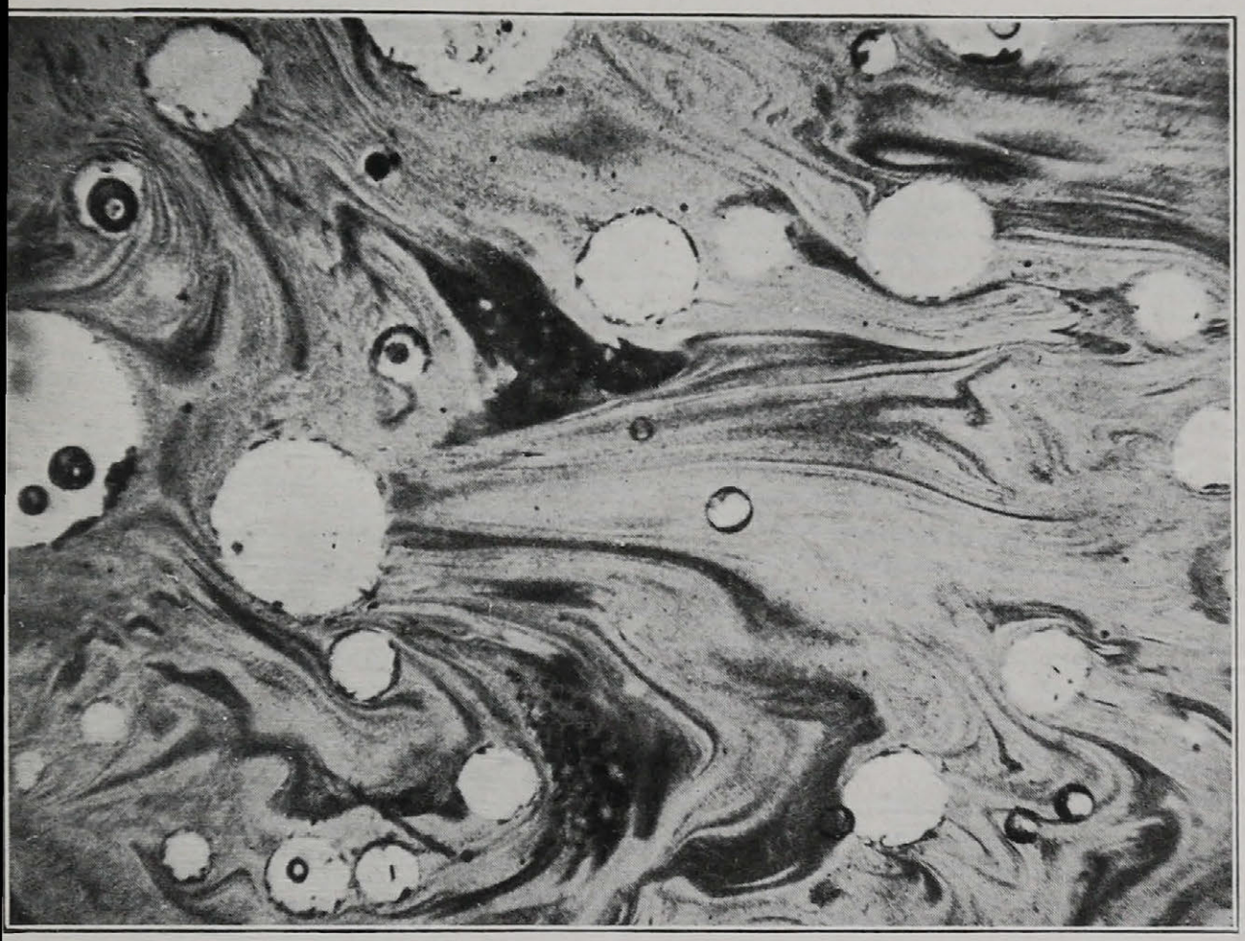

Fig. 57
Glass with flow structure due to movement of gas bubbles. Direction of motion indicated by "tails" behind gas bubbles. Syenite $\frac{\alpha}{\lambda}$: Pyrite 3 : 1 (363) (1410°C) x25. See p. 130

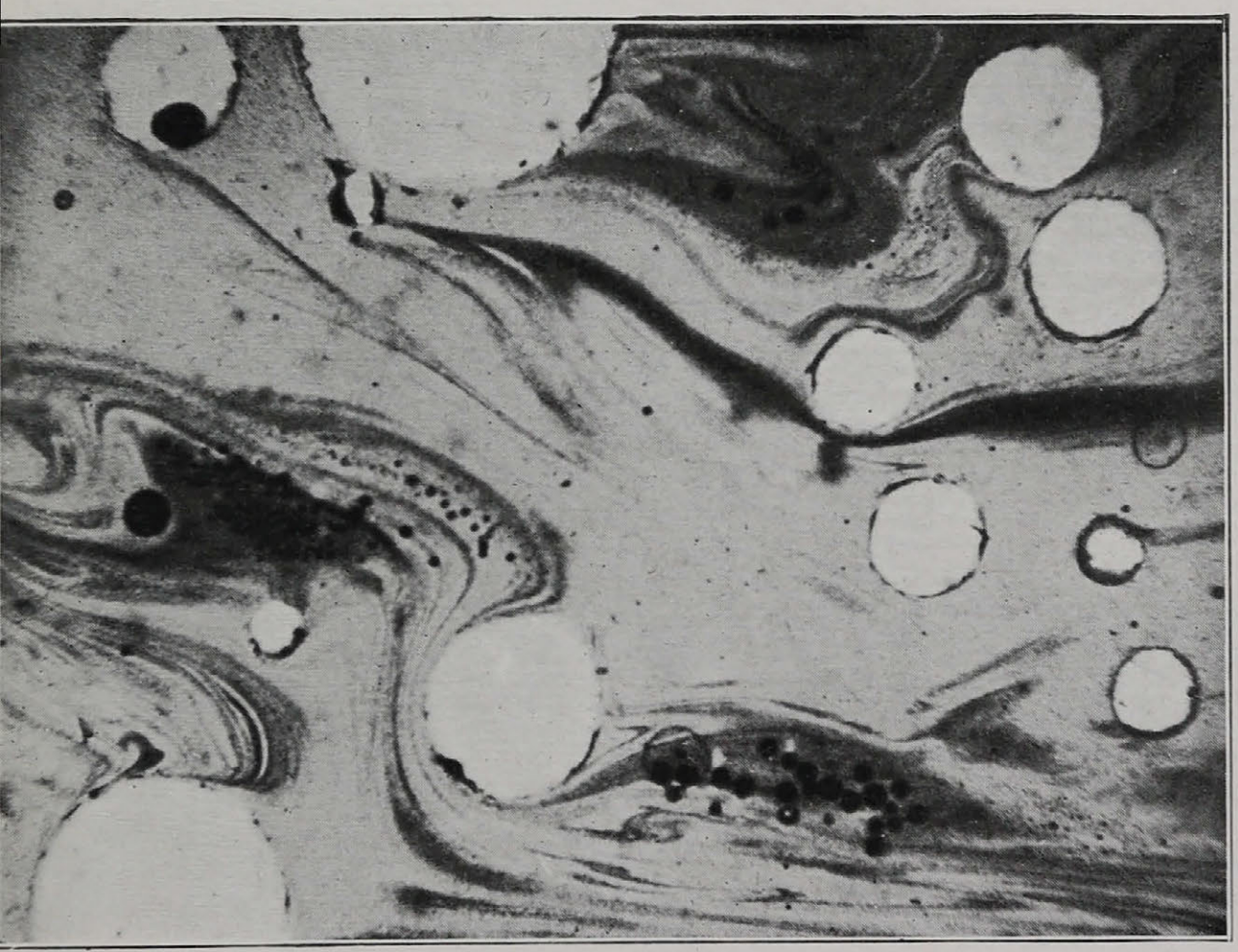

Fig. 58
Flow structure due to movement of gas bubbles.
Andesite porphyrite : Nickeliferous pyrrhotite 3 : 1 (379) (1410° C) x25. See p. 133

Plate No. 30

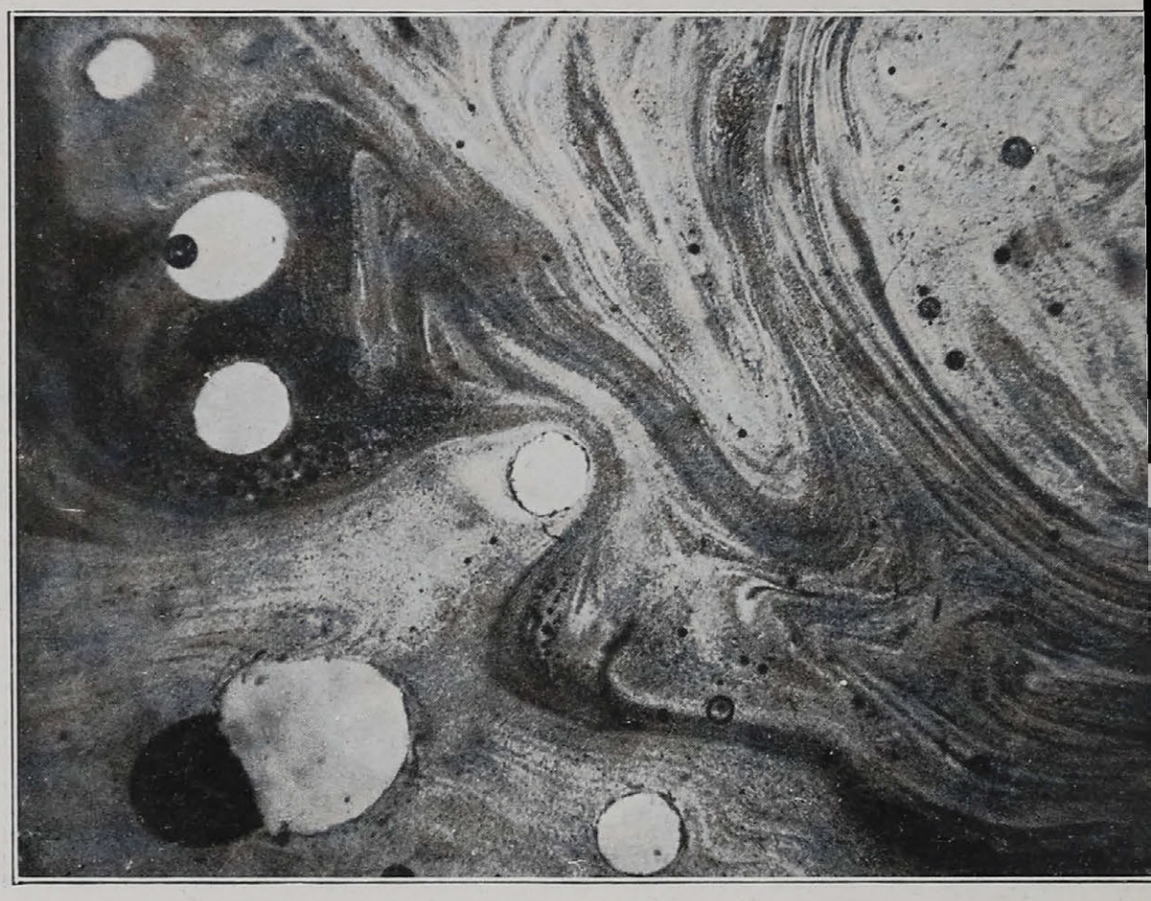

Fig. 59
Glass with gas bubbles, one lead sulphide globule and striking flo
structure. Andesite porphyrite : Galena 3 : 1 (386) (1410° C) x25.
See p. 134

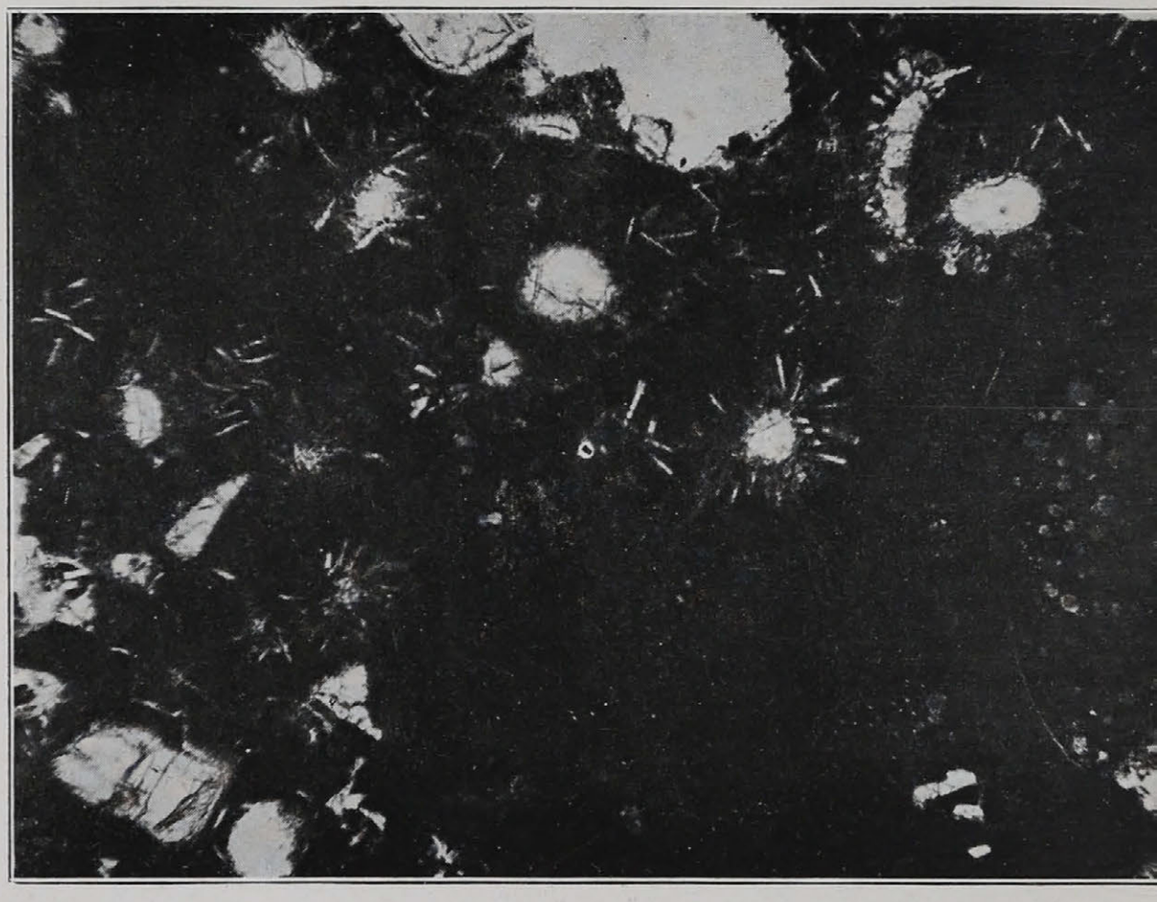

Fig. 60
Separation of two glasses; quartz grains, partly melted, with tridymit
fringes. Minette : Quartz 1 : 1 (467) (1410° C) x80. See p. 88

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