PETROLOGIC AND PETROGRAPHIC DESCRIPTION OF A LAVA FLOW IN CLALLAM COUNTY, WASHINGTON.

Submitted by

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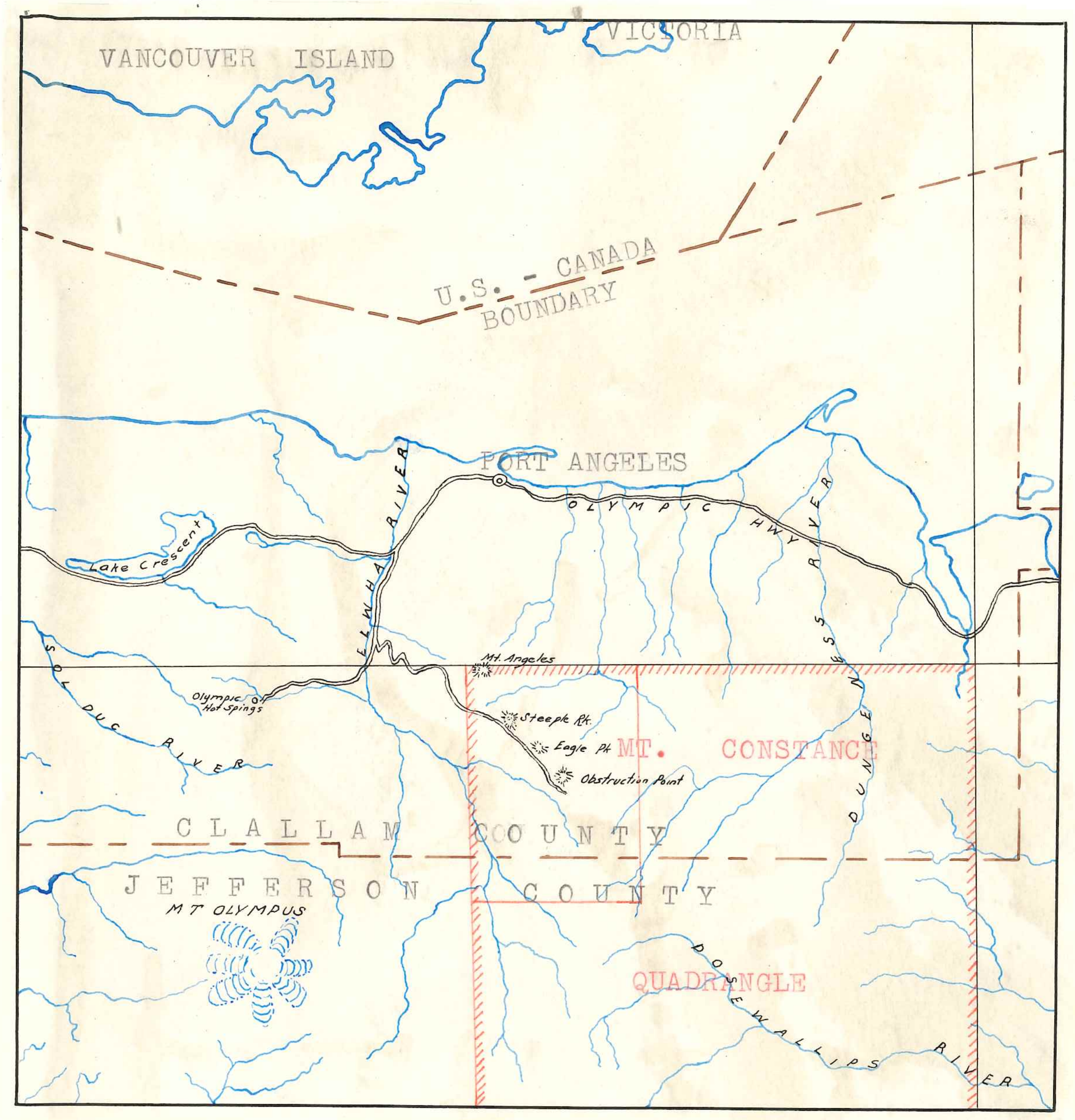
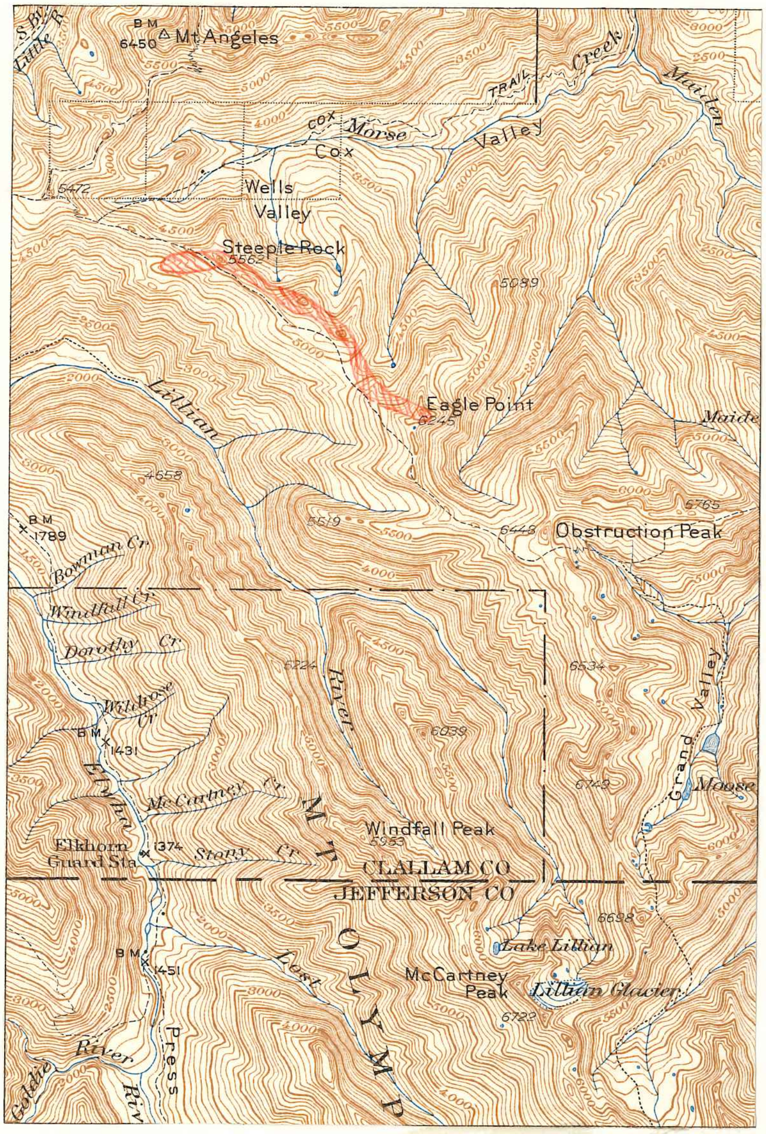
INDEX MAP SHOWING LOCATION OF AREA



Scale: 9 miles equals 1 inch.

NORTHWEST RECTANGLE OF MT. CONSTANCE

QUADRANGLE



VOLCANIC FLOW IN RED

ACKNOWLEDGEMENTS

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Furthermore, the author wishes to acknowledge his indebtedness to all those in the Department of Geology of the University of Washington who have aided in the preparation of this paper in many ways.

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INTRODUCTION

This paper consists of a petrologic and petrographic description of a lava flow included within the sequence of metamorphosed sediments and volcanics which constitute the interior of the Olympic Mountains. The area (3 miles by 300-500 feet) to be described is located in northwestern Washington in the northwest rectangle of the Mt. Constance quadrangle (lat. 47°-30′ to 48°-00′ N., long. 123°-00′ to 123°-30′ W.) As the outcrops in this area are at elevations ranging from 4500 to 5500 feet they are consequently inaccessible during the winter season on account of the heavy snowfall. During the summer months when the mountains are free from snow this locality may be readily reached by motor from the town of Port Angeles which is approximately at a distance of forty miles.

In general the Olympic Mountains are structurally an anticlinal dome with its longer axis trending approximately N 60° W. This dome consists of a thick sequence of Tertiary basic lava flows, sandstones, shales, and occasional thin beds of red limestone overlying a similar but metamorphosed series. In general the beds dip away from the axis of the fold; although there is considerable reversal of dips from overturning. The structures become steeper and more closely folded as the center of the uplift is approached. The flow to be described lies within the zone of the metamorphosed sediments and outcrops in the form of an intermittent arc which lies within and parallels the north and east boundaries of the mountains.

Field work was carried on during the summer of 1938. At this time the writer was engaged in reconnaisance mapping of the areal geology of this region for the United States Geological Survey. This work of the Geological Survey, under the supervision of Charles F. Park, represents the first geological study of this immediate area. However, a chronological sequence for the unmetamorphosed Tertiary sediments as well as the relationship of these sediments to the older metamorphosed sediments of the interior of the mountains has been determined by C.E. Weaver[20]. Weaver determined the age of these rocks as pre-Eocene.

GENERAL STRUCTURE AND STRATIGRAPHY

No detailed study of the rocks which make up the interior of the Olympic Mountains has ever been attempted. Such a study, over wide areas and in great detail is essential before a complete picture of sedimentation can be represented. This lava flow is the competent member of a steeply dipping (60° - 90°) NW-SE trending series of sandstones and shales which have been dynamically metamorphosed into silicic sandstones and phyll-argillites. The grade of metamorphism is not high since the production of phyllites represents the maximum. The sandstones are highly indurated and are filled with secondary quartz and calcite in the form of veinlets and as interstitial material. The shaly rocks which are intercalated with the sandstones do not show a gradation in grain size, but change abruptly from the argillaceous to the arenaceous. These changes may occur within a few inches or the beds may be unvaried for many feet. As outcrops can seldom be followed from one ridge to another it is difficult to determine how much change occurs along the strike. Wherever beds can be walked out variation in the amount of shaly to sandy material is consistently apparent. Although the possibility that overlapping relationships play an important part in the stratigraphy, it would require work in great detail to prove the existence of facies change. Key beds are apparently absent and this makes correlation very difficult. As yet, determinable fossils have not been found. Because of the absence of faunal zones and key beds the measurement of a stratigraphic section was not undertaken. From all indications at least a thickness of over a mile is represented, but it is very probable that several times that thickness is represented.

As previously mentioned the volcanics within the sedimentary sequence serve as the competent member. Major structure has not only been controled by this member, but the development of miner structures near its boundaries has been intensified. Shearing within the sediments is more pronounced near the north contacts than on the southern boundary of the flow. In this area crosscutting of structures cannot be offered as proof for unconformable relationships as this same discordande is present in the surrounding rocks and outside of the immediate sphere of influence of such a competent body. However, there is a marked consistency to the dominant structural trend and discrepancies of dip and strike suggest to the writer only local differential adjustments to stress that have been brought on by the relative competency of the shaly and sandy members.

This diversity of stress reaction is evident in the minor structures exhibited in both types of clastics. Parting of the sandstone in the form of gash fractures is common with later filling of these fractures by quartz and calcite. Isoclinal folds seen on individual outcrops show smooth curves with the adjustment within the sandstone taking the form of tensional breaks. The argillaceous sediments have reacted to stress in an entirely different manner. In many cases secondary cleavage has developed. This cleavage is locally indistinguishable from bedding as color changes have occured along the cleavage planes through the action of katamorphic solutions.*

* Katamorphic used in the sense of Van Hise.

This slaty cleavage may parallel the bedding or diverge at any angle from it. There is no apparent relationship between the major stresses and the cleavage attitude, as cleavage directions are often reversed in only a few feet. Beds have been greatly widened and narrowed by squeezing. Where the squeezing has been intense pencil schistosity has often developed. These long slender fragments produced may be up to 16 inches in length with a diameter of less than one half inch, thus giving a ratio of one to thirty-two.

LITHOLOGY OF COUNTRY ROCKS.

Megascopically the sandstones vary from light gray to dark gray, from fine to medium grained rocks. A microscopic examination reveales angular quartz grains making up over 60% of the rock with about 5% of plagioclase (andesine-oligoclase) and a somewhat smaller amount of muscovite and a trace of biotite. Inclusions of apatite and zircon are found within the quartz grains. The plagioclase is exceedingly free from alterations and exhibits polysynthetic twinning. The muscovite is at least in part authigenetic as it may be seen in several stages of development parallel to the bedding, and much of it shows the effects of stress as it occurs bent around the quartz grains. The biotite appears to be authigenetic. The cementing material of the rock is a mesostasis of finely divided quartz and muscovite (sericite). Many of the quartz grains have been enlarged by the deposition of this quartz cement around the grain and in optical continuity to it. Veinlets of quartz and calcite are very numerous within the sandstones as well as within the shales to a lesser extent.

The argillites and phyllites range from brownish-black to black in color. Thin sections reveal that this darkness is due to the presence of carbonaceous material modified by minor amounts of iron oxide. The thin sections further reveal that these shaly types are very similar in composition and texture to the mesostasis of the sandstones. In fact, the only striking difference is the presence of carbonaceous material which is absent in the sandstones. Kaolinitic minerals are not abundant; although they might be expected from a magascopic examination. The sheen of the phyllites is the result of the incipient crystallization of the muscovite.

MEGASCOPIC DESCRIPTIONS OF THE VOLCANIC ROCKS.

Megascopically the volcanic rock is dark green in color, and aphanitic to medium grained in texture. Although it is more resistant to weathering than the enclosing sediments, it presents a more highly altered appearance. In the coarser varieties feldspar and pyroxene may reach a length of five tenths of a centimeter. The feldspar in these coarse varieties is elongate. The entire rock, feldspar included, is stained a deep green because of the abundance of a large amount of chloritic material. In spite of this alteration, the rock is much more resistant to weathering than the sediments which show fresh unaltered feldspar under the microscope. This relative resistance may be seen in the rugged spires produced by the outcrops of volcanics in contrast to the more subdued topography of the sandstones and argillites. There are no porphyritic phases; but the lava may be locally amygdaloidal and occasionally slightly vesicular. Near the top of the flow at the west side of Needle Rock, a brecciated phase occurs. This fragmental rock - a band six feet thick and a hundred feet long - is composed of shale fragments and vesicular fragments of the igneous rock within a light green matrix. The fragments are aligned with their long dimensions parallel to the bed. Microscopically the matrix consists of an aggregate of calcite, zeolites and chlorite.

The most prominent feature of the flows is the local abundance of pillow structures. These pillows are not characteristic of the lavas throughout the entire length of the exposure, but are only local developments, and even then, grade into the more massive lava. The best developed pillows appear on the immediate west side of the spire of Needle Rock. Here they range in size from small forms, some less than six inches in diameter, to those several feet in diameter. Between the pillows is a gray-white to green, silicious to calcareous rock. This light green color indicates the presence of finely disseminated chlorite. The fact that this interpillar material is quite high in carbonate is shown by honeycombed structures produced by weathering.

The pillows show a certain amount of fracturing. Jointing from cooling contraction has produced in some pillows radially arranged columns. A later tensional adjustment has produced gash fractures which have been filled by later quartz and calcite. These later fractures may trend across the primary fractures. Along both contacts of the flow may be found small reniform structures - up to 1 cm in diameter - with their convexity toward the sediments.

There is great variety within the flow, both as to structures and as to grain size. The coarser variety occurs within the central regions of the flow and grades into an aphanitic type as both upper and lower contacts are approached. Within the flow there are no sharp changes to suggest a multiplicity of extrusions. (This only holds for the area in discussion, and not for other outcrops of the same lavas.) Chilled phases are found at both the upper and lower contacts with the sediments. The sediments immediately overlying the flow show greater alteration (production of carbonate, chlorite, etc.) than do the sediments underneath. An explanation of this anomaly is offered in the conclusion of this paper. The altered sedimentary rocks near the contacts of the flow are often hard to distinguish from the igneous rock in the field. However, a microscopic examination reveals that the microscopic sedimentary textures are still retained.

INTRA-LAVA-CHERTS.

As interstitial material within the flow are found gray cherty masses that are ovate, lenselike or veinlike in form. Although megascopically it is chert, a microscopic examination suggests that the silica was derived from a different source than that of colloidal precipitation. This rock consists of approximately 80% quartz which forms a fine interlocking mosaic. Interlocked with the quartz is brown hornblende, epidote and a minor amount of chlorite. Minute euhedral inclusions of apatite occur within the quartz. Throughout these minerals is disseminated a murky amorphous material indeterminable in character.

However, the most peculiar feature of this rock is the appearance of incipient (1 mm.) porphyroblasts of plagioclase feldspar. (See plate 1) For the most part, these porphyroblasts show clear centers with a concentration of the same type of murky material at their peripheries, which is found throughout the rock. The borders of the porphyroblasts are highly irregular. The concentration of inclusions at the borders of the crystals may be explained as the result of crystallization pressure. This same hypothesis of clearing of inclusions through crystallization pressure was applied to similar plagioclase porphyroblasts forming within hornfels by G. E. Goodspeed.[8]

A postulated origin for these "cherty" rocks is the metamorphism of shaly sediments that have been "picked up" and transported by the lava. The shales are remarkably low in alumina (microscopic estimate), but rather high in carbonaceous material. Any shale included in a lava might readily be freed of its carbon content by the application of heat from the lava. The alumina, iron, magnesia and alkalies are now present as epidote, chlorite and plagioclase. To support or refute this hypothesis, numerous chemical analyses of both the shales and silicious rocks would be essential. The question as to whether the source material for these silicious rocks was in the form of consolidated shale fragments or as a viscous mud could not be determined from the material examined. The production of such a rock from a semifluid (unconlidated) substance would probably be more feasible from a physical and chemical standpoint than from a more solid material. The physical state of unconsoli-

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dated material would at least permit a more rapid transfer of heat and of solutions. Actual fusion of the shales may or may not have taken place as neither positive nor negative evidence was detected which would prove or disprove this fact. Stability was apparently reached in a relatively short time, ie., during the cooling of the flow. Thus it seems with the transfer of heat, endothermic in respect to the lava, and the presence of connate water within the shaley material, a vapor pressure might be built up as the recrystallization went on and all transfer of substance would be from the inclusion, to the lava. In short, subtractive processes would be dominant. On the basis of texture and composition these rocks might well be called micro-quartz-hornfels.

In support of the above hypothesis is the occurrence of microscopic areas of similar nature within the argillites (see plate 2). Here circular patches of clear mosaic quartz containing feldspar porphyroblasts may be seen within the dark carbonaceous groundmass of these shaley rocks. The peripheries of these areas are marked by black rims representing a concentration of carbonaceous material. The interpretation being that here, in the argillites, the same process of hornfelsation has been going on that went on to a greater degree, and at a much higher rate in the "cherts" of the volcanics. Through a rapid transfer of heat energy at high temperatures, recrystallization was able to proceed more rapidly and with greater completeness within the included material in the lavas than was possible under the type of metamorphism which the argilites were subjected to.

MICROSCOPIC DESCRIPTIONS OF THE VOLCANICS.

An average representative thin section of the flow shows a medium grained intergranular texture consisting of kaolinized plagioclase, intergranular pigeonite a little euhedral magnetite, and abundant chlorite. The most outstanding microscopic feature of all phases of the flow is the high degree of mineral alteration as practically all of the primary minerals are affected by either deuteric or katamorphic action. This high degree of alteration greatly handicaps accurate mineral determinations. As closely as could be determined by extinction angles and indices the plagioclase was found to be sodic andesine. The crystals are lathlike to blocky euhedral in form, but are usually seen only as an outline of kaolin or sericite, or sericite and calcite. The pigeonite is sub to anhedral in character and possesses a 2V that is very close to 0°.

Three distinctive textures have been developed within the flow. The chilled margins are represented by needle-like plagioclase laths set in a dark brown glassy mesostasis. The central zone may exhibit a holocrystaline arrangement of blocky plagioclase, partially enclosed in subhedral pigeonite. Both euhedral pigeonite and euhedral plagioclase are locally present. The intermediate phase which makes up the greater part of the flow and ordinarily occupies the position occupied by the coarser phase is an intergranular relationship of plagioclase laths and granular pigeonite. There is in the flow a complete gradation from the finest texture to the coarsest.

The glassy zone is only a few inches in width and is found both at the boundaries of the flow and on the peripheries of the pillows. A glass, dark brown from included iron oxide, acts as the matrix for needle-like crystals of andesine. These plagioclase crystals may be divided at their ends with the slender projections representing individual twins. Alteration of these plagioclase crystals to kaolin and to sericite is general. At the extreme periphery of the glassy border, the glass is altered to green chloritic mineral, chlorophaeite. (See plate 3) This peculiar alteration product of basic glass is represented under "Megascopic Descriptions of the Volcanic Rocks". The chorophaeite ranges from green to brown in color and its spherulitic character is characterized by dark brown curved lines greatly resembling fingerprints. Minute spherulites composed of a highly altered murky substance are common to the chorophaeite. These features of altered basic glass have been well described by Fuller[7] and are accredited to quick chilling under water. The presence of calcite- and zeolite-filled vessicles is also common. The zeolites which also appear as veinlets in the optalically altered sedimentary rocks have a fibrous form, with a positive elongation and an extinction with the cleavage traces of twenty degrees. Veinlets of calcite cross-cut all of the minerals. Common pale green fibrous chlorite is abundant and may appear in the form of spherulitic aggregates.

The more abundant aphanitic to fine grained phase shows relatively fresh augite in contrast to the highly altered plagioclase. The pigeonite is sub to anhedral and is colorless under plain light. The plagioclase (sodic-andesine) is almost completely masked by kaolin. The boundaries of the crystals are relatively fresh with the alteration being more or less confined to the central portions of the crystal. The intensification of alteration toward the crystal centers may be ascribed to crystallographic control exerted by cleavage in planes. Evidence for this statement may be seen in plate where alteration of the feldspar is advancing along cleavage planes. (See plate 4) A suggestion of zoning in some of the larger crystals indicates the possibility that a variation in chemical composition might favor selective alteration. Fracture planes (off-setting of twinning) have also had a part in alteration control. In some crystals the early stages of alteration are present with fine hairlike growths of kaolin extending from completely altered regions which are completely opaque.

Hyperthene is present in some sections, and evidence for its former presence may be seen in all sections. This evidence is in the form of psuedomorphs of bastite which still retain traces of the schiller structure of the orthorhombic pyroxene. An occasional partially altered crystal of hyperesthene is seen. The bastite is coarsely fibrous and exhibits radial fibrous growth both under plane and polarized light.

Abundant chlorite is formed throughout the rock and probably makes up a fourth of the mass. Both early and late magnetite is found and is in part altered to hematite and limonite with the alteration staining the adjoining plagioclase.

The coarse grained phase shows in part a sub-ophitic texture. The pigeonite appears as large crystals partly enclosing the plagioclase. The plagioclase may be both subhedral and euhedral. Psuedomorphs of bastite (after hypersthene) make up perhaps 15% of the rock. Skeletal crystals of ilmenite and crichtonite (5%) altered to leucoxene represent the spinels. (See plate 3) The crichtonite was recognized by a faint lavender tinge visible in some of the leucoxene. Kaolinization and chloritization has gone on here to as great a degree as it has in the finer grained varieties. The production of sericite and secondary calcite is not as abundant, however. Quartz derived from the breakdown of the feldspar is minor in amount having apparently been removed by solution. Zeolites were not discovered in this phase.

On the presence of hypersthene and andesine plagioclase this volcanic flow can be called a hypersthene-andesite.

CONCLUSIONS.

The writer of this paper believes that the presence of this volcanic flow within a sedimentary sequence which is lithologically the same both above and below the flow, represents no break in sedimentation that might be caused by diastrophic movements. The presence of well formed pillow and the inclusion of limy and silicious material between the pillows indicates that the flow was erupted upon a sea floor where sandstones and shales were locally accumulating. Variation in thickness of the flow can be accounted for by filling of depressions on the sea floor and by local piling up of the lavas. It is highly probable that the lavas were in part cooled under a cover of unconsolidated sediments. The thickness of this cover is problematical. There may have been actual intrusion into the partially consolidated sediments or merely a scooping or ploughing with consequent overriding of the muds and sands of the sea floor.

The actual depth of aqueous cover is also problematical. The lack of fossils and the absence of conglomerates does not necessarily indicate great depths.

Evidence for submarine origin of lava.

1. Presence of pillow structures.

2. Presence of limy material between the pillows. Locally this material appears to be actively injected between the pillows and may be locally traced by the presence of flow structure to the beds beneath.

3. Presence of sharks teeth within similar lavas of adjacent areas.

4. The higher degree of chloritization, sericitization and production of calcite within the sediments that lie above the flow than appears in the sediments that lie below. This would be difficult to explain unless extrusion under water with at least a thin cover of sediment was postulated.

5. Presence of chlorophaeite, representing an alteration product of aqueous chilled volcanic glass.

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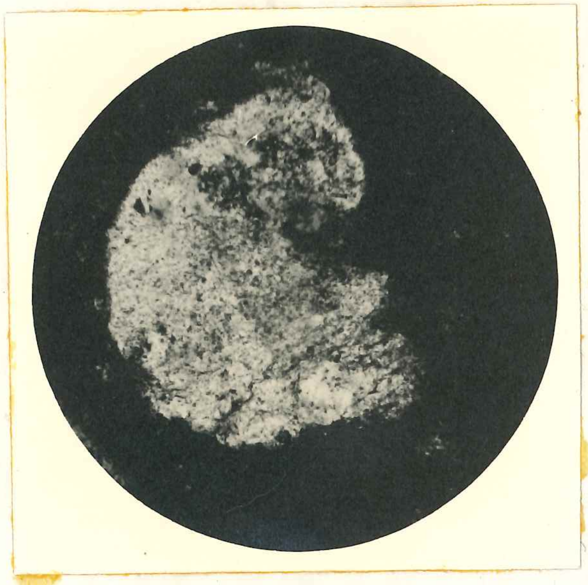
The alteration is in part deuteric, in part katamorphic from weathering and in part optalic.

PLATE I

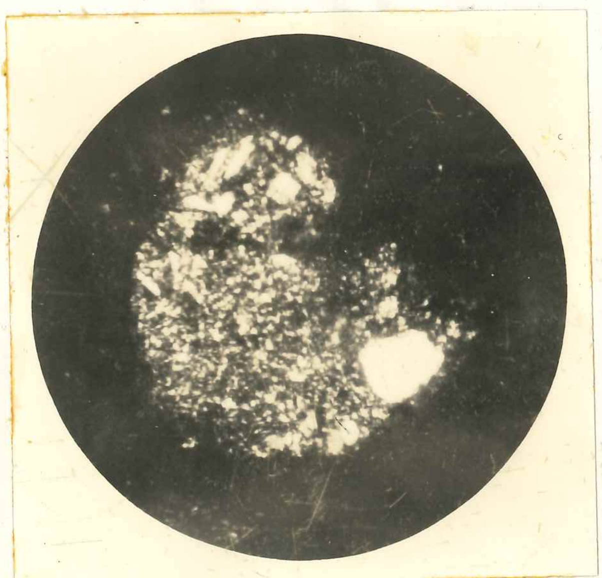
Porphyroblasts in "chert"
High power - crossed nicols

Porphyroblasts in "chert"
Plane light - high power

PLATE II

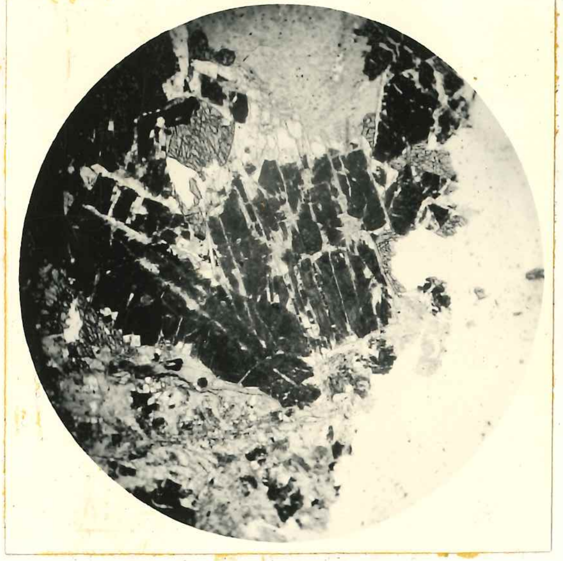


Cleared zone in argillite
Plane light - medium power

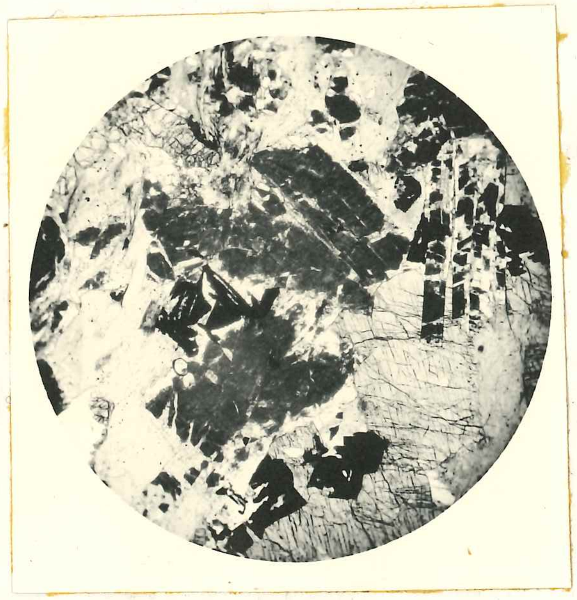


Polarized light showing
incipient porphyroblast.

PLATE IV



Plagioclase altering to kaolin
Medium power - plane light



Plagioclase altering to kaolin
(Note cleavage control)
Low power - plane light

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