THE GEOLOGY
OF THE
INDIN "BREAK" N.W.T

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ABSTRACT

This thesis presents the results of a general geological study of a belt of Archean rocks in the Indin Lake district, N.W.T. The summary results of a summer's field work are incorporated with a brief petrographical investigation of different rock types.

Intermediate to acidic lava flows and pyroclastic rocks overlain conformably (?) by a succession of clastic sediments are invaded by minor acidic intrusives and a plexus of basic dykes and sills. Isoclinal folds in sediments, broader flexures in volcanics, bedded shear zones, and regional foliation and lineation are all attributed to a single system of powerful tangetial forces that affected all stratiform rocks in the area. Zones of weakness at contacts are imputed to differential competence between volcanic and sedimentary rocks, and a theory of folding of rock units of differing competency is applied in modified form to the origin of the Indin "break" - a gold-bearing shear zone close to a major contact. Evidence is presented to suggest that "cross-faults" - clean-cut dislocations that transect the regional structural trend - and emplacement of late basic intrusives are quasi-contemporaneous events that progressed over a protracted interval of time and may have been consequent upon a single deformational pattern. An attempt to explain the propinquity, and thus the possible structural relation, of gold mineralization to cross-faults is embodied in a theory relating the control of mineralization to channeling of ore-solutions in structures developed during the period of strain accumulation that culminated in cross-faulting. An almost completely reconstituted mineral assemblage is ascribed to a moderate grade of regional metamorphism consisting of dynamic metamorphism during orogeny and relatively minor effects of superimposed thermal and retrograde metamorphism. Metacrysts of ankeritic carbonate, believed to be hydrothermal, are discussed, and their superficial genetic or structural association with gold mineralization is offered as a possible guide to future ore discovery.

Rather detailed descriptions are submitted of ankeritic carbonate, an unusual "hornblende" occurring in amphibolite, and a green mica, tentatively called phengitic-muscovite, from a carbonate zone.

ACKNOWLEDGMENTS

The writer is greatly obligated to Trans American Mining Corporation for providing liberal access to maps and aerial photographs, and in particular to Dr. A.P. Beavan of that company who guided the writer in his field work and contributed valuable information pertaining to drilling results and other geological aspects of the area.

Special indebtedness is owing Dr. H.C. Gunning, of the Department of Geology and Geography, who gave a comprehensive outline of the problem, directed and assisted with laboratory investigations, and offered constructive criticism of the preliminary manuscript. Great thanks are also owing Dr. K. DeP. Watson who kindly supplied helpful information and literature relating to the many petrographical problems encountered by the writer.

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Figure 1 Sketch Map Showing Location of Indin Lake

Figure 2 Generalized Geological Map of Indin Lake District

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Geological Map

INDIN LAKE AREA
GEOLOGICAL MAP
APPROXIMATE SCALE - 1in = 1800 ft (air photo base)
LEGEND
Diabase
Diorite and Gabbro
Metadiorite
Altered Basic Dykes
Sediments - Greywacke, Slate, etc.
Sediments - Quartzite, Arkose etc.
Rhyolite, Porphyritic "Rhyolite", Breccia
Quartz-Feldspar Porphyry, Rhyolite, etc.
Andesite, Dacite, Agglomerate Tuff
Altered Rocks, Amphibolite etc.
Rock Cleavage
Bedding - Dip : Top
Fold Axes - Anticline : Syncline
Surface Elongation of Fragments
Fault - Determined : Assumed
Contact - Traced : Probable
Contact - Assumed
Surface Trenching
Gold Occurrence
Quartzite and Arkose Prominent
Biotitic Zone
Pillow Structure
LONG LAKE
PISTOL LAKE
LEX BAY
FLOAT LAKE
INDIN LAKE
JOHNSON ISLAND

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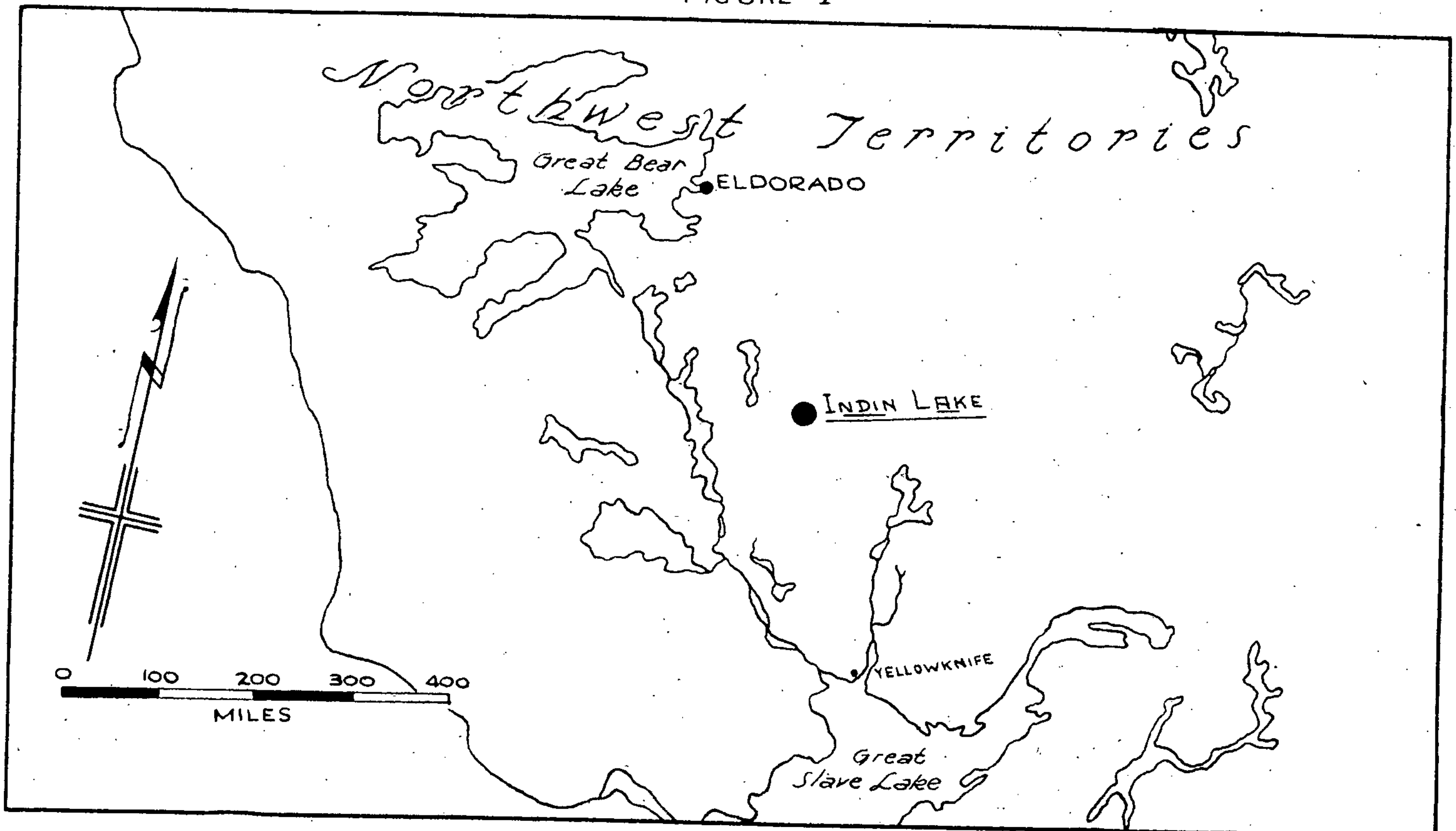
INTRODUCTION

GENERAL STATEMENT

The Indin Lake gold-bearing area, about 125 miles north of Yellowknife, N.W.T., is in the southeast corner of the Ingray Lake Map-Area. The location and regional geological picture, summarized on figs. 1 and 2, can be found on Map 697 A, Ingray Lake, District of MacKenzie, N.W.T., of the Geological Survey of Canada. Prospecting and exploration have been widespread in the area since the first gold discovery in the summer of 1938. No major gold production has ensued, but recent diamond-drilling and underground work by mining companies active in the area have developed several promising gold deposits, and the district currently attracts considerable attention as a potential gold-mining camp.

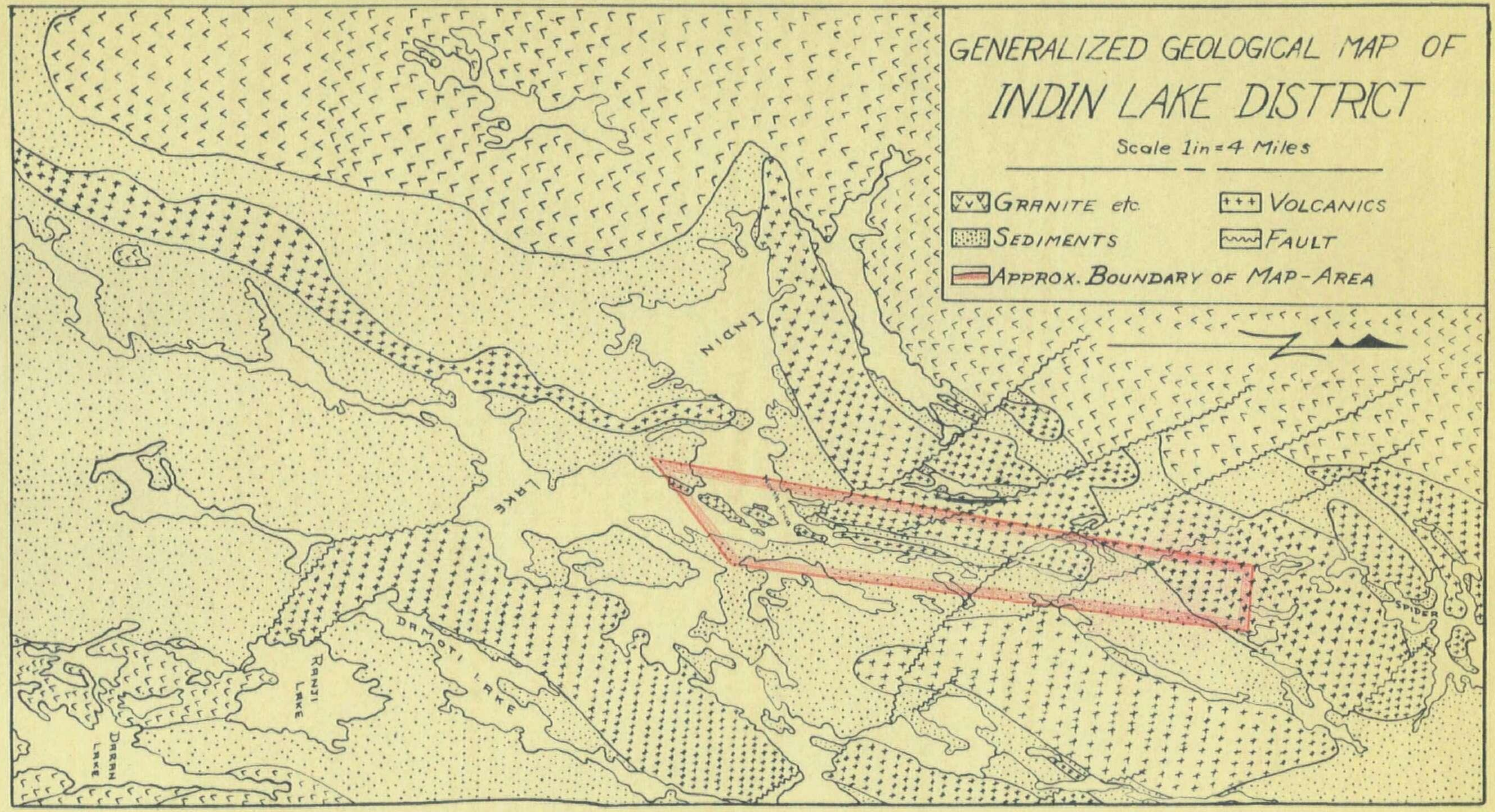
Initial geological mapping of the area was conducted by Wilson and Lord in 1939 and 1940, and the results of their work appear in Geological Survey of Canada Memoir 235, and Map 697 A, which covers the Ingray Lake Map-Area. The Indin Lake section was re-examined in greater detail by the Geological Survey during the summers of 1946 and 1947, but at the time of writing the results of this work have not been

FIGURE 1



SKETCH MAP SHOWING LOCATION OF INDIN LAKE

FIGURE 2


GENERALIZED GEOLOGICAL MAP OF
INDIN LAKE DISTRICT
Scale 1in=4 Miles
GRANITE etc.
VOLCANICS
SEDIMENTS
FAULT
APPROX. BOUNDARY OF MAP-AREA
INDIN
LAKE
DAMOTI LAKE
RANJI LAKE
DARRAN LAKE
SPIDER L.

published.

During the field season of 1947 the writer was employed by Trans American Mining Corporation in the Indin Lake district, and carried out geological mapping in the interests of that company. Information gathered in the field, together with the results of a brief laboratory study of the rocks, form the basis of this thesis. The laboratory work is designed to supply additional, but by no means exhaustive, information on the main rock types in the area. Results are almost wholly those of the writer, but some information was drawn from the scant literature available on the area when dealing with problems of a regional nature. In addition, the geology on Inca Peninsula and parts of Johnson and Tartan islands was previously mapped by Trans American and only partially re-examined by the writer.

The geology on the accompanying map embraces a strip of country about 15 miles long from south to north and 2 to 3 miles wide from west to east. The map-area, which straddles a major contact between sedimentary and volcanic rocks, extends from south of Johnson Island in Indin Lake to a point about 10 miles north of Lex Bay. The southern portion includes the gold properties of Lexindin Gold Mines, Diversified Mining Interests, and North Inca Gold Mines. Development of the latter property is in the hands of Trans American Mining Corporation.

DESCRIPTION OF THE AREA

The area is serviced from Yellowknife, 125 miles to the south, by aeroplanes operating on floats in summer and skis or wheels in winter. A projected air-strip will, when completed, provide year-round landing facilities for aircraft on wheels. Indin Lake may also be reached by canoe, via Russell Lake and Snare River, but the trip is long and arduous, with numerous portages; so that aircraft is the usual means of entering the area.

The topography reflects the general character of the underlying rocks. Sediments occupy low, featureless areas with gently rounded hills, while volcanics usually outcrop as relatively high ridges paralleling the north-south structure and rising 200 feet or more above adjacent lakes. Many sediment-volcanic contacts are marked by an abrupt scarp visible on aerial photographs. Drift-filled depressions, parallel and transverse to the north-south structural trend, are occupied by faults, shear zones, or basic dykes and sills. In the northern part of the area topographic expression of bedrock geology is masked considerably by widespread deposits of glacial debris.

Rock exposure is good in the southern part of the area, but is undesirably scarce in the central and northern parts. In many areas it is limited to broken rubble or scattered frost-heaves and outcrops of volcanics so small and discontinuous as to be improbably representative of the entire volcanic assemblage.

Indin Lake is the largest body of water, and no major rivers cross the map-area. Chains of small lakes drain southward into Indin Lake through a series of small streams connecting adjacent lakes. Although close to the western fringe of the barrenlands the area is well-wooded with stunted spruce and birch up to 12" in diameter. Small, isolated stands of good timber, up to 2' or more in diameter, occur along some of the stream beds. Caribou are plentiful in the spring and fall, and most of the lakes are well-stocked with fish.

OBJECT OF THE FIELD WORK

The main orebodies of Lexindin, Diversified and North Inca lie, in that order from north to south, along a "shear-zone" in sediments close to a major contact with volcanics. What is presumably the southerly extension of the same structure was cut in a drill-hole off the north end of Johnson Island, giving an over-all possible length of approximately 12,000 ft to the structure. The "shear-zone" is termed locally the Indin "break", and has been regarded by some as a major crustal dislocation. Map 697 A shows a fault, stated to have been traced for 46 miles (Lord, 1942, p. 43), that roughly coincides with the Indin "break". This, of course, suggests that the orebodies lie in, or are closely associated with, a major north-south trending fault. Conditions are complicated by well-established, northwest-striking "cross-faults", and the presence, at North Inca, of at least one high-grade orebody, in volcanics rather than sediments, and conceivably related to "cross-faulting". However, as the Indin "break", whatever its origin, is apparently the main structural control of most of the ore deposits, a clear understanding of its nature is of vital importance as an aid in developing known orebodies and in the search for new deposits. Accordingly, a program of geological mapping was initiated involving the coverage of a section along the assumed main "break". Emphasis was placed on structure, but the areal distribution and relationships of associated rocks were considered in some detail.

FIELD METHODS

Geological observations were recorded directly on aerial photographs having a scale of 400 feet to 1 inch. These were enlargements of original Royal Canadian Airforce photos flown at approximately 1800 feet to 1 inch. Two methods were employed to locate ground points on the photographs:

(1) Recognition of ground topographic features on the photos.

(2) Use of base-lines tied to recognizable ground features on the photos.

The first method was used whenever possible as it is quick and accurate, and consists merely of correlating prominent ground features, such as outcrops and lake-margins, with their positions on the photo. Because enlargements tend to be hazy it proved helpful to carry the originals into the field to assist in location. A point located on the original is readily transferred to the enlargement. In addition, original photographs with considerable overlap provide a ready means of obtaining the third dimension, which facilitates the location of ground points in areas of much relief. Three dimensions may be readily obtained from duplicate photos, without resorting to the stereoscope, once the technique has been mastered. In areas of heavy bush or overburden base-lines were cut and tied to points recognizable on the aerial photographs. Such lines, when plotted accurately, assist materially in locating outcrops on the photographs.

So far as possible, outcrop boundaries were delineated, but areas of numerous small outcrops were depicted as a single exposure. Observations on contacts, attitudes of bedding and cleavage, quartz-veining etc., were recorded directly on the aerial photographs. Information on the photographs was assembled on a 400-scale outcrop map embracing the section from the southern boundary of the area to Negus Lake. The outline map and geology were traced directly from the photographs. Noteworthy here is the slight decrease of scale on photos from centre to margin and the desirability of providing considerable overlap between adjacent photos and confining mapping to the central portion of each photo where distortion is a minimum.

The accompanying map of the entire area is a compilation of field data on a scale of about 1800 feet to 1 inch, or more exactly, on the scale of the original photographs. Individual outcrops are not shown, minor details are eliminated, and some inferences have been made to complete the structural and lithological picture.

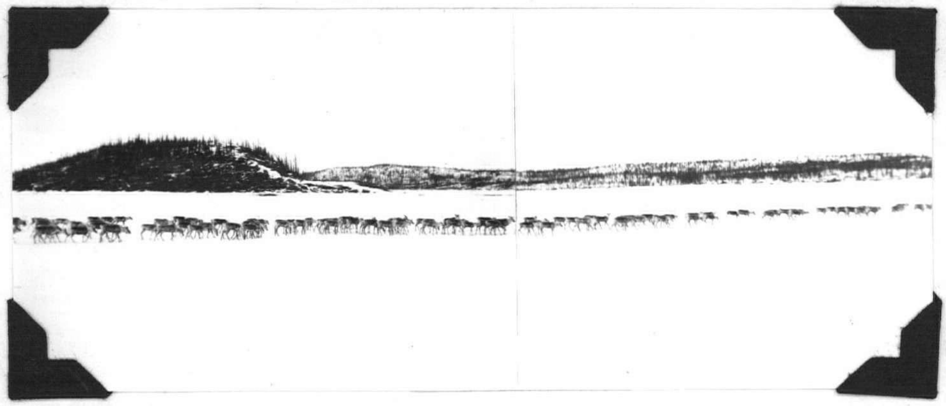


Fig. 3 Caribou herd between Tartan Island and Inca Peninsula (May 1947). Inca Peninsula on left, with Brown veins on extreme point. The Inca fault passes immediately south of the point.

Fig. 4 Aircraft on wheels at North Inca. Last aircraft to land on wheels on the ice at Indin Lake was on June 7,(1947).

Fig. 5 The first aircraft on floats, June 18, 1947, landing at Lexindin camp.

Fig. 6 View looking east across Lex Bay. Diversified camp on right.

Fig. 7 Diversified Mining Interests, headframe and camp, Indin Lake, N.W.T.

Fig. 8 View, looking north from Tartan Island, of Inca Peninsula. North Inca headframe on point. Brown veins on left of headframe and main ore zone (Indin "break") under water on right. Inca fault passes south of point, trending northwest.

Fig. 9 North Inca camp on Inca Peninsula. Rocks in background are volcanics, contact with sediments (and the Indin "break") under water in the foreground. Picture looking west.

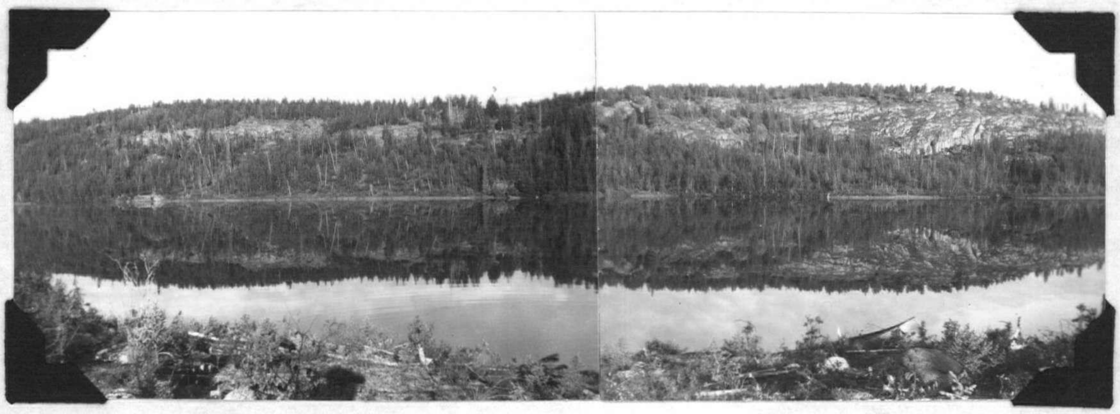


Fig. 10 Looking west across the northern end of Cranston Lake. Foreground in sediments; relatively high, north-south trending ridge in background typical of much of the volcanic terrain. Contact under the lake close to the western shore.

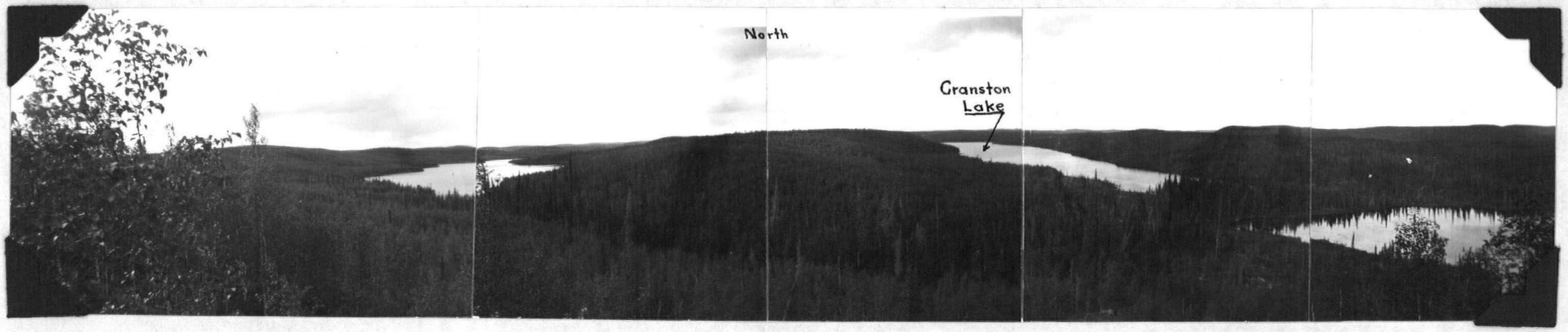


Fig. 11 Panorama, looking north, of the area around Cranston Lake. Sediments on extreme right; volcanics central; sediments underlie much of lake on the left; and volcanics on extreme right. Lineation in foreground marks the locus of a "cross-fault".

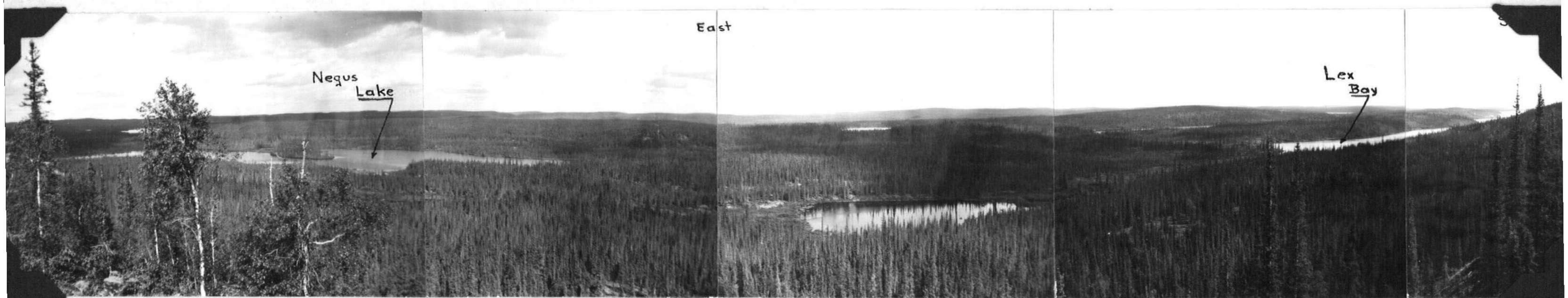


Fig. 12 Panorama of area north of Lex Bay; Indin Lake on the extreme left. Water in foreground marks approximate volcanic-sediment contact (and probable locus of Indin "break". Volcanics in foreground and sediments background.

GENERAL GEOLOGY

SUMMARY

The area is underlain by Precambrian rocks of the Archean Yellowknife group. A heterogeneous volcanic assemblage of andesite, dacite, rhyolite, pyroclastics and altered rocks are overlain conformably (?) by a monotonous succession of clastic sediments comprised mainly of interbedded greywacke, slate and impure quartzite. Volcanics and sediments are locally intercalated at contacts. One band of predominantly coarse-grained sediments may be older than some of the volcanics. Volcanic terrain includes some acid porphyry and dioritic rock probably, in part, intrusive. Volcanic and sedimentary rocks have been intruded by acidic to basic dykes and sills of several ages, including fresh diabase dykes of possible Proterozoic age. Granitic intrusives, which surround the region, are not exposed in the map-area.

Rocks of the Yellowknife group have been disrupted by intense folding and faulting, and have been subjected to a moderate degree of metamorphism. Intense folding, reflecting crustal adjustments to great lateral stresses, may have culminated in the development of shear-zones in incompetent rocks, with possible attendant thrust-faulting along some of the shears. Folding was succeeded by at least one period of major faulting accompanied by the formation of small, steeply-plunging drag-folds. Faulting probably extended over a long time, and was quasi-contemporaneous with intrusions of basic dykes. Dynamic metamorphism accompanying folding, with relatively minor effects of superimposed thermal and retrograde metamorphism, have modified or obliterated primary structures and reconstituted most rocks to an assemblage of new minerals.

No record exists for the deposition of Paleozoic or Mesozoic strata, and since Precambrian time the history of the area may have been one of erosion down to the present level, with slight modifications attributable to the Pleistocene period of glaciation.

TABLE OF FORMATIONS

Intrusive Rocks:	Diabase dykes Diorite and gabbro dykes and sills "Metadiorite" Altered dykes (carbonate and chlorite) Acidic dykes and sills "Bird-Porphyry" and similar rocks.
Sedimentary Rocks:	Greywacke, slate, arkose, quartzite Graphitic slate, slaty greywacke Tuffaceous sediments.
Volcanic Rocks:	Agglomerate and tuff Rhyolite, porphyritic rhyolite, rhyolite breccia Quartz-feldspar porphyry Dacite, porphyritic dacite, fragmental dacite Andesite-massive, fragmental, pillowed, amygdaloidal Amphibolite Carbonate, sericite, and chlorite schists

The units listed in the foregoing table do not necessarily read in the correct age sequence. Too much remains to be learned about the structural set-up and age relationships to permit such a tabulation.

VOLCANIC ROCKS

Problem of the Volcanic Rocks

Volcanic rocks proved difficult to deal with in the field as regards both structural relationships and petrographic classification, and microscopic study does little towards solving the problem. To begin with, rocks in the area have been subjected to great deformation and intense alteration. Volcanic rocks proved particularly susceptible to alteration, and, in many places, have been converted to sericite, carbonate, and chlorite schists to which it is impossible to assign any precise original composition. Relatively fresh-looking specimens show an almost completely reconstituted mineral assemblage that is strikingly similar in many apparently dissimilar rock types in the field. Primary minerals, with the exception of quartz, are rare or entirely lacking. Feldspar can seldom be positively identified - if so it is usually a sodic-variety - and ferromagnesian minerals have been largely converted to chlorite.

Another problem is the separation of intrusive from extrusive. Certain dioritic intrusives closely resemble some facies of massive, recrystallized andesite, and much rock classed as porphyritic rhyolite is very similar to bodies of quartz-feldspar porphyry believed to be, in part, intrusive.

In addition, structural criteria in volcanics are rare and unreliable. Definite horizons can seldom be traced with any degree of certainty beyond a single outcrop, and primary flow structures are either obliterated or so highly deformed as to require cautious interpretation as structural indicators.

Flow rocks were named in the field mainly on the basis of color and quartz content. Typical basaltic lavas were not encountered in the map-area, so that flows range from andesite to rhyolite; the former dark green and quartz-free, the latter light shades of cream or grey and quartz-rich. Intermediate facies are dacites with light-green or grey color and aphanitic or porphyritic texture. Pyroclastics are agglomerates if fragments are numerous and over one inch and tuffs if fragments are less than one inch. However, one aggravating feature of all the volcanic rocks is their imperceptible gradation from one type to another, and since divisions are arbitrary to begin with, it is impossible in practice to adhere to any rigid system of classification. Such rocks can only be described, and grouped as large units for mapping purposes until they are studied in much greater detail.

The writer does not propose to enter into any detailed descriptive or petrographic discussion of rock types. Innumerable accounts of similar rocks appear in the literature, and an exhaustive treatise here would be largely repetition and of doubtful merit in connection with the present problem. Moreover, a complete petrographic study to be of any value would demand consideration of many more than the few typical rock types chosen by the writer for microscopic study.

Description of Volcanic Rocks:

Volcanic rocks are a heterogeneous assemblage of flows, pyroclastics, and altered equivalents. At one place or another most types of volcanics can be seen to grade along or across the strike into another type of the assemblage. Various members of the volcanic pile convey the impression of being lenticular and discontinuous, as if no particular horizon had spread over a wide area of the volcanic field. Save for one band of "rhyolite" that may be intrusive, not a single marker horizon was traced more than a few thousand feet.

Andesites are brown to green weathering, aphanitic to finely crystalline rocks. They are light to dark green or almost black on the fresh surface,and frequently streaked with elongate patches of chloritic material darker than the main rock mass. Well-formed pillows are locally abundant, and amygdules are widespread but seldom restricted to any particular horizon in a flow. Pillows have their long axes parallel with the foliation and average 2 to 5 feet,although "mattress" pillows up to 16 feet long are locally developed. The present pillow alignment and accentuated elongation may be due as much to deformational stresses as to original attitude in the approximate plane of the flow. Largest pillows are noticeably restricted to the more basic andesites. Pillows frequently exhibit a fine-grained, brown to black weathering, peripheral selvage 1/4 to 1 inch wide. Inter-pillow fillings are of the same composition as the pillows. Amygdules show no consistent pattern within pillows and may occur in greatest abundance at the periphery, at the core, or towards the top of individual pillows. Amygdaloidal fillings are chiefly carbonate and quartz with lesser amounts of chlorite, epidote or clinozoisite, and hematite. Where carbonate amygdules are abundant the rock weathers with a pitted surface. Andesites are infrequently fragmental; if so fragments are of about the same composition as the main rock mass and the rock is presumably a flow-breccia.

Andesites are composed almost entirely of secondary minerals. Chlorite is the most abundant colored mineral-present in felted aggregates, irregular flakes and minute, prismatic grains. It exhibits anomalous "Berlin-Blue" and peculiar, dirty-greenish, interference colors. Carbonate is plentiful along with varying amounts of green amphibole, epidote, clinozoisite, biotite, and quartz. Original feldspars are occasionally evident, but are so highly shot with inclusions of other minerals that their determination is impossible. Numerous very small, clear grains are probably quartz and albite, but the relative abundance of the two minerals has not been determined. Where biotite is present it is always in close association with chlorite. Most minerals show ragged outlines and numerous inclusions of other minerals. Highly chloritic andesites grade into rocks with considerable amounts of fibrous amphibole. These rocks are classed as amphibolites and are developed mainly in the northern part of the map-area. They may be recrystallized portions of thick flows but, as already stated, are difficult to separate from some intrusive, dioritic rocks. In the field they are massive to schistose, dark green rocks with a green or brown weathered surface. A section from a typical specimen reveals a rock composed of about 60 percent amphibole and the remainder quartz, epidote, altered feldspar, carbonate, magnetite, and biotite. The amphibole is in fibrous aggregates and idioblastic crystals with local sieve structure. It is very strongly pleochroic with absorption $Y > Z > X$. The pleochroic scheme is:

X - pale yellow

Y - deep olive-green

Z - blue or greenish-blue

Individual grains show variations in color but no corresponding variations in optic properties. The interference figure is biaxial negative and 2V = 45° . Elongate grains are length-slow; the optic plane is parallel with 010; and the angle Z∧c is approximately 17°. The mean refractive index (β) is about 1.67. The amphibole resembles common hornblende in some respects but has a smaller extinction angle, smaller optic angle, and different pleochroism. Undoubtedly, the proportions of the various oxides in the hornblende molecule effect its optic properties, and the writer hoped to estimate the composition of the hornblende using the foregoing optic data. However, no suitable diagram was found for estimating the composition from the optic properties obtained for this particular hornblende, and a cursory review of writings by Deer (1938), MacCarthy (1926), Graham (1926), Billings (1928), and Winchell (1924) leads the writer to conclude that no satisfactory relations between optic properties and chemical composition of hornblende have been established. These writers mention such factors as Fe_2O_3-FeO ratio, MgO-FeO ratio Al_2O_3-SiO_2 ratio, total iron tenor, and valence state of titanium as affecting optic properties of hornblende, but show no general agreement as to how these effects are manifest in the optic properties. They make no mention that soda content has any influence on optic properties; an idea entertained by the writer as a possible explanation of the unusual blue pleochroism of his hornblende. Rice (1935) and Hutton (1938) describe amphiboles with, for the most part, optic properties similar to the amphibole described here. Rice believes his is an uncommon type of hornblende and Hutton styles his an actinolitic amphibole and shows, by chemical analysis, that the formula is nearly that of tremolite. Both amphiboles are high in iron but the ratios Fe_2O_3-FeO do not correspond. The writer concludes that his amphibole is probably a variety of highly ferruginous hornblende with unusual optic properties attributable to abnormal proportions of constituent oxides, but before pursuing the subject any further it would be desirable to obtain a complete analysis and carry out a more exhaustive optical examination of the mineral.

Dacites are porphyritic to aphanitic, streaked rocks that weather pale-green to grey with lighter-colored streaks and patches. On the weathered surface they may show white feldspar phenocrysts that usually disappear on the fresh fracture. They locally exhibit pillows and scattered amygdules of quartz and carbonate. Dacites are frequently fragmental and grade in this direction to rocks classed as agglomerate. Where undeformed, fragments are round to angular and average 3 or 4 inches. They are occasionally of the same composition as the main rock mass, but more often are light, cream-weathering lenses of felsitic material usually resembling common facies of rhyolite in the area, and occasionally amygdaloidal or containing prominent quartz phenocrysts. Undoubtedly, some of these fragmental rocks were produced by brecciation during the advance of the flow, but the majority of fragments, quite foreign to the matrix, must have been introduced by some means during vulcanism. The uniform size and distribution of fragments through large volumes of lava seems difficult to explain.

Most dacites are so fine-grained that few minerals are recognizable under the microscope. They are strongly foliated, with abundant lenses and streaks of a white, opaque material and long, narrow shreds of pleochroic chlorite parallel to foliation. The siliceous-looking matrix shows zones of differing grain-size that may be a reflection of primary flow-banding. Most sections show abundant carbonate and some biotite and small flakes of sericite. A porphyritic specimen shows numerous grains of sodic albite having a preferred orientation. Round to elliptical amygdules, which deflect planes of foliation, are filled with quartz, chlorite, carbonate, biotite, and clinozoisite. One section reveals small, amygdaloidal fragments with a cloudy "reaction-rim"; amygdules are round or elliptical (plate 1), some show concentric banding of minerals or dusty inclusions, and are filled with quartz, carbonate, clinozoisite, and a mineral with grid-twinning, low relief, and low birefringence. Carbonate appears as metacrysts in one aphanitic specimen, (plate 2). Metacrysts contain numerous small inclusions, and some have remarkably sharp boundaries. They tend to be concentrated somewhat along lines parallel to the foliation and, although they show some evidence that their orientation was influenced by the direction of foliation, they obviously

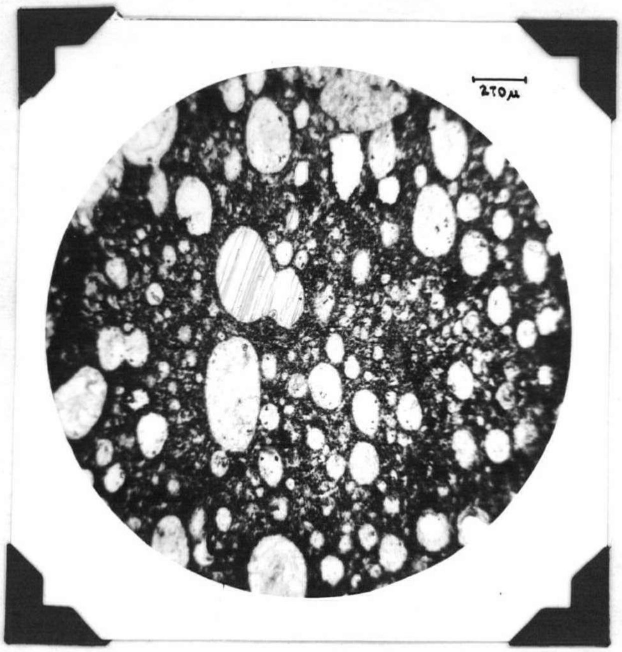


Plate 1: Part of an amygdaloidal fragment in dacite flow. Note elongation of amygdules with the foliation (vertical) in main rock mass.

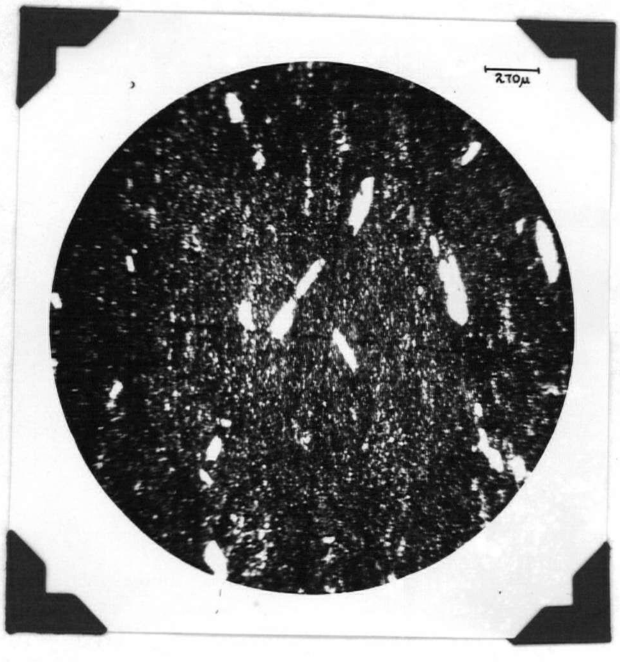


Plate 2: Elongate carbonate metacrysts (white) in fine-grained dacite flow. Foliation vertical. Note apparent controlled orientation of metacrysts by foliation. Crossed nicols.

grew after relaxation of the stresses that developed the foliation.

Acidic volcanics vary from aphanitic to highly porphyritic and from massive to intensely sheared. They weather light shades of yellow, cream, buff, grey and green, and to a minor extent dark green to almost black. Darker varieties resemble some dacites and andesites, but can usually be distinguished by the presence of prominent quartz "eyes". Dense, cherty, aphanitic varieties were termed rhyolite in the field to distinguish them from highly porphyritic types classed as quartz-porphyry; but the division of many intermediate facies is purely arbitrary. Rhyolites locally show primary flow structures in the form of brecciation, amygdules, and sinuous, discontinuous flow-layers. Much rhyolite is fragmental and grades into rocks composed almost entirely of fragments. Fragments are rounded to sharply angular, felsitic to porphyritic, and usually of about the same composition as the matrix. In one place flow-layers were observed to curve around fragments. Porphyritic rocks tend to break to a darker shade of the same color as the weathered surface. Visible phenocrysts are usually rounded quartz "eyes" up to 1/4 inch and averaging 2 mm., but locally grey, fractured feldspars are conspicuous on the weathered-surface.

All acidic volcanics studied under the microscope are porphyritic, including varieties that appear aphanitic in the hand specimen. Feldspar phenocrysts predominate in the fine-grained ones, but in coarser facies quartz becomes abundant until phenocrysts constitute over 20 percent of the rock (plates 3 and 4). Feldspar phenocrysts are stubby, unzoned, euhedral to subhedral crystals of coarsely-twinned albite charged with small inclusions of sericite. Quartz phenocrysts are rounded to irregular grains with local embayments and inclusions of the matrix. Some of them are fractured, and they usually show undulatory extinction. The matrix is fine-grained, allotriomorphic, quartz and feldspar impregnated with sericitic mica. Sericite shows strong directive orientation, except when deflected by phenocrysts, and constitutes up to nearly half of the matrix. The matrix of some specimens exhibits, in addition, irregular patches of green chlorite that imparts the dark green color to the rock in the field. Carbonate, as anhedral patches and euhedral rhombs, has an exceptionally high relief and well-developed cleavage. Some euhedral crystals, or metacrysts, show a brown alteration around margins of crystals and working along cleavage cracks (plate 15). The largest metacrysts have developed in the matrix but some small, perfectly euhedral rhombs were observed within feldspar phenocrysts.

The foregoing acid rocks have been described under the head of volcanics, but the writer is not convinced they are all extrusive. Contacts are usually sheared or under overburden so that field relations are obscure and inconclusive. Coarsely porphyritic phases are locally less foliated than

Plate 3: Porphyritic Rhyolite flow or quartz-feldspar porphyry intrusive. Phenocrysts are albite and quartz (q) in a fine-grained, holocrystalline matrix of quartz and feldspar. Crossed nicols.

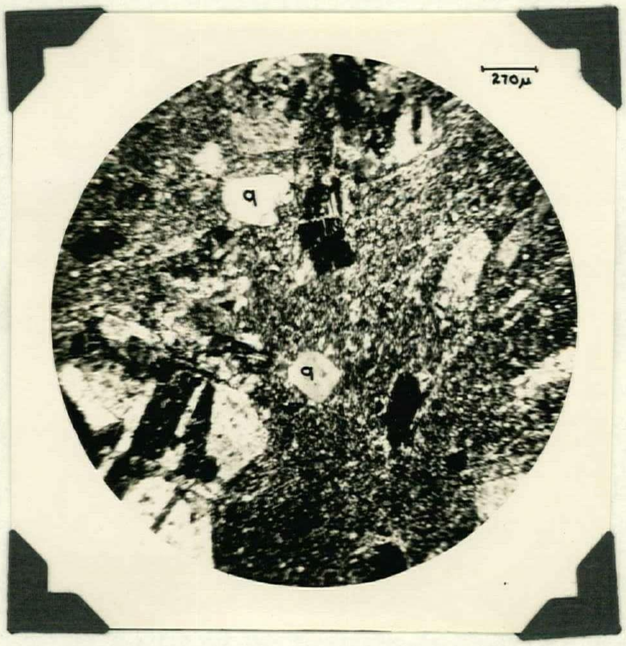


Plate 4: Porphyritic rhyolite. Quartz (q) and albite phenocrysts in a fine-grained, highly-sericitic matrix. Note round shape of quartz phenocrysts. Crossed nicols.

aphanitic varieties but, in general, all have been subjected to the same degree of metamorphism. All of these rocks studied under the microscope are composed of the same essential minerals, and textural differences could be attributed to rate of cooling as a function of, say, thickness of flows or crystallization at depth or on the surface. Briefly, coarsely porphyritic facies could be the central portions of very thick flows, or intrusive bodies emplaced at some distance below the surface and derived from the same magma chamber as the surface flows. Of significant importance in connection with the problem is the mineralogical and textural similarity of coarsely-porphyritic facies to an acid stock mapped by the writer to the south of the map-area. The acid stock invades sedimentary strata and is, therefore, much younger than the volcanic rocks. Evidence in favor of an extrusive origin for these rocks could be summarized as follows:

(1) Primary flow-structures locally developed definately establish some acidic rocks as lava flows.

(2) Elongate bodies conform with the regional structure- does not preclude the possibility of sill-like intrusives.

Evidence for an intrusive origin is:

(1) Lack of fluidal structures and textures in coarsely-porphyritic facies.

(2) Some small masses of dense, cherty rock, superficially resembling fine-grained "flows", show intrusive relations.

(3) Similarity of porphyries to intrusive stock of quartz-feldspar porphyry south of the map-area.

(4) Coarse, holocrystalline porphyries indicate slower cooling than expected in normal flows, unless very thick.

Obviously, more work is necessary to unravel the true nature of these acidic rocks, and present evidence suggests they include rocks of more than one origin, and possibly more than one age.

Pyroclastic rocks probably constitute nearly half of the exposed volcanic strata in the map-area. They grade from coarse, highly fragmental agglomerates to dense, very fine-grained tuffs. They include numerous, diverse, nondescript rocks classed as pyroclastics for want of a better name. Some may be fragmental or brecciated flows; others may be devitrified and altered portions of flow-banded lavas; but the majority are probably accumulations of volcanic debris intermixed, in part, with flow material. Close to contacts with sediments, locally, a transitional zone grading from fine-grained tuff through tuffaceous sediments to normal clastic beds. is so highly sheared, silicified and otherwise altered that separation of tuff from sediment is impossible. Whenever feasible, the writer used the presence of numerous, rounded, quartz grains on the fresh surface as indicative of sedimentary material. Much rock classed as agglomerate consists of scattered, rhyolitic fragments— weathering light-cream, grey or greenish— in a dark-green, chloritic matrix. Many fragments break to show small, green patches; some have quartz phenocrysts. A few are amygdaloidal. These rocks shear to a green and cream, streaked rock locally resembling some varieties of streaked ryholite. Fragments increase in number until they constitute 50 percent or more.

of the rock. They locally occur in crude, discontinuous bands with intervening rock relatively poor in fragments. Other agglomerates exhibit fragments set in a very coarse "white-flecked", tuffaceous matrix. Occasionally, fragments become so abundant that they comprise most of the rock. Such rocks usually appear to have been silicified and some may be highly brecciated, rhyolite lavas. Fragments are angular to rounded or bomb-shaped, and very rarely show rims that weather lighter than cores. The majority of fragments are acidic, and many resemble the rhyolite and acid porphyry in the area.

Tuffs are extremely variable rocks, and range from coarse, crystal tuffs with occasional fragments over one inch to very fine-grained, sometimes slaty rocks with no discernible minerals. Crystal tuffs weather shades of grey, green, or brown, and show numerous, ragged, grey-weathering grains of feldspar on the exposed surface. These phenocryst-like feldspars render the rock difficult to distinguish from porphyritic volcanics. A very few tuffs are finely laminated, or are intercalated with narrow bands or lenses of grey to black, cherty material, but the majority are unstratified and show little evidence of sorting. Good contacts with flows are seldom visible. At sediment-volcanic contact-zones tuffs are extremely variable - probably as a result of concurrent vulcanism and sedimentation - and are usually sheared to a rusty, greenish, grey, or black, slaty rock impossible to distinguish from fine-grained sediments.

A typical crystal tuff is composed of 20 to 60 percent twinned feldspar grains, averaging several millimeters, set in a dirty-looking, tuffaceous groundmass containing patches, lenses, and veinlets of a quartz mosaic with interstitial chlorite and carbonate (plate 5). The feldspar is albite highly charged with tiny flakes of sericite. Feldspar grains almost disappear in the matrix at extinction, and many are bent or fractured and filled with chlorite and carbonate. In more-altered crystal tuffs the feldspar is largely converted to an aggregate of secondary sericite and clinozoisite (?) and other alteration products. Elongate zones of chlorite and associated muscovite or biotite are invariably present. A fine-grained tuff (?) examined reveals a very finely-divided rock with plentiful minute shreds and prisms of chlorite and sericite, and a few scattered, sub-rounded grains of quartz and feldspar of probable clastic origin.

Before leaving the subject of pyroclastics the writer would point out the preponderance of acidic, pyroclastic deposits, and the common occurrence of acidic fragments in flows of a more basic composition. If the area mapped by the writer is representative of the entire volcanic field it appears that during vulcanism much acidic magma was expelled from volcanic vents with explosive violence while more basic material poured out as flows. This exemplifies the relative high viscosity of acidic as compared to basic magmas, and the consequent release with explosive violence of volatile constituents from acidic melts.

Plate 5: Photomicrograph of crystal tuff. Crystals are albite, highly fractured and bent, in a very fine-grained, altered matrix. Albite is well-twinned, and charged with minute inclusions of sericite.

Volcanic terrain includes numerous bands of schistose rocks impossible to relate with any assurance to their unaltered equivalents. Original structures and textures have been obliterated by intense deformation, and primary minerals almost completely replaced by secondary products. These altered rocks are principally chlorite, carbonate, and sericite schists. Generally speaking, basic rocks have altered to chlorite schists and acid rocks to sericite schists; carbonate shows no preference for any particular kind of rock. However, rhyolites do become chloritized, dark-green rocks distinguishable from altered andesites only by the presence of primary quartz. Numerous highly carbonatized rocks weather with a deeply-pitted or ribbed surface, others have crumbled to a rusty rubble. Many narrow bands of very fissile, light-colored, sericite-carbonate schist, locally termed "brown-paper schist", are probably highly sheared and altered rhyolite flows or acidic tuffs. Although chlorite, sericite, and carbonate schists appear throughout the volcanics they are probably most abundant close to major contacts with sediments. Many bands of schist are the loci of concentrated shearing, and some may be zones of movement with the total displacement distributed over a large number of closely spaced slip-planes.

SEDIMENTARY ROCKS

A prolonged period of sedimentation produced a monotonous succession of clastic sediments consisting of alternating beds of predominantly greywacke, slate, and impure quartzites with minor interbeds of arkose, slaty-greywacke, and graphitic schist. Primary sedimentation features are rare with the exception of quite widespread grain-gradation. which is locally evident in all kinds of beds except some pure slates and uniform quartzites and arkoses. Many beds grade from a light-colored, sandy base to a dark-colored, muddy top. The different types of sediments are interbedded, and although one type may predominate in a certain locality other types are usually well represented. Most beds vary from 6 inches to 2 or 3 feet thick, but widths up to 30 feet were observed in some quartzite beds. Despite the persistence of individual beds and the contrast between contiguous beds, the over-all similarity of the sedimentary assemblage and the lack of distinctive horizon markers seldom permits a positive correlation of sedimentary strata between adjacent outcrops. The writer might mention that the so-called "rusty arkose" and certain, wide zones of massive quartzites offer possibilities as marker horizons, but their utilization as such would require more detailed study than was exercised in the present work.

Greywackes are medium to fine-grained rocks that weather dark-grey to greenish-grey or buff. Minerals are difficult to identify megascopically, but some of the coarser-grained varieties show small, rounded quartz and white feldspar grains in an altered, greenish to dark-grey, limonite-specked matrix. Dark, fine-grained greywacke, still somewhat gritty, is classed as slaty greywacke to distinguish it from typical slates. A very few greywackes show dark, indistinct spots on the fresh-surface.

Slates are very fine-grained, compact, usually black rocks with a well-developed, slaty-cleavage. Slate occurs as individual beds and as the fine-grained tops of some sandy beds. A few slate beds are finely laminated, but most are uniform in color and texture.

A very few slate beds are "dappled" or spotted with small nodules of uncertain composition and never over 3 mm. in diameter. They locally appear as tiny protuberances on the weathered surface. Dappled slates were noted in two places very close to the contact with volcanic rocks. At several places delicately dappled slates very close to contacts of basic dykes may be a fortuitous relationship, but the writer suspects they are the product of very local, thermal metamorphism associated with the emplacement of the dykes. The dappled slates are reminiscent of the incipiently-nodular "hot sediments" outside the map area that are the products of thermal metamorphism related to granitic intrusives.

Graphitic horizons are locally developed in slate beds that have been the locus of concentrated shearing. One such horizon, up to 15 feet wide, was traced at intervals for 800 feet along the strike. Graphitic zones usually have rusty-weathering patches. They are locally veined by quartz or brown carbonate, and are frequently heavily mineralized with pyrite. In many places they exhibit peculiar, white or grey weathering circular to elliptical patches of siliceous material that resemble quartz pebbles. Shear-planes curve around the patches, which have their longest visible axis parallel with the direction of shearing. Small, irregular patches less than 1/8 inch in diameter are composed of fine-grained, sugary quartz, but other larger, compact patches up to several inches have a smooth periphery and suggest pebbles of quartz. These quartzose patches could conceivably be deformed quartz pebbles; but are more likely secondary quartz, possibly injected under pressure as rods and kidneys along planes of weakness in highly sheared slate beds.

Quartzites and impure quartzites are medium to coarse-grained, well-cemented rocks that weather very dark grey to almost black, light-grey, greenish-grey, or buff. They are characterized by prominent, rounded, highly vitreous, dark, quartz fragments on the fresh fracture. The thickest beds are the coarsest-grained, and show no recognizable stratification and little or no grain variation. Quartzites are typically massive, and have tended to fracture rather than shear. Fractures are usually filled with quartz, resulting in a haphazard network of reticulating veinlets, bedded veins, or en echelon quartz lenses approximately paralleling the regional foliation. Zones of fine, pebble-conglomerate occur locally in some quartzite beds. They consist of rounded pebbles, predominantly white quartz, averaging 1/16 to 1/8 inch but up to 1/4 inch in diameter and constituting 25 to 75 percent of the rock. Conglomeratic zones are discontinuous and appear to be restricted, intraformational lenses and pockets in the quartzite beds.

In some places wide bands of massive quartzite beds can be followed up to nearly a mile. They may grade along the strike into other sedimentary types but their scattered occurrence over most of the map-area suggests that they represent a fairly extensive period of deposition of coarse, detrital material. Individual beds in such bands average 8 to 10 feet wide, are usually coarse-grained, massive, light-weathering, and well-fractured. Bands as a whole are more resistant to erosion than surrounding sediments and stand up as low, rounded, elongate outcrops.

Rocks termed "rusty arkose" in the field weather buff with a rusty hue. Beds average 5 to 10 feet wide and are massive with little perceptible stratification. On the broken surface they are grey or bleached-green, veined by tiny, rusty seams, and show a few small, vitreous quartz grains in a dense, ashy-looking matrix. They locally show indistinct color-banding that may be a reflection of stratification. These rocks are not abundant, but are conspicuous when encountered in the field, and very careful work might prove them to be valuable horizon markers.

Mention must be made here of the band of sediments lying between volcanics and extending from west of Lex Bay to Cranston Lake, with possible faulted extensions both north and south. On straight lithological grounds these rocks are markedly different than the main belt of sediments to the east. They are comprised mainly of coarse, massive, frequently ferruginous, quartzite and arkose beds, with minor slates and finely fragmental beds. Coarse rocks weather variegated shades of green, brown, reddish, buff, and grey. Slates are greenish-grey, tan, brown, and black, the latter occasionally purplish-red on water-worn surfaces. Some unusual, light-colored, "buff-beds" are largely replaced by carbonate and silica; and may be acid tuffs or acidic, sill-like intrusives. Close to volcanics beds locally get very coarse, and may carry various kinds of round to angular fragments up to 1 inch in diameter. This band of sediments may represent an interval of aqueous deposition before the close of vulcanism, or may be a belt of in-folded sediments of the same age as those to the east. The problem will be discussed later under structure.

Sedimentary rocks were not studied in any detail under the microscope and the following observations, recorded as a brief adjunct to field descriptions, were obtained from the study of a very few thin-sections.

No sediments examined show profound recrystallization, but all have been altered and deformed. Slates show a strong foliation, or slaty cleavage, accentuated by oriented shreds and flakes of micaceous minerals. They consist of very finely-divided, sub-microscopic material impregnated with white-opaque alteration, chlorite, and sericite. Abundant minute crystals with very high relief and yellowish color are probably rutile. Dappled slates show a maculose structure, with round to ovoid patches (plate 6), mainly of quartz (?), much coarser-grained than the rest of the rock. These

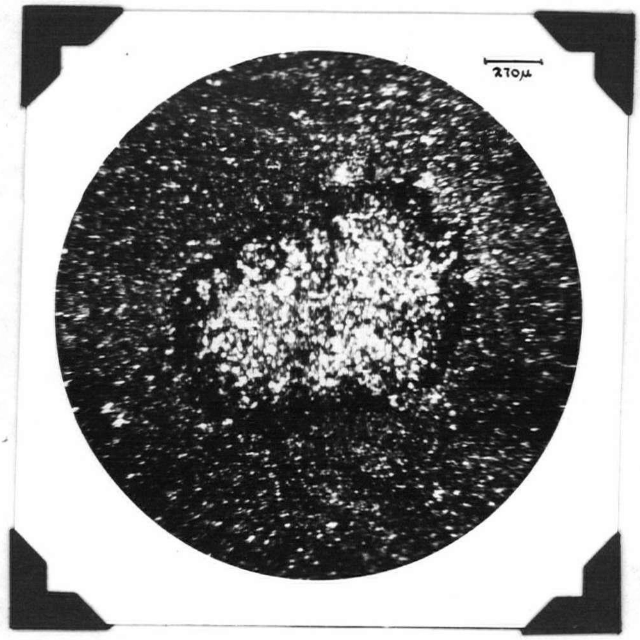


Plate 6: Photomicrograph of "dappled" slate. Note relative coarse-grain and lack of foliation exhibited by the "spot". Dark, peripheral rim is apparently due to a diffusion outwards, and concentration around the circumference of chlorite within the "spot". Main rock mass is highly impregnated with minute shreds of chlorite and sericite parallel with the foliation (horizontal). Very little sericite appears within the "spot". Crossed nicols

recrystallized patches are unfoliated and practically devoid of sericite. Chlorite is coarser and has apparently diffused outwards from the centre of the patch to give a peripheral zone enriched in chlorite.

Greywackes show rounded to angular grains, mostly quartz with some sodic plagioclase, set in a fine groundmass containing abundant chlorite and sericite. Quartz and feldspar grains are original clastic constituents little affected by processes that have altered the fine-grained groundmass. Very minor tourmaline in elongate crystals may be recrystallized, allogenic tourmaline, or may have been introduced. Spots, which are rare in greywackes and probably analogous to "dappling" of slates, are indefinate zones enriched in chlorite and depleted of sericite.

RELATION OF VOLCANIC AND SEDIMENTARY ROCKS

General:

Though very unsatisfactory, the evidence for the structural relationship between volcanic and sedimentary rocks provides no sound basis for any marked angular discordance. Accordingly, volcanics and sediments are tentatively regarded as constituting a conformable succession of rocks. Beds in sediments close to volcanic contacts always face away from, and nearly always strike parallel to, the contact zone. Sediments and volcanics show the same degree of metamorphism, and both possess a foliation with the same general trend. Traceable horizons in volcanics, contact zones, and beds in sediments are essentially parallel.

Nature of the Contact Zone:

Sediment-volcanic contacts are usually obscured by overburden, and the contact zone is commonly marked by a drift-filled depression that rises in an abrupt scarp to volcanics. At many places contacts are sheared. Shearing was probably initiated during folding, with possible later adjustments as witnessed by local shearing in a basic dyke where it traverses a rhyolite-sediment contact on the southwest shore of Lex Bay. Contacts appear to be steeply-dipping, but surface observations on such poorly-defined features as contact zones are seldon reliable.

In some places, sediments and volcanics are intercalated at contacts. In other places, as southwest of Slit Lake, there is a transition from fragmental volcanics, through tuffaceous sediments and peculiar beds of intermixed sandy and argillaceous material, to normal sediments. In still other places, as on the central-east side of Johnson Island, the rock grades upwards from volcanics; through a twelve-foot zone with sub-angular to rounded boulders, up to 12 inches or more across, in a tuffaceous or sandy matrix; through rusty beds; and finally into interbedded slates and greywacke. Boulders are mostly of volcanic rocks, but include some grey chert.

Thus, there is evidence on the one hand to suggest an erosional interval between vulcanism and sedimentation, and on the other hand to suggest a progressive change from vulcanism, through a transitional period of intermittent and concomitant vulcanism and sedimentation, to sedimentation.

Other features observed commonly, but by no means universally, at contacts are:

(1) Black to brown, pulverulent "gouge".

(2) Abundant, coarsely-crystalline pyrite.

(3) Carbonatization, as disseminated carbonate and metacrysts of a ferruginous carbonate.

(4) Ferruginous breccia of diverse, round to angular, volcanic and sedimentary fragments - probably recently consolidated debris cemented by iron salts provided by oxidation of pyrite in the contact-zone.

(5) Minor acidic intrusions (?) injected along contacts, usually pyritized and sheared to a light-colored, rusty, very-fissile schist of uncertain composition.

(6) Basic intrusives injected along contact zone.

Conclusions:

The foregoing data supply no evidence of a major stratigraphic break between volcanic and sedimentary rocks. Field evidence indicates contacts have acted as zones of weakness along which shearing, and probably movement, have taken place, and hydrothermal solutions have moved; so that they may be the loci of major structural breaks. The problem will be reconsidered in connection with the Indin "break" which, as already mentioned, is postulated to coincide approximately with a main sediment-volcanic contact.

INTRUSIVE ROCKS

General:

No large intrusive masses are exposed in the area, but numerous, small, hypabyssal dykes and sills invade sedimentary and volcanic strata. They range in composition from acidic to basic and in age from pre-sediments (?) to Proterozoic (?) Relative ages of the different intrusives are poorly known, as clear-cut relations are discouragingly rare in the field. Relative age can, in most cases, be assessed only on the basis of the degree of alteration. The oldest intrusives probably include some small, highly-altered, chlorite-carbonate dykes and sills. Others of these altered intrusives probably belong to a later period. Certain types of acidic rocks are probably intermediate in age, and the youngest consist of a plexus of basic dykes and sills that cut all other rocks, and probably include dykes of several different ages. The possibility of quartz-feldspar porphyry intrusives has already been considered. In addition, "Bird-Porphyry" and similar rocks, easily mistaken for crystalline flows, are of uncertain origin and age.

Late basic dykes are divided into two types - altered gabbro and diorite and relatively unaltered diabase. Since these basic dykes may shed some light on the problem of age of faulting in the area they will be described here in some detail.

"Bird-Porphyry" and Similar Rocks:

Under this head are included massive to schistose, crystalline rocks with dioritic texture and composition. Their areal distribution is limited to volcanic rocks in the northern quarter of the map-area, with the exception of one dyke, in volcanics, on the southwest side of Negus Lake.

Within these limits, they increase in abundance from south to north. These rocks were not recognized in sediments although, admittedly, some rocks in sediments, classed as late diorites, are very similar. Over wide areas in the north the "porphyries" constitute nearly half of the rock exposure, but their apparent abundance may be a reflection of superior resistance to erosion over enclosing strata. Some show definate chilled margins and apophyses against volcanics, but most occur as isolated outcrops that tell nothing of their relation or origin. Meagre structural data imply that at least some bodies of this rock conform with the general structure in volcanics. The rock may be, in part, the intrusive counterpart of andesite flows, intruded along structure planes in the volcanic pile, and contemporaneous with outpourings of andesite lava. However, the freshness of these rocks compared to most volcanics suggests they belong to a much later period of igneous activity; their confinement to volcanics is due to structural control rather than contemporaneity. Exceedingly poor exposure permitted no field separation of these rocks on maps so they are grouped with volcanics, but the writer feels they are largely intrusive and should be described under that heading.

They are mottled, green or brown weathering rocks frequently characterized by anhedral, light-weathering, felsic patches, or small, quartz "eyes". They are dark-green on the fresh surface, massive to schistose, holocrystalline, with a poorly developed diabasic texture.

The felsic patches are white, cream, or greenish, altered feldspar, average 1/4 to 1 inch across, and probably are large, partly adsorbed phenocrysts. They are erratically distributed, never constituting more than 5 or 10 percent of the rock and usually very widely scattered or almost entirely absent. Rocks with these felsic patches were called "Bird-Porphyry" in the field because of marked similarity to rocks of that name seen by the writer from the area around Yellowknife. Quartz "eyes", which occur with or without felsic patches, are rounded blebs of opalescent, bluish quartz that average about 1 mm. in diameter. Occasionally these rocks show abundant, scintillating flakes of black mica. Outcrops are featured by lenticular fractures filled with white, usually barren, quartz. Quartz veins are up to 2 feet wide, but seldom more than 20 feet long.

Microscopic examination reveals the rock is composed mainly of hornblende, altered feldspar, chlorite, and quartz. Hornblende is green to almost colorless, moderately pleochroic, and shows extensive alteration to chlorite. Original lathy feldspars with random orientation remain as opaque masses of secondary products. Clear quartz, as irregular grains up to 1 mm., showing undulatory extinction, and scattered smaller grains, composes 15 percent or more of the rock. Some quartz is intergrown with altered sodic (?) feldspar and resembles interstitial granophyre. Locally, however, quartz is seen penetrating the margins of feldspars, suggesting that the intergrowths may be of replacement origin and unrelated to late-stage crystallization of the rock. Some large quartz grains show parallel trains of minute, colored inclusions. Much of the quartz has probably been introduced, or possibly released from the breakdown of primary constituents. Chlorite, as aggregates and scattered flakes, usually shows a dark, purplish-blue or purplish-red, interference color. A seim-opaque material, white in reflected light, has exceptionally high relief and constitutes over 5 percent of the rock. It shows almost total reflection, so that no optical properties are obtainable. Some well-defined, wedge-shaped cross-sections suggest that it may be sphene partially altered to leucoxene. It frequently carries small kernels of a black, opaque mineral. Other minerals present in varying proportions are carbonate, epidote, pyrite and apatite.

The felsic patches show definate, but very irregular outlines, and consist of feldspar almost entirely converted to a semi-opaque aggregate of secondary minerals including clinozoisite or epidote, carbonate, sericite and chlorite, and possibly some kaolin minerals.

Varieties containing biotite show less hornblende, more chlorite-showing a dirty-greenish interference color - and an abundance of the leucoxene-like material. Biotite, constituting around 5 percent of the rock, is strongly pleochroic and invariably lies within, or closely associated with chlorite.

Altered Dykes:

Numberless highly altered, usually small, intrusive bodies are included under this heading. Their original composition is unknown for they are now composed almost entirely of secondary minerals. They probably include rocks of different compositions and ages. Some are known to cut acidic intrusives in sediments, and some are cut by late basic dykes. Others resemble altered phases of late basic dykes, and may themselves belong to that same period of igneous activity.

They weather brown, reddish-brown, or green, are infrequently cut by veinlets of a green, fibrous mineral, and usually show sharp contacts against the confining rock. On freshly-broken surfaces they are grey, green, or brownish, and aphanitic or studded with small, glistening, cleavage-faces of carbonate. Others show well-developed, euhedral crystals of ferruginous carbonate up to several millimeters across, and still others are almost completely carbonate.

In thin-section they consist of a structureless aggregate of carbonate and pale-green chlorite, with lesser amounts of muscovite, quartz, and a plagioclase believed to be albite. Pyrite is usually present, along with iron-ores and brownish-white, opaque, alteration material. Muscovite is secondary and shows a sieve structure. One variety exhibits evenly-distributed, rounded clots of deep-green chlorite with minor quartz and carbonate. Opaque minerals are very abundant in the main rock mass but practically absent in the clots of chlorite.

Since carbonate metacrysts are linked with metamorphism and alteration, their discussion will be withheld until a later page. In passing, the writer would mention that dykes and sills of the present-considered rocks have apparently offered very permeable "channels" for the passage of carbonate solutions, and frequently they have been highly carbonatized while the adjacent rocks have been but slightly affected. This suggests that carbonatization is controlled, at least to some extent, by the composition of the dykes and sills; a composition probably considerably more basic than the adjoining rocks.

"Metadiorite"

Intrusive rocks classed as "metadiorite" are found only in sediments, and these mainly in that narrow stretch of land separating Indin and Float lakes. None of these rocks were recognized in the northern half of the area. "Metadiorite" occurs almost invariably as sill-like bodies intruded along bedding-planes and conforming in strike and dip with the enclosing strata. Numerous small sills from one to three feet wide are difficult to prove as intrusive. They possess sharp contacts with no appreciable chilling or other intrusive criteria. However, one such small body was observed trending at right angles to bedding along the axial plane of a small syncline in thinly-bedded sediments, so other similar rocks were concluded to be intrusive and correlated with larger, somewhat similar bodies of typical "metadiorite". Sills of "metadiorite" occasionally attain widths of 30 feet or more, but are usually exposed along edges of drift-filled depressions so that true widths are indeterminate. Some have been intensely cracked and filled by a network of smoky to milky quartz veins that rarely penetrate the enclosing rocks. Others are highly schistose, or show a poorly-developed augen structure, parallel to the regional foliation. Thus these rocks have yielded to stress conditions by both fracturing and shearing, and appear to have been subjected to at least some of the forces that caused folding.

The weathered surface of larger bodies is usually reddish-brown or greenish, with myriads of tiny, white flecks that project slightly above the surface. Least deformed varieties show, on the fresh surface, a granitoid texture and about equal amounts of felsic and mafic constituents. Schistose varieties break with a waxy sheen along irregular cleavage surfaces, and show lenses of light-colored minerals in an altered, greenish-grey matrix specked with brown alteration.

Under the microscope unsheared varieties (plate 7) are a medium-grained, granular rock composed mainly of plagioclase feldspar and chlorite. Chlorite is interstitial to feldspar, and was probably derived from the breakdown of primary, ferromagnesian minerals. It is in large, optically-continuous masses locally intergrown with coarse sericite. Plagioclase is a twinned, very-sodic albite, host to numerous coarse inclusions of carbonate, sericite, and chlorite. Some untwinned feldspar grains showing good cleavage may be orthoclase. Feldspar grains are locally fractured or bent, with arcuated twin lamellae. Strained quartz constitutes less than ten percent of the rock. Apatite is very abundant as prismatic, cross-fractured crystals up to 1/2 mm. Carbonate,

Plate 7: Unsheared "metadiorite". Note lack of any directive texture. Rock composed mainly of albite (white) and chlorite (black), with minor quartz, carbonate, sericite and apatite. Crossed nicols.

Plate 8: Sheared "metadiorite", showing crude augen-structure accentuated by sinuous zones of chlorite that curve around lenticular patches of albite, quartz and carbonate. Much micropegmatite and minor schiller-structures probably were developed during shearing. Crossed nicols.

comprising about 15 percent of the rock, magnetite, and skeletal frameworks of white, opaque material mainly in chlorite complete the mineral assemblage.

Sheared varieties (plate 8) show increased amounts of carbonate and chlorite and a lesser amount of sericite. Schistosity is accentuated by long, sub-parallel strings of shredded chlorite that curve around lenticular zones of feldspar, quartz, and carbonate. Quartz and feldspar have been crushed to granular aggregates that have been drawn out in the direction of schistosity and impregnated with carbonate and chlorite. Some quartz is in graphic intergrowth with a feldspar of much lower refringence. Irregular grains of opaque, brownish material are abundant in chlorite. Delicate, acicular to filiform crystals appearing as inclusions in feldspar and chlorite are arranged locally in a crude sort of schiller-structure. Apatite is abundant and sericite is absent, except as a few minor inclusions in feldspar.

The name "metadiorite" was adopted in the field for the foregoing rock and has been retained in this report. Obviously, the rock has been altered and deformed, but probably initially approached a diorite in composition - with subsequent albitization of the feldspar, conversion of ferromagnesian constituents to chlorite, and introduction of carbonate (or at least of CO_2).

Minor Acidic Intrusives:

With the exception of quartz-feldspar porphyry, already discussed, and very numerous quartz veins, many of them feldspathic, acidic intrusives in the area are limited to a few small, sill-like bodies in sediments. These bodies are exposed as a single sill on the small island off the southeast end of Johnson Island, and again close to the eastern shore of Indin Lake as several, discontinuous sills extending from a point directly across the lake from North Inca to half way up the shore of Lex Bay. It is not known whether these exposures are parts of the same intrusive system. Other so-called "buff-beds" in sediments west of Lexindin may be similar intrusives. In addition, some volcanic-sediment contacts are locally marked by a light-colored rock, usually pyritized and sheared to a rusty, very-fissile schist that was thought to represent minor acidic intrusives injected into contact-zones. Clear-cut relations of these rocks were not encountered in the field, and petrographic similarity, under the microscope, to sericitized rhyolite leads to the idea that they are sheared acidic lavas rather than minor intrusives.

The sill-like acidic intrusives in sediments usually conform with the attitude of the enclosing strata, but locally cut the beds at a small angle, and very infrequently swing at right angles to bedding for a few inches. Along strike they pinch and swell from less than a foot to more than eight feet in width. They are locally mineralized and cut by irregular stringers of quartz. In a few places they are almost completely replaced by quartz. Smooth slickensides covered by a sericite film, at contacts with sediments and within the rock itself, give evidence of movement along the sills after their emplacement. The rock is aphanitic, white to light-grey, dense to sugary, and in some places speckled with limonite or patches of green chlorite.

In thin-section the rock is comprised of an inequigranular, interlocking, allotriomorphic aggregate of albite and quartz, with possibly some orthoclase. Ferruginous carbonate altering to limonite is abundant. The rock is veined by coarsely-crystalline quartz associated with a lesser amount of albite. Quartz is fractured and highly strained. Sericite occurs as interstitial films between quartz grains, as fracture-fillings in quartz, and as a few small inclusions in feldspar grains. Coarse lines of dusty inclusions traverse the rock and quartz veinlets with no regard for crystal boundaries.

Gabbro and Diorite:

These are the most widespread and abundant intrusive rocks in the area. They have been intruded in several well-defined sets, and their emplacement probably took place over a long period of time. One set trends in a northwesterly direction, approximately parallel to "cross-faults", and another set trends, in general, a few degrees east of north, approximately parallel to the regional structure. Some northwesterly-trending dykes appear to follow, and be younger than, "cross-faults"; and other northerly-trending dykes are offset by, and older than, "cross-faults". Dykes usually show weak resistance to erosion, and weather to drift-filled depressions, but in some places in contact with the same rocks they stand well above the surrounding strata. Dykes, which attain widths of 100 feet and average 20 to 30 feet, vary considerably in thickness along the strike, and in places become quite irregular, with numerous off-shoots and ramifications. They show indistinct contacts against fine-grained sediments, and against all rocks a chilled, marginal facies frequently lighter-weathering than the interior. Fine-grained sediments close to the contact are usually baked to a cherty, buff, grey, or greenish hornfelsic rock in which all signs of foliation are obliterated - signifying that these intrusives are later than the development of foliation. The location of a dyke can be detected frequently by the presence of baked sediments on the edge of a lineal depression. Coarse grained sediments and volcanic rocks have not been appreciably altered by the dyke-intrusions.

In the field different dykes, or specimens from the same dyke taken at different localities, vary somewhat in detail; but in general these rocks all show sufficient similarity to be classified under the same head. For that matter, some of these rocks are so like the previously described "Bird Porphyry" and allied rocks that the validity of creating the two divisions is questionable, and can be justified with some degree of certainty only by seeing the two types of rock in the field.

The rock, noticeably heavy in the hand, is massive, fresh-looking, green to brown weathering, and has a mottled dioritic to diabasic texture. It is dark-green on the fresh surface, and shows varying amounts of mafic and felsic constituents, the former usually predominant. Pyrite is usually visible in the hand specimen. A few dykes are cut by veinlets of salmon-pink feldspar, or contain irregular segregations of coarsely-crystalline quartz and pinkish or white feldspar. Others are fractured and filled with white to grey, vitreous quartz, occasionally well-mineralized with chalcopyrite and pyrrhotite. Still others are cut by small, seldom-persistent stringers of white, vuggy quartz. Large, irregularly-distributed, yellowish-green to cream patches appear in some of the dykes. They may constitute up to 25 percent of the rock at one exposure and be entirely absent on the next exposure of the same dyke. They never show crystal outlines, and for the most part are very irregular in shape.

In thin-section the freshest rocks are composed mainly of amphibole and altered plagioclase with lesser, varying amounts of chlorite, quartz, epidote, clinozoisite, biotite, carbonate, magnetite, pyrite, leucoxene (?) and apatite (plate 9). Amphibole, which probably includes hornblende and tremolite-actinolite, is brown, green, and colorless. It is weakly to strongly pleochroic in tints of green and brown. Variegated shades of green and brown appear locally in a single grain. Much amphibole, reminiscent of a secondary origin, exists in fibrous aggregates with or without chlorite. Other optically continuous, occasionally twinned, subhedral

Plate 9: Late diorite dyke, consisting mainly of secondary green to brown amphibole (dark) and andesine feldspar (light). Compare with plates 10 and 11.

grains may be primary. Feldspar is lathy plagioclase, locally fresh, with regular, polysynthetic twins; but usually altered and charged with inclusions of clinozoisite or epidote and chlorite. Chlorite locally replaces feldspar along zones parallel to lamellation, and occasionally feldspar is "cleared up" where in contact with chlorite. Positive identification of feldspar is not easy but the index of refraction and maximum extinction angle favor an andesine of composition about Ab_{55}. Epidote or clinozoisite and chlorite are always plentiful, and pyrite, magnetite and leucoxene (?) are usually present. Other minerals noted in some slides are biotite, carbonate, apatite, quartz, and micropegmatite. Quartz, when present, is never over 10 percent, and in some sections appears to have been introduced. Biotite, which is absent in most sections but quite plentiful in a few, occurs as small flakes associated with amphibole and chlorite. It is strongly pleochroic from tan to almost colorless. The relation of biotite to amphibole is not clear, but in a few places amphibole appears to be altered to biotite through an intermediate stage in which green amphibole turns brown, to a final stage in which the brown mineral takes on the optical properties of biotite. Both biotite and amphibole are altered to chlorite.

Light patches, which were originally composed of plagioclase, now consist of a mass of secondary products and a very few cloudy remnants of the original feldspar. The secondary mass consists primarily of an equigranular aggregate of one or more of the epidote minerals (probably mainly clinozoisite) with minor amounts of chlorite, and could probably be termed "saussurite". The original feldspar was not identified, but could be expected to have been quite calcic.

Two sections taken from altered portions of these rocks, one from close to a mineralized zone and the other from the sheared portion of a dyke where it crosses a sediment-volcanic contact, show greatly increased amounts of chlorite and carbonate, and diminished amphibole and clinozoisite or epidote.

Diabase:

Diabase dykes are probably the youngest rocks in the area, although nowhere were they found intersecting gabbros and diorites. They are not abundant and in no case was a single dyke traced any great distance. In several localities they are intruded parallel with, and only several tens of feet away from, a diorite or gabbro dyke; in all instances both dykes are in sediments and strike approximately parallel with bedding. A very short section of a diabase dyke was found in a silicified breccia-zone believed to be the locus of a "cross-fault". The dyke was perfectly fresh, and apparently post-dated faulting and silicification.

Typical diabase has a smooth, brown, weathered-surface, and sharp, regular contacts with a chilled, marginal selvage. The rock is nearly black on the broken surface, with myriads of tiny feldspar needles that sparkle when the rock is rotated in the hand. Less typical varieties weather greenish, are dark-green on the fresh surface, and difficult to separate from fresh diorite and gabbro in the field.

The rock has a diabasic texture, and consists of about equal amounts of pyroxene and feldspar, and abundant accessory magnetite, (plate 10). Marginal facies are porphyritic (plate 11), with phenocrysts of pyroxene and feldspar in a fine-grained, merocrystalline matrix of the same minerals and magnetite. Pyroxene, with an optic angle of about 40 degrees, is a pigeonitic augite. It locally shows incipient uralitization or alteration to chlorite. Feldspar is labradorite, occasionally zoned, and replaced by chlorite (?) along narrow seams predominantly transverse to the length of the feldspar grain. Magnetite is evenly scattered through the rock in anhedral, highly corroded grains. Small flakes of biotite partly altered to chlorite, probably belong to a late, deuteric stage of crystallization. Biotite is brown, strongly pleochroic, and usually surrounded by chlorite. The diabase, as a whole, is a fresh rock, and apparently has not been exposed to the same vicissitudes as the other basic intrusives in the area.

Plate 10: Fresh diabase, consisting of pigeonitic pyroxene (grey), labradorite (white) and magnetite (black) Compare with plate 9. Crossed nicols.

Plate 11: Fresh diabase, showing crudely-porphyritic, contact facies, with phenocrysts of pyroxene and feldspar in a fine matrix of the same minerals and magnetite. Some feldspar is zoned. Crossed nicols.

STRUCTURE

General Statement

When dealing with such regional features as structure the fragmentary data gathered from the study of a small area is inadequate to formulate a sound analysis of the structural set-up. Apart from this, the general character of the rocks and the paucity of rock exposure in some areas, imposed severe restrictions on the number of reliable structural determinations available, and consequently, conclusions must be based on undesirably few observations. The scale of the accompanying map of the entire map-area precludes the inclusion of numerous minor details of structure recorded on the 400-scale map. The writer offers here a few ideas of structure in the area, with the realization that the theoretical phases may have several equally valid interpretations, and in the hope that additional field work will lead to a clearer understanding of the structural pattern in the area. The ensuing discussion is not intended as an exhaustive treatise of structure in the area, but rather as a preliminary consideration of a topic that necessitates considerable additional information before it may be dealt with in any great detail.

Structure in the area is complex. Sedimentary rocks have been thrown into a series of tight, isoclinal folds with axial planes trending, in general, a few degrees east of north. All sedimentary strata dip from 70 degrees to vertical, and in many places beds are overturned as much as 10 or 15 degrees.

Folding appears to have been less complex in volcanics. They have resisted intense buckling by the development of zones of shearing in incompetent members of the assemblage and, in general, probably behaved as a competent unit under the influence of tectonic forces to which the rocks were subjected. Movement, if any, along shear zones was probably mainly vertical, and took place as a very late-stage adjustment to stresses; consequent upon the relaxation of stresses; or even during a later period of deformation. Many small-scale folds in sediments may be minor flexures related to the main period of folding, but some, and probably the majority, are related to later earth movements that developed steeply-plunging dragfolds and imposed crenulations upon regional foliation produced during the main period of folding.

Regional stresses subsequent to folding culminated in major northwest-trending "cross-faults" of considerable magnitude. "Cross-faults" affect all rocks in the area with the possible exception of some late basic dykes.

FOLDING

Apparent structural conformity between volcanics and sediments leads to the assumption that these rocks have been subjected to a single period of regional folding. Discussion of the nature and origin of the forces that caused this folding will be withheld from this report except for saying that the fold pattern suggests compressional stresses operating in a general east-west direction perpendicular to the trend of fold axes, and incidentally, perpendicular to the long axes of granitic intrusives and a belt of rocks of the Snare group (Proterozoic) to the west.

Generally speaking, the map area lies astride a volcanic-sediment contact, with volcanics on the west and sediments on the east. To the east and out of the map area a second band of volcanics is exposed. The belt of sediments is about a mile wide at its narrowest part. The contact strikes a few degrees east of north over most of the area, but swings to about north 30 degrees east above Cranston Lake. Lord (1942, p. 41) regards the volcanic bands as, in part, the cores of complex, anticlinal structures. If so, the sediments, flanked on either side by older volcanics, would occupy the trough of a synclinal structure, and the map area would lie essentially on the western limb of this syncline. Field observations, while not vitiating the fundamentals of this concept, introduce many complications.

That the sedimentary strata do not occupy a simple, synclinal trough is shown by numerous reversals of tops-best explained in such steeply-dipping beds by tight, isoclinal folding. Divergence in strike of beds from the regional trend may reflect plunging folds, or later flexing or dragging of strata already standing on edge as a result of isoclinal folding. In many places beds can be followed around the noses of small anticlines and synclines. In some, regional foliation is perpendicular to bedding on the crest or trough, and in others the foliation follows bedding around the nose or has been crumpled into a series of closely-spaced crenulations or tiny foldlets. Some of these folds are probably drag-folds contemporaneous with major folding, and others are probably associated with one or more later periods of deformation. Since the two types of folds cannot be distinguished with confidence they are of little value as a guide in interpreting the major structure. The axes of some of these folds are shown on the accompanying map. In no case were they traceable for any great distance, and in most cases could be followed only a very few tens of feet.

The axis of the major structure is indeterminate, and its plunge is a matter of some uncertainty. Most small folds plunge steeply (usually to the north), but as already stated, the majority are probably genetically unrelated to major folds. For reasons given later, secondary linear features were not considered reliable indicators of regional plunge. However, the essential parallelism of sedimentary and volcanic belts suggests gentle regional plunge. The belt of volcanic rocks along the eastern edge of the map-area appears to plunge to the north and south under younger sedimentary rocks, and suggests an elongate dome structure with gentle northward plunge in the northern part of the area reversing to a southward plunge in the southern part of the area. These relations, however, are not duplicated so as to be readily apparent by volcanics in the western part of the map-area. To what extent the picture is complicated by unrecognized faults, especially strike-faults, is not known.

The narrow band of sediments in volcanics west of the main contact zone deserves some consideration here. That portion extending from west of Lexindin to Cranston Lake, on the basis of structural criteria, appears to be the trough of a narrow syncline. Stratigraphic tops on the west side face east, and on the east side face west. In addition, a rusty-weathering "buff-bed", either an acidic sill or a tuff-aceous bed, is exposed west of Lexindin on each side of the sedimentary belt at approximately the same stratigraphic horizon, as if it were being repeated on each limb of a syncline. On the other hand, as already discussed, sediments constituting this band are not similar, lithologically, to the main belt of sediments on the east. Also, rhyolite lying on the western side of the sediments does not appear on the eastern side as it should if the structure were a simple syncline, and discounting any complications possible through discontinuity of the rhyolite horizon or unrecognized faulting. Thus, there is on one hand evidence to suggest a shallow syncline or infolded band of sediments, and on the other hand evidence to suggest the sedimentary band is the result of a major interval of sedimentation before the close of vulcanism, and thus a wide sedimentary interband within the succession of volcanics.

The writer is extremely dissatisfied with the fold picture established by mapping and summarized briefly on the foregoing pages. However, when we consider that the rocks now exposed at the surface are the cores of what were presumably great mountainous belts produced by crustal orogeny and modified by later disturbances, it is not surprising that the structural constitution of the rocks is complicated to such an extent that structural information accumulated in the course of a single field season leaves much to be desired.

Regional Foliation and Lineation

Compressional stresses to which the region was subjected imposed a schistose or foliate structure upon most rocks in the area. The writer applies the term "regional foliation" in a broad sense to include the approximately parallel disposition in layers, lenticules, or undulating lamellae, of rock elements and minerals. In general, it includes schistosity, flow-cleavage, and augen-like structures - secondary features probably developed during folding by stresses transcending the limits of the map-area, and consequently conforming to a regional "grain" or trend of such structures that compares in extent to the extent of the causal stresses.

The degree of development of regional foliation varies in different rocks, and in separate bodies of the same rock. Pre-folding intrusives are frequently somewhat less foliate than the enclosing rocks. Some bodies of one rock type may be highly foliate, and other bodies of the same rock be quite massive. Coarse-grained sediments and some intrusives have fractured rather than sheared. Slate beds lying between relatively competent greywackes and quartzites are usually more highly sheared than adjacent formations. Late basic dykes, introduced after most or all of the folding, have not been affected except where late movement, unrelated to stresses causing regional foliation has developed some local shearing.

Foliation strikes between northwest and northeast, predominantly a few degrees east of north, and dips very steeply to vertically. In sediments it is usually parallel to beds, or cuts bedding-planes at a small angle. Cleavage planes passing from coarse-bottomed to fine-topped beds are refracted towards closer parallelism with bedding upon entering the fine-grained top.

Secondary linear features are developed in some parts of the area, usually in rocks where foliation is strongly developed. Linear features are elongate elements whose long axes are oriented parallel with foliation, and include pillows, fragments, and streaks of chlorite in volcanics, and a few pebbles in sediments, and "quartz patches" in graphitic beds. Fragments in agglomerates are locally deformed into irregular, ellipsoidal bodies, or squeezed and flattened into "pancake-shaped" bodies that may reach a foot in length and less than an inch in width on the surface of an exposure. Such extreme deformation, which is of rare occurrence, must have taken place when the rocks were in a very plastic condition as there is no visible evidence of cataclastic structures associated with the deformation. Pillows in volcanics invariably have their longest visible axis parallel with foliation, and the same can be said for pebbles in coarse sediments and "quartz patches" in graphitic slates. However, pillows may owe their elongation and orientation as much to primary shape and disposition in the flow as to secondary processes, and "quartz patches" in graphitic beds probably owe their shape and orientation to control by pre-existing structures rather than to deformation subsequent to their formation.

Fragments in agglomerate and numerous, elongate lenses and streaks of dark-green, chloritic material in volcanics, when viewed in the plane of foliation, usually show a very steep to vertical inclination on their longest axis. In the field this was interpreted as indicating a steeply plunging regional structure. However, since such elongate elements may be conceived to have developed by more than one mechanism, either as a stretching perpendicular to fold axes or as a squeezing or rolling-out parallel with fold axes, the interpretation reached on the basis of lineation depends upon which mechanism is adopted by the interpreter. If stretching perpendicular to fold axes is presupposed, steeply inclined lineal elements indicate gentle plunges; if squeezing or "rolling-out" parallel with fold axes is adopted, steeply inclined lineal elements indicate steep plunges.

In an area of intense folding there is considerable lengthening along the folded belt parallel with the fold axes. Such lengthening is relieved by the development of salients or plunging folds, the latter probably the usual method of relief. If the apparent lengthening of a few observed fragments be taken as a quantitative index of the total lengthening along the folded belt the resultant plunge would be considerable, assuming, of course, stretching of fragments to be parallel with fold axes. However, extreme stretching is probably confined to relatively small areas of greatest stress intensity, so that highly deformed elements in these restricted areas are not representative of deformation of the entire area. Since there is no unanimity regarding the genesis of elongate, lineal elements, and since proof to the contrary is lacking, the writer prefers to think of the major fold axes as being gently undulating lines rather than lines that stand nearly vertically, as would be indicated by the attitude of the majority of lineal elements in the planes of foliation.

In conclusion, lineal features are elongated essentially in the plane of regional foliation, and lineation, foliation, and folding are probably contemporaneous features developed by a single system of tectonic forces.

FAULTING

Faults in the area may be divided into two main classes:

(1) Shear zones, usually paralleling the regional structure.

(2) Northwest-striking "cross-faults", oblique to the regional structure.

Although the shear zones are classed as faults no positive evidence exists of appreciable displacement along them, and all that can be said is they are zones of intense shearing roughly parallel with the regional structure and usually accompanied by carbonatization and other kinds of alteration. Included with them are the Indin "break" and other zones of shearing localized at major contacts.

"Cross-faults" are definate crustal breaks attended by considerable displacement but practically no intense shearing.

Shear Zones:

Exposed shear zones in volcanics are ill-defined bands of schist that grade laterally into less-schistose rocks. Pronounced shear zones are not abundant in sediments, and when they do occur there are frequently localized in slaty horizons between coarser beds of a more competent nature. The attitude of the schistosity in shear zones seldom shows much deviation from the attitude of regional foliation in the surrounding rocks, and for this reason are thought to be a late-stage adjustment to stresses that caused folding, or at least to have been controlled by zones of weakness initiated during folding.

Shear zones are frequently accompanied by quartz-veining, especially in sediments, and by carbonate in veins, interlacing stringers, and carbonatized wall-rock. Highly carbonatized shears, or "carbonate-zones", are widespread in volcanics, and although sometimes mineralized, seldom contain appreciable precious-metal values. Many outcrops weather rusty from the decomposition of the carbonate. Other shear zones in volcanics are composed of highly schistose sericitic and chloritic rocks. The walls are poorly defined, and the shear zones gradually lose their identity in the regional foliation. Chlorite and sericite probably developed mainly as a result of dynamic metamorphism, and their presence and abundance ~~be~~ was probably dependent upon the composition of the original rock, but as already discussed, certain chloritized rhyolites attest to the fact that during deformation, some of the constituents necessary for the formation of chlorite, and for that matter other minerals generated by dynamic processes, must have been introduced.

No attempt has been made to show shear zones on the accompanying map. For the most part they are obscured by drift and muskeg and their delineation, to be of any value, would have required more time than was available in the present work.

The Indin "Break".

Paradoxically, the Indin "break", which is economically the most significant structural feature in the area, is not indicated on the accompanying map. There are several good reasons for this. In the first place, the only positive evidence within the map-area to support the existence of such a "break" is to be found in the results of diamond-drilling at and around North Inca, and since drilling results were not incorporated with field studies this record is lost for the purpose of this report.

The writer does not intend, at this point, to disagree with the results of mapping set forth on map 697 A showing, at intervals, a north-trending fault that coincides at North Inca and vicinity with the position of the ore-bearing shear zone or "break" established by drilling. This fault has been postulated from field work having a much wider scope than the writer's investigations. Nevertheless, mapping along the assumed position of the fault produced little evidence to support the existence of a fault having a displacement to the right even approaching the magnitude indicated by the offset sediment-volcanic contact south of Slit Lake. Careful mapping at this point revealed the contact to maintain essential continuity, with little likelihood of being displaced, if at all, more than a few tens of feet. This, of course, still admits the possibility of a fault having a large vertical component of movement - a possibility enhanced by a deep, lineal depression extending from Slit Lake to Leg Lake, and poor correlation between volcanic rocks on adjacent sides of the depression. Several obscure exposures of late basic intrusive along the depression, together with numerous exposures of the same rock to the south, and approximately in line with the depression, suggest that it may be the result of differential erosion of a basic dyke, since basic intrusives in the area are known to offer relatively weak resistance to weathering.

Turning to positive evidence of the "break", one cannot deny the existence of the zone of shearing established by drilling to extend from its intersection with the Inca fault northwards almost to Lexindin camp, a distance of about 9000 feet. This zone of shearing, hitherto termed the Indin "break", would probably be better described as the Indin "shear" until positive evidence of movement, if any, is obtained. Of course, the most important structural problem of the area is whether this zone of shearing is a comparatively small structure, the limits of which have been pretty well defined, or whether it is a major structure that continues a considerable distance north and south of where it has been detected by drilling. Field work was extremely disappointing insofar as results that have any bearing on the problem, and no direct evidence was obtained either for or against extending the structure beyond its presently-defined limits. At North Inca the shear is in sediments close to their contact with volcanic rocks, and is believed to dip steeply to the west with the contact, which lies a few feet west of the shear. If it be assumed to maintain this essentially bedded character, and especially if movement along the shear is not great, it might continue for a great distance without being detected on the surface. Its southerly extension would lie under the waters of Indin Lake and could be located only by drilling. In this connection, a hole drilled from the northeast shore of Johnson Island, about 3000 feet south of the Inca fault, intersected a zone of mineralized schist in sediments at about the same horizon as the main shear at North Inca. This suggests that the main shear extends south of, and is displaced by, the Inca fault. Going north of where the shear was last identified by Lexindin its path easily could follow the low ground that marks the volcanic-sediment contact from Lex Bay to south of Cranston Lake. Here the shear would presumably be displaced to the northwest by a "cross-fault", and extend northwards along Cranston Lake. The structural conditions north of Cranston Lake are not at all clear. It is not known whether the belt of volcanics between Cranston Lake and the lake to the west is in faulted contact against, or plunges beneath, the younger sediments on the north, so it would be folly to attempt even an assumed position of the shear beyond Cranston Lake. As a matter of fact, sediments are highly sheared over widths up to a mile north of Cranston Lake, and it is unlikely that any concentrated zone of shearing does exist. It may be that this marks the transition from a more or less well-defined shear zone into a wide belt of distributed shearing in which mineralization, if present, would be so widely spread that its concentration in economic amounts would be unlikely.

Before leaving the subject, the writer would point out the obvious fact that additional information is sorely needed before the nature and origin of the Indin "break" may be evaluated. However, the none too valid suggestion is made that the Indin "break", localized as it seems at a major contact, may have been initiated during folding, and reflect adjustment to stresses causing folding of rocks of different competency. Prior to folding the rock assemblage can be thought of as a competent volcanic basement overlain by a relatively incompetent succession of sediments. Shortening across the folded belt, after the position of major folds was determined, was accomplished by intricate buckling of the sediments and broader warping and shearing in the volcanic basement. Such deformation, in an intermediate stage, would probably necessitate slippage or shearing along, or close to, major contacts between volcanic and sedimentary rocks which, in an advanced stage, might develop into high angle thrust faults along steeply inclined or overturned limbs of major folds. At any rate, adjustments during folding likely develop zones of weakness at contacts between rock units of different competency which, in themselves, may prove favorable structures for ore deposition. Or, zones of weakness inaugurated at contacts ~~inaugurated~~ during folding may determine the position of later faults unrelated to the stresses causing folding. Carrying this idea further, a fault, controlled in its location by structures developed during folding, may be an aftermath of, and indirectly related to, folding. With the relaxation of lateral compression and the cessation of folding, gravity may attempt to compensate for the crustal shortening during folding by active crustal extension in the form of gravity faults. Such faults would tend to follow zones of weakness pre-determined by ~~during~~ folding.

Whether the Indin "break" is merely a zone of shearing or a fault of some magnitude is not known. It is, however, closely related in space to a major contact between rocks of different competency that have been intensely folded. The foregoing hypothesis, relating the origin of such a structure, or at least its control, to folding, is entirely speculation, and its application to the genesis of the Indin "break" may be found invalid when more information is obtained.

<u>"Cross-Faults:"</u>

"Cross-fault" is the term used to denote those structural breaks that cross the map-area in the northwest quadrant and intereect the regional strike at a large angle. Cross-faults invariably possess a left-hand offset, or in other words, rocks on the northeast side of a fault have moved northwest relative to those on the southwest side. Little is known of vertical movement along cross-faults, but the greater part of the displacement is probably in a horizontal direction. Fault-planes, or more correctly fault zones, are seldom visible in the field. In the southern part of the area cross-faults are marked by narrow, lineal depressions usually apparent on aerial photographs. Cross-faults appear to be clean-cut breaks. Pronounced shearing is not evident, and indications of movement are limited to a local crumpling of regional foliation and dragging of beds in the immediate vicinity of a fault. Drag-folds and axes of crumples usually pitch steeply.

North of Negus Lake, the surface expression cross-faults may have had is masked by a heavy mantle of overburden, and although faulting may be indicated by displaced horizons the delineation of the surface trace of a fault is largely a matter of inference.

At one place, north of Corner Lake, what is believed to be a short section along a cross-fault zone is exposed in sedimentary strata. The sediments are brecciated, intensely silicified, and veined by quartz over a width of more than 100 feet. A breccia-zone cemented by quartz is probably the locus of most of the movement along the fault. Breccia fragments are sub-angular, highly silicified, and show no evidence of foliation that presumably existed prior to the introduction of silica. On both sides of the breccia-zone rocks are highly silicified and cut by reticulating stringers and veins of white to grey quartz. Although quartz veins trend in every direction one set of north-trending veinlets is cut and offset to the right by another set trending about northeast. Quartz locally exhibits depositional banding and vuggy structure that may be attributable to low pressures prevailing at the time of deposition. Silicified wall-rock varies from a grey to black, flinty rock composed almost entirely of cryptocrystalline silica to a rock that, though silicified, maintains its essential sedimentary character. Quartz veins are barren, but silicified wall-rock is locally mineralized with finely disseminated pyrite. Farther northwest along the probable extension of the same zone small, irregular quartz stringers exposed on the edge of several outcrops of sediments are probably related to the same cross-fault. Brecciation and silicification, if present, are obscured by overburden.

The zone just described is similar in many respects to the "giant quartz veins" occurring in various parts of the Northwest Territories. Descriptions by Furnival (1935) and Kidd (1936) of giant quartz veins around Great Bear Lake reveals them to be zones of quartz and quartz-cemented breccia flanked by stockworks of quartz stringers. Many occupy large faults, and there is evidence of two or more generations of quartz, separated by long time intervals and deposited in an environment of low pressure and temperature. The zone described by the writer, and believed to occupy a cross-fault, exhibits features vastly different from cross-faults in the southern part of the area where wall-rock alteration is negligible and brecciation is largely supplanted by drag. However, if its origin be ascribed to the same stresses that produced other cross-faults, and if it be considered an analogue of giant quartz veins, the conclusions of Furnival and Kidd, that giant quartz veins represent a very prolonged period of deformation and silica deposition, might offer some support for the contention to be put forth later that cross-faulting represents adjustment to stresses applied over a very extended interval of time.

In the southern part of the area three cross-faults, the Inca, Aztec, and Leta faults, are fairly well established. The Inca fault, which is closely associated spacially with gold mineralization at North Inca, will be considered later in some detail. The Aztec and Inca faults are inferred to converge at the southern end of Float Lake and to continue southeast as a single zone of movement. Between Lexindin and Cranston Lake several probable cross-faults are indicated by displaced sediment-volcanic contacts that, in some cases, may be irregularities in the contact rather than genuine offsets. North of Cranston Lake the faulting pattern is not clear. Probably several cross-faults are responsible for the apparent left-hand displacement of the main sediment-volcanic contact, but unusually scarce exposure, heavy overburden, and poorly understood structural conditions render their delineation impossible.

The Inca Fault

The Inca fault is the best understood cross-fault in the area. It is under water except where it crosses the narrow neck of land separating Indin and Float lakes, and again on the mainland west of Inca Peninsula. In the field an offset of approximately 1000 feet (a horizontal displacement along the fault of approximately 1800 feet) along the Inca fault is indicated by two dykes, one of "metadiorite" and the other of "gabbro", that intersect the south side of the fault on the southern tip of Float Lake and reappear on the north side of the fault on the southwest shore of Float Lake. On both sides of the fault the dykes are essentially parallel, and on the north side the two dykes strike parallel with north-striking sediments, and both sediments and dykes are dragged to the east upon approaching the fault zone. The two dykes are approximately the same distance apart on both sides of the fault which, unless they have identical dips, would imply that the vertical component of movement along the fault is very small. However, the attitudes of both dykes are probably controlled by steeply-dipping beds, or in other words they are sill-like bodies with almost identical dips. If this is so, and assuming no pronounced rotation along the fault, a vertical component of movement would have little effect on the relative positions of the two dykes on opposite sides of the fault. A rough measure of the offset along the Inca fault is afforded by a shift to the left of the east shore of Indin Lake where it crosses the fault. That the lake margin represents approximately the same horizon in the sediments is indicated by a series of very closely-spaced fold axes along the shore for some distance on both sides of the fault. The fault traverses Indin Lake, where it presumably displaces the Indin "break", passes close to the southwest shore of the Inca Peninsula, and enters the western shore of Indin Lake in sediments. Close to the shore the sediments show pronounced drag on both sides of the fault zone. Going inland, the locus of the fault is marked by a poorly defined lineation that disappears when the fault approaches volcanics. From here, as far as the fault was followed, rocks on the south side are dominantly sediments and those on the north volcanics, leading to the conception that volcanics are in faulted contact against the sediments. However, one small exposure of rhyolite was seen south of where the fault is believed to pass.

Relation of Cross-Faulting and Mineralization:

The age of cross-faulting, or at least of the final movement along cross-faults, cannot be defined more exactly than post-Archean and pre-Pleistocene. Cross-faults appear to bear no relation to the system of forces that caused folding, and are undoubtedly later than the bedded shear zones developed during the final stages of folding. On map 697 A cross-faults are shown penetrating for three miles the main granite mass to the west, so that if they be assumed to have formed as a result of stresses activated by the intrusion of the granite a sufficient time lag between emplacement of granite and formation of cross-faults must be allowed for a thick shell of granite to crystallize and become sufficiently brittle to fail by rupturing. It is likely that cross-faulting resulted from a system of forces unrelated to, and much later than, either folding or intrusion of granite.

Likewise, the age of gold mineralization in the area is not known. No intrusive bodies are exposed with which mineralization can be associated with any degree of assurance. With the exception of basic dykes, the most proximate intrusives are a few small, acidic sills that are probably much older than gold mineralization. However, it is interesting to note that many of the known gold occurrences in the area, including those at North Inca and vicinity, are closely related in space to cross-faults, and although cross-faults apparently displace the ore-bearing structures and carry no auriferous lodes themselves. it is not easy to dispel the notion that cross-faults played some role in the localization of ore. The spacial relationship between gold mineralization and cross-faults certainly lends support to the idea, but the timing factor presents a serious obstacle to any theory relating gold deposition to cross-faulting.

Structural conditions at North Inca, although not necessarily representative of the entire area, will be elaborated upon here to present some of the details, so far as known, concerning the relation between cross-faults and gold mineralization. The main ore-bearing shear or Indin "break", in sediments under the waters of Indin Lake, strikes about north-south, roughly parallel to the eastern shore of Inca Peninsula. Its possible origin and relation to the contact have already been discussed. In addition, the gold-bearing Brown veins are exposed in the volcanics on the southern tip of Inca Peninsula. The main, or No. 1, Brown vein is approximately parallel with shearing along the contact, and thus with the main shear, but appears to dip steeply in the opposite direction, i.e. to the east. The main shear is probably offset by the Inca fault, certainly the reverse is not true. The No. 1 vein is offset by several minor parallel faults, notably close to the best ore shoot in the vein, but drilling south of the Inca fault has thus far failed to pick up the faulted extension of the vein. This suggests that the vein may be confined to the north side of, and possibly genetically related to, the Inca fault. If so, it would not be the normal gash-fracture type of vein-filling frequently associated with faulting, as such a structure related to a left-hand, northwest-trending fault should strike in an approximate east-west, rather than north-south direction. The Brown veins are more likely controlled by subsidiary structures related to the formation of the main shear-zone. Mineralization and quartz are similar in the Brown veins and the main shear zone, so that they were both probably mineralized by hydrothermal solutions having a common origin. The Inca fault itself shows practically no quartz, mineralization, or wall-rock alteration, and evidence of movement is restricted to drag, minor brecciation, and crumpling of foliation in the wall-rock.

To recapitulate briefly, the north-south, ore-bearing structures (Brown veins and main shear or Indin "break") are intersected by the northwest-trending Inca fault and, although the ore appears to be pre-faulting, its disposition in relation to the cross-fault suggests that its localization may have been influenced by the cross-fault. As already noted, drag is considerable along the fault zone - an indication that the present level of erosion truncates the fault zone where plastic deformation and bending were considerable prior to any actual rupture along the fault. In other words, the strain, ~~which~~ that culminated in faulting may have accumulated over a long period of time before the advent of rupture. During the accumulation of strain the effect on steeply-dipping strata may have been to develop steeply-pitching, highly-appressed drag folds that might act, in some manner, as channels for ascending hydrothermal solutions; and orebodies might be developed wherever such "channels" intersected structures favorable for the deposition of ore. This, of course, necessitates coincidence in time and space between the formation of ore-solutions and adequate strain accumulation to develop permeable channels for the movement of the ore-solutions. With the consummation of ore deposition strain accumulation would not necessarily cease, and might continue until the elastic limit of the rock was reached and dislocation occurred along the line of maximum strain. Such a conception requires a long time interval between the initial application of stress and the final movement along the fault, but the time factor is probably commensurate with modern views on rates of faulting movement and application of forces that produce the faulting.

The relation of cross-faults to basic dykes in the area suggests that dyke intrusions and cross-faults are quasi-contemporaneous events that proceeded over a long period. Dykes and cross-faults conceivably could represent adjustments to a single set of stress conditions. In some places, as exemplified by the Aztec fault, intrusions of diorite and gabbro apparently follow cross-faults. In the previously described silicified fault-breccia zone north of Corner Lake fresh diabase is exposed in silicified wall-rock, itself apparently unaffected by the alteration. Other dykes show a considerable change in trend as they approach the cross-fault to which the silicified breccia is believed associated, as if there is large-scale drag connected with the fault. These same dykes apparently are older and younger than the cross-fault. In this connection, Kidd (1936) finds late basic intrusives older and younger than giant quartz veins which, if the analogy already made between giant quartz veins and the silicified breccia-zone is genuine, and the breccia-zone occupies a cross fault, could be offered as additional support to the close time relationship assumed between cross-faulting and dyke intrusion.

A gabbroid dyke north of Cranston Lake is chilled against ferruginous gouge that may, or may not, be related to cross-faulting. The same dyke, a few hundred feet south of the above locality, is highly carbonatized and altered where it passes a few feet from the foot-wall of a mineralized zone carrying minor gold values.

Basic dykes are definately offset in the southern part of the area by the Inca and Lèta faults. No shearing or alteration were observed in the dykes where they cross the fault zones, the actual intersections being obscured by drift, and there is always the remote possibility they are post-faulting and occupy structures that were displaced by the faults before being filled by the dyke-rock. However, a more logical explanation is to assume more than one age of dyke-intrusion, or faulting, or both; or as already stated, that dyke emplacement and faulting are more or less contemporaneous events that took place over a protracted time interval.

The foregoing discussion does little to elucidate the problem of the relation between cross-faulting and mineralization, but might serve to strengthen the idea that cross-faulting reflects a very slow adjustment to regional stresses; and help justify the theory that ore-solutions may have been channeled by structures developed during the accumulation of strain that culminated in cross-faulting; and that between initial application of stress and final rupture a sufficient time interval elapsed for mineralization to be effected. Such a conception, to advance beyond a proposed theory, requires a great deal more information than at the writer's disposal, and drilling must be relied upon to supply much of this information. Resolution of the problem would necessitate an extremely detailed examination of cross-fault zones and any subsidiary structures. In particular, the validity of the theory would be enhanced by evidence for the control of mineralized lodes by steeply-plunging structures, such as drag folds, related to cross-faults; and evidence for the control, in mineralized lodes (such as the Indin "break") intersected by cross-faults, of mineralization by fractures (say earlier quartz fractured and veined by metallics) whose pattern could be related to the assumed stress pattern operative during strain accumulation, mineralization, and faulting.

Undoubtedly, as drilling and underground work proceed in the area, and more is learned of the geology, many of the present ideas will be revised, and any conclusions based on evidence available at present should be regarded as tentative and of use only insofar as they prove to be correct.

REGIONAL METAMORPHISM

The writer classes under "regional metamorphism" those changes induced in the rocks by the interaction of heat and pressure operative on a scale transcending the limits of the map-area; and excludes such effects as hydrothermal alteration associated with mineralization, thermal metamorphism related to minor intrusives, and weathering related to the present level of erosion. The present mineralogy and internal structure of the rocks reflect an attempt to attain physical and chemical equilibrium with a new environment resulting from changes in heat and pressure. The tremendous tangential forces to which the region was subjected during folding developed powerful differential pressures or shearing stresses that, in conjunction with any frictional heat evolved by shearing and crushing, constitute the principal agents of metamorphism. Any frictional heat generated in situ by shearing may have been augmented by heat associated with the invasion of granitic batholiths that surround, and presumably underlie, the map-area.

Changes effected by metamorphism consist of mineralogical transformations and internal structural rearrangements or mechanical changes. The latter have already been discussed, and include regional foliation (flow cleavage, schistosity, and augen-like structures) and the development of linear elements such as elongated fragments and lenses of mafic minerals, as well as permanent strain effects and cataclastic deformation of individual minerals as exemplified by strained quartz, bent or fractured feldspar grains, and twinned carbonate.

Most rocks have been partially or wholly reconstituted to a new mineral assemblage that is relatively simple for a suite of such diverse rock types. Quartz, chlorite and carbonate are almost universal, and are usually supplemented by clinozoisite, zoisite (?) or epidote and amphibole in basic volcanics, and sericite in acid volcanics and sediments. Feldspar, except in late basic intrusives, when identifiable is almost invariably albite. In most rocks albite occurs as small, clear, untwinned grains intergrown with other minerals and difficult to distinguish from quartz, and primary phenocrysts in flows, fragments in tuffs, and detrital grains in sediments. The former albite was probably either introduced or released by the break-down of primary minerals; and the latter were probably plagioclases of varying composition that were albitized by molecular replacement that failed to destroy the form and lamellation of the original feldspar grain. The writer does not feel qualified to theorize on the basis of the few sections studied under the microscope, but suggests that the apparent prevalence of albite feldspar may denote either that the rocks belong to a sodic province, or the "spilitic suite" of British petrologists, or that subsequent to their formation the rocks were "soaked" by soda-rich emanations, possibly concomitant with intrusions of granitic magmas, that converted all feldspar to sodic varieties. At any rate, such an association of minerals as chlorite, albite, epidote and sericite are typical of a fairly low grade of metamorphism in which the dominant factor was differential stress somewhat abetted by elevated temperatures and accompanied by material introduced from meteoric, and possibly abyssal, sources. Chlorite, sericite, and albite (?) are diagnostic stress minerals whose abundance, coupled with the absence of abundant typical anti-stress and high temperature minerals, attests to the pre-eminence of dynamic forces of metamorphism under low or intermediate temperature conditions.

Up to this point no mention has been made of biotite, which is widespread and in some places abundant, and which is most likely of metamorphic origin. In the field, biotite became conspicuous in volcanics in the northeast corner of the map-area, but unfortunately mapping was suspended here so that the extent and significance of the "biotite zone" were not pursued to completion. In the field, the sudden appearance of biotite suggested a discontinuity in the regular disposition of metamorphic grade as might result from:

(1) unrecognized faulting bringing a zone of higher grade metamorphism to the surface.

(2) a fortuitous irregularity in isograd surfaces as could result from an unexhumed intrusive (possibly satellite to the main granitic intrusives) or a summit cupola in the roof of a deep-seated granitic basement.

Also significant is the spacial relation between the "biotite-zone" and tourmalinized sulfide deposits and quartz veins, as well as the only pegmatitic vein observed in the map-area. Thus the higher metamorphic grade indicated by the presence of biotite is accompanied by a higher temperature type of veining and the apparent derivation of boron from a source not far removed from the same locality.

Field conclusions, however, are somewhat complicated by microscopic examination of the rocks. In thin-section biotite was observed in most rock types - exceptions being minor acid intrusives, some of which may post-date the formation of biotite, and acid volcanics where the necessary constituents for its formation probably were not present. Biotite in basic intrusives may be primary or the alteration product of ferromagnesian constituents, but in other rocks its features are characteristic of a metamorphic origin. It is the brown, ferruginous variety of biotite, strongly pleochroic from brown to pale tan or almost colorless. The optic angle is very small, approximately zero for most grains tested. In some places biotite is relatively free of inclusions and possesses regular margins, but in other places it exhibits a well-developed poikiloblastic structure and sutured margins. The one feature in the habit of biotite that seldom varies is its intimate association with chlorite. It is almost invariably surrounded by, or in contact with chlorite. The problem arises of which is the older mineral and whether one is an alteration product derived from the other. Contacts between biotite and chlorite vary from very sharp to relatively gradational across the contact, and from linear to irregular along the contact. Various relationships between the minerals may be summed up as follows:

(1) irregular, diffuse patches of chlorite within biotite grains.

(2) small "residuals" of biotite surrounded by chlorite (plate 12)

(3) chlorite "eating into" the margin of biotite grains

(4) parallel intergrowths of alternate bands of biotite and chlorite.

(5) wedges of chlorite penetrating biotite grains from the margin and tapering out within the biotite grains (plate 13).

The writer interprets the foregoing as evidence favoring the formation of chlorite after biotite.

In many sections are minute, prismatic grains of a greenish mineral with parallel extinction and very low birefringence. The habit suggests biotite but the optic properties indicate chlorite or a mineral closely allied to chlorite; so that these small prismatic grains may be pseudomorphs of chlorite after biotite. In one section grains of chlorite showing an anomalous "Berlin-Blue" interference color are quite definitely pseudomorphs of chlorite after biotite. The chlorite maintains the same form and cleavage orientation as the parent biotite (plate 12).

Therefore, although none too well founded on the basis of such a limited scope of work, the writer concludes that biotite is of metamorphic origin, formed at the expense of

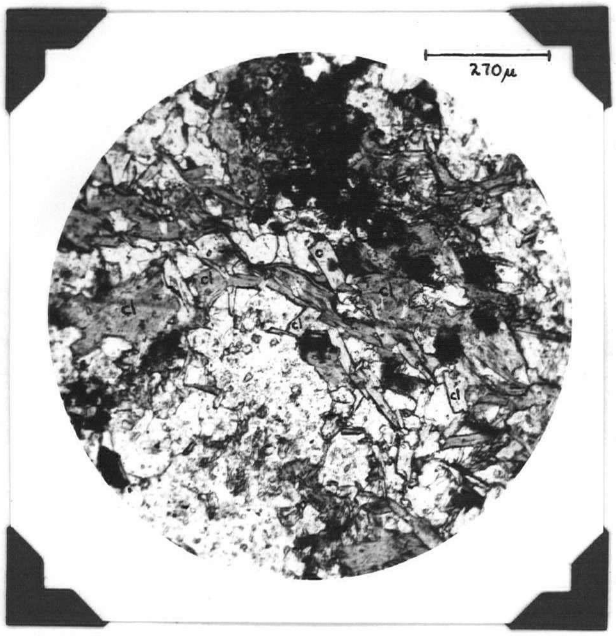


Plate 12: Pseudomorphs of chlorite (cl) after biotite. Slightly above centre of photomicrograph a small "residual" of biotite (dark grey) appears in chlorite (c).

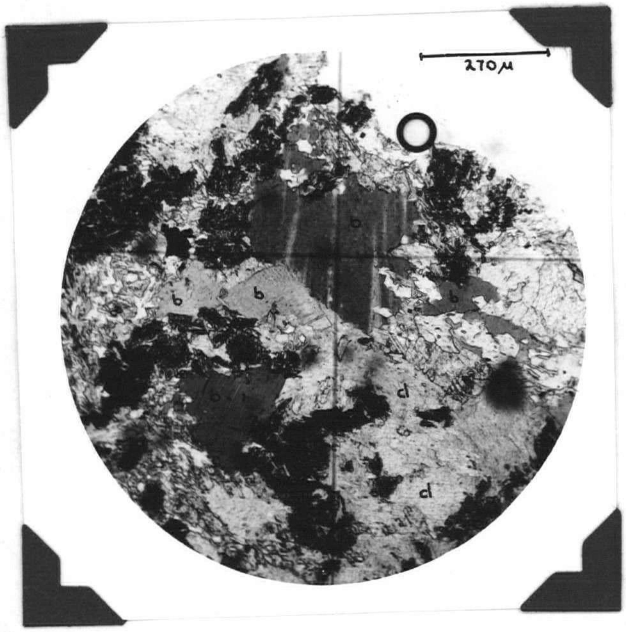


Plate 13: Biotite (b) altered to chlorite (cl) along bands and "wedges" parallel with cleavage in biotite (best seen in largest biotite grain.

minerals developed mainly by dynamic processes during folding, and that, since its formation, much has partly or wholly reverted to chlorite. The writer is not prepared to say how much of the chlorite now present in the rocks was developed by metamorphism accompanying folding, and how much was derived from biotite. Presumably, the biotite formed largely at the expense of chlorite, which would exert considerable influence on the abundance and disposition of biotite in the rocks. It is unlikely that the chlorite, which would provide the starting-point for biotite, and the chlorite derived from biotite, would vary markedly in optical properties; and it cannot be assumed that all of the later chlorite presents itself as pseudomorphs after biotite. In short, the extent to which the rocks were biotitized previous to retrogression to chlorite is difficult to evaluate, and the appearance of more biotite in some areas than others might be a reflection of irregularities in the degree of biotitization, differences in the degree of retrogression to chlorite, or be dependent on other factors set forth earlier in this discussion.

Turning to the probable genesis of biotite, some consideration must be given its relation to regional foliation. Where developed in considerable quantity, biotite occurs, with chlorite, in lenticular zones elongated parallel with foliation. Individual grains of biotite rarely show evidence of bending or contortion and have grown at all angles to foliation. Admittedly, a great many biotite flakes lie closely parallel to the direction of foliation, but an almost

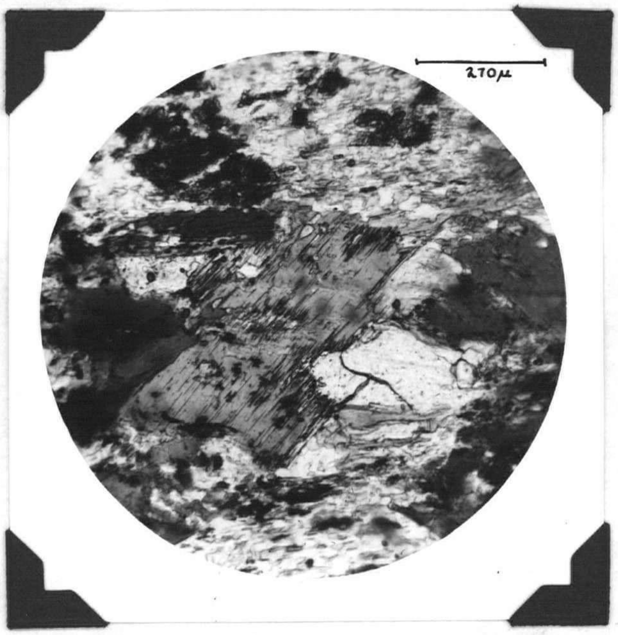


Plate 14: Metamorphic biotite that has grown at a large angle to regional foliation (approx. horizontal), indicating the biotite was generated after relaxation of the stresses causing foliation.

equal number lying athwart the foliation lends support to the contention that most of the biotite developed subsequent to foliation, i.e. after relaxation of the stresses causing folding (plate 14). The extent to which biotite orientation conforms with foliation might be the combined effects of the influence of chlorite, oriented with the foliation and providing a nucleus for biotite; of any recurrent stresses concurrent with the growth of biotite; and possibly of early growth of biotite, before cessation of folding and before the main spread of biotitization, in local zones of above-average heat intensity.

Biotite may be attributable to a rise in temperature during the ebbing stages of folding when mechanical and frictional heat developed by folding would likely reach its maximum. Or, it may be related to a rise in temperature accompanying the invasion of large, plutonic masses of granitic rocks whose emplacement was soon after, or much later than, the consummation of folding.

To summarize, regional metamorphism in the area may be divided into three categories:

(1) Dynamic metamorphism associated with folding and accompanied by the generation of stress minerals.

(2) Thermal metamorphism due to a temperature rise and tending to substitute anti-stress minerals for stress minerals.

(3) Retrograde metamorphism - a degradation process including the reversion of biotite to chlorite.

The writer is aware that the foregoing is an exceedingly incomplete treatise of such a complex mechanism as regional metamorphism, particularly where more than one kind of metamorphic process is involved. Along with the transformations described, analogous changes would take place in other members of the mineral assemblage. The changes that have been described are intended only as an index to the types and intensity of the metamorphic process involved.

Then, too, some of the changes noted could not have obtained without the intervention of some element of metasomatism, probably involving additions of some material from both abyssal and atmospheric sources, and partial elimination of other material. Any changes in the bulk composition of the rocks have been omitted in the foregoing discussion on metamorphism.

CARBONATE ALTERATION

Widespread carbonate alteration of rocks in the area is of sufficient interest to warrant a brief consideration here. Its relation to gold mineralization is not known, so the following discussion will be mainly descriptive.

As already stated, in the field "carbonate-zones" are abundant in volcanic rocks, usually associated with zones of intense shearing. They vary from rocks almost completely replaced by carbonate to rocks highly impregnated with disseminated carbonate but maintaining their essential original characteristics. Carbonate zones usually weather rusty, and locally break down to a rusty gossan. Carbonate also appears in veins, with or without quartz. Vein-carbonate is usually in coarsely-crystalline, cleavable masses, and is white, buff, or brown and to a lesser extent pinkish or grey.

The most unusual occurrence of carbonate, and the one on which the greater part of this discussion will be centred, is as metacrysts. Carbonate metacrysts, although most abundant in volcanic terrain, are not limited in distribution to any particular rock type. They were observed only in the southern half of the map-area, where they are localized, to some extent, in rocks close to volcanic-sediment contacts. They reach their maximum development in altered dykes and sills, but were observed in all kinds of volcanic rocks and in fine-grained sediments. The altered, so-called "carbonate-dykes" have apparently proved the most favorable site for the development of carbonate metacrysts. The "dykes" were probably originally quite basic in composition, but are now composed essentially of chlorite and carbonate. They are definately intrusives that have been subsequently carbonatized, rather than regular zones of alteration; as they frequently traverse the structural trend and show intrusive relations against the adjacent rocks. They vary from rocks that are almost entirely carbonate, through rocks that show large metacrysts set in a green or grey groundmass, to metacryst-bearing rocks that resemble some varieties of diorite and gabbro dykes. The latter occasionally have metacrysts concentrated in the marginal zone of the dyke. It is not known whether "carbonate-dykes" represent one kind of dyke, or whether they include dykes of several kinds and ages. In many places rocks adjacent to dykes carrying carbonate metacrysts exhibit metacrysts that diminish in size and peter out a few inches away from the dyke. It is as if the agents that formed the metacrysts ascended along the dyke fissure, affecting the dyke-rock and at the same time exerting a minor influence upon the wall-rock. In many localities, however, metacrysts in volcanic rocks show no particular spacial relation to "carbonate-dykes", but these same localities are usually not far removed from a major volcanic-sediment contact.

The metacrysts vary from a fraction of a millimeter to nearly 1/4 inch across. They usually weather to form a square or rhombic pit partially filled with indigenous limonite. Where metacrysts are small and abundant their tendency to weather out imparts a porous appearance to the surface of the rock. Carbonate metacrysts are light brown to pale tan when fresh, but weather dark brown or rusty for 1/4 to 1 inch below the surface of an exposure.

Metacrysts are revealed under the microscope in rocks where they are quite unapparent megascopically. They usually show prominent cleavage and an extremely high birefringence and pronounced change of relief, and occasionally exhibit very coarse twinning or brown alteration at crystal margins and working along cleavage planes (plate 15). Some have sutured boundaries and a sieve structure (plate 16), while others, from which all inclusions have been expelled, have sharp, regular boundaries, Metacrysts usually have grown in the fine-grained portion of rocks, but many were observed completely enclosed in feldspar grains. With the exception of twinning, metacrysts show no evidence of deformation, have not been affected by or exerted any effect upon foliation, and appear to have grown passively after the development of foliation.

The metacryst-forming carbonate exhibits an idiomorphic tendency not displayed by normal calcite. Since the optical properties of the various members of the calcite group are not distinctive, the writer attempted to ascertain the composition of the carbonate by specific gravity and chemical methods. A series of nine specific gravity determinations were made on fragments of the mineral picked as clean as possible under binoculars. The results gave a value of $2.87 \pm .03$ (with an average of 2.88) for the specific gravity of the carbonate.

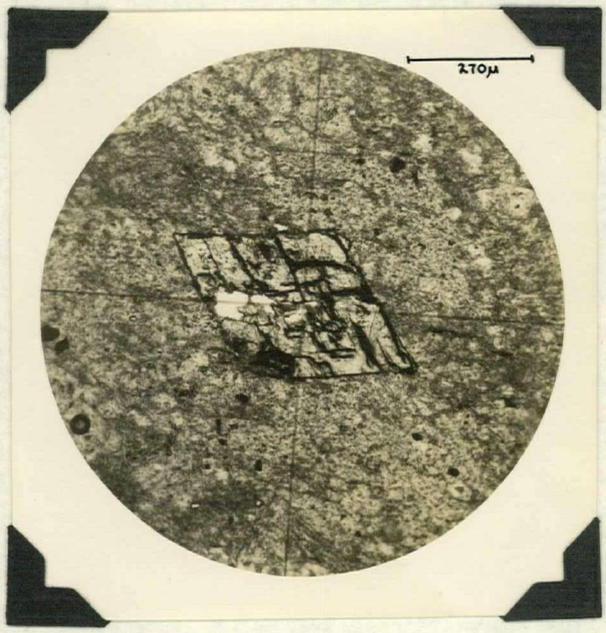


Plate 15: Carbonate (ankerite) metacrysts in rhyolite flow. Note pronounced cleavage and brown alteration (black) around margin and penetrating cleavage cracks of the metacryst (foliation approximately horizontal).

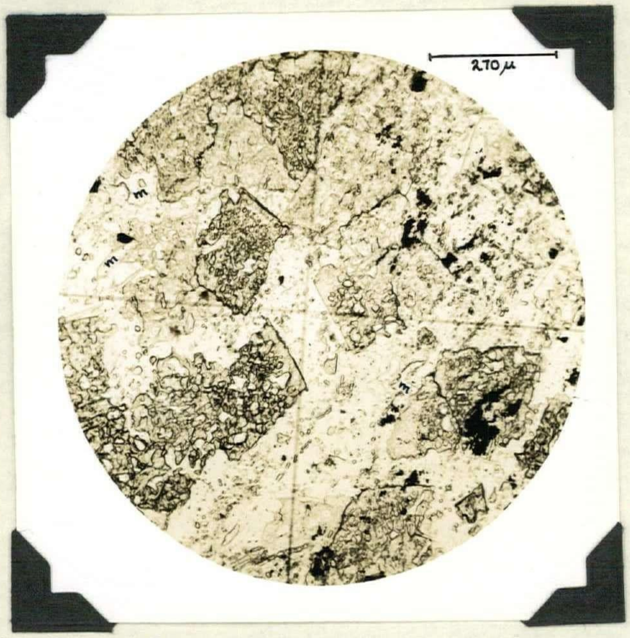


Plate 16: Poikiloblastic metacrysts of ankerite (high relief) in carbonate zone with green, phengitic-muscovite (m). Note variation in relief between different grains of carbonate. Foliation in N.E. - S.W. quadrant.

However, undue emphasis cannot be placed upon specific gravity measurements owing to inevitable contamination by minute inclusions of other minerals. Extremely slow effervescence of the carbonate in cold acid is accelerated rapidly by heat. A fragment heated to red heat becomes strongly magnetic upon cooling. Chemical tests confirmed the presence of Ca, Fe, Mg, Mn, and CO_2. Tests for Mg and Mn were not as conclusive as might be desired, but the writer feels certain the two elements are present in considerable amounts. The results of the foregoing tests indicate the carbonate is a type of dolomite intermediate between magnesiodolomite and ferrodolomite, with some manganese probably replacing magnesium in the molecule. Its composition could be represented by the formula $Ca\,CO_3 \cdot (Mg,Fe,Mn)\,CO_3$, and it would probably be correctly termed an ankerite. The specific gravity obtained by the writer (2.87) agrees with that of dolomite (2.8-2.9) rather than the accepted value for ankerite (2.95-3.1), as given by Dana (1932, pp. 516 and 517) The discrepancy could probably be imputed to minute inclusions of feldspar, sericite, and quartz that, incidentally, were observed in a thin-section of the same rock from which the carbonate for specific gravity determinations was obtained. Inclusions of such minerals having a lower specific gravity than the carbonate would tend to lower its average specific weight, and yet if uniformly distributed would yield fairly consistent results to specific gravity determinations.

Ankerite is by no means limited to euhedral crystals, or metacrysts, but exists rather commonly as highly sutured, poikiloblastic grains (plate 16) and mosaic patches in various kinds of rocks. It is abundant in acid volcanics, where it has a marked tendency to replace feldspar grains.

On the southwest shore of Negus Lake an exposure of volcanics reveals a highly carbonatized zone with abundant flakes of a brilliant green, micaceous mineral not observed elsewhere in the area. In the field the green mineral was thought to be a chromian mica of the mariposite-fuchsite-muscovite series, especially in view of the fact that chromium-bearing micas frequently accompany zones of ferruginous carbonate alteration adjoining prominent faults.

Rock from the carbonate zone exhibits inherent regional foliation, has a rusty, finely-pitted, weathered surface, and a variegated grey to buff fresh surface that shows myriads of tiny, sparkling, cleavage-faces of carbonate. The green mineral occurs in narrow streaks elongated parallel with the foliation.

The microscope reveals the rock is composed of over 50 percent ankerite as euhedral rhombs, mosaic patches, and irregular grains with a very pronounced sieve structure. Quartz and pale-tan, opaque, alteration material are plentiful along with varying amounts of colorless chlorite (?), fine crystals of rutile (?), sulfides, and minute, prismatic crystals of an unidentified mineral with very low birefringence The green mineral constitutes about 5 to 10 percent of the rock. Its optical properties are:

(1) one perfect cleavage; parallel extinction; length-slow

(2) pale green color; very weakly pleochroic

(3) prominent change of relief

(4) biaxial (-); 2V = 35^{o}

(5) birefringence = .035

(6) $1.599 > \beta > 1.588$

The optical properties indicate that the mineral belongs to the mica group of minerals, and more particularly to the potash micas. The green color is not typical of normal muscovite. The moderate optic angle and mean index practically eliminate the possibility of mariposite. The optic properties correspond closely to those of fuchsite, reputed to contain from .27 to 4.81 percent Cr_2O_3 (Whitmore, Berry and Hawley, 1946, p.15), although fuchsite carrying only a trace of Cr_2O_3 has been noted (Whitmore, Berry and Hawley, 1946, p.13). In testing for chromium, the writer, cognizant of the inseparability of ankerite from the green mineral and the consequent adulteration with iron, felt that the inconclusive positive bead-test obtained for chromium could not be relied upon. A check was made by spectrographic analysis and yielded negative results for chromium, practically eliminating all possibility of the mineral being chromiferous. The writer then concluded that the mineral is probably a member of the muscovite-phengite system, the small optic angle attributable to a high tenor of phengite and the unusual green color possibly the result of an appreciable iron content contributed by the phengite molecule (Winchell 1932, P 268).

In conclusion, the writer might add that the problem of carbonate alteration in the area might lead to significant results if pursued to completion. Carbonate-zones and carbonate metacrysts should probably be divorced from the minor carbonatization of all rocks as a result of the breakdown of primary minerals during regional metamorphism. The former are the result of hydrothermal action, probably operative after regional dynamic processes and possibly quite late as indicated by the presence of metacrysts of carbonate in some of the diorite-gabbro intrusives. Also worth reiterating is the fact that some of these same basic dykes have been affected by carbonatization (not as metacrysts) associated with sulfide mineralization accompanied by very minor gold values. Proof is lacking of whether carbonate metacrysts represent an early stage in the conversion of rocks to carbonate-zones. Certainly the carbonate of both is the same ankeritic variety. On one hand, abundant metacrysts in altered basic dykes ("carbonate-dykes") suggests that the dyke fissures, after they were filled by dyke-rock, proved in some manner permeable conduits for the ascent of carbonate-bearing solutions. On the other hand, the apparent close relation of carbonate metacrysts in other kinds of rock to the main sediment-volcanic contact suggests that the phenomenon is a phase of alteration controlled in some measure by the contact, and not restricted to any particular rock type. The general proximity of metacrysts to the best, known ore-bodies in the area, ie, their restriction to the southern part of the map-area, if genuine, suggests that the metacrysts are in some way genetically associated with gold mineralization or controlled by the same structures that have localized mineralization. If carbonate alteration, particularly metacrysts, could be related spacially or genetically to gold mineralization, it could conceivably become a useful indicator of gold potentialities in other parts of the region. Admittedly, it would not be decisive evidence and its application would be on a broad scale, but it might lend assistance in the selection of favorable prospecting and testing ground.

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