THE GEOLOGY AND HYDROTHERMAL ALTERATION
OF THE SULPHURETS DEPOSITS,
NORTHWEST BRITISH COLUMBIA

A Thesis
Presented in Partial Fulfillment of the Requirements for the
DEGREE OF MASTER OF SCIENCE
Major in Geology

in the
UNIVERSITY OF IDAHO GRADUATE SCHOOL
by

THOMAS MASON SIMPSON
January, 1983

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A preliminary draft of the thesis entitled "The Geology and Hydrothermal Alteration of the Sulphurets Deposits, Northwest British Columbia" by Thomas Mason Simpson for the Master of Science degree with a major in Geology has been reviewed and found adequate. The committee hereby grants permission for the preparation of the final copy incorporating suggestions made by the committee. Permission is also given for the scheduling of the final examination to be held when authorized by the graduate dean after submission of two final copies of the thesis to the Graduate School.

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ABSTRACT

The Sulphurets region during early Jurassic time was the site of an isolated marine basin. This marine basin was infilled with sedimentary detritus of the Hazelton Formation. This detritus formed mainly arkosic and lithic arenites of very juvenile character. Siltstones and mudstones were also deposited. Some felsic volcanic rocks of lava(?) flow origin occur within the sedimentary pile.

The sedimentary-volcanic pile, during later stages of diagenesis, was intruded by calc-alkaline magma which differentiated over time in a hypabyssal environment and formed the Mitchell Intrusions. Intrusive rocks vary from earlier hornblende-bearing feldspar porphyries to later hornblende-poor feldspar porphyries, monzonites, granites and syenites. The intrusive rocks could have been contaminated by marine connate waters from the sediments which resulted in albitization of all plagioclase feldspars within the Mitchell intrusive complex. Plagioclase in the sedimentary-volcanic pile was also albitized possibly due to static thermal metamorphism by the intrusive rocks.

Hydrothermal alteration in the study area is very intense and results in almost total destruction of original texture in all the rocks. The hydrothermal system, believed to have commenced during the later stages of Mitchell intrusive activity, propylitized the earlier Mitchell

Intrusions. Sericitic alteration, silicification and potassic alteration overprinted almost all of the earlier formed propylitic alteration as the hydrothermal system expanded. Sericitization is characterized by the development of sericite after feldspar and in the groundmass. Quartz-sericite-pyrite rock is very commonly the result of sericitization. The only important variation of sericitic alteration is the occurrence of tourmaline in local areas. Silicification is most common in the sericitic zone, but is also found with mineralization in the potassic zone. Silicification is characterized by addition(?) of quartz in brecciated areas and veins. Potassic alteration is characterized by fine-grained biotite with minor orthoclase. Alteration zones grade from propylitic on the west to sericitic on the east. Potassic alteration is patchy in areal distribution and occurs only on the eastern side.

A wide, prominent north-south fault zone is apparent in the Sulphurets region. Microbreccias due to cataclasis have been found. Microbrecciation could be due to movement along the north-south zone. The north-south fault zone probably provided a zone of weakness which allowed migration of intrusions and later hydrothermal fluids.

Mineralization is of the Southeast Asia gold-rich porphyry copper type. Chalcopyrite and pyrite are found as disseminations and in veins closely related to the potassic alteration zone. Gold-pyrite mineralization occurs within the sericitic zone as disseminations with tourmaline in intrusive breccia, and with quartz in veins in shattered blocks of quartz-sericite rock. Pyrite is ubiquitous and formed during several generations over the entire time period involved. Pyrite occurs as disseminations, with quartz in veins and as massive replacements, commonly with minor chalcopyrite and molybdenite. It is unknown how the gold occurs, but it is suspected to be associated with a single generation of pyrite. Molybdenite is found in minor quantities with massive pyrite bodies in the sericitic zone and, in a few places, as fracture coatings within the potassic zone. Copper and gold values are generally proportional to each other in both potassic and sericitic zones, but gold content is lower in the potassic zone. Galena and sphalerite are rare, and are found with intensely silicified zones within the sericitic zone. The Sulphurets prospect is overall a high-total-sulfide deposit with 3 to 5 percent pyrite.

All previous workers at Sulphurets considered it to be an alkaline suite porphyry deposit. Alkaline porphyry systems are characterized by: association with alkaline intrusive complexes intruded into coeval volcanic rocks; a core of potassic alteration surrounded by a very large propylitic zone with little or no sericitic alteration; and

gold enrichment. Sulphurets is characterized by: association with a calc-alkaline intrusive complex; the enclosing strata are non-coeval; irregular patches of potassic alteration surrounded by a very large zone of sericitic alteration; the potassic alteration is characterized by development of biotite; and gold enrichment.

Few correlations to other gold-rich porphyry deposits in British Columbia exist except for gold enrichment. Similarities between Sulphurets and porphyry copper deposits of Southeast Asia are: high-total-sulfide content; calc-alkaline intrusive rocks which acted as the source for the mineralizing and altering fluids; and potassic alteration characterized by biotite with minor or no orthoclase. Sulphurets should be classified with the Southeast Asia deposits on the basis of these similarities.

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INTRODUCTION

The study area (figs. 1,2,3) is located within the Unuk River region of northwest British Columbia and lies in the Sulphurets valley about 5 kilometers above the confluence of the Sulphurets Creek with the Mitchell Creek (fig. 2). The nearest settlement, the town of Stewart, is approximately 88 kilometers by air to the south (fig. 2). The international border and the city of Ketchikan, Alaska are located approximately 19 kilometers and 177 kilometers, respectively, to the southwest. The area lies near the crest of the Coast Range Mountains which are very steep and rugged with relief of 1200 to 1500 meters. Active glaciers and icefields enclose the area on the north, east and south sides.

Access is gained either by overland travel on foot from the west or by air. No airstrips exist in the area, limiting air access to helicopter only.

Previous Work

Activity in the area dates back to the late 1800's when the first placer claims were staked in Mitchell valley. The only work in the area until 1960 was performed by a few prospectors hardy enough to hike into the area.

Newmont Mining Corporation commenced a regional exploration proram in the Unuk River region in 1960 and became further interested by the discovery of "porphyry-

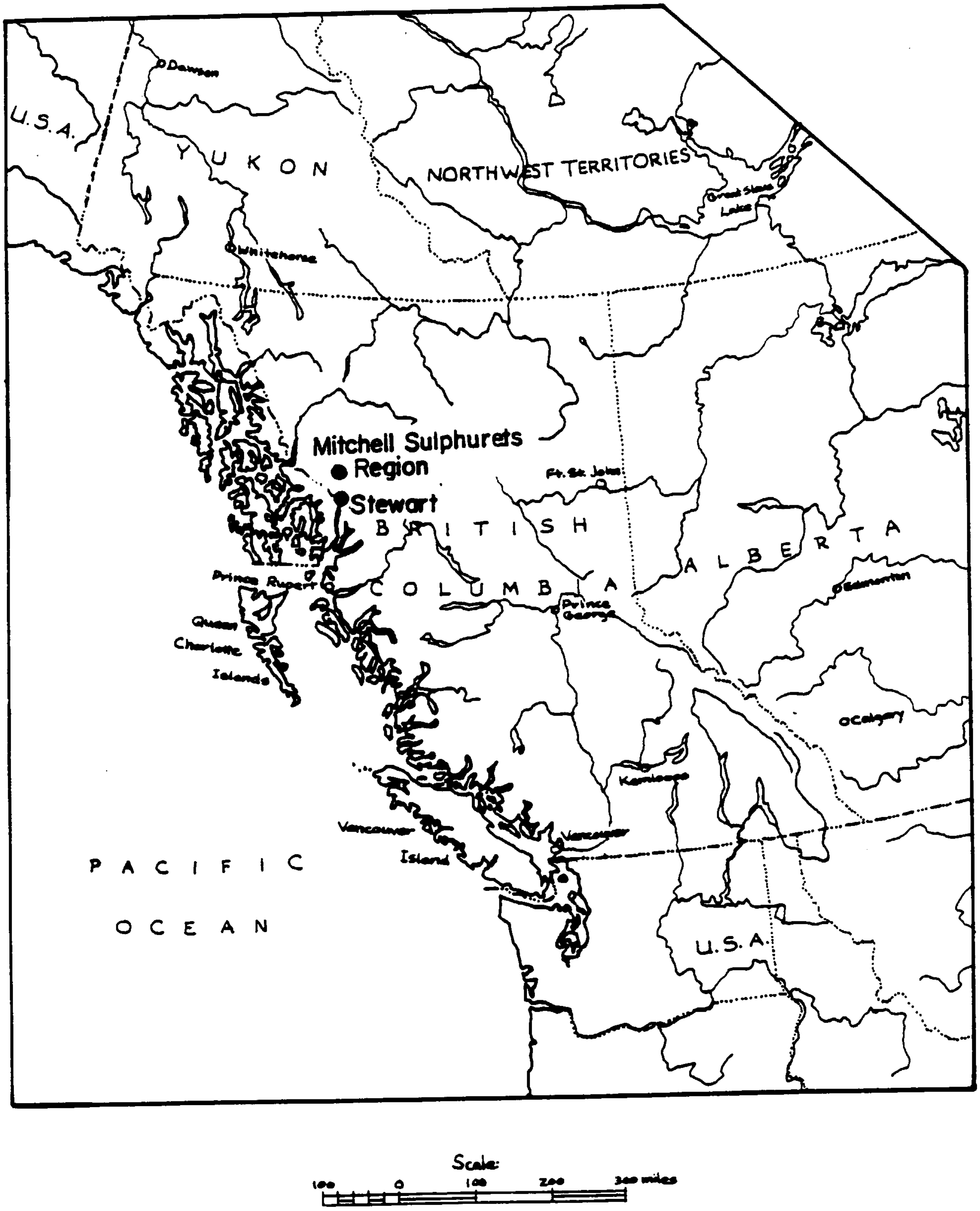


Figure 1. Location of Sulphurets region in British Columbia

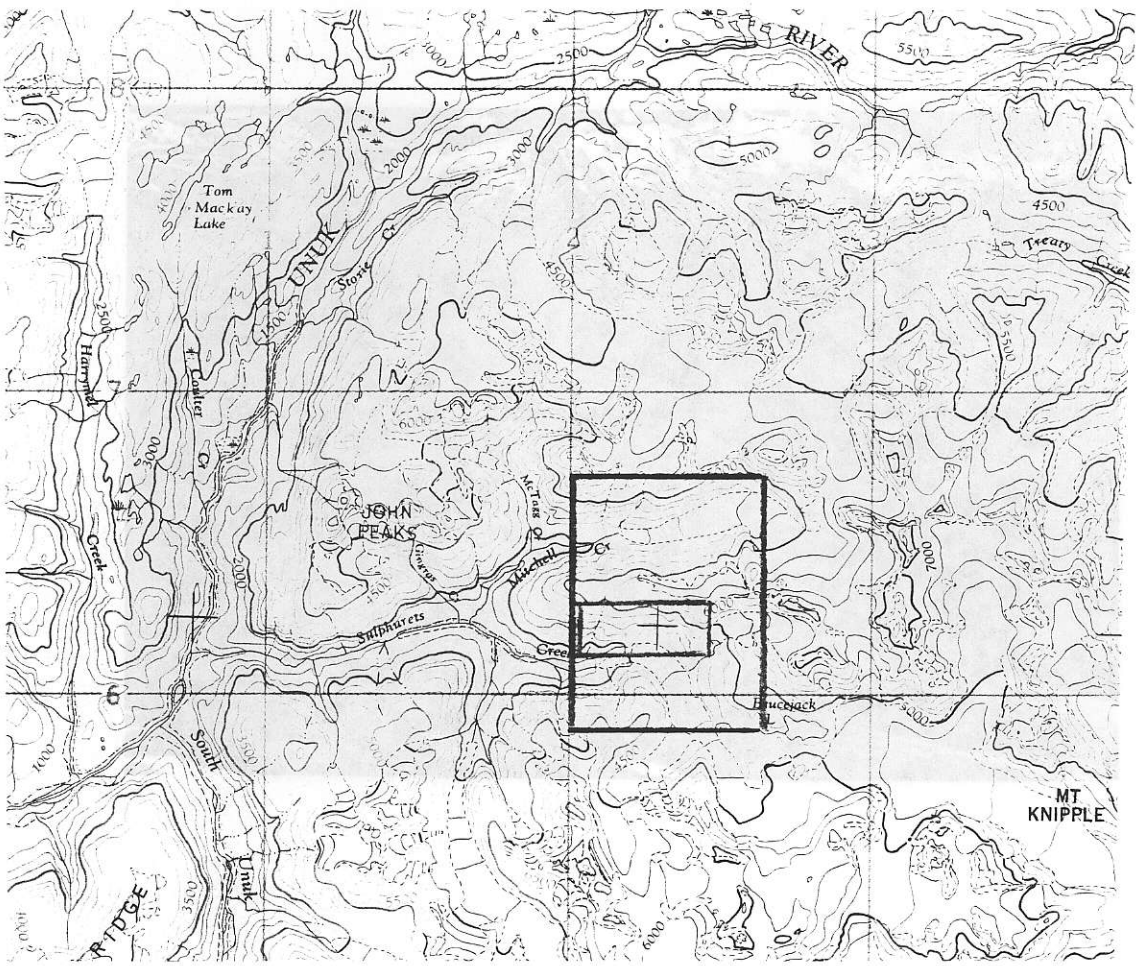


Figure 2. Location map of study area. The area for this paper is outlined in red. Study area of Kirkham (1963) is outlined in blue. Scale is 1:250,000.

Figure 3. Oblique aerial photograph of the Sulphurets gold zone. The Suphurets Glacier is at the lower left of photograph. Looking northwest.

copper" type mineralization in the area of the Mitchell-Sulphurets valley (Kirkham, 1963). As part of the follow-up work by Newmont Mining Corporation a M.Sc. thesis was written by R.V. Kirkham in 1963 at the University of British Columbia. Kirkham mapped and studied the petrology of a large area centered over the Mitchell-Sulphurets drainages (fig. 2). Kirkham's work is the only detailed published account of the geology of the area. Grove (1971) discussed the geology and mineral deposits of the Stewart area, which comes within 32 km of the Mitchell-Sulphurets region, and has some reference to the geology of the region.

Since Newmont Mining Corporation's work the area was acquired by Granduc Mines Ltd.. The property is currently under option to Esso Minerals Canada as operator. Several reports concerning the study area have been generated by the companies working there, but they remain the proprietary information of the respective companies.

Purpose and Scope

The purpose of this investigation is to study the geology and hydrothermal alteration of areas with anomalous gold values which are associated with porphyry copper-type mineralization. The main area of widespread anomalous gold values is concentrated along the north side of the Sulphurets valley (fig. 3). This area is referred to as the Sulphurets gold zone. Regional and detailed geology, hydrothermal alteration, petrochemistry and structure are studied, with emphasis on detailed geology and hydrothermal alteration, to aid in the understanding and interpretation of the geologic history of the mineralized areas.

Methods of Study

The study area of five square kilometers was mapped and sampled in detail during the summer of 1981. The western one-third of the Sulphurets gold zone was mapped and sampled, using air photographs at a scale of 1 to 5000. The central one-third and eastern one-third portions of the Sulphurets gold zone were mapped by W. Melnyk and D. Bridge, respectively, at the scale of 1 to 5000. Plates 1 and 2 are outcrop maps derived from compilation of the field maps. Eight diamond drill holes were sampled in detail by the author for petrographic study.

Laboratory work was completed during the winter and spring months of 1981-82. A total of 130 thin sections, including 37 surface samples and 93 core samples were studied with a petrographic microscope. All thin-section, cut-off slabs were stained by sodium cobaltinitrite for potassium feldspar. Forty-one samples were prepared and analyzed by X-ray fluorescence at Washington State University. Thirty-six of the 41 samples were analyzed by atomic absorption spectroscopy for Na_2O and K_2O at Acme Analytical Laboratory in Vancouver, B.C. A total of 7 samples were analyzed by X-ray diffraction at the University of Idaho to aid in mineral identification of certain alteration minerals. Petrochemical analysis of major oxide chemistry was performed at the University of Idaho using computer program number C542 (R.W. Bowden of the USGS Computer Center Division, Denver, Colorado). A Lambert equal-area projection net is used for analysis of fracture attitudes collected while in the field.

GEOLOGY

The geology of the Sulphurets area is difficult to interpret due to the intense and widespread hydrothermal alteration. Sericite is a ubiquitous alteration product and colors most of the rocks various shades of green, thus making sedimentary rocks indistinguishable from intrusions and lava flows. Lithologies of the study area were identified by thin section study. In most thin sections lithologies are indecipherable, but several valuable observations were made which helped with reconstructing the history of the area.

Due to the nature of this study, only a small area (approximately five square km.) was mapped (fig. 2) and studied in detail. Therefore, the author has had to rely on the studies by Kirkham (1963) for the regional geology. Kirkham also had difficulty in distinguishing the original lithologies of the region. He collected unaltered samples outside of his study area that he inferred to be equivalent to rocks in the study area.

The Mitchell intrusive complex in the Mitchell-Sulphurets region was originally thought, by all previous workers, to be of the alkaline suite, similar to alkaline copper porphyry deposits in British Columbia described by Barr, Fox, Northcote and Preto (1976). The present study finds that few similarities exist between Sulphurets and alkaline porphyry deposits.

The study area is situated within the western edge of the Mesozoic-age Bowser Basin, approximately 20 km. east of the contact with the Coast Crystalline Complex of Tertiary age. The volcanic-sedimentary package of rocks is considered part of the Hazelton assemblage of Jurassic age and (or) possibly belonging to the upper Triassic age Takla(?) Group (Kirkham, 1963). The intrusive rocks are also thought, by Kirkham and this author, to be Jurassic in age. Prior to the intrusive event the volcanic-sedimentary sequence was subjected to cataclasis that formed microbreccias.

Hazelton Formation

The sedimentary members of this assemblage in the study area, as recognized by this author (see pl. 3), are represented by black, fine-grained siltstone, altered mudstones, lithic to arkosic arenites and lithic to arkosic wackes. Lithic to arkosic arenites predominate followed by aphanitic mudstones. The basal unit of the volcanic-sedimentary sequence is a dense, fine-grained siltstone that, unlike the other members, is unaltered. The basal siltstone is also found as xenoliths which range from 20 cm to 30 m long (pl. 2) in monzonite porphyry. Higher in the section the lithologies rapidly alternate between arenites, aphanitic mudstones, wackes and volcanic beds which vary in thickness from 20 cm to 30 m, and are most commonly from 5 to 15 m.

Lithic arenites (fig. 4) and wackes are characterized by grains of detrital chert with subordinate feldspars. Arkosic arenites (fig. 5) and wackes are recognized by a paucity of detrital chert and feldspar content (albite and orthoclase) greater than 15 percent.

Apatite, as much as 5 percent in volume, is a common constituent in all units. Zircon is less common and generally less than 1 percent in volume. Calcite is ubiquitous in sedimentary rocks, volcanic rocks and intrusions. Calcite in the interstices of the sediments may be interpreted as being mainly of diagenetic origin and amounts to as much as 20 percent. Orthoclase is the predominant feldspar varying from 5 to 15 percent in lithic sediments, and from 15 to 50 percent in arkosic sediments. Biotite and hornblende grains are rarely found. Plagioclase (albite) is subordinate, rarely exceeding 15 percent. Table 1 lists the ranges of mineralogic compositions of sedimentary units.

Sedimentary units are extremely immature (Kirkham, 1963). Angular to sub-angular shapes and very poor sorting are typical. Also, the high percentage of feldspar is indicative of deposition close to the source. According to Kirkham (1963), the sedimentary units are of marine origin. No stratigraphic sequence has been determined, by Kirkham or myself, in the field.

Kirkham (1963) recognized that volcanic rocks occurred to the east of, and overlying, the sedimentary strata.

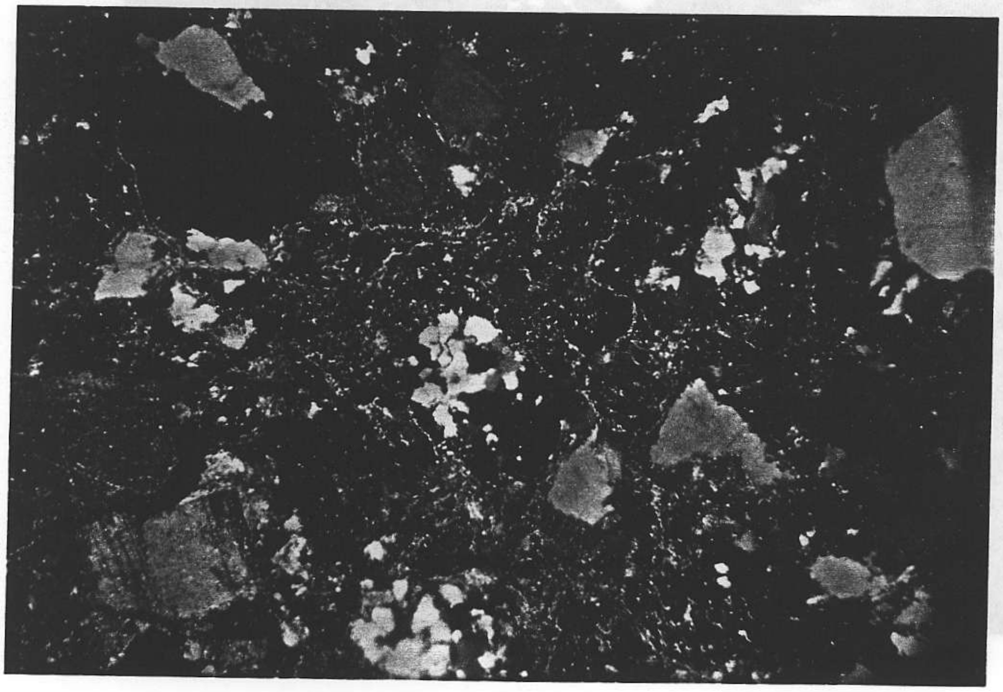


Figure 4. Microphotograph of typical lithic arenite. Orthoclase, albite and chert grains are in a matrix of calcite and secondary sericite. Sample 20-8, 28x, crossed nicols.

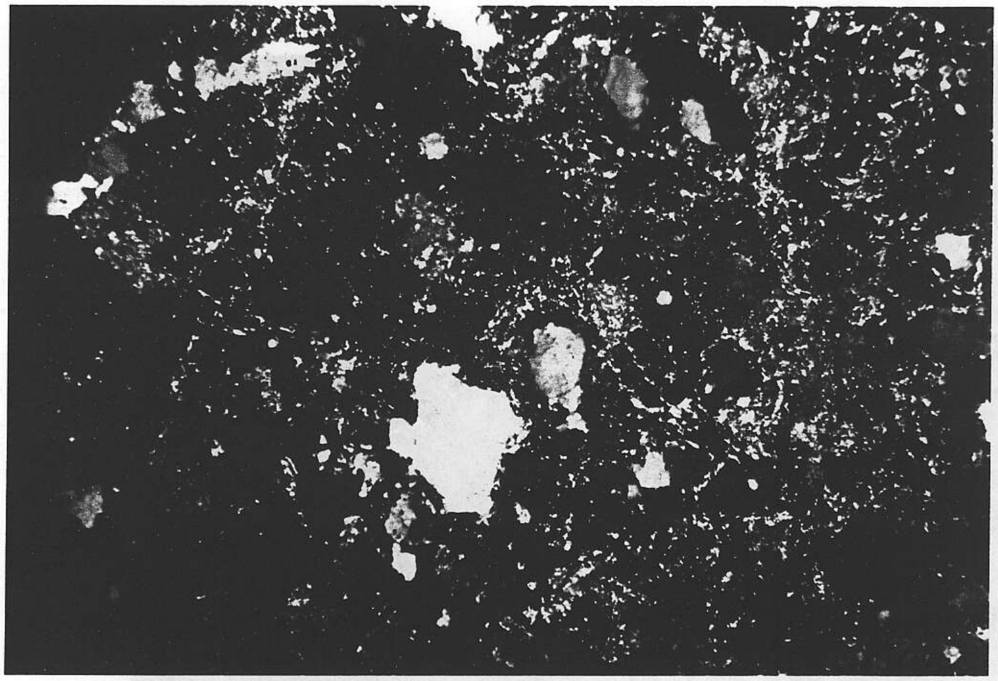


Figure 5. Microphotograph of typical arkosic arenite. Orthoclase feldspars in a matrix of secondary sericite. Cemented by calcite. Sample 24-19, magnification 28x, crossed nicols.

Table 1. Average ranges of mineralogic compositions in percent of sedimentary rocks. All values are from visual estimates.

Rock Type	Aphanitic Mudstone	Lithic Arenite	Arkosic Arenite	Lithic Wacke	Arkosic Wacke
Orthoclase	15-40	5-10	10-30	5-10	10-30
Plagioclase	-	2-5	2-15	2-10	5-15
Quartz	-	5-15	5-15	5-10	5-10
Chert Fragments	-	15-25	5-15	15-25	5-10
Other Rock Fragments	-	<2	-	-	-
Hornblende	-	Rare	Rare	Rare	Rare
Biotite	-	Rare	Rare	Rare	Rare
Apatite	1-2	1-5	1-2	1-5	1-2
Zircon	<1	<1	<1	<1	<1
Sericite	5-10	5-10	5-20	5-10	5-10
Calcite	5-20	2-20	0-10	0-10	0-20
Chlorite	<5	<5	2-3	<3	<5
Opaque Mins.	1-3	1-5	1-3	1-3	1-3
Matrix	0-40	0-10	0-10	15-20	15-20
Number of Samples	15	4	16	1	2

Kirkham identified lapilli tuff and volcanic breccias as the most common rock types; pyroclastic flows and feldspar porphyry lava(?) flows are less common. The volcanic units described by Kirkham are just to the east of the study area of interest for this paper and were not examined. However, in thin section, volcanic rocks were identified from drill core, and these are interlayered with the sedimentary rocks.

Volcanic rocks identified are trachyte and feldspar porphyry (fig. 6). It is possible that more of the units within the sedimentary pile are volcanic rocks but the intense alteration has destroyed all vestiges of primary textures and minerals. The amount of volcanic rocks identified in the Hazelton assemblage within the study area is volumetrically rather small, perhaps less than 20 percent. Trachyte and feldspar porphyry are recognized in drill holes 23 and 24, respectively (pl. 5). Other rocks that are suspected to be volcanic are found in drill holes 18 (pl. 5) and 26 (pl. 6), but cannot be positively identified as volcanic rocks. Recognition of feldspar porphyry as a volcanic rock is based on sub-parallel lineation of feldspar phenocrysts, and this texture could be that of a hypabyssal intrusive rock. Volcanic units vary from 5 to 15 meters in thickness and could be of lava flow origin.

All volcanic and enclosing sedimentary rocks are various shades of green. Kirkham (1963) noted that the volcanic rocks assumed a green color upon intense alteration. The

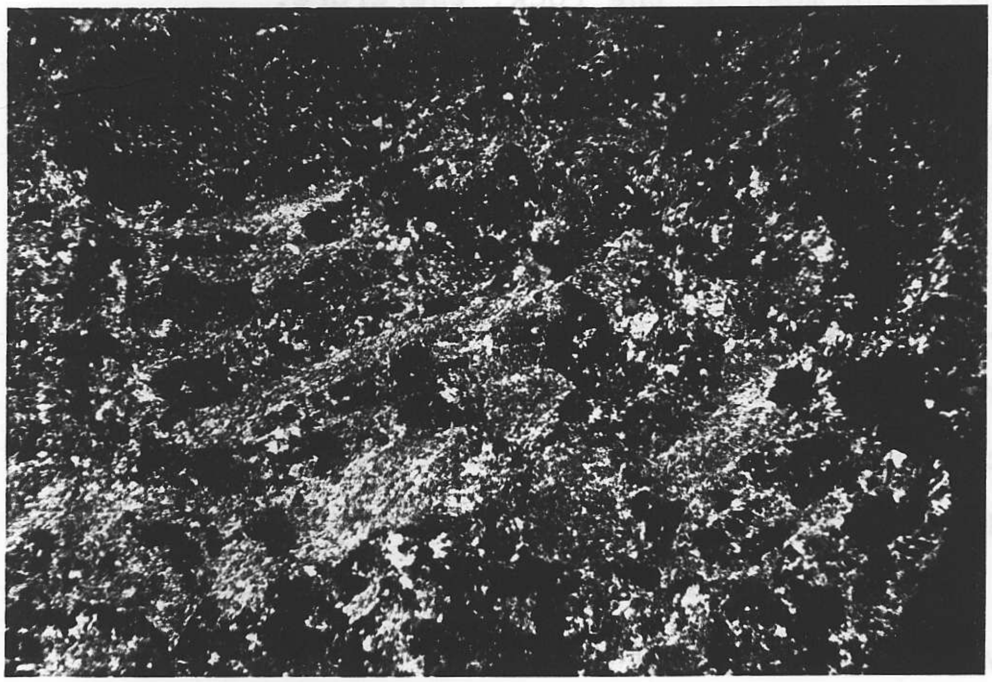


Figure 6. Microphotograph of volcanic(?) feldspar porphyry. Secondary sericite completely replaces plagioclase feldspar. Orthoclase is relatively unaltered. Opaque mineral is pyrite. Sample S-4, magnification 28x, crossed nicols.

green color is thought to be due to the sericite content. Volcanic rocks are porphyritic to seriate porphyritic and microporphyritic with anhedral phenocrysts as much as 2 mm in length. Table 2 gives typical mineralogic compositions. Volcanic units have a very fine-grained matrix that consists of sericite, calcite and opaques (sulfides and leucoxene). This matrix makes up most of the rock, therefore, classification based on the mode is tenuous.

Orthoclase is the only feldspar present in trachyte. Sample 24-13 from drill hole 24 (pl. 5) has a basaltic texture with abundant microlites of plagioclase and crystallites. Sericite after plagioclase(?) is common.

Feldspar porphyry is generally too altered to distinguish the type of feldspar present. Albite commonly occurs in feldspar porphyry but is generally subordinate to orthoclase. Quartz is commonly present in small quantity, but is rarely recognizable in the mode.

Five samples of volcanic rock were analyzed by X-ray fluorescence for SiO_2, Al_2O_3, FeO, Fe_2O_3, MgO, CaO, TiO_2, P_2O_3, MnO and by atomic absorption for Na_2O and K_2O. Figure 7 is a plot of Na_2O and K_2O versus SiO_2. The alkaline-subalkaline boundary is from MacDonald (1968). Figure 7 shows that most of the volcanic rocks are subalkaline in character. Although the statistical population is rather small the trend is indicated. Figure 8 is a plot of CaO versus Na_2O versus K_2O that indicates

Table 2. Range of mineralogic compositions in percent of rocks, based on visual estimates from stained slabs and petrographic sections.

Rock Type	Trachyte	Feldspar Porphyry
Quartz	0-5	0-5
Orthoclase	10-40	0-10
Plagioclase	0-5	5-10
Sericite	10-30	10-30
Calcite	0-15	0-10
Chlorite	0-3	0-5
Leucoxene	0-5	0-5
Sulfides	0-3	0-3
Number of Samples	2	1

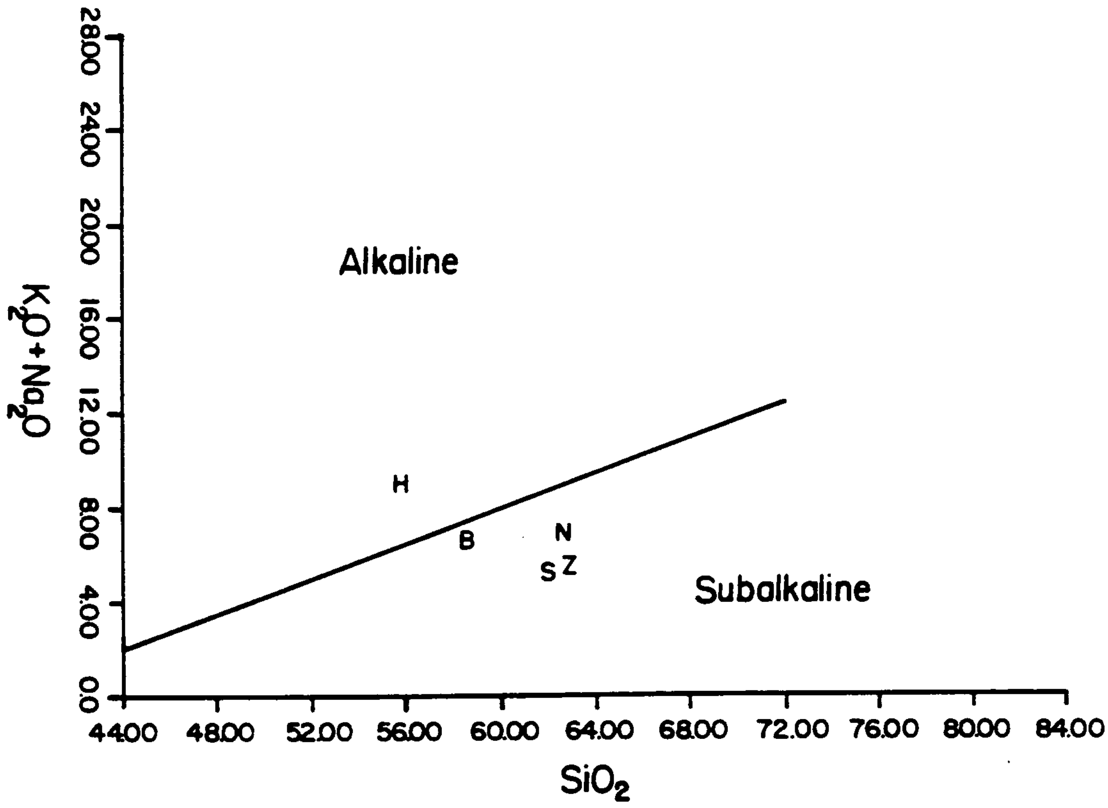


Figure 7. Binary plot of K_2O + NA_2O - SiO_2 for volcanic rocks at Sulphurets. Alkaline boundary from MacDonald (1968). See appendices for descriptions of samples.

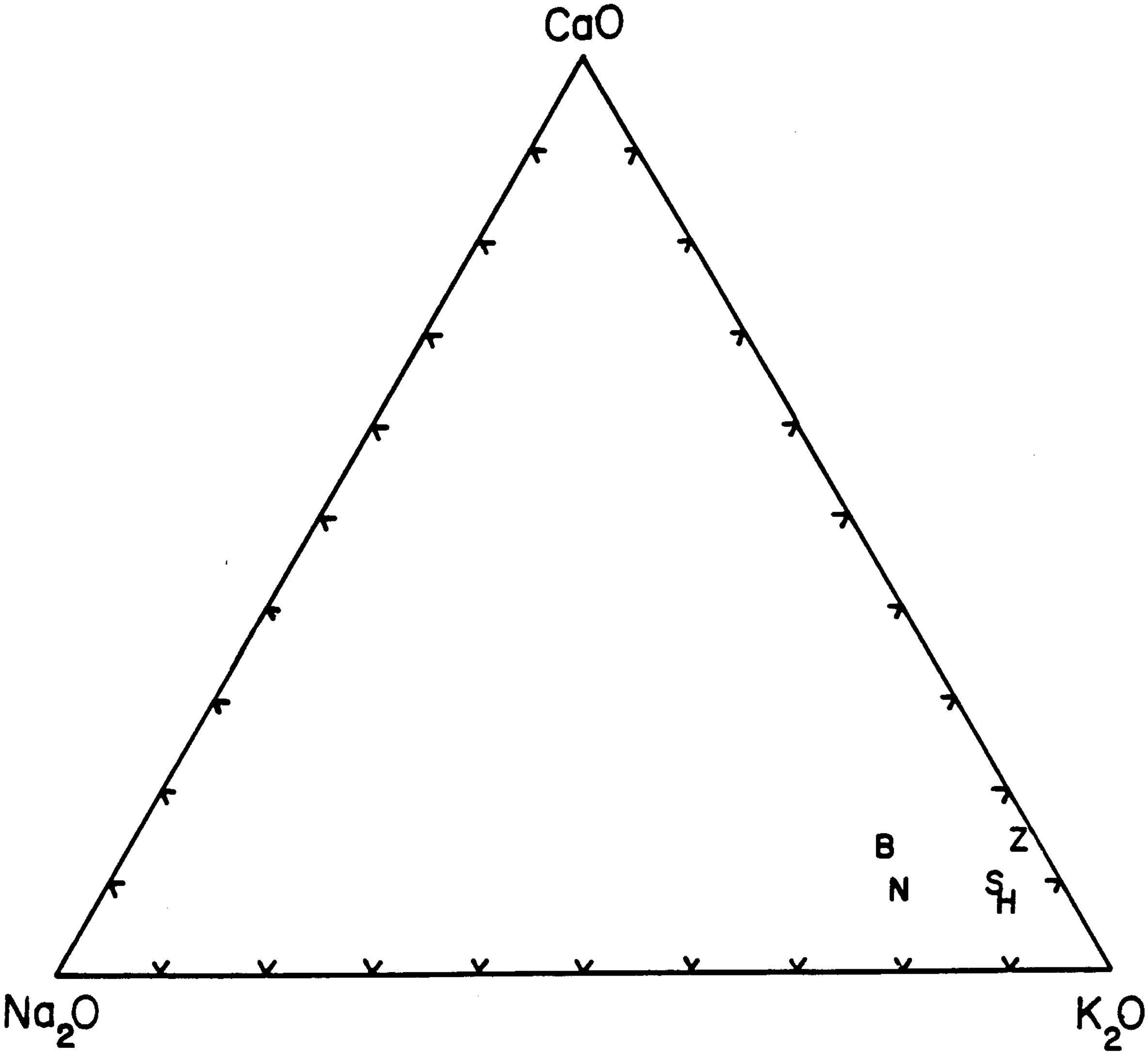


Figure 8. Ternary plot of CaO - Na_2O - K_2O for volcanic rocks at Sulphurets. See appendices for sample descriptions.

that the volcanic rocks are potassium-rich rather than sodium-rich, and calcium-poor. Figure 9 is a classification plot based on the normative composition which places the volcanic rocks mainly in the trachyte field with minor alkalic trachyte (after Barr and others, 1976). In comparison with petrochemical data from porphyry copper deposits of alkaline affinity in British Columbia, the volcanic rocks at Sulphurets are sub-alkaline (fig. 7). According to Barr and others (1976) volcanic units at other locales are of sodic and potassic types with potassic-rich types dominating. Rocks at Sulphurets are of potassic affinity but without enough potassium to plot them in the alkaline field (fig. 7). The volcanic rocks at Sulphurets do not compare very well with volcanic rocks of alkaline suite porphyry deposits.

Mitchell Intrusions

The name "Mitchell Intrusions" was introduced by Kirkham (1963) to apply to all the igneous rocks occurring in the vicinity of Mitchell and Sulphurets valleys, except for late dikes.

In the study area, I have recognized 4 separate lithologic types (pl. 1-3,5) which appear to be differentiates of the same magma: feldspar-hornblende porphyry, syenite, monzonite and late dikes. In outcrop the rocks are almost always unrecognizable. Only syenite and

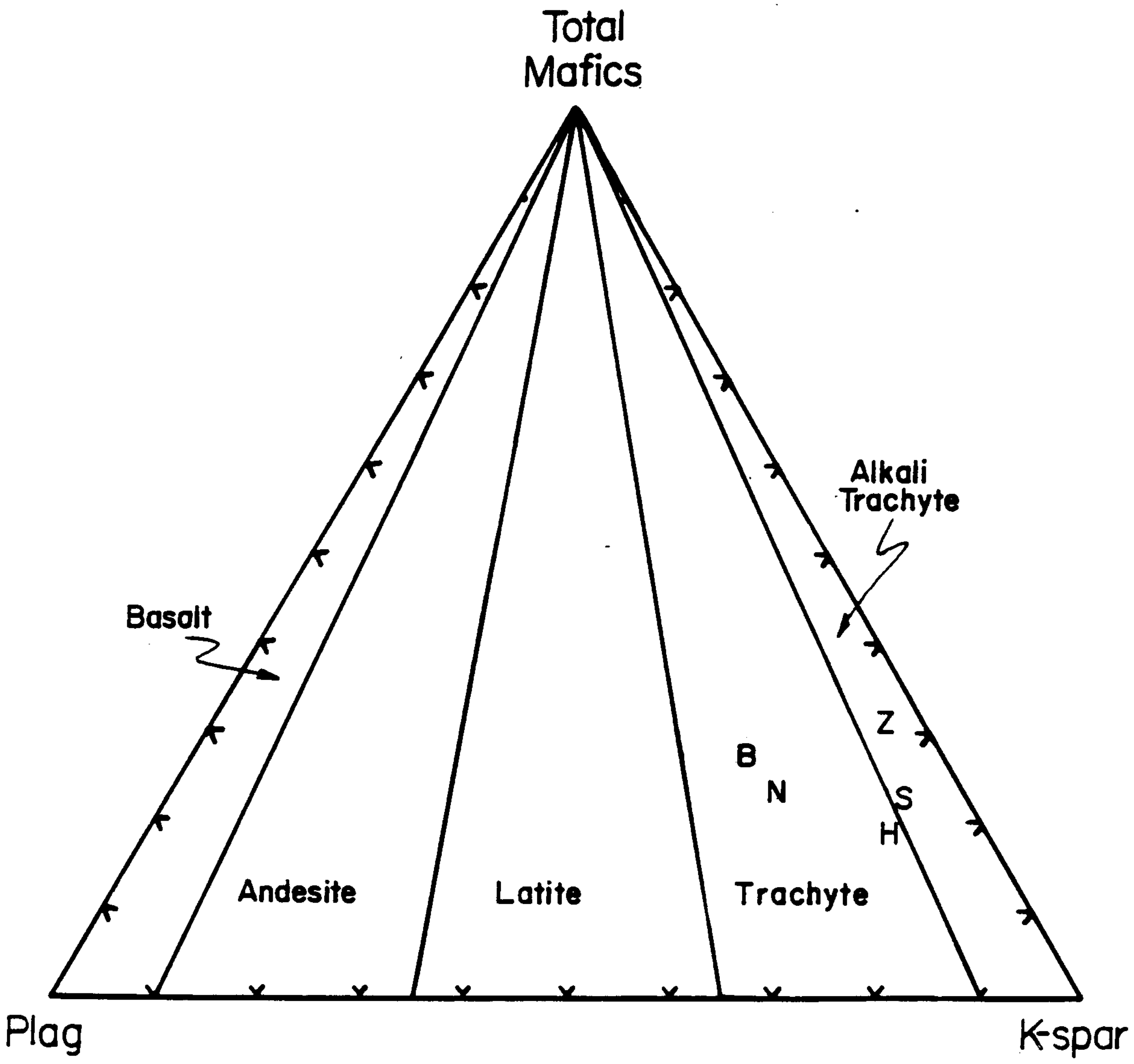


Figure 9. Ternary classification plot of total mafics-plagioclase-K-spar for volcanic rocks at Sulphurets. From Barr and others, 1976. See appendices for sample descriptions.

feldspar-hornblende porphyry have been identified in the field. Kirkham (1963) recognized that syenite may contain orthoclase phenocrysts that are variously colored to shades of pink and red. Feldspar-hornblende porphyry is locally recognizable in the field by relict hornblende laths. Because of intense hydrothermal alteration all intrusive rocks are generally unidentifiable in outcrop, hand and core samples. I have been able to identify rock types only in thin section and all descriptions, unless otherwise noted, are thin section descriptions.

Kirkham (1963) recognized 3 separate lithologic types which he considered to be differentiates of the same magma; plagioclase-hornblende porphyry, syenite and quartz syenite, and granite. He used the name plagioclase-hornblende porphyry to refer to almost all hornblende-rich rocks because they vary in modal composition. I have found that modal composition does indeed vary greatly and commonly no plagioclase is found, only orthoclase. In the study area, I believe a better field name for this rock type is feldspar-hornblende porphyry.

I have grouped the dikes together with the Mitchell Intrusions on the basis of petrochemical evidence which will be discussed later. Sulfide mineralization and hydrothermal alteration are thought to be a result of the Mitchell Intrusions.

Feldspar-Hornblende Porphyry

Feldspar-hornblende porphyry (fig. 10) is recognized by the presence of hornblende laths which are very rarely unaltered (pl. 1,2). Hornblende is commonly altered to a mixture of chlorite (penninite), calcite, Fe-oxides and sericite. Feldspar composition varies from plagioclase to orthoclase. With greater intensity of alteration plagioclase alters to calcite, minor clinozoisite and sericite. Orthoclase resists alteration. Feldspar-hornblende porphyry is porphyritic to seriate porphyritic. Plagioclase feldspar occurs as laths as much as 3 mm in length, whereas orthoclase is rarely observed greater than 2 mm and is generally less than 0.5 mm in length. Orthoclase contents for this study were mostly estimated from stained slabs. Hornblende is from 2 to 4 mm in length. Leucoxene is common and sulphides, mainly pyrite, are ubiquitous. The groundmass of feldspar-hornblende porphyry is described by Kirkham (1963) as being "dense, light gray". The groundmass is generally a mixture of orthoclase and sericite. Table 3 lists average modal compositions of the Mitchell intrusive rock. Kirkham (1963) also noted that large crystals of sphene are found only in syenite. In Sulphurets valley, however, sphene has been found to occur in feldspar-hornblende porphyry. Figure 11 is a plot of CaO versus Na_2O versus K_2O for the intrusive rocks in Sulphurets valley. The feldspar-hornblende orphyries appear to be calc-alkaline in composition varying

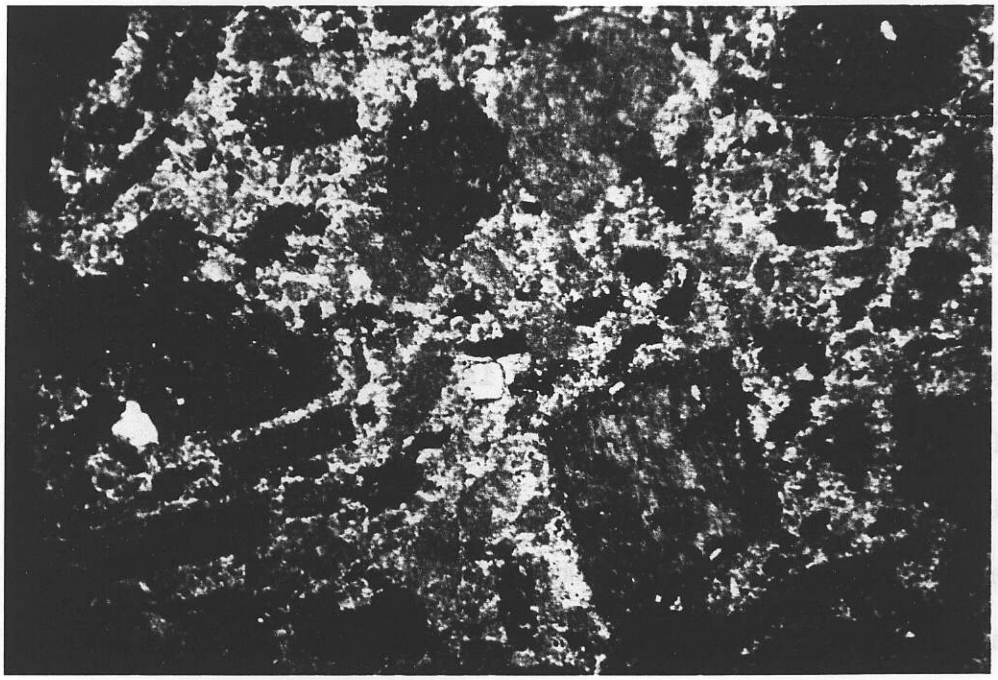


Figure 10. Microphotograph of typical feldspar-hornblende porphyry. Plagioclase is totally replaced by sericite. Hornblende is altered to chlorite, calcite and opaques. Light colored groundmass is sericite. Sample S-1, magnification 28x, plane light.

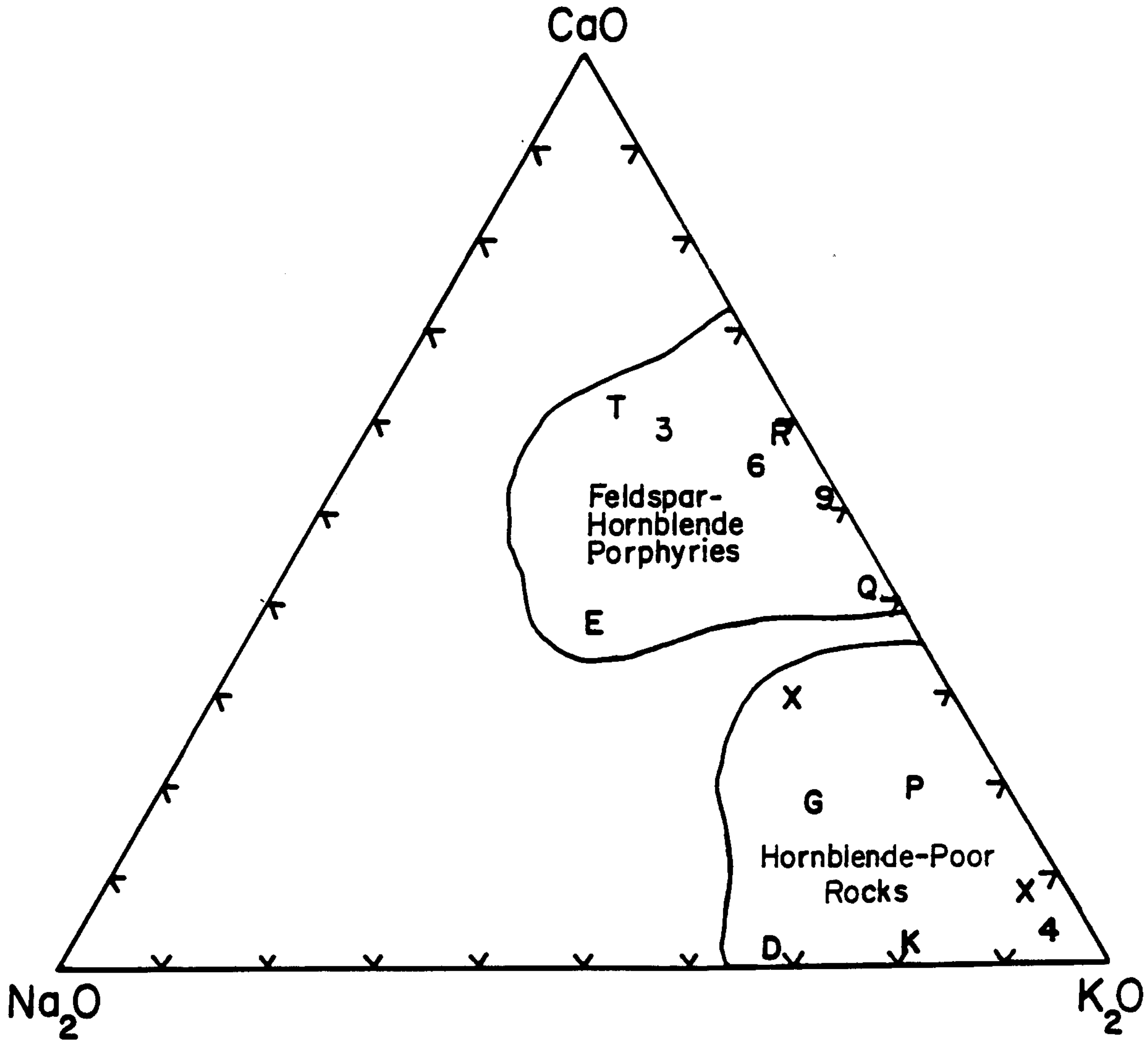


Figure 11. Ternary plot of CaO - Na_2O - K_2O for Mitchell Intrusions. See appendices for sample descriptions.

from almost equal parts of CaO and K_2O to being calc-rich. Only one sample showed an appreciable amount of sodium; however, the sodium value for the sample (E) is in doubt because it is a value from X-ray fluorescence analysis rather than atomic absorption. In figure 12 the feldspar-hornblende porphyries plot in the monzonite field based on their normative values.

Syenite

In thin-section, syenite (pl. 1,3,4) is porphyritic to seriate porphyritic with phenocrysts averaging 2 to 3 mm in size, but grains up to 200 mm have been found (Kirkham, 1963). Phenocrysts are predominantly orthoclase (Table 3) which is commonly perthitic. Orthoclase phenocrysts are variously colored to shades of pink and red (Kirkham, 1963). Plagioclase is found only in minor quantities. Quartz is rare as phenocrysts and generally occurs as very small anhedral grains in the groundmass. Overall, modal minerals are anhedral in outline. Green tourmaline (schorl) is locally present in syenite, but is also observed in feldspar-hornblende porphyry and monzonite. Tourmaline occurs as a secondary mineral in highly altered brecciated rocks generally in crystals less than 1 mm in size. Rarely, radiating aggregates of tourmaline (suns) as much as 2 mm in diameter are found. Clinozoisite is present in some thin-sections as an alteration product of plagioclase.

In the field (pl. 1,3,4) the most conspicuous difference between syenite and feldspar-hornblende porphyry is that syenite has pink to red phenocrysts set in a gray matrix. Feldspar-hornblende porphyry has a high percentage of hornblende in a fine-grained green matrix. Hornblende is rarely found in syenite and does not occur as more than 5 percent of the rock (Kirkham, 1963). In contrast with hornblende-bearing intrusions, hornblende-poor rocks are potassium-rich (fig. 11). In Figure 12, the hornblende-poor rocks occur in the syenite and alkali syenite fields (after Barr and others, 1976).

Monzonite

Another important type (Table 3) of intrusion recognized in the Sulphurets valley (pl. 1-4) was identified as a result of thin section study as monzonite (fig. 13). The rock is mineralogically very similar to feldspar-hornblende porphyry except it lacks hornblende. Samples "P" and "?" (fig. 11) occur with both the hornblende-poor and hornblende-bearing rocks due to a variation in CaO content. In Figure 12 these samples plot in different fields again due to differences in the CaO content. The sample with higher CaO has higher normative plagioclase content and is a monzonite whereas the other sample is a syenite. Also noticed in the monzonite is the presence of anhedral apatite grains up to 1 mm in size.

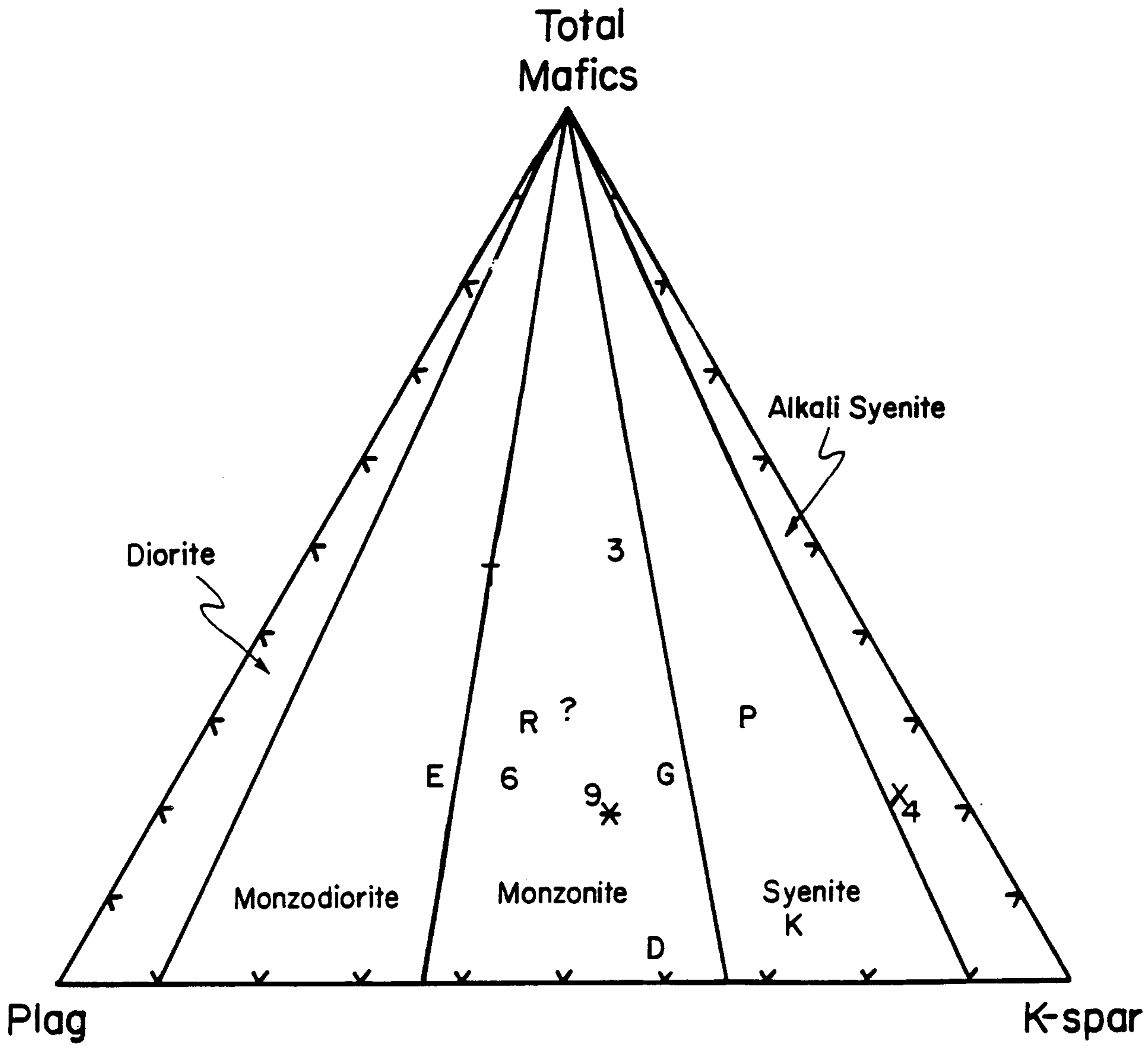


Figure 12. Classification plot of Mitchell Intrusions, based on normative compositions. See appendices for sample descriptions.

Table 3. Range of mineralogic compositions in percent of Mitchell Intrusions in Sulphurets valley, based on visual estimates from stained slabs and petrographic sections.

Rock Type	Feldspar-Hornblende Porphyry	Syenite	Monzonite
Quartz	0-20	0-10	0-10
Orthoclase	5-30	20-30	10-30
Plagioclase	5-30	2	10-20
Hornblende	15-60	-	-
Apatite	1-2	-	1-2
Sphene	1	1	-
Rutile	Found in one slide	-	-
Sericite	10-40	5-40	10-30
Chlorite	5-25	0-2	0-5
Calcite	5-15	5-15	0-15
Tourmaline	Rare	Rare	Rare
Clinozoisite	5	3	3
Unresolvable Clays	5-15	0-10	0-10
Leucoxene	0-5	0-5	0-5
Sulfides	2-3	2-3	2-5
Number of Samples	11	6	4

Comparison with Alkaline Porphyry Intrusions

The Mitchell Intrusions exhibit some similarities to intrusions associated with alkaline porphyry deposits in British Columbia. The principal rock type at other localities is monzonite and most of the plutons are of the potassic suite. None have strongly sodic compositions (Barr and others, 1976). The intrusions at other locations are of upper Triassic to lower Jurassic age and are emplaced within their own effusive pile.

At Sulphurets the intrusive rocks are predominantly potassium-rich monzonites but are sub-alkaline in character (fig. 7). Also at Sulphurets the intrusive rocks are not considered to be coeval with the enclosing sedimentary-volcanic strata. Most intrusions are different in composition from the volcanic rocks, which are trachytic (fig. 9,12). In Sulphurets valley at the base of the north valley wall, monzonite porphyry is found with many large xenoliths of the basal sedimentary unit which indicates that the porphyry is younger than the sedimentary-volcanic succession. The intrusions, although not coeval, are thought to be slightly younger than the Hazelton assemblage and are considered early Jurassic in age.

Dikes

Dikes of hornblende syenite and hornblende diorite (pl. 3) have been found in drill holes 19 and 20, respectively (pl. 4). Kirkham (1963) did not consider dikes to be part of the Mitchell Intrusions and used the term "late dikes". However, I found in thin-section that, mineralogically, these dikes are almost identical to feldspar-hornblende porphyry. Chemical analysis of the dikes also shows that they are petrochemically similar to feldspar-hornblende porphyry. Samples "T" and "3" in Figure 11 are of dike rocks and plot in the same field with feldspar-hornblende porphyry. In Figure 12 these same samples plot in the monzonite field. The only difference I have found between Mitchell Intrusions and dikes is that the dikes are very fresh in appearance and are only incipiently altered with clinozoisite and calcite after plagioclase. Because of their petrochemical and mineralogic aspects, I consider the dikes to be part of the Mitchell Intrusions. Due to the lack of alteration they could represent a very late intrusive phase which was volumetrically very small and occurred after the mineralizing and hydrothermal alteration event, or, they could represent lamprophyres that were altered by late-stage hydrothermal solutions.

Conclusions

During early Hazelton time (early Jurassic) the Sulphurets region was the site of a marine basin. This basin was infilled with sedimentary and volcanic debris and flows, ›rimarily lithic and arkosic arenites. The sediments are very juvenile in character and may have been deposited by turbidity currents (Kirkham, 1963) close to their source. The presence of volcanic flows in the sedimentary pile could also indicate deposition close to the source area. Deposition may have taken place in an isolated, back-arc basin. Sillitoe (1979) states that during late Triassic-early Jurassic time British Columbia represented a continental margin setting. Subsequently, the sedimentary-volcanic pile was subjected to uplift, compaction and cementation by calcite.

Following or perhaps, during, diagenesis of the sedimentary-volcanic units the pile was intruded by the Mitchell Intrusions (Kirkham, 1963). Chemical analysis of the Mitchell Intrusions indicates that they are of calc-alkaline affinity. This differs from the conclusions of previous workers (Kirkham, Grove) who believed that the intrusives were alkaline in character. The Mitchell Intrusions show differentiation from earlier hornblende-bearing porphyries to later hornblende-poor, subalkaline monzonites and syenites (fig. 11,14).

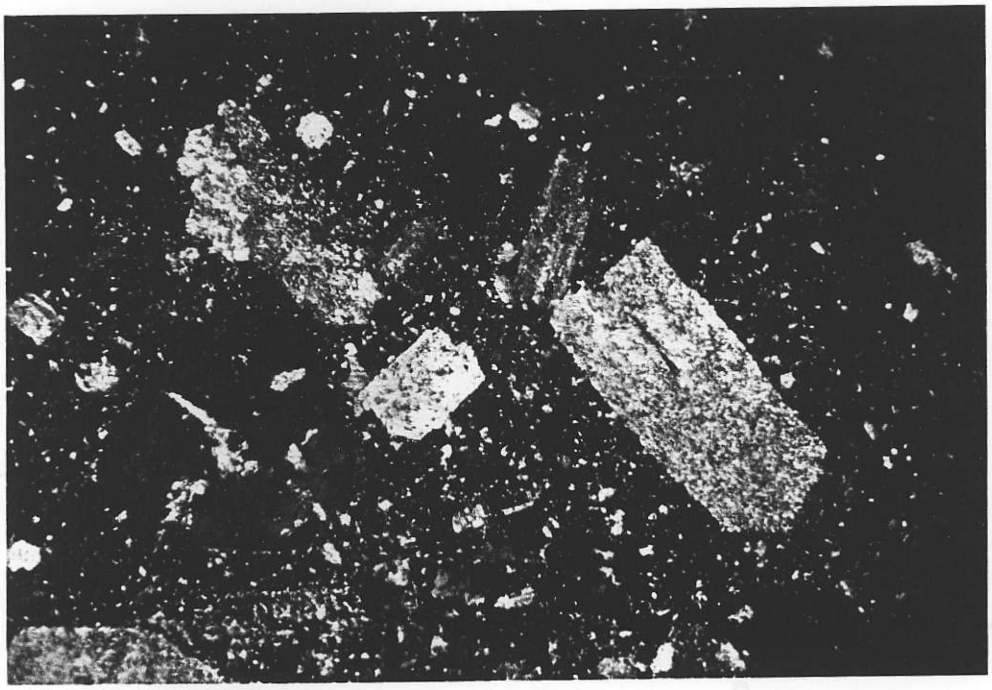


Figure 13. Microphotograph of monzonite porphyry. Plagioclase and orthoclase phenocrysts are set in a fine-grained groundmass with sericite and calcite. Sample 3093, magnification 28x, crossed nicols.

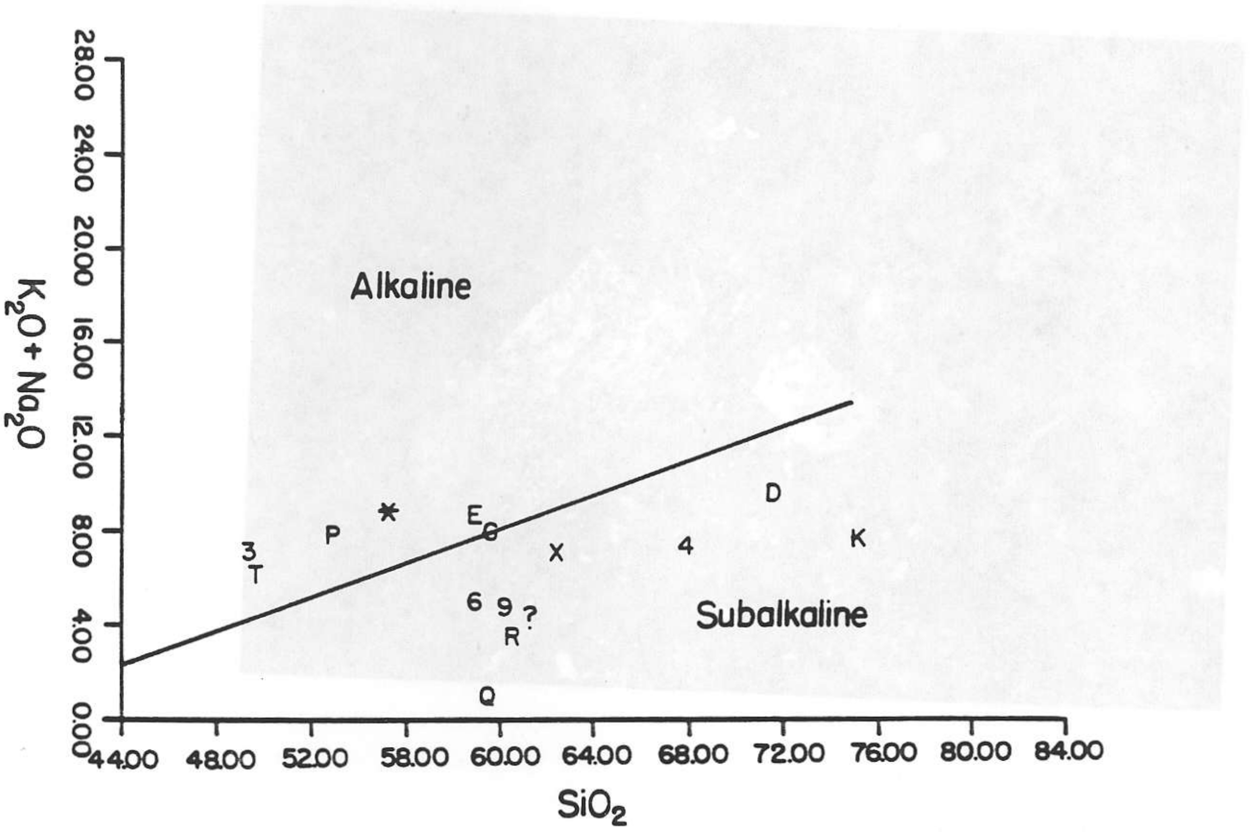


Figure 14. Binary plot of K_2O + Na_2O - SiO_2 for Mitchell Intrusions. Alkaline boundary from MacDonald 1968. See appendices for sample descriptions.

STRUCTURE

A structural analysis of the Sulphurets area is a very difficult undertaking. Hydrothermal alteration has masked almost all field relationships of the geology, hence evidence of folds and offset along faults is unrecognizable. No evidence of bedding or flow layering could be found. Few conclusions can be drawn concerning the structural geology from the surface geology. During the course of the thin section study it became apparent that the area has undergone some cataclasis which formed microbreccias. Kirkham (1963) recognized mylonite to the north in Mitchell valley but not in Sulphurets valley. Perhaps cataclasis was more intense to the north which could be responsible for the mylonite found there.

Folds

Hydrothermal alteration has obliterated almost all primary textures in Sulphurets valley; therefore destroying all evidence of folds. Kirkham had the same problem during his field work and only solved the problem by examining an unaltered section approximately 10 km to the north of Mitchell valley, where he found a large major fold. This fold is a broad antiform with a 1 km wide hinge zone and steep opposing dips on the limbs. The axis of this fold strikes approximately north and plunges gently to the north

(Kirkham, 1963). Kirkham also found some accordian-type folds on one limb of the large fold and describes these in detail in his thesis (1963). The large fold was interpreted by Kirkham to be of regional extent and to overlie the Mitchell-Sulphurets area to the south. No evidence of this could be discerned in Sulphurets valley but hydrothermal alteration could well be masking this fold in the study area.

Fractures

Hydrothermal metasomatism in the study area has obliterated almost all surface evidence needed to differentiate faults from joints and it is more appropriate to discuss evidence of fractures rather than separate faults and joints.

Within the study area block faulting, with a north-south strike is the only type of faulting recognized. The Mitchell Intrusions appear to be localized along the north-south fault zone. This fault zone could have acted as the major avenue for ascending igneous rocks and subsequent hydrothermal alteration.

Block faulting is apparent in the Breccia zone (fig. 31) by displacement of the lithologies in that area. Amount and direction of displacement are unknown. The fault that displaces the rocks in the drill hole cross-section (fig. 15) has not been recognized at the surface. This faulting is clearly later than some of the intrusive activity, but is

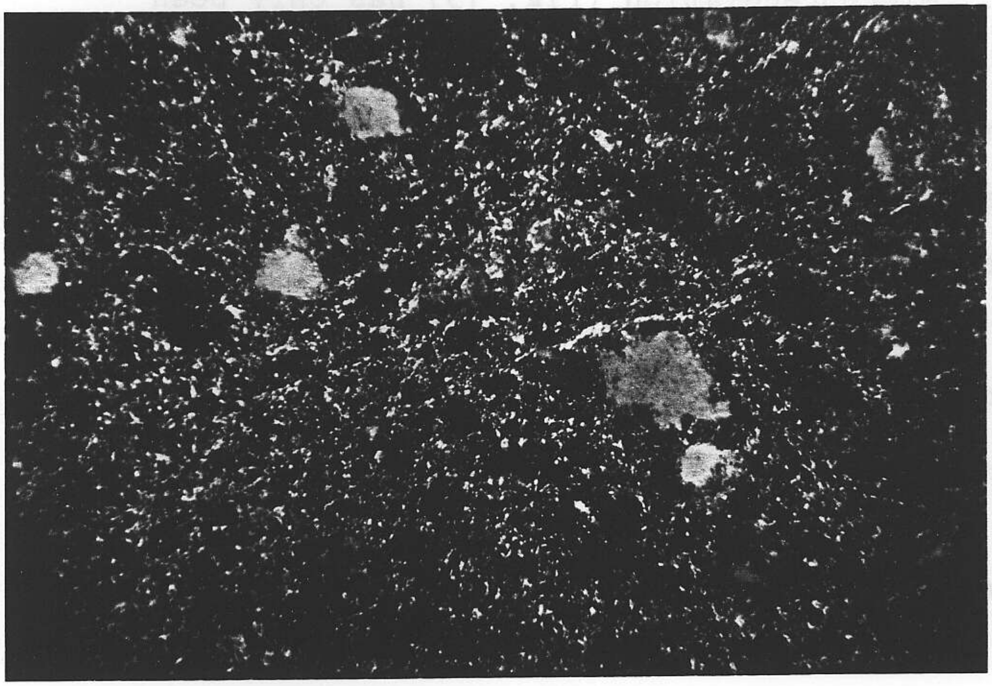


Figure 15. Microphotograph of microbreccia. Sample 18-10, magnification 70x, crossed nicols.

also prior to the formation of the intrusive breccia. So it could be possible that faulting was occurring throughout the active history of mineralization and alteration in the study area.

Microbrecciation due to cataclasis is present in 28 thin-sections. Microbrecciation (fig. 15) has only been recognized in thin section and is characterized by clasts less than 1 mm in diameter. The clasts are generally subangular in shape. Due to the small size of breccia fragments it may be possible that many rocks identified as mudstone are microbreccias but there is not evidence to support this. Many of the intensely altered rocks may also be microbreccias, but alteration has obliterated any evidence of this.

Kirkham (1963) also recognized this major north-south fault trend. However, he observed faults which trended north-south, but had moderate westerly dips of approximately 40 degrees. A stereographic plot of all fracture data (fig. 16) indicates a strong north-south pattern but also shows the N-S fractures to dip steeply to the west, at approximately 70 degrees. Some fracture poles indicate only the more moderate dips, but most have steeper dips. It is possible that across the Sulphurets area the dips could be somewhat variable due to the differing refractive properties of the various rock types.

The Sulphurets fault which forms the western boundary of

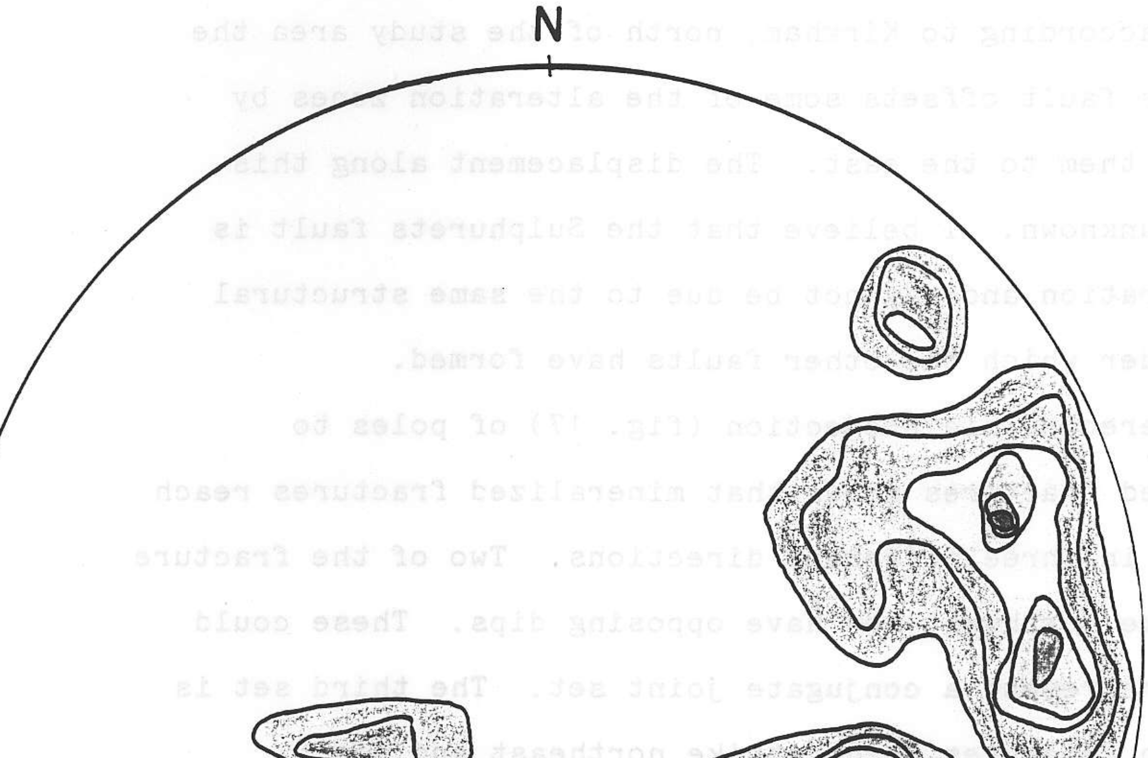


Figure 16. Plot of poles to fractures.

the study area trends north-south and dips approximately 40 degrees west. Kirkham (1963) considered this fault to be of the same generation as the other north-south faults. However, according to Kirkham, north of the study area the Sulphurets fault offsets some of the alteration zones by thrusting them to the east. The displacement along this fault is unknown. I believe that the Sulphurets fault is post-alteration and may not be due to the same structural regime under which the other faults have formed.

A stereographic projection (fig. 17) of poles to mineralized fractures shows that mineralized fractures reach a maximum in three different directions. Two of the fracture sets strike northwest and have opposing dips. These could possibly represent a conjugate joint set. The third set is related to fractures which strike northeast and dip moderately to the northwest. It is unknown what this set relates to.

Conclusions

Structure in the area is dominated by a set of north-south structures which dip from moderately to steeply west. Variations in dip could be due to cleavage refraction in rocks of different competency. Cataclasis in the form of microbrecciation was found in thin section and could be due to movement along the north-south fractures. The strong north-south fractures and brecciated areas could have

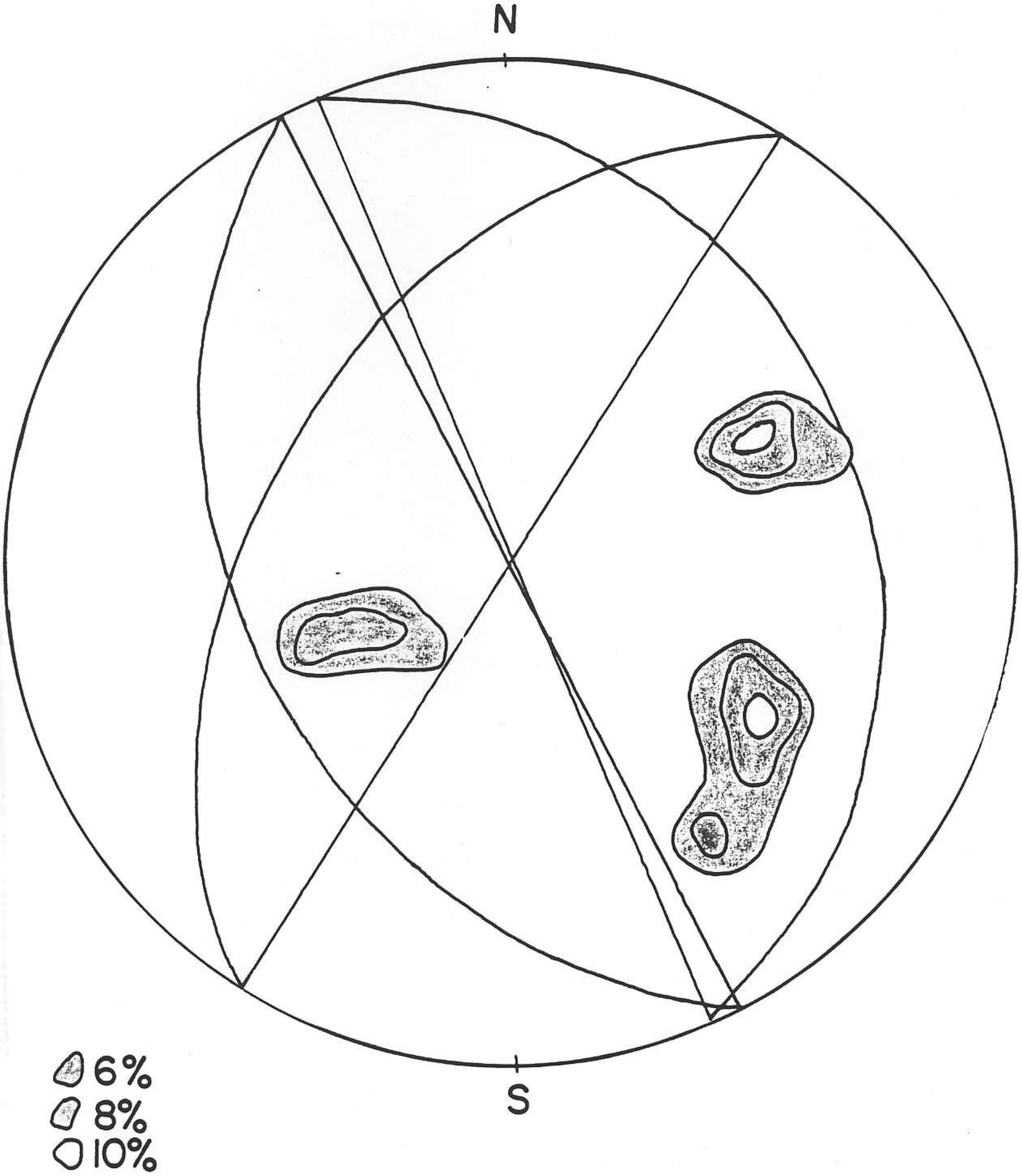


Figure 17. Plot of poles to mineralized fractures only.

provided a zone of weakness which allowed the intrusions to rise near the surface and provided conduits for the altering fluids.

HYDROTHERMAL ALTERATION

In hand specimens almost all primary textures are obliterated, which renders the rocks virtually unrecognizable. In the altered areas the rocks are various shades of green on fresh surfaces and buff to reddish-brown on oxidized surfaces. The green color is due to sericite content, and reddish-brown to buff hues are the result of weathering of iron-bearing minerals, mainly pyrite.

Kirkham (1963) believed the alteration to be due to the Mitchell Intrusions but was puzzled by the total area involved. An aerial survey of the area shows approximately 100 square kilometers (60 square miles) to be heavily iron-stained. This area is about three times greater than the area of the Mitchell Intrusions, according to Kirkham. However, in the Sulphurets valley I found the Mitchell Intrusions to be more widespread than originally thought by Kirkham. Due to the detailed nature of this study, examples of intrusive rocks were recognized in thin-section that were not recognized as such in hand specimen or in core. Also, Kirkham did not recognize any strong zonation in alteration and considered all alteration to be the same. I believe that there is definitely zonation to the alteration, but only on a large scale. Kirkham (1963) noted that major periods of faulting and rock alteration were very close in time. It is possibility that not only was faulting and hydrothermal alteration close in time, but also diagenesis of the sedimentary-volcanic pile was occurring contemporaneously, which, in turn, has had an effect upon the hydrothermal alteration.

Pyrite is an ubiquitous alteration mineral found in all of the alteration types noted. Kirkham (1963) concluded that pyritization was occurring throughout the time span of the hydrothermal event. I also believe that the ubiquitous nature of pyrite indicates that it was forming in all the various stages of alteration.

Four types of hydrothermal alteration have been recognized at Sulphurets:

(1) Albitization. This is the earliest alteration in time (Kirkham, 1963). However, a second period of albitization has been recognized that is contemporaneous with sulfide deposition.

(2) Propylitic. This is very weak and confined to the outer fringes of the sericite zone.

(3) Sericitic. This is the most widespread alteration in the area of the intrusions; only one important variation of this has been found which is the occurrence of tourmaline with sericite.

(4) Potassic. This is characterized by biotite and is very localized occurring with copper mineralization.

Albitization

Albitization has occurred at Sulphurets during two periods. The first period is the earliest type of alteration and is the most significant of the two. Kirkham (1963) suggested that albitization covered a larger area than other types of alteration and that it may be independent of the processes that formed the other types.

The first period of albitization (fig. 18) is characterized by the total replacement of earlier calcium-rich plagioclase with albite. Inclusions of calcite occur within many albitized feldspars which could be the result of the albitization process. Clinozoisite is rarely found with this alteration. All plagioclase feldspar in the study area was found to be albitic in composition.

The second period of albitization (fig. 19) appears to be very limited in extent. In well-mineralized rocks in the potassic zones (pl. 2) hydrothermal albite occurs as small laths of less than 1 mm length in veins with sulfides and quartz. Veins of hydrothermal albite occur without any other vein minerals. This second period of albitization is contemporaneous with deposition of sulfides and post-dates most of the other types of alteration.

An interesting feature of the sedimentary rocks, is that all plagioclase feldspar is of albite composition and very fresh in appearance. The albite may be of either primary detrital origin, authigenic origin, or else the feldspar is a result of albitization during diagenesis or shortly thereafter. According to Pettijohn, Potter and Siever (1972) authigenic feldspar is generally a pure end member of Na or K varieties but authigenic feldspar is almost exclusively

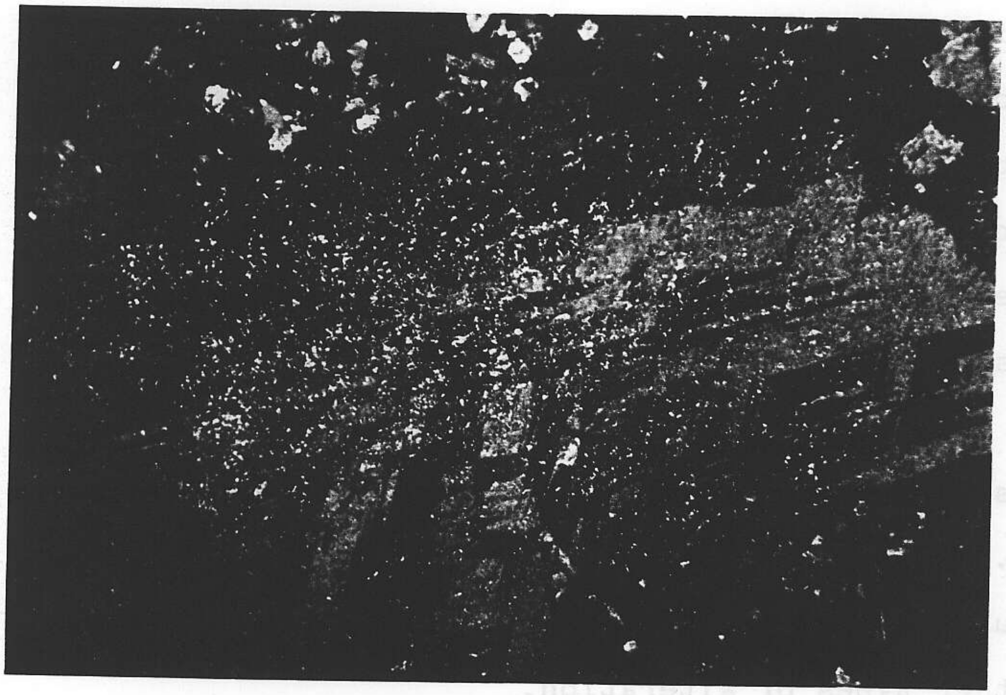


Figure 18. Microphotograph of albitized plagioclase feldspar in first stage of albitization. Sample S-10, magnification 28x, crossed nicols.

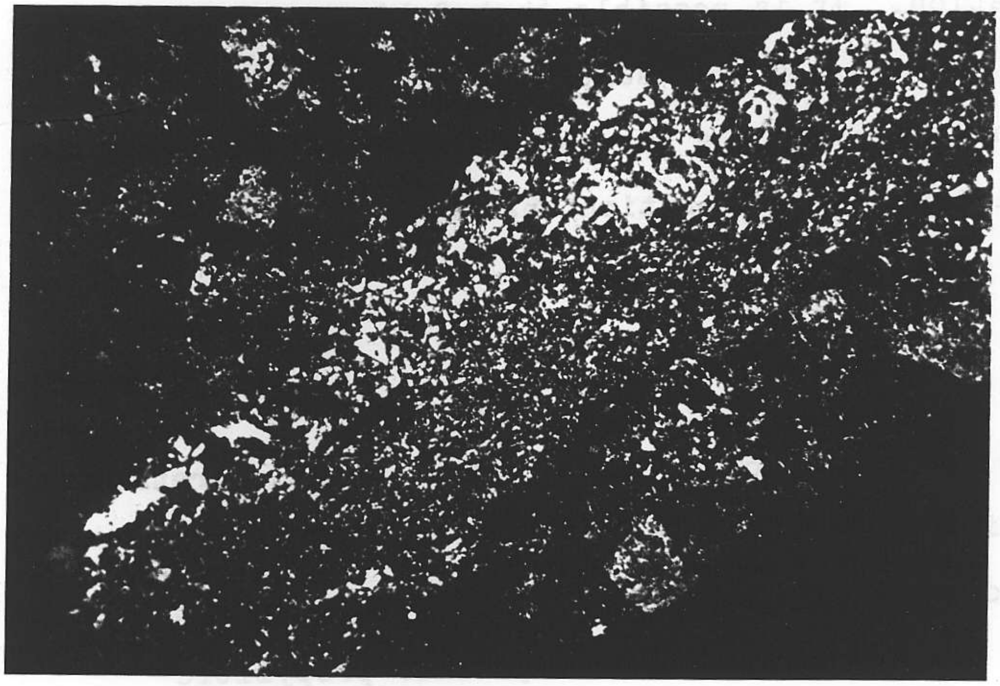


Figure 19. Microphotograph of second stage of albitization. Vein in photograph is approximately 2 mm across and consists solely of hydrothermal albite. Sample P20-2A, magnification 28x, crossed nicols.

limited to overgrowths on detrital feldspar grains. No such overgrowths have been found in the study area, so an authigenic origin is improbable. Plagioclase of detrital origin would unlikely be exclusively albite in composition. In areas where the sedimentary rocks have been hydrothermally altered it is clear that albite was present before any other type of alteration. It is possible that feldspar in the sediments was albitized at the same time as the intrusive rocks and perhaps by the same process. The early albitization is the only alteration that is atypical of a porphyry type of system.

Propylitic Alteration

This type of alteration is rarely found at Sulphurets. It is found mainly on the western fringes (pl. 1) of the Sulphurets gold zone and is only present in fault contact with sericitic altered rocks. The only other propylitic altered rocks are the late dikes which cut the sericitic zones.

Propylitized rocks were identified in the field by the presence of chlorite, calcite, epidote and an almost total lack of sericite. No thin sections were made of these rocks (except for the dikes in core) as they are volumetrically a small component and for the most part buried by overburden.

However, from observations (see page 23) made in the sericitic altered rocks (mainly feldspar-hornblende porphyry) it is possible that propylitic alteration was the earliest type of hydrothermal alteration but has largely been overprinted by the ensuing expansion of the sericitic alteration.

Propylitic alteration of feldspar-hornblende porphyry probably took place during the end of the first stage of albitization or shortly afterwards. Hornblende is altered to mixtures of calcite, chlorite and opaque iron minerals. Hornblende is everywhere altered to this pseudomorphous assemblage even in rocks that have only been incipiently sericitized. Therefore, it appears to predate sericitization. Chlorite, in general, is penninite but in some sections another variety is found that is darker green and strongly pleochroic. Kirkham (1963) suggested that this darker green chlorite may be more closely associated spatially with ore deposition. I have not found this to be the case. In almost all samples penninite was found to be the only chlorite regardless of the presence of economic minerals. Iron minerals formed after hornblende are generally pyrite; some limonite is found but this is probably due to oxidation of pyrite. In one sample rutile is present.

Inclusions of calcite are common in plagioclase feldspar of incipiently sericitized rocks and these indicate that calcite too could be the result of an earlier propylitic alteration. However, the inclusions of calcite could also represent displaced calcium when albitization of plagioclase occurred.

Sericitic Alteration

This type of alteration is the most intense found in the study area. Sericitization (pl. 1-6) in many instances results in total loss of primary texture in hand specimens and in thin sections. For many of the rocks in the study area that have undergone microbrecciation the loss of texture is very common and it could be that all rocks that have lost their texture have undergone microbrecciation before sericitization. The resultant quartz-sericite-pyrite rock (pl. 1-6) is one of the most common rock types in the study area (table 4). It is impossible to distinguish the original rock type if this type of alteration is very extensive.

Three stages of sericitization are found. The first (fig. 20) produces rare examples of incipiently sericitized rocks. Only the dikes and sedimentary rocks show incipient sericitization. In these rocks plagioclase (albite) begins to alter to sericite and sericite begins to appear in the groundmass. As alteration progresses, the second stage (fig. 21) is reached. This stage is characterized by total replacement of plagioclase by sericite but the outlines of the feldspar grains are retained. Sericite also partly replaces the groundmass. The third stage of sericitization is reached when grain outlines have disappeared and only a fine-grained rock consisting of quartz, sericite, and pyrite

Figure 20. Microphotograph of first stage of sericitic alteration of feldspar-hornblende porphyry. Note minor sericite after plagioclase. Sample S-10, magnification 70x, crossed nicols.

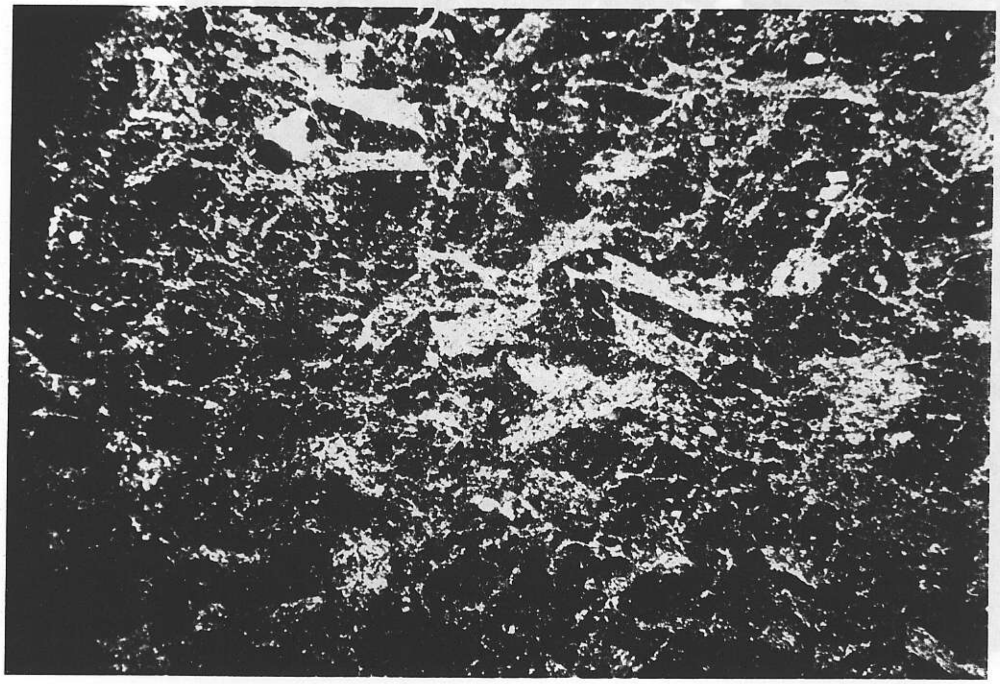


Figure 21. Microphotograph of second stage of sericitization. Plagioclase is completely replaced by sericite but grain outlines are retained. Sericite begins to form in the groundmass. Sample 18-6, magnification 28x, crossed nicols.

remains. This last stage is referred to as quartz-sericite rock.

Alteration of hornblende to calcite, chlorite and iron-oxides in the feldspar-hornblende porphyry is probably related to propylitic alteration which could have occurred before an expanding sericitic zone.

Only one important variation of sericitic alteration has been recognized at Sulphurets. In thin-section the occurrence of green and pale blue tourmaline, schorl, has been found in two localities within the sericitic zone. The first locality near the west end of the study area in the Lake zone (pl. 1). Here tourmaline (fig. 23) is obvious in two separate stages of formation. In the first stage, dark-green tourmaline occurs as disseminated clots and suns in the groundmass with sericite. In the second stage pale-blue tourmaline occurs lining the walls of cross-cutting quartz veins and sparsely interspersed with the quartz. Tourmaline rarely exceeds 2 m in length in either stage. The rock type in this area is unrecognizable, but syenite is recognized within 10 m so it seems likely that the rock is part of the Mitchell Intrusions.

The second locality where tourmaline occurs is over 2 km to the east of the first locale in an area referred to as the Breccia zone (fig. 31, pl. 2). Green tourmaline (fig. 24,25) occurs as part of the fine-grained groundmass of an intrusive breccia. This breccia cuts several rock types, mainly

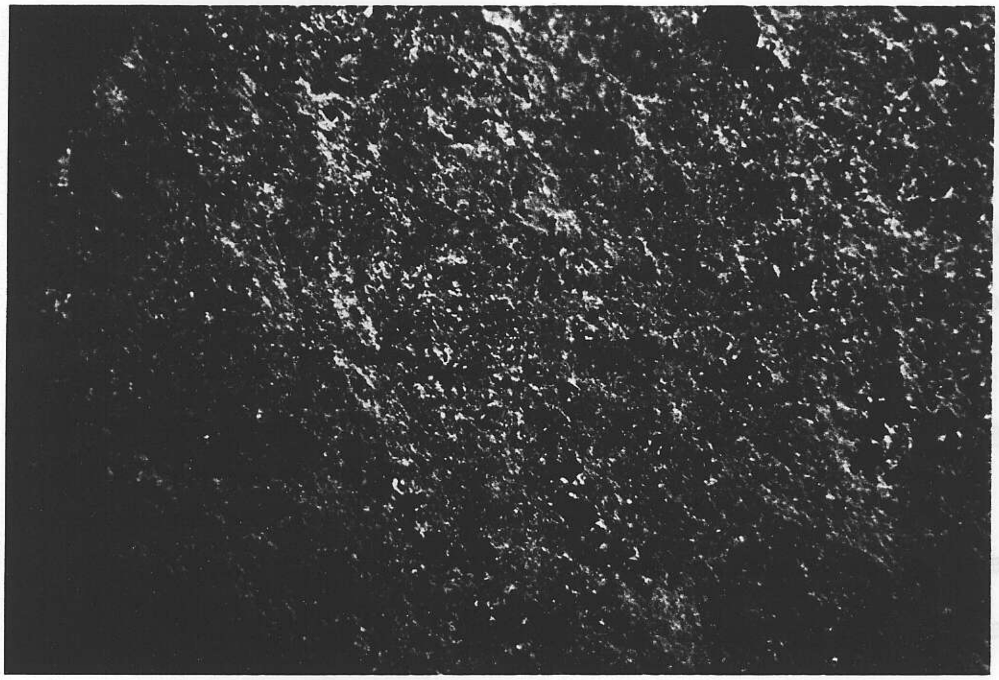


Figure 22. Microphotograph of quartz-sericite rock, the third stage of sericitic alteration. All primary textures are obliterated. Sample S-13, magnification 28x, crossed nicols.

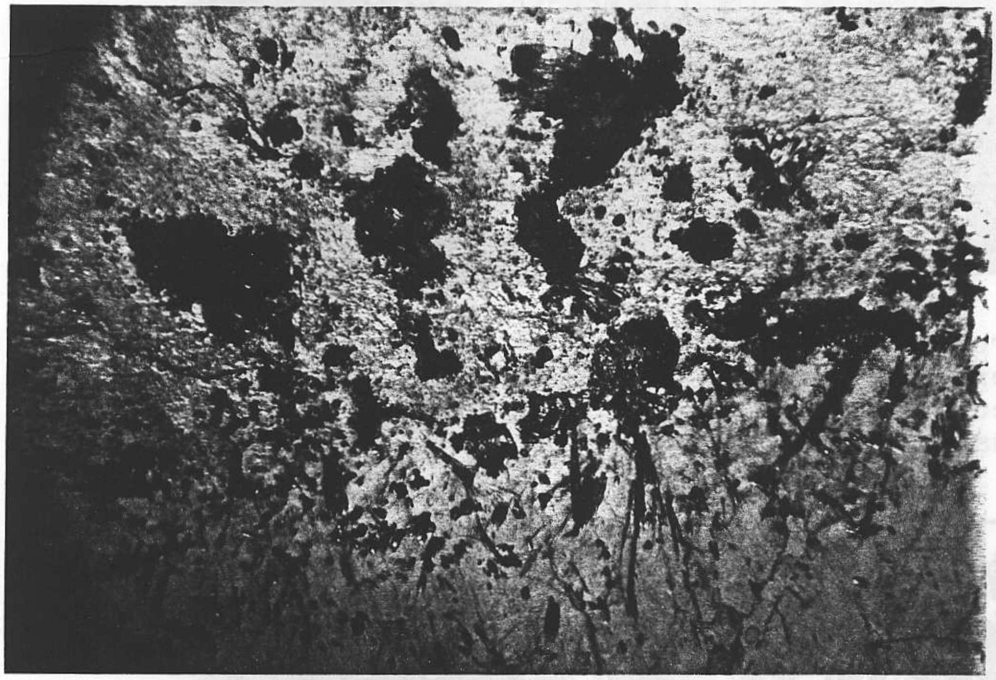


Figure 23. Microphotograph of tourmaline. Note the green tourmaline in the groundmass and the pale-blue tourmaline in the cross-cutting vein. Sample 3021, magnification 28x, plane light.

Figure 24. Microphotograph of tourmalinized microbreccia. Green tourmaline occurs as groundmass around breccia clasts. Sample P20-2A, magnification 28x, crossed nicols.

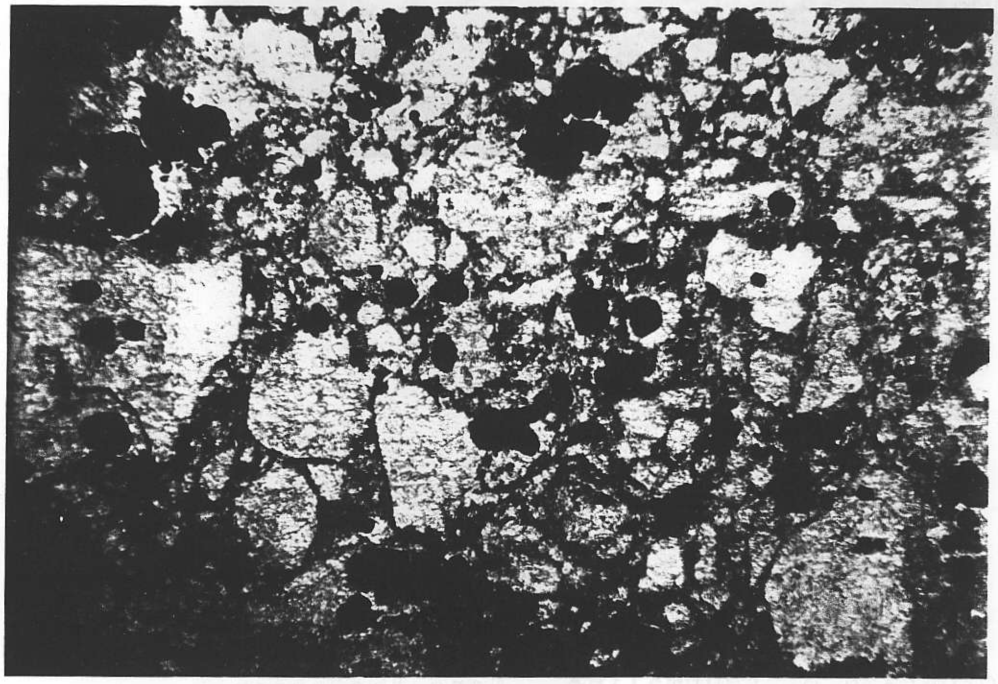


Figure 25. Microphotograph of tourmalinized microbreccia. Same as Figure 24, but plane light.

itchell Intrusions and sedimentary rocks. Tourmaline content is at a maximum in the uppermost part of the breccia and at the upper contact makes up almost 100 percent of the matrix. This may indicate a possible zonation of volatiles within the breccia. Breccia clasts are incipiently sericitized, sub-angular to round, and do not contain any tourmaline. In the breccia, tourmaline is very fine grained and generally less than 1 mm in size.

Tourmaline is an important variant in the alteration scheme because it is associated with elevated metal contents. Tourmaline is everywhere found with very high copper and (or) gold values, some of which reach economic grade. However, the reverse is not always true because sub-economic to economic metal values are not everywhere found in conjunction with tourmaline.

Silicification occurs mainly within the sericitic zone. Local areas up to 15 m by 4 m in size have appreciable amounts of silica, in the form of microcrystalline, milky quartz. Veins of quartz that are curvilinear, lenticular and have irregular attitudes occur in the most intensely silicified rocks. Almost all of the silicified areas are mineralized with chalcopyrite and molybdenite. In the Lake zone (pl. 1) where the rock has been tourmalinized, silica has also been added. Very commonly, in thin section, the secondary quartz will show an unusual "bent" texture. icrocrystalline grains and crystals of quartz appear to be, bent curved or very wavy in form (fig. 26). However, quartz of this type does not show any fracturing or evidence of strain and interference figures still display a sharp uniaxial figure.

Seven samples of sericite (numbers S-9, 18-4, 2401, 3021, 3081, 3093, 3097) were analysed by X-ray diffraction because sodium-rich sericite (paragonite) was suspected. X-ray diffraction analysis indicated that the secondary white mica is muscovite and not paragonite.

Potassic Alteration

This type of alteration is very limited in area, in close proximity to economic grades of copper mineralization. Molybdenum mineralization may be associated but mostly in sub-economic concentrations.

Potassic alteration is characterized by formation of very fine grained biotite which is less than 1 mm in length. Hydrothermal biotite (fig. 27) is green and occurs as disseminations in the groundmass. Less commonly biotite will occur in veins with quartz and sulfides.

With increasing intensity of potassic alteration, very small, less than 1 mm, anhedral grains of orthoclase begin to appear in the groundmass. Secondary orthoclase of this nature only occurs in the most intensely altered rocks where biotite content exceeds 10 percent. Orthoclase content rarely exceeds 1 percent of the total rock (table 4).

Figure 26. Microphotograph of "bent" quartz grains. Sample 3077, magnification 70x, crossed nicols.

Figure 27. Microphotograph of hydrothermal biotite in a potassic altered rock. Sample P-2, magnification 28x, crossed nicols.

Table 4. Typical mineralogic compositions in percent of sericitic and potassic altered rocks at Sulphurets. Based on visual estimates from stained slabs and petrographic sections.

	Sericitic Alteration 25-11 Quartz-Sericite Rock	Potassic Alteration P-3 Monzonite
Primary Minerals		
Quartz	10	-
Orthoclose	25	10
Plagioclase	?	15
Rutile	<1	-
Alteration Minerals		
Sericite	25	5
Biotite	-	10
Chlorite	3	10
Calcite	5	5
Quartz	5	5
Pyrite	3	<5
Albite	-	<5
Leucoxene	3	-
Limonite	-	5

Silicification in the potassic altered rocks is limited to veins. Microcrystalline to macrocrystalline anhedral grains of quartz up to 3 mm long occur with sulfides.

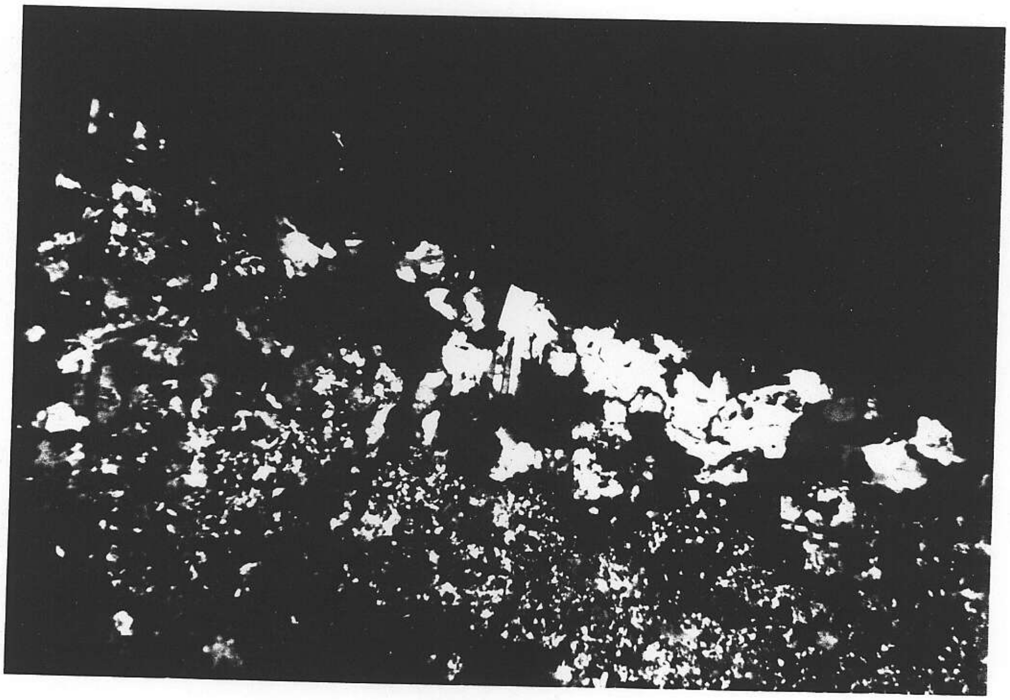
An interesting feature of the potassic altered zones (fig. 28) is that second-stage hydrothermal albite occurs intimately with the sulfide minerals. This appears to be an association with mineralization rather than with potassic alteration, as albite is only found with the sulfides in veins and not in the groundmass. It is possible that, because higher grades of mineralization are associated with potassic zones, second-stage albite will only be found in potassic zones.

Potassic altered rocks occur only near the eastern end of the study area. Higher values of copper and molybdenum mineralization are found in association with the potassic zone in this area.

Paragenesis and Chemistry of Alteration

From thin section study it is apparent that alteration at Sulphurets progressed in an orderly fashion following the progression outlined by Lowell and Guilbert (1970). Only the initial albitization event is out of place in a zoned porphyry system.

Sodium metasomatism caused replacement of calcic plagioclase with albite. Albitization (fig. 29) was the first alteration. Kirkham (1963) suggested that the interval



F·gure 28. Microphotograph of hydrothermal albite surrounded by pyrite in a vein. Sample P-2, magnification 70x, crossed nicols.

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                         Time ----->

-------------------------------------------------------------

Albitization       ------
  Hydrothermal
  Albite                               --------

Propylitic            -?-?----?-?-

Sericitization                -?-?----------
 -Tourmalinization                       -----
 -Silicification                  ----------

Potassic                             ---------

Diagenesis         -?-?-?-


Pyritization       -----------------------------
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Figure 29. Paragenetic sequence of alteration.

between albitization and younger alterations was long. I have found no evidence to support or disprove his conclusion.

As the hydrothermal system expanded, hydrogen metasomatism was responsible for propylitic alteration. In the propylitic zone hornblende was altered to chlorite, calcite and iron minerals. Minor amounts of sericite and clinozoisite were formed after plagioclase.

As hydrogen metasomatism became more intense the sericitic zone rapidly expanded across the propylitic zone overprinting and, in most cases, obliterating any prior alteration and (or) textural features. Sericitic alteration is characterized by a preponderance of sericite. In most of the sericitic zone the chlorite and calcite relics of hornblende were destroyed and iron, calcium and magnesium removed from the rocks. Silicification, by addition of quartz, also occurs within the sericitic zone; consequently, the fluids also carried appreciable amounts of silica. One important variation in the sericitic zone is tourmaline addition in local brecciated areas. This indicates a higher volatile content.

Potassium metasomatism occurred inward of, and presumably contemporaneous with, or perhaps during, the final stages of sericitization (fig. 29). Potassic alteration, characterized by formation of biotite with minor orthoclase, is confined; closely associated with higher grade copper mineralization.

The residual fluids responsible for mineralization must have been rich in sodium because hydrothermal albite is intimately related to sulfide deposition. Hydrothermal albite occurs as small laths within quartz-sulfide veins and in one sample (No. P20-2A) a 2 mm wide vein of albite was found.

Pyritization occurred during all phases (fig. 29) of alteration and mineralization.

Comparison with Alkaline Porphyry Alteration

All previous workers at Sulphurets considered the deposits to be of the alkaline porphyry suite. However, alteration at Sulphurets is very different from alteraton at alkaline deposits. At Sulphurets the most prominent feature is a very large sericitic alteration zone. Propylitic alteration is insignificant. The potassic alteration is erratic in distribution and is found in small patches. Potassic alteration is characterized by the development of biotite with little or no orthoclase.

Alteration of alkaline porphyry deposits is characterized by propylitic and potassic alteration. Sericitic alteration is absent or poorly developed. Biotite is prominent in the potassic zones, but orthoclase is much more common than it is at Sulphurets. The propylitic alteration zones occur peripheral to centralized potassic zones (Barr and others, 1976).

The major difference between Sulphurets and alkaline deposits is the sericitic alteration zone, generally absent in alkaline porphyry deposits. The size and distribution of the potassic and propylitic zones also do not correlate well. Hydrothermal alteration at Sulphurets has few similarities with that of alkaline porphyry deposits.

Conclusions

During the waning stages of magmatic activity the intrusions and sedimentary-volcanic rocks that were associated with the intrusions were hydrothermally altered. The earliest alteration was albitization of pre-existing plagioclase. This may have taken place prior to or at the beginning of propylitic alteration. Not only were the intrusive rocks affected by albitization but the sedimentary-volcanic pile was also albitized. Albitization may be due to marine connate waters trapped within the sediments during sedimentation and diagenesis.

There are three possible hypotheses that would explain how albitization took place in the study area. The first possibility is that the Mitchell Intrusions could represent two separate intrusive events from two different sources. The first set of intrusions and the sedimentary-volcanic rocks could have been albitized by static thermal metamorphism by the second intrusive event. This second set of intrusions was subsequently so altered as to make identification of its feldspar impossible. Problems with this hypothesis arise very quickly. Kirkham (1963) thought that all of the Mitchell Intrusions were from a single parental source magma and noted gradational types that indicated differentiation. The petrochemical data presented in Chapter II (fig. 11) also supports the idea that all of the Mitchell Intrusions are from a single source and differentiated through time from that source. The amount of hydrothermal alteration indicates that alteration was very dynamic rather than static. This first hypothesis also does not account for the hydrothermal albite found in late-stage quartz veins related to mineralization, nor does it account for the presence of albite in the dikes.

The second hypothesis is that albite is primary in nature. In the sediments albite would be of detrital origin and albite was the primary feldspar in the Mitchell Intrusions. Problems with this possibility also arise quickly. Kirkham (1963) who covered a much larger area than the area of this study noted that albite occurred as the only feldspar over the entire area and in many different rock types. The albite displays a texture indicative of secondary origin (fig. 18) and Kirkham (1963) concluded that albite is of secondary origin. This hypothesis, like the first, does not explain the origin of albite in the dikes or hydrothermal albite in the late quartz veins.

In the third hypothesis the magma could have been contaminated by marine connate water trapped in the sediments. If the intrusive event occurred during diagenesis (after uplift and during the last stages of cementation) enough connate water could have been incorporated into the intrusive rocks to albitize the feldspar. Because only the feldspar was affected by sodium metasomatism and not hornblende, it would appear that only a finite amount of water was available, but not enough to spilitize the rocks. Spilites and keratophyres are characterized by soda contents of 4.5 to 5.5 percent (Carmichael, Turner, Verhoogen, 1974, p. 599), whereas at Sulphurets Na_2O contents are much lower (average 0.75 percent). For this reason, it seems likely that intrusion took place during the last stages of diagenesis when the sedimentary-volcanic pile was almost dewatered and cemented. Only those sediments that were incorporated into the intrusions contributed water to them. The sediments that were not in direct contact could have been albitized by static thermal metamorphism. Cementation of the sediments would have rendered them impermeable to hydrothermal solutions. A survey of the areas affected by hydrothermal alteration shows them to be in close proximity to intrusive rocks. The sedimentary rocks that were not in close proximity to the intrusives show almost no alteration except for albitization and minor developmnt of sericite in the matrix.

If the intrusions were contaminated by marine connate waters it is possible that the residual fraction could be enriched enough in sodium to generate hydrothermal albite during mineralization. Also the albite in the dikes could be due to any residual concentration of alkali in a late fraction. The dikes could represent lamprophyres which were contaminated by any residual solutions. I favor this last hypothesis because it explains all of the albite occurrences within the study area. Kirkham (1963) also concluded that dikes were albitized due to contamination and that the hydrothermal fluids carried considerable alkali material with them.

Propylitic alteration is characterized by development of clinozoisite and calcite from plagioclase and by development of chlorite, calcite, pyrite and (or) rutile after hornblende. However, calcite after plagioclase could also be a result of the albitization process.

Sericitization of the rocks followed propylitization and is the most intense and widespread alteration found. Sericitic alteration overprinted the earlier propylitic assemblage out to the very fringes of the propylitic zone, so that only very small areas can be recognized in the field as being a result of propylitization. Sericitization is characterized by development of sericite after plagioclase and in the matrix. Two areas have been found where tourmaline also occurs in the sericitic zone. The tourmalinized localities are both strongly brecciated and may indicate areas where volatiles were able to concentrate. Silicification also was contemporaneous with sericitization and continued during mineralization.

Potassic metasomatism is characterized by the development of biotite and minor orthoclase. This alteration is confined to areas of higher levels of copper mineralization with subordinate molybdenum values. Silicification also occurs with mineralization. Hydrothermal albite occurs intimately with sulfides in the potassic zone.

Hydrothermal alteration at Sulphurets is typical of a porphyry copper type of deposit, where a core of potassic alteration grades outward to a sericitic zone which in turn grades into a propylitic zone at the fringe (Guilbert and Lowell, 1974). At Sulphurets the sericitic zone has encroached upon and largely replaced the propylitic zone except for a few small isolated remnants at the far western edge of the sericitic zone.

The Sulphurets deposits were considered by previous workers to be of alkaline affinity and grouped with porphyry deposits of the Intermontane zone of British Columbia (Sillitoe, 1979). However, hydrothermal alteration at Sulphurets does not compare very well with the Intermontane zone porphyries,where a large core of potassic altered rock is surrounded by a large zone of propylitic alteration. A sericitic zone is generally of very limited extent or not present at all (Sillitoe, 1979). This contrasts sharply with

Sulphurets where small local patches of potassic alteration are surrounded by a huge sericitic zone and small remnants of a pre-existing propylitic zone at the outer fringe.

MINERALIZATION

Within the intrusive rocks mineralization is found mainly as vein fillings in a vein stockwork system. Where it is found in the sedimentary rocks, mineralization occurs as disseminations and in formerly more porous horizons can be found as massive replacement bodies. Overall the Sulphurets area is characterized by a high total sulfide content. The rocks contain from 3 to 5 percent (by volume) pyrite. Magnetite has not been found in the Sulphurets gold zone although Kirkham (1963) reports magnetite to be associated with intrusive rocks to the north on Mitchell-Sulphurets ridge.

Mineralization Associated with Potassic Alteration

The highest grade of copper mineralization in the Sulphurets valley is found within and adjacent to potassic altered zones of igneous or sedimentary rocks. Molybdenum values increase closer to the potassic zones, but rarely exceed 500 ppm. Copper values up to 1 percent can be found, but they more commonly vary from 0.1 to 0.6 percent. In potassic altered areas the primary textures are generally so destroyed that recognition of rock type is difficult. In outcrop and hand specimen mineralized, potassic altered rocks are black, dense, and very fine grained. Chalcopyrite and pyrite occur as fine-grained disseminations. Molybdenite is found coating some fractures. In thin-section chalcopyrite and pyrite are found as disseminations in veins and veinlets, with quartz and hydrothermal albite. Molybdenite is confined to the veins.

Kirkham (1963) mentions that the most promising area for developing tonnage of copper mineralization is near the top of Mitchell-Sulphurets ridge which would be just to the northeast of the study area for this paper. This corresponds well with the increase in copper values and the appearance of local patches of potassic metasomatism in that direction. Kirkham (1963) discusses the occurrence of "disseminated copper and molybdenum in mylonite zones" on the upper northern slopes of Sulphurets valley. These "mylonite zones" are located in the northeast portion of the study area, but I believe that the mylonite zones may actually be mudstones or very fine-grained siltstones. Thin-section study shows that the mylonite is very similar in appearance to fine siltstones in other locations. Also coarse-grained lithic and arkosic arenites occur within 30 m of these mylonites.

The main metallic sulfide minerals are invariably chalcopyrite and molybdenite. Chalcopyrite occurs as anhedral grains in the groundmass, veins and veinlets. Molybdenite only occurs as anhedral grains in veins and is one of the last minerals to be deposited. Other sulfides such as bornite, galena and sphalerite have not been found in or near the potassic zones. A gray metallic mineral has been found, but remains unidentified. The unknown mineral is very fine-grained, has low reflectance, no bireflectance, very weak anisotropism and the polishing hardness is less than chalcopyrite. Commonly, it is found as inclusions in pyrite. Several Vickers hardness tests were tried with variable results. Hardness ranged from a low of 278 to a high of 710 Vickers hardness number. The variability of hardness could be due to either faulty equipment or to mineralogical differences in different thin sections.

Gold values are erratic in comparison to copper values in and near the potassic zones. In general, gold values increase as copper content increases, but gold values remain consistently lower than in other alteration types. Gold values range from 0.005 oz./ton to 0.06 oz./ton and average approximately 0.02 oz./ton. It is unknown how the gold occurs, but it is suspected to be associated with pyrite.

Gangue minerals in and near the potassic zones are pyrite, calcite, quartz and albite. Pyrite occurs throughout the Sulphurets area and in all of the various alteration zones. It is unknown which generation of pyrite is associated with Cu-Mo-Au mineralization because pyrite formed over a longer period of time at Sulphurets than Cu-Mo-Au mineralization. Calcite also is ubiquitous and could be remobilized from the sedimentary rocks. Quartz and albite occur intimately associated with chalcopyrite and pyrite as ein minerals. It is possible that the economic minerals were localized with quartz and albite as the last event at Sulphurets.

Secondary minerals are hematite, limonite and malachite. Leucoxene is also a common secondary mineral but it is not known whether it is derived from ilmenite or sphene. Hematite and, especially, limonite are very common and are derived from weathering of pyrite. Malachite is common in the east end of the study area where the chalcopyrite content is higher.

Mineralization Associated With Sericitic Alteration

Sericitic alteration has affected almost all of the study area (pl. 1,2) and the corresponding mineralization is slightly different from the potassic zones. Mineralization in the sericitic zone occurs as disseminations in microbrecciated and intrusion-brecciated rocks; also it occurs in vein stockworks and massive replacements.

The Breccia Zone

The most important area for gold mineralization found to date in the study area has been in the Breccia zone (fig. 30, pl. 2). In this area igneous and sedimentary rocks have been cut by an intrusive breccia with igneous and sedimentary clasts. Dark-green tourmaline is present as the groundmass in the uppermost portion of the breccia. Pyrite, chalcopyrite and the unidentified gray metallic mineral

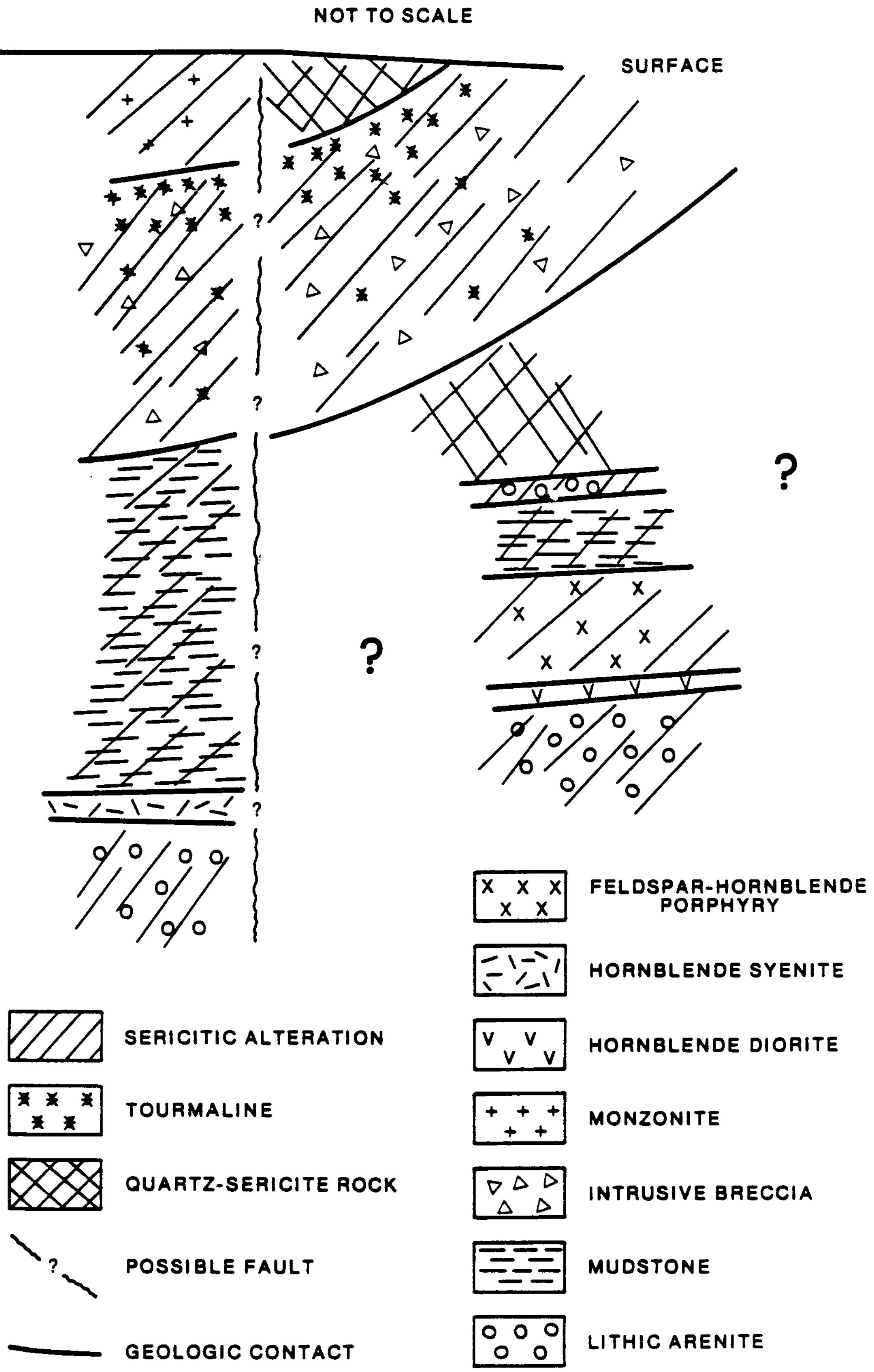


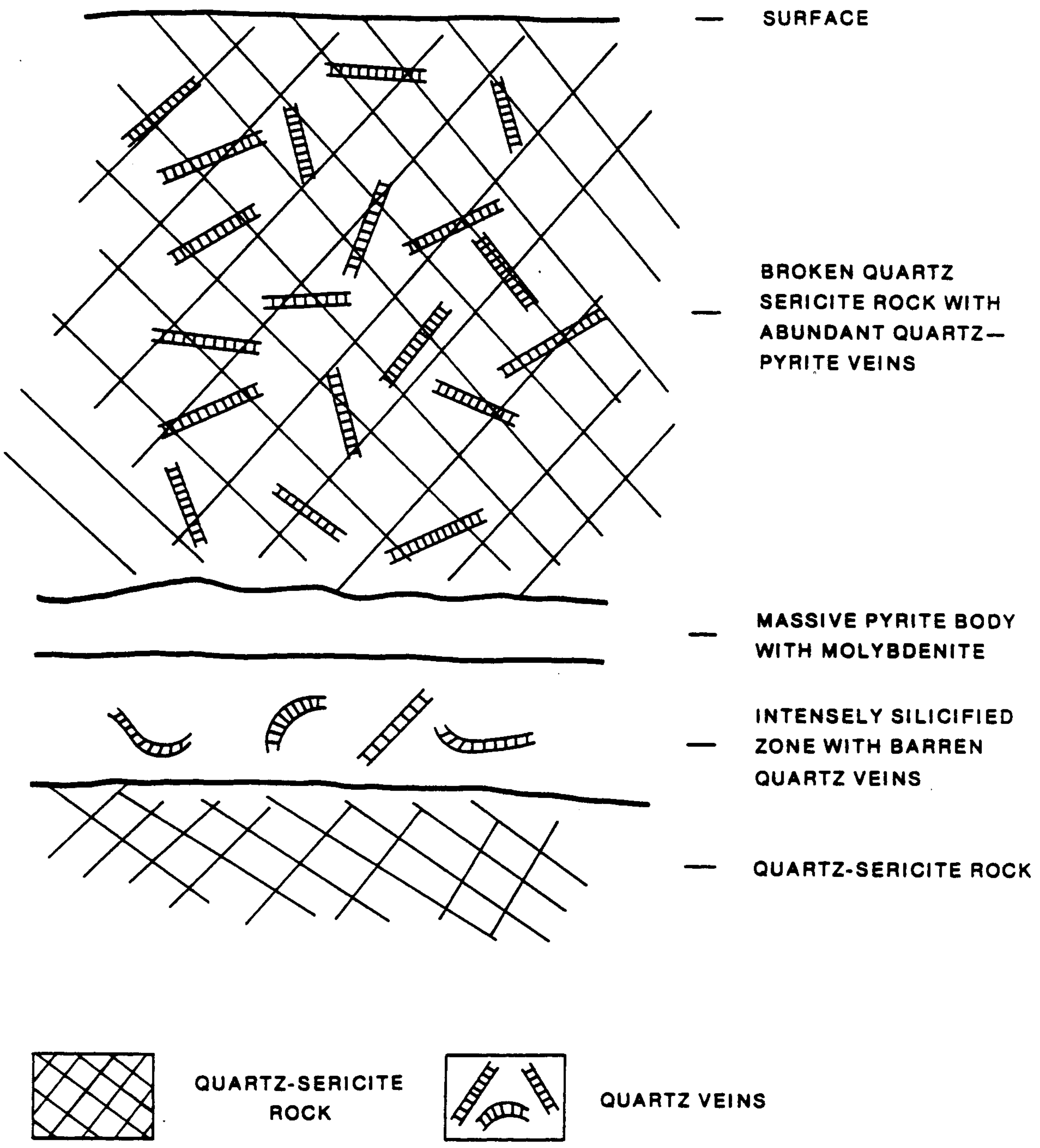
Figure 30. Geologic cross-section sketch of the breccia zone. Section is approximately 200 m high. After plate 4.

previously described are found as anhedral disseminations, in veins and veinlets within the breccia.

Gold values are highest in the breccia and, in general, are proportional to copper and tourmaline contents. Copper values are in the range 200-300 ppm, with some values up to 1300 ppm. Gold values range from 0.05 to 0.06 oz./ton. Although copper values in the breccia are much lower than in the potassic altered rocks, copper and gold are proportional to each other. Vertically below the breccia are thin, up to 10 cm thick, lensoid massive replacement bodies of pyrite and chalcopyrite. The massive sulfide bodies appear to be replacing sedimentary horizons. In these replacement bodies copper is higher in content but gold has lower values, similar to the potassic zones.

The Canyon Zone

Another area within the sericitic zone, referred to as the Canyon zone (fig. 31, pl. 1), is also of interest for gold mineralization. In the uppermost section of the Canyon zone quartz-sericite-pyrite rock has been brecciated (fig. 31) and mineralized with a quartz stockwork. Veins of quartz and pyrite are commonly about 4 mm wide and occur from 3 to 12 cm apart. Veins end abruptly against fractures and pinch out rapidly. Quartz occurs as anhedral, clear to milky grains up to 5 mm in length. Pyrite is euhedral to anhedral in shape and up to 4 mm in size. Pyrite is well oxidized to



NOT TO SCALE

Figure 31. Geologic cross-section sketch of the Canyon zone. Section is approximately 70 m high.

limonite. Pyrite is the principal sulfide mineral and the gold is believed to be associated with it. Chalcopyrite is rare and copper values range from 100 to 2000 ppm, but average approximately 900 ppm. Gold values are lower than in the Breccia zone and lie near 0.02 - 0.04 oz./ton.

At the base of the upper brecciated section (fig. 31) is what appears to be a massive replacement body of pyrite (fig. 32). The sulfide replacement body has an irregular upper surface, a flat lower surface, varies from 3 m to 10 cm in thickness and is approximately 50 m in length. Very minor molybdenite is associated with this replacement body as disseminations with the pyrite. Veins and veinlets, up to 4 mm wide, that radiate outward from this body carry pyrite, molybdenite, chalcopyrite and quartz.

Directly below the massive sulfide body is a 3 m thick section of intensely silicified quartz-sericite-pyrite rock (fig. 31, 33). Pyrite content is very low and quartz veins within this section are barren. Quartz veins are up to 2 cm wide and very irregular in shape and continuity. Quartz is microcrystalline and white.

The basal unit of the Canyon zone is typical quartz-sericite rock (fig. 31). Secondary minerals in the Canyon zone are hematite, limonite, and malachite. Leucoxene is common, as in the potassic zones, but it is unknown whether it is derived from ilmenite or sphene. Malachite is rare in the Canyon zone but hematite and limonite are very common as

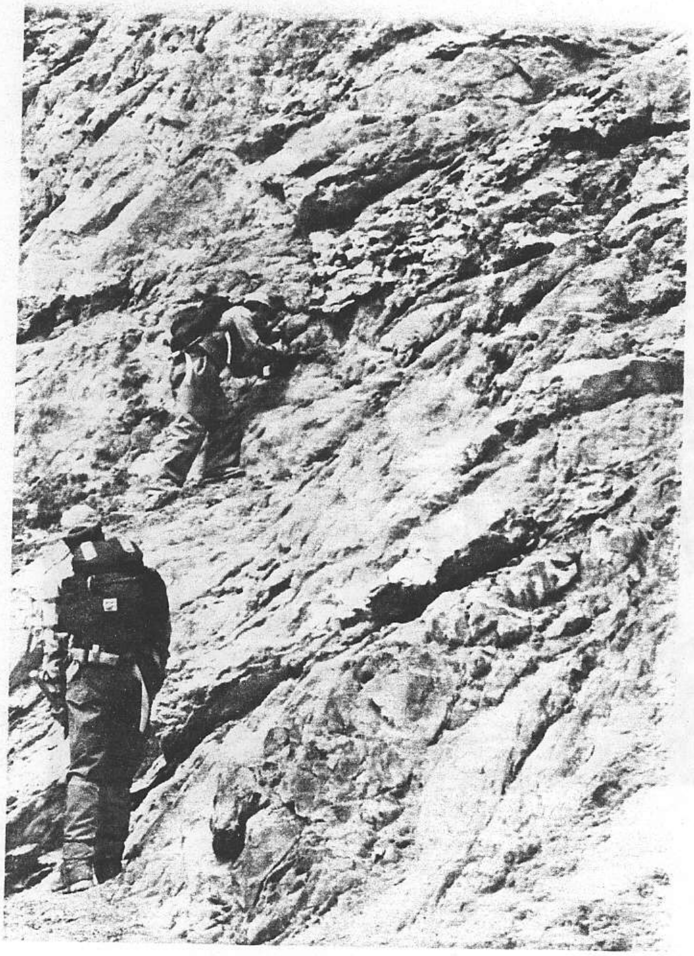


Figure 32. Photograph of massive replacement body of pyrite. People are approximately 1.8 m tall.

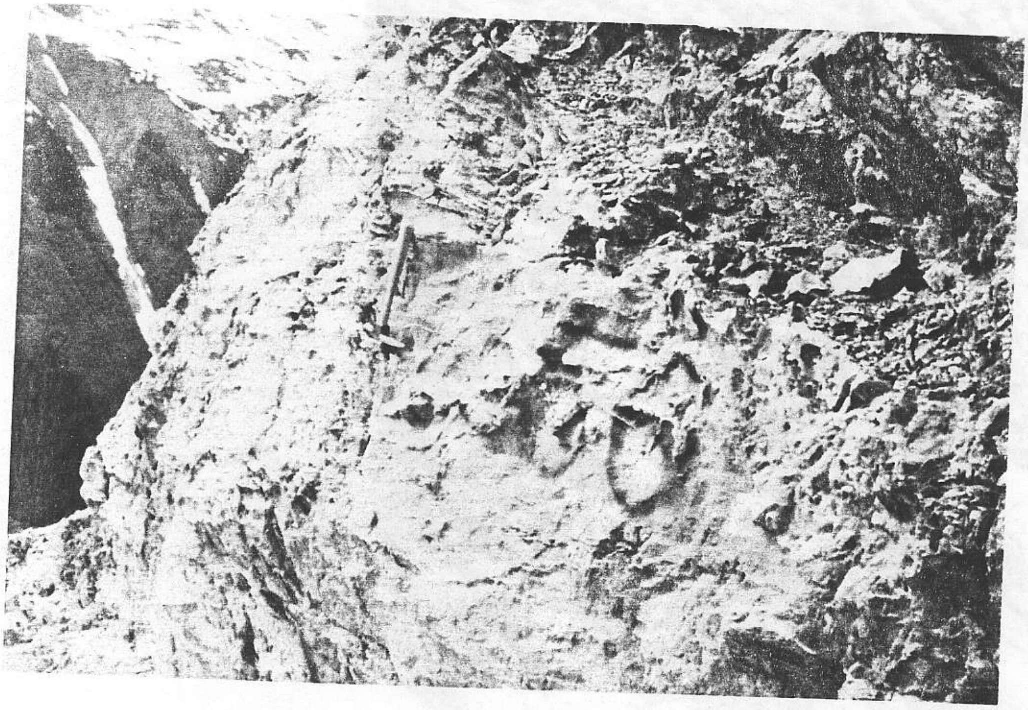


Figure 33. Photograph of silicified zone with barren, very irregular quartz veins. Section is approximately 3 m high.

oxidation products of pyrite.

The Lake Zone

Within the Lake zone (pl. 1) are 3 gold occurrences of minor significance. The first occurrence is with massive pyrite replacement bodies. These bodies are generally less than 1 m long and are very irregular in shape. Not all of the pyrite bodies carry gold values. In the ones that do have gold values it is unknown how the gold occurs. Mineralogy is similar to that of the Canyon zone. The second occurrence is in microbrecciated syenite. This is of interest because tourmaline also occurs in the rock. This area is insignificant in size, less than 1 sq. m, but has much higher gold values than the surrounding rock. Mineralogy is the same as the Breccia zone.

The last occurrence of elevated gold values is of special interest because it has no corollary anywhere else in the study area. A quartz vein approximately 10 cm wide and 3 m long is present in quartz-sericite rock at the west end of the Lake zone. This vein contains arsenopyrite with pyrite and high gold values. It is believed that the gold is associated with the arsenopyrite at this locality.

Age and Origin of Mineralization

Due to the disseminated character and large areas that are mineralized, plus the intimate association of mineralization with intrusive rocks it is probable that the mineralization is of the porphyry copper type.

It seems likely that mineralization resulted from the final episodes of intrusive activity. The earlier of the Mitchell Intrusions, the feldspar-hornblende porphyries, was followed by hornblende-poor intrusions (fig. 11). Mineralization is thought to be related to the later more-differentiated intrusions. The earlier hornblende-bearing intrusions have propylitic alteration that has been overprinted by the sericitic alteration. Therefore, it seems likely that the intrusions were largely in place before the mineralization event took place. Kirkham (1963) also related mineralization with the "waning stages of magmatic activity".

An interesting feature of mineralization in the sericitic zone is that only a few of the massive sulfide replacement bodies have high gold values. If gold is associated with pyrite it is probable that gold mineralization occurred during a relatively narrow time interval, inasmuch as pyrite was deposited over a much longer time. Just when this time period occurred is unknown, but is suspected to be late in the hydrothermal event, and could be contemporaneous with the copper-molybdenum mineralization.

Comparison with Gold-Rich Porphyry Copper Deposits

In general, at Sulphurets, higher gold values are associated with sericitic alteration and higher copper values are associated with potassic alteration. Alkaline porphyries of British Columbia most commonly have ore zones associated with a potassic zone close to the associated alkaline pluton (Barr and others, 1976). Sillitoe (1979) remarked that in most gold-rich porphyries, "Gold is normally present in potassium silicate alteration, which commonly carries an unusually high magnetite content.". No magnetite has been found at Sulphurets in either the potassic or sericitic zones. So, in comparison, the high gold content of Sulphurets has little in common with most other porphyries. However, Taylor and Van Leeuwen (1980) list a few deposits in Southeast Asia, such as Tapadaa, where gold-rich porphyry copper mineralization is associated with sericitic alteration. In the Southeast Asia deposits, also, the potassic zones are characterized by biotite and little or no orthoclase (Taylor and Van Leeuwen, 1980) which correlates well with Sulphurets.

Other similarities between Sulphurets and the deposits in Southeast Asia are: high-total-sulfide content; and calc-alkaline intrusive rocks which acted as the source for the mineralizing and altering fluids. On the basis of these similarities Sulphurets compares much better with the Southeast Asia deposits than deposits in British Columbia and elsewhere.

Conclusions

The Sulphurets gold zone is a high-total-sulfide area. No magnetite has been found in the area although Kirkham (1963) reported magnetite associated with intrusive rocks to the north of the study area.

Overall, the Sulphurets deposits do not correlate well with gold-rich porphyries found elsewhere. Most other gold-rich porphyries have gold mineralization localized in the potassic alteration facies with quartz and magnetite as major constituents (Sillitoe, 1979). At Sulphurets higher gold values are found with sericitic alteration and no magnetite has been found in the study area. However, Sulphurets is a high-total-sulfide deposit and potassic alteration is characterized by development of biotite and minor orthoclase, which is more typical of gold-rich porphyries in the Southeast Asia (Sillitoe, 1979). Almost no correlations with alkaline gold-rich porphyry deposits found in British Columbia have been recognized, not even petrochemistry of the source intrusions. The petrochemical data show the Sulphurets deposits to be similar to calc-alkaline porphyries found in island-arc terranes.

SUMMARY

The geologic sequence of events of the Sulphurets gold zone may be summarized by the following:

1. During early Jurassic time, or possibly late Triassic, deposition of juvenile sedimentary detritus occurred along a continental margin, possibly in an isolated marine basin along the margin. Volcanic lava(?) flows were also deposited within the sedimentary pile. Sedimentary rocks range from a basal black siltstone to lithic and arkosic arenites and wackes. Volcanic rocks identified are trachyte and feldspar porphyry.

2. Faulting along a north-south zone occurred after deposition of the sedimentary-volcanic pile. Within this fault zone, microbreccias occurred. Faulting along the north-south zone may have created a zone of weakness which aided migration of intrusions and hydrothermal fluids.

3. The Mitchell Intrusions were emplaced. The earliest intrusion was feldspar-hornblende porphyry. Over time, differentiation within the magma chamber took place which led to the emplacement of monzonite and

syenite, in that order. The Mitchell Intrusions may have been emplaced during the late stages of diagenesis of the sedimentary-volcanic pile. Connate water from the sedimentary units was incorporated into the intrusions albitizing the plagioclase feldspar. Plagioclase in the sedimentary units was also albitized.

4. During the waning stages of intrusive activity a hydrothermal system was established. This system was responsible for hydrothermal alteration and porphyry copper mineralization. Hydrogen metasomatism was responsible for propylitic alteration of the surrounding rocks. As the hydrothermal system expanded and increased in intensity the propylitic zone was almost completely overprinted by sericitic alteration. Sericitization was very intense and resulted in formation of quartz-sericite rock. Potassium metasomatism may have occurred at this time in patchy areas.

5. Porphyry copper mineralization is closely associated with potassic alteration. The highest grades of copper mineralization occur in the potassic altered rocks. Low-grade disseminated gold mineralization occurred within the sericitic alteration zone. The

highest grades of gold mineralization found occur with microbrecciated and intrusion brecciated rocks; and with green tourmaline indicating an association of gold with a more volatile-rich phase.

6. Dikes were emplaced that were rich in alkali feldspars, orthoclase and albite. These may represent lamprophyres that were altered by residual alkali material. Late-stage veins were formed at this time with sulfides, quartz, and hydrothermal albite. Veins of only hydrothermal albite also occurred at this time.

7. Faulting was occurring throughout the intrusive and hydrothermal events.

8. The Sulphurets deposits exhibit similarities with porphyry deposits of the Southeast-Asia region and are classified with them. High gold content is the only similarity that Sulphurets has with alkaline suite porphyry deposits of British Columbia.

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APPENDIX A

List of all samples analyzed by X-ray fluorescence with plotting symbols.

APPENDIX A

Plotting Symbol	Sample No.	Rock name (Microscopic ID)
1	S-8	Quartz Stockwork
2	S-13	Sericite-Quartz-Pyrite Rock
3	20-7	Hornblende-Feldspar Dike
4	19-2B	Alkali Feldspar Syenite
5	S-3	Quartz-Flooded Breccia
6	2401	Sericitic Altered Feldspar-Hornblende Porphyry
7	20-2B	Incipiently Sericitized Arkosic Arenite
8	19-8	Lithic Arenite
9	S-9	Sericitized Feldspar-Hornblende Porphyry
0	3021	Sericite-Tourmaline Rock (Andesite Flow?)
A	3097	Quartz-Sericite Rock
B	18-6	Sericite-Calcite-Chlorite Rock
C	24-17	Quartz-Sericite-Pyrite Rock
D	P-8	Monzonite
E	S-11	Feldspar-Hornblende Porphyry
F	20-4	Arkosic Arenite
G	26-4	Feldspar-Hornblende Porphyry
H	26-6	Quartz-Sericite-Pyrite Rock
I	24-13	Sericite-Chlorite Rock
J	26-10	Quartz-Sericite-Pyrite Rock

APPENDIX A (Con't)

Plotting Symbol	Sample No.	Rock name (Microscopic ID)
K	P-9	Granite
L	24-7	Arkosic Wacke
M	20-8	Lithic Arenite
N	3568	Feldspar Porphyry
O	26-2	Sericite-Tourmaline Rock
P	19-1	Monzonite
Q	3081	Hornblende Porphyry
R	S-10	Feldspar-Hornblende Porphyry
S	24-10	Trachyte
T	19-5	Alkali Feldspar Hornblende Syenite
U	26-8	Quartz-Sericite Rock
V	20-1	Quartz-Sericite Rock
W	P-5	Sericitized Microbreccia
X	19-2A	Syenite
Y	19-7	Lithic Arenite
Z	18-4	Quartz-Sericite-Pyrite Rock (Flow?)
/	2403	Quartz-Sericite Rock
=	18-10	Quartz-Sericite Rock
*	19-6	Alkali Feldspar Syenite
?	3093	Monzonite Porphyry
+	18-2	Quartz-Sericite-Pyrite Rock

APPENDIX B

Petrochemistry of all samples analyzed by X-ray fluorescence.

PETRCCHEMISTRY OF SULPURETS GOLD ZONE

	3093	19 6	192A	19 5	19 1	P 9	S 11 ✓	P 8	S 9	2401	1928	20 7 ✓
SYMBOL	?	*	X	T	P	K	E	D	9	6	4	3
SIO2	61.08	55.02	62.21	49.41	52.68	75.50	58.80	71.44	60.06	58.69	67.68	49.17
AL2O3	16.17	17.14	16.10	14.26	17.04	9.23	17.37	13.56	17.50	16.40	11.59	14.63
FE2O3	2.43	3.41	2.97	4.83	5.52	0.67	2.98	0.27	2.42	2.28	3.01	4.63
FEO	2.79	3.90	3.40	5.54	6.33	0.77	3.42	0.31	2.77	2.61	3.44	5.30
MGO	2.51	2.09	1.16	7.29	2.15	0.36	2.32	0.40	1.56	2.25	1.01	7.73
CAO	4.09	3.63	0.46	9.45	1.77	0.17	5.15	0.17	4.75	5.82	0.21	9.92
NA2O	0.38	1.90	0.37	2.45	0.88	1.36	4.06	3.04	0.13	0.71	0.37	2.04
K2O	3.77	6.83	6.54	3.46	6.89	6.08	4.42	6.50	4.48	4.20	6.89	4.85
TIO2	0.38	0.41	0.43	1.10	0.82	0.02	0.67	0.04	0.44	0.46	0.31	1.15
P2O5	0.24	0.31	0.34	0.48	0.51	0.02	0.33	0.01	0.23	0.24	0.14	0.42
MNO	0.13	0.19	0.01	0.19	0.14	0.01	0.15	0.01	0.23	0.20	0.02	0.19
TOTAL	93.97	94.83	93.99	98.46	94.73	94.19	99.67	95.75	94.57	93.86	94.67	100.04
ADJUSTED OXIDES												
SIO2	65.00	58.02	66.19	50.18	55.61	90.16	58.99	74.61	63.51	62.53	71.49	49.15
AL2O3	17.21	18.07	17.13	14.48	17.99	9.80	17.43	14.16	18.50	17.47	12.24	14.62
FE2O3	2.59	3.60	3.16	4.91	5.83	0.71	2.99	0.28	2.56	2.43	3.18	4.63
FEO	2.97	4.11	3.62	5.63	6.68	0.82	3.43	0.32	2.93	2.78	3.63	5.30
MGO	2.67	2.20	1.23	7.40	2.27	0.38	2.33	0.42	1.65	2.40	1.07	7.73
CAO	4.35	3.83	0.49	9.60	1.87	0.18	5.17	0.18	5.02	6.20	0.22	9.92
NA2O	0.40	2.00	0.39	2.49	0.93	1.44	4.07	3.17	0.14	0.76	0.39	2.04
K2O	4.01	7.20	6.96	3.51	7.27	6.46	4.43	6.79	4.74	4.47	7.28	4.86
TIO2	0.40	0.43	0.46	1.12	0.87	0.02	0.67	0.04	0.47	0.49	0.33	1.15
P2O5	0.26	0.33	0.36	0.49	0.54	0.02	0.33	0.01	0.24	0.26	0.15	0.42
MNO	0.14	0.20	0.01	0.19	0.15	0.01	0.15	0.01	0.24	0.21	0.02	0.19
Q	33.384	6.307	33.901		13.635	45.750	4.933	29.049	30.702	23.643	38.103	
C	4.898	0.806	8.927		6.479	0.160		1.293	4.602	0.723	3.673	
OR	23.708	42.561	41.118	20.766	42.980	38.145	26.205	40.115	27.994	26.443	43.007	28.708
AB	3.422	16.954	3.331	19.567	7.861	12.218	34.468	26.865	1.163	6.401	3.307	6.622
AN	19.924	15.854	0.065	17.970	5.752	0.757	16.171	0.813	23.329	29.091	0.134	16.403
NE				0.807								5.760
WO				11.049			3.048					12.546
EN	6.652	5.489	3.074	7.971	5.652	0.952	5.797	1.040	4.108	5.970	2.657	9.249
FS	2.905	4.240	3.296	2.072	6.302	0.898	3.001	0.312	2.949	2.686	3.544	2.095
FO				7.336								7.034
FA				2.102								1.749
MT	3.749	5.214	4.582	7.113	8.449	1.031	4.335	0.409	3.710	3.522	4.610	6.710
IL	0.768	0.821	0.869	2.122	1.644	0.040	1.277	0.079	0.884	0.931	0.622	2.183
AP	0.605	0.774	0.857	1.155	1.275	0.050	0.784	0.025	0.576	0.606	0.350	0.994
TOTAL	100.015	100.019	100.019	100.027	100.030	100.001	100.019	100.001	100.015	100.016	100.008	100.024
SALIC	85.335	83.481	87.341	59.110	76.707	97.029	81.777	98.135	87.739	86.301	88.224	57.492
FEMIC	14.680	16.538	12.677	40.918	23.322	2.972	18.242	1.865	12.227	13.715	11.783	42.532
D.I.	60.513	65.821	78.350	41.139	64.476	96.112	65.606	96.029	59.859	56.486	84.417	41.090

PETROCHEMISTRY OF SULPURETS GOLD ZONE

	S 10	3081	26 4	18 2	1810	2403	20 1	26 2	2610	2413	3097	3321
SYMBOL	R	Q	G	&	=	/	V	D	J	I	A	0
SIO2	60.31	59.32	59.29	59.32	67.29	62.61	63.79	53.88	55.26	60.54	63.47	68.69
AL2O3	16.35	19.72	18.77	19.07	17.03	16.31	18.48	17.82	17.39	15.27	7.86	13.88
FE2O3	2.40	3.23	3.03	3.41	1.33	2.40	1.93	3.32	2.37	5.12	1.22	1.65
FEO	2.75	3.69	3.47	3.91	1.52	2.75	2.22	3.80	2.71	5.87	1.39	1.88
MGO	2.48	1.53	2.01	1.06	1.15	1.51	1.19	1.88	1.90	2.94	1.30	2.24
CAO	4.74	0.62	1.61	0.71	1.36	2.38	0.89	4.65	6.18	0.96	12.61	1.15
NA2O	0.21	0.04	1.84	0.45	1.15	0.15	0.20	2.08	1.43	0.13	1.97	0.29
K2O	3.26	0.88	5.93	6.21	5.12	3.14	7.50	5.13	5.89	5.02	3.58	3.79
TIO2	0.39	0.49	0.40	0.66	0.66	0.54	0.87	0.62	0.58	2.08	0.31	0.45
P2O5	0.27	0.40	0.34	0.13	0.21	0.15	0.51	0.45	0.33	0.45	0.20	0.28
MNO	0.14	0.23	0.08	0.05	0.10	0.50	0.06	0.45	0.32	0.18	0.47	0.07
TOTAL	93.30	90.15	96.77	94.98	96.92	92.44	97.64	94.08	94.26	98.56	94.38	94.37
ADJUSTED OXIDES												
SIO2	64.64	65.80	61.27	62.46	69.43	67.73	65.33	57.27	58.63	61.42	67.25	72.79
AL2O3	17.52	21.87	19.40	20.08	17.57	17.64	18.93	18.94	18.45	15.49	8.33	14.71
FE2O3	2.57	3.58	3.13	3.59	1.37	2.60	1.98	3.53	2.51	5.19	1.29	1.75
FEO	2.95	4.09	3.59	4.12	1.57	2.97	2.27	4.04	2.88	5.96	1.47	1.99
MGO	2.66	1.70	2.08	1.12	1.19	1.63	1.22	2.00	1.91	2.98	1.38	2.37
CAO	5.08	0.69	1.66	0.75	1.40	2.57	0.91	4.94	6.56	0.97	13.36	1.22
NA2O	0.23	0.04	1.90	0.47	1.19	0.16	0.20	2.21	1.52	0.13	2.09	0.31
K2O	3.49	0.98	6.13	6.54	5.28	3.40	7.68	5.45	6.25	5.09	3.79	4.02
TIO2	0.42	0.54	0.41	0.69	0.68	0.58	0.89	0.66	0.62	2.11	0.33	0.48
P2O5	0.29	0.44	0.35	0.14	0.22	0.16	0.52	0.48	0.35	0.46	0.21	0.30
MNO	0.15	0.26	0.08	0.05	0.10	0.54	0.06	0.48	0.34	0.18	0.50	0.07
Q	34.618	57.174	19.509	30.185	37.776	44.763	31.909	9.363	9.812	34.327	23.138	49.607
C	4.828	20.557	7.452	11.190	7.869	9.408	9.869	1.561		9.086		8.350
OR	20.648	5.768	36.212	38.636	31.217	20.073	45.391	32.222	36.925	30.098	22.415	23.732
AB	1.905	0.375	16.089	4.009	10.040	1.373	1.733	18.708	12.837	1.116	17.662	2.600
AN	23.313	0.513	5.958	2.814	5.546	11.713	1.109	21.395	25.076	1.849	2.152	4.107
NE												
WO									2.156		26.199	
EN	6.620	4.227	5.173	2.779	2.955	4.068	3.035	4.977	4.756	7.429	3.430	5.912
FS	2.876	4.133	3.469	3.544	0.814	3.359	1.185	4.303	2.818	3.500	2.020	1.564
FO												
FA												
MT	3.730	5.195	4.540	5.205	1.990	3.764	2.866	5.117	3.646	7.532	1.874	2.535
IL	0.794	1.032	0.785	1.320	1.293	1.109	1.692	1.252	1.169	4.008	0.624	0.906
AP	0.685	1.051	0.832	0.324	0.513	0.384	1.237	1.133	0.929	1.081	0.502	0.703
TOTAL	100.017	100.026	100.019	100.008	100.012	100.015	100.028	100.031	100.022	100.026	100.017	100.016
SALIC	85.312	84.388	85.220	86.835	92.448	87.330	90.012	83.250	84.650	76.476	65.367	88.397
FEMIC	14.705	15.638	14.799	13.173	7.565	12.686	10.016	16.781	15.372	23.550	34.650	11.619
D.I.	57.171	63.318	71.809	72.830	79.033	66.209	79.033	60.293	59.574	65.541	63.215	75.939

PETROCHEMISTRY OF SULPURETS GOLD ZONE

	S 3	S 13	S 8	18 4	2410	3568	26 6	18 6	19 7	P 5	26 8	29 8
SYMBOL	5	2	1	Z	S	N	H	P	Y	W	U	M
SIO2	67.40	59.06	70.17	62.82	61.89	62.53	55.70	58.45	68.42	64.81	62.71	69.24
AL2O3	6.80	18.18	17.79	16.91	12.67	17.24	15.34	19.04	13.69	12.94	17.06	13.80
FE2O3	4.37	2.86	0.76	3.82	4.15	3.15	3.93	3.11	1.51	3.79	2.30	2.20
FEO	5.01	3.28	0.87	4.37	4.75	3.61	4.50	3.57	1.73	4.34	2.63	2.52
MGO	0.55	1.65	0.99	1.32	0.83	1.26	0.81	1.81	0.83	1.95	1.46	1.43
CAO	0.05	2.50	0.07	0.78	0.54	0.64	0.89	0.97	0.92	1.26	2.15	1.22
NA2O	0.04	1.02	0.26	0.12	0.32	1.13	0.52	1.06	0.52	0.15	0.27	1.77
K2O	0.70	6.42	4.61	5.00	4.66	5.57	8.39	5.32	8.24	3.11	5.35	4.63
TIO2	0.19	0.46	0.29	0.60	1.84	0.43	0.35	0.39	0.23	0.38	0.42	0.37
P2O5	0.03	0.46	0.04	0.40	0.37	0.25	0.22	0.29	0.10	0.24	0.25	0.11
MNO		0.05		0.05	0.02	0.12	0.05	0.17	0.05	0.08	0.16	0.07
TOTAL	85.14	95.94	95.85	96.19	92.04	95.93	90.70	94.18	96.24	93.05	94.76	97.36
ADJUSTED OXIDES												
SIO2	79.16	61.56	73.21	65.31	67.24	65.18	61.41	62.06	71.09	69.65	66.18	71.12
AL2O3	7.99	18.95	18.56	17.58	13.77	17.97	16.91	20.22	14.22	13.91	18.00	14.17
FE2O3	5.13	2.98	0.79	3.97	4.51	3.28	4.33	3.30	1.57	4.07	2.43	2.26
FEO	5.88	3.42	0.91	4.54	5.16	3.76	4.96	3.79	1.80	4.66	2.78	2.59
MGO	0.65	1.72	1.03	1.37	0.90	1.31	0.89	1.92	0.86	2.10	1.54	1.47
CAO	0.06	2.61	0.07	0.81	0.59	0.67	0.98	1.03	0.96	1.35	2.27	1.25
NA2O	0.05	1.06	0.27	0.12	0.35	1.18	0.57	1.13	0.54	0.16	0.28	1.82
K2O	0.82	6.69	4.81	5.20	5.06	5.81	9.25	5.65	8.56	3.34	5.65	4.76
TIO2	0.22	0.48	0.30	0.62	2.00	0.45	0.39	0.41	0.24	0.41	0.44	0.38
P2O5	0.04	0.48	0.04	0.42	0.40	0.26	0.24	0.31	0.10	0.26	0.26	0.11
MNO		0.05		0.05	0.02	0.13	0.06	0.18	0.05	0.09	0.17	0.07
Q	71.933	21.551	51.413	40.200	43.243	31.779	17.652	27.926	31.367	48.491	35.283	36.699
C	6.997	6.368	12.875	11.270	7.610	9.160	4.754	11.116	2.580	8.179	7.930	4.028
OR	4.858	39.543	28.421	30.717	29.919	34.311	54.662	33.380	50.595	19.750	33.363	28.102
AB	0.398	8.996	2.295	1.056	2.942	9.967	4.851	9.524	4.572	1.364	2.411	15.393
AN	0.061	9.795	0.090	1.306	0.284	1.607	3.283	3.098	4.064	5.033	9.532	5.478
NE												
WO												
EN	1.609	4.283	2.572	3.418	2.246	3.271	2.224	4.786	2.148	5.219	3.837	3.658
FS	6.197	3.120	0.512	4.128	2.491	3.690	4.996	3.884	1.707	4.685	2.673	2.392
FO												
FA												
MT	7.442	4.322	1.150	5.758	6.537	4.761	6.282	4.788	2.275	5.906	3.519	3.276
IL	0.424	0.911	0.575	1.185	3.797	0.851	0.733	0.786	0.454	0.776	0.842	0.722
AP	0.093	1.136	0.099	0.985	0.952	0.617	0.575	0.729	0.246	0.611	0.625	0.268
TOTAL	100.002	100.025	100.002	100.022	100.021	100.015	100.013	100.018	100.006	100.014	100.016	100.007
SALIC	84.247	86.253	95.094	84.548	83.999	86.824	85.203	85.044	93.176	82.819	88.519	89.691
FEMIC	15.755	13.772	4.908	15.473	16.023	13.191	14.810	14.974	6.829	17.197	11.496	10.316
D.I.	77.189	70.091	82.129	71.973	76.104	76.057	77.165	70.830	86.533	69.606	71.057	80.194

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                 PETROCHEMISTRY OF SULPURETS GOLD ZONE

                24 7        20 4        2417        19 8        2028
SYMBOL           L            F           C            9           7

SIO2            61.55       68.52       57.24       61.07       55.51
AL2O3           18.13       14.88       15.18       12.95       18.85
FE2O3            2.69        1.05        4.39        3.87        3.65
FEO              3.08        1.20        5.03        4.44        4.18
MGO              1.14        1.02        1.61        0.90        1.20
CAO              1.02        0.41        2.88        1.14        0.47
NA2O             0.20        1.17        1.48        0.21        0.34
K2O              6.40        5.51        6.25        6.90        6.60
TIO2             0.35        0.32        0.50        0.33        0.49
P2O5             0.24        0.13        0.34        0.11        0.38
MNO              0.06        0.03        0.17        0.05        0.02
TOTAL            94.86       94.24       95.07       91.97       91.69

ADJUSTED OXIDES
SIO2            64.89       72.71       60.21       66.40       60.54
AL2O3           19.11       15.79       15.97       14.08       20.56
FE2O3            2.84        1.11        4.62        4.21        3.98
FEO              3.25        1.27        5.29        4.83        4.56
MGO              1.20        1.08        1.69        0.98        1.31
CAO              1.08        0.44        3.03        1.24        0.51
NA2O             0.21        1.24        1.56        0.23        0.37
K2O              6.75        5.85        6.57        7.50        7.20
TIO2             0.37        0.34        0.53        0.36        0.53
P2O5             0.25        0.14        0.36        0.12        0.41
MNO              0.06        0.03        0.18        0.05        0.02


Q               33.033      40.538      15.545      30.355
C               10.114       6.958       1.639       3.617
OR              39.869      34.550      38.848      44.334
AB               1.784      10.505      13.173       1.932
AN               3.681       1.257      12.692       5.368
NE
WO
EN               2.993       2.696       4.218       2.437
FS               3.128       0.916       5.365       4.897
FO
FA
MT               4.112       1.615       6.695       6.101
IL               0.701       0.645       0.999       0.681
AP               0.599       0.327       0.847       0.283
TOTAL          100.014     100.007     100.021     100.007         0.0
 SALIC          88.481      93.809      81.897      85.607         0.0
 FEMIC          11.532       6.199      18.123      14.400         0.0


D.I.            74.686      85.593      67.566      76.621         0.0
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Quaternary Deposits

Qco	Colluvium and scree
Qm	Glacial moraine
Qsg	Sulphurets glacier

Unconformity

Early Jurassic

Mitchell Intrusions

Jmhs	Hornblende syenite, occurs as a dike in DDH 19.
Jmhd	Hornblende diorite, occurs as a dike in DDH 20.
Jmib	Intrusive breccia. Contains clasts of Mitchell Intrusions and Hazelton fm. rocks. Contains fine grained tourmaline in groundmass.
Jms	Syenite. Contains pink and red orthoclase phenocrysts up to 2 mm. in length.
Jmm	Monzonite. Latite porphyry? Distinguishable only in thin-section.
Jmfh	Felspar-hornblende porphyry. Contains relic hornblende phenocrysts up to 3mm. long.

Hazelton Formation

Jhla Jht Jhm Jhfp	Jhla. Lithic and arkosic arenites and wackes undifferentiated. Only distinguishable in thin-section. Jhm. Mudstones. Interbedded with Jhla. Only distinguishable in thin-section. Jht. Trachyte. Lava flow? Only distinguishable in thin-section. Jhfp. Feldspar porphyry. Lava flow? Only distinguishable in thin-section.
Jhs	Black siltstone. Basal member of Hazelton fm. in this area.

Hydrothermal Alteration

▩	Propylitic alteration. Characterized by calcite, chlorite, and iron oxides.
░ ▨ **	Sericitic alteration. Partial destruction of texture. Distinguishable only in thin-section Quartz-sericite rock. Total destruction of texture. Only distinguishable from sericitic alteration in thin-section. Quartz-sericite rock is indicated by heavier stippling. Original lithologies unknown. Tourmaline indicated by asterisks.
░	Potassic alteration. Distinguishable only in thin section.

Symbols

〰	Faults
╱ - -	Geologic contact. Dashed where inferred or approximated.
⊙ DDH 18	Diamond drill hole. Showing course of hole corrected to plan view.
m.p.	Massive pyrite
Q ╱	Quartz veins
18-7 P20-2A	Drill core sample numbers at their respective locations on cross-sections.

LEGEND

Plate 3

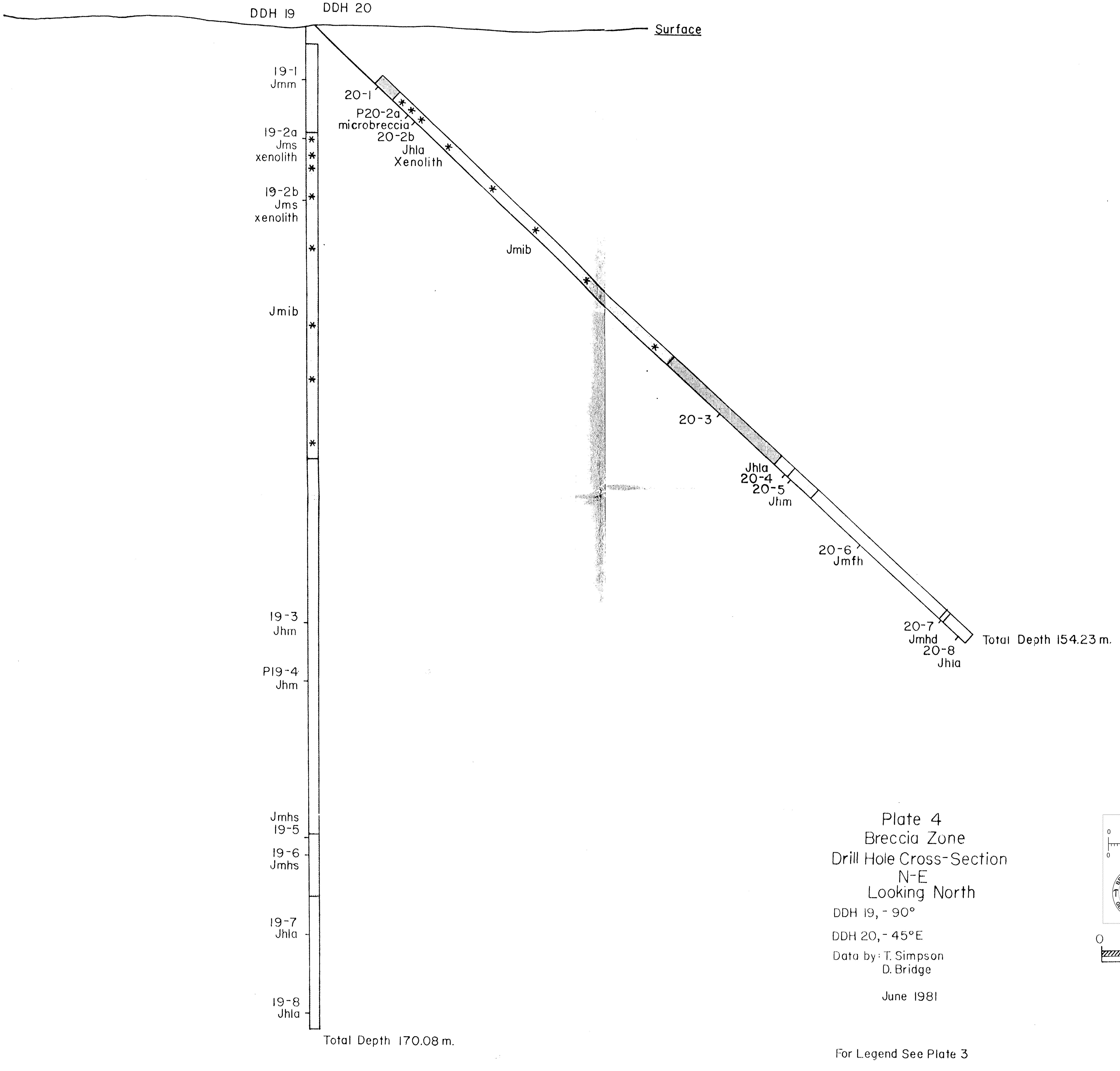


Plate 4
Breccia Zone
Drill Hole Cross-Section
N-E
Looking North

DDH 19, - 90°

DDH 20, - 45°E

Data by: T. Simpson
D. Bridge

June 1981

0 25m.
Scale
1:500

For Legend See Plate 3

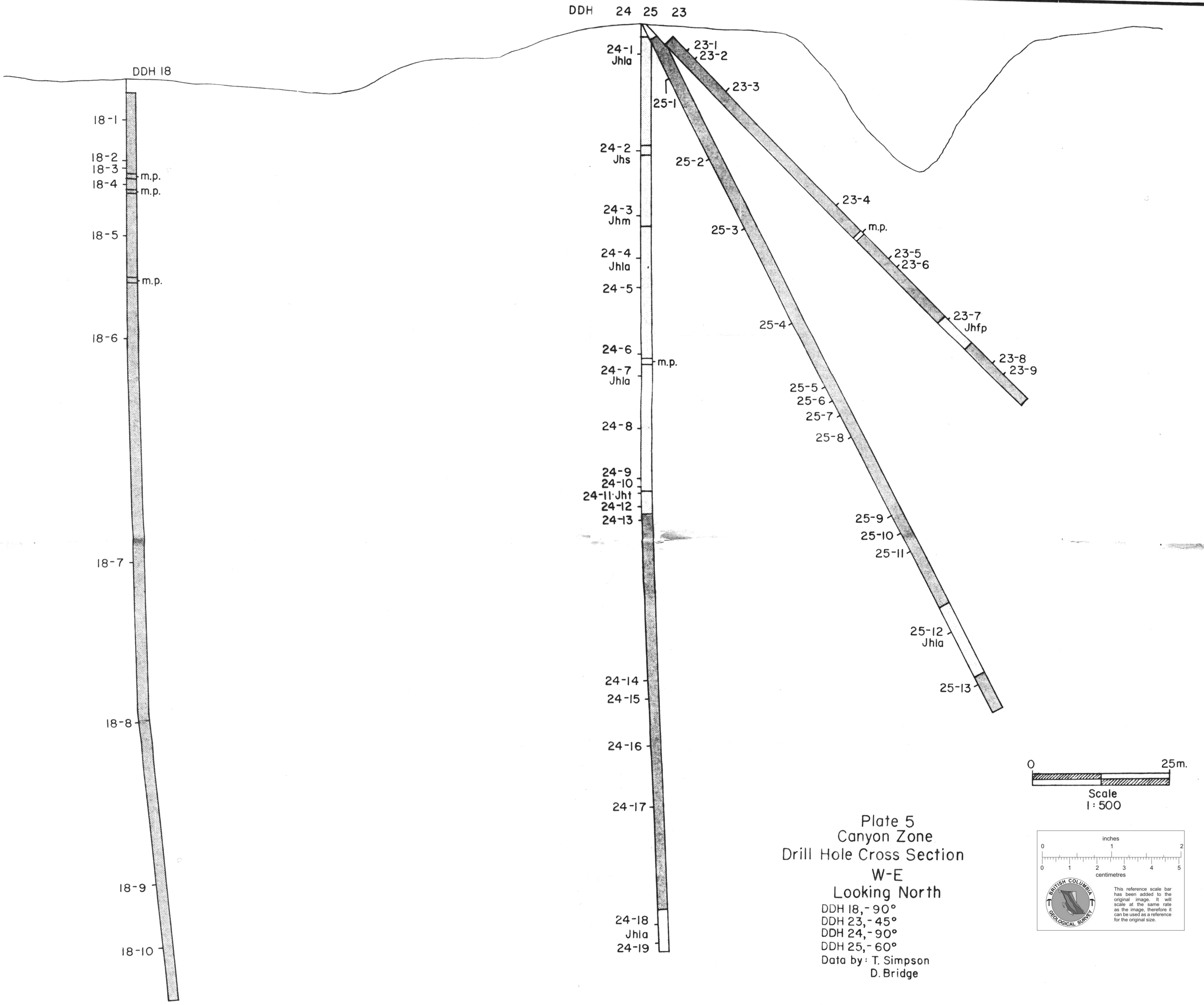


Plate 5
Canyon Zone
Drill Hole Cross Section
W-E
Looking North

DDH 18, -90°
DDH 23, -45°
DDH 24, -90°
DDH 25, -60°
Data by: T. Simpson
D. Bridge

See Plate 3 for legend.

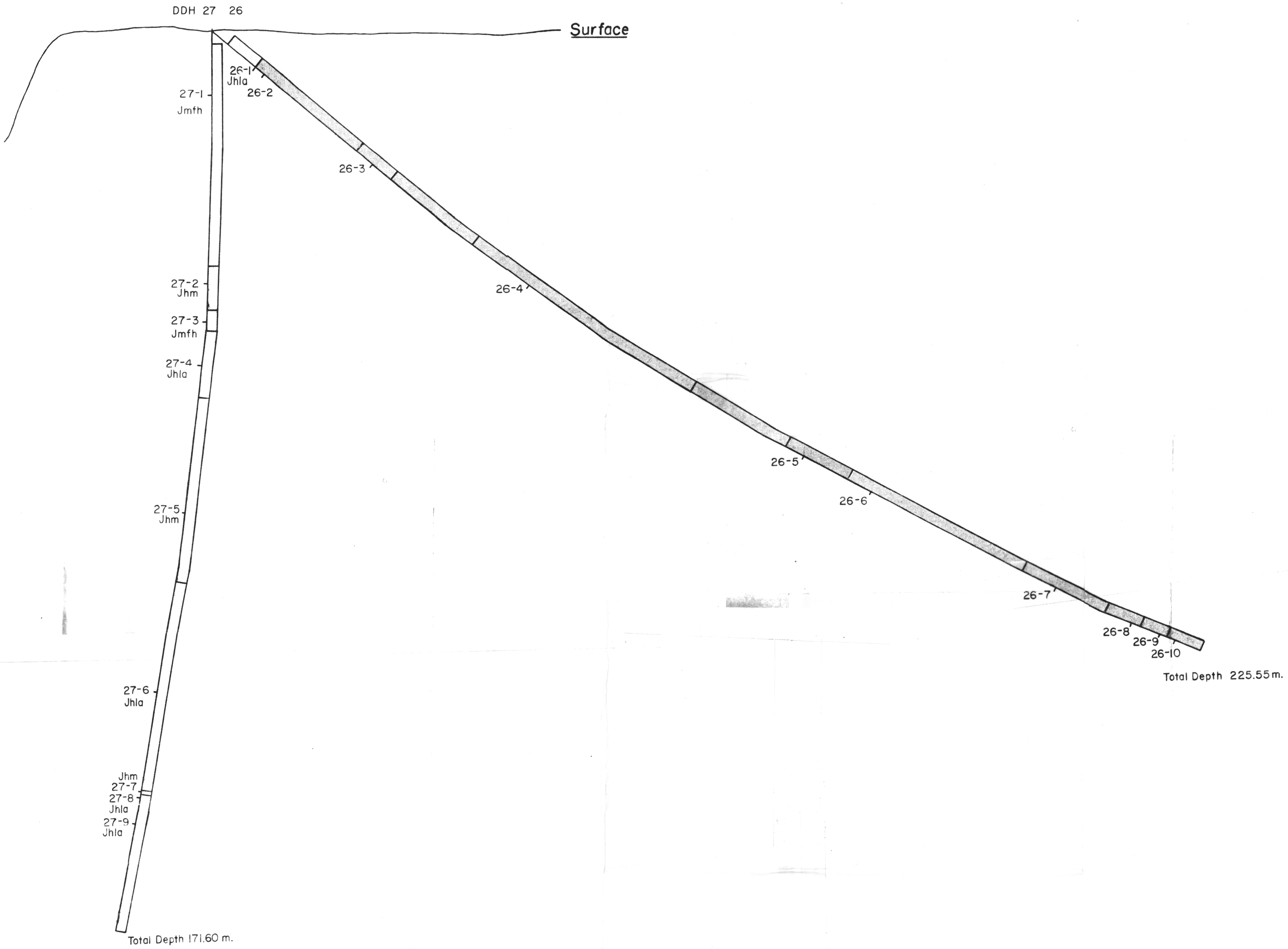


Plate 6
East Side Canyon Zone
Drill Hole Cross Section
Looking NW
045°

DDH 26, - 45°
DDH 27, - 90°

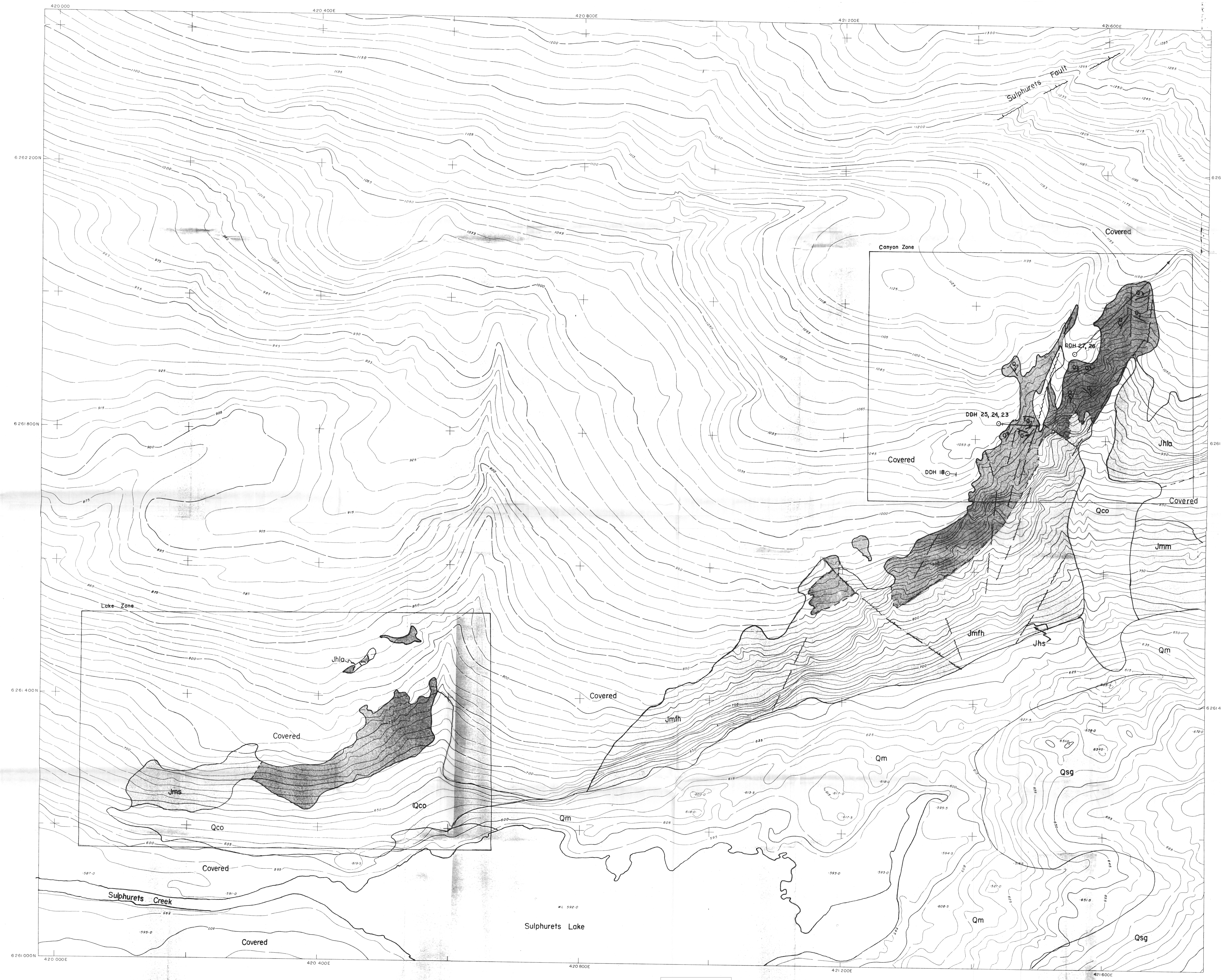
See Plate 3 For Legend

Data by : T. Simpson
D. Bridge

June 1981

0 25m

Scale
1 : 500



Note: Reconnaissance Map.
Control derived from
1:50000 N.T.S. Maps
104B/9 & 104B/8

SCALE 1:2000

inches
0 1 2
0 1 2 3 4 5
centimetres

This reference scale bar has been added to the original image. It will scale at the same rate as the image, therefore it can be used as a reference for the original size.

Data by: T. Simpson
D. Bridge

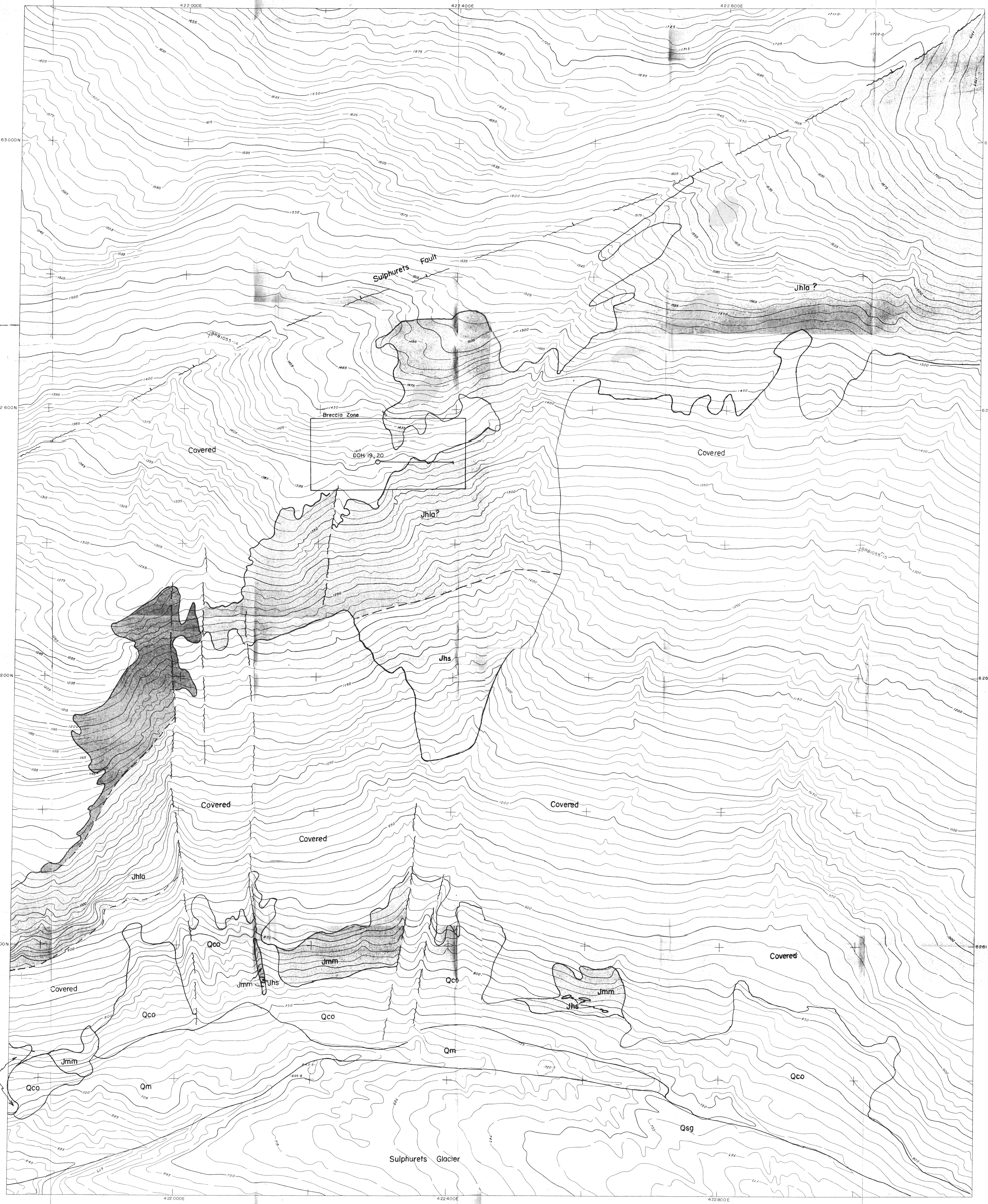
Magnetic Declination

SHEET INDEX
2

ESSO MINERALS CANA

SULPHURETS CREEK

DATE OF PHOTO.: AUG., 1981
JOB No.: 82-1014



Note: Reconnaissance Map
Control derived from
1:50 000 N.T.S. Maps

SHEET INDEX
1
2

SCALE 1:2000

METRES 50 0 50 100 150 200 250 300 METRES

inches 0 1 2
centimetres 0 1 2 3 4 5
BRITISH COLUMBIA GEOLOGICAL SURVEY
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Data by: T. Simpson
D. Bridge
W. Melnyk

June 1981

N Magnetic Declination 29° E

ESSO MINERALS CANADA
SULPHURETS CREEK

DATE OF PHOTO.: AUG., 1981
JOB No.: 82-1014

SHEET 2 OF 2