

## NEWMONT EXPLORATION OF CANADA LIMITED

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Vancouver, B.C. V6C 1K3

RAS

Return to INM for file

Tom Schwetz  
Aug. 23/06

January 13, 1984

Mr. R. Linnen  
Department of Geological Sciences  
Frank Dawson Adams Building  
McGill University  
3450 University Street  
Montreal, P.Q. H3A 2A7

FRONT LAKE MO

885288

MAX

Dear Bob:

Thank you for your letter of November 24, 1983, and the accompanying progress report. As related to you on the phone yesterday, there is nothing in this report that we wish to keep confidential. I understand that you will be presenting a paper to the GAC this spring in London and may seek to have it published. The main item that we would not like you to disclose is the reserves at the higher cut-off grades of 0.20, 0.25, 0.50% MoS<sub>2</sub>. The reserves at the 0.10 cut-off (48.7 million tonnes of 0.193% MoS<sub>2</sub>) have already been published in Boyle and Leitch's CIM paper, and there is no objection to the use of that figure. In fact, I would think it would be useful to inform your reader of the size of the deposit. If you wish to state the ownership, be sure to use the Newmont Mines Limited-Esso Resources Canada Ltd. joint venture.

When your thesis is complete, would you send us two copies as we will have to provide Esso with one. In addition, we will make a copy for Don Hausen so could you include an extra set of anything that won't photocopy, such as colour photos or large maps. *(We will pay these costs)*

where are they?  
Aug/06

The discovery of the Ce-bearing zoisite and its relation to mineralization is very interesting and could have important economic applications. We hope to test its usefulness by re-analyzing some of our stored sample pulps. Also, your work on the potassic alteration (biotite and K-feldspar) has shed light on a difficult topic that has caused confusion in the past. Your findings here will also be useful.



McGill  
University

Department of Geological Sciences  
Frank Dawson Adams Building

Nov. 24, 1983

T.N. Macauley,  
Newmont Exploration of Canada Ltd.,  
1400-750 West Pender St.,  
Vancouver, B.C.,  
V6C 1K3

RECEIVED

NOV 30 1983

NEWMONT EXPLORATION

Dear Terry:

Enclosed is a progress report of research on Trout Lake. Work on the thesis is progressing well, as the research is nearly complete and the writing well underway. The thesis will be completed by spring and I am planning on presenting a talk at the upcoming G.A.C. conference this spring in London. I will of course send Newmont a copy of the abstract, but if there are any aspects of the deposit still considered confidential please contact me. 1.

Within this report there is one aspect which is potentially of interest for tungsten and molybdenum exploration in the Kootenay Arc. A cerium-bearing zoisite (approximately 10 wt.% Ce) is common within the contact aureole of Trout Lake, and its distribution far exceeds that of either molybdenum or tungsten. Cerium is a late stage magmatic differentiate as is molybdenum and tungsten so its occurrence may indicate plutons favourable for tungsten and molybdenum mineralization are nearby. Therefore I suggest a cerium geochemical orientation survey be conducted around the Trout Lake and another known deposit such as the Thanksgiving deposit to determine if there is a useful application of the cerium-zoisite distribution to exploration. 2.

As a last note I will be seeking employment for this summer and would appreciate it if 3.  
you will consider me an applicant.

Best Regards

Robert Linnen

Postal address: Department of Geological Sciences  
Frank Dawson Adams Building, McGill University  
3450 University Street, Montreal, PQ, Canada H3A 2A7

PROGRESS REPORT OF RESEARCH ON TROUT LAKE

*R. Linnen*  
*Nov. 24 /83*

SUMMARY

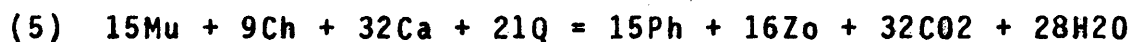
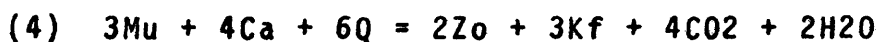
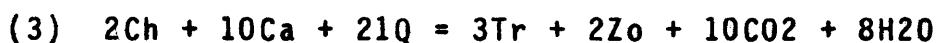
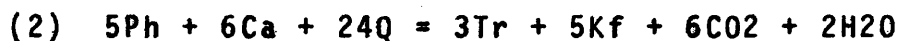
The conditions of contact metamorphism and alteration at Trout Lake have been characterized by using mineral assemblages and T-XCO<sub>2</sub> diagrams. Contact metamorphic aureoles exist around the Trout Lake stock and a small quartz diorite dyke southwest of the deposit. Neither igneous body is large enough to cause the observed aureoles, therefore it is assumed that a larger pluton at depth caused these aureoles. The aureole around the Trout Lake stock is poorly defined because the metasediments in that area are quartz biotite schists, and no useful reactions can be written to characterize the contact metamorphism. However, reactions involving tremolite and zoisite do characterize the aureole around the quartz diorite dyke which have resulted from the calcareous metasediments being located in that area. It is assumed that these assemblages represent contact metamorphism in general since both contact aureoles resulted from the same pluton at depth. Using the reactions involving tremolite and zoisite, and noting the absence of metamorphic diopside, the conditions of contact metamorphism are restricted to 360-400 C and XCO<sub>2</sub> of 0.02-0.03 if the total confining pressure was 2000 bars, or 300-360 C and XCO<sub>2</sub> of 0.01-0.015 if the total confining pressure was 500 bars. A cerium-bearing zoisite is also present within the contact aureole, and the occurrence of this mineral may prove useful as an indicator of plutons which cause tungsten and molybdenum mineralization elsewhere in the Kootenay Arc region.

Four alteration types can be distinguished at the Trout Lake deposit: silicic, potassic, phyllic, and skarn. The silicic alteration is the most restricted, found only at the core of the deposit. Potassic alteration is less restricted, and phyllic alteration is the least restricted but is controlled somewhat by faults. Skarn distribution is also structurally controlled, being associated with the intersection of the limestone unit with faults. Using mineral assemblages and T-XCO<sub>2</sub> diagrams it is determined that the skarn unit formed at temperatures of 375-425 C or 325-375 C, and XCO<sub>2</sub> of less than 0.01, if the total confining pressure was 2000 or 500 bars respectively. The presence of corundum with biotite + calcite + quartz in the quartz biotite schist at the centre of the deposit is unstable, which implies that the potassic alteration is in fact two separate events. The early event, characterized by corundum, represents fluid temperatures of at least 455 C (at 2000 bars) or 425 C (at 500 bars), with XCO<sub>2</sub> conditions probably similar those during skarn formation. The later event, characterized by biotite + calcite + quartz, represents a fluid at 425 C and XCO<sub>2</sub> of 0.15-0.20 (at 2000 bars), or 400 C and XCO<sub>2</sub> of 0.25-0.30 (at 500 bars). The presence of ankerite + albite + K-feldspar + calcite + quartz + rutile suggests that phyllic alteration occurred at lower temperatures, and possibly higher XCO<sub>2</sub> conditions than the second stage of potassic alteration.

NB

## METAMORPHISM

As discussed in the previous report contact metamorphic aureoles can be interpreted from mineral assemblages around the Trout Lake Stock and around a small quartz diorite dyke 500 meters southwest of the stock. Based on mineral assemblages isograds representing the reactions listed below have been interpreted (see base map Fig. 1a ; and assemblage distribution diagram Fig. 1b). A well defined aureole exists around the small quartz diorite dyke whereas a poorly defined halo is present around the Trout Lake Stock. For an explanation of the abbreviations of the minerals consult Figure 2.



A typical mineral assemblage within the contact aureole consists of biotite, chlorite, muscovite, tremolite, zoisite, K-feldspar, plagioclase, quartz, and carbonate in the calcareous units, and biotite, chlorite, muscovite, quartz, and plagioclase in the quartz biotite schist unit. Outside the contact aureole tremolite and zoisite are not present in the calcareous schist, and titanium is represented by rutile instead of sphene. The mineralogical content of the quartz biotite schist does not change outside the aureole, but the relative abundance of the different sheet silicates does vary.

Temperature versus mole fraction of carbon dioxide diagrams

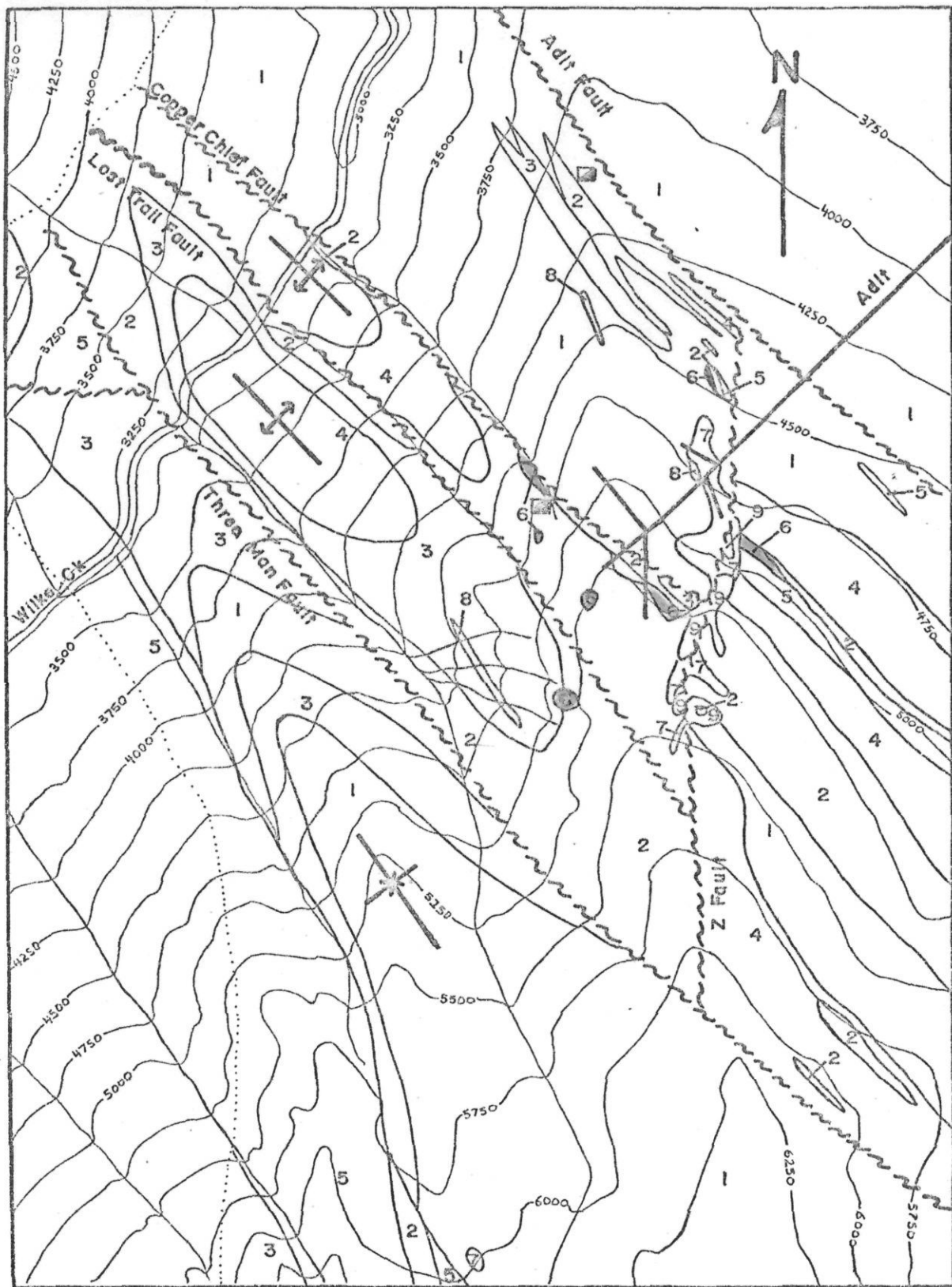


Fig. 1a Geological Map

Units

- |                         |                    |
|-------------------------|--------------------|
| 1 Quartz Biotite Schist | 6 skarn            |
| 2 Limestone             | 7 Granodiorite     |
| 3 Calcareous Schist     | 8 Quartz Diorite   |
| 4 Biotitic Quartzite    | 9 Quartz Stockwork |
| 5 Volcanics             |                    |

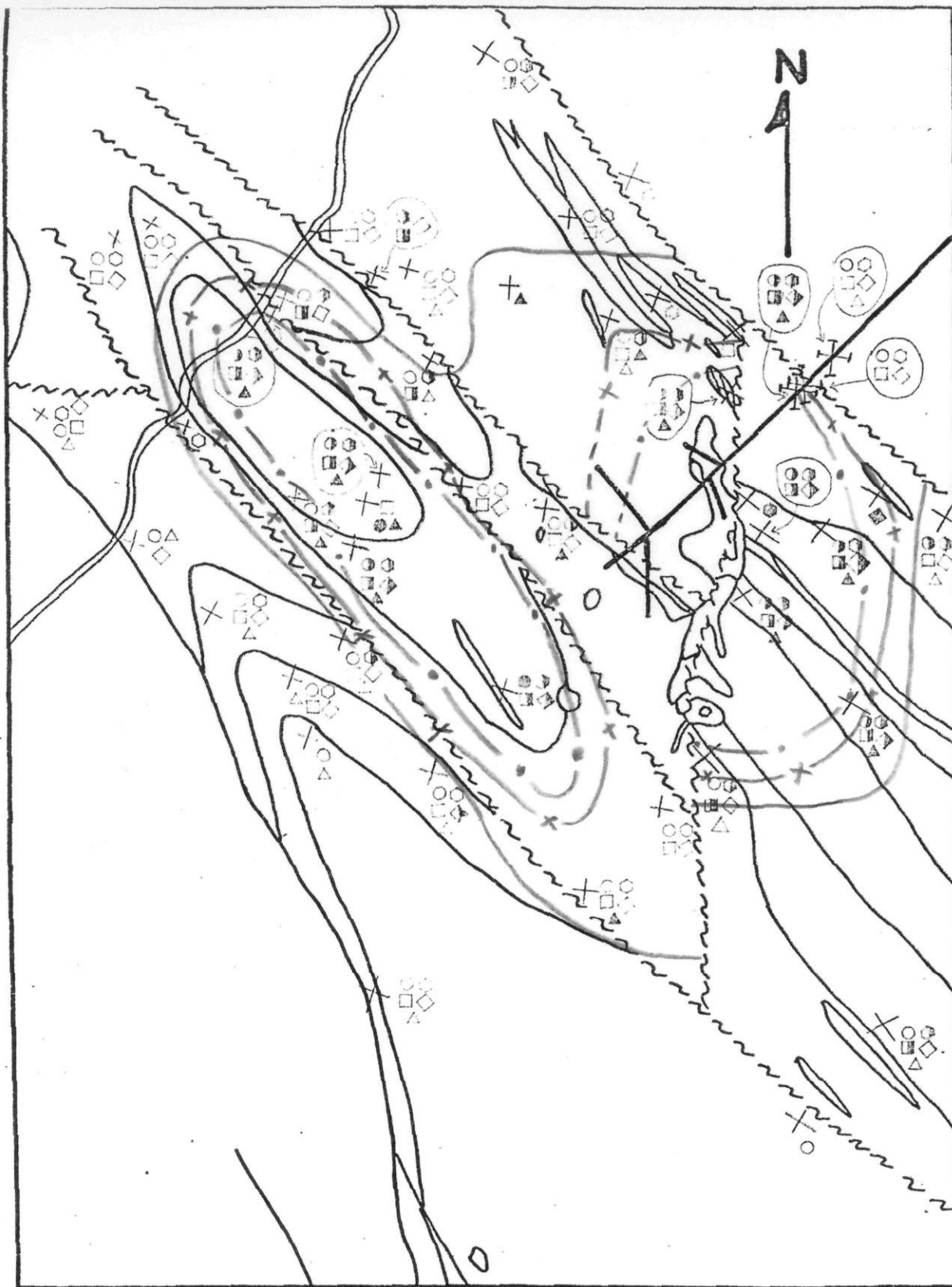


Fig. 1b

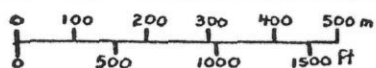
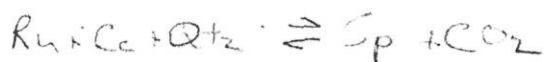
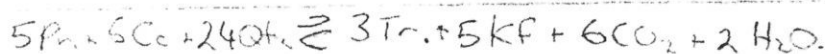
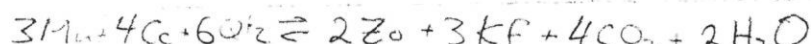
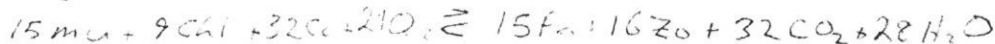
TrZo isograd

PnZo, KFZo, TrKF isograds

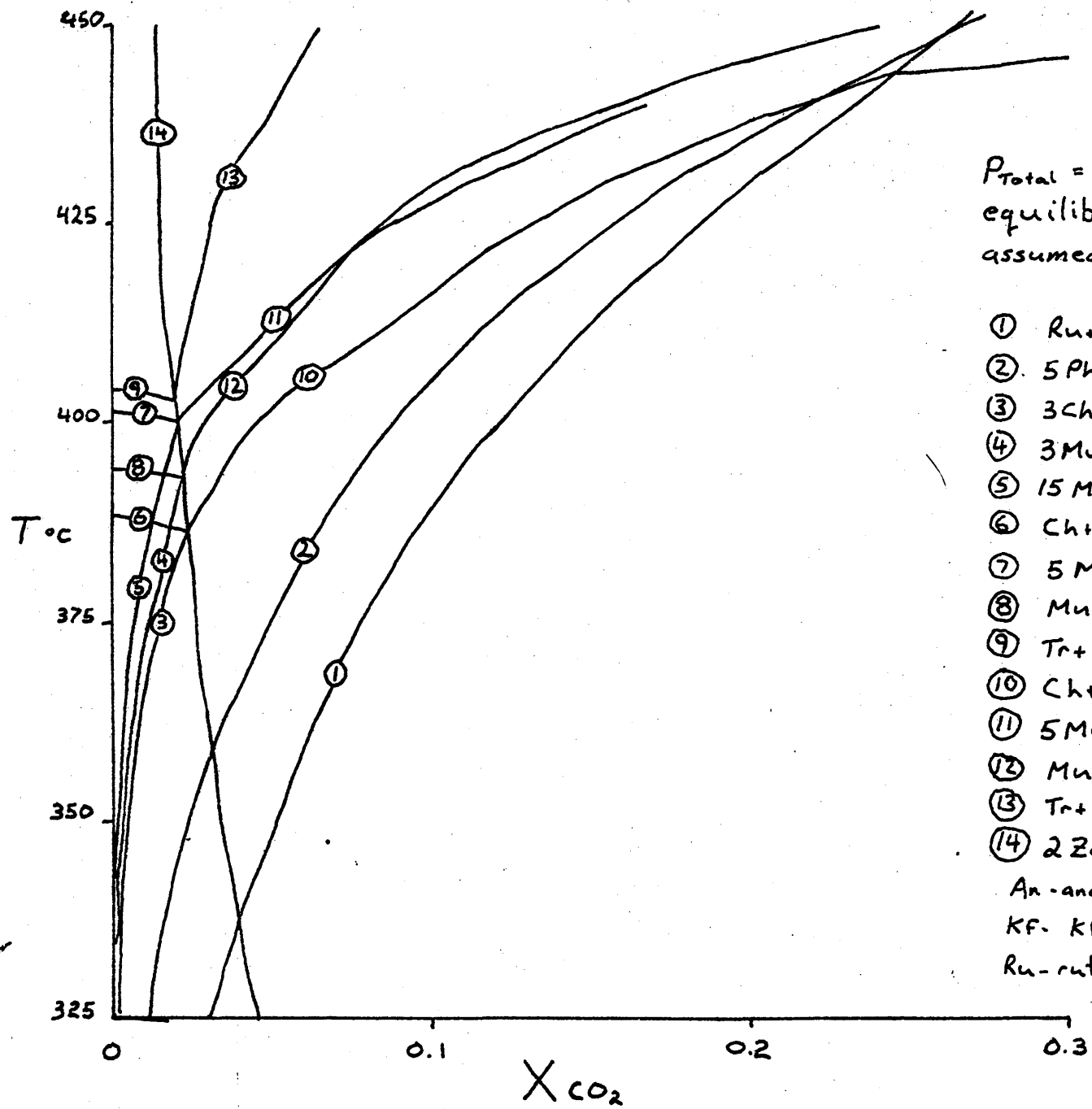
Sp isograd

X Surface Sample Location

Projected Location of Sample from outcrop



low Temp assemblage	divergent	high Tc
○	⊙	⊗
○	⊖	⊕
□	⊠	⊡
◇	⊠	⊡
△	▲	▲



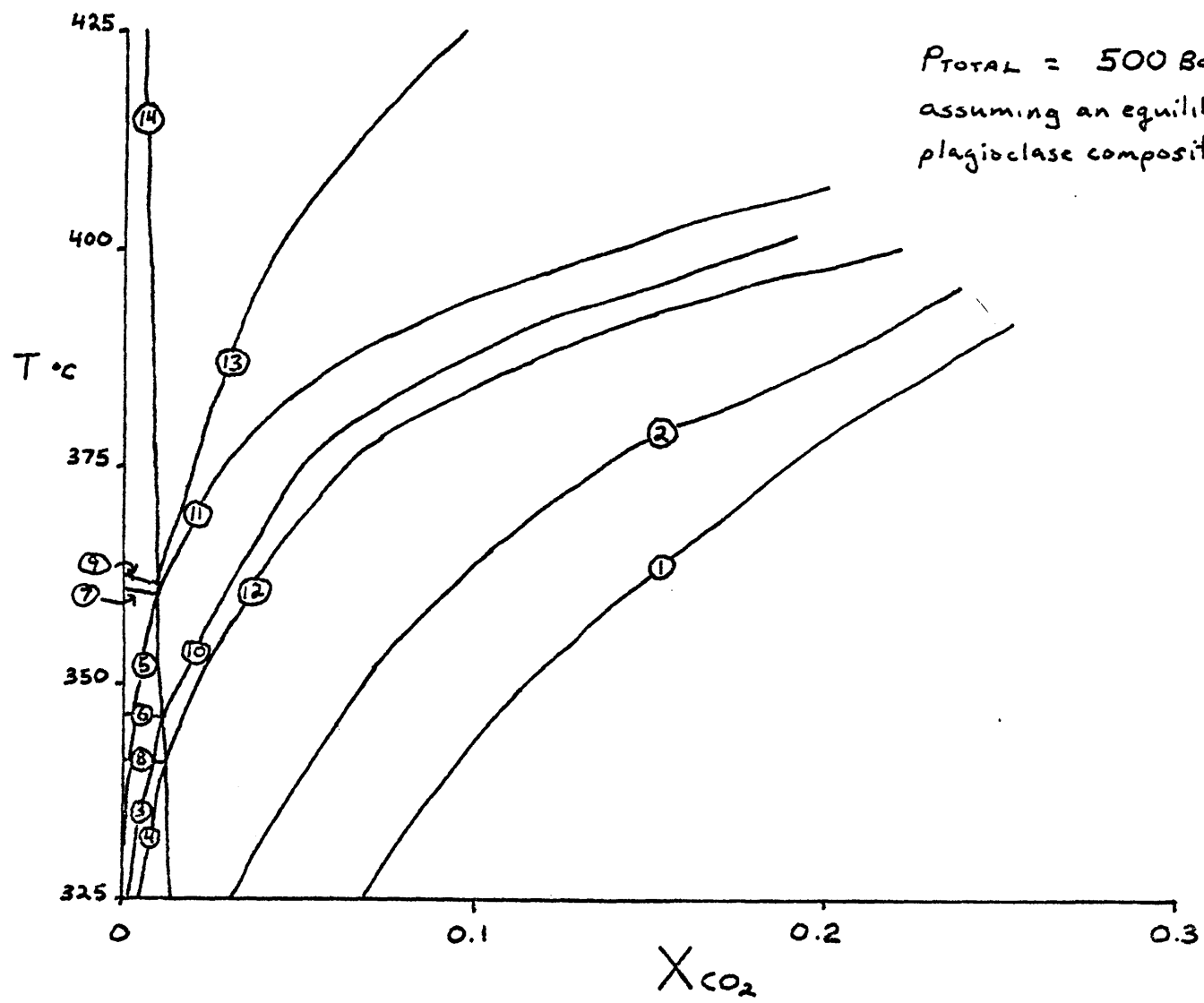
$P_{\text{total}} = 2000 \text{ Bars}$   
 equilibrium composition of An<sub>50</sub>  
 assumed for plagioclase

- ①  $Ru + Ca + Q = Sp + CO_2$
- ②  $5Ph + 6Ca + 24Q = 3Tr + 5KF + 6CO_2 + 2H_2O$
- ③  $3Ch + 10Ca + 21Q = 3Tr + 2Zo + 10CO_2 + 8H_2O$
- ④  $3Mu + 4Ca + 6Q = 2Zo + 3KF + 4CO_2 + 2H_2O$
- ⑤  $15Mu + 9Ch + 32Ca + 21Q = 15Ph + 16Zo + 32CO_2 + 28H_2O$
- ⑥  $Ch + 6Zo + 7Q = Tr + 10An + 6H_2O$
- ⑦  $5Mu + 3Ch + 16Zo + 7Q = 5Ph + 32An + 20H_2O$
- ⑧  $Mu + 2Zo + 2Q = KF + 4An + 2H_2O$
- ⑨  $Tr + 6Zo + 2Q = 5Di + 9An + 4H_2O$
- ⑩  $Ch + 3Ca + 7Q = Tr + An + 3CO_2 + 3H_2O$
- ⑪  $5Mu + 3Ch + 8Ca + 7Q = 5Ph + 8An + 12H_2O + 8CO_2$
- ⑫  $Mu + Ca + 2Q = KF + An + CO_2 + H_2O$
- ⑬  $Tr + 3Ca + 2Q = 5Di + 3CO_2 + H_2O$
- ⑭  $2Zo + CO_2 = 3An + Ca + H_2O$

An - anorthite, Ca - calcite, Ch - chlorite, Di - diopside,  
 KF - Kfeldspar, Mu - muscovite, Ph - phlogopite, Q - quartz,  
 Ru - rutile, Sp - sphene, Tr - tremolite, Zo - zoisite

Fig. 2





P<sub>TOTAL</sub> = 500 Bars  
 assuming an equilibrium  
 plagioclase composition of An<sub>50</sub>

Fig. 3

(T-XCO<sub>2</sub>) have been constructed in order to interpret the conditions of contact metamorphism (Figs. 2 and 3). These diagrams were constructed using thermodynamic data derived from various experimental sources which will not be reviewed at this time. The diagrams are constructed using an ideal mixing model and a non-ideal mixing model is currently being employed to recalculate all the curves presented in this report. The non-ideal mixing model will not drastically change any of the conclusions below. However, there are two assumptions used to construct these diagrams that must be explained.

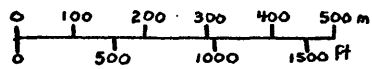
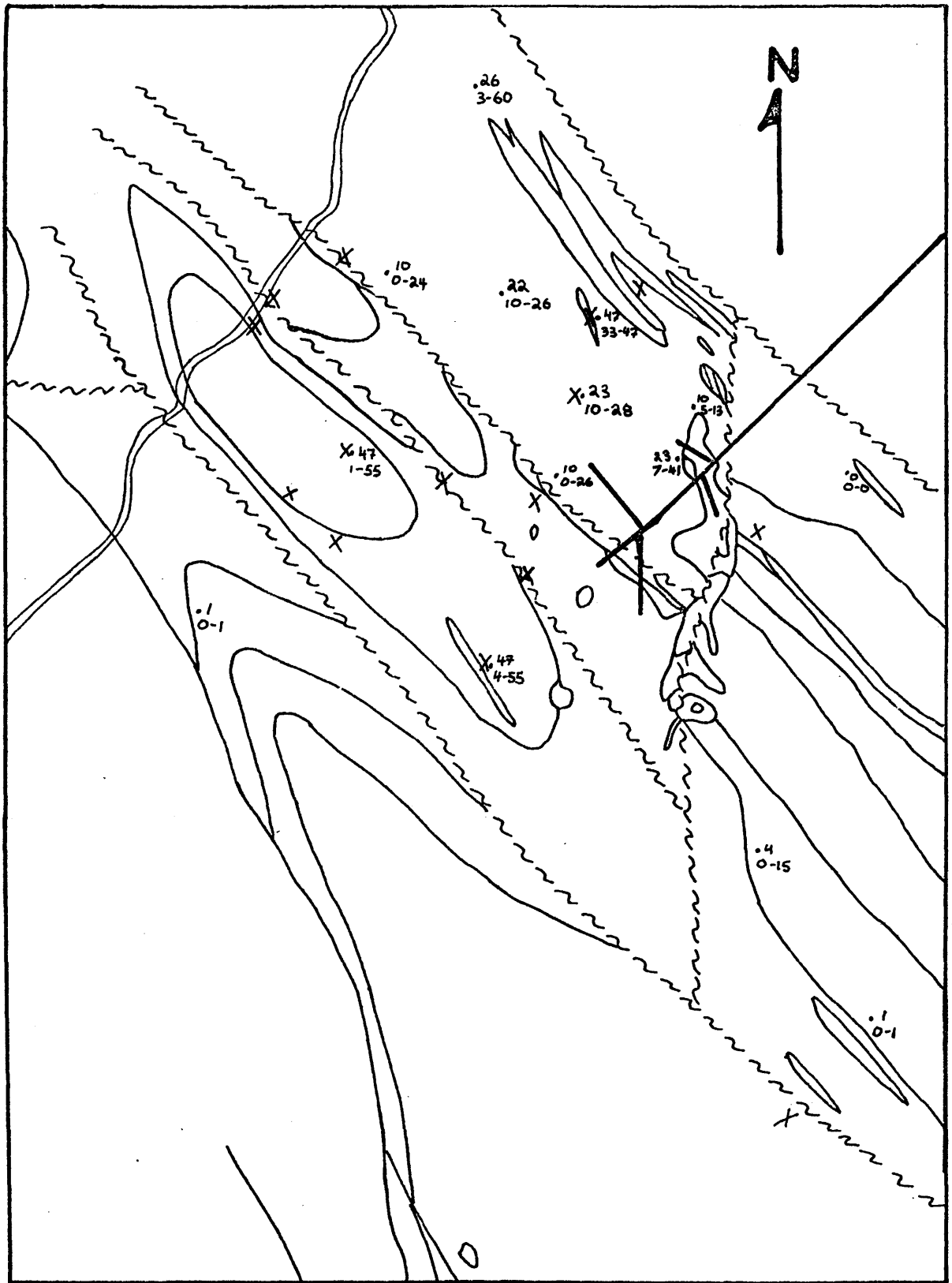
First, the diagrams are isobaric and since to date no suitable geobarometer has been found, pressure must be assumed. The volcanic related Climax-Henderson type deposit forms at depths of 0.6 to 4.5 km or greater (Westra and Keith, 1981). Since there are no chilled contact margins in the Trout Lake Stock nor are there any extrusive equivalents it may be assumed that this deposit formed at a greater depth. Approximately 100 km southwest the Bluebell Pb-Zn-Ag deposit, which is similar in age, is estimated to have been formed at a depth of 6 km under hydrostatic conditions (Ohmoto and Rye, 1970). It is likely that the Trout Lake deposit was formed at a depth similar to the Bluebell deposit but the confining pressure is still undefined as it is not known whether lithostatic or hydrostatic conditions prevailed, although for contact metamorphism conditions are probably nearly lithostatic. Therefore two diagrams have been constructed by assuming either lithostatic or hydrostatic pressures (2000 bars for Fig.2, and 500 bars for Fig.3) for a

depth of formation at 6 kilometers. Conversely a variety of depths are possible for the pressure range of 500-2000 bars dependent upon the lithostatic and hydrostatic components, so the true formation pressure of the Trout Lake deposit probably lies within this pressure range.

The second assumption concerns using a plagioclase composition that represents equilibrium conditions within the contact aureole. Several of the reactions in Figures 2 and 3 involve anorthite which is not the composition of the observed plagioclase. Electron microprobe analyses of metasedimentary feldspars with the sample location are displayed in Figure 4. Although the range of feldspar composition varies, the most representative composition for a plagioclase from the calcareous schist within the contact halo is An50. The quartz biotite schist contains a slightly more sodic plagioclases (An25) but since calc silicate reactions were used to define isograds therefore Figures 2 and 3 were constructed using An50 plagioclase compositions, and the appropriate activity coefficient from Saxena and Ribbe (1972).

From Figures 2 and 3, the intersection of divariant reactions (2), (3), (4), and (5) with the zoisite-plagioclase curve (reaction 14) in Figures 2, defines isobarically invariant points (using the phase rule  $f=c-p+2$ ). The distribution of samples containing invariant assemblages (Fig.5) shows that several invariant assemblages are present within the same thin section, which by the phase rule is impossible (negative degrees of freedom). Two possible explanations for this are: 1) the number of components in nature is greater and therefore in the

$f$  = degrees of freedom  
 $c$  = components  
 $p$  = phases



- 25 Sample location, median plagioclase composition, range
- 2-34
- X location of sample containing cerium zoisite

Fig. 4

"real system" the above points are not invariant, or 2); one or more of the phases are metastable. The assumption that chlorite is stable with tremolite is suspect as chlorite commonly contains inclusions of carbonate and sphene and therefore is possibly of retrograde origin. On the other hand there are chlorite grains that contain no inclusions and which appear to be in equilibrium with the rest of the rock. In addition no chlorite replacement of tremolite is observed. Independent of the explanation of the coexistence of apparently invariant assemblages, the occurrence of tremolite + zoisite + plagioclase + carbonate + quartz without diopside can be used to estimate the maximum temperature of contact metamorphism from reaction (9): 405 C at 2000 bars and 365 C at 500 bars. Therefore the conditions of contact metamorphism were 360-400 C and  $X_{CO_2}$  of 0.02-0.03 if the total confining pressure was 2000 bars, and 300-360 C and  $X_{CO_2}$  of 0.01-0.015 if the total confining pressure was 500 bars.

*This is what Hausen suggests*

A common mineral found on the southwestern slopes of Wilke Creek is a cerium-bearing zoisite (Fig.4), and its distribution approximates that of the contact halos (Fig.1b). This mineral is optically distinct from allanite, and typically forms subhedral cores that are surrounded by clinozoisite. A semiquantitative microprobe analysis indicates that this mineral contains approximately 10 wt.% cerium, and since detrital allanite is rare and metasomatic allanite is common it is assumed that the cerium-bearing zoisite is also metasomatic in origin. Cerium, being an incompatible element is concentrated in late-stage magmatic fluids and therefore it is not surprising that the first fluid

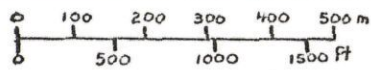
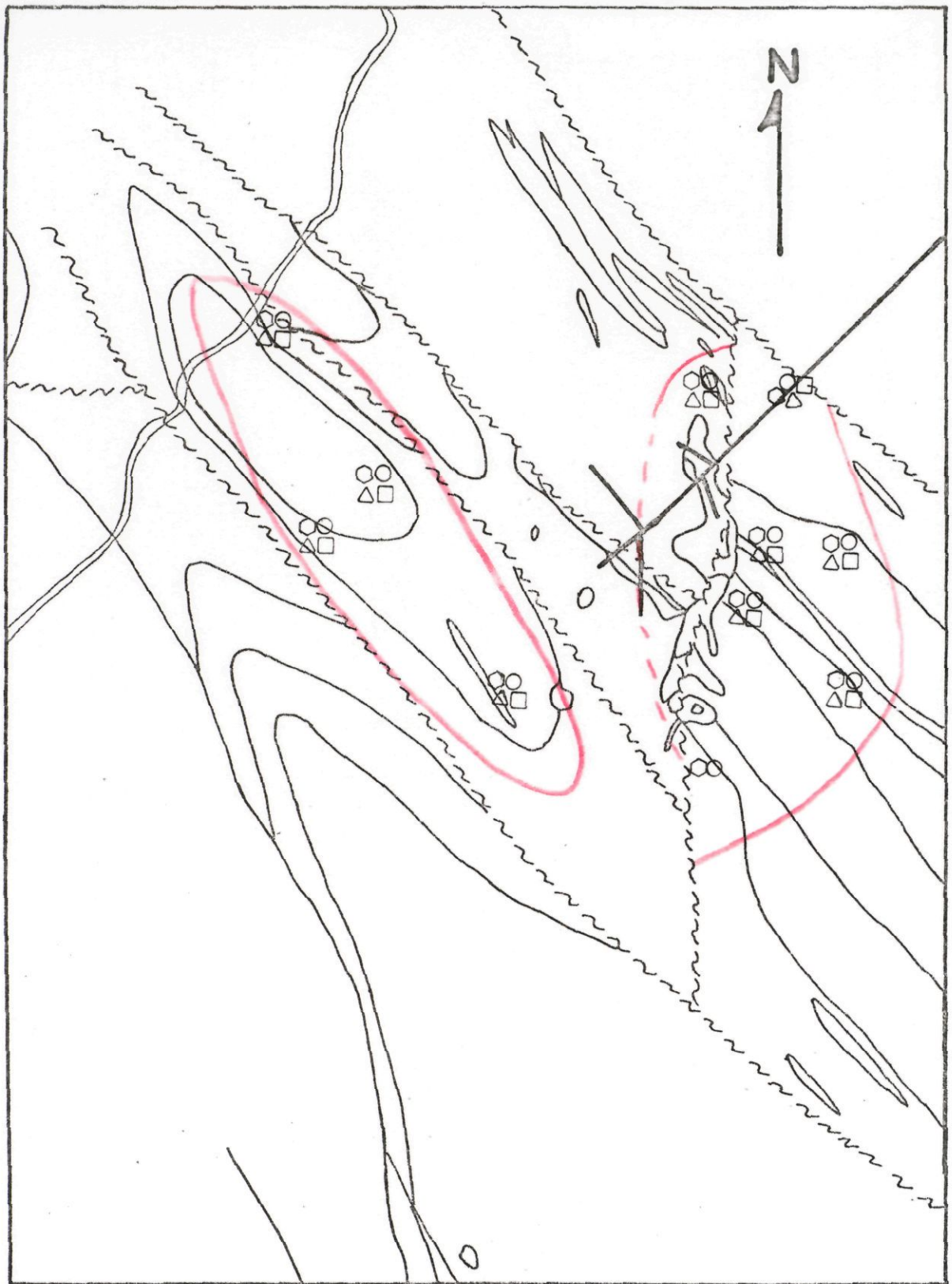


Fig. 5

Apparent Isobaric Invariant Assemblages

○ ph ca q mu ch zo an

○ mu zo q kf An ca

□ tr an ch zo ca q

△ tr kf ph ca q zo an

— zone of contact metamorphism

exsolved (the one causing contact metamorphism) contains anomalous cerium. This of course implies that metamorphism is in part metasomatic, but very few metamorphic processes are truly isochemical (i.e. loss of volatiles). The occurrence of cerium-bearing zoisite may be an important geochemical indicator of plutons favourable for tungsten and molybdenum mineralization since its distribution far extends that of the tungsten and molybdenum mineralization.

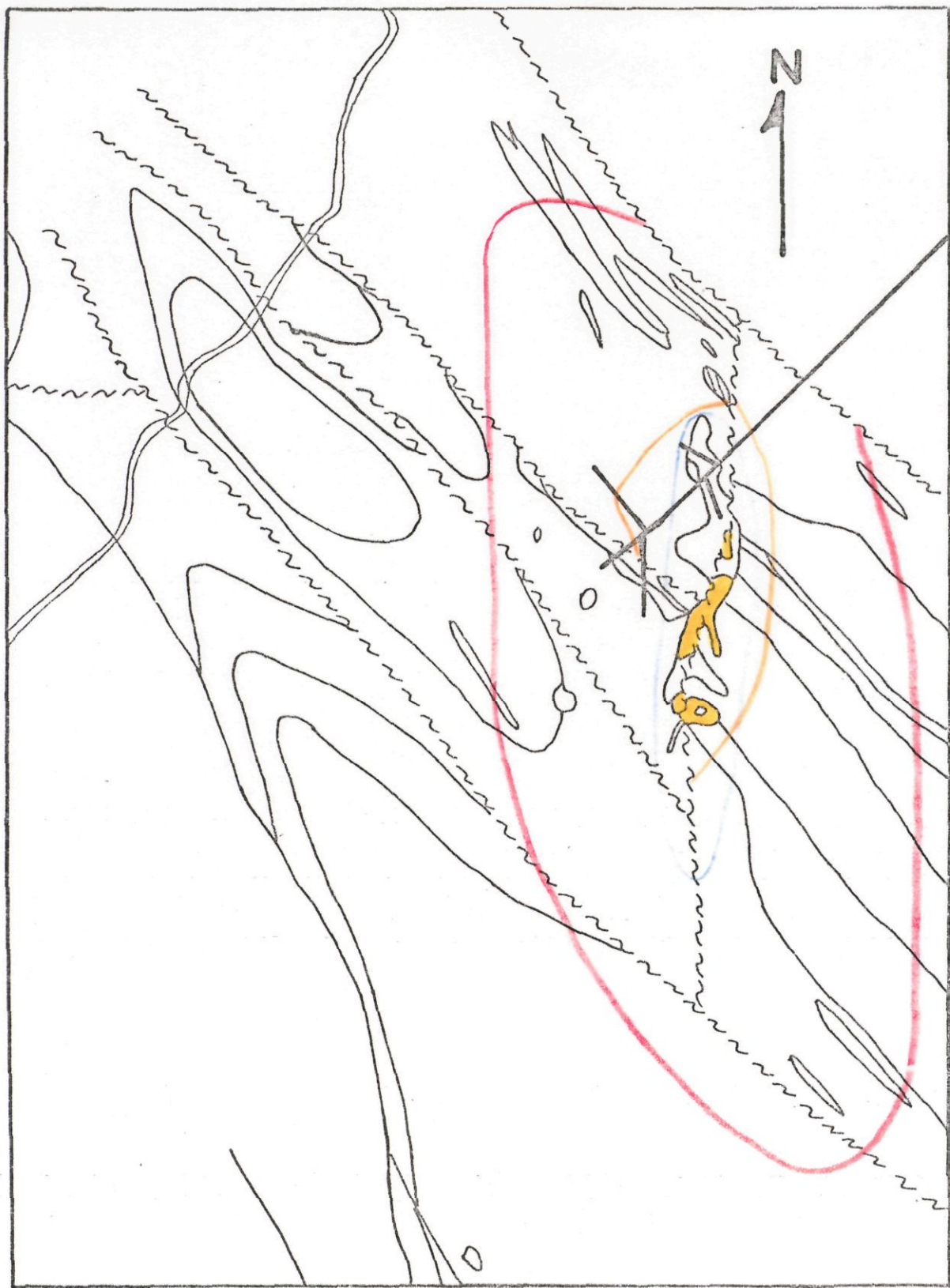
## ALTERATION

Silicic, potassic, and phyllic are the three major types of alteration associated with the Trout Lake deposit. On surface the sericitic alteration has the widest distribution (Fig.6), potassic alteration is more restricted, and silicic alteration is the most restricted being associated solely with mineralization. The subsurface distribution of alteration is discussed below.

### SILICIC ALTERATION

Massive quartz replacement as opposed to quartz veins is limited in extent but has been distinguished as quartz stockwork. This unit is located at the center of the deposit (Fig.7), has replaced both metasedimentary and igneous rock types, and contains relatively high grade molybdenum mineralization. Albite, K-feldspar, sericite, carbonate, and sulphides are the only minerals present in addition to quartz. Replacement is indicated texturally by very fine grained quartz which forms a





0 100 200 300 400 500 m  
0 500 1000 1500 Ft

Fig 6

Surface Alteration

- limit of molybdenite mineralization
- silicic alteration
- limit of potassic alteration
- limit of phyllic alteration



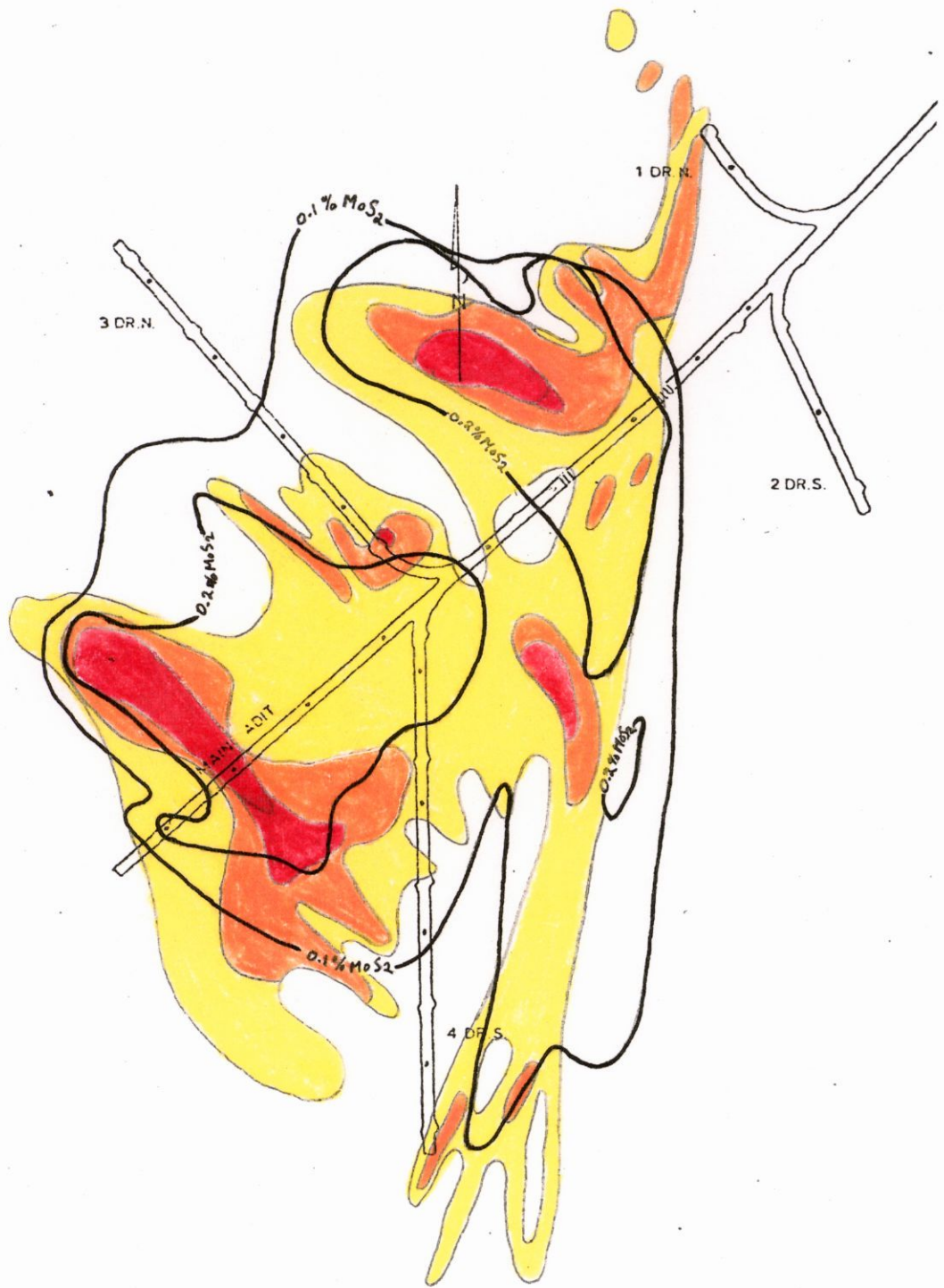






Fig. 7 Plan View of the Adit Level

-  Contour of Molybdenum Grade
-  20-40% Quartz Veins
-  >40% Quartz Veins
-  Quartz Stockwork (pervasive silicification)

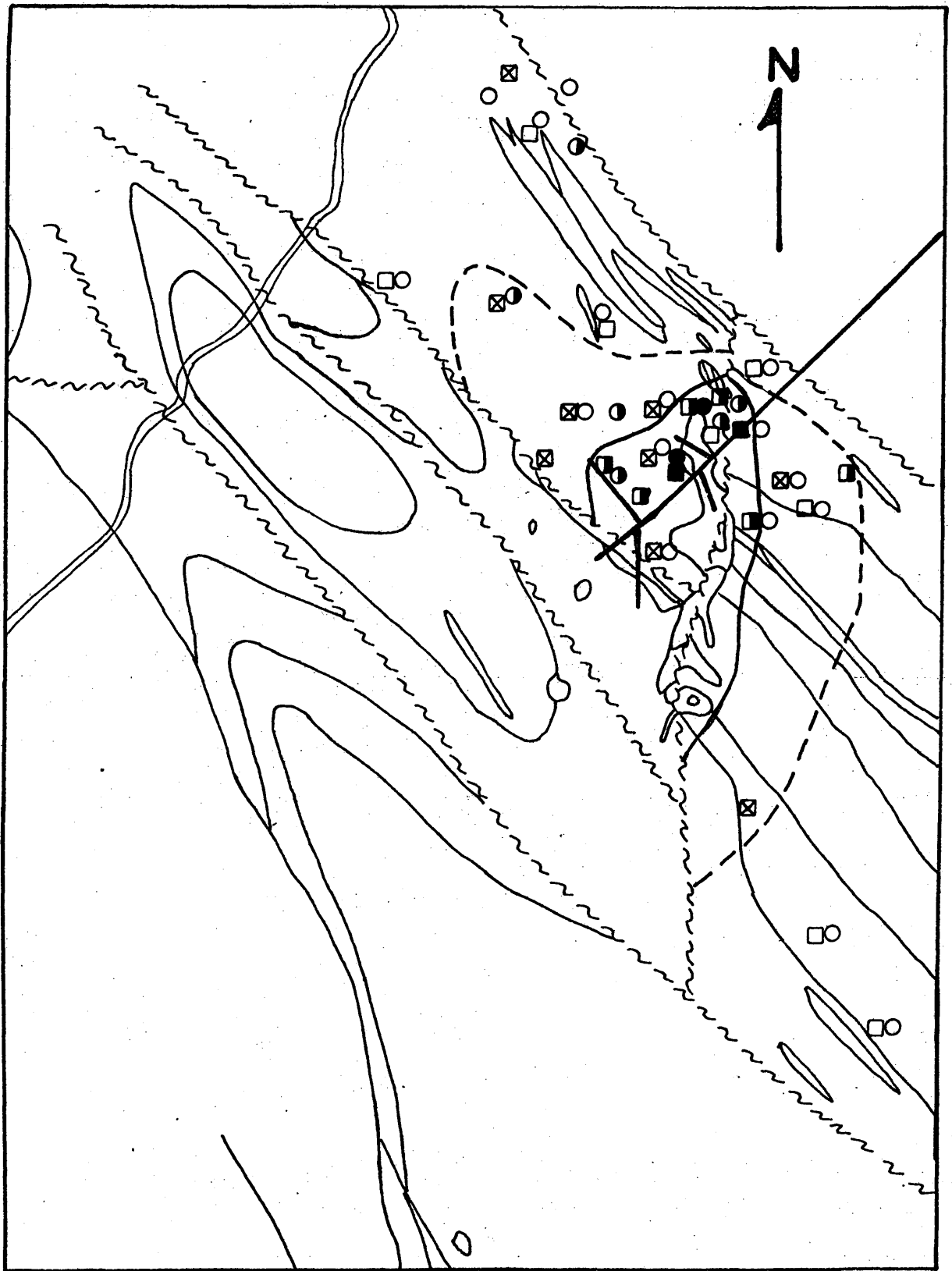
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matrix surrounding coarse grained relict feldspars that are partially silicified (embayed by fine grained quartz). All feldspars have undergone cationic exchange with the hydrothermal solutions as indicated by their alkali compositions. Coarse grained vein quartz and feldspar are also present in the quartz stockwork demonstrating that feldspars also precipitated from hydrothermal fluids which passed along open fractures. The amount of vein quartz present in a given volume of rock can also be considered a measure of silicification, even though true alteration (replacement of minerals) may not have taken place. Figure 7 shows the volume percent of quartz veins present as determined over 10 meter intervals in the adit and drill core. The shape of the contours of these values correlates well with contours of molybdenum grade indicating that the degree of silica flooding is important in the control of mineralization.

#### POTASSIC ALTERATION

Potassic alteration is difficult to recognise because biotite or K-feldspar haloes are poorly developed, and these two minerals are present in unaltered metasedimentary and igneous samples. Minerals from the area surrounding the deposit have four potential origins: detrital, regional metamorphic, contact metamorphic, or hydrothermal. In the case of biotite a detrital origin can be discarded, and the regional metamorphic phase is easily recognised because the grains define foliation(s). This distinguishes them from the contact metamorphic and hydrothermal biotite grains which are coarser and have random orientation.

In an effort to distinguish between the texturally similar



0 100 200 300 400 500 m  
 0 500 1000 1500 ft

Fig. 8 Distribution of Biotite and K-Feldspar

Biotite as % of total sheet silicates

% K-Feldspar

- < 25%
- ⊠ 25-50%
- 50-75%
- > 75%

- 0-1%
- ◐ 2-5%
- > 5%

- Zone of Potassic Alteration
- - - Zone of Contact Metamorphism

metamorphic and hydrothermal types, biotite abundance was measured as modal percent versus modal percent of total sheet silicates in thin sections. It is apparent that by using the biotite content in the quartz biotite schist, a zone of intense biotization is associated with the deposit at surface (Fig.8), and that this can be considered to be potassic alteration. Within this zone of alteration, secondary biotite occurs as veins or haloes and clearly crosscuts previously existing biotite. To the northwest toward Wilke Creek a zone of moderate biotite content is defined, with a more elongate zone east of the Z-fault. The difference in shape is probably a topographic effect since the pluton is plunging to the northwest. It is interesting that this zone of moderate biotization also contains plagioclase with an approximate composition of An<sub>25</sub> (Fig.5) and may contain the cerium-bearing zoisite, depending on whether or not clinozoisite is present. The lack of cerium-bearing zoisite and the occurrence of albitic plagioclase <sup>(An<sub>10</sub>)</sup> outside the zone of moderate biotization coincides with the occurrence of biotite at regional background abundance levels. In a sample northwest of the deposit in the moderately biotized zone randomly oriented biotite occurs along fractures accompanied by cerium-bearing zoisite, which illustrates their correspondence in time and space. It is also noteworthy that in this sample the randomly oriented biotite in the matrix appears to be coeval with the fracture-filling biotite. Therefore the fluids which caused contact metamorphism probably also deposited cerium-bearing zoisite, changed the plagioclase compositions, and altered the relative abundance of biotite. This implies that the zone of

(2)

moderate biotization can be considered a contact metamorphic halo. It can be argued that the early assemblage should be considered alteration due to cerium metasomatism and the presence of biotite along fractures, but by comparing contact metamorphic halos around the thin quartz diorite dyke (Fig.1) to cerium-bearing zoisite distribution (Fig.4) it is highly probably that the same fluid caused both distributions and therefore the fluid is classified as contact metamorphic.

The surface distribution of K-feldspar mimics that of biotite (Fig.8). Intense K-feldspathization is associated solely with the deposit and therefore is part of the potassic alteration zone. As the distance from the deposit is increased, the K-feldspar content decreases sharply. The high K-feldspar contents near the deposit are definitely hydrothermal in origin but the lower K-feldspar contents away from the deposit probably reflect either metamorphic or detrital origin. In addition to biotite and K-feldspar the quartz biotite schist within the potassic alteration zone also contain quartz, plagioclase (An30), muscovite, carbonate, and less commonly chlorite, garnet, and corundum.

#### PHYLIC ALTERATION

Phyllic alteration is the most easily recognised as haloes around quartz veins are commonly well developed. These haloes are sharply defined as the light coloured muscovite contrasts strongly with the dark brown biotite. Figure 9 displays the distribution of phyllic and potassic alteration on the plan view at the adit level. Pervasive phyllic alteration is generally

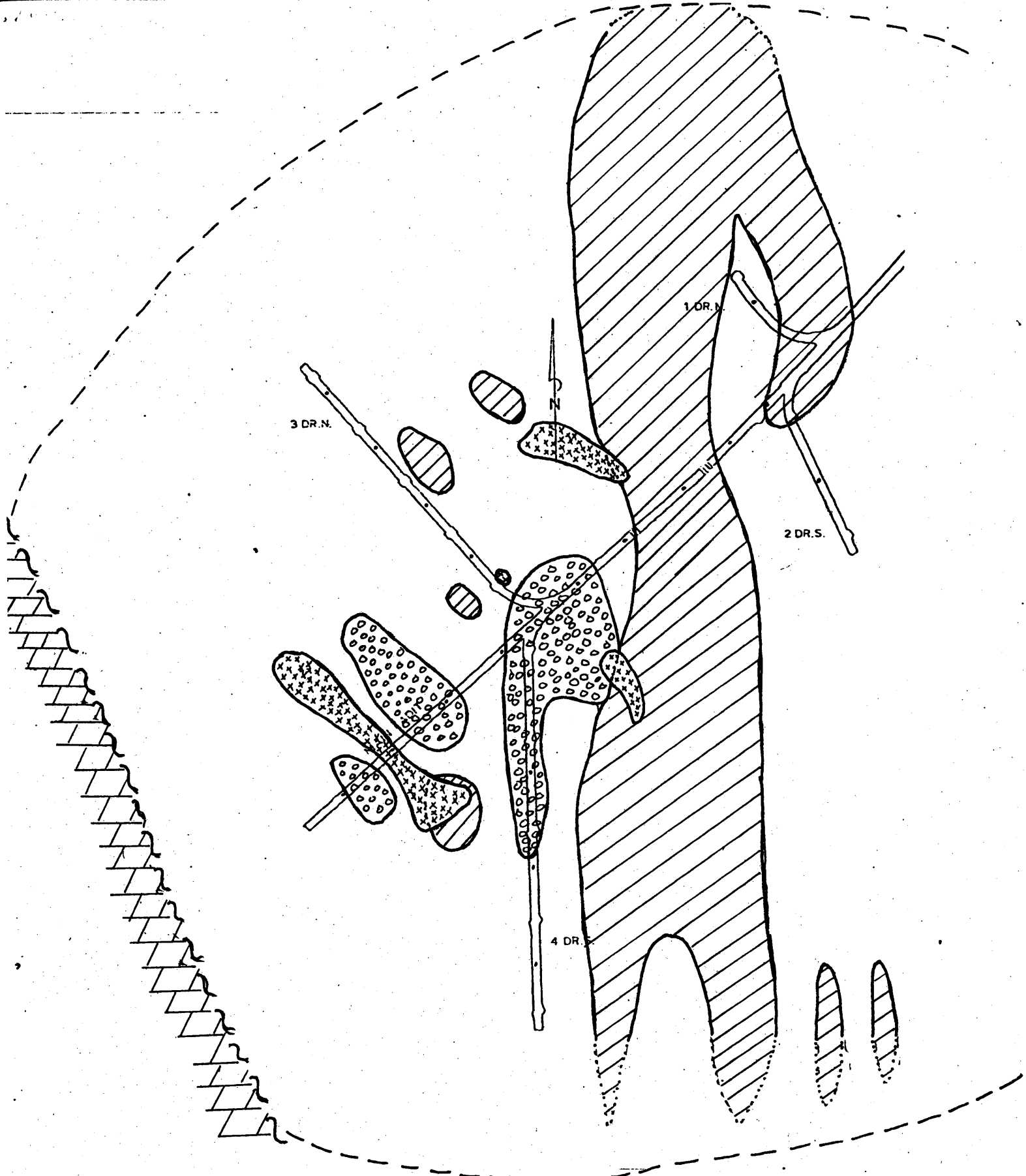


Fig. 9 Plan View of Alteration

- |  |  |   |  |   |
|--|--|---|--|---|
|  Pervasive Siliceous |  Pervasive Potassic |  Pervasive Phyllic |  Mixed Alteration |  Skarn |
|--|--|---|--|---|

--- Projected Limit of Alteration

Scale 1:2000

associated with faults, particularly the Z-fault, but variable amounts of phyllic alteration are present throughout the deposit except in the core where potassic alteration is dominant. The phyllic assemblage is typically muscovite with subordinate to minor quartz, K-felspar, albite, carbonate, pyrite, and rutile. The occurrence of muscovite alone does not constitute phyllic alteration as muscovite is stable in all alteration types. Thin section inspection of the "aplite dykes" shows these to have undergone strong phyllic alteration, and therefore these are altered granodiorite and not a separate igneous phase. Dyke/vein features, noted in previous reports can be explained if the fluids which caused the vein also completely altered the surrounding dyke-rock. Although there is strong K-feldspathization this event is still associated with phyllic alteration.

#### SKARN ASSEMBLAGES

Massive replacement of limestone by calc silicate minerals comprises the skarn unit. The surface distribution of skarn shown on the geological map (Fig.1a) seems to be controlled by the intersection of limestone units with faults. This also applies to the subsurface where the skarn is associated with limestone at the Ethel fault (Fig.9). A typical skarn assemblage consists of pyroxene, garnet, tremolite, calcite, quartz, clinozoisite, and less commonly idocrase and wollastonite. Diopside and clinozoisite may also be present in quartz veins which can contain molybdenite.

## CHEMISTRY OF THE ALTERATION

By applying the logic used in defining the physical conditions of contact metamorphism, T-XCO<sub>2</sub> diagrams were constructed in order to estimate the conditions during alteration. Reactions were written which involve the alteration minerals discussed above, and two diagrams were constructed for the total confining pressure conditions of 2000 and 500 bars (Figs.10,11).

### SKARN

The stability of clinozoisite in the skarn assemblage, restricts the fluid to a high XH<sub>2</sub>O (reaction 14, Figs.10,11). The stability of pyroxene in the presence of plagioclase indicates that the skarn event took place at a higher temperature than contact metamorphism (from reaction 9). The XH<sub>2</sub>O conditions for wollastonite formation must be even greater than that for zoisite (less than 0.01 using reaction 15), and where reaction (15) crosses reaction (9) all the observed phases would be stable except for grossular. In the presence of zoisite, grossular is first formed by reaction (20) but this is a problem as it is coexisting with tremolite + zoisite + quartz and therefore one or more phase is apparently metastable. The problem of apparent metastability is similar to that encountered in the contact metamorphic assemblages and the explanation of this problem is also similar. The addition of extra components will shift some of the curves, in particular the grossular curve since the skarn garnets are almost certainly not end-member grossular. Even if



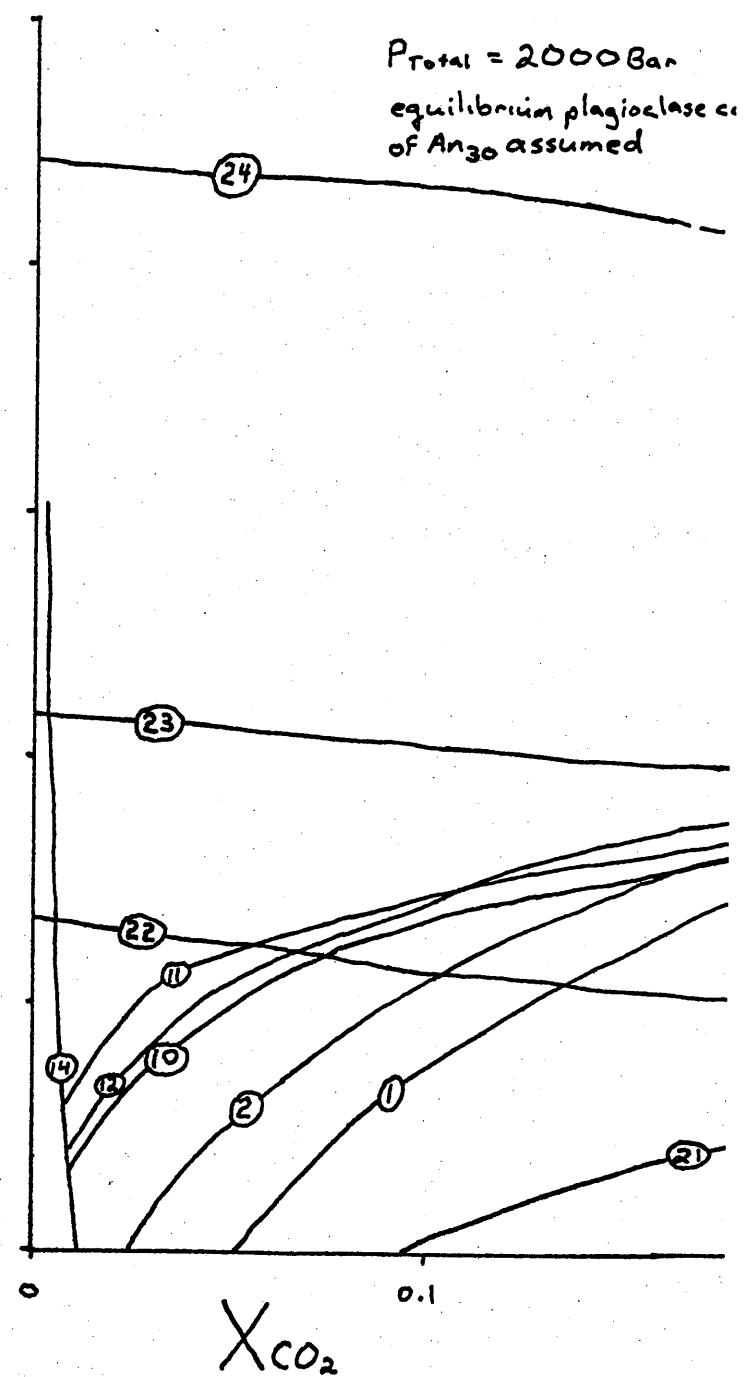
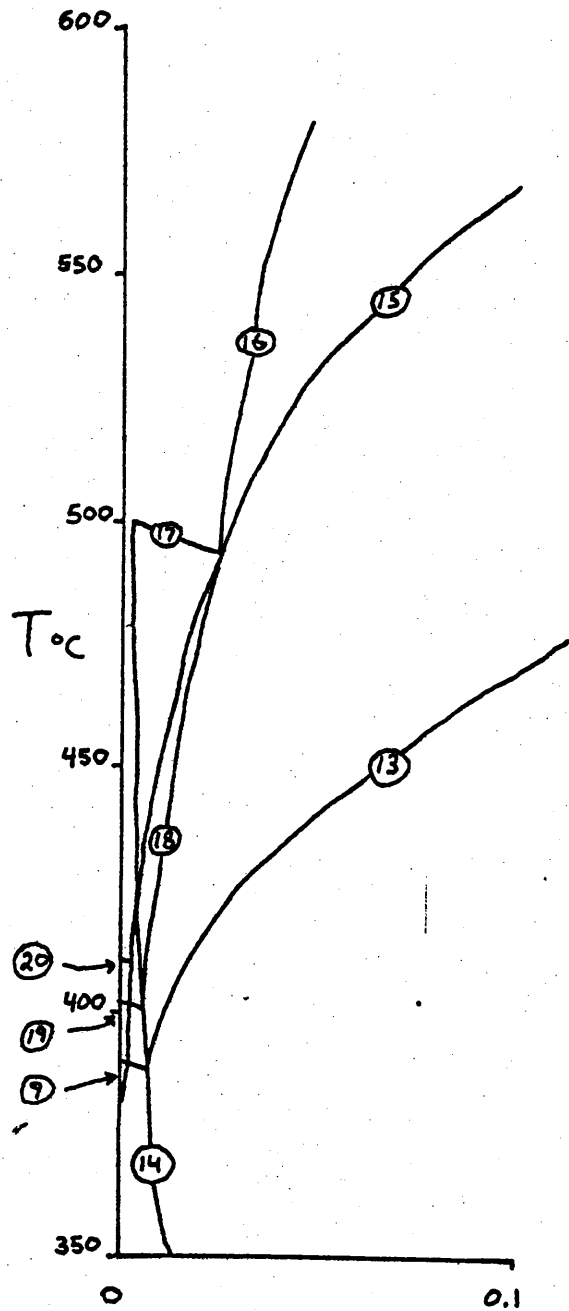


Fig. 10

some minerals represent disequilibrium the above curves (reactions 9,19,20) all lie within 20 C of each other and therefore it is reasonable to estimate that the skarns formed at 375-425 C if the confining pressure was 2000 bars and 325-375 C if the confining pressure was 500 bars.

#### POTASSIC ALTERATION

From thin section inspection of rocks from the potassic alteration zone it can be concluded that at least two separate events have occurred from the coexistence of corundum with biotite + calcite + quartz. Corundum is present as anhedral grains within sericitized porphyroblasts. A thin layer of margarite (Ca mica) characteristically separates the corundum from muscovite. In the quartz biotite schists, which were affected solely by contact metamorphism corundum is never present, but the sericitized porphyroblasts are common, rarely with remnant andalusite at the core. The andalusite was probably regional metamorphic in origin, and was sericitized during contact metamorphism. The breakdown of andalusite + K-feldspar to form muscovite + quartz is represented by reaction (24) and the stability of muscovite + K-feldspar is consistent with the temperature of contact metamorphism estimated in the previous section. Andalusite will be preserved if K-feldspar is totally consumed locally. The restricted distribution of corundum implies that it formed solely during hydrothermal alteration, although it is also possible that it formed during contact metamorphism and represents higher temperatures as it is closer to the "pluton at depth". If corundum formed by muscovite

? or was completely removed?

So why not the corundum also?

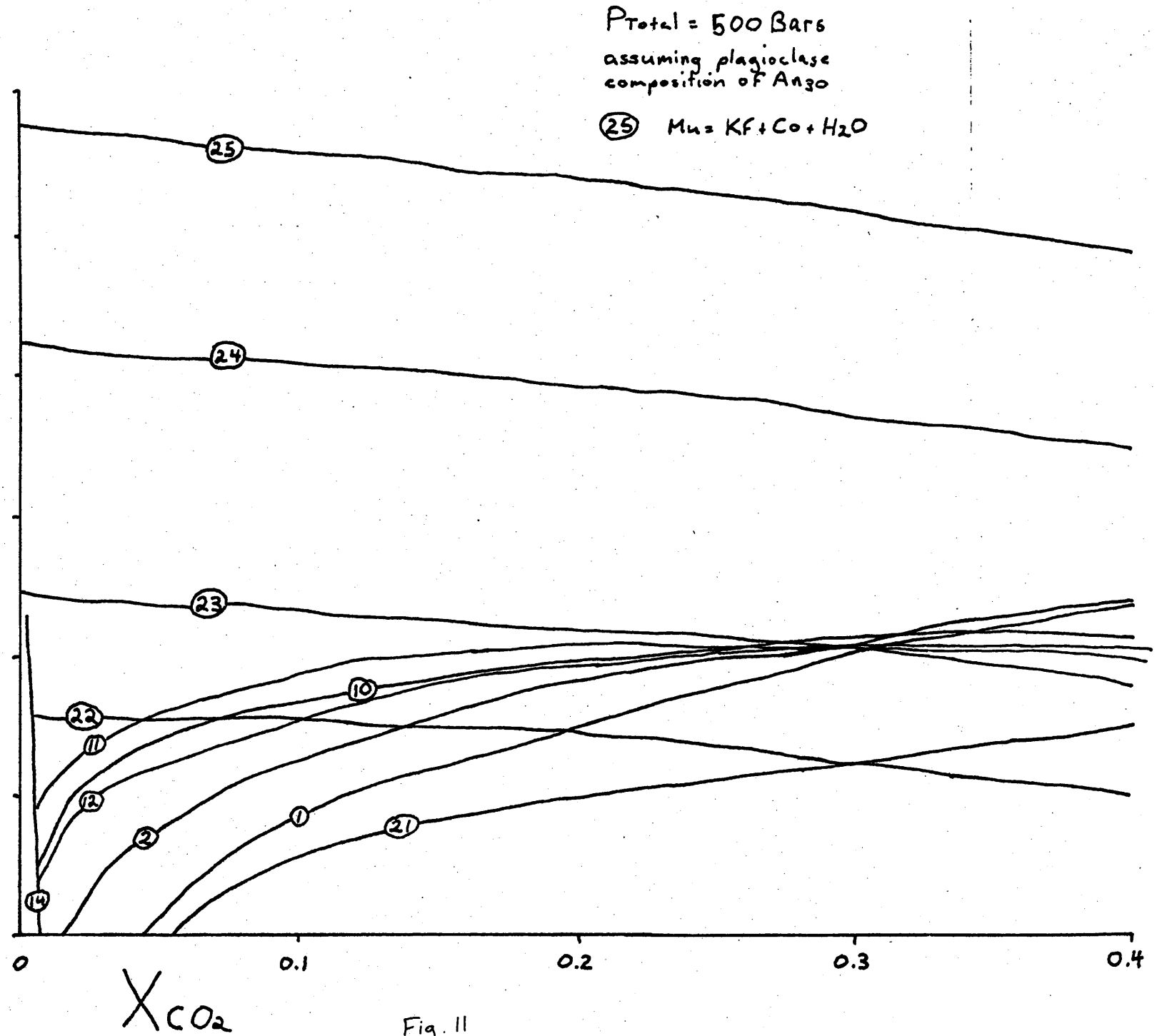
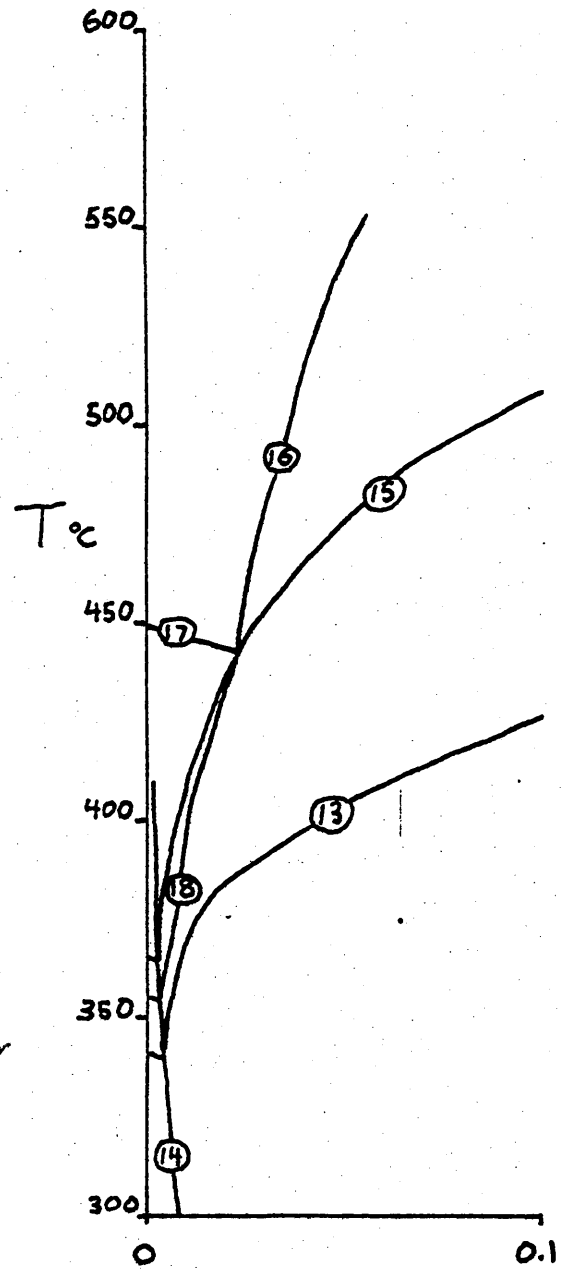


Fig. 11

breakdown (reaction 25) the temperature must have been approximately 600 C at 500 bars (Fig.11) or 675 C at 2000 bars (off the scale of Fig.10). The formation of corundum from margarite by reaction (23) occurs at significantly lower temperatures. Matrix plagioclase is consistently An30 (from microprobe analyses), this composition was used to construct the margarite-corundum reaction (reaction 23, Figs.10,11) and all other reactions involving anorthite. As there are no other high temperature minerals present all the corundum probably formed from the margarite breakdown reaction, which is at approximately 455 C if the confining pressure was 2000 bars (Fig.10), or 425 C if the confining pressure was 500 bars (Fig.11). There are no mineral assemblages which can be used to estimate the  $X_{CO_2}$  conditions at this time but since the other early events (contact metamorphism and skarn formation) occurred at very low  $X_{CO_2}$  conditions it is reasonable to assume that corundum also formed under these conditions. Also because the temperatures of formation are closer to that of the skarn formation rather than those previously estimated for contact metamorphism, it is more probable that corundum formed during hydrothermal alteration than during contact metamorphism.

By using reactions (11) and (12) it is apparent that during the formation of corundum, carbonate would not have been stable in a rock containing muscovite + biotite + chlorite + K-feldspar + plagioclase + quartz for  $X_{CO_2}$  conditions less than .3, and therefore was not stable during the period of corundum formation. However, carbonate is abundant within the matrix of the quartz

biotite schist indicating that an additional fluid at lower temperatures interacted with the rock at some later time. The formational conditions of the biotite + calcite + quartz assemblage, which is dominant in the ore zone, are restricted to the low temperature side of reaction (2) ( $ph+ca+q=tr+kf$ ) since tremolite is not observed. However, sphene is a common mineral in this assemblage so the fluid must be characterized by conditions above reaction (1) but below reaction (2).

At this point we will consider a different lithology. A common lithologic unit found only with the potassic alteration zone is the tremolite biotite schist which is comprised of tremolite, biotite, chlorite, muscovite, plagioclase (An30), quartz, calcite, and sphene. Using reaction curves in Figures 10 and 11, the fluid in equilibrium with this assemblage must lie along the conditions of reaction (10) because it contains  $ch + ca + q + tr + an$ , lie on the low temperature side of reaction (2) since it is K-feldspar absent, and on the high temperature side of reaction (1) as it contains sphene. The consistency of mineral compositions as determined by microprobe analysis justifies the assumption of equilibration between the fluid and the tremolite biotite schist. Therefore the tremolite biotite schist formed at 425 C and  $X_{CO_2}$  of .15 to .2 if 2000 bars was the confining pressure, and 400 C and  $X_{CO_2}$  of .25 to .3 if the confining pressure was 500 bars. The tremolite biotite schist is texturally similar to the quartz biotite schist (low temperature phase), and both are cut by later quartz veins some with biotitic halos, so it is probable that both these units formed at the same time. Since both units contain plagioclase with an identical

composition it is highly probable that the same fluid interacted with each unit i.e. neither unit buffered the fluid. Therefore the low temperature assemblage in the quartz biotite schist formed at the identical temperature, pressure, and  $X_{CO_2}$  conditions as the tremolite biotite schist. Corundum grains are preserved because they are surrounded by muscovite which separated them from the later fluid.

#### PHYLIC ALTERATION

Phyllic alteration occurred at lower temperatures and possibly higher  $X_{CO_2}$  conditions than any of the previously discussed events. This is indicated by the presence of rutile + carbonate + quartz (reaction 1) rather than sphene. The carbonate is an ankerite with approximately equal amounts of iron and magnesium which is important when the mechanism for biotite breakdown is considered. The addition of iron to reaction (21), the biotite breakdown reaction, further restricts the conditions of phyllic alteration since the observed assemblage of K-feldspar + ankerite is stable only below this curve. Therefore phyllic alteration occurred at a maximum of 400 C at 2000 bars, or a maximum of 350 C at 500 bars, and probably at much lower temperature depending on the  $X_{CO_2}$  conditions at that time.

#### ADDITIONAL RESEARCH

The conditions of silicic alteration have not yet been determined which are related to the conditions of mineralization but T- $X_{CO_2}$  diagrams will not prove useful as there are no

appropriate reactions. An extensive study on hydrothermal feldspars has been completed in order to give insight to this problem but I am still processing this data. All hydrothermal feldspars are alkali feldspars with compositions that range from 90 to 99% Na or K. Molybdenite is commonly intergrown with muscovite and carbonate at feldspar interfaces but the muscovite and carbonate compositions are distinct from those found in phyllicly altered rocks. Therefore molybdenite mineralization is linked to muscovite formation but not phyllic alteration. Hopefully quantitative treatment of the chemistry of the various phases will give insight as to the conditions of molybdenite deposition.

#### REFERENCES

- Ohmoto, H., and Rye, R.O., 1970, The Bluebell Mine, British Columbia. I. Mineralogy, Paragenesis, Fluid Inclusions, and the Isotopes of Hydrogen, Oxygen, and Carbon: *Econ. Geol.*, vol. 65, pp. 417-437.
- Saxena, S.K., and Ribbe, P.H., 1972, Activity-Composition Relations in Feldspars: *Contrib. Mineral. Petrol.*, vol. 37, pp. 131-138.
- Westra, G., and Keith, S.B., 1981, Classification and Genesis of Stockwork Molybdenum Deposits: *Econ. Geol.*, vol. 76, pp. 844-873.