CIM
GEOLOGY OF ORE DEPOSITS

Geology of the Trout Lake molybdenum deposit, B.C.

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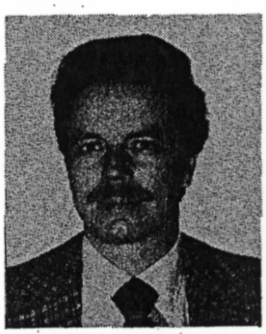
ABSTRACT

The Trout Lake stockwork molybdenum deposit is located in the Selkirk Mountains of British Columbia, 50 km southeast of Revelstoke. The property is being explored by a joint venture between Newmont Exploration of Canada and Esso Minerals Canada.

The deposit is associated with a small granodiorite stock of Upper Cretaceous age (76 Ma) which has variably altered the surrounding schists, argillites and marbles of the lower Paleozoic Lardeau Group to hornfelsic biotite schists and skarn. The intrusive is composed of a small stock and an intersecting network of northeast- and northwest-trending dykes at surface that coalesce downward into a larger stock. There are two main phases of intrusion, with an earlier quartz porphyritic granodiorite cut by an intra-mineral "quartz diorite" porphyry. A strong sub-vertical north-trending fault controls the distribution of the mineralized stockwork and displays post-mineral movement.

Molybdenite, accompanied by pyrite and pyrrhotite, is mainly present along the margins of veins in a well-developed quartz stockwork, but occasionally is strongly disseminated in microfractured intrusives. The stockwork is strongest in and around the contacts of the intrusive and its apophyses, and occurs over a vertical range of more than 1,000 m. As defined by the 0.10% MoS_2 contour, the main mineralized zone is up to 300 m long by 200 m wide. Preliminary drill-indicated reserves, currently being revised, are approximately 50 million tonnes of 0.23% MoS_2, within which are several zones of higher-grade material. Hydrothermal alteration, as defined by quantitative X-ray diffraction studies on composite core sections, is composed of a central quartz/K-feldspar/albite/minor biotite zone coincident with molybdenum mineralization, which is overlapped by a slightly later, antipathetic quartz/sericite/pyrite zone. Ankeritic carbonate is also a common alteration mineral, but only traces of fluorite, and no topaz or sulfosalts, have been observed. Analysis for trace elements such as Sn, W, Bi, Sb, As, Hg, U, Ag, Au, Mn, Cu, Pb, Zn and F has been limited except for Sn and W, which appear to be zoned inside and outside the Mo zone respectively; the other elements do not show detectable patterns thus far.

A strong molybdenum soil geochemical anomaly is present immediately over and down-ice from the outcropping mineralization. No streams drain the area over the deposit, so it could not be detected by conventional stream silting. A proton magnetometer survey showed only a few scattered anomalies related to the skarns containing pyrrhotite.



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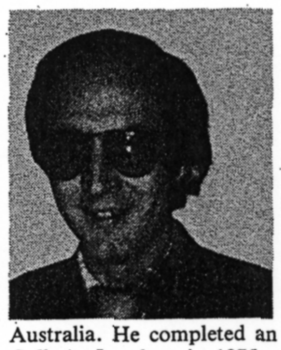

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Keywords: Economic geology, Molybdenum deposits, Trout Lake deposit, Stockwork deposits, Metamorphism, Alberation, Mineralization, Soil geochemistry.

Introduction

The Trout Lake molybdenum deposit is located in the Selkirk Mountains of southeastern British Columbia, 50 km southeast of Revelstoke and 400 km east of Vancouver (Fig. 1) at 50°38'N, 117°36'W (N.T.S. 82K/12 E). The property lies 3 km west of Trout Lake Village at elevations ranging from 700 to 2700 m (Fig. 2). The Trout Lake area falls within the Kootenay - Upper Arrow Lake district of the Columbia Mountains, a rugged northwest-trending range immediately west of the Rocky Mountains. Slopes on the property range from 25 to 40 degrees on either side of a north-trending ridge underlying the deposit.

Access to the property is by 80 km of road from either Revelstoke (on the Trans-Canada Highway and C.P.R. main line) or Nakusp (on a C.P.R. branch line).

The property is heavily covered with mature hemlock and cedar forest grading to scrub balsam at higher elevations. Underbrush is prevalent in most areas.

History

Claims were first staked on the property as the Lucky Boy and Copper Chief in 1897 and 1901. Early work concentrated on quartz veins, with 450 t of Ag-Pb ore being shipped from the Lucky Boy. In 1942-43, 20 t of tungsten ore was also shipped from the Lucky Boy (Stevenson, 1943).

Molybdenite associated with intrusive rock was reported as early as 1917, but it was not until 1969 that a subsidiary of Scurry Rainbow Oil Ltd. optioned the property from prospector Alan E. Marlow of Trout Lake and explored it by bulldozer trenching and 1000 m of diamond drilling. Thus, these prospects had been examined by mining companies over the years, and indeed had been examined by various Newmont personnel in 1953 as a tungsten skarn, in 1958 as a silver vein, and in 1969 and 1974 as a molybdenum prospect, before optioning it in 1975 on the recommendation of prospector S.W. Barclay. Since 1976, the property has been explored by a joint venture between Esso Minerals Canada and Newmont under the supervision of T.N. Macauley and H.C. Boyle. Over 20,000 m in 40 surface diamond drill holes led to the decision to go underground via 2 km of adit and drifts and to complete 22,000 m of undergroud ring drilling in 87 holes. A program of underground bulk sampling was carried out to test the distribution and continuity of molybdenum grades, and their correlation with diamond drill hole grades.

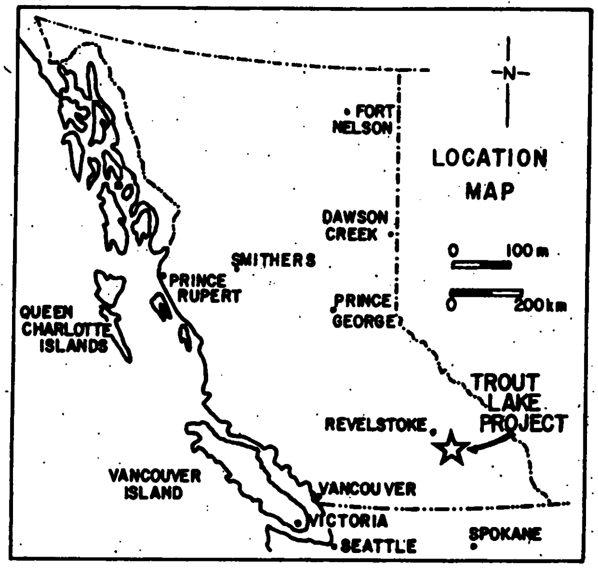

FIGURE 1. Location map.

Regional Geology

The geology of the area has been mapped and reported on by Brock (1903), Emmens (1914), Gunning (1929), Holland (1952, 1953), and Fyles and Eastwood (1962). The most recent mapping is that of Read and Wheeler (1976), from which Figure 3 is taken.

The property lies near the north end of the Kootenay Arc, a belt of highly deformed, heterogeneous sedimentary rocks bowed around the eastern margin of the Nelson and Kuskanax batholiths, at the south end of the Lower Jurassic Shuswap metamorphic terrane.

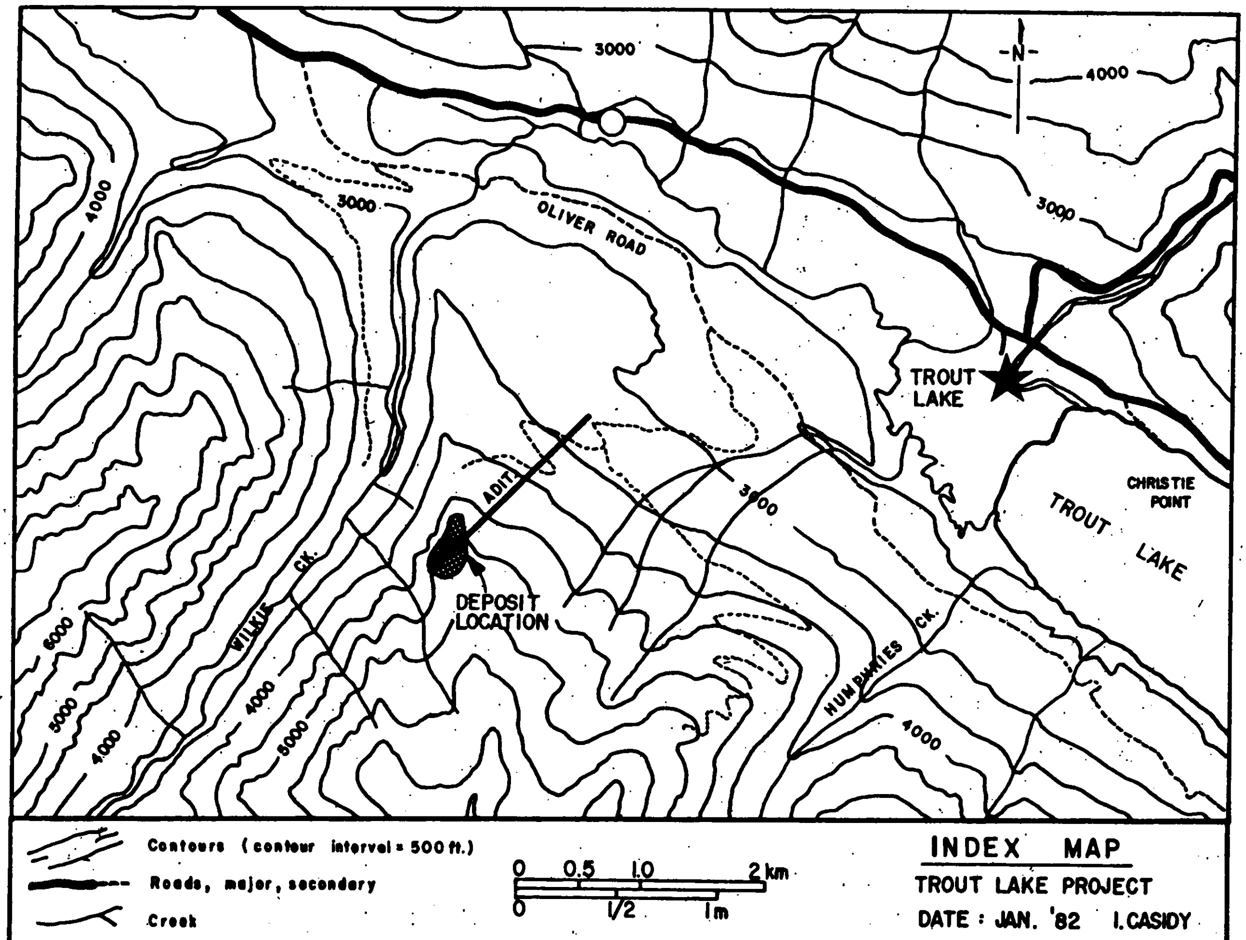

FIGURE 2. Index map, Trout Lake deposit.

The oldest rocks of the district around the deposit are schists, phyllites and quartzites, with minor greenstone, of the Lower Cambrian - Middle Devonian Lardeau Group. These metasediments have been tightly folded and strongly sheared in northwest-trending folds which are broken into panels by northwest and north-trending faults. Unconformably overlying these rocks are conglomerate, limestone and sandstone of the Upper Mississippian Milford Group. The Jurassic Kuskanax Batholith, an aegirine-augite-bearing leucoquartz monzonite, lies 5 km to the south of the property; it is dated at 178 Ma. A series of calc-alkaline stocks of Jurassic to Cretaceous age (150-74 Ma) includes the Trout Lake stock, which has been dated by K/Ar on biotite as 76 Ma. Molybdenum mineralization is associated with several of these calc-alkaline stocks in the Kootenay - Upper Arrow Lake area.

Local Geology

The surface geology of the property and location of the deposit are shown in Figure 4. Rock units of the Lardeau Group, with the exception of the carbonate unit, are not dif-

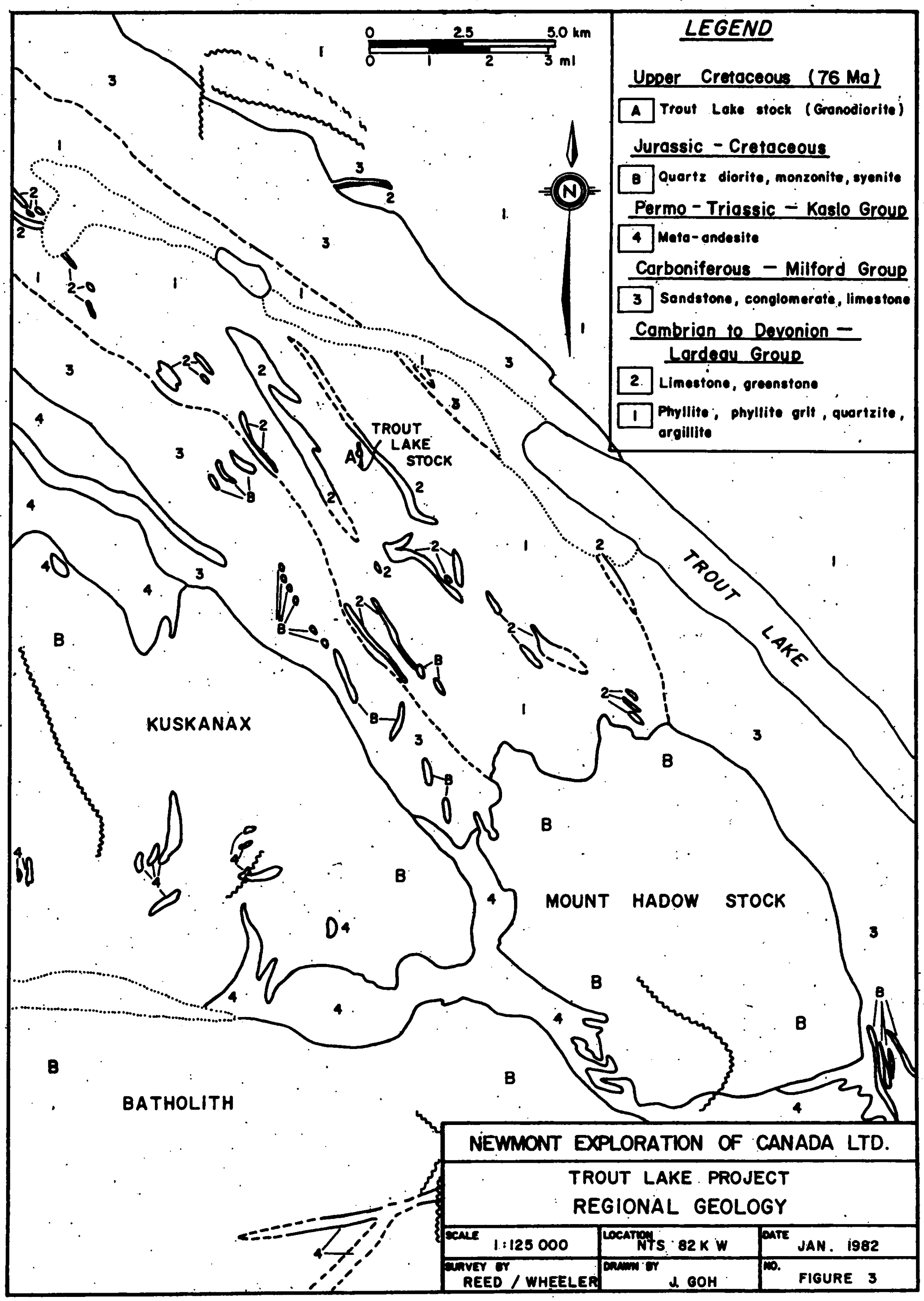

FIGURE 3. Regional geology, Trout Lake project.

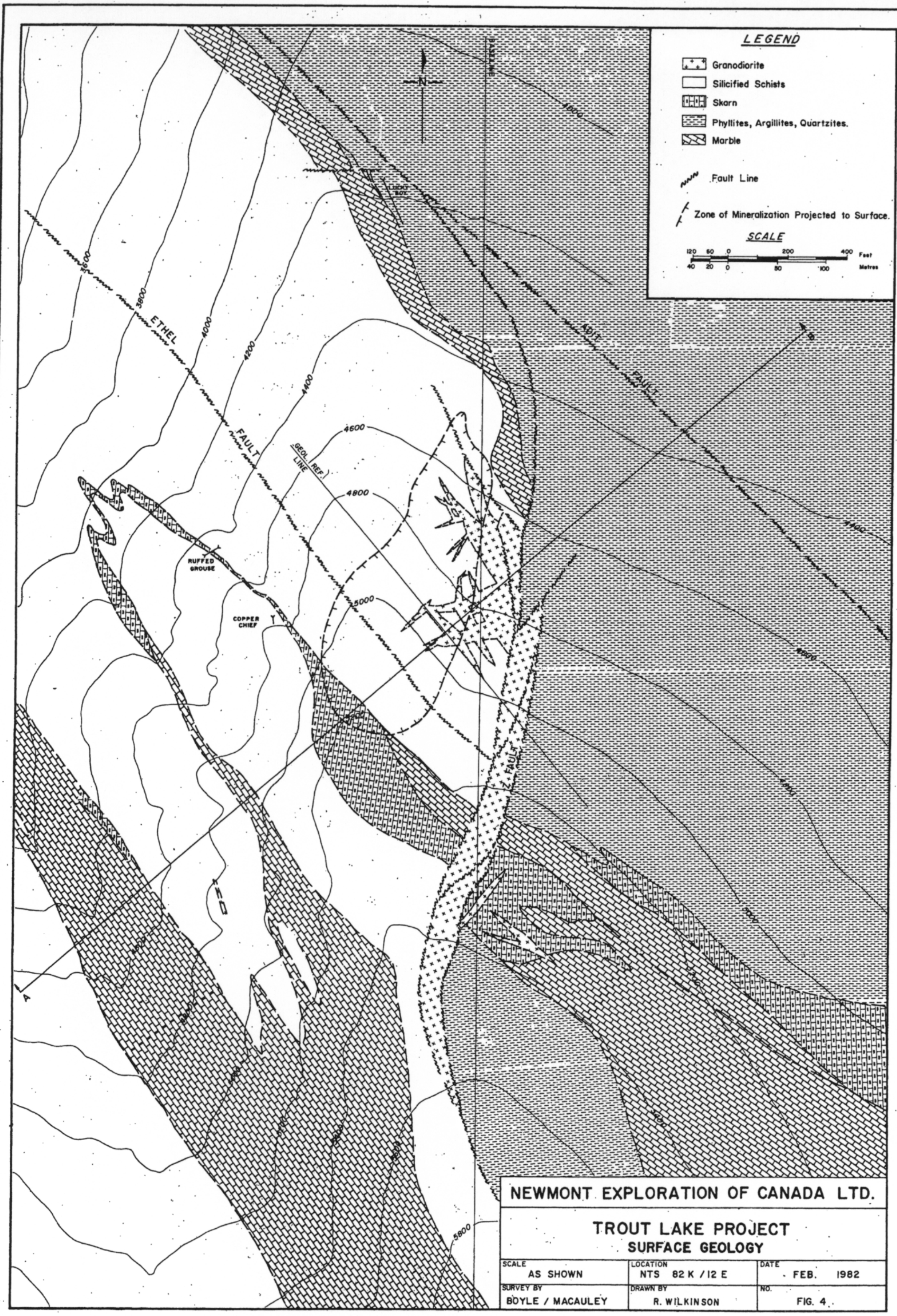

FIGURE 4. Surface geology, Trout Lake project.

ferentiated and are mapped as schists.

Rock Types

The Lardeau Group includes light grey to black aphanitic argillites, very fine-grained grey to tan phyllites, and green to brown biotite-chlorite-sericite schists with prominent segregated quartz layers or lenses. Quartzite units are medium to coarse grained and impure, occurring in lensoidal beds; the carbonate unit is composed of massive to banded grey to white limestone and dolostone with variable skarn development. Skarn minerals include quartz, calcite, epidote, diopside, garnet, prehnite, phlogopite, and minor idocrase, wollastonite, sphene and actinolite (Hill, 1980).

Milford Group rocks, which are not involved in the mineralization, unconformably overlie the Lardeau. A basal conglomerate is overlain by shale, siltstone, phyllite and schist interlayered with sandstone, quartzite and limestone units.

The intrusive rocks of the Trout Lake stock vary from porphyritic granodiorite to quartz diorite porphyry as a network of intersecting dykes and irregular masses. There appear to be as many as four distinct intrusive phases, with the earliest porphyritic granodiorite making up the bulk of the stock, followed by aplite dyking, and being cut successively by a quartz diorite porphyry set of dykes, an "intermediate" dyke set of granodiorite composition and finally a later quartz diorite set. The dykes are inter-mineral, as they both cut off and are cut by mineralized quartz veins.

In detail, the porphyritic granodiorite is a grey, medium-grained rock consisting of 10% large euhedral (to 0.5 cm) quartz "eyes" in a seriate-textured groundmass of euhedral plagioclase phenocrysts (35%), anhedral quartz (35%) and K-feldspar (10%), and sericitized/chloritized biotite relics (10%) (Hausen 1977). The later quartz diorite porphyries are darker, with a characteristic "salt-and-pepper" appearance caused by fine biotite flakes in the groundmass. They contain slightly less quartz (35%) and finer plagioclase phenocrysts (45%), less K-feldspar (under 5%) and slightly more biotite. Rare hornblende phenocrysts and late magmatic K-feldspar porphyroblasts, as well as a generally finer, more distinct groundmass containing fine biotite flakes, also distinguish the quartz diorites.

The aplite dykes are usually only a metre or less thick and are gradational to pegmatitic quartz/K-feldspar veins. They sometimes contain molybdenite as erratic disseminations and along vein margins. There may be more than one period of aplite dyking, as they both cut and are cut by the quartz diorite dykes.

Metamorphism

Regional metamorphic grade in the phyllite and schists of the Lardeau Group increases from north to south on the property, with chlorite, biotite and finally garnet/oligoclase (Psutka *et al.*, 1982) appearing as the Kuskanax Batholith is approached. There is a suggestion of an underlying arm of the batholith along an anticlinal axis, with intrusive apophyses manifesting themselves as dykes at surface.

Superimposed on this regional matamorphic gradient is a thermal biotite hornfels surrounding the Trout Lake stock. The hornfels is difficult to recognize in hand specimen at surface due to overprinting by later sericitic alteration and subsequent weathering. In underground exposure, it is possible to see the complex interplay of regional metamorphic biotite, thermally recrystallized to hornfels biotite, altered to hydrothermal sericite, and reconverted to hydrothermal biotite both along veins and pervasively at the core of the deposit.

Structure

The schistosity of the Lardeau rocks follows the regional northwest trend of this part of the Cordillera, dipping steeply northeast. First-phase folding, recognized only locally, has been largely obliterated by the second phase (Psutka *et al.*, 1982). The dominant second-phase fold axes trend northwest, with nearly horizontal to undulating moderate plunges. Folding as outlined by carbonate horizons varies from tight and isoclinal in the Lardeau group to more open in the Milford rocks.

The other dominant structural feature is strong north and northwest faulting, which separates the country into "panels". The strong north-trending "Z" fault appears to have exerted a control on the location of the Trout Lake stock and subsequent mineralization, as well as showing post-mineral movement. Many small conjugate and splay faults cut the deposit underground, but displacements on these faults are generally less than 10 m.

Dyke and quartz vein orientations also show interesting conjugate patterns, with prominent northeast and northwest sets as well as north-south sets, and lesser flat-dipping veins. In general, both the dykes and veins appear to fill northwesterly b-c and northeasterly a-c joints, with the latter being, as expected, more dilational and therefore often better mineralized. In detail, both the amount of veining and its predominant orientation vary from place to place. Veining increases toward several centers associated with intrusive apophyses, as north- and northwest-trending vein sets are developed in addition to the more widespread northeast-trending set. Flat-dipping veins also become more prevalent along with randomly oriented veins to form a true stockwork.

Alteration

Hydrothermal alteration patterns are well developed in the Trout Lake system, but are difficult to define except by quantitative X-ray diffraction techniques developed by Hausen (1979). That is, in hand specimen or core, alteration type and intensity may vary so widely over short distances that the over-all zoning may be hard to see. However, when 15- or 30-m composites of drill-hole pulps are made and the alteration mineralogy measured by XRD, significant patterns stand out clearly. It shoud be noted that these measurements must always be considered with gross changes in lithology in mind (e.g. between schists, carbonates and intrusive), but this does not alter the over-all pattern.

The principal zoning established (Fig. 5 a-d) is from a strong silica-potassic zone with MoS_2 at the center outward to a quartz-sericite-pyrite (phyllic) zone and possibly an outer zone where ankerite and chlorite are more prevalent, although chlorite concentrations rise again in the unaltered core of the intrusive mass. Both the central silica high, measured by total % quartz, and the potassic enrichment, measured as a ratio of K-feldspar to plagioclase, correlate well with the best molybdenum grades (Hausen, 1981). It should be noted that as at many other molybdenum deposits associated with calc-alkaline intrusives, the secondary feldspars at Trout Lake include not only K-feldspar, but also alkali feldspar transitional to albite (Leitch, 1981), and these cannot be separated from "plagioclase" by the XRD method. "Brain texture", or convoluted layers of quartz and intrusive material considered indicative of a good molybdenum system, has been noted in underground exposures in the central silica-rich zones.

Petrologic examination of a selected suite of thin sections from surface and drill-core specimens has helped to elucidate the alteration patterns. In detail, many local fluctuations, reversals and retrograde minerals are observed. For instance, on a microscopic scale molybdenite flakes are often intergrown with sericite, quartz and even calcite rather than with K-feldspar (although this apparent relationship may only be due to later alteration of K-feldspar to sericite and quartz). In the central "potassic" zone, much of the alteration feldspar in vein selvages is actually an alkali feldspar; true K-feldspar is often restricted to the vein itself, and the pervasive alteration feldspar replacing plagioclase phenocrysts (away from veins) is albite. True secondary biotite is only rarely developed in the intrusives, but may be clearly seen replacing sericite (itself presumably hydrothermal) along vein margins in the schists, with pervasive development in the centre of the deposit. These same veins in the schist often contain true K-feldspar (not albite) well outside what is shown as the "potassic" zone in Figure 5c. The relationships of biotite, sericite and chlorite are very complex due to the presence of a) regional metamorphic sericite, chlorite and biotite; b) thermal (hornfels) biotite development around the stock, on which has been superimposed c) hydrothermal sericite and biotite, both related to vein margins, and d) retrograde chlorite as the system cooled.

In a similar fashion to that described by Jambor and Beaulne (1978) and Sheppard (1977), it appears that quartz-sericite-(pyrite) alteration at Trout Lake was later than the "potassic" alteration which accompanied molybdenum mineralization. That is, the phyllic alteration envelopes on many quartz veins cut and replace earlier feldspathic alteration implying that as the hydrothermal system cooled and collapsed inward on itself, cooler metoric waters became an important part of the system.

Fluorite and topaz are notable by their absence in the Trout Lake system, which again is typical of a calc-alkaline molybdenum system (Westra and Keith, 1981). Only traces of green fluorite have been seen. By contrast, geochemically anomalous fluorine (400-500 ppb) has been detected in stream waters draining the Kuskanax Batholith.

Mineralization

Molybdenite mineralization occurs over a vertical range of more than 1000 m in two zones: the upper, smaller 'A' zone, which outcrops and was explored by Scurry-Rainbow drilling, and the larger, irregular, vertically attenuated 'B' zone, which

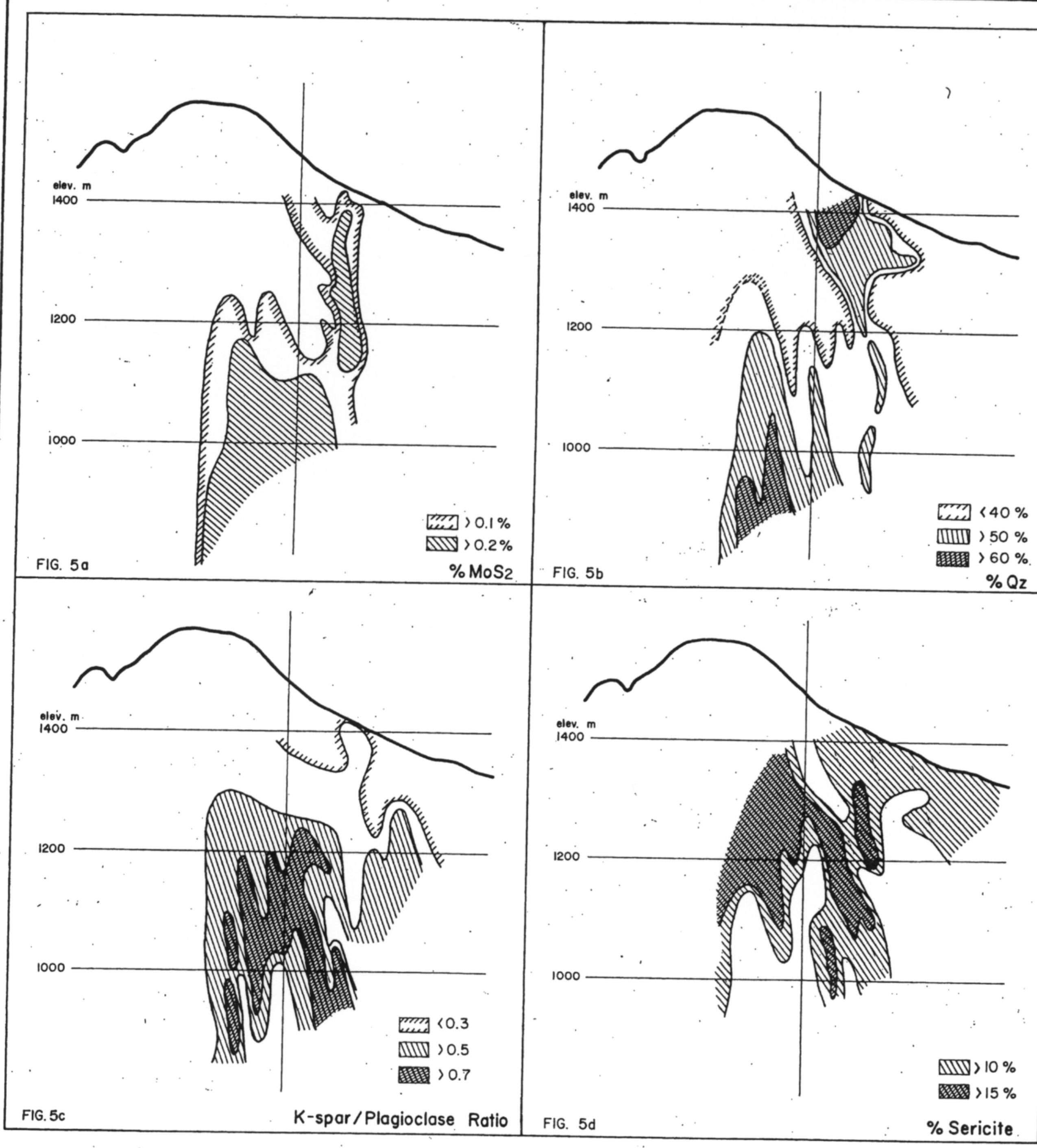

FIGURE 5. Generalized XRD alteration patterns.

is up to 300 m by 200 m wide as defined by the 0.10% MoS_2 contour (Figs. 6 & 7). Geologic reserves (as indicated by drilling) are currently estimated at 50 million tonnes of 0.23% MoS_2, within which are several zones of higher-grade material.

Molybdenite, as fine to medium flakes and rosettes accompanied by pyrite and pyrrhotite, is mainly present along the margins of veins in a quartz stockwork. Occasionally, in higher-grade zones (in excess of 1% MoS_2), the molybdenite is strongly disseminated in microfractured intrusive bodies up to 20 m wide by 200 m long, accompanied by large (over 10 cm)

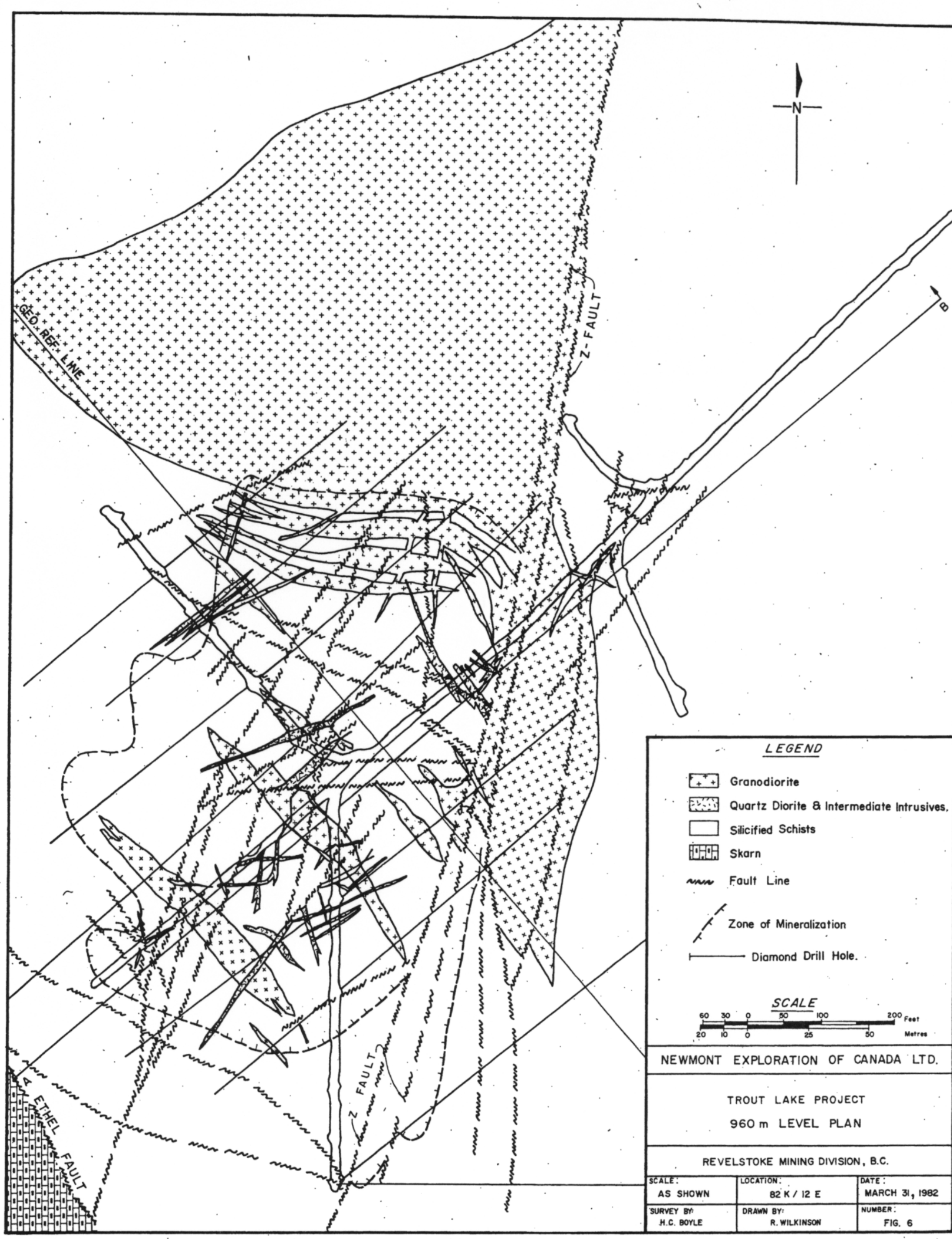

FIGURE 6. 960-m level plan, Trout Lake project.

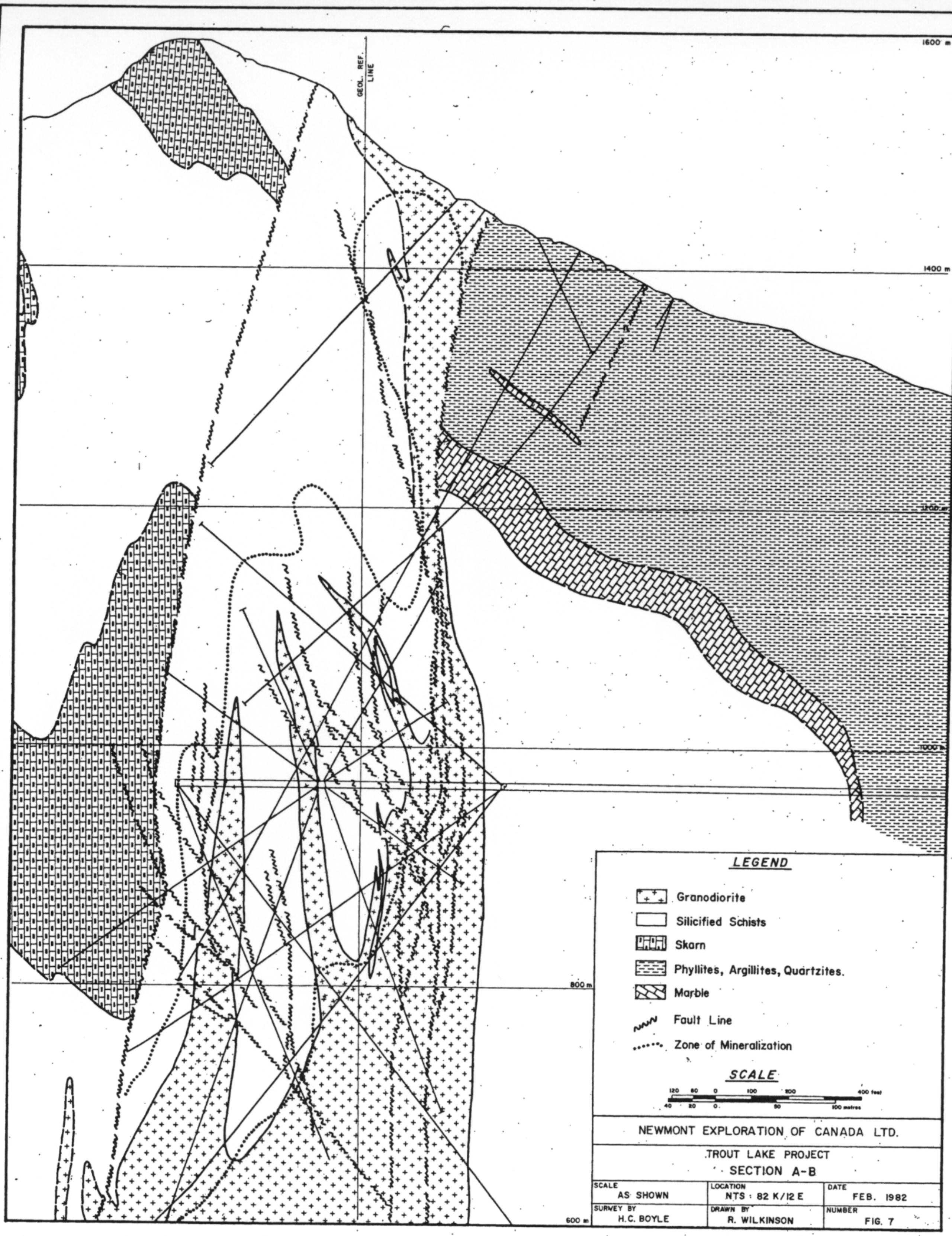

FIGURE 7. Section A-B, Trout Lake project.

quartz veins and intense quartz flooding. The quartz vein stock work is best developed in and around the margins of the intrusive and its dyke-like apophyses. Thus, the major control of molybdenum grades is the location of the schist-intrusive contact; a lesser control is exerted by pre-mineral faults.

Post-mineral faults have been observed in drill core to cut off good-grade molybdenite, but in underground exposure the displacements are seen to be only minor readjustments between blocks. Only the 'Z' fault which bounds the deposit on the east appears to have significant dip-slip movement. The interrelationships of cross-cutting dyking, veining and faulting show a suitably complex style of repeated opening of fractures and regeneration of mineralizing fluids as an intrusive differentiated at depth.

Molybdenum grades generally drop off sharply in the later, inter-mineral quartz diorite dykes which often cut off mineralized veins; there is a suggestion that grades are better around these dykes due to their having superimposed another episode of mineralization on the earlier veins caused by granodiorite. In the centre of the large granodiorite mass, grades drop off to very low (0.00x% MoS_2) values.

Tungsten mineralization (with minor molybdenum and copper) is virtually restricted to lenses of skarn occurring as replacements of limestone bands peripheral to the main molybdenum zone. The tungsten occurs as scheelite, with pyrrhotite and minor chalcopyrite as at the Copper Chief showing, or as scheelite in quartz veins with galena, sphalerite and tetrahedrite as at the Lucky Boy.

The zonation of trace elements has been studied to a limited degree by X-ray fluorescence analyses (Hausen, 1981). Analyses for Sn and W were done on 15-m composites over selected holes, and indicated that although Sn values are very low (10-20 ppm), close to the detection limits of 5 ppm, they may be centrally zoned with the Mo. Tungsten (to 300 ppm) is zoned outside the Mo, and As may be concentrated (to levels of 500 ppm compared to 50 ppm in central zones) outside the tungsten again. Traces of chalcopyrite occur throughout the system, up to 200 ppm Cu, but copper was not analyzed for routinely, so no Cu zonation can be determined. Galena and sphalerite occur rarely in late quartz-carbonate veins cutting the molybdenite stockworks, but again so few analyses were done for Pb and Zn that no geochemical zoning pattern can be postulated. Bismuth minerals and sulfosalts have not been identified, and Bi, Sb, Ag, and Au do not show detectable patterns (at levels close to their detection limits in each case). No patterns were detected from the few composites analyzed for Mn, F and U. Mn and F values both ranged from 300 to 400 ppm and uranium up to 2 ppm. Rhenium values were less than the detection limits at 2.5 ppm in drill-core composites.

An indication of peripheral Pb-Zn-Ag metal zoning may be suggested by the veins of the Lucky Boy, Ruffed Grouse, Ethel and Kathleen prospects at distances of 100 to 1000 m beyond the central Mo zone. However, this region of the Lardeau is known for its Pb-Zn-Ag veins, most of which occur in a belt lying from 5 to 10 km to the northeast.

Semi-quantitative XRF analyses for ZrO_2 (0.005-0.017%), SrO_2 (0.01-0.05%) and Rb_2O (0.01-0.04%) showed very low values and no detectable patterns. Concentrations of iron, expressed as Fe_2O_3, suggest a distribution peripheral to the main molybdenum zone which may represent an iron sulphide halo of pyrrhotite related to the thermal biotite hornfels and/or pyrite related to the phyllic zone of hydrothermal alteration.

Geochemistry and Geophysics

A molybdenum geochemical anomaly (Fig. 8) defined by the 100-ppm contour in B-horizon soils extends for 1000 m southeast of the outcrop of the 'A' zone mineralization; values range up to 500 ppm Mo over the mineralized zone. The tungsten anomaly overlaps the Mo anomaly to the southwest and is even more extensive, being 500 m wide by 2000 m long at the 120-ppm contour, with values up to 1000 ppm. Anomalous zinc values (to 1300 ppm) are scattered over the sampled grid. The strong southeasterly extension of anomalous values is due to glacial smear, which apparently carried mineralized debris for at least 1000 m down-ice while actually lifting it slightly in elevation.

Silt samples taken in small seeps immediately below this transported soil anomaly show anomalous Mo values (40 ppm), but these values diminish rapidly to background (2-6 ppm) downslope toward the main valley. A heavy-mineral sample taken at the mouth of Wilkie Creek shows only 25 ppm Mo after very careful size classification, heavy-liquid separation and magnetic classification.

A proton magnetometer survey run over the property showed only a few scattered anomalies presumably related to skarns containing pyrrhotite; the granodiorite stock could not be outlined magnetically.

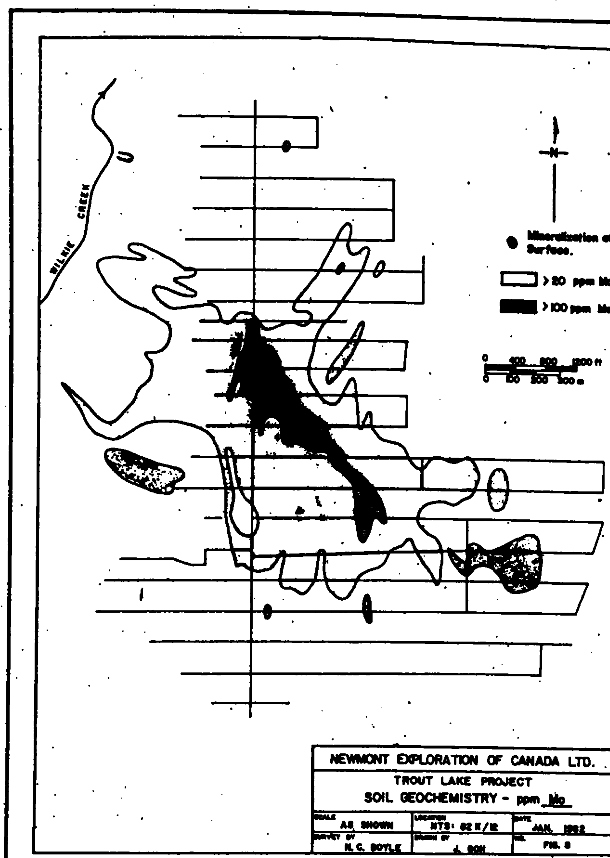

FIGURE 8. Soil geochemistry (ppm Mo), Trout Lake project.

Discussion

Looking back over the history of the Trout Lake property, there are a few features of interest to exploration. First is the length of time from the discovery of molybdenite in 1917 to the discovery hole in 1977 which indicated a sizable deposit of molybdenum, over which time Newmont examined the property four times in all. Second is the difficulty of discovery of this type of deposit by conventional silting of tributary streams along the floors of major valleys, or by prospecting, as the discovery outcrop was very small, only a few m². Third is the perseverance to keep drilling deeper and deeper to make the significant discovery, drilling which was predicated partly on favourable patterns of alteration as defined by persistent quartz-sericite and increasing K-feldspar/plagioclase ratios.

From a geological viewpoint, the Trout Lake deposit is unusual in its location in the Canadian Cordillera, well into the Omineca belt, where Pb-Zn-Ag deposits are prevalent and significant Mo deposits were not known (Sutherland-Brown *et al.*, 1971). However, when looked at in a regional sense, the deposit lies on a molybdenum linear that extends southeast across the regional grain of the Cordillera from Quartz Hill, Alaska through Kitsault, Glacier Gulch, Endako and Boss Mountain, B.C. On a continental scale (Kendall, 1977), there is a suggestion that this linear, if projected southeastward, would also include deposits such as Cannivan Gulch or Big Ben, Idaho, and might be stretched to include the Climax-Henderson district in Colorado and Questa, New Mexico. However, the Colorado deposits are more strongly controlled locally along a northeast-trending linear.

Also unusual for calc-alkaline stockwork molybdenum deposits is the petrology of the intrusive suite associated with the Trout Lake mineralization. The granodiorite to quartz diorite composition contrasts with the usual quartz monzonite to granite intrusives found in these systems. However, it is postulated that the Trout Lake system still does display the most important feature of a stockwork molybdenum system, i.e. excess quartz, as indicated by the modal quartz content (35-45%) and the prominent quartz 'eyes' in all the intrusives.

Finally, the Trout Lake deposit does not fit the classical Climax-Henderson "inverted cup" or "multiple shell" model (Wallace *et al.*, 1968; 1978; Westra and Keith, 1981) in its shape or alteration features. The strong vertical attenuation of the Trout Lake deposit leads to a sausage or cigar shape rather than a shell. The elongation of the mineralized zone is presumably caused by the faulted and complexly folded metasediments leading to vertically extensive fracturing and dyking at Trout Lake. In contrast, the laterally extensive "shatter zone" at the top of a typical Climax-type stock appears to be in response to fracturing of a more isotropic medium. The mineralized "hood zone" at Questa (Carpenter, 1968) may be more like the Trout Lake zone except that at Questa the long axis of the zone is horizontal rather than vertical.

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1983 IPMI award nominations requested

Nominations for IPMI's 1983 awards are now being accepted by the Awards Committee. The Distinguished Achievement Award was established in 1977 to recognize important career contributions to the advancement of precious metals, be it technological, economic or business. The prize consists of a plaque bearing a precious-metal medallion. The recipient will be designated IPMI's 1983 Man of the Year and will present the Award Lecture at the Annual Meeting in June at San Francisco, California.

The Henry J. Albert Award was established in 1979 by Engelhard Industries as a memorial to Dr. Henry J. Albert, who served as the Carteret Division's technical director. Its purpose is to recognize and encourage outstanding theoretical or experimental contributions to the metallurgy of precious metals. The prize consists of a palladium medal struck in the likeness of Dr. Henry J. Albert, and a certificate citing the contributions made by the recipient.

In 1980, IPMI, wishing to recognize and encourage outstanding work by a graduate or undergraduate student in precious metals research, established a Student Award consisting of $500 and a certificate citing the recipient's contributions. Nominations for the Student Award will be accepted from bona fide members of school faculties with a minimum one-page review of the student's work, which may have been published or presented within the prior twelve months, although this is not required for consideration.

Nominations for the aforementioned awards will be accepted from any member of IPMI. All nominations must be received by the Awards Committee by **February 1, 1983.** The Awards will be presented at IPMI's Annual Meeting in June.

The nominee's name and a brief description of his/her achievements should be forwarded to IPMI, Polytechnic Institute of New York, 333 Jay Street, Brooklyn, NY 11201.