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AFTON: GEOLOGY OF A SUPERGENE COPPER DEPOSIT

(Lat 50°39.5'N, Long. 120°31'W; 92I/10E)

by

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ABSTRACT

The Afton copper deposit is 13 km W of Kamloops and contains 30.84 x 10^6 t of open pit ore grading 1.0% Cu at 0.25% Cu cut-off together with recoverable Au and Ag. At 6300 tpd (metric) this orebody will support a planned mine, mill, and smelter complex. Hypogene material extends below proven depth and contains bornite and chalcopyrite. To a depth of 400 m in the W and a lesser depth in the E, the upper part of the deposit is largely supergene and contains principally metallic copper and chalcocite. Supergene material has an average grade fractionally less than that of hypogene material.

Geologically the deposit occurs at the NW extremity of the Iron Mask pluton, a subvolcanic multiple intrusion of dioritic to syenitic composition. The pluton lies lengthwise in a major cross structure of the Quesnel Trough and is emplaced in contemporaneous volcanic rocks of the Upper Triassic Nicola Group. Control of the cross structure by long-active deep-seated faults is evidenced by the manner of emplacement of plutons and by development of adjacent sedimentary and volcanic basins whose age is Eocene or possibly much earlier. Afton lies apparently at the intersection of inferred N, WNW, and W-trending basement faults. The hypogene copper deposit formed in a shattered part of a 2600 m-long fracture zone which elsewhere contains mainly barren pyrite and magnetite mineralization. The deposit is imposed on a magnetite zone and adjoined in the hanging wall by a pyrite zone.

In its present form the Afton deposit is a 520 m-long tabular body striking WNW and dipping 55° S. The deposit widens and deepens westward with an average width of 90 m and explored depth of 600 m. It is contained by late-phase plutonic rocks which include latite porphyry and related breccias. Eocene strata postdate the supergene event. They unconformably overlie parts of the deposit and to the N are partly in steep fault contact with ore. Hypogene alteration has no recognized pattern and it includes potassic, saussuritic, and phyllic varieties. Supergene alteration is characterized by rock disintegration and abundant earthy hematite with limonites. Faults although numerous mostly defy correlation and cause only minor apparent disruption of the deposit despite the evident post-mineral age of several faults. They include S-dipping strike faults and oblique (ENE) faults and W-dipping cross faults of which one apparently causes the W termination of the orebody.

Geochemically the orebody is scarcely distinguished from widespread subeconomic mineralization in the barren zones. Down-ice to ESE a transported anomaly in soils is short and bifurcated due to the bedrock configuration. I. P. surveys locate barren zones rather than the orebody, except that low resistivities in the supergene zone result in a "Metal Factor" anomaly. Magnetic surveys place the orebody at the end of a conspicuous anomaly related to magnetite in a zone partly coincident with ore.

The very deep supergene zone is attributed to penetration in the Paleocene or early Eocene of highly fractured ore by copious aerated groundwater which then proceeded to a low base-level afforded by the adjacent fault-depressed basin to N; and to oxidation-reduction processes which under these conditions converted magnetite to hematite and, coincidentally, bornite and chalcopyrite to metallic copper and chalcocite. Comparative mineralogies and compositions of average supergene and hypogene mineralization indicate losses of sulfur and soluble salts together with some leaching of copper.

INTRODUCTION

The Afton copper deposit is located at 640 m elevation in sagebrush country alongside the Trans-Canada Highway 13 km W of Kamloops and 420 km by road from Vancouver (Figs. 1 and 12). Except in an old prospect pit near its E end, the orebody was hidden by Tertiary and Pleistocene cover up to 27 m thick and also by a salt-pond. Numerous small mines and prospects occur in the district, from which nearly 200 000 tons of material was mined between 1891 and 1928. This material was mainly ore grading about 1.5% Cu that was milled at the Iron Mask mine 5 km E of Afton, and it included several thousand tons of magnetite ore shipped as smelter flux from the Glen Iron mine 10 km NW of Afton. Old workings on the Afton property date from this early period, and the orebody itself lies partly on a Crown granted claim located in 1904. Axel Berglund first staked the Afton claims in 1949. Subsequent drilling programs explored the area of the Pothook shaft, where modest reserves grading about 0.6% Cu are indicated, and tested the property widely with scattered holes of which DDH 70-4 cut persistent low grade copper mineralization near the old prospect pit by the highway. When in 1971 C. F. Millar resumed exploration for Afton Mines Ltd., he percussion drilled on a grid around this hole and so discovered the Afton orebody.

Under agreement with Afton Mines Ltd., development of the orebody was begun in 1972 by Canex Placer Limited and continued from 1973 jointly by Teck Corporation Limited and Iso Mines Limited. From discovery to end-1974, drilling on the property totalled 49 045 m of which 17 150 m was percussion, 7820 m was rotary, and 24 075 m was diamond drilling. Decision for production was announced in November 1975.

Within a planned open pit 274 m (900 feet) deep the drill-proven ore reserves are 30.84×10^6 tonnes (34 million short tons) grading 1.0% Cu, 0.58 g/t Au, and 4.19 g/t Ag at a cut-off of

0.25% Cu and a waste to ore ratio of 4.2:1. This ore will be milled at 6300 tonnes per day (7000 stpd) to provide two products; a metallic concentrate grading about 97% Cu, and a flotation concentrate grading about 50% Cu. About 87% of the copper will be recovered in milling. The products will be fed on-site to a Top Blown Rotary Converter (TBRC) smelter from which blister copper exceeding 99% in purity will be produced. The copper smelter will be the first operating in British Columbia since 1935 and with this low-sulfur ore its operation will satisfy exacting environmental considerations.

This paper is a preliminary account prepared before the orebody was stripped and it is based on routine core-logging and other studies related primarily to economic evaluation of the deposit. Persons whose work has assisted us but is not specifically referred to include geologists of Canex Placer Limited and C.G. MacIntosh of Teck Corporation Limited. Thanks are expressed to Directors of Afton Mines Ltd. for authorizing publication.

GEOLOGICAL SETTING

The Quesnel Trough in which the Afton deposit lies is a 30 to 60 km-wide belt of Lower Mesozoic volcanic and related strata enclosed between older rocks and heavily intruded by batholiths and lesser intrusions (Campbell and Tipper 1970). Portions of the Trough are obscured by subsequent depositional basins and late plateau lavas, which together extend for 30 km immediately N of Afton and separate the S part of the Trough almost completely from the rest. The S part is the well-known Nicola belt, continuing nearly 200 km to its termination at the U.S. border and containing the important copper mines of Highland Valley, Craigmont, Copper Mountain, and Brenda, and the former Hedley gold camp.

In the vicinity of Afton, the Iron Mask district is part of a major structure extending NW across the general N trend of the Nicola belt. This cross structure is less than 10 km wide and about 35 km long according to the isomagnetic contours shown on Figure 1. To the NW it is largely obscured by later stratified rocks of an adjoining basin. To the SE it contains two related plutons formerly believed to be a single connected body named the Iron Mask batholith (Cockfield 1948). The plutons are emplaced in Upper Triassic strata of the Nicola Group that extend widely S and W of the district but are restricted eastward by Paleozoic rocks of the Cache Creek Group and northward by Tertiary rocks. The Nicola strata include andesitic and basaltic flows, breccias (some described as lahars of mudflow breccias: Northcote 1974), tuffs, and lesser amounts of argillite and limestone. They strike NW and possess moderate dips except near inferred faults. Their degree of metamorphism is low, not exceeding the greenschist facies.

The Afton orebody is at the NW end of the 18 km-long Iron Mask pluton. The separate and smaller Cherry Creek pluton occurs some 5 km farther NW, outcropping on either side of Kamloops Lake and apparently comprising only the later of the units described below.

The Iron Mask pluton comprises successively-emplaced units all apparently of late Triassic age (190 to 205± 6 m y: V. A. Preto, pers. comm; and Carter and Christopher, this Volume) and ranging in composition from basic to somewhat alkalic (Carr 1957, Preto 1968, Northcote 1974). On geological evidence the Iron Mask and Pothook units were earliest, being chiefly of diorite and gabbro. Succeeding units of finer-grained, more porphyritic rocks are emplaced mainly along NW and W linear structures that frame and dissect the pluton. Picrite basalt preceded the others to form steep, lenticular bodies that are poorly exposed, commonly possess sheared, serpentinized margins, and are generally to be found within 300 m of most prospects in the district. One such body nearly 2 km long extends

E to a position about 300 m S of Afton and has proved difficult to drill through (Figs. 2 and 3). Picrite basalt is found in drill holes on the SW side of the Cherry Creek pluton and, since it also occurs far from the plutons (for example, N of Kamloops Lake at both Carabine and Watching Creeks: Cockfield 1948, Carr 1957), it has more than a local significance and is believed to occupy faults of a regional system. Succeeding it in this district, a unit named Sugarloaf diorite comprises generally elongate bodies, some as wide as 1 km and others narrow dykes such as occur S and SW of Afton.

Latest was the Cherry Creek unit which hosts the Afton copper deposit and is widely distributed elsewhere in the plutons. This unit comprises mainly diorite, monzonite, and syenite which together form relatively large bodies, including the Cherry Creek pluton and the NW part of the Iron Mask pluton near Afton. The unit also includes equivalent porphyries and associated intrusion breccias as irregular dykes, emplaced mainly in the larger Cherry Creek bodies. In reporting that Nicola pyroclastic beds near Afton contain fragments of Cherry Creek rocks, Northcote (1974) emphasized the close relationship which existed between the Nicola volcanism and Cherry Creek intrusive activity.

Significant copper occurrences found in the district to date are all in the plutons, mainly close to the plutonic margins (Fig. 2). They take the form of veins, stockworks, and fracture-controlled disseminations in which the principal hypogene copper mineral is chalcopyrite, locally accompanied by bornite. Small but significant values in gold are common. Molybdenite is rare but occurs in small amounts in the Galaxy (Evening Star) deposit, located centrally in the Iron Mask pluton 6.5 km E of Afton (McDougall and Pilcher, this Volume). Lead and zinc minerals are virtually unknown in the district. Pyrite accompanies chalcopyrite in some deposits and also forms barren zones in the plutons and adjacent Nicola country rocks. These barren zones, which contain stockwork and disseminated pyrite in amounts of a few per cent without much chalcopyrite, in places flank or enclose the copper deposits. Hydrothermal magnetite occurs as disseminations and in veins with minor apatite and with or without sulfides. Wallrock alterations in the district have no recognized pattern and they include potassic and propylitic (saussuritic) varieties (Carr 1957, Preto 1968). Gangue minerals in veins with sulfides include calcite and epidote and less commonly gypsum, ankerite, specular hematite, quartz, fluorite, and zeolites. The alteration is Upper Triassic according to the 198 m y radiometric date obtained for hydrothermal biotite accompanying sulfides on a property E of Afton (Preto, pers. comm. 1975).

Above 60 m depth but much deeper at Afton, certain deposits contain supergene minerals. Thus copper carbonates, metallic copper, chalcocite, cuprite, and limonites variously occur at the Pothook zone, the former Erin orebody at the Iron Mask mine, and the southeasternmost or Joker prospect.

Post-Triassic strata occupy depositional basins that flank and infringe the major cross structure on either side (Fig. 1). Basins to the SW are discontinuous, elongate, and occupied by non-marine clastics, chiefly conglomerates which at Carabine Creek are assigned by Cockfield (1948) to the Cretaceous but are probably Eocene. The Hughes Lake basin discovered by drilling S of Afton is narrow, steep sided, and contains S-dipping clastics which are grey to the W and red to the E due to a hematite cement. They include graded beds, locally pyritic, and conglomerates with cobbles of granitic rocks and greenstone. The basin is outlined by ground magnetics and electrical surveys for a length of 3 km on the Afton property (Fig. 3) and it extends W toward a similar narrow basin with hematite-free conglomerate and fine-grained clastics that dip steeply NE along Cherry Creek. NE of the major cross structure a very large expanse of non-marine Tertiary strata, assigned to the Kamloops Group and including beds of M. Eocene age (Rouse and Mathews 1961), occupies what appears to be a single major basin from which a salient projects S to Afton.

The Kamloops Group includes tuffaceous sandstone, siltstone, and shale with minor conglomerate; and also flows and agglomerates of basalt and andesite with local dacite, quartz latite, latite, and trachyte. Pyrite occurs locally in drill holes: for example, in agglomerate faulted against Nicola rocks 600 m W of Afton and in tuffaceous beds intruded by diabase sills N of Kamloops Lake. At Afton the strata are directly in contact with supergene ore, partly at faults and partly at a simple unconformity which postdates the supergene event. These Eocene rocks rapidly attain considerable thicknesses as shown 750 m N of Afton where a drill hole on an adjoining property bottomed in these rocks at a depth of 600 m (Fig. 4).

Similar depositional basins are common in SW British Columbia; they originate in a fault-controlled relief and extend in apparent age to as early as M. Jurassic (Carr 1962). The actual age of a long-active basin may be unknown if its oldest strata are deeply buried and therefore unidentified. Farther S in the Nicola belt fault-controlled basins are as old as U. Triassic (Preto 1975) and basins of a similar age may therefore exist near Afton. The orebody lies apparently at a common intersection of structures considered to reflect deep-seated faults that were active intermittently from U. Triassic, as follows:

(a) N-trending, as indicated by an old basin extending S to Afton and inferred from the 3000 γ contour on Figure 1. (b) NW-trending and (c) W-trending, as indicated by intrusive and faulted contacts, and by isomagnetic contours which outline an inferred rhomb-shaped basement structure 10 km long and pointed W at Afton (Fig. 2 and 4).

LOCAL GEOLOGY

Bedrock exposure on the Afton property amounts to about 10%, the rest being covered by glacial drift deposited from Pleistocene ice sheets that moved ESE across the area. Topographic relief above the Afton copper deposit is about 30 m, largely due to a drumlinoid deposit of drift at the W end. The deposit occurs entirely in Cherry Creek rocks which form a W spur of the Iron Mask pluton (Figs. 2, 3, and 4). These rocks are at least 300 m wide, being obscured to the N by overlying Tertiary rocks and possessing to the S a steep, S-dipping intrusive contact against Nicola country rocks. Where seen in drill holes this contact is partly sheared. Nicola rocks N of this contact apparently represent steeply dipping slabs up to a few tens of metres wide, lying roughly parallel to the contact and enclosed by the pluton as large inclusions or screens.

The following description of the principal rock types is based on appearances in drill core supplemented by examination of a few thin-sections and sawn rock slabs which were stained for identification of K-feldspar. Nicola Group rocks are mostly andesite or basalt lavas, agglomerates, and tuffs, but include lighter coloured types which may be dacites. Attitudes are poorly known. The rocks are characterized by ubiquitous epidote disseminated and in fractures and amygdules. Cherry Creek rocks include several varieties whose distribution in the deposit is imperfectly known (Fig. 7(a)). Diorite is known only in the footwall where it forms a slab-like mass extending lengthwise for 200 m. It is a greenish-grey rock, somewhat coarser-grained than the others and distinguished by its spotted appearance resulting from numerous small biotite plates. In this rock plagioclase, pyroxene, and hornblende all attain ½ cm in size and are accompanied by interstitial quartz and K-feldspar in small amounts. Corresponding to Preto's Unit 2, Cherry Creek diorite is dated at 190 ± 6 m y (Preto, pers. comm.). Diorite porphyry predominates in the drill holes and is a grey-green to grey-pink, fine-grained rock with plagioclase phenocrysts to 1 mm size and scattered, smaller biotites in a finely granular to aphanitic groundmass which is largely plagioclase and minor interstitial K-feldspar. Chloritic aggregates scattered through the rock represent former hornblende and pyroxene. Latite porphyry occupies numerous intersections probably representing irregular dykes increasing in size upward in the copper deposit. The rock is more porphyritic than the last, and it exhibits euhedral plagioclase phenocrysts up to 3 mm in an aphanitic groundmass rich in K-feldspar and containing minor biotite. Intrusion breccia is found in narrow intersections throughout the deposit and is thought to be due to explosive emplacement of latite porphyry. It consists of close-spaced sub-rounded fragments of all Cherry Creek rock types in a fine-grained matrix largely of K-feldspar and lesser plagioclase. Most fragments seen in drill core are less than 2 or 3 cm in size although larger ones could be represented by massive rock separating the recognized breccia intersections.

Barren Tertiary (M. Eocene) sedimentary rocks are in contact with supergene ore, mainly at faults but also at a simple, rather flat-lying unconformity which is undisturbed at shallow depth near both ends of the orebody (Fig. 7). The rocks show diverse attitudes in drill core and are grey to blue, or brown, tuffaceous siltstones and sandstones with minor conglomerate. Tuffaceous rocks are bentonitic. Interbedded volcanic rocks N of the orebody are grey to red andesite and latite lavas with some agglomerate. Absence of epidote distinguishes these relatively fresh rocks from their Nicola counterparts. Amygdules in the volcanics contain calcite and zeolites, locally with fluorite and gypsum. Related dykes up to 6 m wide of latite porphyry intrude the orebody and postdate the supergene event.

Wallrock alteration is difficult to distinguish in detail due to prevalent supergene effects, the most obvious of which are disintegration of the rock mass and accompanying intense, pervasive introduction of hematite. Argillic alteration is evident and probably too is supergene; its products include montmorillonite, identified by x-ray diffractometry as the principal clay mineral in a composite sample of supergene ore (Lakefield Research 1973). The hypogene alteration is documented by Preto (1973) and corresponds in general to that found elsewhere in the district. It exhibits the following successive stages whose distribution and relative intensities are poorly known: potassic alteration characterized by secondary K-feldspar and locally by hydrothermal biotite; saussuritic alteration chiefly with epidote-chlorite-magnetite and only rarely quartz and calcite; and phyllic (quartz-sericite) alteration. Potassic alteration is sporadic and possibly related to the distribution of latite porphyry. Saussuritic alteration is more general and is related to a widespread propylitic alteration seen in pyritic rocks S of the deposit. Although calcite is an expected product of propylitic alteration, surprisingly most calcite at Afton occurs as late fracture-fillings that postdate the supergene event and are common to the nearby Tertiary strata.

A large-scale zoning of magnetite, pyrite, and copper minerals is crudely evident in the vicinity of the orebody. Abundant hydrothermal magnetite forms a 300 m-wide zone trending NW from the Magnet shaft to the Afton orebody, a distance of 800 m (Fig. 3). The magnetite zone is flanked on either side by barren pyrite zones, with the Afton orebody occurring in the magnetite zone close to the southwestern pyrite zone. This pyrite zone, which also flanks the Pothook copper deposits, is 1½ km long. NW from the Pothook area it widens to about 300 m at Afton, beyond which it swings westward and is widest at its termination 600 m farther on. S of Afton it contains up to 10% pyrite by volume, chiefly as fracture-fillings in the Cherry Creek intrusives and disseminations in the Nicola volcanics. Near its termination only, the zone contains limonite instead of pyrite in outcrops and drill holes up to 120 m deep. Its north limit here is partly at the faulted Tertiary rocks.

The Afton copper deposit consists of shattered rocks in which the ore minerals occupy fractures and are disseminated. Ignoring complexities, the deposit is tabular inside a 0.25% Cu cut-off and it strikes WNW with an average dip of 55° S. If viewed from the S as a vertical longitudinal slice it appears triangular and increasingly narrow downward between a steep W limit and an E limit inclined moderately W (Fig. 5). The deposit measures 520 m (1700 feet) long, 90 m (300 feet) in average width, and as much as 600 m (2000 feet) in drilled depth. The widening and deepening of the deposit westward results in about half the mineable tonnage occurring in the W-third of the orebody, where too the grade is generally highest (Fig. 6).

Despite the foregoing simple description the shape of the copper deposit is complex in detail, as seen on successive cross sections (Fig. 8), and it remains conjectural to the W at depths below the planned pit floor (365 m elevation). The S dip of the deposit changes noticeably along strike, from about 30^o in the E to as much as 80^o in the centre and decreasing to about 55^o at the W end. Down-dip the deposit is completely defined only at its east end. Its width remains more or less constant except in the W where it increases markedly. Its outline in cross section is generally unbroken, except in the central part where a narrow discontinuity interrupts the deposit at an intermediate but variable depth. Contouring of cross sections using different cut-offs reveals the existence of a higher grade core restricted to the central and W parts of the deposit where it lies roughly midway between footwall and hanging wall. In the upper W part the core is discontinuous and forms separate shoots, apparently devoid of plunge and dipping S somewhat less steeply than the deposit itself. At the lower W end (Fig. 7(b)) the core extends from hanging wall almost to footwall and produces a well-defined hanging wall because higher grade mineralization is directly in contact with rock containing only about 0.03% Cu.

The deposit comprises two distinct zones containing different mineralogies: a deeply penetrating supergene zone embracing most of the proven ore reserves and defined by metallic copper which is commonly accompanied by chalcocite and cuprite; and a lower, partly explored hypogene zone characterized by bornite and chalcopyrite. Average grade in Cu of the supergene zone is somewhat less than that of the hypogene zone.

The <u>hypogene zone</u> is preserved only in the central and W parts of the deposit and mainly below 500 m elevation. By definition without metallic copper the zone contains minor amounts of the possibly supergene minerals chalcocite and covellite in addition to the hypogene sulfides bornite and chalcopyrite. Bornite greatly exceeds chalcopyrite near the hanging wall and decreases across the deposit until near the footwall the ratio is reversed. Pyrite in the adjacent barren zone generally appears to quit in the hanging wall 10 or 20 m short of the copper deposit (<u>Fig 7(b)</u>) but locally is seen infringing the deposit in company not only with chalcopyrite but also bornite. Pyrite is rarely seen in drill core from elsewhere in the deposit although it is reported from metallurgical samples (Lakefield Research 1974), neither does it occur in the footwall rocks. Bornite and chalcopyrite though mainly fine-grained occur also as blebs and veins up to 1 cm wide. Polished-section work done both by Lakefield Research and, in conjunction with microprobe studies, by Harley Hoiles at the University of Alberta demonstrate the presence of enargite and other related sulfosalts in exsolution relationship with bornite and more particularly chalcopyrite. These quantitatively insignificant sulfosalts may include tennantite-tetrahedrite and, together possibly with selenides, are considered likely hosts for gold and silver in the ore (Hoiles, pers. comm. 1975). Bornite and chalcopyrite display their own exsolution relationship, and in drill core it was seen that bornite grains frequently enclose cores of chalcopyrite. These bornite grains are enveloped by shells successively of covellite and a chlorite which is thought to be hypogene and makes the covellite hypogene also.

The supergene zone replaces the hypogene zone mainly above 500 m elevation in the east part and 250 m elevation in the W (Figs. 5, 7(b),and 8). The boundary of the zones is generally sharp and it plunges steeply W from about midway along the deposit. In the W part of the footwall supergene minerals persist to almost sea level, a depth below surface in excess of 600 m (Fig. 7(b)). Steep, narrow hypogene septa are preserved at high elevations locally, for example, along the W part of the hanging wall (Fig. 7(b)) and centrally in the deposit along an ENE trend (Fig. 9). Such narrow extensions of one zone in the other are probably due to individual poorly recognized faults influencing the passage of groundwater during the supergene event.

Table 1 gives estimates of the relative abundances of the principal copper minerals in the uppermost 100 m of the zone (above 550 m elevation) based on point-counts by Lakefield Research on samples prepared from bench-test concentrates of minus 10-mesh feed, and adjusted to compensate for oversize metallic copper that was excluded from these samples.

TABLE 1. Relative abundances of copper minerals in the upper part of the supergene zone.

Metallic copper defines the zone and occurs in fine scales, films, dendrites, and granules but also in masses as wide as 5 mm.

In metallurgical testing a significant fraction of the copper remained on the 10-mesh screen after roll crushing. According to Hoiles (pers. comm. 1975) metallic copper at Afton is all the more likely to be supergene due to its lack of a trace element content in amounts detectable by his microprobe analysis, such as would be expected in copper of hypogene origin. Chalcocite though mostly the typically supergene sooty variety is partly grey chalcocite (digenite) and is both disseminated and in veins up to 25 mm wide. In polished-section it is seen replacing both bornite and chalcopyrite (Lakefield Research 1974), which are relics in the zone as also rarely is pyrite. Both metallic copper and chalcocite are coated variously by cuprite, covellite, and hematite, as especially noted in the upper, more disintegrated rock of the zone. Malachite, azurite, conichalcite, and (?) chrysocolla (Preto 1973) are very minor constituents occurring mostly a few metres from surface and rarely to depths of 200 or 300 m.

Rock in the zone is disintegrated and impregnated with hematite, which clogs fractures and stains the altered feldspars. This earthy hematite is developed spectacularly in the W part of the orebody, probably largely from hypogene magnetite.

Farther E magnetite veins remain partly preserved. Limonite is less prevalent and jarosite is reported only from x-ray studies (Preto 1973). Gypsum is not observed.

In the deposit so far as explored, the average grade in Cu of the supergene zone is fractionally less than that of the much smaller hypogene zone. Possibly therefore, a minor degree of leaching by supergene processes is indicated, although its effect is not easily recognized from contouring of the assay distributions.

Structural details of the deposit are far from clear. Faults evidenced by gouge, breccia, and slickensides are so numerous that they mostly defy correlation. In addition to their late effects many of the faults probably predate the supergene event and some possibly the hypogene period. Three principal fault sets are recognized, largely due to their effect on the contact of Eocene strata (Figs. 9 and 10). They are variously strike faults (W or WNW), oblique faults (NE or ENE), and cross faults (NNE). S dips apparently prevail for strike and oblique faults, an example of each being seen dipping south at 65 - 70° in a trench astride the Eocene contact NE of the orebody. Generally at this contact the direction of apparent movement on both sets of fault is reverse (S wall up). An oblique fault distinguished in drill core by a distinctive, gritty breccia is readily correlated between several holes and it lies deep in the deposit, dipping apparently SSE at about 50°.

This fault at one point encloses supergene ore, confirming the late movement of oblique faults. Although much less evident at other elevations, the shape of the deposit at the 488 m elevation (Fig. 9) suggests a pattern of oblique faults of which only one is shown on Figure 5 and none on Figure 7 (where if shown their apparent dips would be close to 40°). Cross faults are chiefly represented by an inferred 30 m-wide fault zone adjoining the W end of the deposit (Fig. 5). At elevations higher than 488 m this cross fault, possibly in conjunction with an oblique fault, encloses Eocene sedimentary rocks which are apparently displaced as much as 100 m either southward or downward relative to the mass of Eocene strata. Copper mineralization found W of this cross fault lies at considerable depth, is of moderate grade in sulfides, and is only partly explored. Fracturing attendant on cross faults conceivably explains the abrupt descent of the base of the supergene zone at depth centrally in the deposit. Local preservation at the 488 m elevation of hypogene mineralization in contact with Eocene rocks at the footwall may be due as much to inefficient supergene replacement in poorly fractured rock as to displacement on late faults.

A late fault of unusual type disrupts the uppermost W extremity of the orebody and the Eocene rocks, and is a low-angle cylindrical fault of normal displacement (the "landslide" on Fig. 23(3) of Preto 1973)(Fig. 7). Apparent displacement on this fault is 30-40 m.

GEOCHEMICAL SURVEYS

Soil samples were collected at the "B" Horizon about 20 cm deep and analyzed for total copper. A population of background values in samples distant from known mineralization, representing largely Nicola volcanic and sedimentary terrain S of the pluton, has a normal distribution whose mode is 85 ppm Cu, mean is 88 ppm Cu, and standard deviation is 21 ppm. Reflecting mainly the southwestern pyrite zone and broadened eastward because of glacial dispersion, a very large anomalous area defined by values greater than 200 ppm Cu encloses the E part of the Afton orebody and extends SE to Pothook Lake (Fig. 11(a)). Within this broad area several more intense anomalies are defined by the 500 ppm Cu-contour. Three are shown of which the largest is 600 m south of the Afton orebody and coincides with abundant outcrops containing minor, widely distributed sulfides. The orebody lacks any directly overlying, useful soil anomaly because of a thick glacial cover at the W end, Eocene strata partly elsewhere, and the presence of the salt-pond. Immediately to the E however, two parallel ESE-trending anomalies each 300 m-long reflect glacial dispersion of ore around a central hump of bedrock situated at the E limit of the orebody.

Overburden drilling was done in 1973 in hope of providing a classic example of basal till sampling down-ice from an orebody. It was rendered useless because the line of percussion drill holes encountered the bedrock hump a mere 150 m down-ice from the orebody. Here a narrow anomalous layer fans upward through the thin till mantle to produce locally very high Cu-values in the overlying soil.

Under summer conditions using silver gauze collectors, a ground survey for mercury vapour done around the orebody in 1974 by another company gave a moderate anomaly over the W-central part of the orebody and the highest anomaly (up to 50 ng Hg) immediately W of the orebody. Mercury occurs in exceedingly small amounts in the Afton ore. The Hg vapour anomalies probably relate to subjacent faults coincident with Tertiary strata, because our own sampling of total Hg in soils elsewhere on the Afton property gave highest values at Hughes Lake where Tertiary strata likewise occur at faults.

GEOPHYSICAL SURVEYS

Induced Polarization

Induced polarization surveys played a considerable, though not entirely satisfactory, role in previous exploration of the property (Millar 1973). The generalized results of the most recent and complete survey (McPhar frequency-domain) are shown with n = 2 in Figure 11 (b). The orebody itself provides rather weak frequency effects (mostly less than 5%) but it adjoins the north side of a 2600 m-long anomaly with greater than 5% frequency effect, largely representing barren zones of pyrite and magnetite. Increased effects are locally seen in the E and central parts of the orebody at low electrode separations and are probably due partly to preservation of magnetite. Low apparent resistivities in the supergene zone contribute to a "Metal Factor"anomaly within the orebody.

VLF Electromagnetic

Electromagnetic surveys utilizing the signals from Seattle and Cutler (Maine) produced results which are interesting but unexplained, namely, an almost complete, elliptical ring of conductors enclosing the orebody.

Magnetic

The orebody is located precisely at the WNW end of a conspicuous positive anomaly 1000 m-long that reflects unusual amounts of disseminated and vein magnetite (Fig 11(c)). The anomaly terminates in the orebody due to supergene destruction of magnetite.

DISCUSSION

The sequence of events in the formation of the Afton orebody is apparently as follows:

1. In the Quesnel Trough by late Triassic time, sub-volcanic plutons were emplaced in submarine Nicola volcanics in response to movement on major faults affecting the floor of the

Trough. Recurrent fracturing and intrusion were concentrated above the fault traces, and especially above their intersections, and led finally to local extrusion of latite porphyry breccia from linear vents within fracture zones formed mainly at the plutonic margins.

2. Probably overlapping with (1), hypogene alteration and accompanying deposition of magnetite and sulfides occurred in the resulting subvolcanic fracture zones. Hypogene copper deposits formed at this time.

3. By the Paleocene or early Eocene, renewed fault movement led to emergence of a high-relief terrain of structurally-bounded plateaus and adjoining non-marine, volcanically active basins such as those in which rocks of the Kamloops Group occur. The high rainfall of a warm-temperate climate (Rouse and Srivastava 1970) and local high relief allowed deep weathering and penetration of groundwater in permeable shattered zones at the plateau margins, thus producing the supergene event at Afton as discussed below. Hematite mud derived from erosion of the weathered orebody reached the Hughes Lake basin whilst Eocene (?) conglomerate was being deposited. Gradual filling of the basins by M. Eocene time had eliminated the extreme relief and so protected the orebody from further groundwater activity.

4. Neither later erosion in the Tertiary nor abrasion by Pleistocene ice much affected the orebody under its protective Eocene cover.

THE SUPERGENE EVENT

Partial leaching of the Afton deposit and its conversion to a different mineralogy in the supergene zone occurred without effect on the sulfide-bearing wallrocks. Under circumstances outlined in (3) above, aerated ground water channelled downward through the intensely fractured hypogene deposit and caused coincident oxidation of magnetite to hematite and reduction of bornite, chalcopyrite, and minor pyrite to chalcocite and metallic copper. Excess sulfur and soluble salts were removed by the departing groundwater together with a fraction of the copper in the affected zone. Cuprite and hematite coatings on the principal minerals formed probably simultaneously with minor copper carbonates, etc. during some later episode of limited oxidation. Co-existence of magnetite and high-sulfur copper minerals was probably essential to formation of the unusual supergene assemblage by facilitating the necessary oxidation-reduction process. Other important factors were the intensely localized fracturing, proximity to a much lower base-level, and a wet climate all promoting the passage of abundant oxygenated and chemically active waters through the orebody. Trenholme (1973) suggested that high ground temperatures due to adjacent volcanic activity may also have played a part.

REFERENCES

Campbell, R. B. and Tipper, H. W, "Geology and Mineral Exploration Potential of the Quesnel Trough, British Columbia", CIM Trans. LXXIII, 1970. pp.174-179

Carr, J. M., Annual Report for 1956, B. C. Minister of Mines and Petroleum Resources, 1957, pp. 47-69.

Carr, J. M., "Geology of the Princeton-Merritt-Kamloops Area of Southern B. C.", Western Miner and Oil Review, Vol. 35, 1962, pp. 46-49.

Cockfield, W. E., "Geology of Nicola Map Area", Geol. Surv. Canada Mem. 249, 1948.

Jones, R. E., Geologic map (1 inch equals 400 feet) in Assessment Reports Nos. 141 and 192 (D. M., Afton) for Graham Bousquet Gold Mines Ltd. and Axel Berglund, 1957, open files, B. C. Dept. of Mines and Petroleum Resources, Victoria and Kamloops.

Lakefield Research of Canada Limited, private reports etc. by R. W. Deane and D. M. Wyslouzil, to Afton Mines Ltd. and Teck Corporation Limited, 1972-1975.

Millar, C. F., "The Afton Discovery", Western Miner, Vol. 46, No. 2, 1973, pp. 33-36.

Northcote, K. E., "Geological Fieldwork, 1974", B. C. Department of Mines and Petroleum Resources, 1974, pp. 22-26.

Preto, V. A., Annual Report for 1967, B. C. Minister of Mines and Petroleum Resources, 1968, pp. 137-147.

Preto, V. A., "Geology, Exploration and Mining in British Columbia for 1972", B. C. Department of Mines and Petroleum Resources, 1973, pp. 209-220.

Preto, V. A., "The Nicola Group: Mesozoic Volcanism Related to Rifting in southern British Columbia", GAC (Volcanology Division), Symposium on Volcanic Regimes in Canada, Waterloo, Ont., May, 1975. (Abs.)

Rouse, G. E., and Srivastava, S.K., "Detailed Morphology, Taxonomy and Distribution of Pistillipollenites Macgregorii", Can. Jour. Botany, Vol. 48, No. 2, 1970, pp. 287-292.

Rouse, G. E., and Mathews, W. H., "Radioactive Dating of Tertiary Plant-Bearing Deposits", Science, Vol. 133, 1961, pp. 1079-1080.

Trenholme, L. S., "Notes on Structure and Copper Mineralization, Afton Mines Ltd.", Private Report, July 1973.

TABLE 1. Relative abundances of copper minerals in the upper part of the supergene zone (weight %)*

	West	East
metallic copper	>65	>85
chalcocite	30	10
chalcopyrite	-	1
cuprite/tenorite	< 5	trace
other minerals	trace	<1

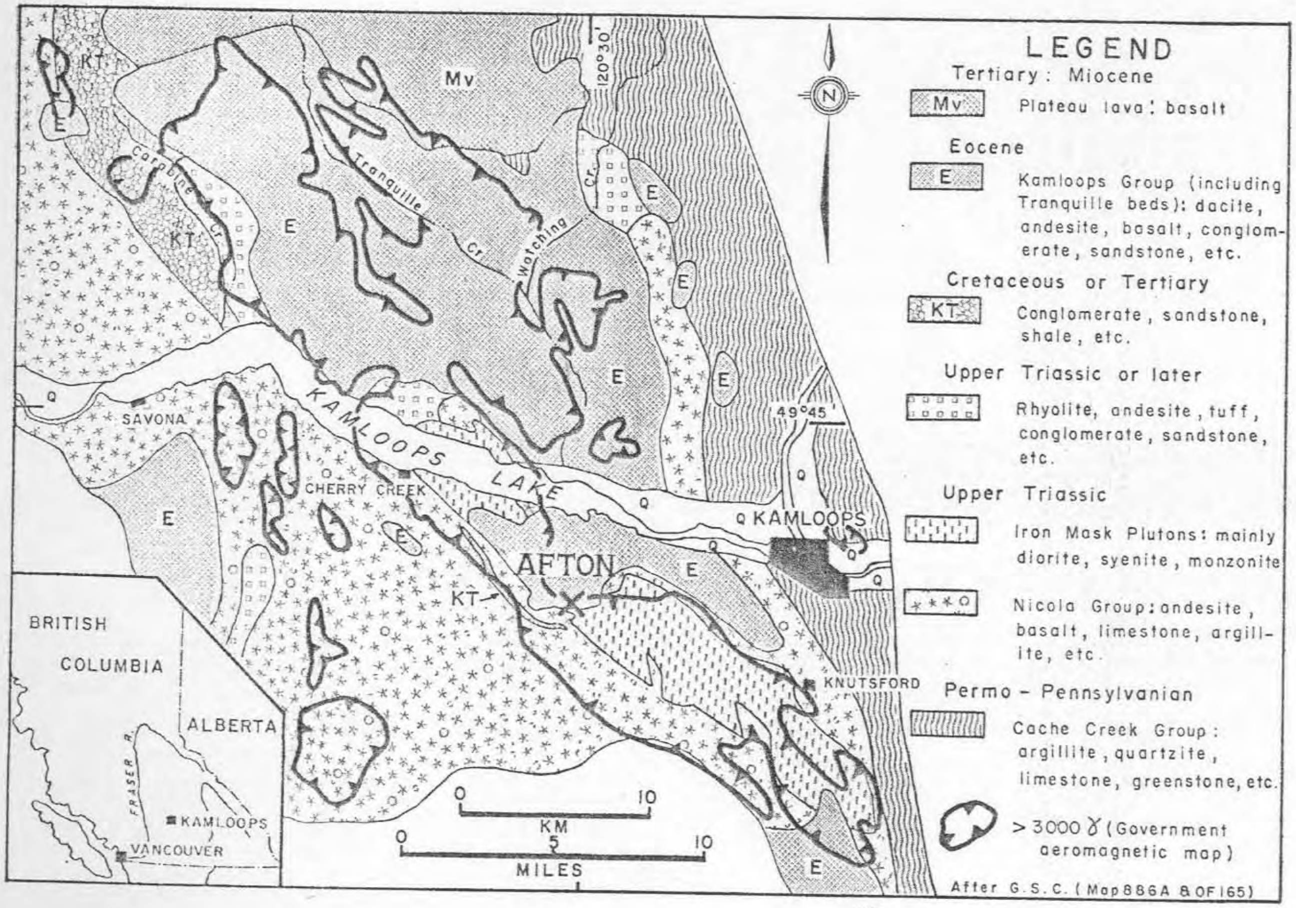
*adjusted from point-counts of minus 10-mesh material from concentrate samples (after Lakefield Research, 1973).

CAPTIONS

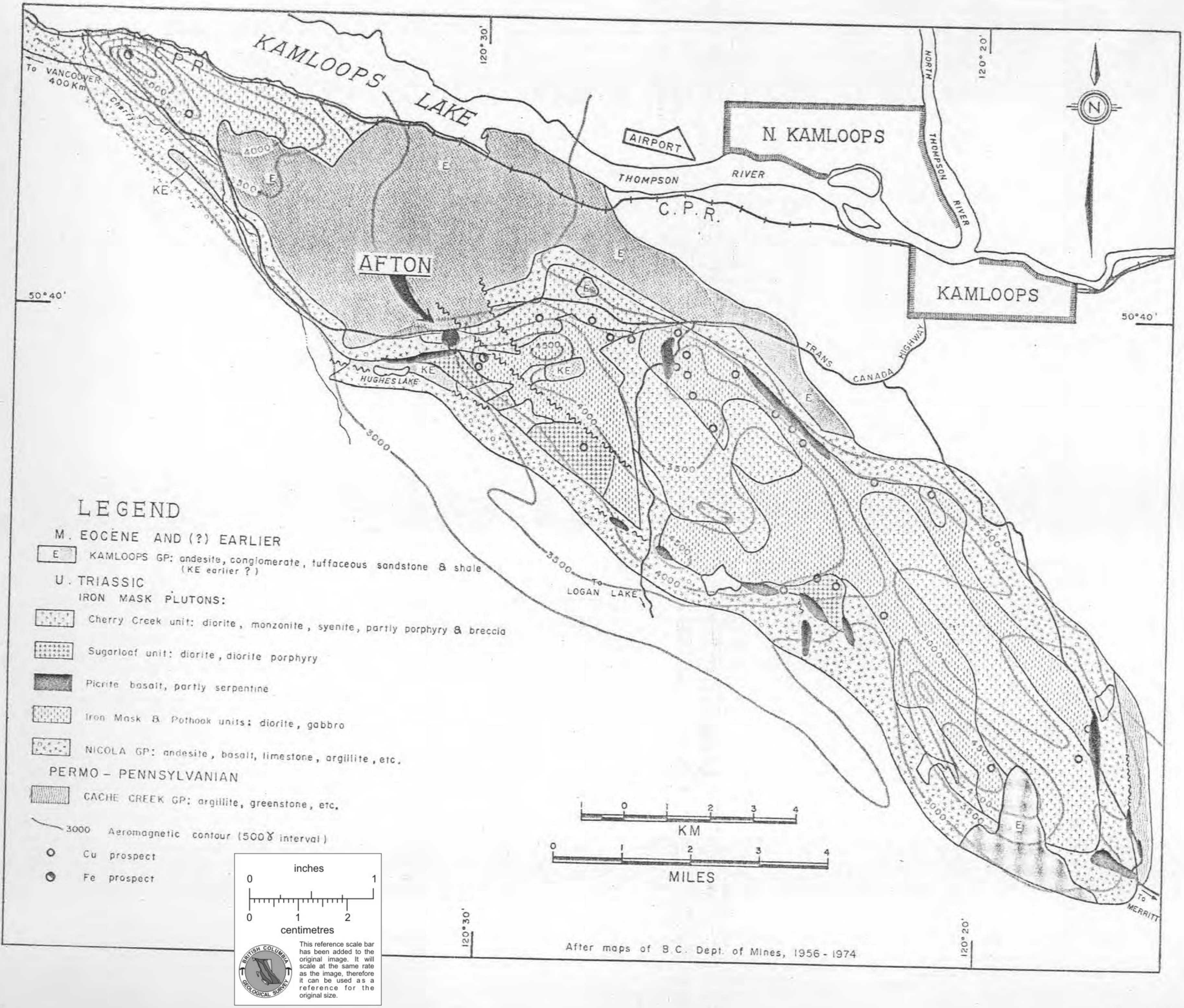
FIGURE 15-JMC-A1. - Regional geological and aeromagnetic map of the Iron Mask district.

2. Geological map of the Iron Mask pluton
3. Geological map of the Afton property
4. Vertical geological section of the Afton property on 18W (extended). Legend as for Fig. 3.
5. Simplified vertical longitudinal slice of the Afton deposit.
6. Tonnage and average grade of successive vertical slices across the Afton deposit.
7. Vertical section of the Afton deposit at 18W:
   a) Geology
   b) Mineralization
8. Block diagram of the Afton deposit (only alternate sections shown).
9. Plan of mineralization at the 488-metre (1620-foot level of the Afton deposit. Legend as for Fig.7.
10. Schematic plan of late faults at the 567-metre (1860-foot) level of the Afton deposit.
11. Geochemical and geophysical plans of the Afton property
    a) Total copper in soil
    b) I.P. survey
    c) Magnetometer survey

(Plate) 12. View northward of the Afton orebody (under the salt-pond) and the Trans-Canada Highway, July 1973


LEGEND
Tertiary: Miocene
Mv
Plateau lava: basalt
Eocene
E
Kamloops Group (including Tranquille beds): dacite, andesite, basalt, conglomerate, sandstone, etc.
Cretaceous or Tertiary
KT
Conglomerate, sandstone, shale, etc.
Upper Triassic or later
Rhyolite, andesite, tuff, conglomerate, sandstone, etc.
Upper Triassic
Iron Mask Plutons: mainly diorite, syenite, monzonite
Nicola Group: andesite, basalt, limestone, argillite, etc.
Permo - Pennsylvanian
Cache Creek Group: argillite, quartzite, limestone, greenstone, etc.
> 3000 γ (Government aeromagnetic map)
After G.S.C. (Map 886A & OF 165)
N
120°30'
49°45'
Mv
KT
E
Q
Carabine Cr.
Tranquille Cr.
Watching Cr.
SAVONA
KAMLOOPS LAKE
CHERRY CREEK
KAMLOOPS
AFTON
KNUTSFORD
BRITISH COLUMBIA
ALBERTA
FRASER R.
KAMLOOPS
VANCOUVER
KM
0
10
MILES
0
5
10

15-JMC-A1



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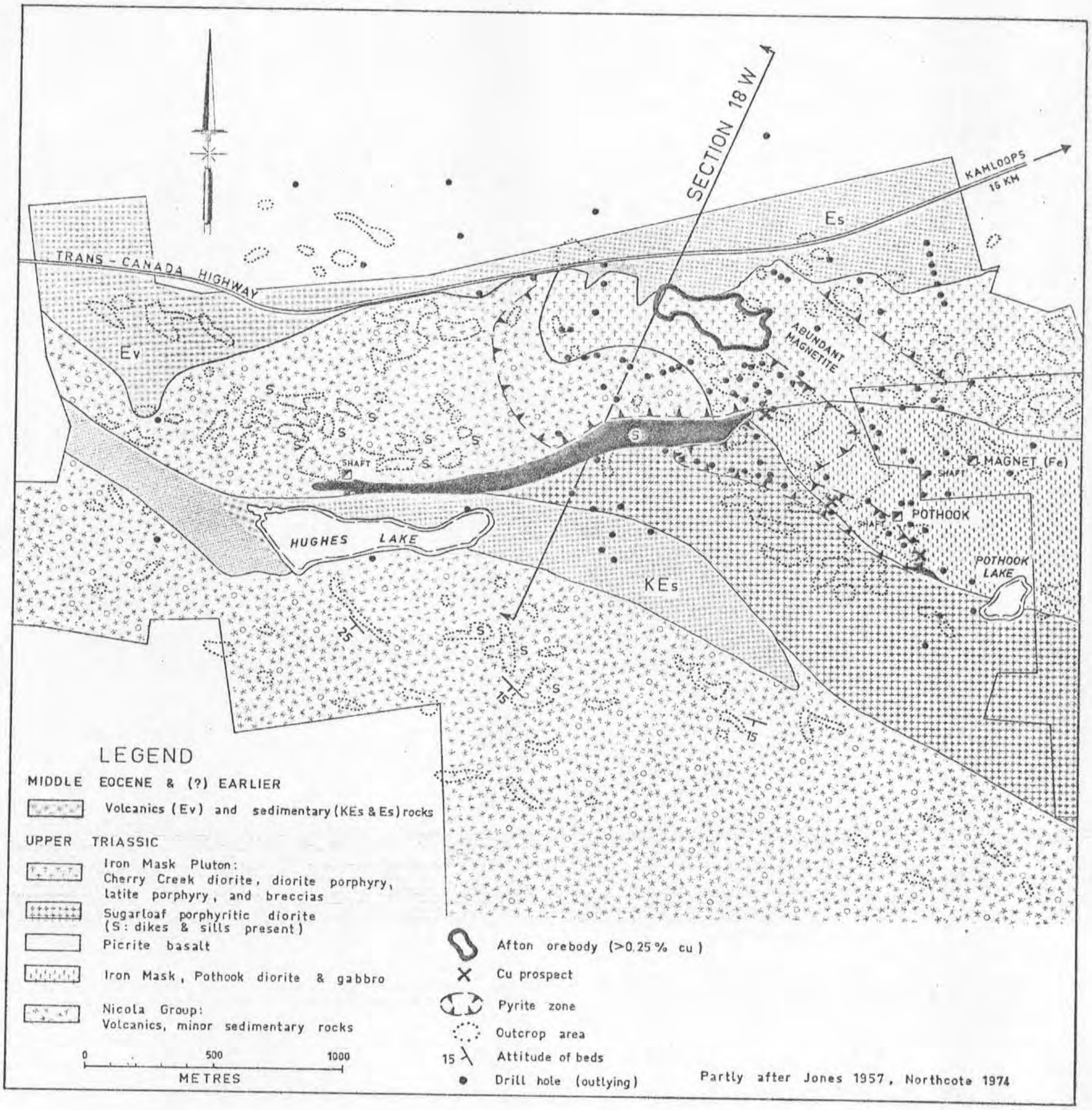
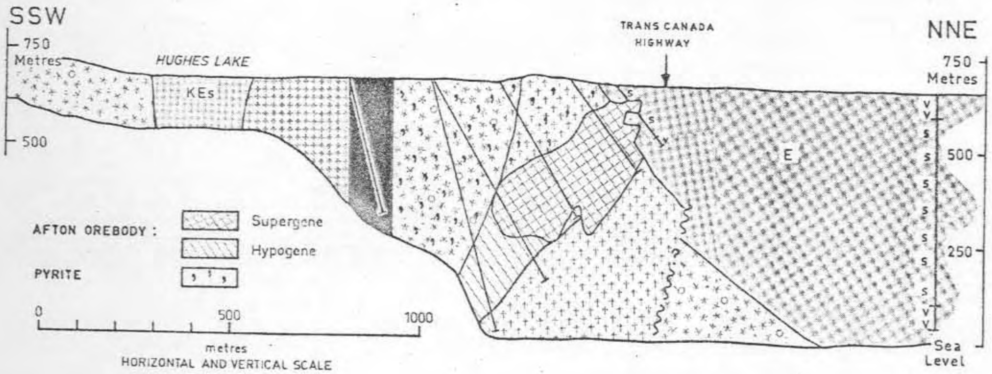
After maps of B.C. Dept. of Mines, 1956 - 1974

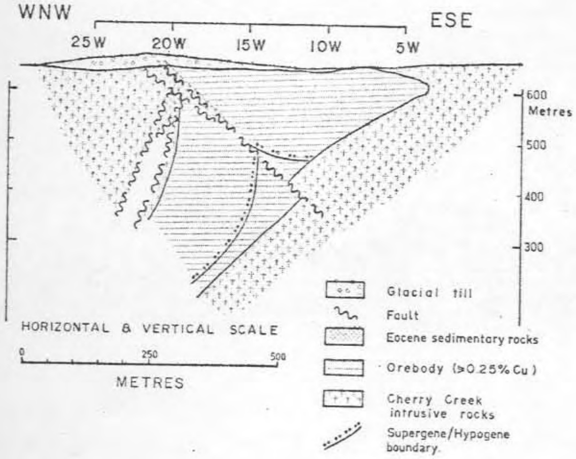
15-JMC-A2


SECTION 18 W
KAMLOOPS 15 KM
TRANS-CANADA HIGHWAY
Es
Ev
ABUNDANT MAGNETITE
S
SHAFT
MAGNET (Fe)
POTHOOK
POTHOOK LAKE
HUGHES LAKE
KEs
25
15
LEGEND
MIDDLE EOCENE & (?) EARLIER
Volcanics (Ev) and sedimentary (KEs & Es) rocks
UPPER TRIASSIC
Iron Mask Pluton: Cherry Creek diorite, diorite porphyry, latite porphyry, and breccias
Sugarloaf porphyritic diorite (S: dikes & sills present)
Picrite basalt
Iron Mask, Pothook diorite & gabbro
Nicola Group: Volcanics, minor sedimentary rocks
Afton orebody (>0.25 % cu)
Cu prospect
Pyrite zone
Outcrop area
Attitude of beds
Drill hole (outlying)
0
500
1000
METRES
Partly after Jones 1957, Northcote 1974

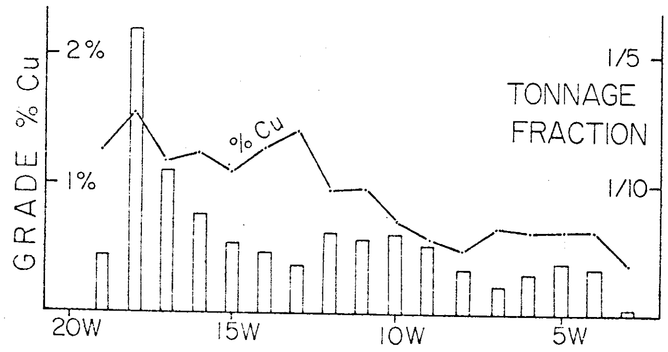


See Legend on Fig 3

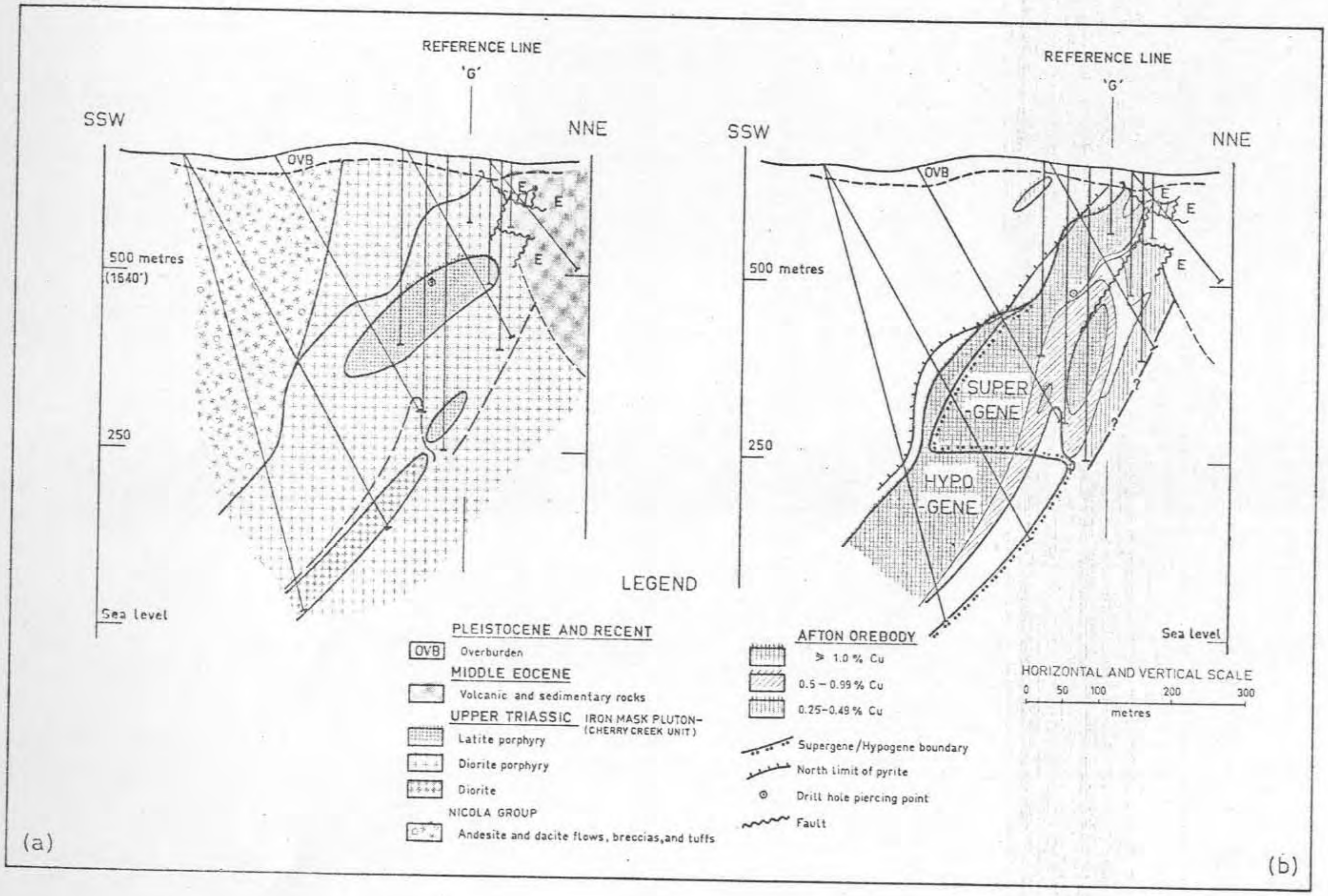
15-JMC-A4


WNW
ESE
25W
20W
15W
10W
5W
600
Metres
500
400
300
HORIZONTAL & VERTICAL SCALE
0
250
500
METRES
Glacial till
Fault
Eocene sedimentary rocks
Orebody (≥0.25% Cu)
Cherry Creek intrusive rocks
Supergene/Hypogene boundary.

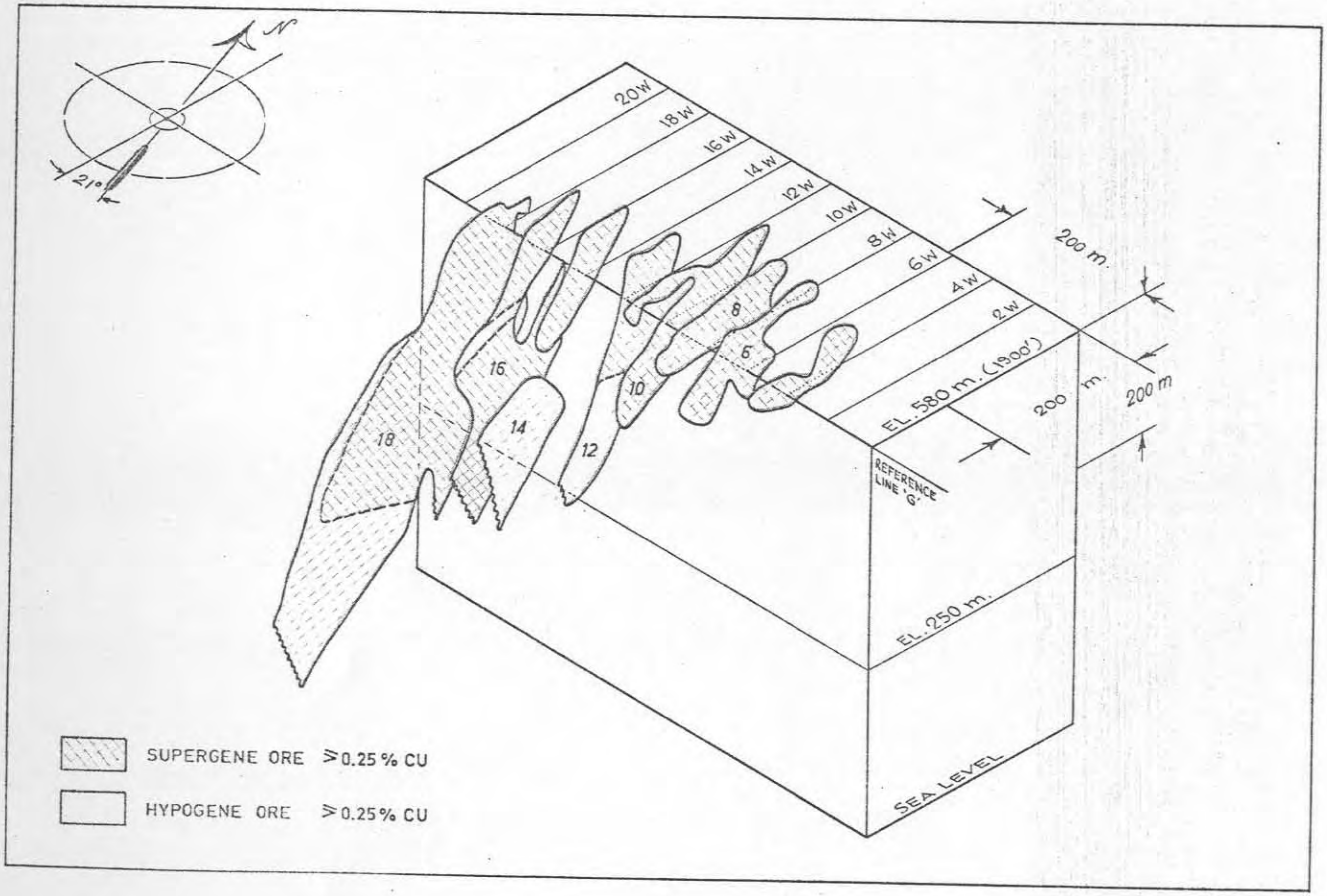
15-JMC-A5

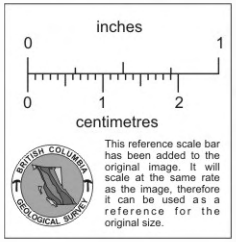


15-JML-A6

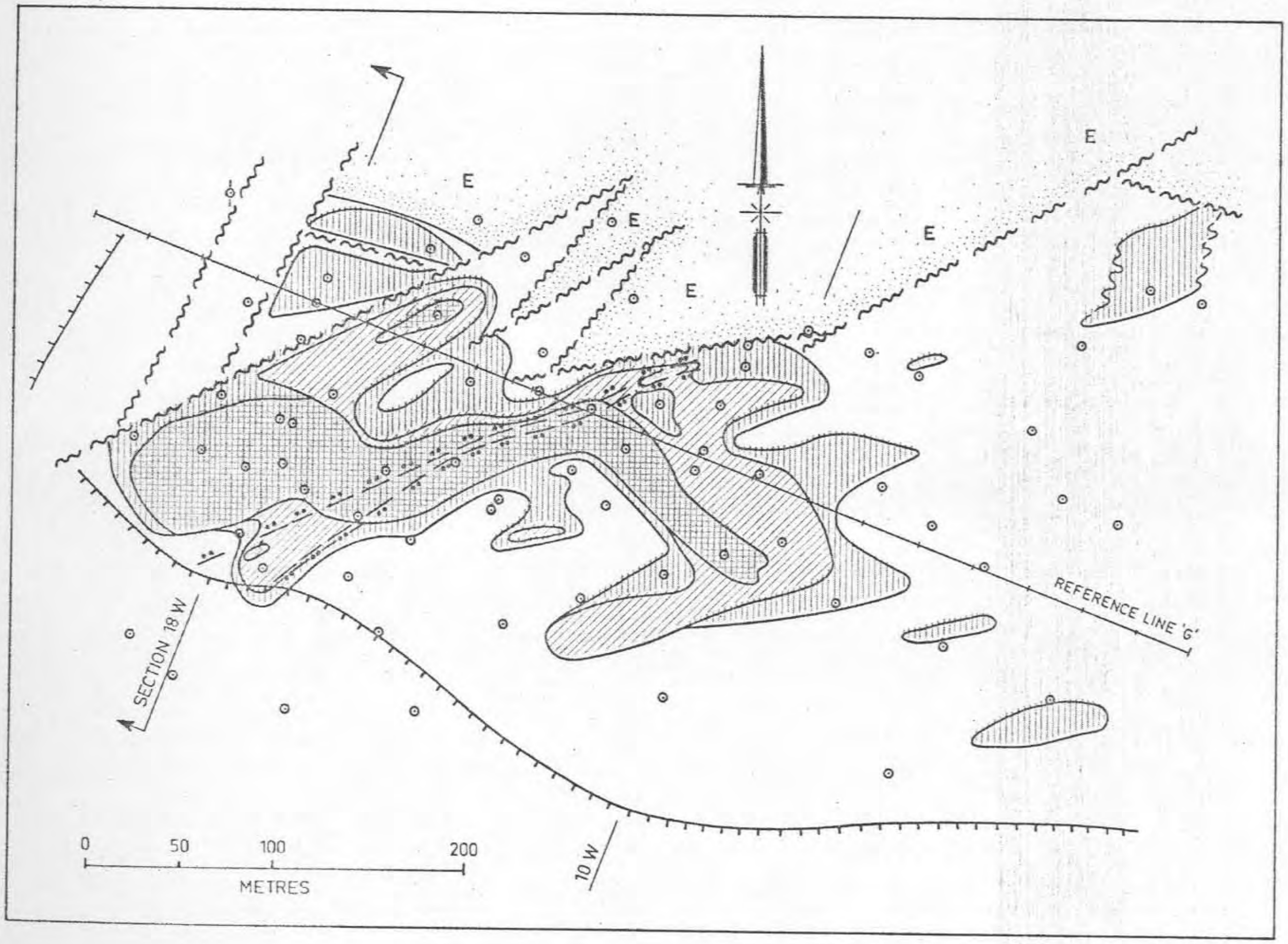

REFERENCE LINE
'G'
SSW
NNE
OVB
E
500 metres
(1640')
250
Sea level
(a)
REFERENCE LINE
'G'
SSW
NNE
OVB
E
500 metres
SUPER
-GENE
HYPO
-GENE
250
Sea level
?
LEGEND
PLEISTOCENE AND RECENT
OVB Overburden
MIDDLE EOCENE
Volcanic and sedimentary rocks
UPPER TRIASSIC IRON MASK PLUTON-(CHERRY CREEK UNIT)
Latite porphyry
Diorite porphyry
Diorite
NICOLA GROUP
Andesite and dacite flows, breccias, and tuffs
AFTON OREBODY
≥ 1.0 % Cu
0.5 – 0.99 % Cu
0.25–0.49 % Cu
Supergene/Hypogene boundary
North limit of pyrite
Drill hole piercing point
Fault
HORIZONTAL AND VERTICAL SCALE
0 50 100 200 300
metres
(b)

15-JMC-A7


N
21°
20W
18W
16W
14W
12W
10W
8W
6W
4W
2W
200 m.
200 m.
200 m
EL. 580 m. (1900')
REFERENCE LINE 'G'
EL. 250 m.
SEA LEVEL
18
16
14
12
10
8
6
SUPERGENE ORE ≥0.25 % CU
HYPOGENE ORE ≥0.25 % CU

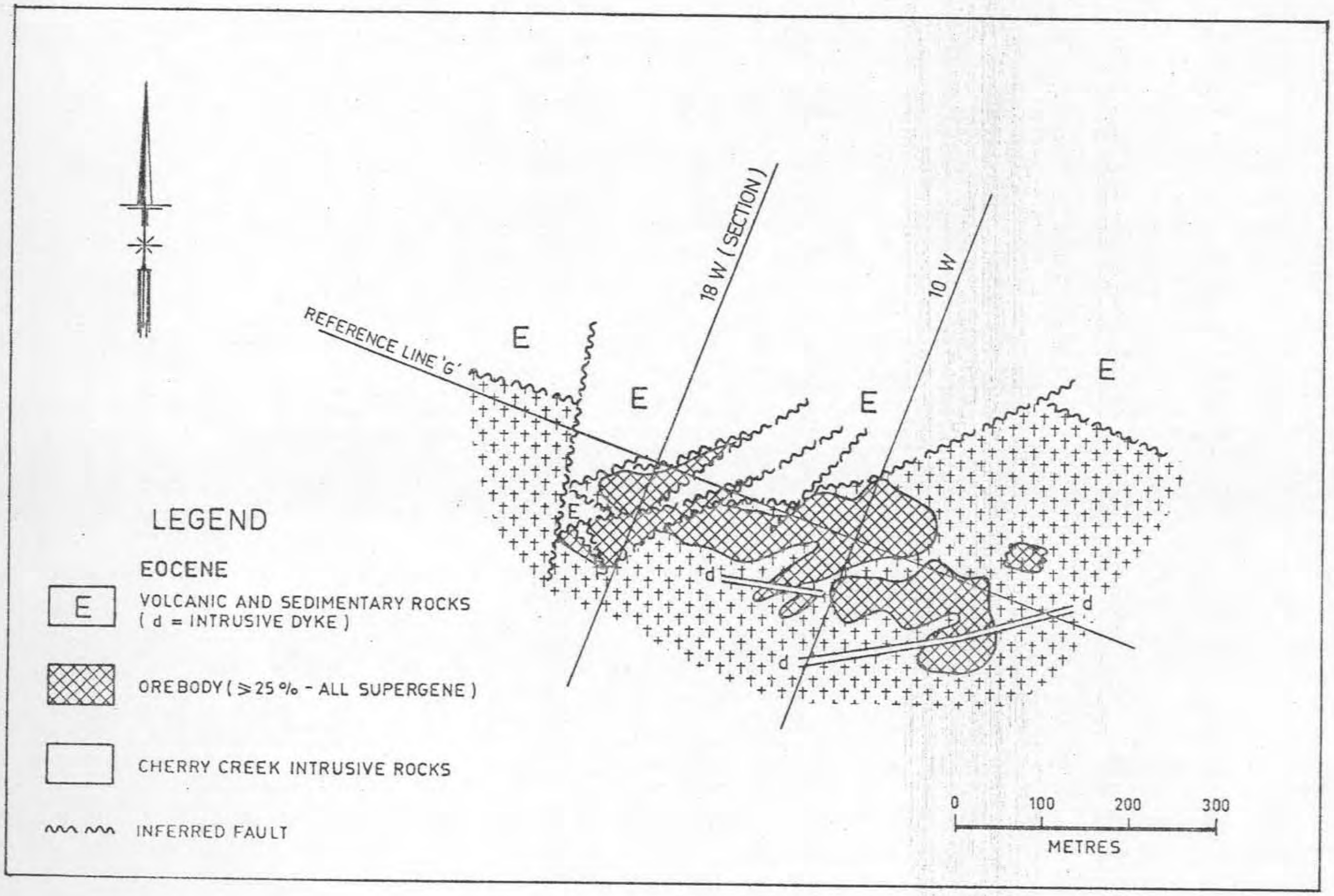

inches
0
1
0
1
2
centimetres

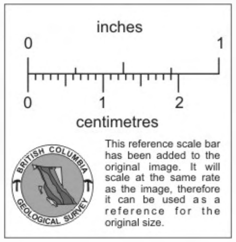
15-JMC-A8



See Legend Fig. 7.

15-JML-A9





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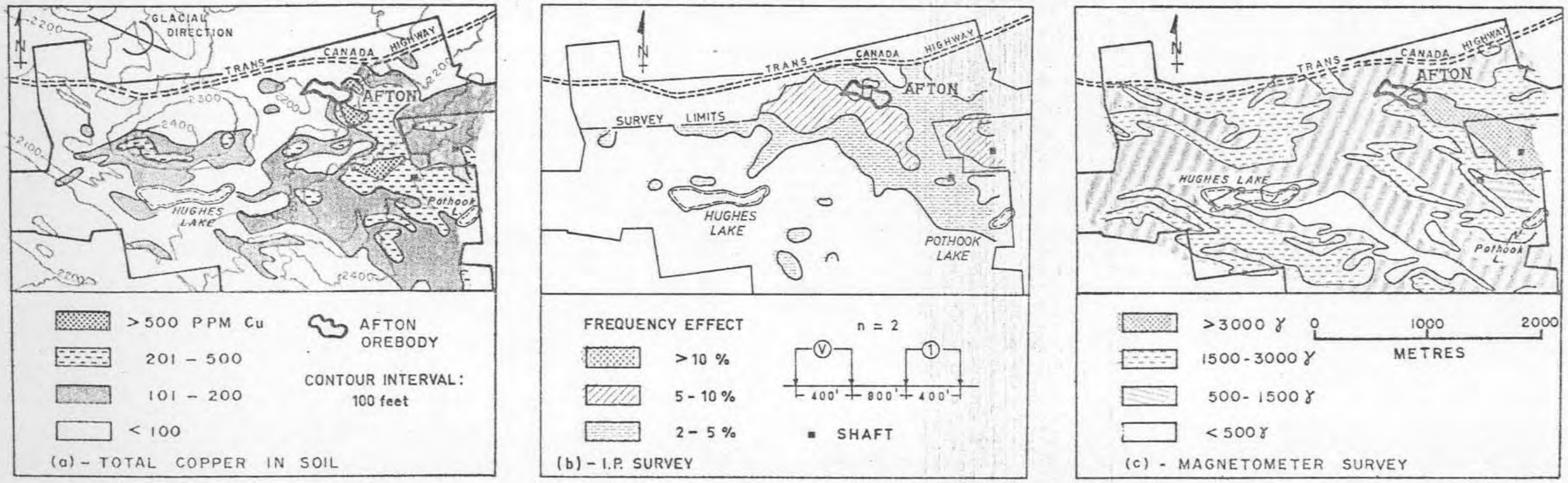
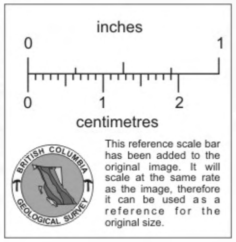
15-JMC-A10



(a) - TOTAL COPPER IN SOIL

(b) - I.P. SURVEY

(c) - MAGNETOMETER SURVEY



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15-JMC-A11