Zeitschrift: Schweizerische mineralogische und petrographische Mitteilungen = Bulletin suisse de minéralogie et pétrographie

Band: 51 (1971)

Heft: 1

Artikel: Reconnaissance mineral exploration in the Yukon Territory, Canada : a case history

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DOI: https://doi.org/10.5169/seals-39815

Reconnaissance Mineral Exploration in the Yukon Territory, Canada

A Case History

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With 14 figures and 2 tables in the text

Abstract

Geochemical stream sediment and soil investigations together with airborne potassium 40 and magnetic surveys in the southeast end of the unglaciated Dawson Range, revealed the presence of distinct metal anomalies. They can be divided into two groups according to their geochemistry, geophysical response and to the geology. One group shows anomalous Cu- and Mo-values, strong geophysical response and occurs exclusively in porphyry stocks. The characteristics of this group are believed to be caused by porphyry ore mineralizations. The other group possesses anomalous Ag, Pb, Zn, and to a lesser extent Sb-values, only limited geophysical response, and occurs in all geological units of the area. Vein-type mineralizations are postulated as the source for these anomalies. Such mesothermal deposits are typical for peripheral zones of porphyry ores.

INTRODUCTION

During the summer of 1970 a geochemical exploration programme, covering some 70 km^2, was carried out by the authors in the Mount Nansen area. The investigated area is situated at the southeast end of the Dawson Range, 150 km northwest of Whitehorse, Yukon Territory, Canada (Fig. 1). Initially, 200 stream sediment samples were collected following a rather detailed pattern in the well-developed drainage systems, and analyzed for various elements. In addition an airborne geophysical survey embracing K 40, isomagnetic, and electromagnetic data collection, was undertaken. These reconnaissance investigations were followed by soil sampling.

The present exploration programme was performed with the hope of

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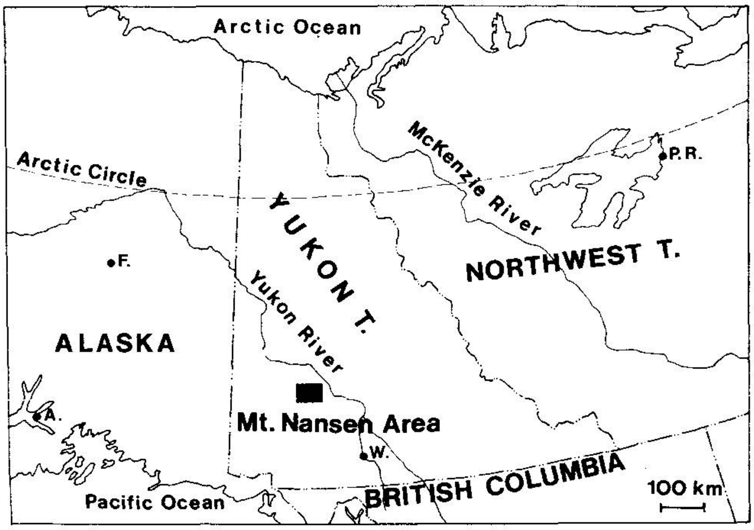

Fig. 1. Location.

finding geochemical anomalies, since the geological setting is favourable for the occurrence of porphyry ore mineralizations and gold-silver veins. Further to the north, at Yukon Revenue Creek and at Casino, two porphyry copper mineralizations have recently been discovered, and several narrow gold-silver veins occur in the southern part of the investigated area. The Mount Nansen vein system to-date has produced 3000 ounces of gold and 85,000 ounces of silver. This ore deposit and the geology of the area are discussed by Saager and Bianconi (1971).

GEOLOGICAL SETTING

As the Mount Nansen area was not glaciated during the last glacial advance, most of the terrain is covered by a thick overburden composed of residual soil and to a lesser extent of alluvial deposits. Due to the northern location of the area the ground is permanently frozen to a depth of approximately 50 m. The geological map given in Fig. 2 is based on Bostock's (1936) and our own observations. The area is part of the Yukon Plateau province, consisting of Precambrian to Palaeozoic metamorphic rocks, folded sedimentary rocks, and volcanics and intrusives which are Mesozoic to Quaternary in age. Some 60 km to the southwest, the Yukon Plateau province borders the Coast Range province which belongs to the Pacific Cordillera (Bostock, 1936).

The oldest geological unit in the area studied is the *Yukon Group*, which is mainly composed of bedded quartz-hornblende gneisses, biotite schists, hornblende gneisses and amphibolites, of Precambrian to Palaeozoic age.

A thick cover of andesitic to basaltic lavas and of andesite-porphyries overlie unconformably the Yukon Group. These rocks belong to the *Mount Nansen Group*, believed to be of Jurassic to early Cretaceous age.

Mesozoic intrusive rocks, comprising porphyritic granites, granodiorites, and diorites, intrude the two older units. They are of late Jurassic to early Eocene age, and can be correlated with the main Cordilleran batholith. K-Ar age determinations, carried out on biotite and hornblende from granodiorite belonging to this unit, yielded ages of 95 m.y. and 99 m.y. (FINDLAY, 1969).

All the above three units are in turn intruded by numerous *quartz-feldspar porphyry* bodies which vary from 30 m to 1500 m in diameter and usually exhibit elongated outlines. They are generally considered an independent unit of Tertiary age. However, the close spatial relationship between these porphyries and the Mesozoic intrusives suggests that the former possibly represent a late phase of the Mesozoic granitic event (SAAGER and BIANCONI, 1971).

A system of northwest striking, high-angle faults offsets all the units, and is partly mineralized by gold-silver veins. A younger, second system of high-angle faults, striking northeast, cuts country rocks and mineralized veins.

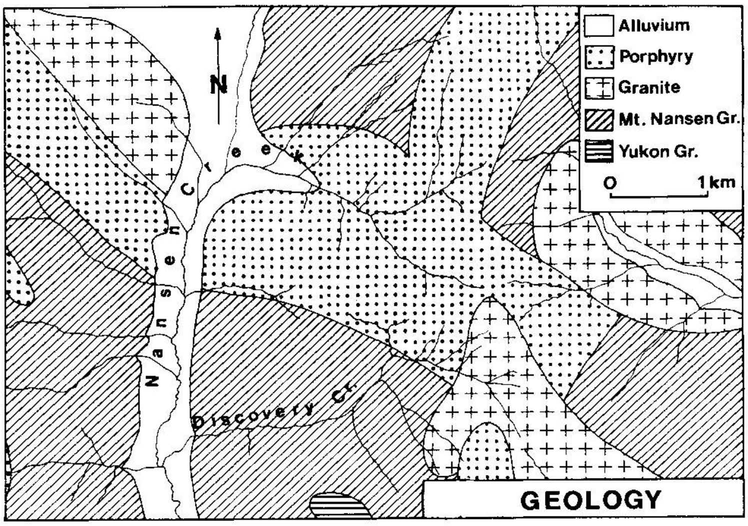

Fig. 2. Geology of Mount Nansen Area.

STREAM SEDIMENT SURVEY

The collection and analysis of stream sediments has proven to be a rapid and efficient method of obtaining reconnaissance data on the mineral potential of geologically unexplored or poorly exposed terrains. *The Mount Nansen area is particularly suited for geochemical exploration, due to the absence of industrial and agricultural contamination and due to the fact that most of the ground is covered by residual soil.*

The transport of ore minerals or metals into a drainage system can be either of a mechanical or a chemical nature. In the first case surface run-off is responsible for the formation of detrital stream sediments. In the second case the metals are generally transported by ground-water, and, according to MENDELSOHN (1961) the metal ions entering the drainage are fixed by one or a combination of the three following processes:

1. Absorption or ion exchange fixation by clay and silt particles.
2. Organic fixation by primitive organisms.
3. Precipitation due to change in pH.

If stream sediment anomalies are found, such reconnaissance surveys are normally followed by detailed geochemical investigations of the residual soil. These geochemical methods are based on the fact that weathered ore deposits are usually characterized by anomalous metal dispersion halos in the soil which overlies and/or surrounds them.

Promising geochemical anomalies delineated in such surveys are further tested by drilling, pitting, trenching, or cross-cutting, depending on the local conditions.

Analyses

The 200 collected samples were dried and the -80 mesh fraction analysed. Cu, Pb, Zn, Mo, Ni, and Ag were determined by the atomic absorption method after hot aqua regia extraction. Sb was determined colorimetrically following fusion with NH_4Cl. The lower limits of detection were 0.2 ppm for Ag, 2 ppm for Pb, and 1 ppm for all other elements. The analytical precision varied in the range of 15 to 25 per cent for the atomic absorption and 10 to 50 per cent for the colorimetric analyses at the 95 per cent level of confidence.

Data Processing

The statistical evaluation of the obtained data follows the graphical method given by LEPELTIER (1969). The theoretical aspect of the technique used is not discussed here, since it has already been described by AHRENS (1957), TENNANT and WHITE (1959), VISTELIUS (1960), HUBAUX (1961), MATHERON (1962), MONJALLON (1963), SHAW (1964) and MIESH (1967).

Since the values of the analyses tend to be lognormally distributed they were plotted on arithmetic-logarithmic graphpaper (Fig. 3). The fit of the obtained distributions with an *ideal* lognormal distribution was checked graphically by plotting the cumulative frequency curves of the distributions on logarithmic-probability paper (Fig. 4). On logarithmic-probability paper the cumulative frequency curve of an ideal lognormal distribution has the form of a straight line. This graphical test avoids the time consuming *Pearson's test*. At the same time the cumulative frequency curves also allow one to find graphically the *background value "b"* and the *threshold value "t"* of the particular element studied (Table 1). The "b" value is found at the intersection

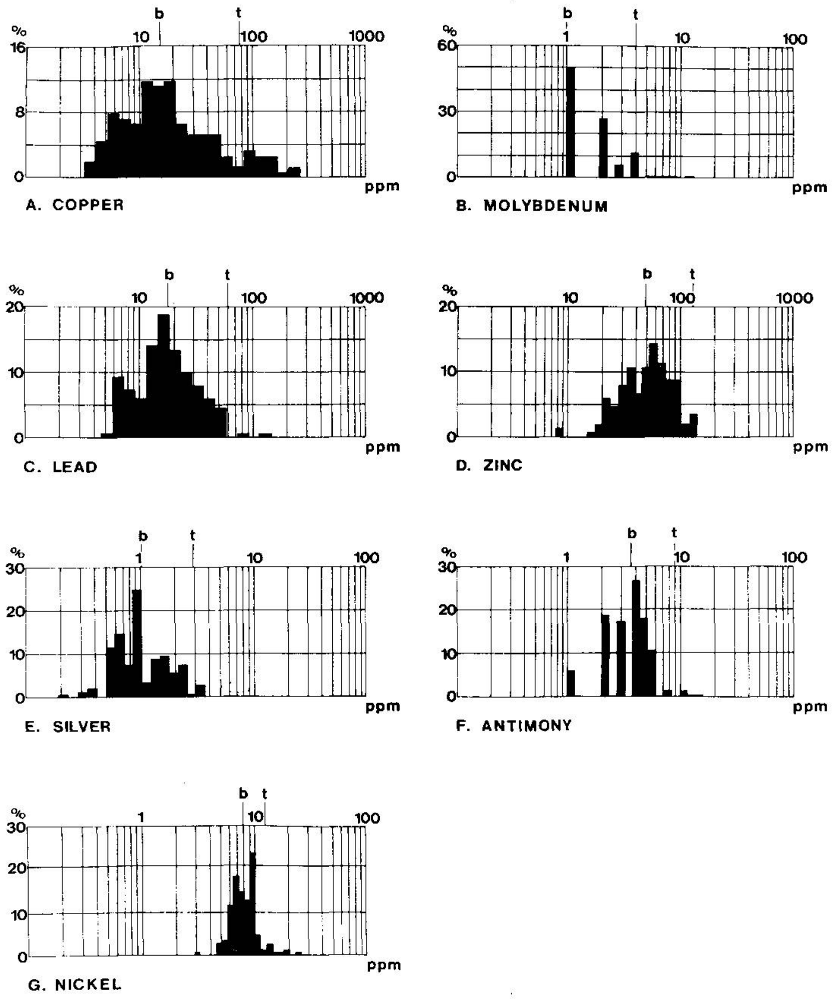

Fig. 3. Relative frequency distribution of the seven elements.

of the cumulative frequency curve with the 50 per cent ordinate. In the case of a perfect lognormal distribution, "b" corresponds with the mean, mode and geometric mean. The threshold value "t" is found at the intersection of the cumulative frequency curve with the 2.5 per cent ordinate, since all values which deviate positively more than two standard deviations from "b" are conventionally considered as distinctly *anomalous*. Where the cumulative frequency line exhibits a break to a flatter or a steeper slope, caused by an excess of high values (Fig. 4, Ni and Cu) or by an excess of low values, respectively (Fig. 4, Zn), the main branch of the line is used to obtain "b" and "t". On the histograms in Figure 3 an excess of high values is reflected in the positive skewness of the distribution, and an excess of low values in the negative skewness. The cumulative frequency curve was not constructed for the Mo-values since the histogram already clearly indicated a non-lognormal distribution. The "b" and "t" values given in Table 1 for Mo were thus estimated.

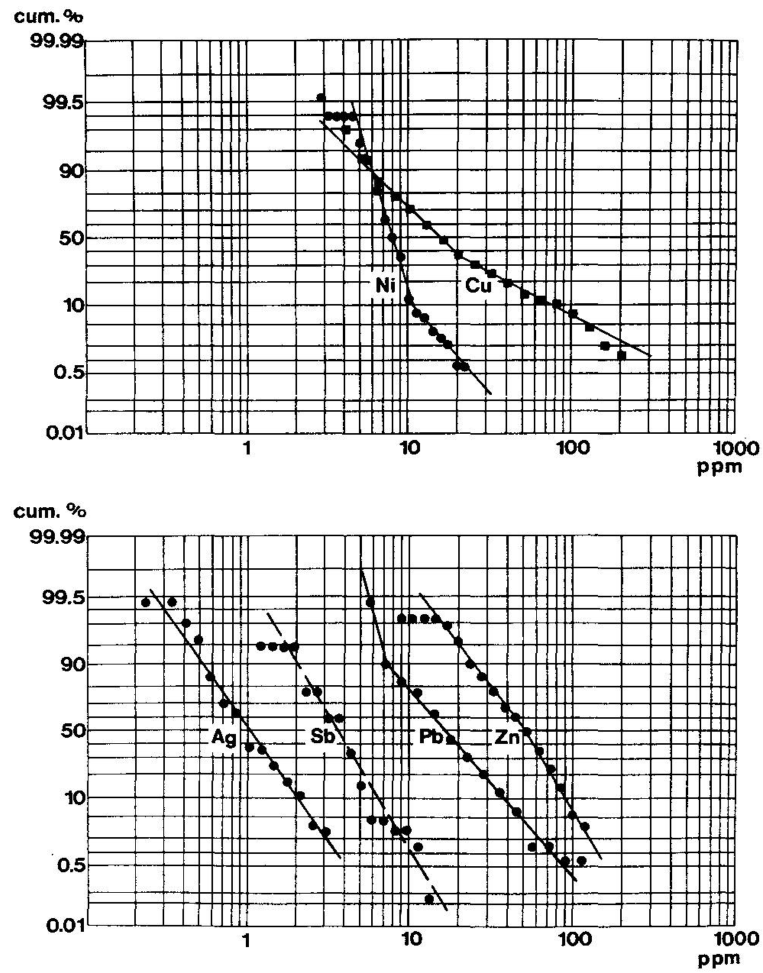

Fig. 4. Cumulative frequency distribution of Ni, Cu, Ag, Sb, Pb, Zn.

Table 1. *Background and threshold values in ppm*

	Cu	Mo	Pb	Zn	Ag	Sb	Ni
background "b"	16	1	17	48	1.0	3.7	8
threshold "t"	78	4	60	128	3.0	9.0	12

Discussion of Results

The geochemical results of 108 samples are given in Figures 5–11. They embrace, however, only the northern half of the area investigated since anomalous values occur only in this portion. Thus, most of the samples which possess values below background are situated outside the area given on the distribution maps (Figs. 5–11).

1. Nickel (Fig. 5)

Nickel shows a weak affinity with Mo as well as with Pb and Zn. A strong anomalous zone, "d"–"e" follows the northeast striking watershed between Victoria Creek and Nansen Creek. A minor anomaly occurs in "c".

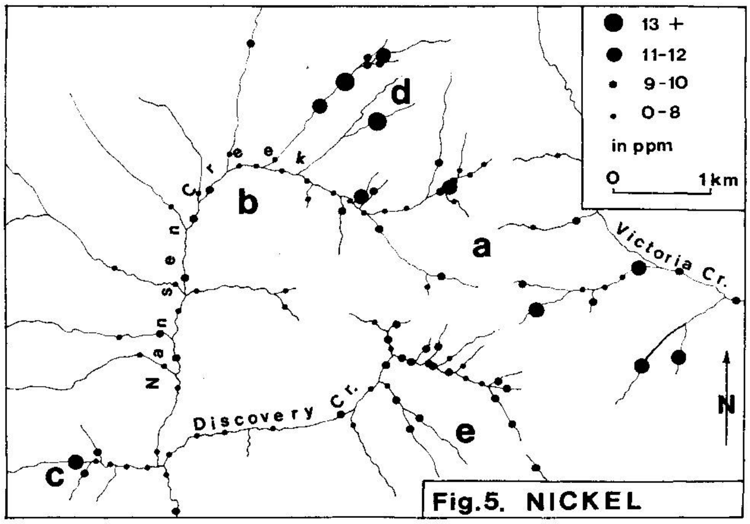

Fig.5. NICKEL

2. Copper (Fig. 6)

Strongly anomalous Cu-values are found in a large section of Nansen Creek, in the headwaters of Discovery Creek, and two highly anomalous values are found in the tributaries of Victoria Creek. The distribution pattern of the anomalous values reveals a distinct Cu-anomaly in the area "a". Of interest is the discrepancy of the dispersion trains in Nansen Creek and Discovery Creek. In Nansen Creek anomalous values are found over a distance of 4.5 km, and the conspicuous gradual dispersion is possibly caused by the presence of another Cu-anomaly in area "b". In Discovery Creek the values show an abrupt decrease close to the anomalous area "a" and no downstream dispersion. This discrepancy could be explained by the fact that, on north sloping drainage areas mechanical transport of the metals prevails, whereas on south sloping areas chemical transport is predominant. This is in accordance with the

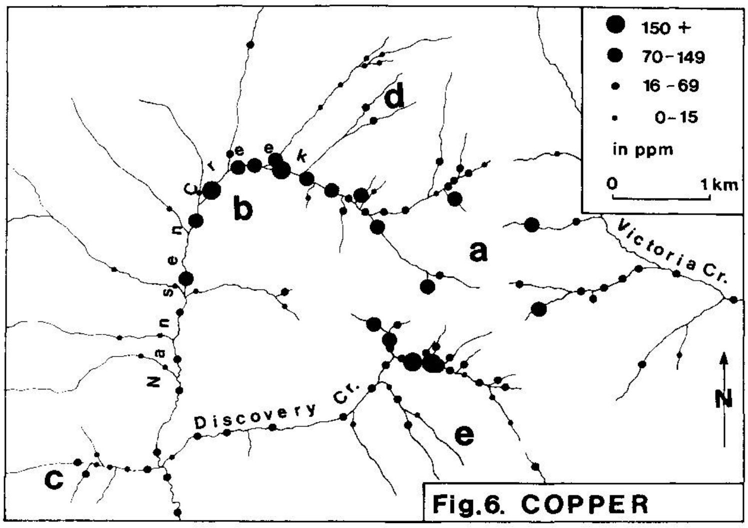

Fig.6. COPPER

findings of Archer and Main (1970), who explain the same behaviour at Casino by the fact that in north facing permanently frozen valleys the water has a pH from 6.5 to 7.0 and is largely derived from surface run-offs, whereas in south facing valleys the pH ranges from 2.6 to 5.0 due to a substantial introduction of groundwater through windows in the permafrost. As a consequence Archer and Main (1970) state: "Permafrost does not appear to have an appreciable effect in the soil response for the metals used. However, it does have the effect of directing copper-rich spring water to unfrozen windows on south slope drainage."

3. *Molybdenum* (Fig. 7)

The areal distribution pattern of the Mo-values coincides to a great extent with that of Cu, with the exception of an additional anomalous area at "c". In area "a", however, it seems that north and east facing slopes carry sediments with higher anormalous Mo-values than Cu-values. This can be explained either by the fact that the primary Cu- and Mo-sources do not overlap, or by the presence of acid waters in south facing slopes which depress Mo-contents (Archer and Main, 1970).

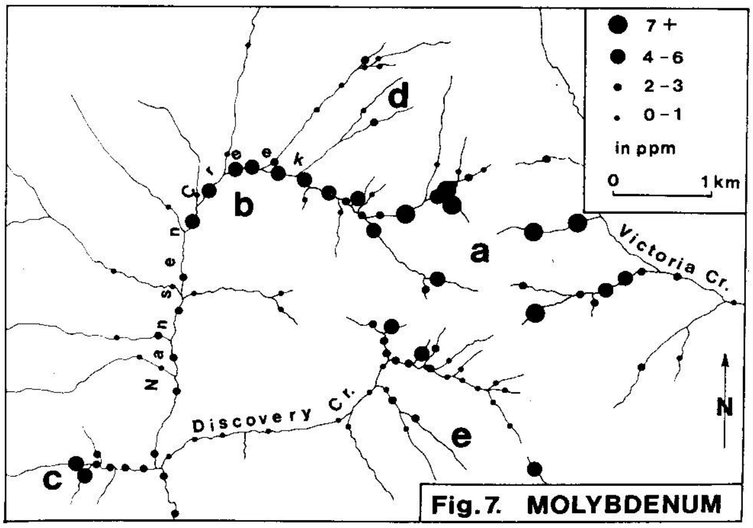

Fig. 7. MOLYBDENUM

4. *Lead and Zinc* (Figs. 8 and 9)

The areal distribution of the two elements are almost identical with the exception of a few anomalous Pb-values in some of the tributaries of Victoria Creek. Three distinct anomalous areas, "c", "d", and "e" can be established, all of which show short dispersion trains of less than 1 km. The somewhat erratic occurrence of Zn in Nansen Creek can possibly be related to its high geochemical mobility which in many cases makes Zn a rather inaccurate indicator element.

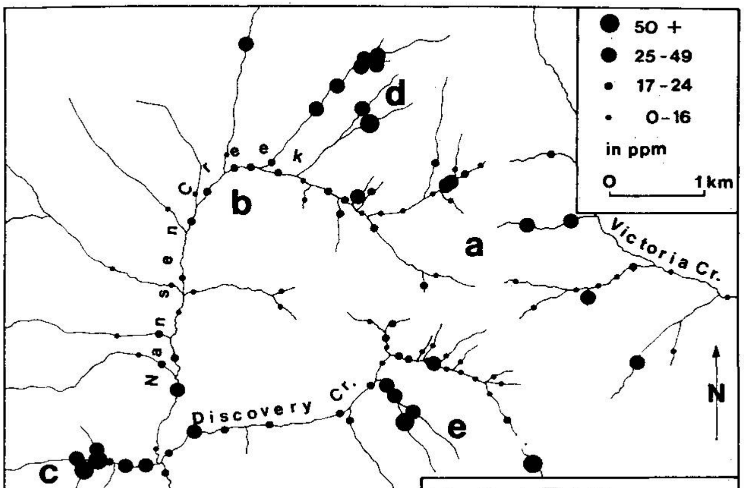

Fig.8. LEAD

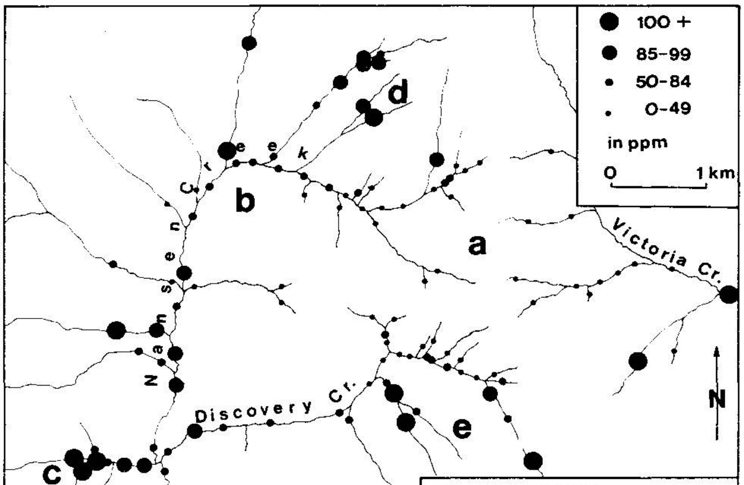

Fig.9. ZINC

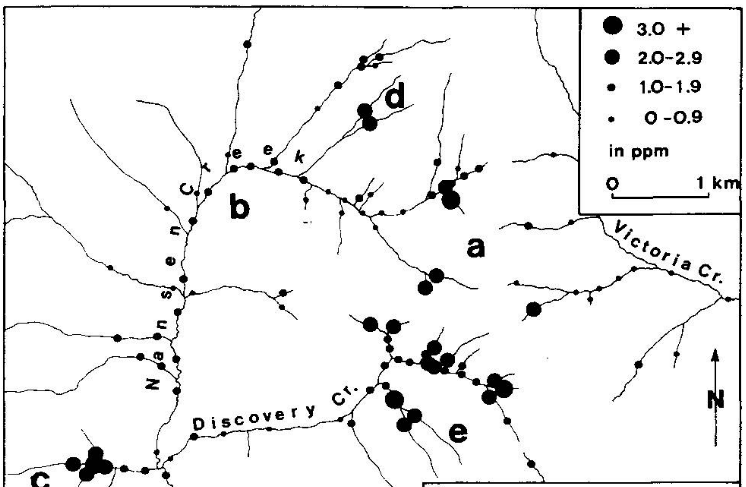

Fig.10. SILVER

5. *Silver* (Fig. 10)

This element shows the most complex areal distribution pattern of all the elements studied. Anomalies "c", "d", and "e" coincide with those of Pb and Zn, and in addition, the anomalous area "a" was also found for Cu and Mo. The dispersion trains are extremely short, which is typical for this element, due to its geochemical behaviour and to its relatively high specific gravity.

6. *Antimony* (Fig. 11)

Only two distinct anomalies were detected, one in "a" and one in "c".

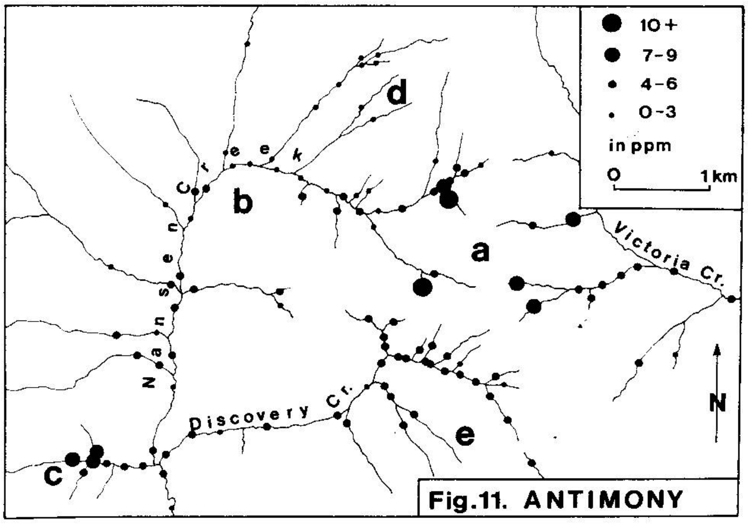

Fig.11. ANTIMONY

GEOPHYSICAL INVESTIGATIONS

Airborne geophysical data, comprising potassium 40 and magnetic surveys, are given in Figures 12 and 13. The magnetic data were obtained from aeromagnetic maps published by the Geological Survey of Canada.

1. **Potassium 40** (Fig. 12)

The area was flown in a N-S direction, with flight lines spaced at approximately 250 m, the altitude being 200 m above ground level, where terrain permitted. In this survey the γ-radiation of the isotope K 40 is measured in counts per second by an airborne scintillometer at 1.3 to 1.6 MeV. The K 40 readings are in principle related to the availability of potassium in the rocks of the measured area. High K-contents in rocks can be *primary* features as in certain acid intrusives, or *secondary* features caused by metasomatic or hydrothermal processes. K 40 readings must always be interpreted with caution,

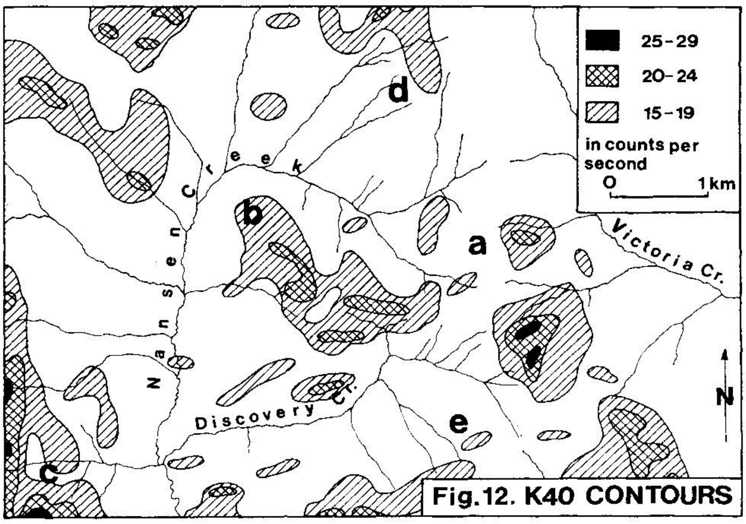

Fig. 12. K40 CONTOURS

since they are affected by the thickness of the overburden and also by the flight altitude above ground level. Therefore outcrops yield relatively high readings as on the watershed between Victoria Creek and Nansen Creek and on the prominent ridge west of Nansen Creek (Fig. 12). However, it is interesting to note that the two highest K 40 readings obtained are closely situated to the two geochemical anomalies "c" and "a". A vague relation between granites, porphyries, and above background areas is indicated. No data are available for the granite of Victoria Creek.

2. **Aeromagnetic Survey** (Fig. 13)

The area was flown in a N-S direction, with flight lines spaced at approximately 1 km, the flight altitude being 300 m above ground level, where terrain permitted (Aeromagnetic Series, Map 3312 G, Victoria Mountain, Geological

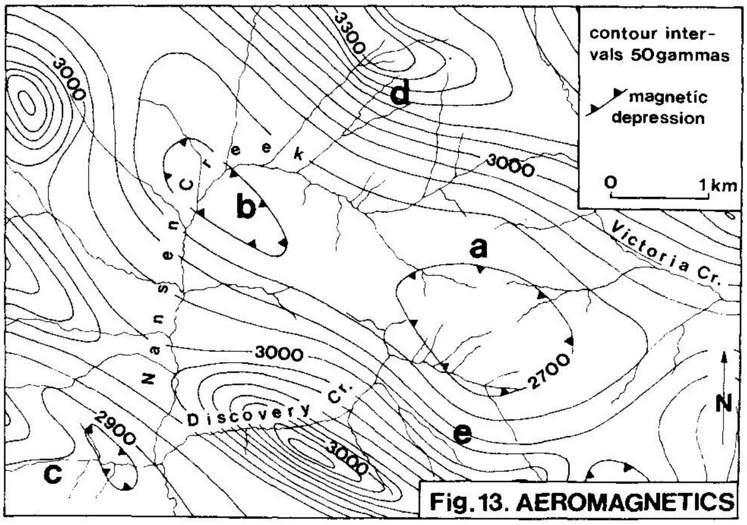

Fig. 13. AEROMAGNETICS

Survey of Canada, 1966). The contour map shows three relatively pronounced magnetic depressions, which more or less coincide with the geochemical anomalous areas "a", "b", and "c". These magnetic depressions can result from altitude or overburden effects, or can be caused by a relative deficiency of magnetic minerals. Such a deficiency can be of primary or secondary nature, in the latter case for instance, as a result of supergenic and/or hypogenic alteration of magnetic minerals. The areas of higher magnetism in Figure 13 coincide fairly closely with the terrain underlain by volcanic rocks of the Mount Nansen Group. Thin and polished sections made from these rocks, especially the andesite-porphyries, revealed a rather high magnetite content (SAAGER and BIANCONI, 1971).

SOIL SAMPLE SURVEY

Two soil profiles have been sampled to check the anomalous area "a", which was delineated through the geochemical stream sampling and the geophysical surveys. The two parallel profiles A-A′ and B-B′ are northeast striking, 1200 m apart, and 2350 m, respectively 2100 m long (Fig. 14). The samples were mainly obtained from the B- and C-horizons at a depth of 15 to 50 cm. The *A-horizon* is the organic layer consisting of humus and decomposed vegetal matter and some clay. The *B-horizon* consists of the residual soil below the humus layer and is composed of brownish sand and some clay. The *C-horizon* comprises rock fragments mixed with usually washed residual soil. According to ARCHER and MAIN (1970) the variation of Cu and Mo-contents in the B- and C-horizons is insignificant.

The samples were analysed for Cu and Mo, using the same analytical procedure as for the stream sediment samples.

Discussion of Results (Fig. 14)

The two profiles clearly enhance the findings obtained from the stream sediment survey. Profile A-A′ shows three narrow Cu-anomalies and one wide Mo-anomaly. It is interesting to note that the two northwestern Cu-anomalies coincide with the Mo-anomaly, whereas the southeastern more pronounced Cu-anomaly is accompanied by below threshold Mo-values. Profile B-B′ shows one wide Cu- and Mo-anomaly which can probably be correlated with the broad Mo-anomaly and the two narrow Cu-anomalies of profile A-A′.

The threshold values for Mo and Cu used in the soil sample profiles are those generally used in the unglaciated Dawson Range.

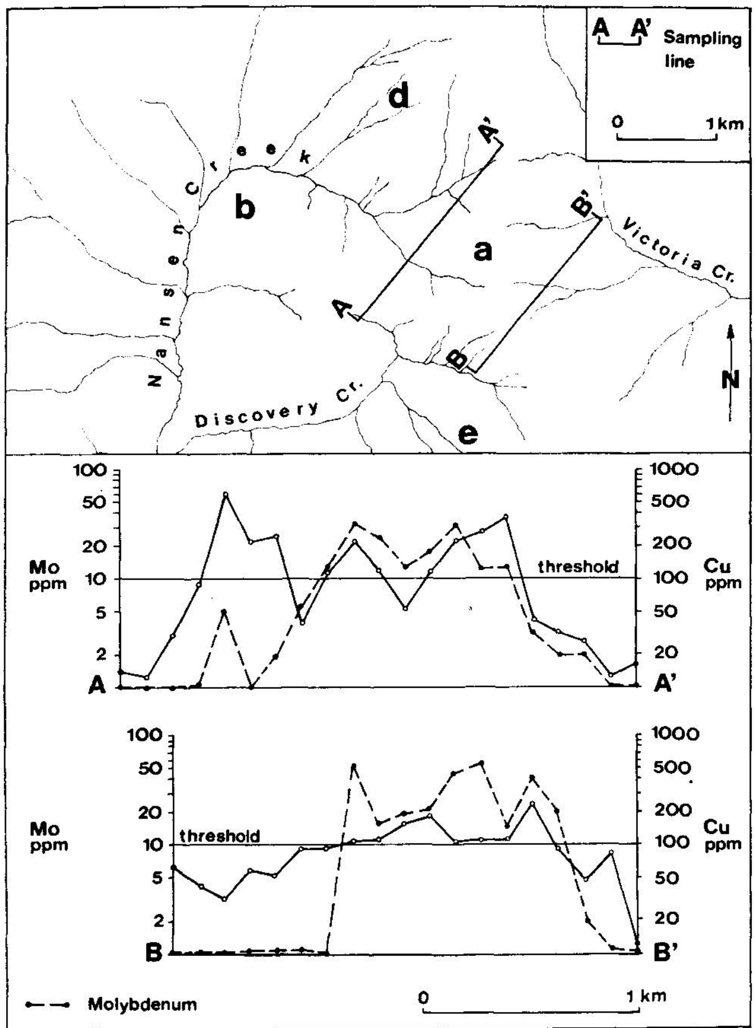

Fig. 14. SOIL SAMPLES PROFILES

CONCLUSIONS

In order to compare the five detected anomalous areas with each other and also to correlate them with the geological, geochemical, geophysical variables, the data have been summarized in Table 2.

The comparison of the five anomalous areas reveals the presence of two distinct groups, I and II.

Group I (anomalous areas "a" and "b"), is characterized by high Cu- and Mo- and low but distinct Ag- and Sb-values, and it is related with strong magnetic depressions and K 40 peaks. Geologically it occurs exclusively in the porphyries.

Group II (anomalous areas "c", "d", "e") shows high Pb, Zn, Ag and erratic Mo, Sb and Ni-values. Cu is practically absent. With the exception of

Table 2. *Grouping of the five anomalous areas*

Group	I			II	
Anomalous area	a	b	c	d	e
Cu	+++	+++	—	—	—
Mo	+++	+++	++	—	—
Pb	+	—	+++	+++	+++
Zn	—	—	+++	+++	++
Ag	++	—	+++	++	+++
Sb	++	—	+++	—	—
Ni	+	—	+	++	—
K 40	++	+	++	—	—
Magnetic Depression	+++	+++	++	—	—
Geology	Porph.	Porph.	Nansen volc.	Nansen/ Porph.	Gran./Porph./ Nansen volc.

+ = weak; ++ = strong; +++ = very strong

anomalous area "c", no distinct geophysical response has been observed. Geologically, Group II seems not to be bound to the porphyries but occurs in all the lithological units of the area investigated.

This conspicuous grouping can be explained as follows: anomalies "a" and "b" (Group I) are caused by porphyry ore mineralizations, which explains the characteristics of the group. The distinct features of a porphyry ore deposit are summarized by Lowell and Guilbert (1970) as: "a copper and/or molybdenum sulfide deposit consisting of disseminated and stockwork veinlet sulfide mineralization emplaced in various host rocks that have been altered by hydrothermal solutions into roughly concentric patterns. The deposit is generally large, on the scale of several thousands of feet, although smaller occurrences are recognized. The relatively homogeneous and commonly roughly equidimensional deposit is associated with a complex, passively emplaced stock of intermediate composition including porphyry units. It contains significant amounts of pyrite, chalcopyrite, molybdenite, quartz, and sericite associated with other alteration, gangue, and ore minerals and metals including minor lead, zinc, gold, and silver. Mineralization and alteration suggest a late magmatic-mesothermal temperature range. The deposit is generally associated with breccia pipes, usually with a large crackle brecciation zone, and is surrounded by peripheral mineral deposits suggestive of lower temperature mineralization. The grade of primary mineralization in typical porphyry copper deposits ranges up to 0.8 per cent Cu and 0.02 per cent Mo, and porphyry deposits in which molybdenite is the chief economic mineral have grades ranging up to 0.6 per cent Mo and 0.05 per cent Cu."

The above definition gives a plausible and obvious explanation for the high correlation of Cu- and Mo-values, for the dimension of the anomalous areas delineated by the stream sediment survey, for the magnitude of the values found in the two soil profiles, and for the exclusive occurrence of the anomalies in porphyry terrain. The K 40 peaks might reflect, in order of decreasing importance, the *potassic* (quartz-K-feldspar-biotite-sericite), *phyllic* (quartz-sericite-pyrite), *argillic* (quartz-kaolin-montmorillonite), and *propylitic* (epidote-calcite-chlorite) alteration zones, which are typical for porphyry ore mineralizations. The magnetic depressions might be caused by a near-surface supergenic alteration which in many cases is responsible for the formation of an enriched oxidation and cementation zone. Recent genetical models for the formation of ore deposits of the porphyry ore type are given by BURNHAM (1967), FOURNIER (1968), NIELSEN (1968), and WHITE (1968).

The elemental distributions in anomalies "c", "d", and "e" (Group II) suggest that they are caused by lead-silver vein deposits of a type similar to the Mount Nansen ore body further to the south. In accordance with the definition of porphyry ores given by LOWELL and GUILBERT (1970) these veins are probably peripheral ore deposits genetically related to the porphyry mineralizations. The genesis and the mode of emplacement of such peripheral narrow lead-silver veins in the area have been described by SAAGER and BIANCONI (1971). Since these vein mineralizations are to a large extent controlled by tectonic structures, the anomalies "c", "d", and "e" do not show such a distinct limitation to porphyries as anomalies "a" and "b". Since the size of such narrow vein deposits can generally be considered as small, they usually show no response in airborne geophysical surveys. The distinct geophysical anomaly found in area "c" would thus indicate a relatively large vein mineralization. This is also underlined by its somewhat odd elemental configuration with unexpected high Mo-, Sb-, and Ni-values.

The present geochemical and geophysical reconnaissance exploration revealed the occurrence of two possible copper-molybdenum mineralizations as well as a number of possibly genetically related, peripheral lead-silver mineralizations. This indicates that these methods are rapid and powerful exploration tools, which can be successfully used in conditions similar to those encountered in the Mount Nansen area.

Further study by means of multivariate regression analysis and factor analysis of the geochemical data is planned to investigate the two distinct groups of anomalies described in the present paper.

Acknowledgments

The authors wish to express their sincere thanks to Gesellschaft für Metallwerte, Zürich, for permission to publish the results of this investigation.

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