KEEVIL, Jr., Norman Bell, 1938-
EXPLORATION AT THE CRAIGMONT MINE, BRITISH COLUMBIA.

University of California, Berkeley, Ph.D., 1965
Engineering, mining

Exploration at the Craigmont Mine, British Columbia

By

Norman Bell Keevil, Jr.

B.A.Sc. (University of Toronto) 1959
M.S. (University of California) 1961

DISSERTATION

Submitted in partial satisfaction of the requirements for the degree of

DOCTOR OF PHILOSOPHY

in

Mineral Technology

in the

GRADUATE DIVISION

of the

UNIVERSITY OF CALIFORNIA, BERKELEY

Approved: ....
....
....

Committee in Charge

Degree conferred..
Date

ABSTRACT

Craigmont's chalcopyrite ore occurs primarily in iron oxide-calcium silicate skarn-altered Triassic limestone near a Jurassic (?) quartz diorite contact. Minor amounts of ore have been found in relatively unaltered greywacke mineralized with pyrite and chalcopyrite. For two miles to the west of the orebody the contact is capped by Tertiary (?) volcanics, and everywhere in the area rock exposures are rare because of extensive cover by glacial debris.

Discovery drilling was due to a magnetometer anomaly with some geochemical correlation. No ore has been found subsequently other than extensions of the original discovery and it appears, because of the glacial cover, that any new discoveries will also be based upon geophysics.

The writer studied applicability of many methods to exploration at Craigmont, and selected several as technically feasible means of locating ore. These are gravity, induced polarization (IP), geochemistry, and, of course, magnetics.

Selection of an optimum program of exploration depends upon economics. The prime factors are estimates of detectability, probabilities of occurrence, present value of an orebody if it occurs, and costs of the program. These may be integrated into an "expected monetary value" (EMV) for the program which, if positive, indicates that its operation may be warranted.

In general, the favored of several alternative possibilities will be the one with highest expected monetary value.

At Craigmont, the favored basic exploration program at the present time appears to be complete coverage by IP. This provides optimum chance of success for expected targets in the various geological environments on the property. Any anomalous conditions resulting from such a survey should be interpreted in view of then-current knowledge of ore controls and other information such as local geologic mapping. An EMV analysis will indicate whether further exploration is warranted and, if so, will assist in determining its nature.

Two targets have been selected already for further exploration. Interpretation of a magnetometer survey carried out northwest of the known orebody indicated two possible orebodies. Estimates of the probability of occurrence of ore, its potential value if there, and the expected results of further geophysical work suggest that a drill program should be devised to test each.

ACKNOWLEDGMENTS

The writer would like to express his appreciation to Messrs. J. D. Little, R. G. Duthie, E. P. Chapman Jr., and C. C. Rennie of the Craigmont Mines group for their interest, advice and support of this research, and to members of the examining committee and other faculty of the University of California who contributed in various ways.

INTRODUCTION

This thesis is concerned with analysis of the applicability and limitations of various exploration methods at and near the Craigmont mine, and with the subsequent design of an exploration program based upon the best technological, economic, and statistical information available.

The Craigmont mine, in south-central British Columbia, was discovered in 1957 and placed in production in 1961 at a milling rate of 5,000 tons of copper ore per day. The writer spent parts of 1962 and 1963 at the mine reviewing geologic information and assessing the feasibility of possible exploration methods for use on unexplored portions of the property. In this thesis, "the property" refers to mining claims held by Craigmont Mines Limited and several associated companies along the south contact of the Guichon Batholith. The conclusions apply to these specific properties, but the exploration methods discussed are applicable elsewhere as well.

Most of the ore at Craigmont occurs in skarn-altered Triassic limestone near the Guichon batholith. Some ore occurs as disseminated chalcopyrite-pyrite mineralization in greywacke of the same age, and some accumulations of disseminated chalcopyrite and/or bornite occur within the batholith.

Exploration in the area is hampered by extensive glacial cover, at Craigmont often exceeding 100' in depth. With only a few percent of the surface available for geological examination, exploration must be based heavily on use and interpretation of geophysical methods. The writer will discuss the applicability of various methods, either upon theoretical or experimental grounds, and will select a group which appear to have a significant chance of pointing to the types of ore expected on the property.

Then, following discussion of decision-making procedures after Savage (1954) and Schlaiffer (1959), the advisability of using the various exploration methods will be discussed in view of the economic potential of the property.

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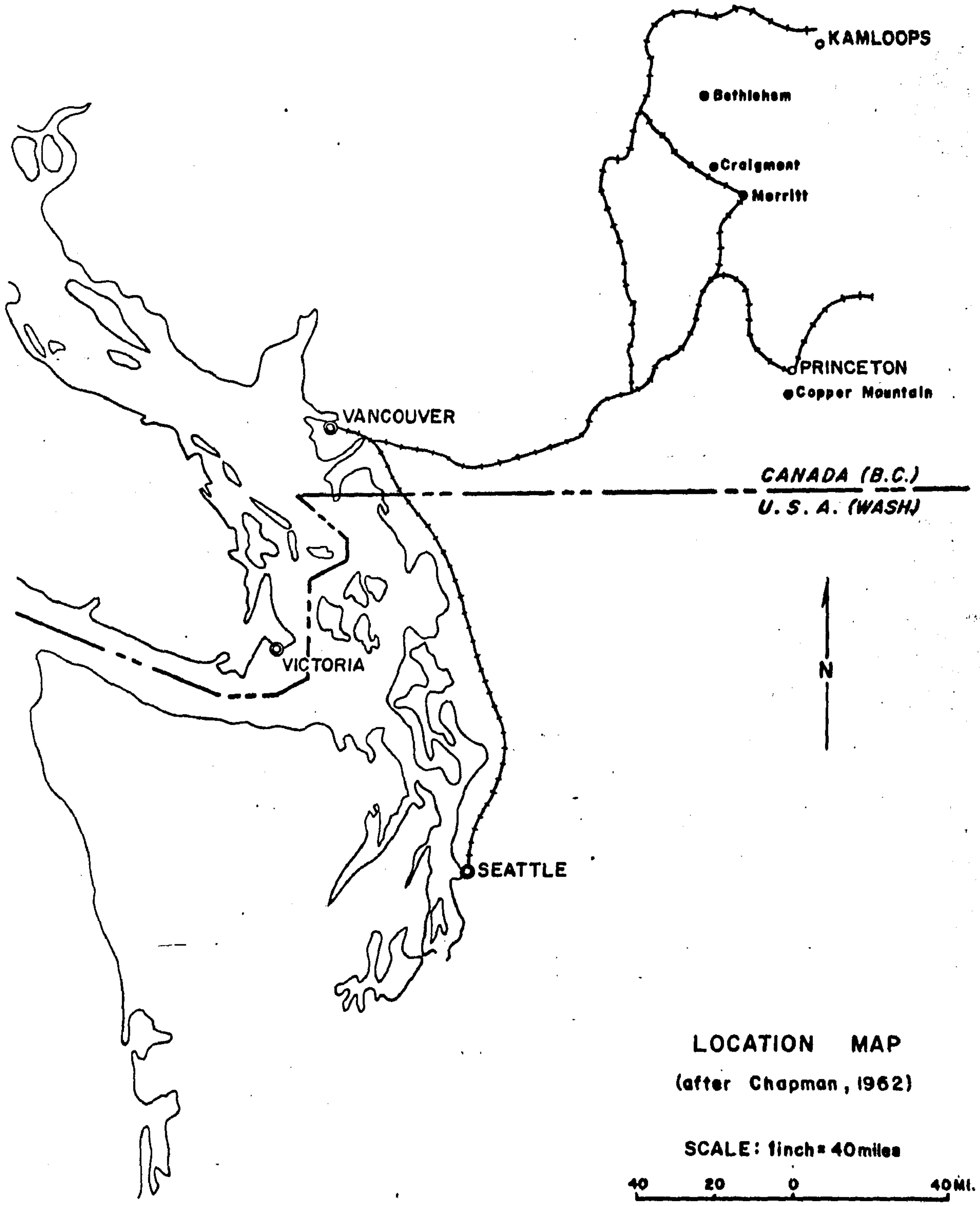
A. CRAIGMONT

LOCATION

The Craigmont mine is 110 miles northeast of Vancouver, B.C., and 10 miles northwest of the town of Merritt (figure 1).

Figure 2 shows the physiographic division of the Canadian Cordillera made by Bostock, Mulligan and Douglas (1957). Craigmont is near the south end of the Interior Plateau Division, characterized by "an old, undulating, dissected, upland surface that rises gradually southward from about 3,500' in the north to near 6,000' at the (Canadian-U.S.) Boundary". Many parts of this plateau, including the Craigmont area, are semi-arid. Thus, although British Columbia is often thought of as a land of high mountains and dense forest, Craigmont lies near the top of a rather gentle hill overlooking a dry sagebrush valley. Local relief ranges from 1,850' above sea level at valley bottom to 5,600' at the peak of Promontory Hill. The presently known orebodies occur from 2,400' to 4,000'.

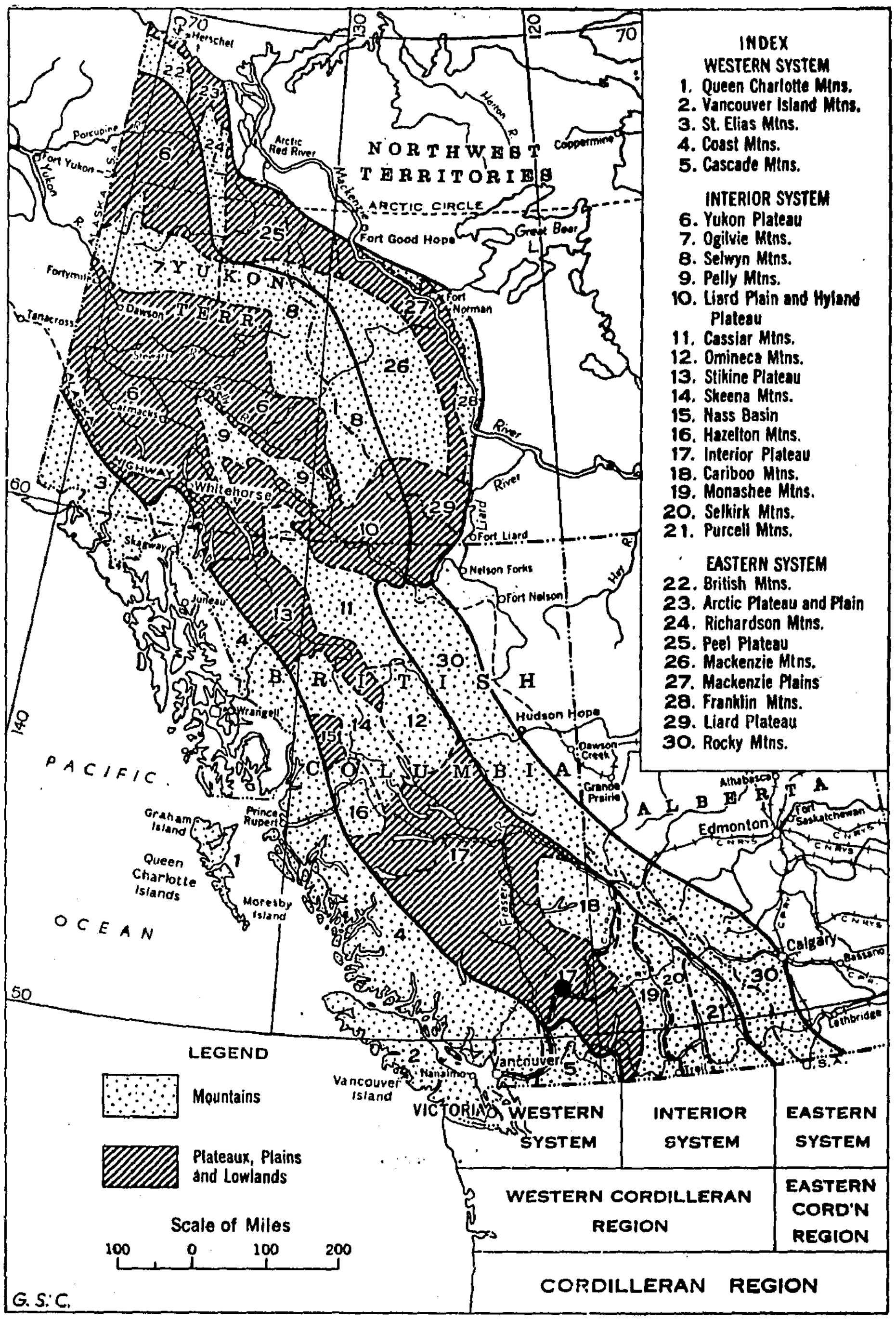
Craigmont is one of three major copper deposits known in south-central B.C. (figure 1). The Copper Mountain Mine, 62 miles to the south-southeast, operated from 1937 to 1957, mining 35 million tons of copper ore (Fahrni; 1962). The Bethlehem Mine, 20 miles to the north, began production in January 1963 and is currently milling more than 6,000 tons per day of copper ore. Craigmont lies almost on a straight line between these two deposits.



LOCATION MAP
(after Chapman, 1962)

SCALE: 1inch = 40miles

Figure 1



● CRAIGMONT

PHYSIOGRAPHIC DIVISIONS OF THE CANADIAN CORDILLERA

(after Bostock et al, 1957)

Figure 2

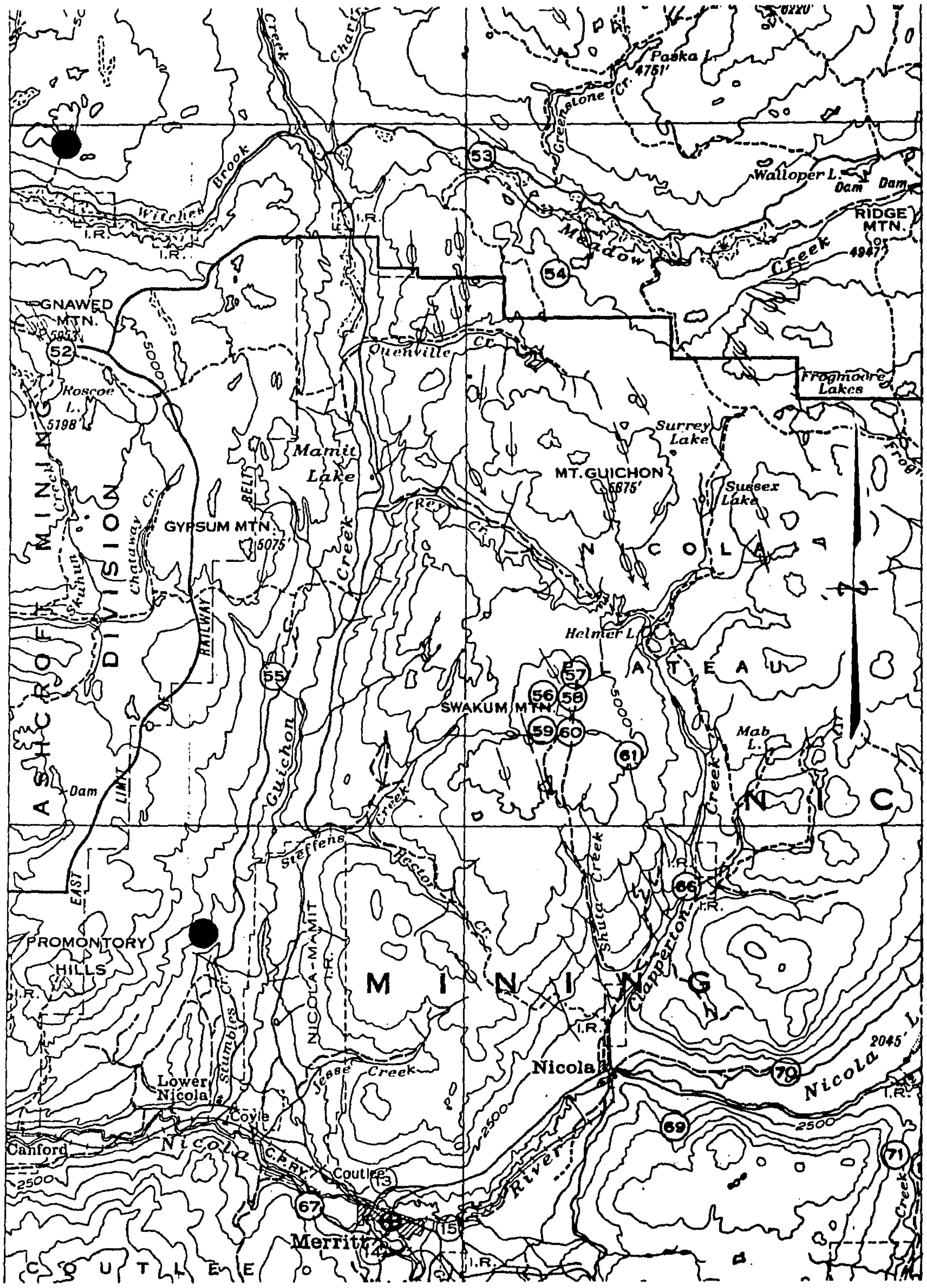
HISTORY

The Craigmont orebody was discovered in late 1957, and was put in production in 1961. In this section the writer summarizes the chronological development of information which led to the discovery.

The Geological Survey of Canada Mineral Map published in 1947 indicated a copper showing at the south end of but within the Guichon batholith. Known as the Eric showing, this prospect now lies 8,000' almost due east of the Craigmont orebody. A portion of this map is reproduced as figure 3.

The Eric showing was known and was drilled without success as early as 1935. Since that time, prospectors have combed the southern parts of the Guichon batholith in an attempt to locate economic copper deposits. This interest derived from sporadic attempts to produce copper from the Snowstorm Prospect (now Bethlehem), and also from the abundance of chalcopyrite and bornite scattered throughout much of the Guichon intrusive mass. With the exception of the Snowstorm area, this exploration was not successful. Although more showings were discovered, none was of major economic significance. By 1954, there were two showings known in the immediate vicinity of what is now the Craigmont orebody, the Eric and Paystin (or Titan Queen) prospects.

In 1954, little more was known of the Eric showing than that described



A PORTION OF

GEOLOGICAL SURVEY OF CANADA

MINERAL MAP (887 A)

INDICATING BETHLEHEM (51) and CRAIGMONT'S ERIC (65)
SHOWINGS; MAP PUBLISHED IN 1947

Figure 3.

by Cockfield (1948). "Copper mineralization (is) associated with basic segregations or inclusions in quartz diorite." "(The rock) is impregnated with epidote, specularite, magnetite, chalcopyrite, and copper carbonates."

At the same time, the Paystin showing consisted of several small pits in an outcrop area approximately 1 mile northwest of the present Craigmont open pit. These exposed chalcopyrite and minor hematite associated with an actinolite-tourmaline 'dyke' cutting the quartz diorite. Recent bulldozing by Craigmont has not established any continuity of the dyke, but has exposed quartz diorite with rare patches of chalcopyrite associated with calcite blebs and stringers.

The initial group of claims now held by Craigmont Mines Limited was staked in 1954, primarily because of interest in the Paystin prospect. While building a road to this showing, a small patch of copper mineralization was discovered in a road cut. This was 1,800' north of what is now the open pit center line. In 1955, it could have been described as a minor showing of chalcopyrite in quartz diorite. The copper mineral occurs as fracture fillings and local disseminations. The quartz diorite contains above normal amounts of disseminated magnetite, and massive magnetite veins occur nearby. Since 1955, trenching has exposed some pegmatitic veining within the quartz diorite.

Craigmont drilled several holes to test the Paystin prospect, but without encountering economic indications. At that point their interest probably turned toward evaluation of the rest of their property.

One can not be sure just what reasoning led to the decision to perform geochemical soil sampling and magnetometer surveys. Renshaw and Price (1958) describe the results, but not the reasoning. American Smelting and Refining Co. had been conducting extensive work on the Bethlehem prospect, and had found much of the mineralization to occur in an area of anomalously low magnetic intensity. The Paystin showing contained little magnetite. On the other hand, the Eric showing was close to accumulations of magnetite, the road cut showing contained magnetite, and the writer has been told of then-current rumors of anomalously high dip-needle readings to the north. Finally, magnetometer surveys were gaining favor as an inexpensive and rapid approach to mapping in areas of glacial cover such as Craigmont. Similarly, geochemical soil-sampling was gaining popularity in British Columbia.

In any case, these two types of surveys were run in late 1956 and early 1957. The magnetometer survey indicated an area of anomalously high magnetic intensity more than 1,000' long and several hundred feet wide with peak values more than 10,000 gammas over background. No precise data are available from these early days, and the map included herein (figure 11) shows values obtained later. The geochemical survey consisted of soil sampling and analysis for cold-extractable copper, and is described later. Results were reported only as either high or low.

The location of the magnetometer anomaly and the results of the geochemical survey are shown in figure 4.

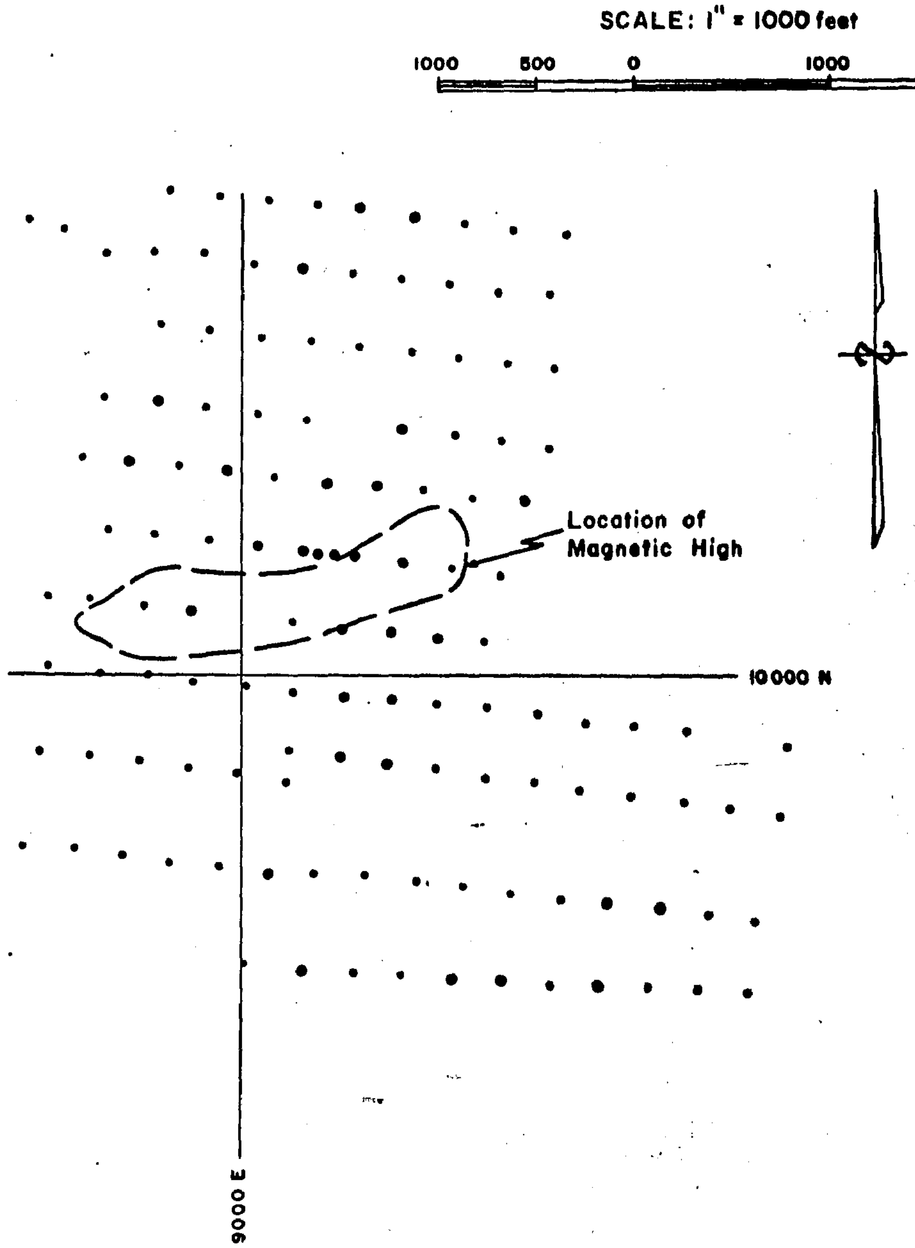
After the two initial surveys had been run, several drill holes were put down without intersecting significant mineralization. Finally, a more detailed magnetometer survey was performed using a 50' grid. This showed that the strongest part of the anomaly had not been detected before. A drill hole on that "high" intersected 157' of 0.96% copper. Subsequent drilling soon indicated a major copper deposit, holes 7 and 15 intersecting 530' of 2.2% copper and 640' of 4.4% copper respectively.

In November of 1957--after the drilling of hole 7--Canadian Exploration Limited contributed additional financing and undertook direction of exploration. In July 1958 this company was joined by Noranda Mines Limited and Peerless Gas and Oil Company. These three and the original Craigmont Mines Limited form the nucleus of the present Craigmont Mines Limited.

In September 1961 the mine was placed into production at a milling rate of more than 5,000 tons per day, primarily from open pit mining.

The most recently reported ore reserves are 23,000,000 tons of 1.76% copper as of 31 October 1964. Approximately 5,500,000 tons of similar grade material had been mined at that time.

RESULTS OF INITIAL GEOCHEMICAL SURVEY
and
LOCATION OF MAGNETIC ANOMALY



NOTE 1: Geochemistry by Renshaw and Price;
• represents sample site "high" in copper
• a site low in copper

NOTE 2: Magnetic anomaly as defined by Craigmont surveys subsequent to discovery; original data used by Renshaw and Price not available

Figure 4

GENERAL GEOLOGY

The interior plateau division of south-central B.C. consists primarily of steeply-dipping Cretaceous and late Palaeozoic eugeosynclinal rocks intruded by granitic to dioritic stocks and capped by relatively flat volcanic flows and tuffs. To the west, intrusives become more predominant until the Coast Range Batholith is reached. The system is bounded on the east by the primarily sedimentary sequences of the eastern Cordillera.

Figure 5 illustrates these relationships in the vicinity of the Craigmont.

Intrusive Rocks:

The Jurassic* "Guichon Batholith", one of the larger stocks, intrudes the Triassic Nicola series to the south and both the Nicola and Permian Cache Creek series to the northwest (Duffel & McTaggart, 1952). This stock is mainly of quartz diorite composition. However where detailed mapping has been performed at Bethlehem and near Craigmont, it is seen to be a composite of many separate intrusive phases. At Bethlehem several distinct porphyritic units have been mapped, as well as non-porphyritic units and strong aplite dykes. The southern portion near Craigmont contains abundant coarse hornblende diorite, more "normal" fine to medium-grained biotite and both

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*There is some doubt of this age; see appendix 1.

GENERAL GEOLOGY
CRAIGMONT MINE AREA

(after Rennie et al; 1960)

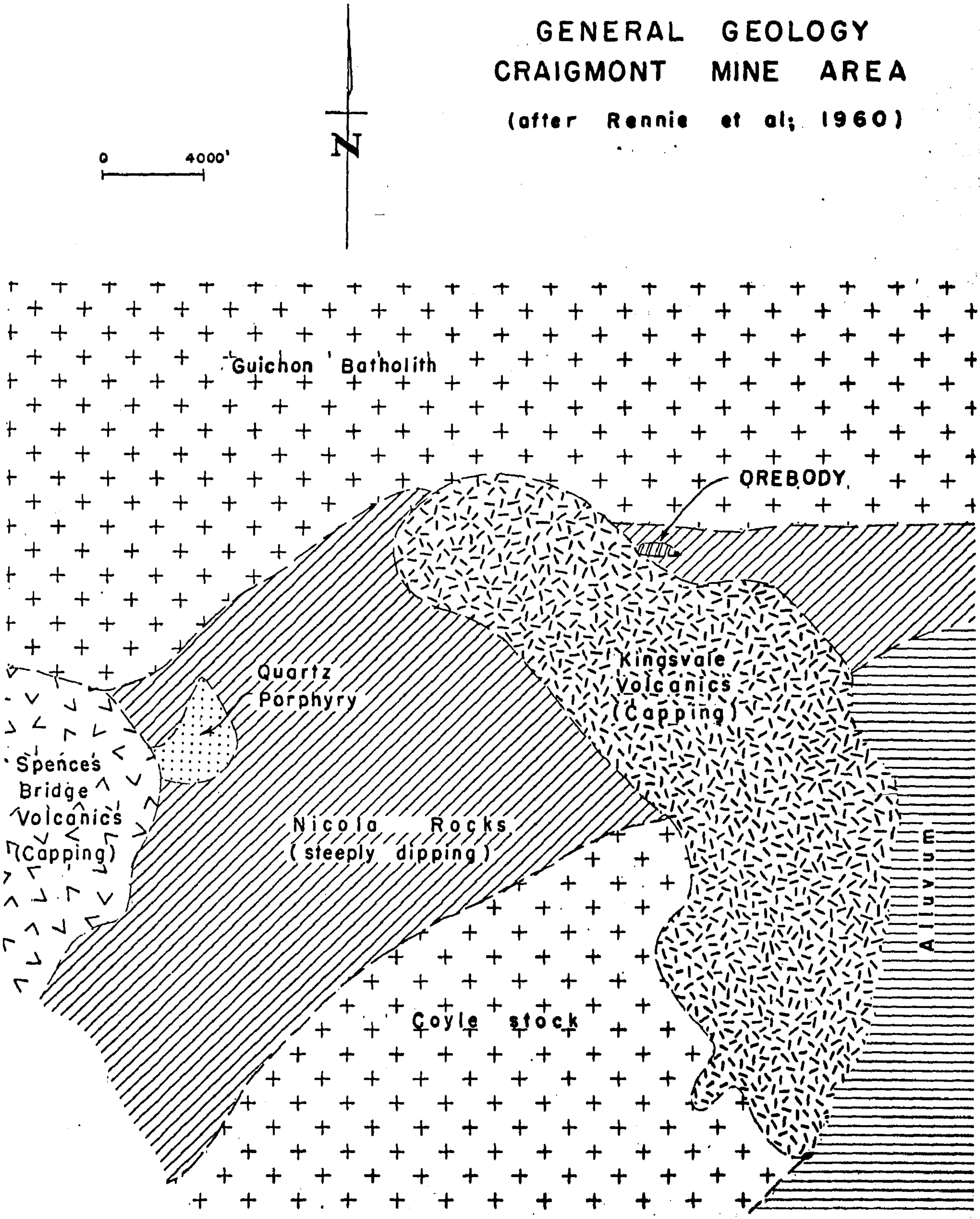


Figure 5

hornblende diorite and aplite dykes.

The Coyle stock is reported (Carr, 1960) to intrude Nicola rocks 2 miles to the south of the orebody and the Guichon contact, although no contacts have been observed. The stock is principally quartz diorite with some quartz monzonite. The latter is composed chiefly of quartz, microperthitic orthoclase, and plagioclase with less than 10% mafic minerals (Carr). This phase cuts the quartz diorite, and is in turn cut by small dykes of aplite. The micropegmatitic quartz-feldspar texture of this quartz monzonite is very similar to the 'aplite' dykes at Bethlehem and Craigmont; the writer has not seen the aplites reported to cut this stock.

Another small stock occurs 5 miles to the east of the orebody across valley-fill. This has not been mapped, and is not shown in figure 5. The writer has observed coarse hornblende diorite and micropegmatitic quartz monzonite in various parts of this stock. Both phases carry small amounts of copper as chalcopyrite and/or bornite.

Intruded Rocks:

The Upper Triassic Nicola series consists largely of volcanic rocks with minor local areas of limestone, argillite, greywacke and conglomerate. The Craigmont orebody occurs in an area with greater than normal limestone and greywacke.

The assumed age of the Nicola series is based upon fossil evidence (Cockfield, 1948; Carr, 1960; Hillhouse, pers.comm.). W.R. Danner (in Carr, 1960) identified the pelecypod Halobia from limestone on Lookout Point, 3 miles west of Craigmont. This places the limestone in the Karnian stage of the Upper Triassic. Although glacial overburden and later volcanics cover much of the intervening ground, this limestone strikes towards the ore-limestone to the east, and is probably the same or a parallel band of nearly the same age.

Observed strikes and dips in the Nicola south of the Guichon are generally from 070° to 090° and vertical to about 70° south. In the area immediately west of the volcanic overlap (figure 5) there is little outcrop, but no evidence of major disruption of the series. On Promontory Hill, further to the west, there is more outcrop. C.W. Ball has mapped this in detail for a company affiliated with Craigmont. With one exception, strata continue to strike 070° to 090° and dip steeply south. However, at the west of the outcrop area flat dips and unusual strikes suggest a strong right handed fold, possibly related to a northeast fault. A tight fold may appear within the mine workings as well; this is described later.

The Nicola series on Promontory Hill consists of greywacke with discontinuous thin limestone bands. The limestone is rarely recrystallized and carries only minor traces of epidote. Between Promontory Hill and the mine there are several small outcrops of limestone and limey greywacke as well as greywacke. To the south there is a parallel--striking system of reddish agglomerates without associated limestone. Within the mine, on the east side of and under the later volcanics, the Nicola rocks are represented by greywacke and recrystallized or skarn-altered limestone. Except for a possible drag fold, the thick limestone band in the mine appears to be more continuous than the thin ones on Promontory Hill.

The mine limestone apparently is truncated by the Guichon batholith. There are no outcrops of Nicola rocks immediately to the east, although drilling from underground shows that Nicola rocks continue for some distance beneath the glacial cover.

Extruded Rocks:

Volcanic flows and tuffs of relatively shallow dip cover the Nicola rocks for about a mile west and south of the orebody. Andesitic to rhyolitic flows are interbedded with tuff, tuffaceous sandstone and--near the base--some carbonaceous material (Cockfield, 1948; Carr, 1960). The contact with the underlying Nicola is unconformable; dips in the volcanic assemblage are generally less than 15° while those in the Nicola are generally greater than 70°.

The eastern contact with the Nicola has been mapped in the open pit, where it is a loose gravel and boulder zone several feet thick; it is interrupted by steep east-west faults. The western contact occurs in an area of extensive glacial cover and has not been traced in detail.

The age of this patch of volcanics has not been determined definitely. It seems to be later than the Nicola group, overlying weathered Nicola rocks unconformably. It is also probable that the volcanics are post-ore. Although no strong chalcopyrite has been found in the unconformity, boulders of specularite and magnetite are common. Ore in places occurs directly below the volcanics, but never within them. Rouse (pers.comm.) has dated micro-fossils from the basal carbonaceous tuffs as Eocene. A potassium argon determination by the Geological Survey of Canada on biotite from just above the ore suggested an age of 80 million years, or Upper Cretaceous.

Thus the volcanic series is almost certainly post-ore, but the question of whether it is Cretaceous or Tertiary in age has not been solved. It is probably not critical to exploration at Craigmont.

There are many small patches of post-Nicola volcanics scattered throughout south-central British Columbia. One, 20 miles south of Craigmont, has been dated (by fossils) as Lower Cretaceous (Cockfield, 1948); this is the type locality for Kingsvale volcanics. The patch at Craigmont has been called Kingsvale as well (Rennie et al, 1960).

MINE GEOLOGY

General

This section is a summary of the geology within the mine. It represents the results of underground and open pit mapping, primarily by R. J. Young and E. Kimura, the logging of drill core by Young and others, and the interpretation of these data by C.C. Rennie and members of his staff. The writer has logged selected drill holes and has studied maps and interpretations by the others.

Most of the ore occurs in a steeply dipping limestone band approximately 100' wide. This band appears to be relatively continuous in strike compared to the thinner ones on Promontory Hill (figure 5). At the west end of the mine workings it is apparently faulted several hundred feet to the northwest (Young, pers.comm.) To the east, it is apparently truncated by the Guichon intrusive.

At the west end of the workings there is little alteration of the main limestone other than recrystallization and a few patches of skarn. Within the ore zones, skarn alteration is intense. This may be a function of proximity to the Guichon diorite, which is apparently farther north of the limestone at the west end. However, it is possible that the alteration within the mine may be controlled by diorite dykes rather than the main batholith, or by some other control such as faulting.

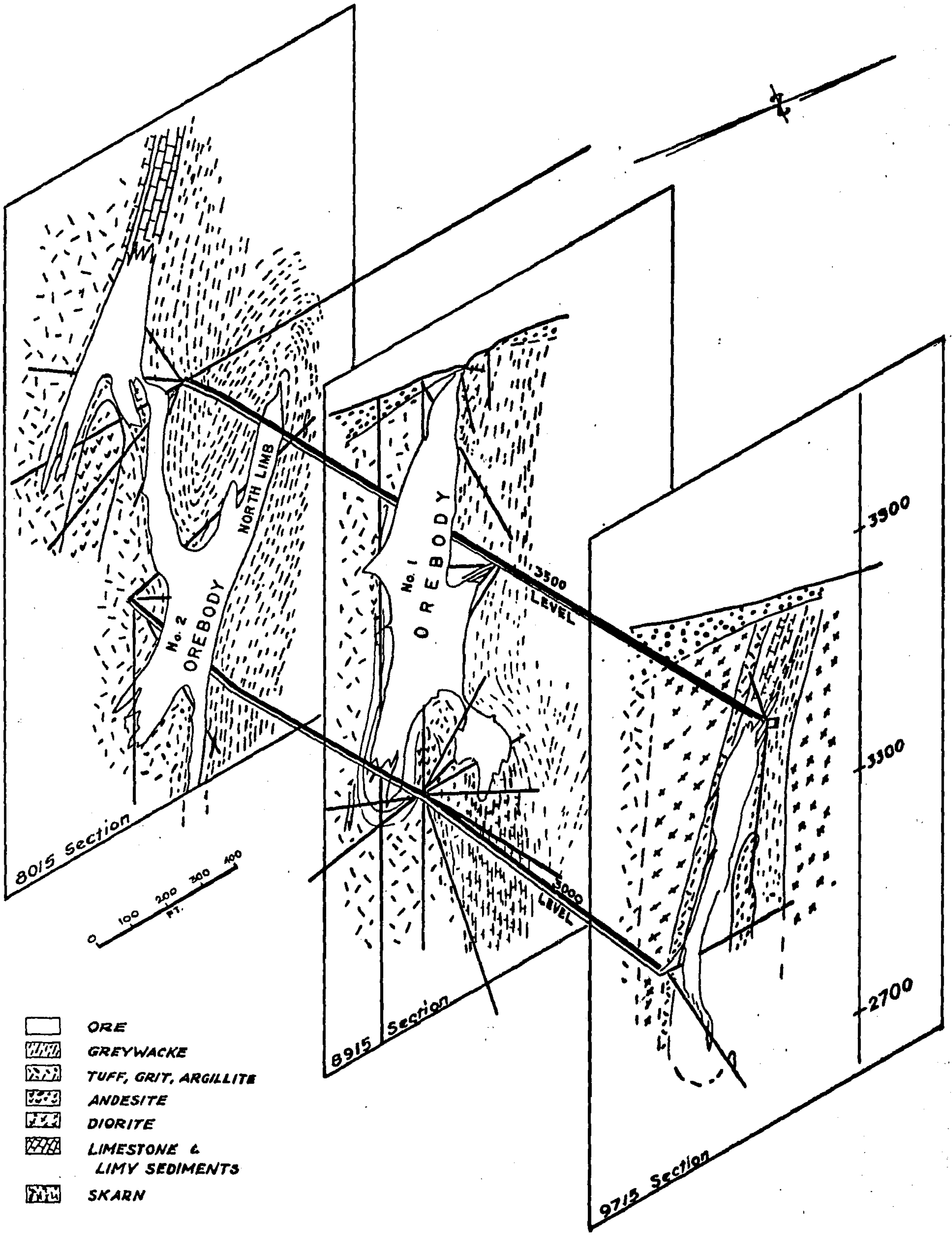
Heavy skarn alteration occurs in the major ore zones. It consists predominantly of garnet and actinolite phases, although epidote is common and in places is the major skarn mineral. Some areas contain heavy magnetite and/or specularite, and some contain abundant pyrite and/or chalcopyrite. Quartz and K-feldspar are common.

Figure 6, after Rennie et al (1960), illustrates the drag fold thought to occur in the ore zone. The lower orebody is displaced to the north. This displacement has been corroborated and detailed by later drilling and underground mapping. However, the writer is not aware of any firm evidence indicating drag folding rather than faulting. As mining progresses, further mapping should clarify this.

The Orebodies

The only important ore mineral at Craigmont is chalcopyrite. At present, the iron contained in magnetite and specularite is not considered economically extractable. Minor bornite occurs in scattered localities, especially in the lower east end of the orebody, but it is quantitatively insignificant. Native copper occurs in faults in the upper levels of the pit, but is thought to be a weathering product.

Four orebodies have been outlined: the Number 1, Number 2, North Limb, and Number 3. All but the Number 3 are skarn orebodies. Figure 6 illustrates



ISOMETRIC SECTION OF CRAIGMONT OREBODIES

(After Rennie et al. 1960)

Figure 6

the skarn type, which the reader will see is essentially continuous. Figure 8 shows the relative location of the Number 3.

The skarn orebodies are of similar nature. All contain approximately 2% copper as isolated blebs of chalcopyrite, generally from 1/20" to 1/4" in diameter, or as discontinuous veins. The gangue consists of varying proportions of magnetite, specularite, quartz and actinolite, with lesser amounts of epidote and garnet. A typical specimen contains about 25% magnetite or specularite, with roughly equal amounts of actinolite and quartz making up most of the remainder, but these relations vary widely.

Except in the Number 3, pyrite is very rare within the orebodies. However it often occurs abundantly (about 5%) in garnet skarn close to ore, and is found in greywacke, andesite and diorite near the ore zone. Thus, although ore-forming conditions did not favor pyrite formation within the main orebodies, it was stable or metastable very close by. Pyrrhotite has been found in large amounts in only one part of the mine, in epidote skarn at the west end of the 3,000 level in an area of intermittent skarn alteration.

The Number 3 orebody consists of disseminated chalcopyrite and pyrite in interbedded argillite and siliceous greywacke. Magnetite, specularite and skarn minerals are rare. Except for the nature of the sulphides and the possibility that this orebody is more highly fractured, the rock appears very similar to barren pyritic argillites and greywackes which are common south of the main ore zone. However, within the orebody chalcopyrite and pyrite are about equally abundant and make up from 10 to 15% of the rock.

GEOLOGICAL INTERPRETATION
SECTION 7415
(Showing apparent relationship between skarn zoning and ore)

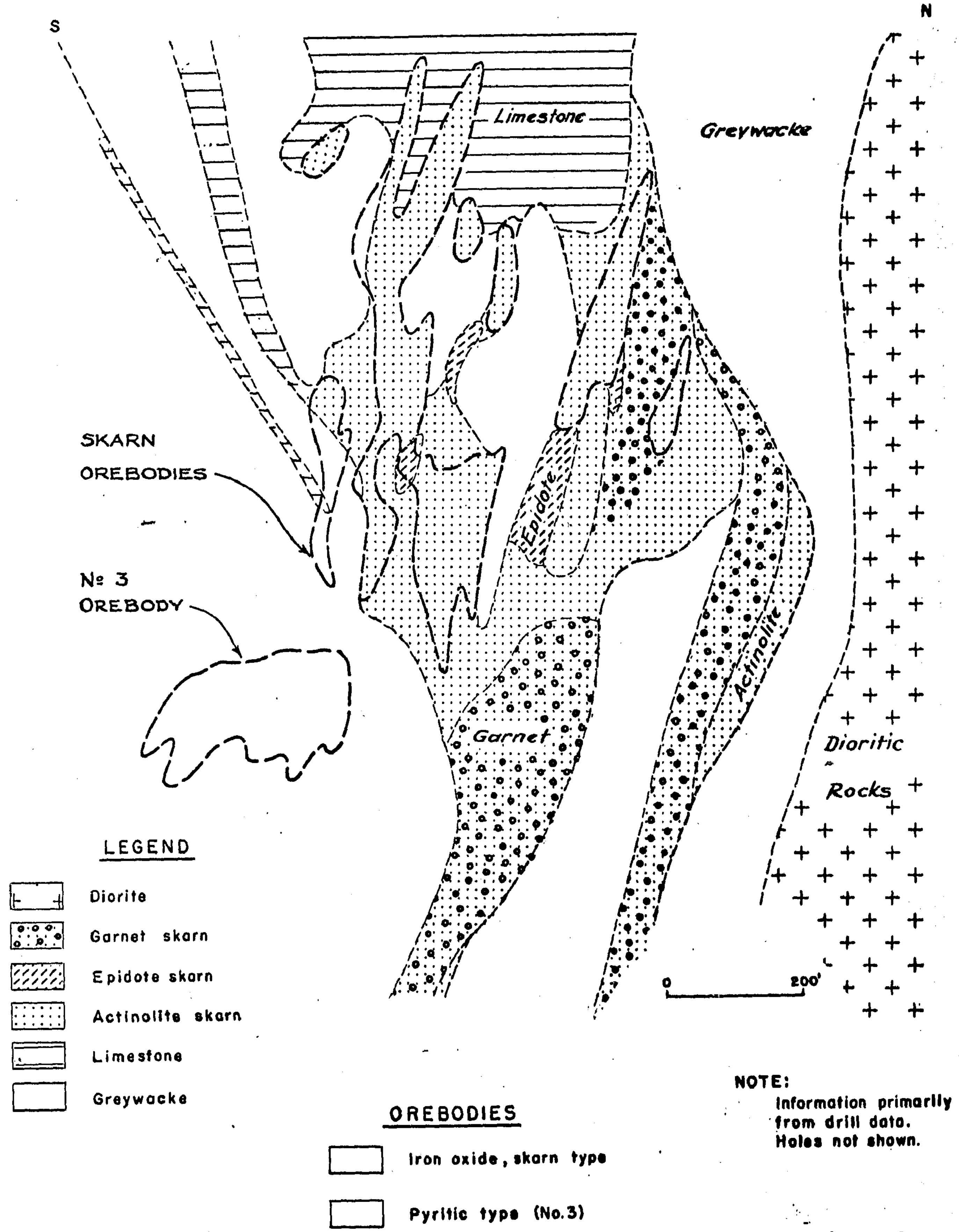


Figure 8

Much more than 95% of the ore outlined is skarn ore. However this may reflect the relative ease of exploration for it, both by geophysics and by following the limey zone. The Number 3 is the most recently discovered. As it is mined and studied, ore guides may be found which will lead to further discoveries.

The Alteration

Prior to the writer's arrival, the mine staff had had little opportunity to study the distribution and nature of alteration minerals at the mine. Such a study is now in progress. This section contains a preliminary description of the situation.

The conspicuous alteration minerals are those found within and near the orebodies, and which are not abundant elsewhere in the vicinity. These include the lime-silicate skarn minerals: epidote, actinolite and garnet; as well as the iron oxides: magnetite and specularite; and the copper minerals. Parts of the ore zone contain abundant K-feldspar. Limestone immediately west of the ore zone is recrystallized.

Other minerals which may represent alteration or addition of material are quartz and pyrite.

No simple zonal relationship of the lime-silicate alteration has been defined by mapping as yet. Limestone near Promontory Hill several miles west of the orebodies is fine-grained and grey. Although outcrops are scarce, the limestone observed at the west edge of the Kingsvale volcanic overlap two miles west of the orebody is coarser and whiter, and is probably recrystallized; it contains minor disseminated epidote. Within the mine workings all of the limestone is recrystallized. At the west end of these workings, patches of skarn mineralization (epidote) occur. The major skarn zone containing the orebodies begins abruptly. It is a complex mass of epidote, garnet and actinolite zones with no simple order obvious to the writer.

In spite of the above, the type of skarn does seem to have an effect on the occurrence of ore. The bulk of the chalcopyrite occurs in the actinolite zone with abundant iron oxides and quartz. Occasionally epidote is also abundant. Areas consisting predominantly of garnet skarn, on the other hand, are noticeably barren of ore. They are often rich in pyrite, contain minor epidote and calcite with little quartz, and very seldom contain more than token amounts of copper. Figure 8 shows a typical cross section: not all of the actinolite skarn contains ore; none of the garnet zone does.

The distribution of magnetite and specularite, although of prime importance from both geophysical and geochemical viewpoints, is essentially unknown. Hence the controls of that distribution are also unknown. It is complicated by the fact that in different places each mineral replaces the other. Thus one frequently finds octahedral grains of specularite, on the one hand, and lamellae of magnetite resembling specularite, on the other.

The distribution may be controlled primarily by a geometric change in the fugacity of oxygen, i.e., away from a source. Alternatively, the main control may be lithologic; i.e. control by the chemistry of the particular host rock. There are not sufficient data at present to assess the relative importance of these two controls.

The main orebodies contain abundant magnetite. The exploration geologist wonders whether or not all large skarn orebodies at Craigmont must contain magnetite. If so, the lack of large magnetic anomalies near a volume of rock will indicate the lack of ore therein. If not, then magnetometer surveys cannot be as diagnostic. Knowledge of the distribution of the two oxides may be of considerable importance for the conclusions which may be drawn from it.

K-feldspar and quartz occur together in certain areas scattered throughout the orebody. The K-feldspar occurs as small euhedral crystals in irregular veins with quartz, as well as an alteration product of some of the feldspars in the greywacke. Some of these areas, such as in the 971 crosscut on the 3500 level, are intensely brecciated. The strongest K-feldspar and brecciation have both been observed in the upper parts of the ore zone; whether this is a function of original rock type or of intensity of hydrothermal action is unknown as yet.

Parts of the Guichon batholith and the other smaller intrusives in the vicinity contain abundant K-feldspar; however, it is rare in Nicola rocks. In the mine area, the only strong K-feldspar in Nicola rocks occurs within or close to the orebodies.

In addition to its occurrence with K-feldspar, quartz is abundant throughout the skarn orebodies. Much of the actinolite-iron oxide skarn contains up to 30% clear quartz in the matrix. This contrasts with the garnet skarn which, as was noted earlier, is low in quartz. It also contrasts with the pyrite-chalcopyrite orebody in greywacke (Number 3), which appears to contain only normal grains of quartz.

Pyrite is rare within the main skarn orebodies. It is abundant in barren garnet skarn and in the greywacke and argillite wallrocks. It is also abundant in similar Nicola greywacke and argillite elsewhere in the region, so that its presence near the orebodies probably represents nothing abnormal. The consistent lack of pyrite in the oxide-skarn orebodies and its occurrence nearby in barren skarn suggests that the relative fugacities of oxygen and sulphur may have been closely related to the control of ore deposition.

Tourmaline has been observed as a minor constituent of the quartz and K-feldspar-rich areas. It is abundant in the high K-feldspar portions of the aforementioned small mineralized stock 5 miles east of the mine.

Sericite has been recognized in thin sections from within the ore zone (company reports by C.W. Ball and C.C. Sheng), but rarely has been seen macroscopically. Visible sericite occurs in some of the greywackes south of the ore zone, and was abundant in greywacke in an isolated drill hole 2,500' east of the orebody.

DISCUSSION

The main Craigmont orebodies are--in most respects--typically "pyrometasomatic" or "contact metasomatic". They occur in skarn-altered rocks near an intrusive contact, and apparently have had material added from an external source. They are atypical in that they combine to form such a large deposit; the ore zone is more than 1,000' long and contains more than 20,000,000 tons of ore.

Brown (1962) describes a number of "pyrometasomatic iron-copper deposits on the west coast" of British Columbia; these are similar, with their "skarn envelopes, relation to dioritic intrusives, and the ubiquitous presence of limestone". Most are smaller and contain less copper than Craigmont. Some are being placed into production as iron mines. These occur on the other (west) side of the Coast Range Batholith, but duplicate the Craigmont situation in that they are in Triassic limestone near Jurassic (?) dioritic intrusives.

Many of the major disseminated copper deposits of the western United States, such as Bingham, Utah (Hunt, 1957) and Bisbee, Arizona (Blanchard, 1926) occur within intrusives rimmed partially by contact metasomatic orebodies. In general, and in both of these cases, the contact orebodies are small, contain proportionately more sulphides than oxides, and often contain zinc. The bodies within the intrusives often contain molybdenum as well as copper.

The Craigmont skarn zone is large, contains more oxides than sulphides, and no zinc bodies have yet been discovered. Nevertheless, it is a pyrometasomatic orebody, and many of the nearby intrusives do contain disseminated copper minerals. It would appear that the advisability of searching for both large disseminated copper or molybdenum and small pyrometasomatic zinc orebodies should not pass unconsidered.

The possibility that major orebodies similar to the Number 3 may exist should also be kept in mind. The main skarn zone was originally detected by virtue of the strong magnetic anomaly due to the magnetite, and it is a reasonable assumption that other similar orebodies nearby would--if they existed--be discovered as easily. The Number 3 would almost certainly never have been detected had mining not been carried out adjacent to it. There may be other similar deposits, either larger or smaller.

In summary, the following types of ore should be considered as possibilities at and near Craigmont:

1. pyrometasomatic copper-iron oxide skarn orebodies;
2. copper-iron sulphide bodies similar to the "Number 3" orebody;
3. pyrometasomatic zinc-rich orebodies;
4. large disseminated copper and/or molybdenum orebodies.

B. THE EXPLORATION PROBLEM

INTRODUCTION

It may be said that the most important exploration at Craigmont has already been accomplished. This was the original discovery. Any future successes will be built on the foundation laid by the management and staff of the original Craigmont Mines Limited.

Nevertheless, consideration of further exploration is also important. At the current rate of mining, presently-known ore reserves will have been mined out by the late 1970's. If the mine is to continue operating past that time, significant new discoveries must be made.

In the following, the writer discusses the various geophysical and geochemical techniques that may be of assistance, and reports the results of tests of some. These will then be analyzed and integrated into an exploration program.

The emphasis is on the search for major additions to ore reserves. This implies, although it does not necessitate, search away from the immediate vicinity of known ore. Within and near the present workings, careful geologic mapping will probably result in the discovery of new reserves from several hundred thousand to several million tons. The writer assumes, a priori, that this will be done well, and directs his attention to the rest of the property and adjoining areas.

Emphasis on exploration away from the mine workings results in emphasis on geophysical and "applied geochemical" techniques rather than those more often associated with "mapping". This is because of the paucity of outcrops resulting from extensive glacial and volcanic cover. The outcrops that have been mapped in these areas serve primarily as a guide to the exploration methods to be used and as an aid in their interpretation.

ANALYSIS OF APPLICABILITY AND LIMITATIONS OF POSSIBLE METHODS

In analysing this type of exploration situation, it is desirable to list the geophysical (or other exploration) methods which might apply. Then, using information from orientation surveys, mathematical computation, basic data on physical properties, and physico-geologic reasoning, one may attempt to predict the applicability and limitations of each method. Subsequent to this technical evaluation, one must then consider the economics of each method as it relates to probable success. After this process, one is able to recommend a technique (or sequence of techniques) which seems most appropriate to the situation at hand.

In the case of Craigmont, the following methods shall be considered:

1. Magnetic surveys (airborne, surface, underground and drill hole);
2. Gravity surveys (surface and underground);
3. Electromagnetic surveys;
4. AFMAG surveys;

5. Resistivity surveys;

6. Induced polarization (IP) surveys;

7. Applied geochemical methods.

The succeeding pages contain discussions of the technical efficacy of each of these as methods of discovering the types of mineralization known or expected at Craigmont. These will be followed by consideration of the economic expectations of using each and, finally, by recommendations for exploration at or near Craigmont.

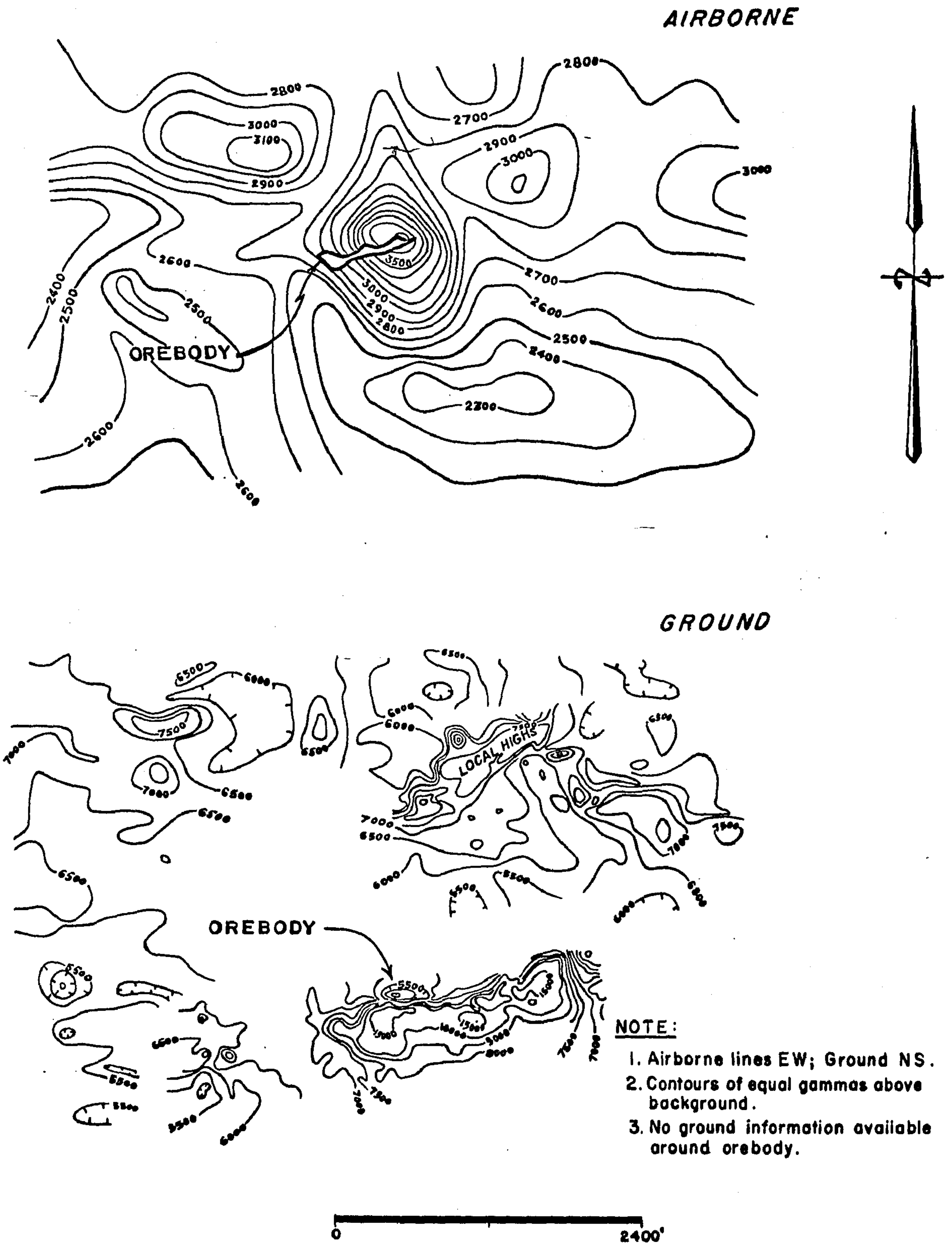
MAGNETIC SURVEYS

The discovery of Craigmont after location of approximately coincident magnetic and geochemical anomalies has been described, and was illustrated in figure 4. Figure 9 shows the strong airborne and ground magnetic anomalies related to the orebody.

Airborne Magnetic Surveys

The results of an aeromagnetic survey of the Craigmont area were presented by Chapman (1962). This showed a strong anomaly of about 500 gammas (figure 9) over the known orebody--not surprising inasmuch as nearly massive magnetite sub-outcropped beneath only several feet of glacial cover.

It is of interest to compute the magnetic anomaly expected from Craigmont-type skarn orebodies buried at greater depths. Since the host limestones are



AIRBORNE AND GROUND MAGNETIC ANOMALIES AT CRAIGMONT

Figure 9.

expected to be nearly vertical and any skarn orebodies to have greater length and depth extent than width, the formula for a buried vertical dyke (Dobrin; 1952) is reasonable. Figure 10 shows the computed magnetic anomaly for dykes 100' wide and various magnetic susceptibilities* at various depths below the magnetometer.

The aeromagnetic survey was flown parallel to the strike of ore and of Nicola rocks with a fixed-wing aircraft. This flight direction provided the minimum probability of detection of ore, while the fixed-wing factor limited the extent of depth of exploration below surface. It may be wise to re-fly parts of this survey area which have not subsequently been covered by ground magnetic surveys.

Ground Magnetic Surveys

When the writer first arrived at Craigmont, the only ground magnetic data available were from the immediate vicinity of the orebody and from scattered areas elsewhere. Nearly complete coverage is now available, and is shown in figure 11. These data were taken on north-south picket lines 200' apart with stations every 100' or, where appropriate, more closely. Only the contours are shown in the figure.

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* Magnetic susceptibility (K) is commonly translated into percent magnetite (%) by K = % /400. This relationship can vary, but is considered reasonable for the Craigmont environment (N.R. Paterson; pers.comm.).

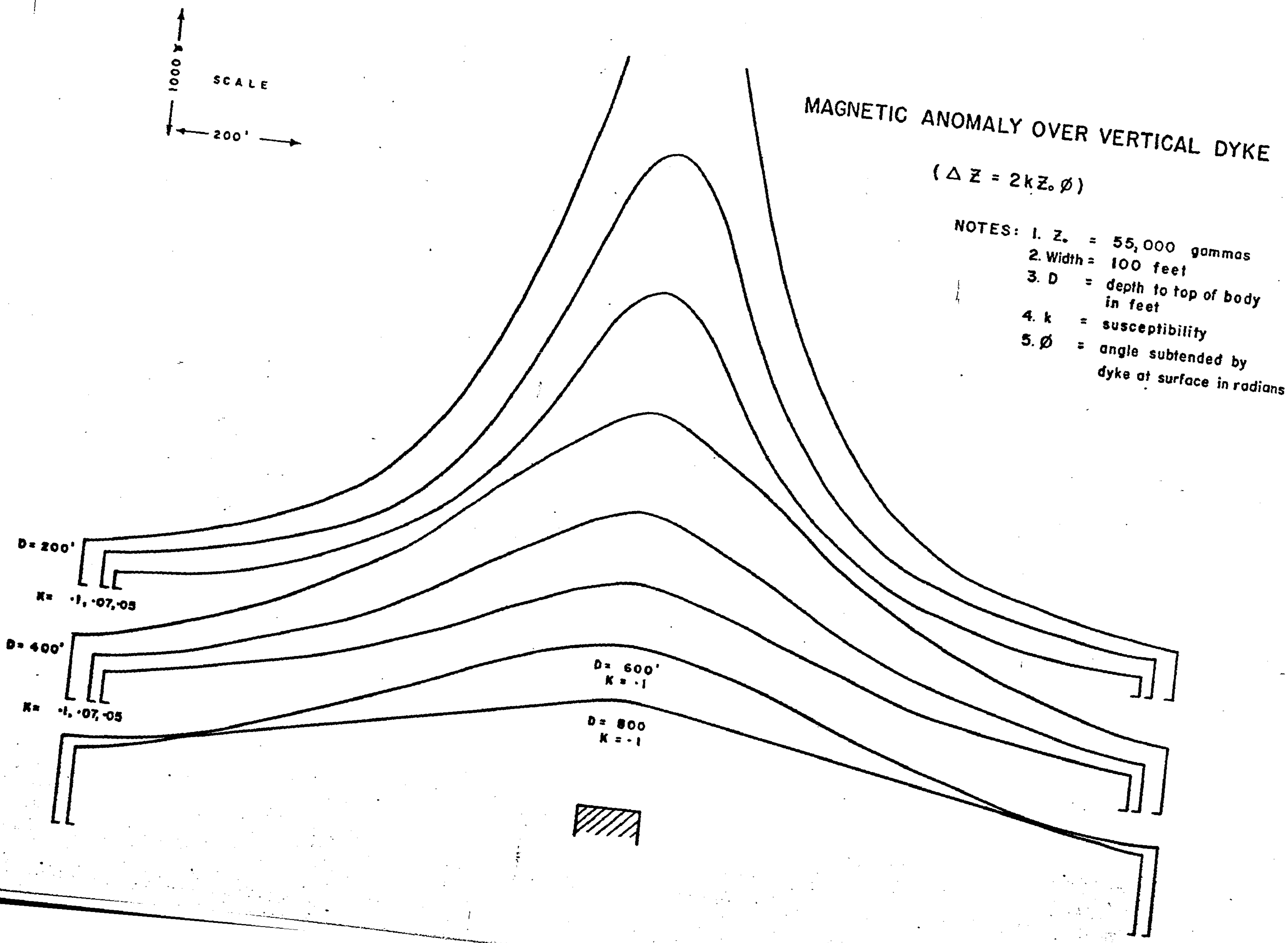

1000 γ
SCALE
200'
MAGNETIC ANOMALY OVER VERTICAL DYKE
(△ Z = 2kZ₀ Ø)
NOTES: 1. Z₀ = 55,000 gammas
2. Width = 100 feet
3. D = depth to top of body in feet
4. k = susceptibility
5. Ø = angle subtended by dyke at surface in radians
D= 200'
K= ·1, ·07, ·05
D= 400'
K= ·1, ·07, ·05
D= 600'
K = ·1
D= 800
K = ·1

Figure 10.

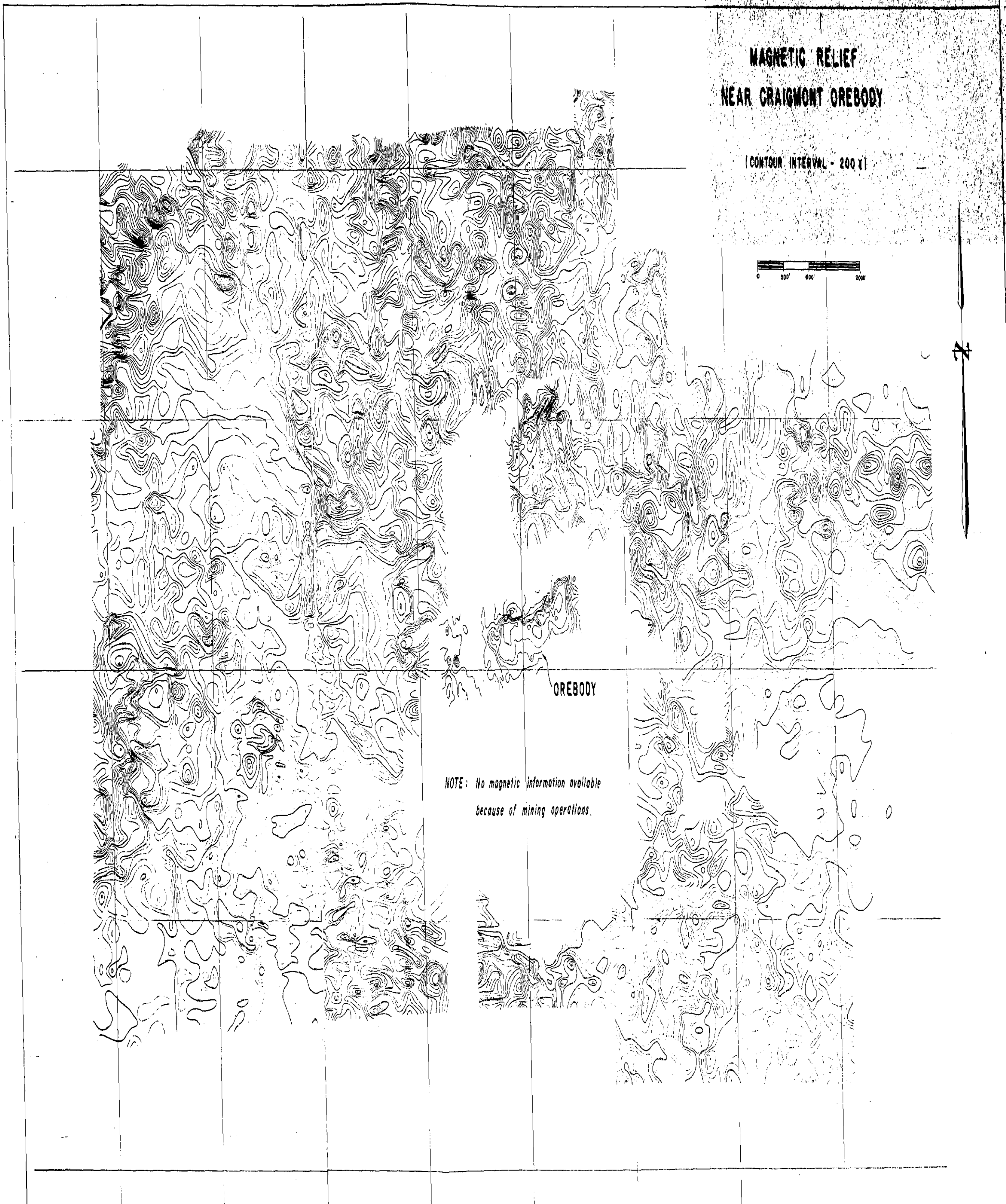

MAGNETIC RELIEF
NEAR CRAIGMONT OREBODY
(CONTOUR INTERVAL - 200 γ)
0
500'
1000'
2000'
N
OREBODY
NOTE: No magnetic information available
because of mining operations.

FIGURE 11

In general, these data reflect variations in near-surface geology, and can be used to extrapolate from and interpolate between other geologic observations. At Craigmont, these other observations are maps of scattered outcrops or occasional drill holes which are not included herein. Figure 12 shows the approximate boundaries of the three rock units at the surface. The fault shown in green is suggested by a marked linear discontinuity in magnetic relief. R.J. Young (pers.comm.) has mapped strong right-lateral faults with this orientation in Nicola rocks within the mine workings; hence the assumption that this fault is right-lateral as well. Geologic control is scanty, and leaves wide scope for unverifiable magnetic interpretation. Rather than go further at this stage, the writer suggests that the magnetic data be used as a base in future mapping, and that an attempt be made to explain as many anomalous patterns and discontinuities as possible.

No anomalies were found with magnetic intensities approaching that of the original discovery anomaly, indicating that no similar orebodies occur at shallow sub-outcrop.

However, it is possible that magnetic skarn orebodies could occur at greater depths, producing weaker and broader anomalies. In order to assess this possibility, all data were reduced to profiles and compared with the curves of figure 10. As may be seen from the contoured data, local near-surface

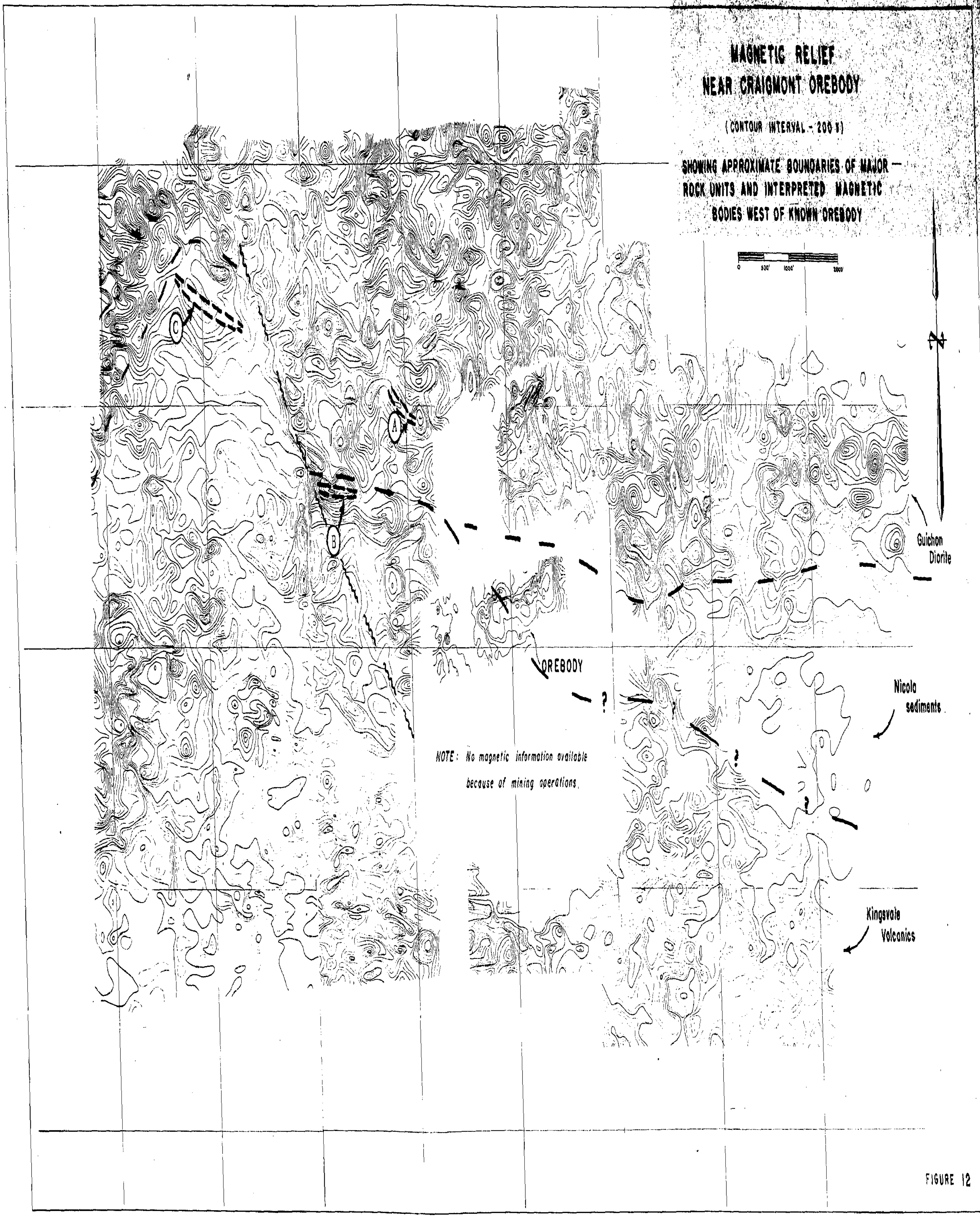

MAGNETIC RELIEF
NEAR CRAIGMONT OREBODY
(CONTOUR INTERVAL - 200 ɣ)
SHOWING APPROXIMATE BOUNDARIES OF MAJOR ROCK UNITS AND INTERPRETED MAGNETIC BODIES WEST OF KNOWN OREBODY
0 500' 1000' 2000'
N
A
B
C
OREBODY
NOTE: No magnetic information available because of mining operations.
Guichon Diorite
Nicola sediments
Kingsvale Volcanics

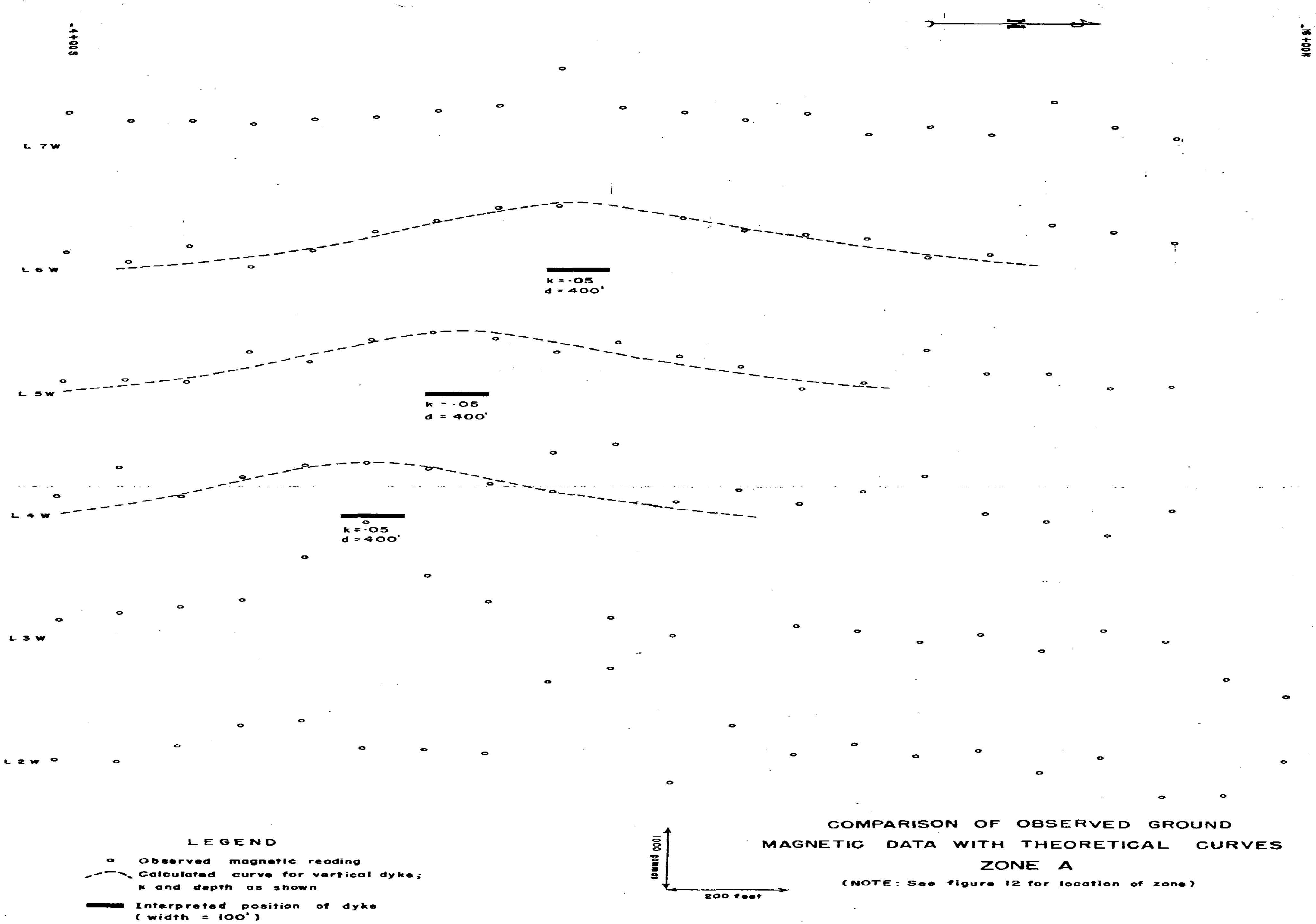
FIGURE 12

magnetic anomalies of several thousand gammas occur, especially within the Kingsvale volcanic area west of the orebody. Normally such surface noise can be visually eliminated in the search for broad, deep-seated anomalies indicative of ore, although it can not help but reduce the effectiveness of this approach for deeper targets.

Figures 13, 14 and 15 illustrate three anomalous areas which can be interpreted to reflect buried magnetic dykes. The locations are shown in figure 12. Anomaly "A" (figure 13) is assumed to occur within the batholith, and is therefore unlikely to indicate ore. Anomalies B and C may occur in Triassic rocks beneath Kingsvale or glacial cover close to the batholith, and thus are in a favorable geologic environment. They may indicate buried orebodies, and should be investigated further. Interpretations are shown in figures 13, 14, 15.

Each of the above anomalies occurs on several parallel lines and is thus consistent with a buried dyke interpretation. No other similar situations were observed on the profiles.

The surface magnetic survey has indicated two targets which warrant investigation. In addition, it has provided a map of broad magnetic variations which should be of assistance in interpreting results of other surveys and of geologic mapping.

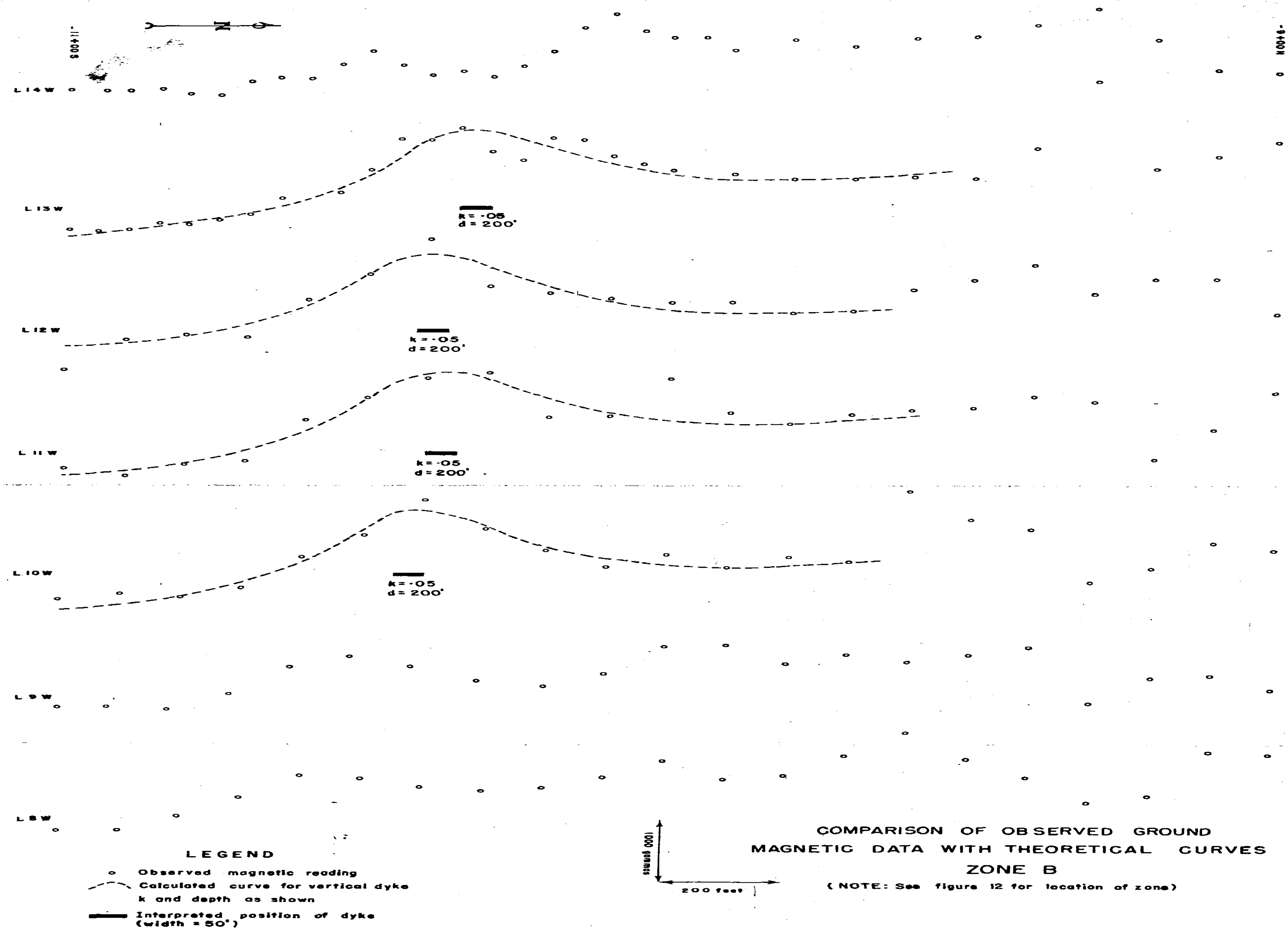


COMPARISON OF OBSERVED GROUND MAGNETIC DATA WITH THEORETICAL CURVES

ZONE A

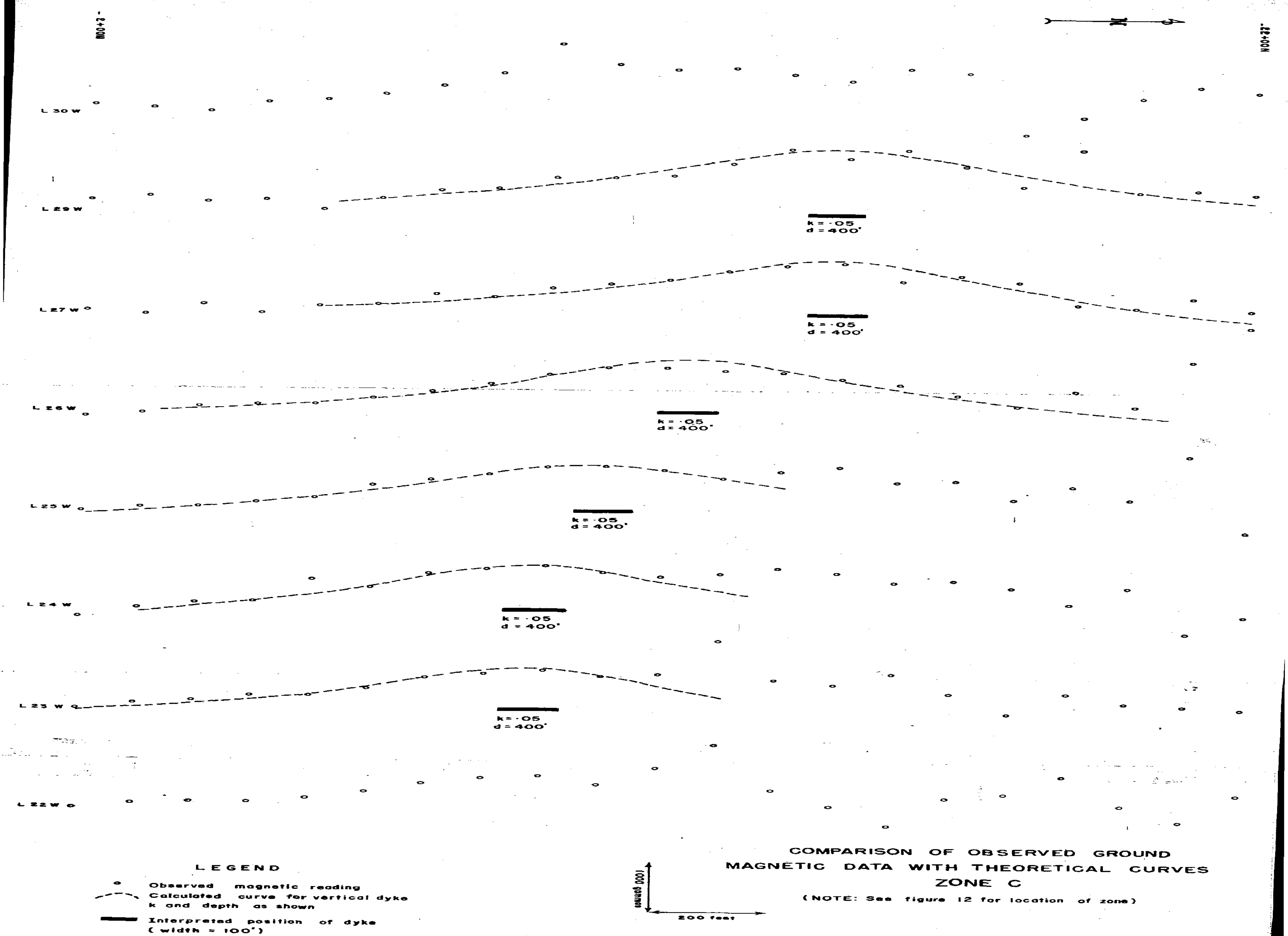
(NOTE: See figure 12 for location of zone)

Figure 13



COMPARISON OF OBSERVED GROUND
MAGNETIC DATA WITH THEORETICAL CURVES
ZONE B
(NOTE: See figure 12 for location of zone)

Figure 14



COMPARISON OF OBSERVED GROUND MAGNETIC DATA WITH THEORETICAL CURVES ZONE C

(NOTE: See figure 12 for location of zone)

Figure 15

Underground Magnetic Surveys

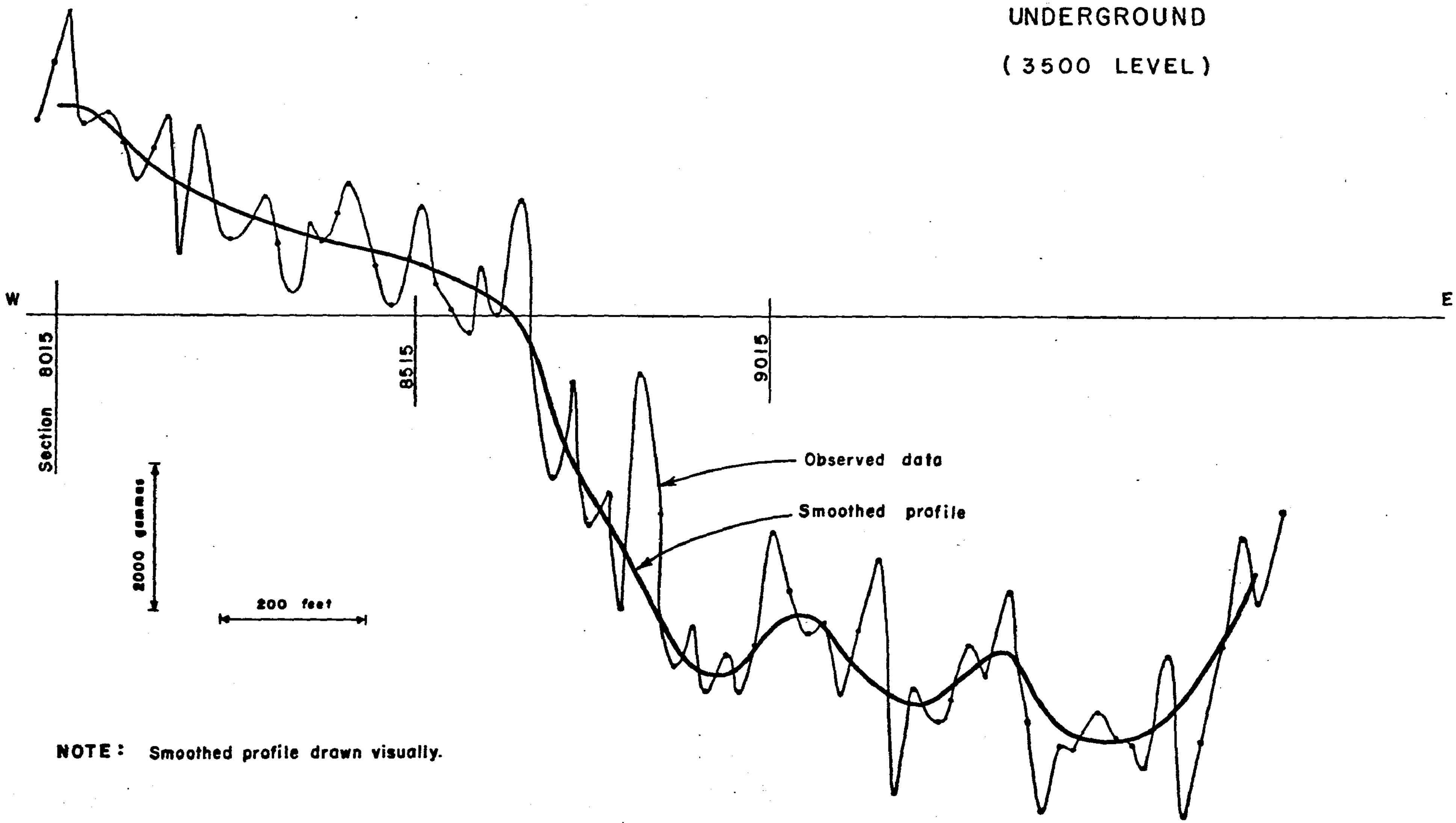
Underground magnetometer surveys are not common in the mining industry. Because of the proximity of magnetite-bearing rock in the drift walls to the sensing head and because of the presence of steel mining equipment, local variations (noise) are expected to be much greater than for surface surveys.

However, because of the strong magnetic response of known ore, the writer desired to obtain an indication of the noise level with respect to broader patterns. The 3500 level of the mine was traversed with a hand-held vertical field magnetometer, with stations every 25'. The results are shown in figure 16.

These data indicate that broad patterns reflecting geologic changes at a distance may be extracted even though local noise may be as much as 2,000 gammas. Since this level passes through and very close to pods of massive magnetite, this noise level can be considered to be abnormally high compared to that expected in, say, an exploration drift away from ore.

This test was made with a vertical field instrument. It would be preferable to measure the magnetic field intensity in three orthogonal directions, so that the source of an anomaly could be located and interpreted more precisely.

VARIATIONS IN VERTICAL MAGNETIC INTENSITY
UNDERGROUND
(3500 LEVEL)



NOTE: Smoothed profile drawn visually.

Figure 16.

Underground magnetic surveys do not fit into the writer's frame of reference, i.e. exploration away from the mine workings. However, he submits that detailed three-component surveys of all levels, especially any future exploration drifts, should be considered.

Drill Hole Magnetic Surveys

Just as underground magnetic surveys have a higher noise level than surface ones, so drill hole magnetic surveys are expected to be higher still. However, since the known skarn ore at Craigmont is so strongly magnetic, the cost of drilling at Craigmont so high ($12 per foot) and since drill holes have been known to miss ore by only a few inches, the writer believes that an orientation survey is warranted.

GRAVIMETRY

General

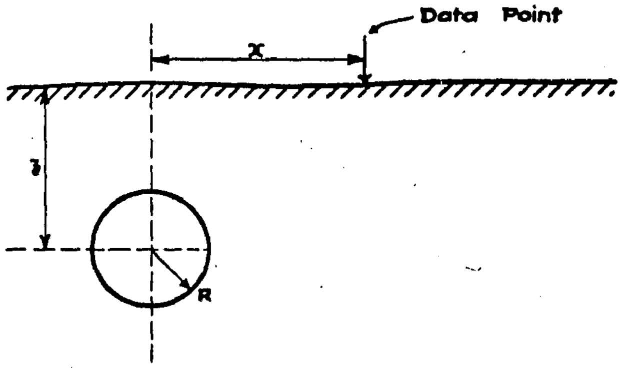
Gravimetric surveys involve measurement of very minute changes in the earth's gravitational field between different points. These may be due to differences in elevation, latitude, topographic relief, and in the densities of rock surrounding the data point. The effect of the first three may often be removed by calculation, with the resultant reflecting changes in the bedrock only. In such cases, local volumes of higher or lower density may be detected.

Instruments are available which measure vertical gravitational differences as low as .01 milligal, or $1/10^8$ of the earth's equatorial field at sea level.

Formulae have been derived by which we can compute the gravitational anomaly from various shapes of bodies in a uniform background. For example, the anomalous response of a sphere buried in a homogeneous earth may be calculated from the formula shown in figure 17; the maximum gravity anomaly under the following conditions is shown on the next page.

GRAVITY ANOMALY FROM BURIED SPHERE

(from Dobrin; 1952)



$$G_z \text{ (milligals)} = \frac{8.53\, R^3 \sigma}{z^2} \; \frac{1}{\left(\frac{x^2}{z^2} + 1\right)^{3/2}}$$

Where: G_z = *vertical component of gravity anomaly*

R = *radius of sphere (kilofeet)*

z = *depth of sphere (kilofeet)*

x = *horizontal distance of measuring point from sphere (kilofeet)*

σ = *density contrast between sphere and surrounding material.*

Figure 17

Specific Gravity Contrast	Radius (feet)	Depth (feet)	Tonnage (approximate)	Maximum Anomaly (milligals)
1.0	10'	100'	400	0.008
1.0	100'	200'	400,000	0.2
		400'		0.05
		800'		0.01
0.5	100'	200'	400,000	0.1
		400'		0.03

If the conditions of a survey are such that a probable error of 0.03 mgal exists for each data point, a reasonable situation in moderately rugged terrain, then an anomaly of 0.1 mgal should be easily detectable. (The above example indicates that a spherical body of sulphides 100' in radius with a specific gravity around 3.7 in country rock of 2.7 would be detectable at a depth of about 300'.)

Because of the possibility that gravity surveys would be useful at Craigmont, the writer measured the specific gravity of a number of specimens of limestone, epidote skarn, garnet-rich skarn, and Kingsvale volcanics. Data were already available for greywacke, diorite, andesite and ore. The results are shown in figure 18. The average for each rock type is shown in the table on the top of page 31.

SPECIFIC GRAVITY OF CRAIGMONT ROCKS

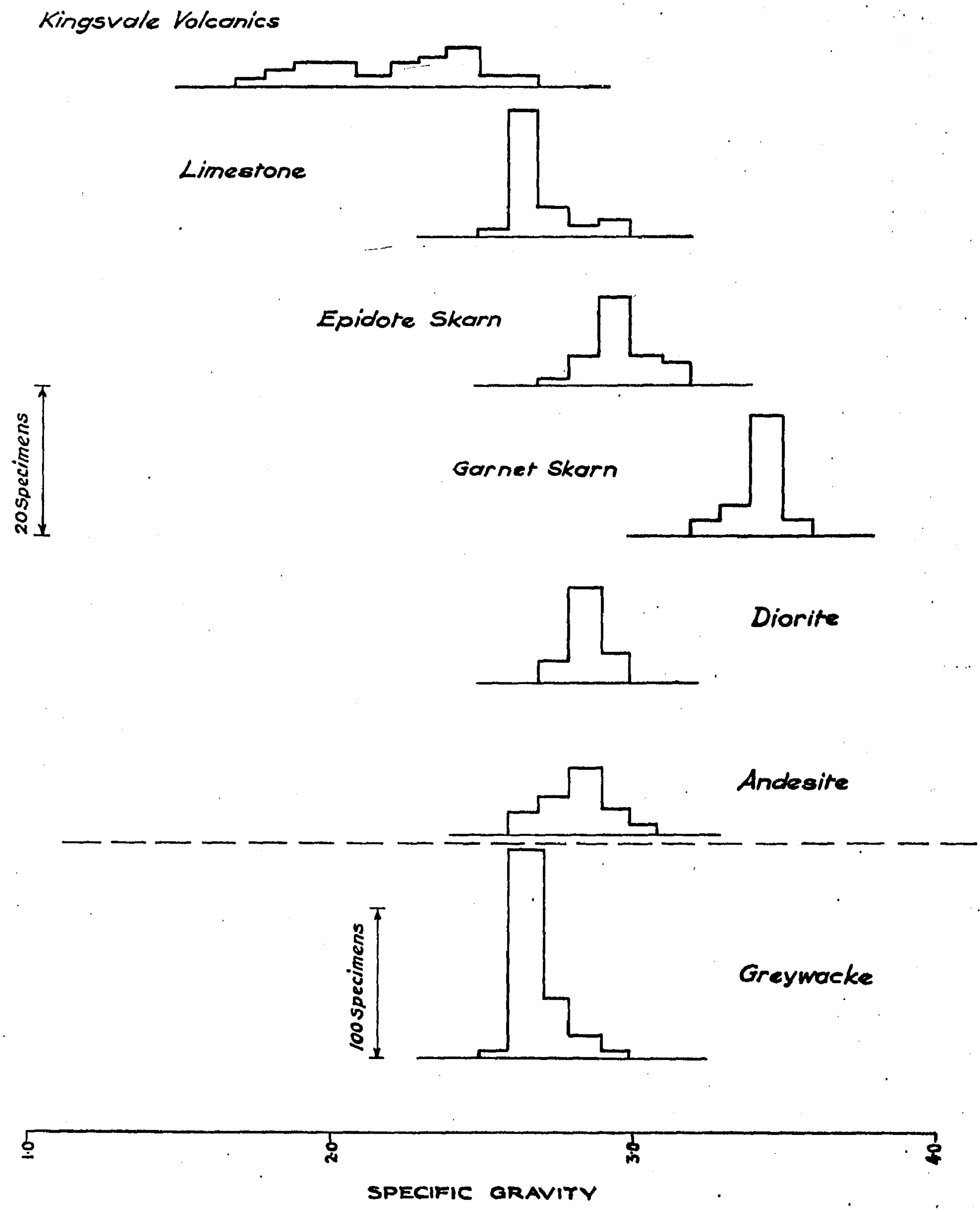


Figure 18

Table 1.

SPECIFIC GRAVITY TESTS

Rock	Number of Samples	Average Specific Gravity
Kingsvale	24	(2.28)
Greywacke	207	2.67
Limestone	25	2.69
Andesite	21	2.83
Diorite	20	2.84
Epidote skarn	25	2.96
Ore	210	3.18
Garnet skarn	24	3.39

The Kingsvale average is placed in parentheses because data were widely scattered; the average has little meaning.

Surface Gravity Surveys

Using the above specific gravity data, one can compute the gravity anomaly due to various possible targets beneath a flat, homogeneous earth. Again, a finite vertical dyke is a realistic model. The computation is not as simple as for spheres, and it is common to use the graticule method (Dobrin, 1952).

The maximum gravity anomaly was found for the following situations:

1. Density contrast = 0.5 gm/cc.
2. Depth extent = twice strike length.
3. Strike length = 200', 300', 400', 500', 600'.
4. Width = 150'.

5. Depth to top of body = 100', 200', 300'............

The results are presented in figure 18(a).

The above situations represent skarn ore, which has a specific gravity contrast of approximately 0.5 with Nicola rocks. Since the gravity anomaly varies directly with this contrast, it may be computed for other situations as well. For example, an orebody of the Number 3 type containing 6% pyrite (S.G. - 5.0) and 6% chalcopyrite (S.G. - 4.2) in 88% greywacke (S.G. - 2.67) would have a specific gravity of 2.90, or a contrast with normal Nicola rocks of about 0.2.

A number 3-type orebody may be more nearly equidimensional. Table 2 shows the gravity anomaly calculated for spheres at various depths, using the formula of figure 17.

Table 2.

GRAVITY ANOMALY DUE TO NUMBER 3-TYPE SPHERES IN UNIFORM NICOLA WALLROCKS

Radius (feet)	Size (Tons)	Depth to Centre (feet)	Maximum Anomaly (Milligals)
100	400,000	200	0.04
150	1,300,000	200	0.14
		400	0.03
		600	0.02
200	3,200,000	200	0.3
		400	0.08
		600	0.04
		800	0.02

The above estimates assume uniform Nicola wallrock. A vertical mass of andesite (S.G. - 2.83) would produce an anomaly of approximately 1/4 the intensity of an identically shaped body of skarn ore. Since andesite bodies are known to sub-outcrop, spurious anomalies of similar intensity to those expected from more deeply buried ore are to be expected. The same reasoning applies to dykes or apophyses of diorite (S.G. - 2.84). However, careful interpretation should indicate which explanations are more probable.

The noise level of surveys in areas underlain by Kingsvale volcanics will be much higher. This is due to (1) greater topographic relief over these rocks, (2) the probability of buried hills and valleys on the underlying Nicola-Kingsvale surface*, and (3) the wide variations in specific gravity indicated within the Kingsvale itself** (figure 18).

It appears to the writer that gravity surveys would be a feasible means of detecting near-surface skarn ore in Nicola rocks, where a signal of more than 0.1 milligal should be extractable from noise. However surveys over Kingsvale volcanics may be expected to have a signal extraction limit as high as 0.5 milligals, and to be much less useful. Even here, though, gravity should be considered as a means of checking anomalies found by other methods.

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* For example, a buried valley 200' long, 200' deep and 150' wide filled with material with a specific gravity contrast of 0.5 will produce a maximum anomaly of 0.15 milligals at a depth of 100' to the top.

**These variations may be the result of weathering and not be as important at depth.

Underground Gravity Surveys

Ore may exist at a depth too great for detection by a surface gravity survey. It is possible that an underground survey could detect such ore.

Underground surveys lack the freedom in two dimensions of surface surveys. If the gravimeter is placed vertically above or below an orebody, then the anomaly measured is equivalent to the peak calculated for the surface condition. However it is more likely that underground workings will pass beneath ore at some other angle. The anomalous reading for various situations may be calculated from standard formulae, such as that of figure 17 for spheres.

There are no underground workings at Craigmont sufficiently far from known ore and Kingsvale volcanics that could be used for an orientation survey. The writer is not able to assess the probable magnitude of background fluctuations. However it seems likely that anomalies of the order of 0.1 or 0.2 milligals could be extracted. Major skarn bodies could then be detected several hundred feet above or below the drift.

Underground gravimetry could only be used away from the current workings. In these, the proximity of skarn zones of unknown extent would make data extremely difficult to interpret.

Craigmont management has considered extending both the 3000 and 2400 levels to the west. Gravity surveys along the 3000 would be complicated because of the unknown distance (probably small) from the base of the Kingsvale volcanics. A survey west of the 2400, if it is extended, may be valuable.

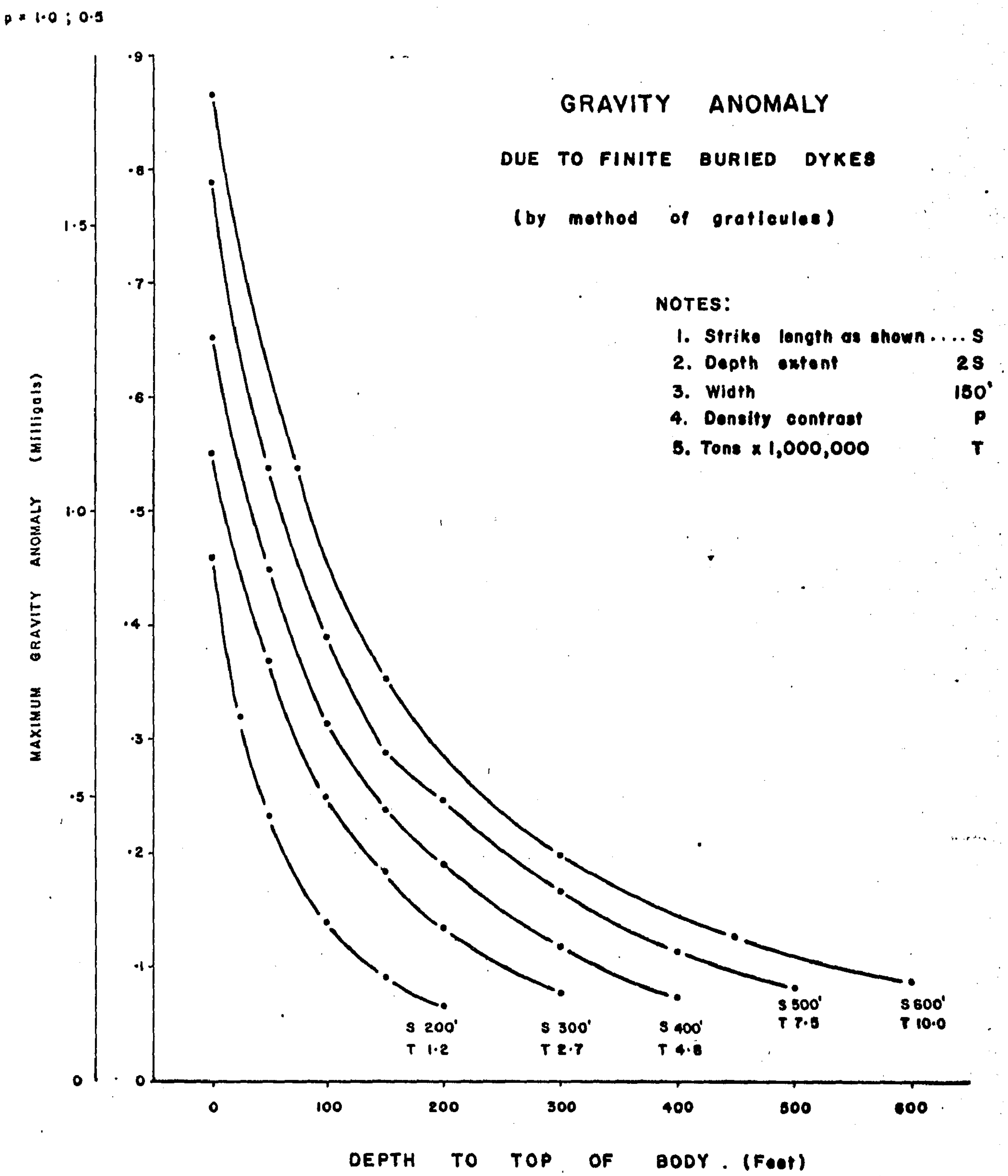
J. S. Sumner, in a paper to be published in the forthcoming Mining Geophysics Volume of the Society of Exploration Geophysicists, describes underground gravity surveys conducted at Bisbee, Arizona. He shows that skarn ore at Bisbee can be detected using this method. However, this ore is massive sulphides and occurs in relatively unaltered country rock without extensive barren skarn zones to confuse the pattern.

Although underground gravity surveys may be feasible away from the present workings, underground magnetometer surveys could be more useful. They are less expensive to perform and can provide more data (i.e., three-components). Provided skarn ore is expected to be magnetic, they would appear to be more appropriate.

Summary

Gravity surveys are a feasible method of exploration for both skarn and Number 3-type ore in areas underlain by Nicola wallrocks. Figure 18(a) shows the maximum anomaly expected for various situations, and indicates that large skarn orebodies (10,000,000 tons) may be detectable as deep as 800'. Such surveys are not expected to be as useful over Kingsvale outcrop, although similar large bodies within 200' or 300' of surface may be detectable.

Underground gravimetry should be useful away from areas of extensive skarn mineralization, but not in the currently existing workings.



p = 1·0 ; 0·5
GRAVITY ANOMALY
DUE TO FINITE BURIED DYKES
(by method of graticules)
NOTES:
1. Strike length as shown .... S
2. Depth extent 2S
3. Width 150'
4. Density contrast P
5. Tons x 1,000,000 T
MAXIMUM GRAVITY ANOMALY (Milligals)
1·5
1·0
·5
0
·9
·8
·7
·6
·5
·4
·3
·2
·1
0
S 200' T 1·2
S 300' T 2·7
S 400' T 4·8
S 500' T 7·5
S 600' T 10·0
0
100
200
300
400
500
600
DEPTH TO TOP OF BODY . (Feet)

Figure 18(a)

ELECTROMAGNETIC SURVEYS

Electromagnetic systems are capable of detecting massive sulphides, magnetite, graphite and electrolytic conductors. The minimum sulphide content normally detectable by EM methods varies from 10% to 15%, depending upon the degree of dissemination. Craigmont ore contains--on the average--7% sulphides; it is--on the average--not a good EM target.

Magnetite in the skarn orebodies will give an EM response. Two test surveys were made in 1959 using Noranda's "Junior EM" and the "Doolimeter". In each case the maximum response is reported to have been over the strongest part of the magnetic anomaly (C.C. Rennie, pers.comm.). This may be in part a function of proximity of ore to surface.

There are veins up to several feet wide of massive chalcopyrite in the main orebody; these could be detected by EM to a depth of, say, 200'. However, no massive sulphides have been observed outside of the high magnetite skarn, which is more easily and thoroughly explored for by magnetic methods.

Unless further information leads Craigmont geologists to suspect that massive sulphides alone are an important target, the thought of using surface EM to detect ore may be dismissed. The same reasoning applies to drill hole EM.

AFMAG

R. J. Perelli tested an AFMAG unit for E.P. Chapman Jr. on three lines over the Craigmont orebody. Chapman reports that adequate signals were obtained, and that the results are reliable. Some of the dip-angle data are shown in figure 19. No significant azimuth variations were observed.

There are no crossovers indicative of large, highly conductive masses on any of the three profiles. An inflection in the low frequency dip angle data occurs in the vicinity of the ore zone on profiles 8915 and 9615 but not on 7815. However, these can not be considered with certainty to be caused by ore. Other inflections to the south overlie Kingsvale volcanics; they probably reflect either faulting or conductivity variations within the volcanics.

The orientation survey was not continued as far away from the ore zone, especially to the north, as would be desirable. Unfortunately, mining has progressed to the point where a sufficient test can not now be made. Nevertheless, although the results do not eliminate the possibility that AFMAG may be useful in exploration at Craigmont, they do suggest that any response from ore would be no greater than background variations due to faults.

The writer dismisses AFMAG as an important exploration method for detection of ore at Craigmont. However, it may prove valuable as a means of mapping strong fault zones.

AFMAG TEST PROFILES

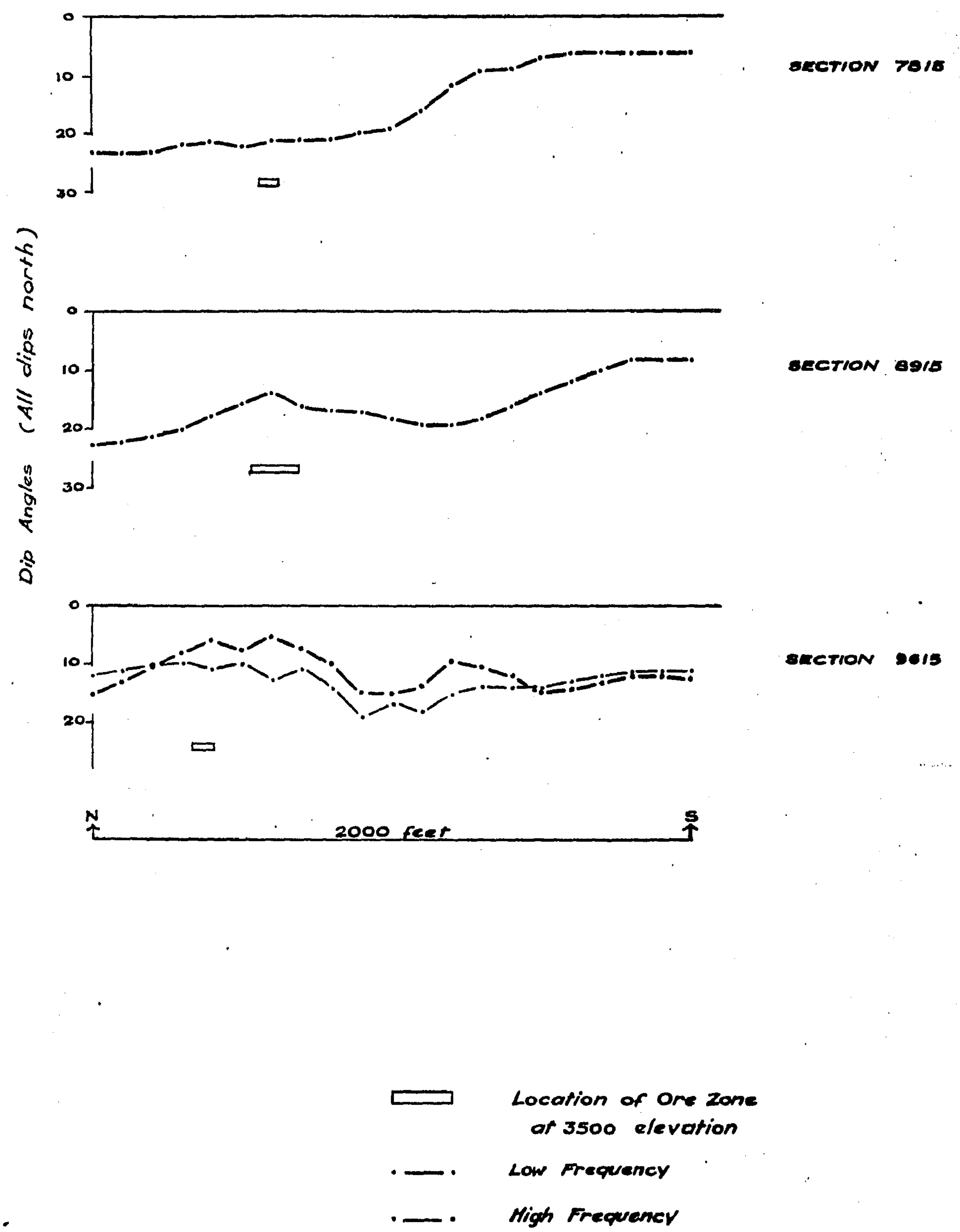


Figure 19.

INDUCED POLARIZATION (IP)

General

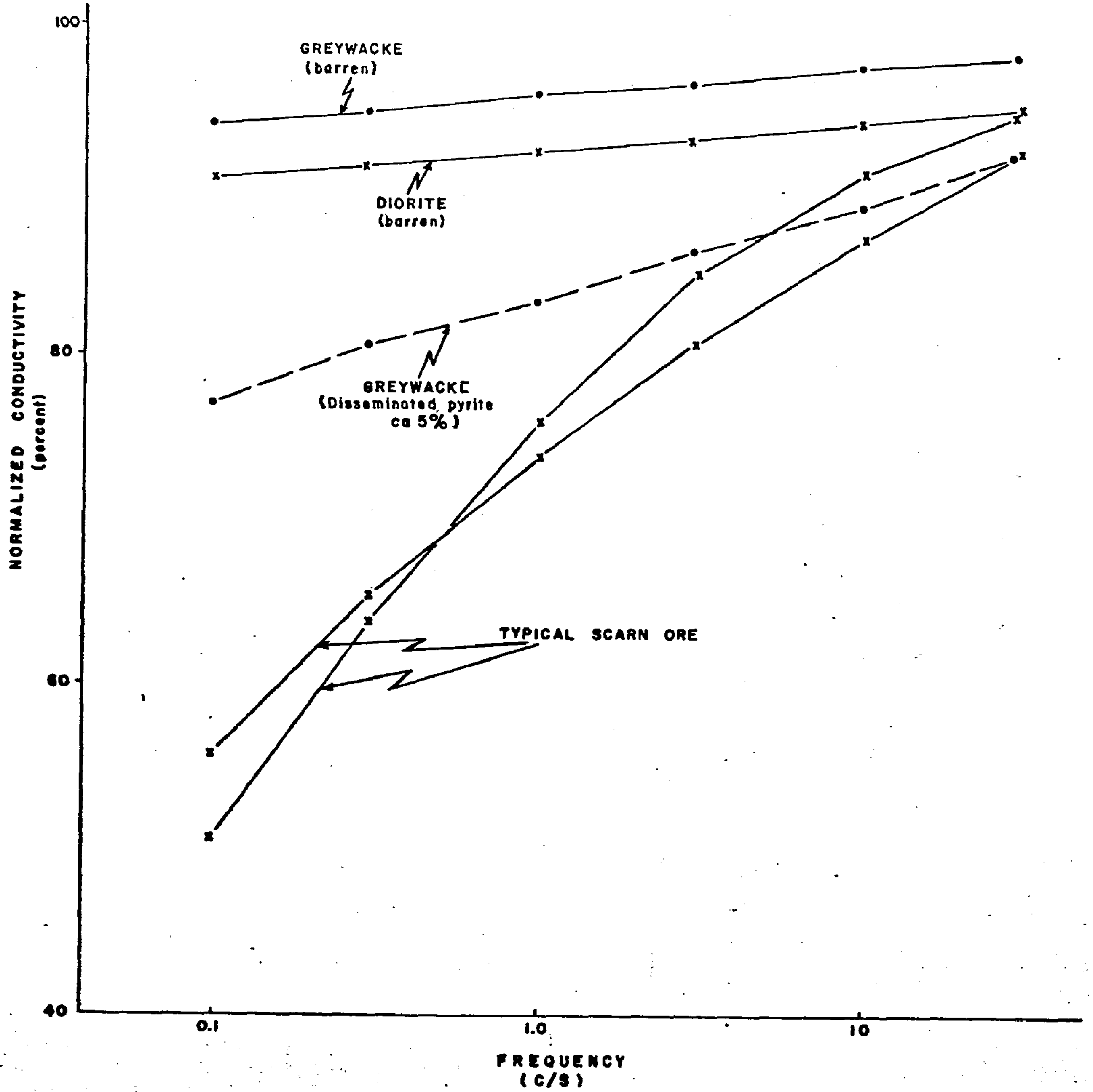
IP (Marshall and Madden, 1959) is a recently-developed geo-electrical method which responds to disseminated or massive metallic conductors such as the sulphides.

Craigmont ore contains disseminated chalcopyrite. It is theoretically a good IP target. However because of the high cost of IP surveys and their relative novelty, the writer decided to perform certain field and laboratory tests.

Laboratory Tests

In order to assess whether or not Craigmont skarn ore is substantially more polarizable than the country rocks, the author selected more than 40 samples of the various units for laboratory tests. Measurements of conductivity were made at frequencies from 0.1 to 1000 cycles per second. The change in conductivity with frequency is a measure of polarizability.

Results for five selected typical specimens are shown in figure 20, using the graphical method described earlier (Keevil; 1961). The two skarn-mineralized cores are substantially more polarizable than the barren greywacke and diorite cores; disseminated pyrite in greywacke showed



LABORATORY I.P. DATA

(Measurements courtesy of D.C. Fraser)

NOTES:

1. Results from selected "typical" speciments
2. Method of Keevil (1961)
3. Conductivity normalized at 1000 c/s.

Figure 20

intermediate polarization*. Results for the rest of the specimens were similar, with the exception of those samples high in specular hematite, which showed anomalous response curves. These data are presented in Fraser, Keevil and Ward (1964).

It is evident that the skarn orebodies at Craigmont are more polarizable than the country rocks, and should be detectable through field surveys.

Field Tests

Both time and frequency domain IP surveys were run over known ore in the early days of the mine. The contractors were Hunting Survey Corp. and McPhar Geophysics Ltd. respectively. Selected results are included as figure 21.

Both surveys suggested weak responses to known ore mineralization. However, neither provided an adequate test of IP. The time domain data were obtained only in the "anomalous" zone, and provide little information on background variations. This survey should have been continued to the north and south for another 1,000'. On the other hand, the frequency domain data are more widely spaced than one would prefer. The example given using a

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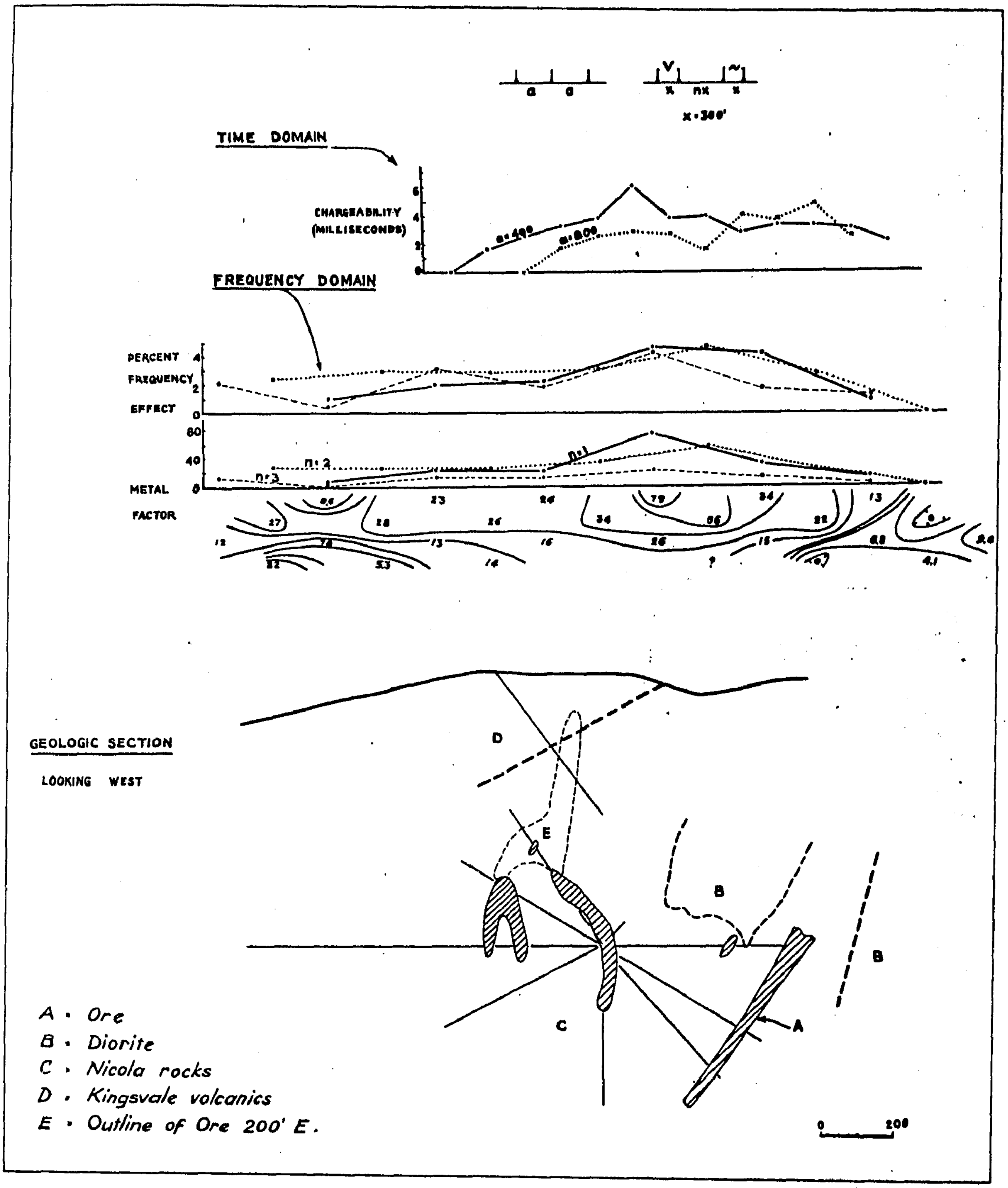
* Polarizability is indicated by the change in conductivity with frequency; large changes reflect high polarizability.



SELECTED I.P. RESULTS OVER KNOWN ORE

(After Fraser, Keevil and Ward; 1963)

Figure 21

300' dipole-dipole array measured data only at 300' intervals. Since the orebodies are less than 100' wide in most parts of the mine, this spacing is far too great. Information at 50' or 100' intervals would be preferable.

The writer had hoped to counter these objections with his own observations, using equipment belonging to the University of California*. However, the equipment was not powerful enough for use in areas of low resistivity. Since the only areas of known ore which could be utilized were covered by more than 100' of Kingsvale volcanics, with resistivity of 10 to 50 ohm feet, tests over ore were not possible.

The low-power equipment was used to assess background variations in other parts of the property. Data were obtained over barren greywacke and diorite and over greywacke carrying about 5% pyrite. Scattered data were obtained over more resistive parts of the Kingsvale volcanics, but these may not be representative.

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* This equipment was built by McPhar Geophysics Ltd., and is known as their "lightweight portable unit".

Typical profiles are shown in figure 22. Background over diorite is very low, and those values of percent frequency effects which could be obtained over the Kingsvale were low as well. Background over Nicola rocks is somewhat higher, perhaps due to disseminated pyrite. Where 5% pyrite can be seen in outcrop, the IP data are decidedly anomalous.

Comparative results over known ore are included in figure 22. Although these were extracted from the test survey run in 1959 with different equipment, the percent frequency effects should be comparable. Except for the pyritic greywacke, the response over ore is markedly greater than background.

In addition, results in the time domain were obtained by Hunting over Kingsvale volcanics and Nicola rocks. These background data were lower than that obtained over the ore zone.

The field and laboratory results both indicate that IP is a feasible method of exploration for Craigmont-type orebodies.

Drill Hole IP

Drill hole IP systems are still in the development and testing stage. Electromagnetic coupling problems have restricted frequency domain surveys to 2-hole methods. The time domain technique suffers less from this problem, and one working system for single holes has been developed (Wagg and Seigel, 1963). Hunting Survey Corp. is working on a similar system.

SELECTED TYPICAL I. P. RESULTS
(Field tests; frequency domain)

(x = 200')

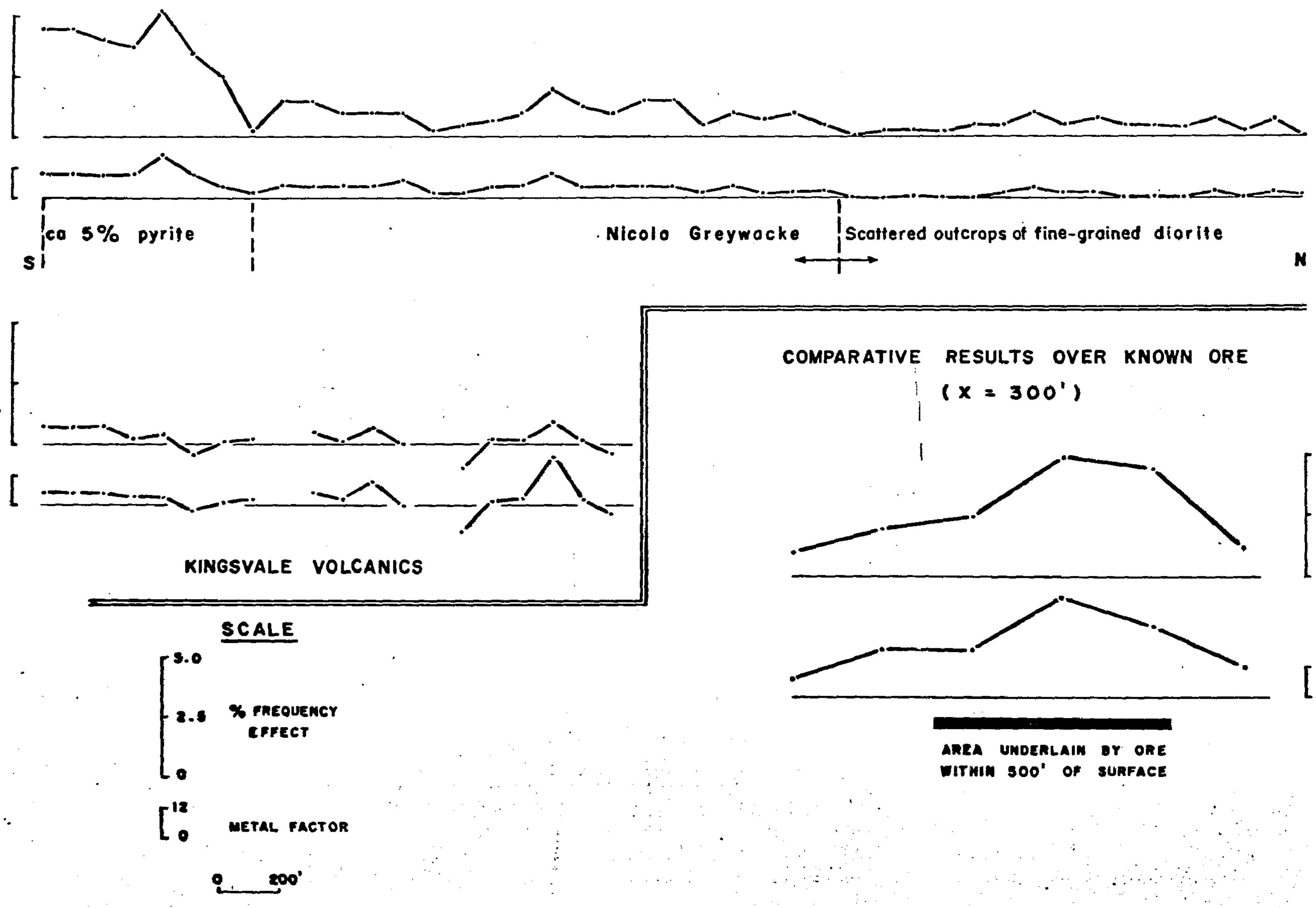


Figure 22

Single-hole equipment is more versatile, and is preferable. Dr. N.R. Paterson of Hunting has offered to perform an orientation survey of their equipment when it becomes available. If this orientation survey is unsuccessful, others should be considered. The only other drill hole geophysical system which appears feasible at Craigmont is the magnetometer; it will only detect magnetic bodies, and could miss ore of the Number 3 type.

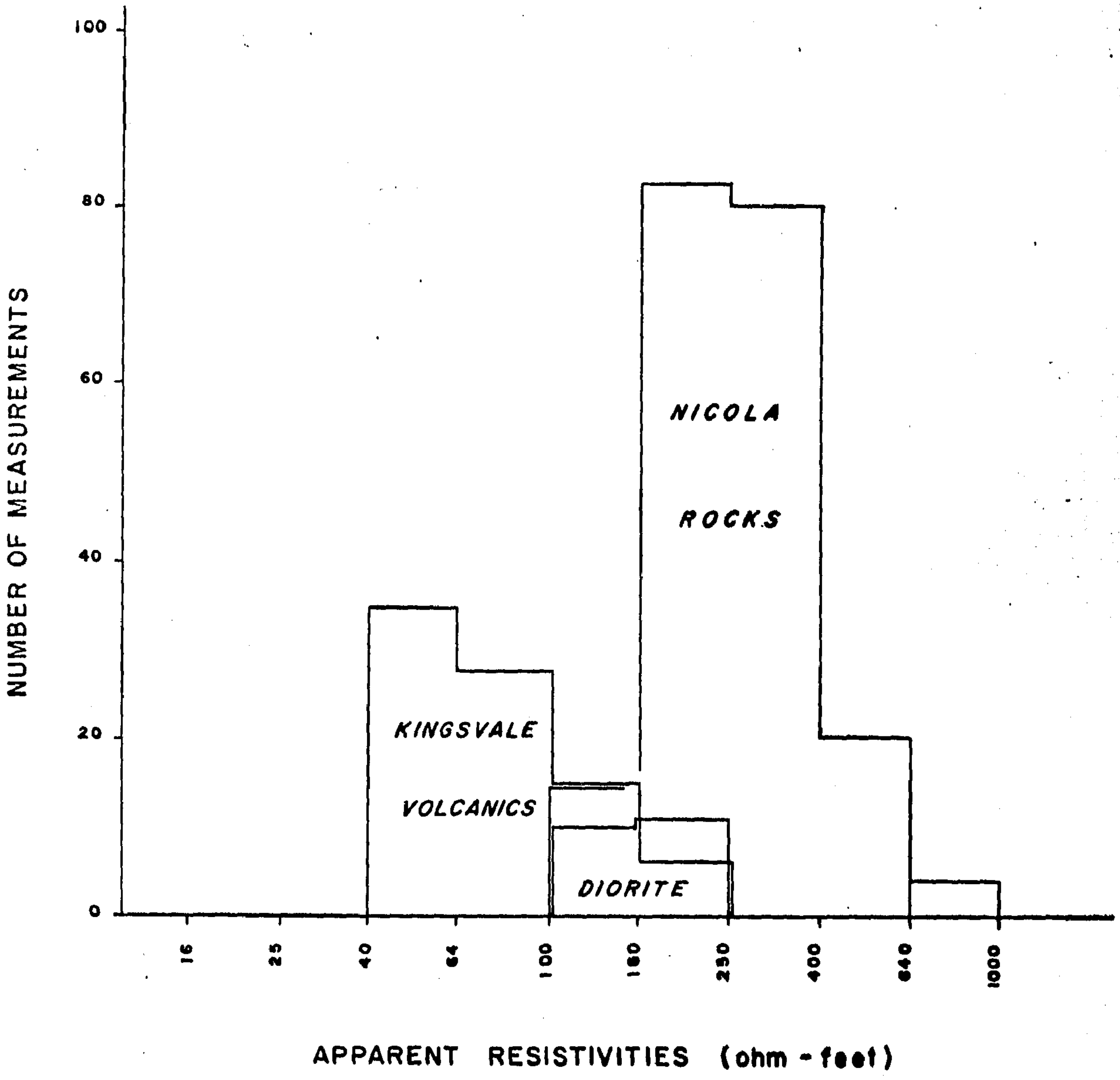
RESISTIVITY

Both types of IP survey require the measurement of resistivity. Thus if one chooses to use IP in the exploration program, he will at the same time produce a resistivity survey.

However, resistivity surveys alone are substantially less expensive. They do provide different information which may be of some value by itself. Although resistivity probably would not detect Craigmont ore directly, it may provide important geological information.

Figure 23 shows the resistivities obtained in Kingsvale, diorite and Nicola rocks during orientation surveys.

VARIATION OF APPARENT RESISTIVITY IN CRAIGMONT ROCKS



NOTE: Data taken during I.P. survey using dipole - dipole configuration with electrode seperations of 100 and 200 feet

Figure 23

It is evident that differentiation by resistivity between areas underlain by Kingsvale and either Nicola rocks or diorite should be quite effective. It may also be possible to distinguish between areas of diorite and Nicola rocks. In addition to such distinctions, resistivity data can be used to estimate depth of overburden and possibly even of Kingsvale volcanics, and to detect the presence of water-filled fault zones.

Thus while a resistivity survey may not lead directly to discovery of ore, it can be of assistance in interpretation of geology, and be a useful indirect exploration technique.

RADIOACTIVE METHODS

Ordinarily, radioactive methods would probably not have been selected as a possible exploration method at Craigmont. However, it had been reported to Craigmont geologists that an airborne scintillometer traverse over the then-undiscovered orebody in 1955 had shown anomalous gamma response. This could have been due to some unsuspected radioactive mineral associated with the ore, to potash alteration, or some other source.

A traverse from 1,500' north of the orebody (over diorite) to 200' south of it (over Kingsvale), showed no anomalous response on a continuously-monitored scintillometer. During the traverse, 12 random specimens of ore and Nicola rocks were brought near the scintillometer probe. Two of these-- a 6" boulder of K-feldspar and quartz and a 36" boulder of magnetite, epidote and chalcopyrite--produced very slight anomalous responses of 0.008 milli-roentgens per hour over background 0.004.

Core specimens at 50' intervals in 2 holes extending 1,000' north and south of the orebody were brought up to the probe. None showed any anomalous response. Finally, 25 randomly chosen specimens of ore were tested, again with no observable response.

It appears unlikely that the reported airborne anomaly was due directly to ore at Craigmont. If it was in fact observed in the vicinity, it seems most likely that it emanated from some part of the Kingsvale volcanics.

GEOCHEMICAL METHODS

General

The writer will use "geochemistry" in the sense of geochemical prospecting. As such, it deals with trace analysis of natural materials for elements, normally metals, which may indicate the presence of ore. Materials analysed may include rock, soil, sediments, vegetation, water and even air.

Some geochemical prospecting had been done prior to the writer's arrival at Craigmont. In fact, the discovery of the orebody has been attributed partially to geochemistry by Renshaw and Price (1958). In succeeding sections, both the early and more recent work will be discussed under headings denoting the material sampled.

Soil Sampling; Surveys

Renshaw and Price (op.cit.) describe the results of a simple "soil sampling" survey in which soil collected at grass roots was analyzed for its readily-extractable copper content using a cold acetic acid extraction and rubeanic acid estimation (Warren and Delavault, 1958).

The results were presented in figure 4.

Subsequent to the initial survey, run in December and January, 1957 and 1958, Noranda Mines Limited attempted to duplicate the results. Their results, obtained in August 1958 are shown in figure 24.

It has been reported in the literature (Rennie et al, 1960) that this second survey did not "duplicate the (original) anomaly". This appears to be true. However, precise duplication of any geochemical survey is unlikely. Cold-extractable copper tests are imprecise (Hawkes, 1963). Slight differences in material sampled or in analytical procedure can cause marked variation in results. The two surveys were conducted in different seasons. The writer has seen the "spots" from the original survey, and can attest to their reality*; what variables caused the poor correlation is unknown.

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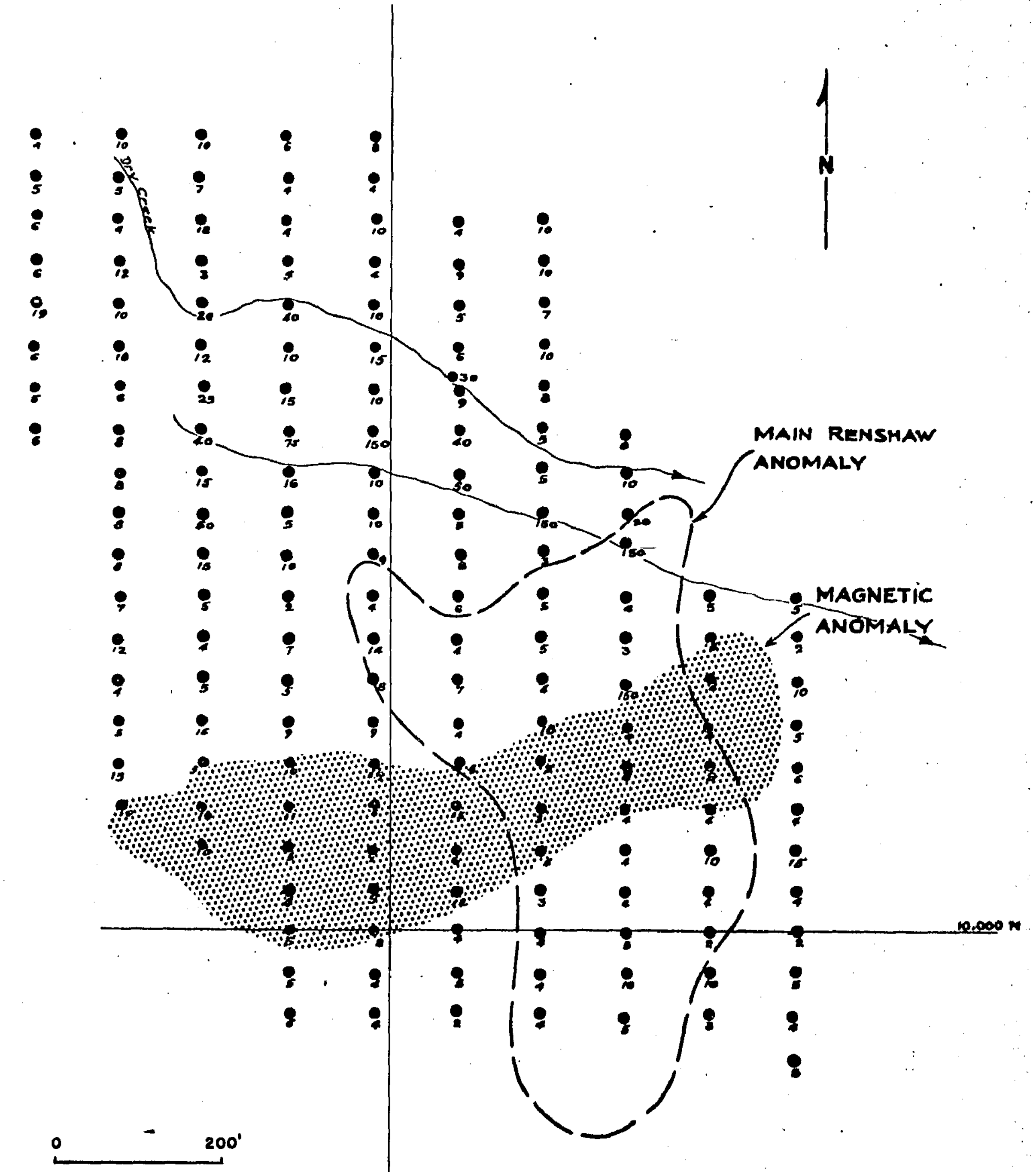
* The amount of cold-extractable copper is determined by the size of spot on a piece of treated paper. These papers were retained in Craigmont files.

NORANDA GEOCHEMICAL DATA

COPPER IN SOILS



NOTE:
Values are ppm
Cold-extractable Cu in soils;
samples taken at grass roots.

Figure 24

Soil Sampling; Tests

Two tests have been made to determine the effect of depth of sample on results.

J. J. Brummer (unpublished information in Craigmont files, 1958) sampled soil in 5 vertical profiles in the walls of a trench which exposed low grade copper mineralization (0.7% copper over 90'). The profiles are shown in figure 25.

These data suggest two things. First, high copper values occur in the soil immediately above bedrock high in copper, but do not persist for more than a foot; values above that are low and probably represent background. Second, the upper 2' to 5' contains anomalously low amounts of cold-extractable copper. The same 2' to 5' is described as a "sandy boulder till" as opposed to "dense clayey till with few boulders" below. It seems likely, in view of data to be described next, that the lack of cx-copper in this upper zone is due to leaching. Brummer's trench has been eradicated by mining and can not be re-visited.

The writer performed a similar test in a deep trench over probable barren rocks near Promontory Hill. The trench was put down to test a magnetic anomaly but did not reach bedrock; later a churn drill hole returned chips of diorite suggesting that the anomaly was caused by a diorite dyke. An IP survey in the area suggests that no mineralization is present. The geochemical results are shown in figure 26.

COLD-EXTRACTABLE COPPER IN SOILS

(Profiles in walls of trench; bedrock 0.7% copper)

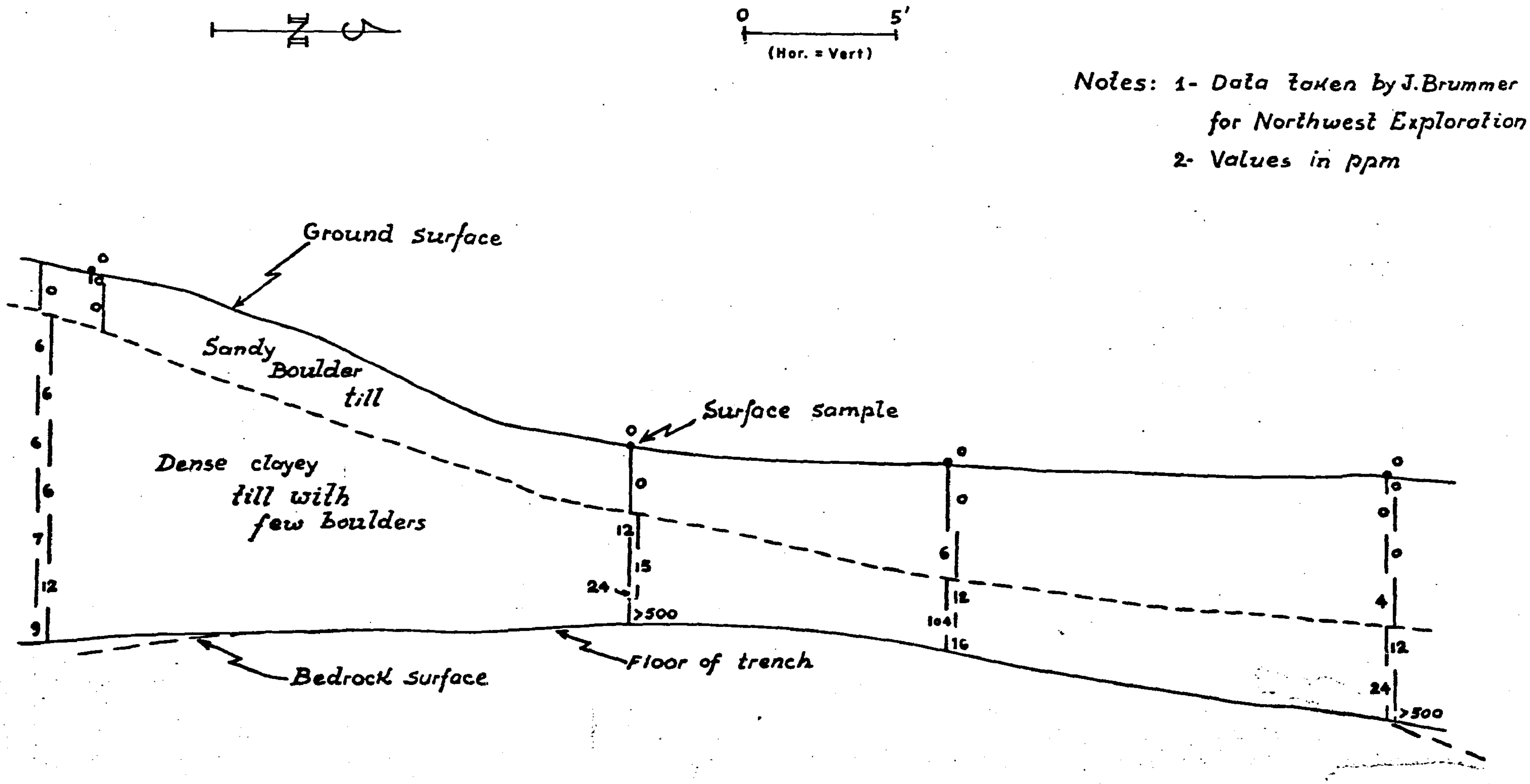


Figure 25

COLD-EXTRACTABLE COPPER IN SOILS

(Profiles in trench wall)

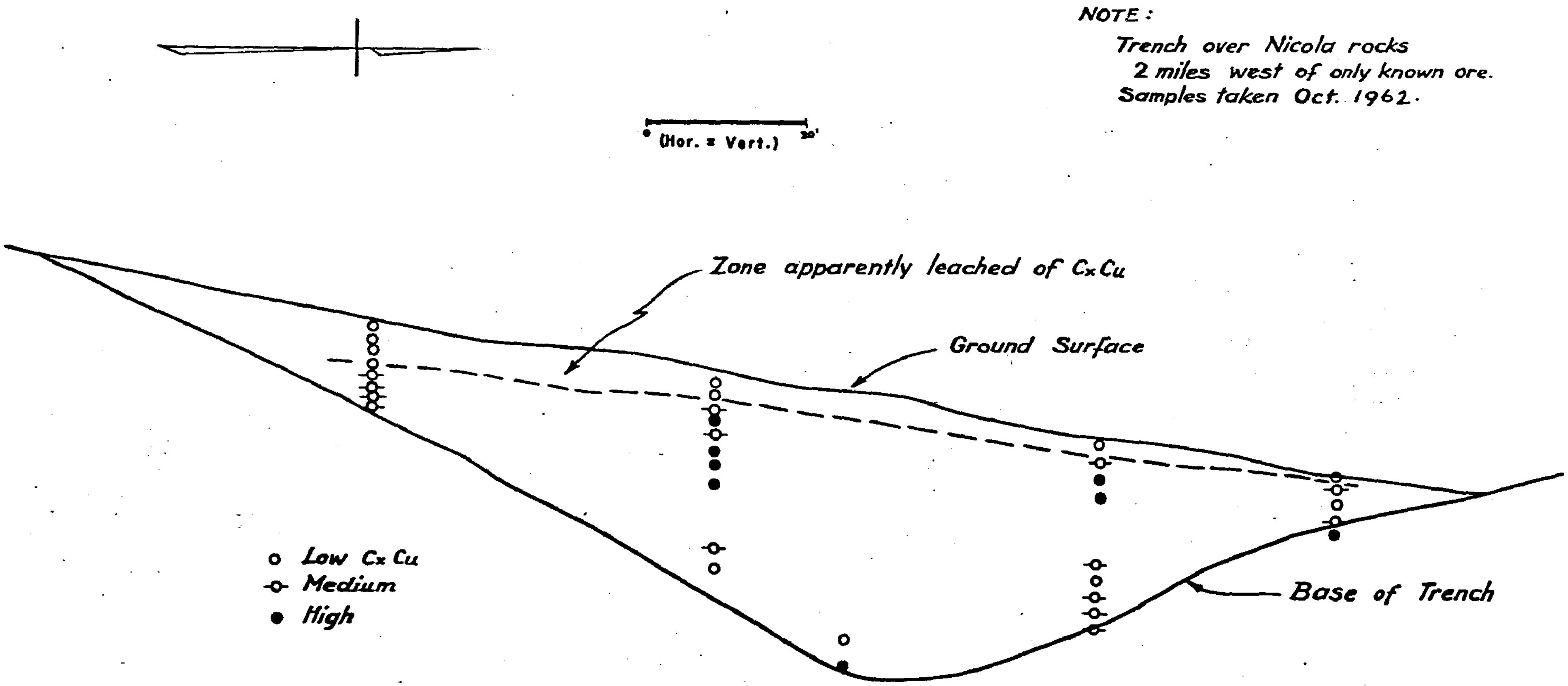


Figure 26

These corroborate Brummer's data. The upper 5' appears to have been leached of cold-extractable copper. In this case, there appears to be no difference between the till in the upper and lower zones; both are brown, fairly sandy, and contain a moderate amount of boulders.

The writer performed a qualitative test to show that the same soil is leached of calcium carbonate as well. A constant volume of 1:2 HCI was added to a constant weight of sieved (-80 mesh) sample. The degree of effervescence was estimated visually. Results are shown below.

Depth (feet)	Number of Samples	Degree of Effervescence		
		None	Weak	Moderate
0 - 5	14	9	3	2
5 +	16	1*	4	11

*This sample was from 6', and perhaps should have been in the surface group.

These suggest that the upper 5' contains less calcium carbonate than the deeper parts of the soil profile.

These two profiles may explain the lack of correlation between the Noranda and Renshaw soil sampling surveys. If the upper 5' of soil is partially leached of copper, results of such surveys may be expected to be erratic.

These tests make one skeptical of the value of soil geochemistry at Craigmont. Areas in which bedrock is high in copper may be indicated by nearby cupriferous soils, but the copper is liable to be placed there by local drainage, and be only indirectly related spatially to the metal source.

Soil sampling is an inexpensive means of locating areas high in copper. Interpretation of one such survey led to the discovery of the Craigmont orebody. Therefore, the method can not be dismissed from consideration entirely.

Vegetation Sampling (Biogeochemistry)

Often it is more convenient to sample soils than vegetation. Anomalous metal in the latter enters the soil upon death and decay, so that metal patterns may be related. Soils tend to be more homogeneous in metal content; each part of a plant (e.g., second-year twigs vs. first-year twigs) often has a different background. Also, soils are usually more widely distributed than vegetation of any one type.

However, when the upper parts of the soil profile are barren of metal, biogeochemical methods may be useful. This appears to be the case at Craigmont.

The choice of sample material is critical. The plant must be distributed widely enough that a reasonable coverage of the property is possible. Also, the particular part of the plant which provides the best pattern must be selected. If the orebody was newly-discovered and undisturbed, it would be a simple matter to test all reasonable parts of all common plants on a traverse from wallrocks across ore, and to choose the system giving the best pattern, if any, as an exploration method. However this is no longer possible because of the disruption by mining.

Newmont (June 1959) sampled an unknown part of trees on several traverses over the orebody before mining had begun. They report one "anomalous" (H in figure 27) and 3 "possibly anomalous" (M) sites of 62 sampled; no quantitative figures are available.

Of the 62 samples, 47 were Jackpine, 11 Douglas Fir, 3 Spruce and 1 Mountain Fir. The anomalous sample and 2 of the 3 possibly anomalous ones were Douglas Fir, the other being Jackpine. It is quite possible that these merely represent a higher background of copper in Douglas Fir, and are not representative of anomalous copper in the vicinity at all.

H. V. Warren (pers.comm.) sampled second-year twigs from trees several thousand feet east of and downhill from the known ore. The specimens were analysed for copper and compared with similar data from elsewhere in British Columbia. They were anomalous. However, this information is of questionable value, since the specimens were taken after mining had begun (fall of 1962), and may well have been contaminated by copper-rich dust from the pit operation.

At this point, there appears to be no convenient way in which a reasonable orientation survey can be carried out at Craigmont. A protracted study does not seem to be warranted.

NEWMONT GEOCHEMICAL DATA
COPPER IN TREES

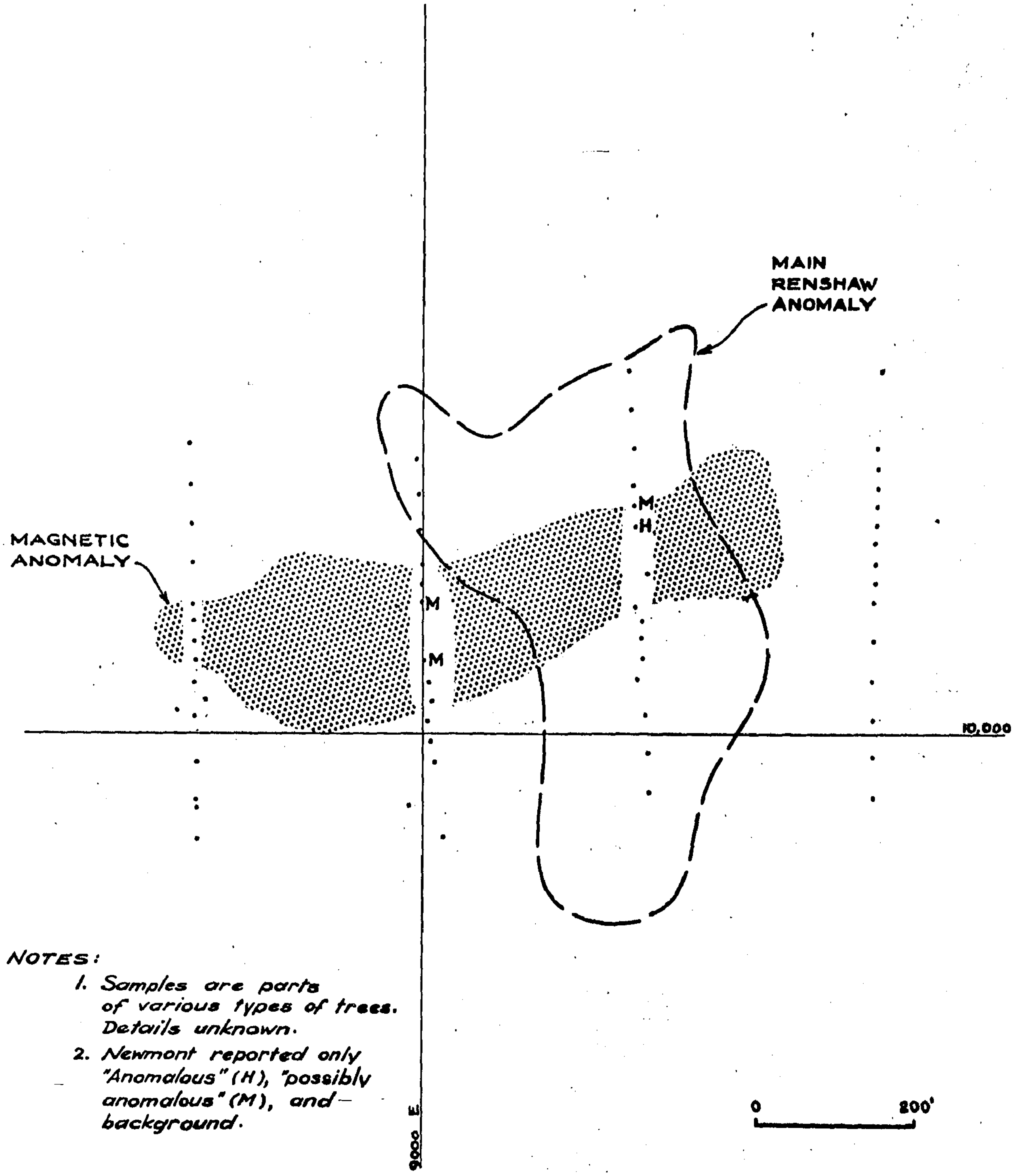


Figure 27

Stream Sediment Sampling

Analysis of active stream sediments for trace metals is the most common form of geochemical prospecting. Detectable anomalies often occur several miles downstream from base metal orebodies (Hawkes and Webb, 1962). However, such patterns are usually much shorter in limestone areas, as the copper ion travels more readily in more acid environments.

H. V. Warren (pers.comm.) carried out reconnaissance stream sediment sampling in the Craigmont region before the orebody was known. His closest sample was about a mile from the orebody, and this was not considered anomalous. By contrast, samples several miles downstream from the Bethlehem deposit were anomalous. This suggests that the limey Nicola rocks at Craigmont may have depressed the copper dispersion pattern. Alternatively, it may merely reflect the greater surface exposure of copper-rich rocks at Bethlehem.

During trips made for other reasons, the writer has sampled and analysed stream sediments from small streams on various parts of the property; no attempt was made to cover the property systematically. Interesting variations exist in cold-extractable copper content, both in streams draining Nicola rocks west of the Kingsvale overlap and in intrusive rocks to the north; the latter streams tended to have a higher background. Detailed sampling of all streams, no matter how small, may be an inexpensive means of directing exploration attention toward more favorable areas. Special attention should be directed towards seepages, where changes in oxidation potential may cause precipitation and accumulation of metal at the seep.

Rock Sampling

Trace analysis of rocks is a little-used method of geochemical prospecting. James (1957) reports an example in which the arsenic content of Precambrian schists increased as auriferous quartz veins were approached.

The amount of minor and trace elements in rocks depends on (1) the major element composition, and (2) the mineralogy in addition to (3) hydrothermal action. Thus a traverse through different rock types may reveal large variations in, say, copper content which depend only slightly upon proximity to ore. The same applies to other "pathfinder" or "indicator" elements (Hawkes and Webb, op.cit.). These unwanted fluctuations may be reduced and desirable halos emphasized by making all samples (1) the same rock type or (2) the same mineral (separated from any rock) or by measuring the major element composition as well as the minor and working with ratios between the two.

The writer chose several from the large number of possible combinations. Samples of core were taken from a long drill hole away from ore into the north wallrocks. Samples were taken geometrically, with no regard for rock type or major-element composition. They were subjected to semi-quantitative spectrographic analysis. Results are shown in figure 28. No halo is indicated for copper, molybdenum or calcium. Diorite appears to contain more

SOME SPECTROGRAPHIC ANALYSES OF DRILL CORE (DDH 35-U-35)

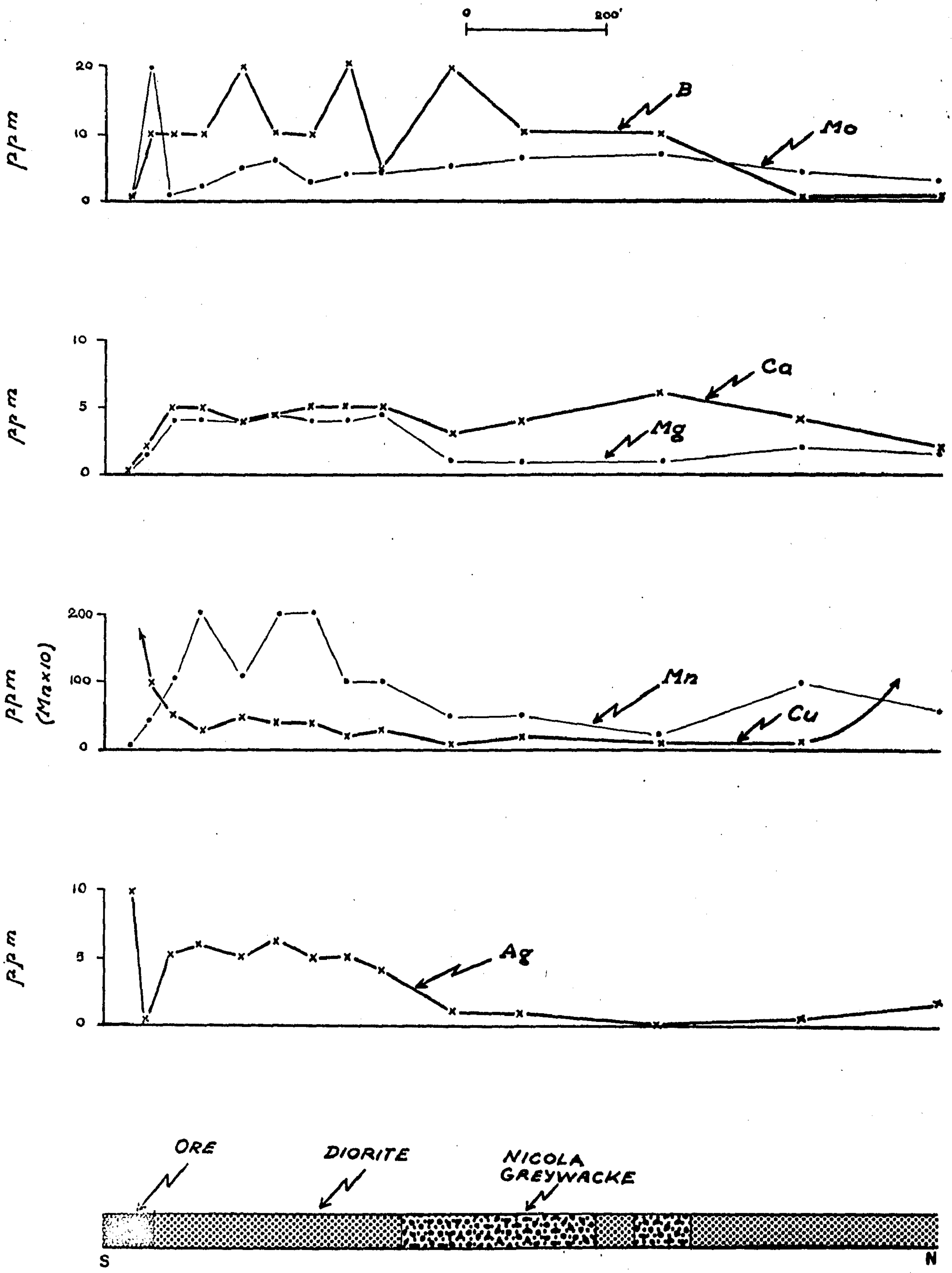


Figure 28

manganese, magnesium and silver than greywacke. Boron data show wide scatter, but a tendency to diminish away from ore. No obvious halos are indicated, although further detailed work may be warranted in an effort to explain these variations. This is probably best done during and after the alteration research mentioned on page 14.

As a second test, the writer obtained quantitative analyses for copper, manganese and zinc in limestone close to ore. Zinc and manganese were chosen because of their common association with copper in Cordilleran ores, because their distribution often suggests greater mobility from a center of mineralization than copper, and because they both form carbonates. The results, shown in figure 29, suggest a possible minor halo for copper (based on one analysis) and none for zinc; data for manganese are erratic. Any halo which may be present appears to be too small to serve as an exploration tool.

Mercury Analysis

Recent publications (Hawkes and Williston, 1962; Williston, 1963) have described anomalous mercury halos around several mineral deposits and districts in the Western Cordillera. The most striking halos occur around silver-zinc mineralization, but several have been reported around copper as well. Although both rocks and air have been used, the most common sample material is soil. Halos are reported to be present in some cases even though the ore zone is capped by barren later volcanics.

VARIATIONS IN
COPPER, ZINC, AND MANGANESE
IN LIMESTONE APPROACHING ORE

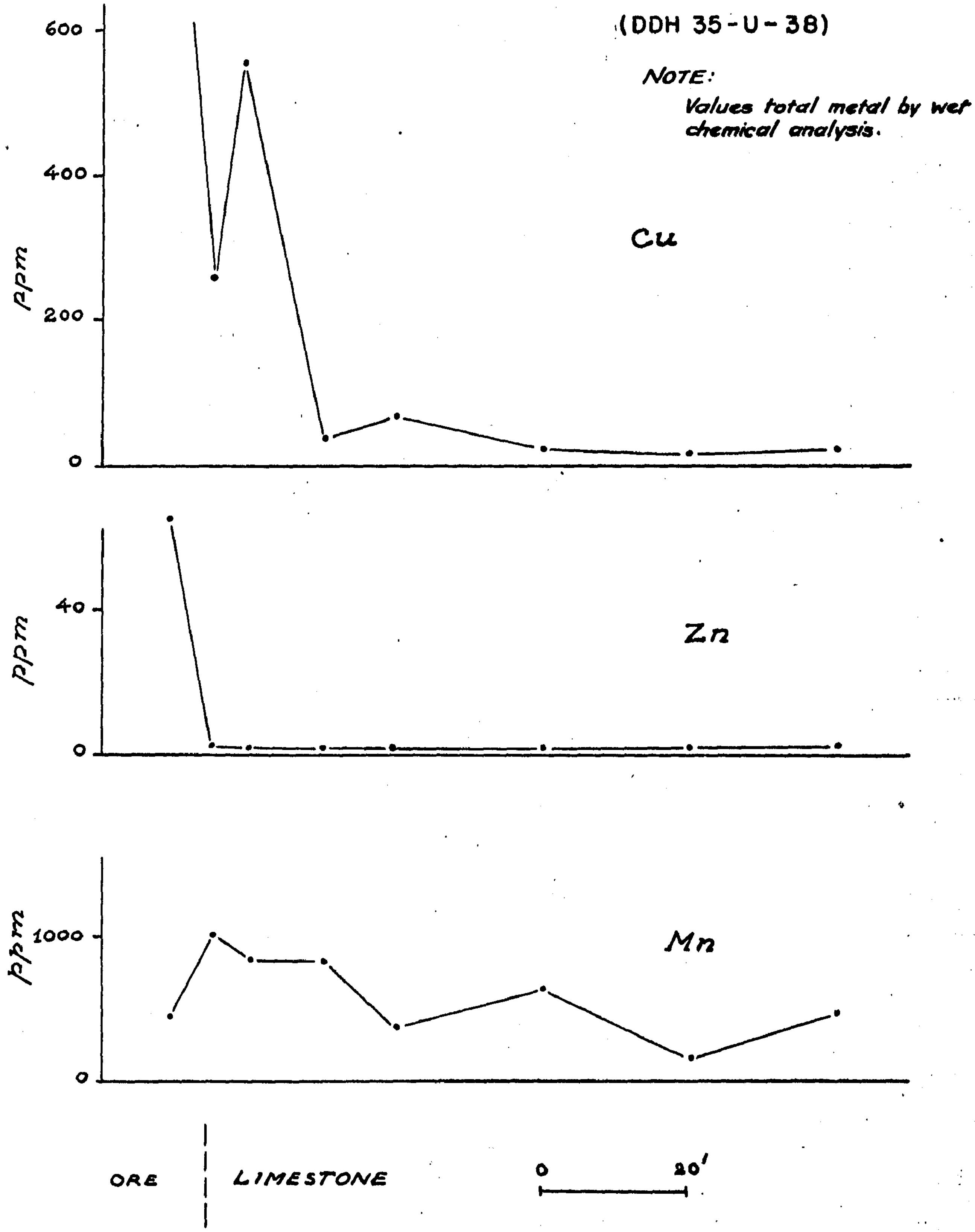


Figure 29

The writer collected samples of soil from 9" below surface, as suggested by Williston (pers.comm.). Approximately 30 samples were taken along a profile two miles long across the west end of the orebody. Most were taken over Kingsvale volcanics, but eight at the north end of the profile were of soil overlying diorite. Analyses by Williston showed no significant variations in mercury content relative either to the location of the orebody or to underlying rock type.

SUMMARY

Of the methods considered, the following appear to be technically feasible for locating ore of one or more of the types expected at Craigmont:

- airborne magnetometer surveys
- surface magnetometer, gravity and IP surveys
- underground magnetometer and gravity surveys
- drill hole magnetometer and IP surveys
- stream sediment or seepage sampling.

Other methods considered are assumed to be unproven or less liable to result in detection of ore.

Of these, airborne and surface magnetometer surveys have already been performed over much of the Craigmont property and its vicinity, and two targets have been selected for further investigation. These two methods are included with the others--which have been employed less thoroughly if at all--for the sake of completeness.

C. DESIGN OF EXPLORATION PROGRAM

INTRODUCTION

It is not enough to decide that certain exploration methods are technically feasible. Mere feasibility does not ensure that use of any or all is wise in an exploration program. The advisability must also take into account economics, for the goal of exploration is "ore"--a mineral deposit that may be located and mined at a profit.

In the next few pages, the writer diverges from description of Craigmont and its exploration problems, and discusses methods of evaluating economic desirability of various programs. These methods will then be used on the Craigmont situation.

EXPECTATION OF PROFIT

It may be assumed that exploration programs are not undertaken without expectation of profit. For purposes of this thesis, that profit will be assumed to be measured in monetary units.

Since exploration programs are seldom--if ever--assured of success, the expectation must be based upon "the law of averages", or probabilities. The person formulating the program is presumed to believe that "the odds are reasonable" for each project upon which he embarks.

> If, for example, he is risking $100,000 on a chance to discover an orebody worth $10,000,000, he should feel that the chances of success are at least as good as 1 in 100. If so, the "probability of success" makes the venture attractive.

No matter what the probability of ore the outcome of an exploration venture will--in essence-- be either discovery or failure. However, for a large number of cases, the net result will approach that predicted.

> For example, a firm that drills 1,000 targets each with 1 in 100 chance of being worth $10,000,000 and each costing $10,000 to test will spend $10,000,000 and should locate ore worth close to (1,000)(.01)($10,000,000) or $100,000,000.

In mineral exploration, one seldom tests two identical situations. The costs, potential values and odds all vary. Nevertheless, the net result of many ventures will approach that predicted by "the law of averages". In this case, the net value will approach the algebraic sum of all the probabilities of success times the potential values less the probabilities of failure times the costs.

$$\text{i.e., NET} = \sum_{i=0}^{\infty} \left(p_{(s)} . V_{(s)} - p_{(f)} . C_{(f)}\right)_i$$

There can be little argument with this in principle. In practice, however, it is difficult to determine the probability of success of an exploration venture. Two geologists are liable to assign the same possible event a different probability. Neither is necessarily wrong; there are just too many unknowns involved, and the assignment becomes an expression of opinion rather than fact.

Because of this imprecision, few geologists or engineers are willing to assign probabilities to the possible results of an action. The consensus--in the writer's experience--appears to be that the use of numerical odds is meaningless and may be misleading, and that realistic numbers are impossible to assign.

Nevertheless, the mere act of recommending or adopting any exploration venture implies that the individual involved believes the probability of monetary success to be favorable. If this is so for a large number of ventures, then the appropriate odds and values must have been used--albeit implicitly--for each. Only if this is true can there be any consistent expectation of profit. By his act of choosing ventures, that individual has stated that, in his opinion, the probability of success of each one and of the whole set of ventures is favorable. If it were not, then none would have been chosen. He has implicitly assigned probabilities.

PERSONAL PROBABILITY

The phrase--in his opinion--is the key. These implicit probabilities are not derived from repeated events. Neither are they based on sound, precise theoretical principles. Instead, they result from experience with more or less similar situations; they depend upon some combination of many geological hypotheses and possibilities. Since each geologist has a different background of experience, and favors a somewhat different set of hypotheses, it is to be expected that he will assign an event a different probability than does another geologist.

This imprecision distinguishes such probabilities from those of the classical statistician*. Savage (1954) distinguishes the two by adopting a new term: "personal probability". The personal probability of occurrence of an event is a statement of opinion.

> For example: "The chance of this well striking oil is, in my opinion, .1, or 1 in 10".

In general, two statisticians will assign the same classical probability to an event if they will assign one at all. On the other hand, just as opinions differ between people, so will personal probabilities.

Geologist 'A' might assign quite a different personal probability to an event than geologist 'B'. Neither is necessarily inaccurate. The difference merely reflects different opinions. In fact, the only time a personal probability is "inaccurate" is when it incorrectly describes the opinion of the person involved.

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* Some (Allais, 1957, Slichter, 1960) have described methods of applying classical probabilities to exploration. However, to do this one must have (1) statistical data from a large number of similar situations, or (2) distinct processes through which precise numerical probabilities can be theoretically derived. It is the writer's belief that economic mineral deposits are less well understood than this approach would suggest. Hence the extension of their ideas as used herein.

The use of a parameter such as this may be criticised because of its imprecision. However, the writer prefers it to even less precise descriptive terms such as "fair", "good", "poor", "probable", "possible" and so on. A "fair chance" may mean 1 in 100 to an optimist and 1 in 2 to a more pessimistic person. At least "0.01", on the one hand, and "0.5", on the other, mean the same thing to all people.

The writer feels that the only major objection to personal probabilities is that they may tend to make one forget the limitations of his estimates. The use of numbers should not add credence to things that are not credible.

Henceforth, the personal probability of an event will sometimes be referred to as 'p' for convenience.

PRESENT VALUE

In addition to assessing the probability of discovery, the potential value must be estimated before the wisdom of beginning a particular exploration program may be ascertained.

It is customary in the mineral industry to reduce projected future earnings to the "present value" (PV). The present worth of a cash flow over a period of time is less than the total of that cash flow. This is because a dollar on hand may be invested to earn interest, so that its future worth will be greater than one dollar; ergo, a future dollar must now be worth correspondingly less.

There are various methods of computing present value ranging from simple discounting methods to complex formulae. The choice depends upon the individual or group involved, and is not critical to this discussion. The value that is combined with the probability of success should be the present value as measured by the person involved. This is discussed further in Appendix 4.

EXPECTED MONETARY VALUE

These two parameters, "personal probability" and "present value", may be used in a formal approach to decisions on exploration ventures.

> Consider a program costing $100,000 which is estimated to have a .001 chance of locating an orebody presently worth $10,000,000. The result of this simple program will be either a loss of $100,000 or a gain of $10,000,000. However, if an infinite number of equivalent programs can be undertaken, the expected average result would be
>
> (.999)($-100,000) + (.001)(+$10,000,000)
> = -$99,900 + $10,000
> = -$89,900

This figure, a loss of $89,900, is the "expected monetary value" (EMV) of the program, after Schlaiffer (1959). It reflects the economic contribution this venture is expected to make to a statistically significant set of ventures.

In practice, no two projects are identical. However, the expected result of a large number of different programs must be the algebraic sum of the EMV's for each single one. If the probabilities and present values used accurately reflect the opinion of the planner, then he can not logically expect any other result.

If one consistently decides in favor of the course of maximum EMV, then his chances of economic success may be expected to be maximized*.

ARGUMENT FOR EMV

The writer's basic argument for applying a probability-present value (EMV) analysis to mineral exploration may be summarized thus:

1. Exploration programs are only undertaken when there is expectation of profit.

2. The decision-maker expecting the profit must have assessed the probability of success and potential value of the program.

3. In a statistically significant number of programs, the end result will approach the algebraic sum of (1) the real probability of success times (2) the potential value less (3) the real probability of failure times (4) the cost of failure, computed for each venture.

4. These four parameters affect any decision on the advisability of a program, and should be known.

5. Since they can not be known, they should be estimated.

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* This is not entirely true in practice, where the number of chances at success may be limited by one early and expensive failure. When the possible loss is large compared to the resources of the decision-maker, then other factors besides strict EMV may have to be considered.

Basically, the unit value of money for a complete loss (bankruptcy) may be different than the unit value for a gain; if such is the case, then a simple EMV analysis placing equal algebraic weight on gains and losses is not consistent with reality.

6. The estimates may be integrated into an "expected monetary value":

$$EMV = \sum_{i=0}^{\infty} (Ps. Vs - Pf. Cf)_i$$

7. In a statistically large number of events, the net result can be expected to approach the algebraic sum of the EMV's of each.

8. If one consistently chooses events with maximum positive EMV, his chance of ultimate net success may be expected to be maximized.

9. If the probabilities and values used are realistic, his chance of ultimate net success will be maximized.

USE AND SENSITIVITY OF EMV

In many cases, an EMV analysis is very sensitive to one factor compared to all others; this may be a present value or a probability. Errors in estimating this factor are then far more important than in any other. This does not make the EMV approach unattractive. In fact, it becomes all the more valuable, pointing out quantitatively the relative significance of factors involved in the decision. Stress may then be placed on arriving at the best possible evaluation of those factors which are most important.

If any project can be shown to have a negative EMV it should not be undertaken, for it reduces the long-term chance of success. If it appears wise from a qualitative or intuitive viewpoint, then either that viewpoint is wrong or the EMV evaluation is. In general, the writer expects the latter to be the case, resulting either from poorly assigned probabilities and values or from a lack of inclusion of important factors.

If, on the other hand, an exploration program can be shown to have a positive EMV, it does not necessarily follow that it should be adopted. In the first place, a different program may be available to perform the same task but with a higher EMV. In the second place, as above, additional factors may exist which have been ignored. All reasonable alternatives and all pertinent factors should be included.

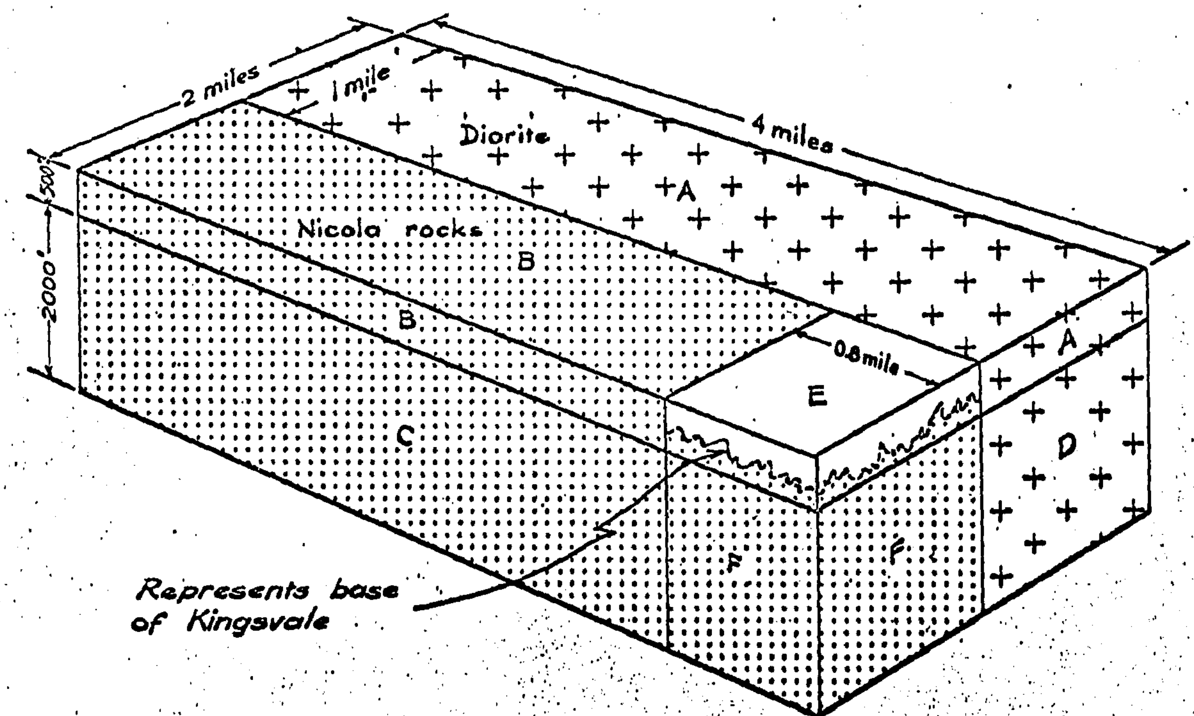
EMV ANALYSIS AT CRAIGMONT

INTRODUCTION

The Craigmont property and adjoining properties held by associated companies are underlain by the Guichon dioritic batholith, the Triassic Nicola series, and the later Kingsvale volcanics. The latter lie on top of both Nicola and Guichon rocks.

It is convenient to consider that the model of figure 30 represents the volume being considered for exploration. The horizontal dimensions include the pertinent properties and show the geologic situations in proportion to their areal extent. The limit of -2,500' below surface represents approximately the lowest level of the mine at the mill elevation. The boundary at -500' represents the approximate limit of surface exploration techniques.

MODEL OF CRAIGMONT SITUATION FOR EMV ANALYSIS



NOTE:
Vertical scale exaggerated.

Figure 30

In fact, boundaries of the various blocks are not well-defined. Extensive glacial overburden makes contacts difficult to trace. Depth of Kingsvale volcanics is known in only a few places, but is probably quite variable; where volcanics are just a thin veneer over Nicola rocks, perhaps one should include the area within Block B rather than E. However, the simplified picture is convenient for analysis of exploration possibilities.

A further change from reality is assumed. Neither the known ore zone and its immediate surroundings nor the two zones known as "targets B and C" (page 26) are included within the model. The former is being explored by the mine staff and is outside of the scope of this thesis. The two targets have been described separately. This model is intended to cover the rest of the property in which no distinct targets have been selected.

In the next few pages, the pertinent probabilities of occurrence of ore and of detection by various methods will be estimated. Then, after a brief discussion of the related potential values and costs, the estimates will be integrated to suggest conclusions regarding exploration within each block.

PROBABILITIES OF OCCURRENCE

Several types of ore considered as possible targets were discussed on pages 18 and 19. These included contact metasomatic copper-iron oxide bodies, copper-iron sulphide bodies, zinc or zinc-copper bodies, and disseminated copper orebodies within the intrusive complex.

The copper-iron oxide bodies may be strongly magnetic or practically non-magnetic. Hereinafter, these will be called either "magnetic skarn orebodies" or "non-magnetic skarn orebodies". It will be assumed that any orebodies within the upper 500' not magnetic enough to have been discovered or indicated to date are "non-magnetic".

The Number 3 orebody is a copper-iron sulphide body. While it is quantitatively of minor importance to date, there may be significant amounts of this type of ore. It will be called "No. 3 type".

"Disseminated copper orebodies" are expected only within or close to the intrusive complex. The grade is expected to be lower and amenable only to open pit mining, so that this type of mineralization more than 500' deep would not be ore. Thus this is only expected within block A.

There is no direct evidence for zinc or zinc-copper bodies on the Craigmont property. The zinc content of the known ore is negligible. As the probability of occurrence and potential value of this ore-type are considered to be substantially lower than copper orebodies, it will be ignored.

The writer's estimates of the probability of occurrence of these types of orebodies within the various blocks are summarized in Table 3.

Table 3.

ESTIMATES OF PROBABILITY OF ORE

TARGETS		PROBABILITY OF OCCURRENCE					
Type	Tonnage	A	B	C	D	E	F
Magnetic Skarn	1,000,000	nil	nil	.002	nil	nil	.002
	3,000,000	nil	nil	.005	nil	nil	.005
	5,000,000	nil	nil	.005	nil	nil	.005
	7,500,000	nil	nil	.005	nil	nil	.005
	10,000,000	nil	nil	.002	nil	nil	.002
Non-magnetic Skarn	1,000,000	nil	.0005	.002	nil	.0002	.002
	3,000,000	nil	.0013	.005	nil	.0005	.005
	5,000,000	nil	.0013	.005	nil	.0005	.005
	7,500,000	nil	.0013	.005	nil	.0005	.005
	10,000,000	nil	.0005	.002	nil	.0002	.002
No. 3 Type		nil	.0005	.002	nil	.0002	.002
Disseminated	3,000,000	.003	nil	nil	nil	nil	nil
	10,000,000	.001	nil	nil	nil	nil	nil
	20,000,000	.0005	nil	nil	nil	nil	nil

PROBABILITIES OF DETECTION

Earlier, the following methods of exploration were chosen as technically feasible or, in the case of the drill-hole methods, probably feasible.

- Magnetometer (airborne, surface, underground and drill-hole)
- Gravity (surface only)
- I.P. (surface and drill-hole)
- Geochemistry (stream sediment and seepage sampling)

It is worth repeating here that these are tools to assist the geologist in his exploration. No mention is made of sound geologic mapping. It is assumed a priori that this, as well as continued interpretation and projection, is an integral part of the exploration program.

Magnetometer

The magnetometer will respond directly to only the first type of ore, which is expected only within Nicola rocks. All of blocks B and E have been covered by a surface magnetometer survey. This resulted in discovery of targets B and C described earlier as well as the original orebody. It is assumed no further discoveries will be made directly from these data, although continued re-interpretation is warranted as new geologic information becomes available. Figure 10 showed the anomalies expected from various bodies at various depths, and the probability of detecting any existing Craigmont type ore in blocks B and E by this method is estimated to be 1.0.

Underground and drill-hole surveys, while feasible, are second-stage tools. The former will not be useful outside of the immediate ore zone until workings are available; the latter must still be tested.

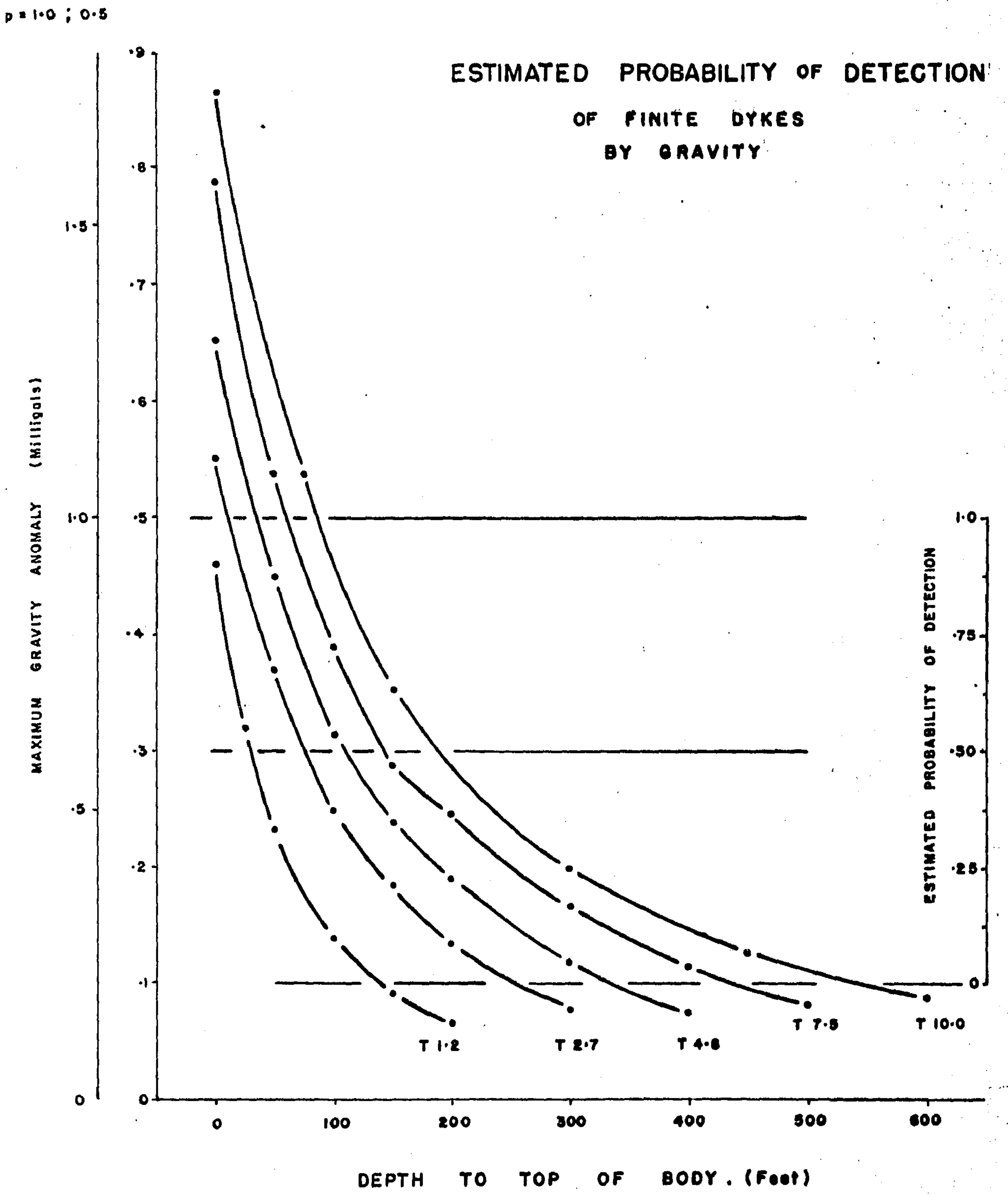
An aeromagnetic survey was performed over blocks, A, B and E in the past, but unfortunately flight lines were parallel to strike of formations and expected strike of skarn ore. Careful profiling with a helicopter at constant height above ground has probability 1.0 of detecting magnetic skarn ore within 500' of surface below the helicopter, with reducing detectability at depth as indicated by the curves of figure 10.

Gravity

This method will detect only the first two types of ore--the skarns. It will also respond to unmineralized skarns, producing unwanted "anomalies". It can be used over any part of the property not covered by Kingsvale volcanics (block E); it is less likely to be useful as a primary tool in E.

The probability of obtaining a recognizable anomaly from ore depends upon the size and shape of body, its depth, its position relative to the gravimeter, and the presence of extraneous geologic anomalies and noise.

Figure 18(a) showed the maximum gravity anomaly for a number of postulated situations. Figure 31 shows the same data with estimated probability of detection presented as well. Detectability is a function of



NOTE
1. For legend, see figure 18(a)
2. Applies to Nicola environment only

Figure 31

noise level, which it is assumed will be substantially higher over Kingsvale rocks; hence the probabilities refer to surveys over Nicola rocks only. These are summarized below.

Depth (Feet)	Probability for Various Lengths of Body				
	200'	300'	400'	500'	600'
0 - 100	0.3	0.6	0.9	1.0	1.0
100 - 200	0.0	0.2	0.3	0.5	0.6
200 - 300	0.0	0.0	0.1	0.2	0.3
300 - 400	0.0	0.0	0.0	0.1	0.2
400 - 500	0.0	0.0	0.0	0.0	0.1
0 - 500	0.05	0.2	0.3	0.4	0.4

These probabilities assume a survey line passing over the central half of the body. If the line passes over the outer half, a probability of detection only half as great will be used.

Induced Polarization

Inasmuch as ore of the fourth type--disseminated copper mineralization--must occur near the surface to be mined by open pit methods, it is a virtual certainty that it will be detectable on an IP profile passing over the centre of the body. The probability of detection is estimated at 1.0 for a line passing over the central two-thirds and 0.5 over the outer third of the body, measurements being along the diameter of a roughly circular orebody in plan.

The probability of detection of the dyke-like skarn orebodies is expected to fall off rapidly with depth. For a survey line passing directly over the central half of the dyke, the following is expected.

Depth (Feet)	Probability for Various Lengths of Body				
	200'	300'	400'	500'	600'
0 - 100	1.0	1.0	1.0	1.0	1.0
100 - 200	0.5	0.7	0.9	1.0	1.0
200 - 300	0.1	0.3	0.6	0.7	0.8
300 - 400	0.0	0.1	0.3	0.4	0.4
400 - 500	0.0	0.0	0.1	0.1	0.2
0 - 500	0.3	0.4	0.6	0.6	0.7

For a survey line over either outer half of the dyke, the probabilities will be taken as half as great.

These estimates are taken from calculations made by W. Faessler of

Huntec Limited, modified by the writer. Inasmuch as IP equipment and methods vary widely and interpretive procedures are still being developed, these estimates are not as precise as might be hoped. They are more a statement of opinion and subject to revision than those for, say, gravity.

The IP method will also respond to uneconomic mineralization such as barren pyrite, and spurious anomalies are to be expected. However, this is true for all the methods considered.

Estimation of the detectability of ore by drill-hole IP should await results of orientation surveys.

Geochemistry

The chance of detecting ore of the disseminated open pit type by geochemistry is greater than that for skarn ore for three reasons. First, the average depth of overburden is less over the intrusive complex. Second, the expected ore would outcrop over a larger surface area. Third, the geochemical mobility of copper in and near limey rocks is generally less than over acid intrusives.

An estimate of the detectability of various types of ore by stream-sediment and/or seepage sampling is difficult to arrive at quantitatively. The following are estimates believed by the writer to be realistic:

(a) For disseminated, sub-outcropping open pit copper ore:

Tonnage*	Horizontal Dimensions	Probability
3,000,000	300' x 300'	.2
10,000,000	500' x 500'	.3
20,000,000	700' x 700'	.4

(*assuming equidimensional bodies, limit of 400' to mining, and 10 cu.ft./ton)

(b) For sub-outcropping skarn ore:

The probability of detection should be of the order of .2 if skarn ore sub-outcrops. The probabilities of occurrence of ore have been estimated for the full block from surface to 500' deep, (page 65), and the probability of occurrence at sub-outcrop may be assumed to be approximately 1/5 of that for the full 500'. The pertinent probability of detection is then (.2)(1/5) = .04.

COSTS AND PRESENT VALUES

The costs of the various exploration methods are estimated as:

IP	$200 per line-mile
Gravity	$300 per line-mile
Aeromagnetics	$ 30 per line-mile
Geochemistry	$ 60 per claim.

J. H. Eastman, Chief Engineer for Canadian Exploration, computed the present value of various expected ore situations. He used a modification of the Hoskold formula (see Appendix 4) preferred by the company with interest rates of 3% and 10%. Present worth was computed for combinations of 3, 6, 10 1/2 and 21 million tons, open pit and underground mining, and various other variables such as distance from mill and elevation. Grade was assumed to be 2.0% copper. His results are summarized in the following table, with several values computed for each situation depending upon particular minor variables.

Table 4.

ESTIMATED PRESENT VALUE OF NEW DISCOVERIES TO CRAIGMONT

I. OPEN PIT SITUATIONS

Tons (x 1,000,000)	Present Values (x $1,000,000)
3.0	3.4, 3.3, 3.3
6.0	5.6, 5.5, 5.4
10.5	7.5, 7.3, 7.2
21	10, 11

II. UNDERGROUND SITUATIONS

Tons (x 1,000,000)	Present Values (x $1,000,000)
3.0	1.0, 0.8, 1.0
6.0	3.1, 2.9, 3.0
10.5	3.6, 4.9, 3.7
21	6.5, 6.4, 8.0

EMV CALCULATIONS

Surface Blocks (A, B, E) Excluding Targets B and C

The primary methods of search which have been chosen as technically feasible on a qualitative basis are:

Block	Methods
A	Geochemistry, IP
B	Geochemistry, IP, Gravity
E	Geochemistry, IP, Gravity

These will detect all or some of the possible targets under certain conditions. The probabilities of detection for these conditions and the cost of the methods have been estimated, and the EMV for each may be calculated.

A complete program of search in any area may involve one or more secondary exploration methods, geological review and drilling after discovery of a primary target. The particular path suggested at Craigmont will depend upon the location and characteristics of that target. The secondary methods need not and should not be planned at this stage*. An individual EMV analysis should be made for various feasible methods of following up each such target when it has been found, as will be done for targets B and C in succeeding pages.

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* In some exploration programs, secondary methods should be planned at the inception. This may occur when mobilization and/or supervision costs are high, so that detailed follow-up surveys are best done at the same time as the

The EMV of one case, IP in block A, is derived in detail below. The rest of the derivations are summarized in tabular form in Appendix 2. This example also illustrates a means of choosing optimum line-spacing for geophysical surveys. This is discussed further in Appendix 5.

Example:

IP in Block A

Only one type of ore was estimated to have a significant probability of occurrence: open pit-mineable disseminated copper. The probability of occurrence and values for various tonnages were estimated on pages 65 and 72 to be:

Tonnage	Present Value*	Probability
3,000,000	$ 3,000,000	.003
10,000,000	7,500,000	.001
20,000,000	10,000,000	.0005

Such an orebody, to be mineable by open pit methods, should top within 100' of surface. In this case, an IP line directly over the centre of the body would have a probability of detection of 1.0. Assuming that a line over the central two-thirds of the body has a p of detection of 1.0 and over the outer one-third of 0.5, the probability of detection at various line spacings may be computed. The following tables show this.

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primary one. It may occur when many primary anomalies are expected and only a few may be scheduled for drilling, so that secondary surveys are essential for selection; for example, this may be the case in airborne EM programs over PreCambrian Shields.

* These values are chosen as typical for the open pit situations of page 69.

1. Size of Orebody

Tonnage	Horizontal Dimensions of Orebody* (feet)
3,000,000	300 x 300
10,000,000	500 x 500
20,000,000	700 x 700

(*Assume equidimensional but can only be mined to 400')

2. Probability of Line Passing over Central Two-thirds

Tonnage	Line Spacing 200'	400'	600'	800'	1,000'
3,000,000	1.0	.50	.33	.25	.20
10,000,000	1.0	.83	.55	.42	.33
20,000,000	1.0	1.0	.78	.58	.47

3. Remnant Probability of Line Passing over Outer One-third

3,000,000	0	.25	.17	.13	.10
10,000,000	0	.17	.30	.21	.17
20,000,000	0	0	.22	.30	.23

The probability of no lines passing over ore at any given spacing is simply 1.0 minus the sum of the two above. Thus for 1,000' line spacing, the probability that no line will pass over a small orebody is 1.0 -(.20 + .10) or .7.

The probability of detection is 1.0 if a line passes directly over the central two-thirds, and 0.5 if over the outer two-thirds. For example, the probability of detection for 1,000' lines of a 3,000,000-ton orebody may be calculated as:

(1.0)(.20) + (0.5)(.10) = .25. Therefore,

4. Probability of Detection if Ore Exists

Tonnage	Line Spacing 200'	400'	600'	800'	1,000'
3,000,000	1.0	.63	.41	.32	.25
10,000,000	1.0	.91	.70	.53	.42
20,000,000	1.0	1.0	.89	.73	.59

Since the probability of occurrence of the three tonnages has been estimated as .003, .001 and .0005 respectively, the probability of discovery may be computed by multiplying the appropriate combinations. For example, the p of discovery of a 3,000,000-ton orebody using 400' line spacing is

(.63)(.003) = .0019. Therefore,

5. Probability of Discovery

Tonnage	Line Spacing 200'	400'	600'	800'	1,000'
3,000,000	.003	.0019	.0012	.0009	.0008
10,000,000	.001	.0009	.0007	.0005	.0004
20,000,000	.0005	.0005	.0004	.0004	.0003

These may now be integrated to determine the EMV of IP at each line spacing. This is done in table 5 which shows that IP at line spacings of 400', 600', 800' and 1,000' have positive EMV's, but that 400' is most favorable.

The same type of computation may be used for the other technically feasible methods for each block. The computations are included in Appendix 2, and the results are summarized in table 6.

Table 6 shows the exploration methods most suitable, in the writer's opinion, for each geological unit. For the Guichon diorite, IP at 400' lines is preferable; for the Nicola area, the same applies; for the Kingsvale area, IP on either 200' or 400' lines has the same EMV.

These methods are only most suitable if the probabilities and costs used are realistic and if no pertinent factors have been ignored. In the event changes or additions become desirable, appropriate changes may be made in the computations of Appendix 2, and a new set of "most suitable" methods chosen.

Consideration of Blocks C, D and F

The methods described to date are capable of exploring only the near-surface blocks, perhaps with some coverage of the upper parts of blocks C, D and F. None are capable of exploring to the base of these blocks.

Drill holes coupled with "down-hole" geophysical methods and underground developments appear to be the only possibilities. Neither can be justified as a basic exploration program.

For example, a pattern of holes might be devised to test block C. The cost of a single hole to 2,500' would be about $25,000. The value of ore "expected" within the entire block is of the order of (.04)($4,000,000) = $160,000. Thus a program with positive EMV could consist of no more than six holes. Each hole would have to test completely (i.e., probability of detection of 1.0) a cylinder 3,300' x 3,300' x 2,500', in order to have a probability of detection of 1.0 and thus justify expenditure of an amount equal to the "expected value" of ore. This is plainly absurd, and pattern drilling can not be justified based upon the premises used herein.

Similar reasoning compels one to eliminate underground exploration workings as a potential method of exploring the deep blocks. One must conclude that exploration of these blocks can not be justified using the tools available.

The reader should bear in mind that this applies only to basic exploration. Tests of particular areas, such as those close to mine workings where higher probabilities of success can be developed, warrant their own analysis.

Consideration of Magnetic Anomalies B and C

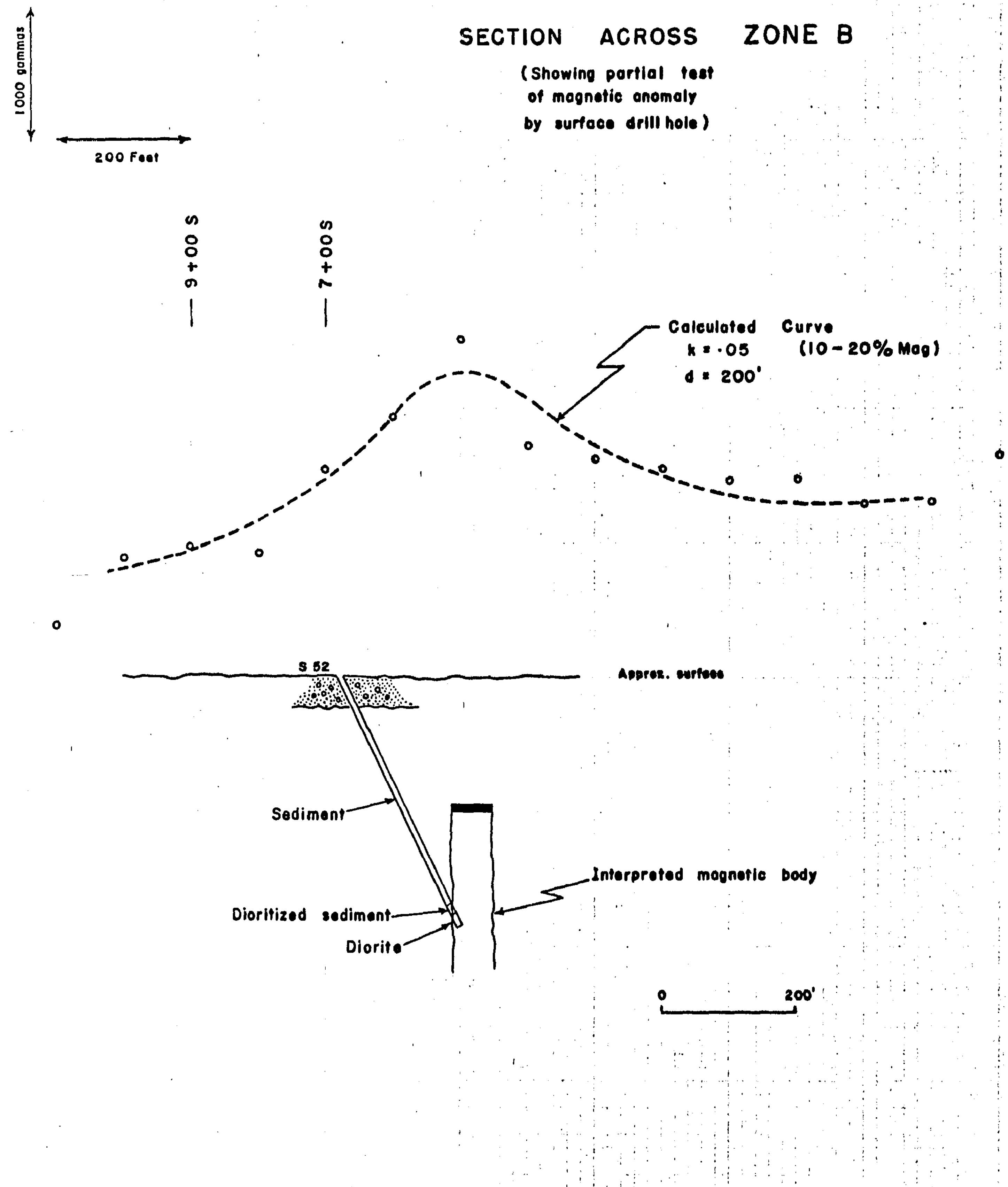
These targets were described earlier (page 26). They were both selected from interpretation of ground magnetic data as important anomalies in a possibly favorable geologic environment, and both appear to warrant further work. They could be drilled immediately or subjected to secondary surveys (gravity or IP).

Anomaly B

Approximate depth	200'
Approximate width	50'
Approximate susceptibility	.05
Approximate magnetite	20%

The anomaly occurs close to the projected Nicola-Guichon contact. Evidence from underground mapping (R.J. Young, pers.comm.) suggests that the Nicola is faulted "west-side-north" in the area immediately to the southeast, so that the anomaly could overlie a limestone-intrusive contact, perhaps the extension of the "ore limestone".

This has been the target of one surface drill hole (figure 32) which passed from greywacke containing minor amounts of chalcopyrite into barren diorite. Neither unit contained more than a few percent magnetite.



1000 gammas
200 Feet
SECTION ACROSS ZONE B
(Showing partial test
of magnetic anomaly
by surface drill hole)
9+00 S
7+00 S
Calculated Curve
k = ·05
(10 – 20% Mag)
d = 200'
S 52
Approx. surface
Sediment
Interpreted magnetic body
Dioritized sediment
Diorite
0
200'

Figure 32

It is possible that the anomaly source is closer to the surface than postulated and is lower in magnetite. Alternatively, the diorite intersected by the drill hole may be a small dyke in an ore zone; similar barren holes have been drilled into dykes within the known orebodies.

If the magnetic anomaly does not reflect ore, it may be caused by barren skarn mineralization of similar geometry, magnetite enrichment in a contact phase of the diorite, or magnetite enrichment in the Kingsvale or Nicola rocks near the surface. If any of the latter are true, then the similarity of the anomaly to that expected from a buried dyke must be fortuitous.

The writer estimates the probability of ore as 0.1. An orebody 800' long, 1,000' deep and 50' wide would contain approximately 4,000,000 tons and be worth approximately $1,500,000 (page 72).

Anomaly C

Approximate depth	400'
Approximate width	100'
Approximate susceptibility	.05
Approximate magnetite	20%

This anomaly occurs in an area of few outcrops several thousand feet north of the known ore zone. The host rock is apparently overlain and obscured by Kingsvale volcanics. As indicated by figure 11, the target lies far enough north that one might expect it to occur in diorite, but it could also occur within a faulted segment of Nicola rocks near the diorite contact.

This zone is evident on more lines and has better correlation with computed curves than target B. Therefore it appears less likely to result from a coincidental pattern of near-surface magnetite. On the other hand, it is farther from known ore than B and is not certain to occur in Nicola rocks.

The writer estimates the probability of ore as 0.05. An orebody 1,200' long, 1,200' deep and 100' wide would contain approximately 15,000,000 tons and would have a present value of the order of $5,000,000.

EMV Calculations

The expected value of target C is (0.05)($5,000,000) = $250,000 and of B (0.1)($1,500,000) = $150,000. Both warrant further testing, either by drilling or by additional surveys.

Secondary geophysical methods which may be useful include gravity and IP*. By the method of graticules, the maximum gravity anomaly due to a dyke 1,200' x 1,200' x 100' topping at 400' and with density contrast of 0.5 gm/cc was found to be 0.16 milligals (Zone C) and to a dyke 800' x 1,000' x 50' topping at 200' to be 0.10 milligals (Zone B). Both anomalies are expected to be undetectable beneath the Kingsvale volcanics.

From page 69, we may estimate the detectability by IP as 0.4 for C and 0.8 for B. The cost of several IP profiles is estimated at less than $1,000 for each.

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* It is assumed, a priori, that careful geological re-examination of each target area will be done, probably with the aid of a magnetometer, and that this will not materially change the above interpretation. If it does, a further analysis should be performed.

A drill program to test target C thoroughly would involve something of the order of 3,000' of drilling at $12 per foot, or $36,000. A program to test B would involve 1,500' or $18,000.

Suppose IP profiles are performed to check C. The probability of ore is estimated to be 0.05, so the probability of a response due to ore is (0.4)(0.05), and of the existence of ore with no response is (0.6)(0.05). If the probability of a spurious anomaly not due to ore is 0.1, then the following table shows the EMV of the program: "DO IP FOLLOWED BY DRILLING AS WARRANTED".

Possible Events	p	PV ($)	p.PV ($) +	p.PV ($) -
Anomaly; ore; drill	(.4)(.05)	+5,000,000	100,000	
No anomaly; ore	(.6)(.05)	- 1,000		30
Spurious anomaly; drill	.1	- 37,000		3,700
No anomaly; no ore	.85	- 1,000		850
		EMV	+$95,000	

The alternative program is: "DRILL IMMEDIATELY".

Possible Events	p	PV ($)	p.PV ($) +	p.PV ($) -
Ore	.05	+5,000,000	250,000	
No ore	.95	- 36,000		35,000
		EMV	+$215,000	

These indicate that, while both approaches have a positive EMV and are acceptable, the best approach is to drill without relying on IP corroboration.

The reason is the relatively large possibility of missing ore through non-detection by IP; since the detectability by gravity is expected to be even lower, it is even less preferable.

For target B, the EMV of IP followed by drilling is found by:

Possible Events	p	$\overline{PV}$ ($)	p.PV ($) +	p.PV ($) -
Anomaly; ore; drill	(.8)(.1)	+1,500,000	120,000	
No anomaly; ore	(.2)(.1)	- 1,000		20
Spurious anomaly; drill	.1	- 19,000		1,900
No anomaly; no ore	.8	- 1,000		800
		EMV =	+$115,000	

The EMV of immediate drilling is found by:

Possible Events	p	PV ($)	p.PV ($) +	p.PV ($) -
Ore	.1	+1,500,000	150,000	
No ore	.9	- 18,000		16,000
		EMV =	+$135,000	

Conclusions re Targets B and C

Both anomalies appear to occur in a favorable geologic environment and to have a strong chance of indicating ore. Subject to confirmation by surface mapping of the assumptions made herein, both appear to warrant testing by drill programs.

CONCLUSIONS

Integration of geological and geophysical information from the Craigmont mine has led to several approaches to exploration for the various geologic units. Those most consistent with the writer's premises are:

(1)	For the area underlain by Guichon diorite:	Induced Polarization at line spacing of 400'.
(2)	For the area underlain by Nicola rocks:	Induced Polarization at line spacing of 400'.
(3)	For the area underlain by Kingsvale volcanics:	Induced Polarization at a line spacing of either 200' or 400'.

No methods have been selected which will explore much of the property more than 500' below surface. The potential ore horizons from 500' to 2,500' (the mill elevation) and below must remain unexplored unless particular parts can be shown to have higher chances for ore than estimated herein.

Magnetic anomalies B and C warrant drilling immediately if detailed geological mapping in the area fails to alter the interpretation herein.

Changes in these conclusions may result if changes are indicated in probabilities or values used, or if new factors are inserted. If alternative programs appear more desirable to the reader, a similar analysis should be performed and the determining changes in premises isolated for consideration.

APPENDIX 1

AGE OF THE GUICHON BATHOLITH

Bostock et al (1957) state that the Guichon batholith near Ashcroft is early Jurassic. Duffell and McTaggart (1952), reporting on mapping in the Ashcroft area, describe the Guichon batholith as intruding both Nicola and (Permian) Cache Creek groups. They observed "much hydrothermal alteration, particularly in members of the Cache Creek group" spatially related to the intrusive. At a different locality, they observed early Middle Jurassic rocks overlying the batholith. From this evidence, they concluded that it was between Upper Triassic and early Middle Jurassic in age.

Bradsgaard et al (1961) obtained a K-Ar date of 186 ($\pm$10) x 10^6 years on a specimen of Guichon quartz diorite from the Bethlehem mine. This corresponds to the Lower Jurassic.

Recent determinations by the Geological Survey of Canada on specimens from both the Bethlehem and Craigmont areas throw some doubt on these ages. The writer understands that investigation is still in progress, but that preliminary data suggest a Permian age by K-Ar methods. If this is correct, then the Triassic Nicola group is later than the batholith. This is possible, since definite intrusive contacts have only been observed for smaller diorite dykes and not for the main batholith. However, it seems unlikely.

APPENDIX 2

COMPUTATION OF EXPECTED MONETARY VALUES

The EMV of IP in Block A was computed in the body of the thesis. Computations for other methods in other blocks are shown in tabular form in the next few pages. Notes follow each table where appropriate.

Tables are presented for:

1. IP in Block B
2. IP in Block E
3. Gravity in Block B
4. Geochemistry in Block B
5. Geochemistry in Block A

TABLE 5. EXPECTED MONETARY VALUE OF IP IN BLOCK A

LINE SPACING (feet)	POSSIBLE EVENTS (ORE - TONNAGE)	PROBABILITY OF DETECTION	PROBABILITY OF EXISTENCE	PROBABILITY OF EVENT (p)	PV OF EVENT ($)	p.PV ($) +	p.PV ($) -	EMV ($)
200'	3,000,000	1.0	.003	.003	3,000,000	9,000		
	10,000,000	1.0	.001	.001	7,500,000	7,500		
	20,000,000	1.0	.0005	.0005	10,000,000	5,000		
	NONE			1.0	-22,000		22,000	
								-500
400'	3,000,000	.63	.003	.0019	3,000,000	5,500		
	10,000,000	.91	.001	.0009	7,500,000	7,000		
	20,000,000	1.0	.0005	.0005	10,000,000	5,000		
	NONE			1.0	-11,000		11,000	
								+6,500
600'	3,000,000	.41	.003	.0012	3,000,000	3,500		
	10,000,000	.70	.001	.0007	7,500,000	5,500		
	20,000,000	.89	.0005	.0004	10,000,000	4,000		
	NONE			1.0	-7,500		7,500	
								+5,500
800'	3,000,000	.32	.003	.0009	3,000,000	2,500		
	10,000,000	.53	.001	.0005	7,500,000	4,000		
	20,000,000	.73	.0005	.0004	10,000,000	4,000		
	NONE			1.0	-5,500		5,500	
								+5,000
1,000'	3,000,000	.25	.003	.0008	3,000,000	2,500		
	10,000,000	.42	.001	.0004	7,500,000	3,000		
	20,000,000	.59	.0005	.0003	10,000,000	3,000		
	NONE			1.0	-4,500		4,500	
								+4,000

TABLE 6. SUMMARY OF EMV'S (See Appendix 2)

BLOCK A (Guichon Diorite)

Method	Line Spacing	EMV ($)
IP	200'	- 500
	400'	+ 6,500
	600'	+ 5,500
	800'	+ 5,000
	1,000	+ 4,000
Geochem	N.A.	+ 3,000

BLOCK B (Nicola Sub-outcrop)

Method	Line Spacing	EMV ($)
IP	100'	-10,000
	200'	- 1,000
	400'	+ 2,000
	600'	+ 1,000
Gravity	100'	-22,000
	200'	- 8,000
	400'	- 3,000
	600'	- 1,500
	800'	- 1,500
Geochem	N.A.	- 4,500

BLOCK E (Nicola beneath Kingsvale)

Method	Line Spacing	EMV ($)
IP	100'	+ 2,000
	200'	+ 5,000
	400'	+ 5,000
	600'	+ 3,500

TABLE 7. EXPECTED MONETARY VALUE OF IP IN BLOCK B

LINE SPACING (feet)	LENGTH OF BODY[1] (feet)	PROBABILITY OF[2] DETECTION	PROBABILITY OF EXISTENCE	PROBABILITY OF EVENT (p)	PV OF EVENT[3] ($)	p.PV($) +	p.PV($) -	EMV ($)
100'	200	.3	.0005	.00015	200,000	-		
	300	.4	.0013	.00052	1,000,000	500		
	400	.6	.0013	.00078	2,500,000	2,000		
	500	.6	.0013	.00078	3,500,000	2,500		
	600	.7	.0005	.00035	4,500,000	1,500		
	NO ORE			1.0	-18,000		18,000	
								-10,000
200'	200	.22	.0005	.00011	200,000	-		
	300	.35	.0013	.00046	1,000,000	500		
	400	.6	.0013	.00078	2,500,000	2,000		
	500	.6	.0013	.00078	3,500,000	2,500		
	600	.7	.0005	.00035	4,500,000	1,500		
	NO ORE			1.0	-8,000		8,000	
								-1,000
400'	200	.11	.0005	.00006	200,000	-		
	300	.22	.0013	.00029	1,000,000	500		
	400	.45	.0013	.00059	2,500,000	1,500		
	500	.48	.0013	.00062	3,500,000	2,000		
	600	.62	.0005	.00031	4,500,000	1,500		
	NO ORE			1.0	-4,000		4,000	
								+2,000
600'	200	.08	.0005	.00004	200,000	-		
	300	.15	.0013	.00020	1,000,000	-		
	400	.30	.0013	.00040	2,500,000	1,000		
	500	.37	.0013	.00048	3,500,000	1,500		
	600	.52	.0005	.00026	4,500,000	1,000		
	NO ORE			1.0	-2,500		2,500	
								+1,000

NOTES TO TABLE 7

1. Tonnage of various bodies shown computed by assuming body is 150' wide and is twice as deep as long. Present values and tonnages for the various lengths are:

Length	Tonnage	PV ($)
200'	1,000,000	200,000
300'	3,000,000	1,000,000
400'	5,000,000	2,500,000
500'	7,500,000	3,500,000
600'	10,000,000	4,500,000

2. Probability of detection as per assumptions made in thesis.

   e.g. For 200' lines, probability of passing over central half of body 200' long is .5 and over outer half is .5. Probability of detection _if_ over central half is .3 and _if_ over outer half is .15.

   Therefore, probability of detection of 200' long body by 200' lines is (.5)(.3) + (.5)(.15) = .22.

3. Costs are as per assumptions made in thesis. However, additional cost of $4,000 is added for additional line cutting for 100' spacing.

TABLE 8. EXPECTED MONETARY VALUE OF IP IN BLOCK E

LINE SPACING (feet)	LENGTH OF BODY (feet)	PROBABILITY OF[1] DETECTION	PROBABILITY OF EXISTENCE	PROBABILITY OF EVENT (p)	PV OF EVENT ($)	p.PV($) +	p.PV($) -	EMV ($)
100'	200	0	.0002	0	200,000	0		
	300	.05	.0005	.00025	1,000,000	250		
	400	.2	.0005	.0001	2,500,000	2,500		
	500	.25	.0005	.0013	3,500,000	4,500		
	600	.3	.0002	.00006	4,500,000	250		
	NO ORE			1.0				
							5,400	+2,000
200'	200	0	.0002	0	200,000	0		
	300	.044	.0005	.00022	1,000,000	220		
	400	.2	.0005	.001	2,500,000	2,500		
	500	.25	.0005	.0013	3,500,000	4,500		
	600	.3	.0002	.00006	4,500,000	250		
	NO ORE			1.0				
							2,400	+5,000
400'	200	0	.0002	0	200,000	0		
	300	.028	.0005	.00014	1,000,000	150		
	400	.15	.0005	.00075	2,500,000	2,000		
	500	.20	.0005	.001	3,500,000	3,500		
	600	.26	.0002	.00005	4,500,000	250		
	NO ORE		—	1.0				
							1,200	+5,000
600'	200	0	.0002	0	200,000	0		
	300	.019	.0005	.0001	1,000,000	100		
	400	.10	.0005	.0005	2,500,000	1,250		
	500	.15	.0005	.00075	3,500,000	2,600		
	600	.23	.0002	.00005	4,500,000	250		
	NO ORE			1.0				
							800	+3,500

Notes on Table 8.

Assumptions: (a) Depth of Kingsvale constant at 300'.
(b) Block is 0.8 x 1 mile or 24 line-miles at 200' spacing.

1. Probability of detection as per assumptions in thesis. Note however that chance of ore from 0 to 300' is nil, so that probability of detection is reduced from that in Table 7.

TABLE 9. EXPECTED MONETARY VALUE OF GRAVITY IN BLOCK B

LINE SPACING (feet)	LENGTH OF BODY (feet)	PROBABILITY OF DETECTION	PROBABILITY OF EXISTENCE	PROBABILITY OF EVENT (p)*	PV OF EVENT ($)	p.PV($) +	p.PV($) -	EMV ($)
100'	200	.05	.0005	.000025	200,000	-		
	300	.2	.0013	.00026	1,000,000	260		
	400	.3	.0013	.00039	2,500,000	1,000		
	500	.4	.0013	.00052	3,500,000	1,800		
	600	.4	.0005	.0002	4,500,000	1,000		
	NO ORE			1.0	-26,000		26,000	-22,000
200'	200	.036	.0005	.000018	200,000	-		
	300	.17	.0013	.00022	1,000,000	220		
	400	.3	.0013	.00039	2,500,000	1,000		
	500	.4	.0013	.00052	3,500,000	1,800		
	600	.4	.0005	.0002	4,500,000	1,000		
	NO ORE			1.0	-12,000		12,000	-8,000
400'	200	.018	.0005	.000009	200,000	-		
	300	.11	.0013	.00014	1,000,000	140		
	400	.22	.0013	.00029	2,500,000	750		
	500	.32	.0013	.0004	3,500,000	1,400		
	600	.35	.0005	.00017	4,500,000	750		
	NO ORE			1.0	-6,000		6,000	-3,000
600'	200	.013	.0005	.000006	200,000	-		
	300	.075	.0013	.00009	1,000,000	-		
	400	.15	.0013	.00019	2,500,000	500		
	500	.25	.0013	.00033	3,500,000	1,200		
	600	.30	.0005	.00015	4,500,000	700		
	NO ORE			1.0	-4,000		4,000	-1,500
800'	200	.009	.0005	.000004	200,000	-		
	300	.056	.0013	.00007	1,000,000	-		
	400	.11	.0013	.00014	2,500,000	350		
	500	.19	.0013	.00025	3,500,000	900		
	600	.23	.0005	.00011	4,500,000	500		
	NO ORE			1.0	-3,000		3,000	-1,500

TABLE 10. EXPECTED MONETARY VALUE OF GEOCHEMISTRY IN BLOCK B

EVENT	PROBABILITY OF[1] DETECTION	PROBABILITY OF OCCURRENCE	PROBABILITY OF EVENT (p)	PV OF EVENT ($)	p.PV($) +	p.PV($) -	EMV ($)
200'	.04	.0005	.00002	200,000	-		
300'	.04	.0013	.000052	1,000,000	50		
400'	.04	.0013	.000052	2,500,000	125		
500'	.04	.0013	.000052	3,500,000	175		
600'	.04	.0005	.00002	4,500,000	90		
NO ORE			1.0	-5,000		5,000	
							-4,500

Notes on Table 10.

1. Assume the probability of detection is independent of the length of the body; i.e. .04 as per assumption in thesis.

TABLE 11. ESTIMATED MONETARY VALUE OF GEOCHEMISTRY IN BLOCK A

SIZE IN PLAN (feet) (1)	PROBABILITY OF DETECTION	PROBABILITY OF OCCURRENCE	PROBABILITY OF EVENT (p)	PV OF EVENT ($)	p.PV($) +	p.PV($) -	EMV ($)
300 x 300	.2	.003	.0006	3,000,000	1,800		
500 x 500	.3	.001	.0003	7,500,000	2,200		
700 x 700	.4	.0005	.0002	10,000,000	5,000		
NO ORE			1.0	-6,000		6,000	
							+3,000

Notes on Table 11.

1. This is the type of ore assumed for the example in the thesis; i.e. disseminated copper amenable to open pit mining.

APPENDIX 3

VALUE OF EMV ANALYSIS

The use of a formal analytical technique such as EMV is rare in mineral exploration, just as is the use of probabilities. However, there are a number of important advantages to the method.

1. Before action is taken on exploration or development ventures, geological opinions must be transformed into economic evaluation. The person formulating the opinion should supply the numbers, as it is easier to communicate precise figures to management than descriptive terms.

2. An EMV analysis is self-disciplinary, since it encourages a rational, formal synthesis of data and re-examination of conflicting points.

3. Critical analysis of an EMV report is encouraged, for single items may often be adjusted or deleted without necessitating discarding of the rest of the report.

4. An EMV analysis encourages the use of specially-trained advisors; one may integrate specific advice on specific questions directly into a quantitative analysis much more easily than into a qualitative, descriptive one.

5. In an EMV report, the reasoning is a matter of permanent record.

These could be elaborated upon and added to. However, it is the writer's opinion that they suffice to indicate the value of this type of formal analysis.

APPENDIX 4

PRESENT VALUE

There are various methods of computing the present value of future earnings. The choice is basically a personal one, since it involves a measurement of value. Therefore it is not realistic to define a particular technique as "correct" and another as "incorrect" for use in EMV calculations. The methods used most commonly in the mineral industry are:

1. Simple compound interest (SCI);
2. Hoskold formula;
3. Modifications of the Hoskold formula.

Simple Compound Interest PV System*

This is the simplest and most common PV system, from which all others are derived. It assumes that the investor can define a single compound interest rate which he expects to earn on his money. The PV of any future payment--or series of payments--is simply equal to the amount he must invest now to equal that payment.

For example, suppose that upon investing a certain sum, payments of $10,000 per year for the next ten years may be assured. Suppose

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* This and the next system are described in Parks (1933) and McKinstry (1948). These texts contain tables from which the present value of an investment under various combinations of the parameters can be determined.

further that the investor believes he can make 8% per annum on his capital. Then although a total income of $100,000 is involved, the PV is only $67,100. (See tables in Parks or McKinstry, op.cit.) This sum, if invested today at 8%, will equal the value of the payments--also invested at 8% as they are received--in ten years.

To illustrate the value of this PV calculation to the investor, suppose that he must invest $70,000 today to receive the $10,000 per year for ten years. Even though the total return is $100,000--nearly 50% greater than the investment--the timing is such that the present value is less. The venture would not be attractive to this investor using his particular yardsticks.

The simple compound interest PV system is sometimes criticized because it does not provide for variable risks; i.e., if an investor desires 8% on his capital this system will always indicate a PV of $67,100 for the series of payments in the example; it will do this regardless of the risk involved, whether it is high or low. One solution is to adjust the interest rate in accordance with expected risk. Thus a very risky venture may warrant computation using 12% while a conservative investment may warrant only 5%.

However, the writer considers the lack of provision for risk an advantage rather than a criticism. The degree of uncertainty should be evaluated separately from purely monetary considerations.

Hoskold PV System*

The Hoskold PV system is similar to but is an extension of simple compound interest, in that a consideration of risk is included. Although developed in 1877 by a British mining engineer for a specific--and no longer used--investment procedure of British collieries, it is still favored by some of the most important North American mining companies.

As with the previous system, a Hoskold evaluation assumes the return of capital at the end of a venture through a series of payments which earn interest. Hoskold assumes that these payments are re-invested at a "safe" interest rate and accumulate to equal the initial investment. However, additional "wages" or "profit" paid for use of the capital are computed separately using a different, "risk" rate of return. This is done because of the high degree of risk involved in most mining ventures.

The PV of a steady stream of earnings is calculated by a formula including: A (the value of incremental payments); r (a safe interest rate, say 4%); r' (a risk interest rate, say 10%) and n (the life of the mine or venture)

$$PV = \frac{A}{\frac{r}{(1+r)^n - 1} + r'}$$

* Parks, op.cit.; McKinstry, op.cit.

As an example, the same \$10,000 payment (A) for 10 years (n) as in the previous example, using a Hoskold "10 and 4" (10% r' and 4% r) has a PV of \$54,600. Thus the present value using the Hoskold "10 and 4" is \$12,500 less than using simple compound interest of 8%; in fact, it is equivalent to a simple compound interest of about 13%.

The writer believes that the Hoskold evaluation system is inconsistent, and that groups using it are not really measuring a present value as much as comparing the PV of assorted ventures. Disagreement is with two facets:

1. Hoskold ignores the fact that part of the invested capital is returned with each payment; it continues to pay a risk interest on all of the original capital even near the end of the venture's life, when unreturned capital may be only a few percent of the investment.

2. Hoskold incorporates risk and PV factors into the same parameter. This is fine, provided the nature of variable risks from venture to venture is reflected by a variable r' in computation. However, in practice, firms using the system tend to apply the same risk rate to all ventures, regardless of their nature. The rate is determined by habit, past experience, or from some industry-wide statistical consideration.

The first disagreement is with the principle inherent in the formula. Few investors would ask for ~~risk~~ interest on capital which already has been returned. However, by inconsistently inserting this premise into a Hoskold valuation, they in effect ask for a greater return on investment than they really want. As a result the calculated PV is erroneously low. Thus an investor selling a property through Hoskold valuation would sell it too cheaply; another buying a property--or setting aside capital for exploration--would underestimate the value of the venture. With such an inconsistency, an investor may define his yardsticks very clearly, and then proceed to apply a Hoskold formula which does not follow them.

The second disagreement is primarily one of practice. Risk and monetary PV factors should be separated as in an EMV analysis. A certain possible series of payments has a definite monetary PV; whether or not the payments will be received is another matter. Although Hoskold does incorporate a separate risk variable, in practice it is seldom varied. Instead, most investors adopt an industry-wide risk rate and apply it to all ventures.

The writer believes that ventures with different degrees of risk can be distinguished. One drill hole is more liable to be successful than another; one mine has a more stable future than another. If technical information allows one to make this distinction, then it is not wise to ignore it.

Even if this practice did not exist, and attempts were made to adjust the risk rate in accordance with the degree of uncertainty of individual ventures, the system would be unwieldy. Tables of Hoskold PV have been worked out for only a small range of risk rates, and would have to be extended. In addition the results would be erroneous: the inconsistency mentioned earlier would still apply.

Modifications of Hoskold PV System

Many mining companies and individuals now using a Hoskold type of evaluation tool have modified the formula to suit their own requirements.

The modifications serve either to raise the calculated PV to some more realistic value, an attempt to counter the first criticism, or to adjust the payout time in accordance with some different yardstick. To the writer's knowledge the changes do not attempt to eliminate the second criticism. If this were the goal of modification, it would be simpler to discard Hoskol entirely. Some have done this.

RECOMMENDATIONS

The writer prefers to use the first system (Simple Compound Interest) with EMV analyses. This is because it ignores the risk factor inherent in the investment project, and merely measures the present value or worth of the postulated monetary outcome. Risk may then be covered completely and separately by the probability parameter. By corollary, the Hoskold system or common modifications thereof do not separate the two parameters, and are not consistent with the principles of EMV.

On the other hand, it must be admitted that Hoskold computations have assumed a meaning in terms of real value to many individuals and companies, and that these are going to continue to use it. Since such values are in part personal, one can not argue strongly against the system used. Also, in most exploration ventures the probability estimate is so much less precise that a difference of a few percent in estimate of PV is immaterial. For these reasons, the writer feels that choice of the particular PV system is not usually critical to an EMV analysis.

APPENDIX 5

DETERMINATION OF OPTIMUM LINE SPACING

Selection of optimum line spacing for geophysical surveys has been a subject of attention for some years. The method of attack has ranged from observation of detection or failure in actual surveys to mathematical exercises based upon geometry and calculated detectabilities.

Paterson (1960), describing discovery via geophysics of several orebodies in the Mattagami camp (Quebec) illustrated that the original AEM survey on flight lines 1/4 mile apart missed one orebody which was subsequently indicated by intermediate lines. Lines at 1/8 mile intervals would have indicated all orebodies known at the time he wrote. At least in part because of experience in this camp, this spacing is most common in Canadian AEM surveys today.

Agocs (1955) described airborne magnetic data from the Marmora iron region (Ontario), and listed formulae for computing detectability of various sizes and shapes of targets under different flight conditions. Slichter (1960), Ellis and Blackwell (1959) and Trost (1962) have presented formulae and techniques for determining optimum line spacing under certain conditions.

The writer submits that the choice of optimum line spacing must depend upon the following parameters:

1. probabilities of detection,
2. probabilities of occurrence,
3. probable present values, and
4. pertinent costs of the survey.

Except for other minor items which might be included under "matters of convenience", the above four allow a unique determination of optimum line spacing when combined in an EMV analysis.

In the example of the thesis (page 76), the EMV of an IP survey over block A was computed for line spacings of 200, 400, 600, 800 and 1,000 feet, and that of 400' was shown to have the highest EMV. For the assumptions made on this particular case, that spacing is optimum.

The relationship between EMV and line spacing may be continuous or discontinuous. In the above case, since surveyed picket lines already exist at 200' intervals, multiples of this spacing are most economical. In other cases, such as airborne surveys or ground surveys with no prior work done, one spacing may be essentially as good as the next as far as convenience is concerned, and the EMV-distance relationship will be continuous.

Particular formulae may be developed to show optimum line spacing for particular situations. However, if they are correct, they will be merely sub-routines of EMV.

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