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PAPER 71-9

RELATIONSHIP OF STRUCTURAL LINEAMENTS AND MINERAL OCCURRENCES IN THE ABITIBI AREA OF THE CANADIAN SHIELD

(Report and 16 figures)

Jan Kutina and Andrea Fabbri

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FOREWORD

This paper presents the results of an empirical study of the spatial relationships of major structural lineaments and trends in the Abitibi area of the Canadian Shield and the distribution of some of the gold and copper deposits associated with them. The coincidence in distribution of mineral deposits near major structural lineaments or deep-seated fracture systems is emphasized in the study but different kinds of mineral occurrences of varied genetic affinity have not been specifically distinguished or classified. Plots of mineral distribution in relation to structural patterns and statistical study of mineral occurrence data have emphasized the importance of some of the metallogenic features previously recognized in the area. Projections of structural trends and postulation of favourable areas for finding mineral deposits based on this empirical study are presented as guidelines for further mineral exploration.

The authors of the paper present the results of their special study carried out during the later part of 1969 and early part of 1970 while Professor Kutina was a visiting research scientist with the Mineral Deposits Section of the Geological Survey of Canada. The senior author was formerly professor of geochemistry at Charles University in Prague, Czechoslovakia and in recent years has been studying the distribution of mineral occurrences in relation to major structural lineaments in Europe, North America, the Caribbean and East Africa. He was invited to the Geological Survey of Canada to apply some of his global concepts on structural control of mineral deposit distribution in the complex geological framework of the Canadian Shield. Mr. A.G. Fabbri the junior author graduated from the University of Bologna, Italy and did graduate study at the University of Ottawa. He is employed with the Geological Survey in the geomathematics program for developing methods for quantification and statistical analyses of geological data. The authors have attempted, in this study, to relate major structural lineaments in the Abitibi area in a systematic structural pattern and to use statistical methods to evaluate geological concepts on mineral distribution.

G.A. Gross
Head, Mineral Deposits Section,
March 1, 1971

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ABSTRACT

The Abitibi and of the Canadian Shield, located between 76° and 84° W and 47° 30' and 49° N in Ontario and between 48° and 49° N in Quebec, was studied in context with the structural geology of a considerable part of the Canadian Shield.

Comparison of lineaments in very distant areas of the Canadian Shield suggests that the Shield structure is strongly influenced by one prominent pattern of deep-seated fractures. A spacing of 100 miles between the east-west lineaments of the Canadian Arctic is recognizable also in the drainage pattern east of James Bay and is reflected in the Abitibi area. It is compatible with a set of east-west trending major fractures by J. Kalliokoski as bounding crustal blocks with cores of granitic rocks. The two schemes have been derived in different ways and fully independently of each other.

The spacing between the Hudson Bay Paleolineament – a significant geofracture of the Canadian Shield – and the Mattagami River Lineament was used as the unit interval in the north-south set of fracture-trajectories of the prospecting net for the Superior Province south of Hudson Bay. The corresponding unit interval in the eastern part of this area is smaller. Fifteen comparable intersections have been postulated. Endogenous ore deposits are known to occur along seven of them and the remaining eight are recommended for prospecting.

In the Abitibi area intersecting fractures of these sets are present and the distribution of gold and copper deposits coincides with them. The ore deposits are clustered at or near the intersections of major fractures (Noranda, Kirkland Lake, Matachewan and Timmins-Porcupine deposit clusters). Several recommendations for prospecting can be deduced from the relationship of the fracture pattern and the distribution of about 1,300 gold and about 700 copper occurrences of the area. Some recommendations are presented in this paper.

With respect to the individual ore districts, the relationship of ore deposits to volcanic centres, as outlined in 1967 by Wilson is emphasized. The large-scale deep-seated fractures may control the general distribution of volcanic centres and the associated ore deposition and this possibility should be tested.

RÉSUMÉ

Dans le contexte de la tectonique d'une importante partie du Bouclier canadien, l'étude a porté sur la région d'Abitibi limitée par les 76° et 84° W de longitude et par les 47° 30' et 49° N de latitude en Ontario, et par les 48° et 49° N de latitude au Québec.

La comparaison entre les traits de régions très éloignées situées dans le Bouclier canadien amène à penser que la structure du Bouclier est fortement influencée par un réseau prononcé de fractures logées en prodondeur. Un écartement de 100 milles entre les linéaments est-ouest de l'Arctique canadien se reconnaît également dans le réseau de drainage à l'est de la baie James et se reflète dans la région d'Abitibi. L'allure de ce réseau est compatible avec une série de fractures importantes dirigées d'est en ouest dont J. Kalliokoski a pensé qu'elles limitaient des blocs corticaux à noyaux de roches granitiques. Les deux réseaux se sont formés de manière différente et tout à fait indépendamment l'un de l'autre.

L'écartement entre le paléolinéament de la baie d'Hudson (géofracture importante du Bouclier canadien), et celui de la rivière Mattagami a servi d'intervalle unitaire dans la série de trajectoires de fracture du réseau de prospection, dans la province du lac Supérieur, au sud de la baie d'Hudson. L'intervalle unitaire correspondant dans la partie orientale de la région est plus petit. On a proposé quinze intersections comparables. On sait que sept d'entre elles contiennent des gisements de minerai endogène et l'on recommande de prospecter les huit autres.

Des fractures d'intersection de ces séries se retrouvent dans la région d'Abitibi et la répartition des gisements d'or et de cuivre coïncide avec elles. Les gisements de minerai se retrouvent aux intersections des principales fractures ou tout près (amas de gisements de Noranda, Kirkland Lake, Matachewan et Timmins-Porcupine). Plusieurs recommandations favorables à la prospection peuvent se déduire de la relation entre le réseau de fractures et la répartition d'environ 1,300 venues d'or et d'environ 700 venues de cuivre dans la région. Quelques recommandations sont présentées dans cette étude.

En ce qui concerne les districts de minerais pris individuellement, on met l'accent sur la relation entre les gisements de minerai et les zones volcaniques, telle que l'a décrite Wilson en 1967. Les grandes fractures profondément logées peuvent contrôler la répartition des centres volcaniques et le dépôt de minerai associé; cette possibilité devrait être vérifiée.

RELATIONSHIP OF STRUCTURAL LINEAMENTS AND MINERAL OCCURRENCES IN THE ABITIBI AREA OF THE CANADIAN SHIELD

INTRODUCTION

H. D. B. Wilson (1967) outlined some of the main genetic concepts for ore deposits of the Canadian Archean and evaluated some of the principal criteria used so far in exploration for ore deposits. Referring to the two volumes on "Structural Geology of Canadian Ore Deposits" (1948, 1957) he emphasized that studies on structural control of ore deposition resulted in the location of much new ore in existing mines, but as structures occurred everywhere in the Canadian Shield they were only of limited use in locating new orebodies in the volcanic sedimentary belts.

Using examples from his earlier studies (Wilson, 1953, and Wilson, et al., 1965) and results of other Canadian geologists, he emphasized that two clear relationships between ore and rock types exist in the Canadian Shield. One is the empirically deduced association of base metal deposits with basic intrusives. H. D. B. Wilson illustrated it mainly by correlating the distribution of copper occurrences with the clustering of basic and ultrabasic intrusions in Quebec. The second rock-ore relationship is that the majority of the ore bodies occur as replacements and disseminations in fragmental volcanic rocks of rhyolite or dacite composition. The Noranda area in Quebec is cited as a good example, where the main massive sulphide deposits containing pyrite, sphalerite, pyrrhotite, chalcopyrite and magnetite and having appreciable content of silver and gold, are located in the top parts of strongly fractured and altered volcanic rocks which are capped by other relatively younger volcanics. In the case of the Horne Mine orebodies at Noranda the underlying rock is a strongly fragmented rhyolite and the overlying rock is andesite. Irregularities of the contact between the latter two, such as humps or domes, play a role in the emplacement of the ore in the Noranda district.

The above seemingly contradictory relationship of ore deposits to both basic intrusions and rhyolites is explained by Wilson by classifying the Archean lavas of the Canadian Shield predominantly as one magma type, the basalt-andesite-dacite-rhyolite association of continental orogenic regions and islands arcs. According to Wilson this sequence is derived from a saturated basaltic magma which probably originated within the mantle with contamination and differentiation producing the acidic phases of the association. Wilson is of the opinion that both ores and rhyolite may be end products of the basic magma and are associated in a volcanic intrusive centre. This early basaltic magmatism and the later granitic magmatism of the Kenoran Orogeny of the Canadian Shield need not be, according to Wilson, completely unrelated, as granitic magmatism generally follows and overlaps basaltic orogenic magmatism.

If the above deductions are correct, recognition of volcanic centres and their local structures, such as domes, may serve as a good guide in prospecting for endogenous ores. It also leads, to the question of what controls the distribution of volcanic centres in the Canadian Shield. If the magma which according to Wilson gave rise to the basalt-andesite-dacite-rhyolite sequence, came from the mantle, and the volcanic centres are connected with it, then it may be expected that zones of weakness or a net of deep-seated

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fracture zones exist in deeper parts of the Shield, along which magmatic activity took place. If the ores and rhyolites are as Wilson expects, end products of this magmatic activity, then their distribution may be a useful guide for recognizing the location of the zones of weakness and these are referred to as deep-seated fractures.

The aim of the present paper is to apply the method used by Kutina (1969) in the Cordilleran area of the United States and in other parts of the work for studying the relationship of ore deposits and ore districts to patterns of deep-seated fractures. As in the preceding papers the principle of equidistances is applied (Kutina, 1968, 1969).

The Abitibi area, which includes the mining districts of Val d'Or, Noranda, Kirkland Lake and Timmins-Porcupine was examined in some detail in this study. It is considered in the structural context of a considerable part of the Canadian Shield so that structural phenomena of a very different scale can be compared. The authors were concerned that they would not overlook some of the significant broad scale structural phenomena which may have been involved and which may not be recognizable on a detailed scale. They do not think that they have examined all of the existing structural relationships in their investigation and are presenting the results as only a small contribution to the understanding of the structural control of ore deposition in a part of the Canadian Shield.

The work was initiated by Dr. A. Gross, Head of the Mineral Deposits Section within the Economic Geology and Geochemistry Division of the Geological Survey of Canada and has been done under his and Dr. S. C. Robinson's supervision. It is a contribution to the Survey's studies of ore prospecting methods and is also linked to studies on the statistical evaluations of the mineral potential of Canada in that it gives a structural geological background for a statistical study of the same area being developed simultaneously by Dr. F. P. Agterberg and A. G. Fabbri.

Acknowledgments

The authors express their sincere thanks to Dr. G. A. Gross and Dr. S. C. Robinson who selected the project, supervised the work, and offered valuable advice. Thanks are extended to Dr. F. P. Agterberg for suggestions on methods of density contouring and for discussions on statistical methods he is simultaneously applying to the same area. His critical reading of one chapter of the manuscript is gratefully acknowledged. Several geologists and other staff members of the Geological Survey of Canada offered valuable help in different stages of the work. Dr. J. Springer and Mr. J. Lepinis offered valuable assistance for which the authors are particularly grateful.

Much of the data on gold and copper occurrences used in this paper was made available from files of the Ontario Department of Mines and Northern Affairs, the Quebec Department of Natural Resources, and the Mineral Resources Branch of the Department of Energy, Mines and Resources. To these organizations the authors express their gratitude.

INDICATIONS OF A SINGLE PATTERN OF DEEP-SEATED FRACTURES IN THE CANADIAN SHIELD

The configuration and shape of the islands in the Arctic Archipelago suggest that they are controlled by several sets of significant, mutually intersecting fractures.

The main east-west trending lineament of the Arctic Archipelago, which is known in its eastern part as the Parry Rift Valley, intersects nearly the whole of the Arctic about latitude 74° N. The spacing of the east-west set of lineaments to which the above structure and two others north of it belong, is 100 miles (Fig. 1, distances A_1 and A_2; Kutina, 1971). The same spacing is applicable to three east-west trending river lineaments east of James Bay (Fig. 1, distances A'_1 and A'_2).

The southern boundary of Hudson Bay Lowlands, which in its western part extends approximately east-west (X-X' in Fig. 1), with Phanerozoic rocks on its northern side and Precambrian rocks on its southern side, surprisingly corresponds to the latitudinal position of the straight north boundary of the St. Lawrence Rift Valley between longitude 60° and 67°W (Y-Y' in Fig. 1). In the latter case, Paleozoic rocks occur on the southern and Precambrian rocks on the northern side (see Geological Map of Canada, Geol. Surv. Can., Map 1250A, 1969).

The drainage patterns around James Bay and Ungava Bay which are located in different parts of the Shield, with southern ends nearly 700 miles apart (Fig. 1), show remarkable similarities. Symmetrical orientation of the main northeast- and northwest-trending river lineaments with distances M and M' and N and N', as well as the location of the main east-west river lineaments with distances A and A' suggest, that the drainage pattern in both cases is controlled by a comparable net of fractures (Fig. 1). The drainage pattern around James Bay and Ungava Bay is strongly influenced by four main sets of fractures in the Canadian Shield which strike northeast, northwest, west and north. The north-south set is particularly well represented in the James Bay region.

Comparison of the drainage patterns of the above two regions, as well as the corresponding spacings in the east-west set of lineaments of the Arctic Archipelago and the area east of James Bay, gives an impression of a broad region having a single pattern of deep-seated fractures. A segmentation of the landmass may have taken place along them in the northernmost part, especially by a prominent breakup along latitude 74°N. Its straight course as well as criteria presented by Fortier et al. (1963) suggest that a long east-west fracture is responsible for the respective continental breakup.

On the other hand the detection of such an east-west trending fracture which may occur in the middle or in the southern part of the Canadian Shield is much more difficult where no segmentation has apparently taken place. The reason for this is that fractures need not manifest themselves in the uppermost portion of the earth's crust in all parts of their course.

Such a deep-seated major fracture may, for instance, run along the traces marked X-X' and Y-Y' in the southern part of the Canadian Shield, but no criteria have been described as yet to trace its course between the above two segments (Fig. 1).

A significant north-south trending geofracture has been postulated recently in the Canadian Shield. The name "Hudson Bay Paleolineament" was proposed for it and its character is expressed over a considerable distance (Kuntina, 1971). It is displaced by intersecting faults at several places. The Nares Rift Valley and/or the 150-mile-long Phanerozoic-Precambrian boundary on Ellesmere Island have been proposed as two possible extensions of the Hudson Bay Paleolineament in the Arctic Archipelego.

CONCENTRATION OF METALS ALONG THE HUDSON BAY PALEOLINEAMENT

Important accumulations of endogenous ore deposits occur at or near the intersections of the Hudson Bay Paleolineament with fractures of other sets (Kuntina, 1971). The Val d'Or-Timmins area with clusters of mineral deposits around Val d'Or, Noranda, Kirkland Lake, and Timmins-Porcupine, is the most significant (area No. 2 in Fig. 1). This mineral area, as a whole, is elongated along intersecting east-west faults, but fractures of the northwest and northeast sets appear to be an important factor in the locatization of ore deposits within this area. The Noranda ore deposits are closest to the Hudson Bay Paleolineament in the Val d'Or-Timmins mineral area. The Cobalt group of orebodies and a group of mineral occurrences southeast of Ville Marie, which occur on the west and on the east side of Lake Timiskaming, respectively, are another important concentration of mineral deposits along the Hudson Bay Paleolineament. They are both shown as area No. 1 in Figure 1. In this case the ore deposits are located in a broader area around the intersection of the Hudson Bay Paleolineament with significant faults which trend northwest.

Preferential distribution of the above two important groups of ore deposits around the intersections of the Hudson Bay Paleolineament with other sets of fractures suggests that mineral deposits may be present along this prominent north-south-trending geofracture in other areas. In Figure 1, four areas, Nos. 3, 4, 5 and 6 have been marked, where east-west trending lineaments are expected to intersect the Hudson Bay Paleolineament. These areas are recommended for prospecting. One (area No. 3) is south of James Bay and the location of its southern part approximates the latitude of the Chibougamau ore district (No. 7 in Fig. 1). The other three areas (Nos. 4, 5 and 6) lie under James Bay. Area No. 6 was marked as an elongated area to cover the probable intersection of the Hudson Bay Paleolineament with the boundary of Proterozoic sediments. This boundary according to Bostock (1969) extends southwesterly from the arcuate shaped eastern side of Hudson Bay.

REGULARITIES IN DISTRIBUTION OF ORE OCCURRENCES IN THE ABITIBI AREA

Geology of the Abitibi Area

The Abitibi area of the Canadian Shield has been the subject of intense studies since the beginning of the century as it is one of the most intensely mineralized areas in the world. It is located between 76° and 84° W, and between 47° 30' and 49° N in Ontario, and between 48° and 49° N in Quebec. Four main mining areas are distinguished and the following references have been selected from the literature: Ferguson (1966, 1968), and Pyke and Middleton (1970) for the Timmins-Porcupine district, Thomson (1948), Savage (1964), and Lovell (1967a) for the Kirkland Lake-Larder Lake district M. E. Wilson (1941, 1948, 1962), Dresser and Denis (1944, 1949), and Dugas (1966) for the Noranda district, and Dresser and Denis (1944), and Latulippe (1966) for the Val d'Or district.

The geology of the Abitibi area shown in Figure 2, was simplified from the following three geological maps: Map 2116 (Carlson and Donovan, 1965), Map 2046 (Ginn, et al., 1964), and Map 1600 V (Dugas and Latulippe, 1967a).

Archean basic to acid volcanics with intercalated sediments are the oldest rocks known in the area. These are overlain unconformably by clastic sedimentary and metasedimentary rocks. Volcanic and sedimentary rocks were intruded by mafic and ultramafic intrusions ranging in type from diorite to peridotite (or serpentinite). Acid intrusions of various types are younger than the mafic and ultramafic rocks and are referred to collectively as "granitic rocks" or simply "granites". To the south the Archean rocks are overlain by undeformed Proterozoic sediments of the Cobalt Group. Two distinct groups of diabase dykes intrude the area. Matachewan-type dykes striking north-south occur mainly in the Timmins area. They are overlain unconformably by the Cobalt Group sediments, and their age was calculated to be approximately 2,485 m.y. (Fahrig, et al., 1965). Keewenawan-type dykes striking northeasterly cut the Cobalt Group sediments and were calculated to be 1,285 m.y. old (Fahrig, et al., 1965). These two types of dykes are shown on Figure 4. East and northeast of Chapleau, and northeast of Foleyet, four alkaline syenite-carbonatite intrusions are reported as late Proterozoic or possibly younger than Precambrian (Carlson and Donovan, 1965). Paleozoic sediments of Ordovician and Silurian age occur south of Kirkland Lake, and extend in a northwesterly direction. Pleistocene and Recent sediments often of considerable thickness cover large areas. They are shown in Figure 2 as areas without pattern, along with unmapped areas.

The rocks of the Abitibi area were deformed by folding and faulting of more than one age and type. Volcanic rocks were first folded intensively during Archean time. Progressive folding and faulting, with an east to southeast axial trend, affected various intrusions, and was accompanied at later stages by intrusion of diabase dykes.

Several sets of fractures may be observed in the Abitibi area. Kalliokoski (1968) concluded that the emplacement of batholiths and plutons of the granitic rocks was controlled structurally by curved major faults which extend along east-west-trending narrow synclinal belts of sedimentary, metasedimentary and metavolcanic rocks in this area. According to Kalliokoski, these granites constitute cores of rather rigid blocks between the major east-west trending faults. Some of these faults have been known for a long time, especially the Cadillac Fault and the Larder Lake Fault in its western extension, and the Manneville Fault and the Destor-Porcupine Fault north of them. The existence of other faults have been suggested by Kalliokoski. Kalliokoski uses a term "massif" for the structural blocks, in the cores of which are the granitic rocks and considers three of them in particular: The Pontiac Massif, the Round Lake Massif and the Nighthawk

Massif (see Fig. 15). Referring to a paper in preparation (by E. Higgins and J. Kalliokoski), Kalliokoski suggests a major north-south fault which may separate the Pontiac and Round Lake Massifs. It is possible that this fault coincides with a segment of the Hudson Bay Paleolineament.

Fracture and Drainage Patterns

The complex fracture pattern of the Abitibi area, shown on Figure 2, has been compiled from several maps: (1) Sheet No. 5, accompanying the "Annotated Bibliography on Metallic Mineralization in the Regions of Noranda, Matagami, Val d'Or, Chibougamau" (Dugas and Latulippe, 1967a); (2) Map 2046, Timmins-Kirkland Lake Sheet (Ginn, et al., 1964), and Map 2116, Chapleau-Foleyet Sheet (Carlson and Donovan, 1965); (3) other geological maps of different scales (including preliminary maps of the individual townships) published by the Ontario Department of Mines, the Quebec Department of Natural Resources, and the Geological Survey of Canada; and (4) an unpublished geological map of the Timmins input area by Kirwan (1968).

Names of the faults in the Quebec part of the Abitibi area, shown on Figure 4 of this paper, have been taken from Dugas and Latulippe (1961). The faults of the Lake Timiskaming Rift Valley were taken from Lovell and Caine (1970, Fig. 1).

Several of the fractures recognized on geological maps of Ontario and Quebec (Fig. 2) have topographic expression as shown by rivers and lakes. The drainage pattern may provide valuable criteria for completing the pattern of fractures, as many river lineaments indicate the possible location of fractures. Drainage pattern as a criterion for recognizing faults in the Canadian Shield in the area south of James Bay, has been used previously by several authors, especially by J. T. Wilson (1948, 1949). A number of papers on lineaments and land patterns in North America were published at the beginning of the century, mainly by Hobbs (1901, 1904, 1905a, b, 1911) and Harder (1906).

The drainage pattern, taken from topographic maps (scale 1:250,000), is reproduced on Figure 4 and is compared with the fracture pattern of Figure 2.

Many other lineaments visible in the drainage pattern may mark the location of faults. Of the many possible criteria which may be used for defining lineaments the following have been used: fitting of lineaments with known sets of faults, the equidistance in their distribution, their extension along strikes of known faults and their continuity over long distances. Many more lineaments could be added if topographic features of other kinds are considered. The final picture for known and suggested faults is obviously complicated and further detailed analysis is required. A few faults have been added to Figure 4 on the basis of observations from aerial mosaics. They are distinguished by the letters AM.

Probably the most significant north-south striking geofracture of the Canadian Shield, the Hudson Bay Paleolineament, which is not readily observed on the map of the Abitibi area, shows up more distinctly when a broader part of the Canadian Shield is analyzed (Kutina, 1971). A minor segment of the Hudson Bay Paleolineament, which crosses the Noranda area southeast of Abitibi Lake (Kutina, 1971, Fig. 1), is shifted eastward from the general course of the long segment D which extends southward from James Bay (see Fig. 1). However, the central part of Lake Timiskaming coincides with the general course of segment D of the Hudson Bay Paleolineament. Evidently the fracture-trajectory* ±0 occupies different longitudinal positions in the northern and southern parts of Figure 4. Study of the aerial mosaic (Fig. 5) showed a probable extension of the Hudson Bay Paleolineament north of Lake Timiskaming which is expressed in Figure 4 as a north-southtrending broken line AM. This portion of the Hudson Bay Paleolineament appears in the aerial photograph (Fig. 5) as a north-south trending belt of farm and cultivated areas. Similarly several of the northwest striking fractures northwest of Lake Timiskaming are expressed as cultivated belts which may follow zones of weakness in the earth's crust, and guide or influence the groundwater circulation. These lines are also distinguished by the letters AM on Figure 4.

Contours which show the distribution of the underground water surface north and northwest of Lake Timiskaming were illustrated by Hume (1925, p. 56). They are in good agreement with the strike of faults postulated by us from the aerial mosaic. Hume correlates the trends of these contours with "clay belts" which lie in the depressions between the knobs and ridges of the old Precambrian surface.

Examination of Figure 1 shows that the drainage pattern in the area south of James Bay appears to be strongly symmetrical with respect to position and trend of the Hudson Bay Paleolineament. On Figure 1 rivers with the spacing M deviate southwestward from the Hudson Bay Paleolineament and rivers with spacing N generally deviate southeastward. Tectonic control of the course of the Moose River which deviates southwestward is well known (MacLaren, et al., 1968).

A symmetrical pattern of distribution of rivers and lakes with respect to the Hudson Bay Paleolineament is also seen in the Abitibi area. In the southern part of Figure 4, the Montreal River Main Fault, the Cross Lake Fault, the Lake Timiskaming West-shore Fault, the Blanche River Fault, and several others, strike northwesterly, away from the Hudson Bay Paleolineament, while in the south-central part of Figure 4, the area east of the Hudson Bay Paleolineament is characterized by a repeated northeast trend in the drainage pattern. Such a pattern strongly resembles a schematic representation of the merging of two relief patterns as shown by Hobbs (1911, Figs. 18 and 30).

The distribution of faults, diabase dykes, and the drainage pattern plotted on Figure 4, give a complex picture in which the following sets of fractures and lineaments are particularly apparent: a north-south set, an east-west set, a northwest-southeast set, and a northeast-southwest set.

The north-south set of fractures and lineaments

Along the ±0 trajectory, in the northern part of the Abitibi area (see Fig. 4) River Duparquet represents an important north-trending lineament that connects the easternmost part of Lake Abitibi with Lake Duparquet on the south. Another north-south lineament at a longitudinal position very close to River Duparquet, is represented by Lake Opasatica and a rather long diabase dyke between the two is known from geological maps which curve northwest and southeast on its northern and southern sides respectively.

Four other north-south lineaments subparallel to River Duparquet are recognizable in the drainage pattern of the northern part of the Abitibi

*Fracture-trajectory is the term applied in this paper to the theoretical position of a fracture.

area. Their spacing is similar so that they may be regarded as a case of equidistnat distribution of lineaments that follow a set of fractures. The intervals between these five north-south lineaments have been distinguished as b_4, b_5, b_6 and b_7, and with the exception of b_7 are roughly 28 miles (45 km).

In the central part of the Abitibi area the most strongly expressed north-south lineaments are represented by north-striking groups of faults and swarms of diabase dykes (see Timmins area and Matachewan area in Fig. 4). The north-south fractures are represented by the prominent north-northwest-striking fractures of the Mattagami River Fault system. The unit intervals b_2 and b_3 have been plotted on the basis of the above accumulation of north-south fractures. The Mattagami River and the fault along it represent one of the most prominent structural lineaments in the area south of Hudson Bay. It runs still farther southward into the northern part of the Sudbury district. The Mattagami River Fault is but one of a system of many faults belonging to the Mattagami River Fault system recently described in detail by J. L. Kirwan (1968, 1969). A dense swarm of diabase dykes in the Timmins area, the Mattagami River system was plotted from Kirwan (1968, 1969).

Plotting of the intervals b_2 and b_3 farther westward gives the interval b_1 with an empirical projection on its western end, where fracturing seems to be more extensive. More data on the tectonics of this area are required before this plot can be adequately substantiated.

The unit intervals b_1, b_2, and b_3 correspond to a distance of 35-38 miles (56-61 km) and are thus larger than the unit intervals b_4-b_6 28 miles (45 km). Although the change in the value of the unit interval b_0 remains unexplained, the fact that this change takes place not far from the Hudson Bay Paleolineament may be significant. The paleolineament represents a very old deep seated fracture, along which movements or tilting of big crustal blocks could have proceeded from earliest times.

Like many other areas in different parts of the world some unit intervals within particular sets of fractures are more important than others. Němec (1970) distinguishes up to 60 orders of unit intervals within sets of equidistantly repeated structures on the earth. These geological structures are classified by Němec according to a universal regularity of structural pattern.

Among the north-south trending lineaments where the intervals b_1 - b_7 have been distinguished, the Hudson Bay Paleolineament and the Mattagami River lineament are no doubt the most important structurally. In Figure 4, the former is distinguished as the ±0 trajectory, the latter as -1 trajectory. An attempt was made to use this unit interval in the compilation of an empirical prospecting net for a broad area in the Superior Province south of Hudson Bay. It appears that an interval of this order B_0 and a relatively smaller interval east of Hudson Bay Paleolineament, along with a corresponding A_0 interval, represents the appropriate spacings between trajectories of deep seated fractures. Their intersections appear to control the distribution of the main clusters of ore deposits in the Abitibi area. Near the east-west trajectory ±0 in this area and in the area west of the Hudson Bay Paleolineament, the unit interval B_0 between north-south striking fractures is about 105-111 miles (170-180 km), and in the area east of the paleolineament about 83 miles (135 km). According to the classification by Němec (1970) these two unit intervals B_0 and A_0 belong to the equidistances of the hyperscale. B_0 is closer to Němec's 6th order of equidistances for which he gives a value of 199.281 km (about 123 miles).

The distances given by the unit interval b_0 in Figure 4 belong to a lower order of equidistances, closer to Němec's 8th order. Still smaller unit intervals in the Abitibi area may be distinguished in the north-south set of fractures. A good example of the next smaller unit intervals in the north-south set of fractures is the distance between the Hudson Bay Paleolineament at the north-trending arm of Lake Timiskaming and the parallel fracture to the west. This interval (b_0) is very distinctly seen in the aerial photo mosaic (Fig. 5). Its length is about 13 miles (21 km) and is referred to the 9th order of Němec's equidistances for which he gives an interval of 24.910 km (about 15 miles).

Still smaller unit intervals are worth studying at a scale of 1:250,000. Good examples are found in the Mattagami River Fault system, where prominent unit intervals of 3-4 miles (5-6 km) seems to be typical. According to Němec's classification they would be of the 11th order (megascale). Intervals comparable with Němec's 10th order are also distinguishable.

Several north-trending structural lineaments have been recognized in the area south of Hudson Bay (see J. T. Wilson, 1948) and the relation of major mining camps of northwestern Ontario to fault zones and east-west and north-south fault intersections were discussed by him (1949).

The east-west set of fractures and lineaments

In widely separated parts of the Canadian Shield east-west lineaments occur with a comparable spacing of approximately 100 miles (about 161 km) (see Fig. 1). This unit interval was applied in developing the empirical prospecting net (Fig. 14). An excellent example of a prominent east-west trending tectonic line in the Canadian Shield is the northern limitation of the Gulf of St. Lawrence north of Anticosti Island. It represents a very straight boundary of a part of the St. Lawrence Rift system (Fig. 1) and was recently described by Kumarapeli and Saull (1966). Much of the southern boundary of the Hudson Bay Lowland occupies a latitudinal position very close to the straight limitation of the St. Lawrence Rift system distinguished by the letters Y-Y' on Figure 1.

South of the southern limit of the Hudson Bay Lowland, several short lineaments in the drainage pattern are recognizable. They can be correlated along an east-west line along which three clusters of ore deposits in the Superior Province are located. One of these is the Chibougamau mining area. This empirical line was plotted on Figure 14 as trajectory +1 and its course is exactly east-west. One of the criteria for plotting it is a prominent east-west lineament of the drainage pattern, as shown in Figure 3, where the Turgeon River shows two abrupt right-angle changes in its course. Such sharp changes are probably caused by tectonic control of the river course. Hobbs (1904, Fig. 4) described similar examples.

The unit interval A_0 of 100 miles (161km) as shown on Figure 1, was projected southward from the east-west trending empirical trajectory +1 of Figure 14. Its course corresponds with the positions of the most important clusters of ore deposits in the Val d'Or-Timmins area. The same spacing plotted farther southward falls in the vicinity of the Sudbury ore district. The relationship of significant ore districts to this net of equidistantly spaced trajectories suggests that deep seated fractures of this trend exist either at or close to the position of the postulated east-west trajectories derived. The trajectories of Figure 14 have been postulated independently of a structural

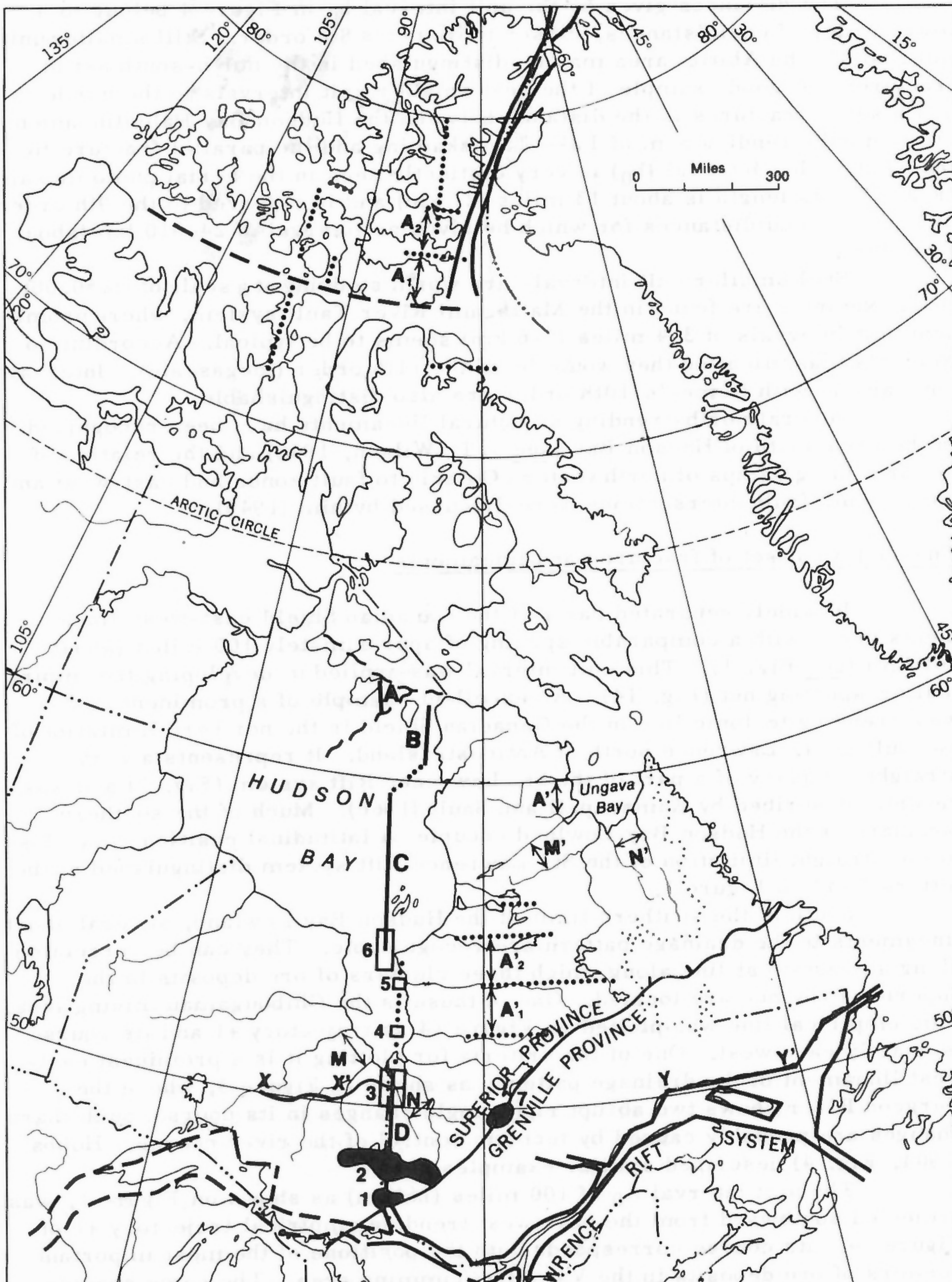

Figure 1. Concentrations of metals along the Hudson Bay Paleolineament.

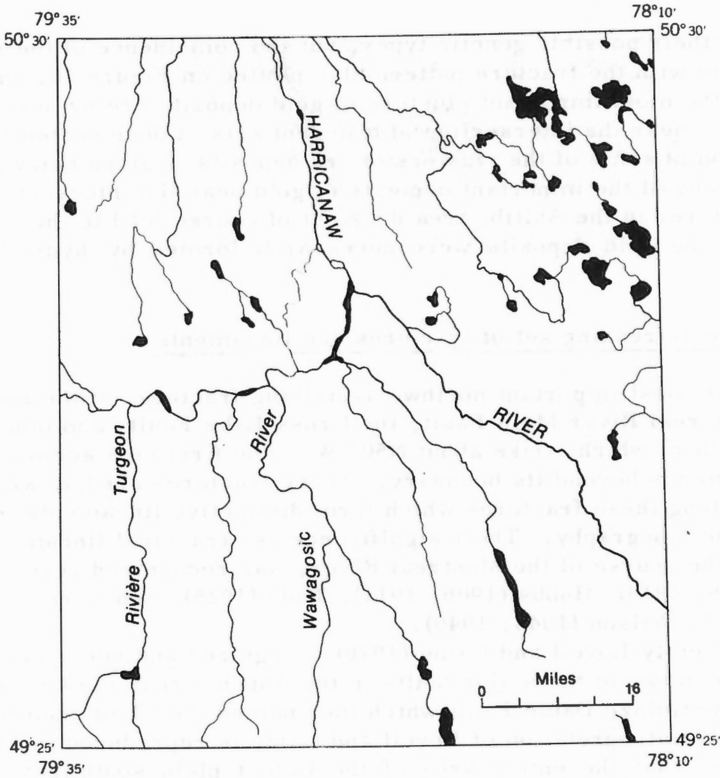

Figure 3. An abrupt change in the course of the Turgeon River along an east-west trending structural lineament north of the intersection of the ± 0 trajectory of the North-South set, with the +1 trajectory of the East-West set (see Fig. 14).

analysis of this area done by Kalliokoski (1968). The east-west set of trajectories of Figure 14, especially trajectory +1, corresponds surprisingly well with one of the east-west boundaries or possible faults postulated by Kalliokoski. They are interpreted as separating structural blocks which have granitic rocks in their cores.

One of the long and curved east-trending structural lines running through the Abitibi area is known as the Cadillac-Bouzan Fault and follows a belt of sedimentary-volcanic rocks. Another running north of the latter splits into several branches. Its main branches are known as the Manneville Fault, the Destor Porcupine Fault, and the Pipestone Fault. For much of its course it also follows a belt of sedimentary–volcanic rocks. Many of the important mineral deposits, especially gold (see Fig. 10), appear to follow the course of these east-west faults as well as belts of sedimentary-volcanic rocks.

Ridler (1970) has recently suggested a relationship between concentrations of gold and geochemical processes involved in the evolution of the sedimentary and volcanic rocks in the Kirkland Lake-Larder Lake area. The simple plots of gold deposits and occurrences on Figures 7 and 10 do not distinguish their possible genetic types, but the coincidence of their distribution and size with the fracture pattern also plotted on Figure 10, suggests that several of the most important clusters of gold deposits are preferentially located at or near the intersection of different sets of deep seated fractures. A discussion of some of the clusters of ore deposits is given below. A clustering of many of the important deposits of gold near the intersections of major fractures in the Abitibi area does not of course lead to the conclusion that all of the gold deposits were necessarily formed by hydrothermal processes.

The northwest-trending set of fractures and lineaments

The most important northwest-striking fractures of the Abitibi area are the Montreal River Main Fault, the Cross Lake Fault, and other faults parallel to them which strike about N50° W. The first cuts across the Abitibi area and extends beyond its boundary. These fractures are followed by rivers and lakes along these fractures which form distinctive lineaments in the drainage and topography. Their significance as structural lineaments, especially the course of the Montreal River, was recognized very early by Miller (1905, 1913), Hobbs (1906, 1911), Todd (1925), and were later emphasized by J.T. Wilson (1948, 1949).

Recently Lovell and Caine (1970) recognized and described a rift valley between two of the major faults in the Abitibi area, the Cross Lake Fault and the Quinze Dame Fault which they named the "Timiskaming Rift Valley". The interpretation of Lovell and Caine is reproduced in Figure 16B. They suggest that the entire area of the Cobalt plain southwest of the Timiskaming Rift Valley may occupy a graben, an idea originally expressed by J.T. Wilson (1948, 1949) who referred to it as the "Cobalt Graben" (1949, Fig. 8).

In the Lake Timiskaming area and to the northwest, we can distinguish unit intervals within this set of northwest faults of different orders. The largest unit interval probably lies between the Cross Lake Fault and the Quinze Dam Fault which according to Lovell and Caine (1970) occur on opposite sides of and are boundaries to the Lake Timiskaming Rift Valley. This unit interval, measured northwest of Lake Timiskaming, is about 25 miles (40 km). An important unit interval of a lower order occurs between the Montreal River Main Fault and the South Montreal River Fault. It corresponds to the interval between the South Montreal River Fault and the Cross Lake Fault , and is about 4.3 miles (7 km). The distance between the minor lineaments as determined from the distribution of cultivated areas north of Lake Timiskaming and four lineaments on the aerial mosaic (Fig. 5), is about 2.5 miles (4 km). These interval distances of 25 miles (40 km), 4.3 miles (7 km), and 2.5 miles (4 km), may be relative to the 8th, 11th, and 12th orders of Němec's equidistances (Němec, 1970) for which he gives values of 49.8 km, 6227.5 m, and 3113.8 m, respectively.

Lake Timiskaming is a good example of a lake form that is controlled by a fault pattern. Figure 5 clearly shows the shape of its most important part which consists of two segments that trend northwest, each being controlled by a northwest-striking fault. The northern segment of the lake follows the Lake Timiskaming West-shore Fault, and the southern segment the South Montreal River Fault. The middle north-trending segment of Lake Timiskaming probably originated along the Hudson Bay Paleolineament. Thus, in this interpretation, the shape of Lake Timiskaming reflects the intersection of the important north-south geofracture of the Canadian Shield with major northwest-striking faults, and a cluster of endogenous ore deposits occur around the intersection of these faults. In the Lake Timiskaming area (Figs. 5 and 6) the most important ore deposits are those around Cobalt which have been studied recently by Thomson (1957, 1967), Petruck (1967, 1968), Halls et al. (1967) and others.

In the distribution pattern of ore deposits in the Cobalt area (see Figs. 5 and 6), we observe that, beside the northwest-trending lineaments, there are others which trend north, northeast, and perhaps east. A northeast trend in the distribution of ore deposits in the Cobalt area was suggested previously by Miller (1913) who mentioned also that few lakes and streams in the area have their longer axis lying in a north-south or in an east-west direction. A set of north-south, northeast-southwest and northwest-southeast "regional disturbances" recognized from the drainage pattern were illustrated by Todd (1925) in the Matabichuan area, south of Cobalt.

Besides the set of faults which strike about N50° W mentioned above there are other northwest-trending faults and lineaments in the Abitibi area which show a somewhat different strike. The longest is the Smoky Creek Fault which strikes about N40° W and crosses the Noranda area; Lake Flavrian lies along this feature. A northwestern extension of the Smoky Creek Fault may be partly responsible for the shape of Lake Abitibi in this area. On the opposite side, an extension of the Smoky Creek Fault may be traced far into the southeastern part of the area shown on Figure 4.

Another long lineament trending northwest or west-northwest in the southern part of Figure 4, west of the Hudson Bay Paleolineament, can be traced for a long distance but its coincidence with a fault has not been proven. It coincides with one side of a tectonically controlled hexagonal pattern, some parts of which have been mapped as faults. It is distinguished as S_1 on Figure 4, and similar, hexagonal patterns which are not fully developed by S_2 and S_3. Such hexagonal drainage patterns were observed by Stur (1858) in Idria, Yugoslavia, and later reported by Hobbs (1905a).

The northeast-trending set of fractures and lineaments

Several northeast-striking lineaments are present in the Abitibi area (Fig. 4). Some in the Noranda area have been recognized as faults. One of the most apparent in the Abitibi area in Quebec is the Hunter Creek Fault, which intersects the northwest-striking Smoky Creek Fault. Their intersection does not lie far from the postulated position of the Hudson Bay Paleolineament. Other faults of a similar strike parallel to the Hunter Creek Fault in the Noranda area are the Quesabe Fault, the Beauchastel Fault, and the Horne Fault.

It is not always clear in the western extension of the Cadillac-Bouzan Fault, which generally strikes east, whether one is dealing with an east-striking fault which is locally deflected southwesterly, or with a separate northeast-striking fault. Recognition of the possible intersection of an east-striking fault with a northeast-striking fault proved to be of economic importance in the search for new orebodies (Gilmour, 1965) as it contributed to the discovery of the ore deposits of Vaute Mines Limited (see Figs. 10 and 11).

A set of northeast-trending lineaments is developed east of the Hudson Bay Paleolineament (Fig. 4). Many of these terminate abruptly at the Smoky Creek Fault and its southeastern extension and it appears that the Smoky Creek Fault here forms the boundary of a crustal block.

Many of the diabase dykes plotted on Figure 4 have a general northeasterly strike but east-northeast and north-northeast strike directions are also present. They were referred to by Fahrig et al. (1965) as the "Abitibi swarm" and are responsible for many positive magnetic anomalies. According to paleomagnetic evidence (Larochelle, 1966) they were intruded during several distinct periods of Precambrian time. In the opinion of Norman (1948) they may represent an extension of the northeast system of fractures which characterize the Chibougamau and Mistassini district northeast of the Abitibi area.

Some more or less linear features of the drainage pattern compiled from geological maps are shown in the easternmost parts of Figure 4. It is not known whether these lineaments represent fractures, however, they fit remarkably well into the surrounding general fracture pattern.

Distribution of Gold and Copper Occurrences

The data on gold and copper occurrences used in this paper were collected from a large amount of published and unpublished material. An attempt was made to locate all occurrences which have been described in the Val d'Or-Timmins mineral area, and to estimate the size of producing and past-producing mines by using production and reserve figures up to and including 1968.

"Ore occurrence"* is a term which in general is not clearly defined. It is used here to represent any concentration of ore forming minerals from that in a large deposit to mineralizalization in outcrops, test pits or isolated drillholes, where spot or grab samples were collected, but for which the tonnage of ore may be unmeasurable (cf. Brisbin and Ediger, 1967).

The selection of gold and copper occurrences corresponds closely to those compiled in Quebec Department of Natural Resources Special Paper 2, Annotated Bibliography on Metallic Mineralization in the Regions of Noranda, Matagami, Val d'Or, Chibougamau, published in 1967. This volume was used as the main source of information for the Quebec part of the Val d'Or-Timmins ore field. Various publications and open files of the Ontario Department of Mines, the Quebec Department of Natural Resources, and the Mineral Resources Branch of the Department of Energy, Mines and Resources were consulted, and a total of 1,333 gold occurrences and 709 copper occurrences were considered. Of these, 179 are mines with production or reserve figures for gold, and 55 are copper mines. They are listed in Tables I and II, and plotted on Figures 10 and 11.

Description of the contour method

To estimate the areal distribution of the occurrences, density contours were traced and compared to various types of mappable geological information.

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* For simplicity the term occurrence will be generally used throughout the text. The term ore as used here refers to accumulations of metallic minerals and does not have connotations of favourable economic significance as normally implied in North America in the use of the term "ore".

The concentration of mineral occurrences within a certain area can be expressed quantitatively as their density within a unit area. Different densities, however can only be detected readily by tracing the density contour lines at proper intervals. Such a method has been used previously by H. D. B. Wilson (1967), to compare the distribution of copper deposits with the distribution of mafic and ultramafic intrusions over a large area in Quebec.

The contour method used here is the so-called "free-counter" method (Turner and Weiss, 1963). A contour cell, in our case a circle of given area, was moved continuously through the area in such a manner that the number of occurrences contained in it remained equal to a given constant value for each contour line. The contours join centres of the contour cells with an equivalent number of mineral deposits.

Two different types of contours were made: unweighted and weighted density contours.

Unweighted density contour maps for gold and copper occurrences

The contour cell chosen for the unweighted density contours is a circle of 4 square inches, corresponding to 64 square miles at the working scale of 1 inch to 4 miles. For these contours, density intervals of 5 occurrences were chosen, for densities ranging from 1 to 45.

The gold occurrence distribution pattern (Fig. 7) shows several distinct maxima, and a more or less continuous distribution along curved lines with an east-west trend. Individual peaks seem to be sharper in the Ontario area (see cluster around Timmins, and clusters near Kirkland Lake) than in the Quebec area (see clusters around Noranda and Val d'Or). The gold occurrence pattern appears to be far from random. Its distribution is influenced by more than one geological factor, but lithology and structures are the main ones.

The copper occurrence distribution pattern (Fig. 8) also shows distinct maxima, however the continuous east-west distribution observed for gold is absent. Densities are somewhat lower in Ontario, as may be expected because the Ontario side of the Abitibi area produces less copper, than the Quebec side. Distinct trends observed for copper distribution extend northwest and north-south, a northeast trend is less distinctive. These trends suggest that structural factors could be the most important control for the distribution pattern of copper occurrences. This aspect will be considered in more detail below.

Weighted density contour maps for gold and copper occurrences

The following facts should be considered. When making an analysis of the distribution of gold and copper deposits in the Abitibi area: (1) a producer cannot always be expressed as a single point on a map, therefore some generalization cannot be avoided; (2) the amount of ore produced and that of the reserves (i.e., the size of every deposit) must be taken into account, because these numbers are intended to express, at least in a semiquantitative way, the concentration of metals in the earth's crust; (3) since a clear relationship between concentration of deposits per unit area and amount of extracted or extractable ore can be observed and statistically determined (Agterberg and Cabilio, 1969, p. 144), and occurrences tend to be clustered around larger deposits, it is desirable and even necessary to consider both factors together. Sizes of deposits and clustering of occurrences around them have been combined as follows. A semiquantitative method of weighted density contouring also was applied for the study of the distribution of gold and copper occurrences in the Abitibi area. The contour cell used for this contouring method is a circle of 1 square inch corresponding to 16 square miles at the working scale of 1 inch to 4 miles to represent the size of a deposit. A value equal to the $\log_{10}$ (P+R) or the logarithm of production, P, plus reserves, R, in troy ounces for gold and in short tons for copper, was assigned to all producing mines. Producing properties were given values ranging from 2 to 7 on the logarithmic scale of 100 to 10,000,000 ounces or tons for gold and copper respectively. A symbolic value of 1 was given to occurrences for which values of P and/or R cannot be established. This corresponds to a value of 10 ounces or tons. It should be remembered that logarithmic values have been rounded off on the logarithmic scale. For example, a value 1 can represent any value for the interval between 0.5 and 1.5. In terms of ounces or tons this corresponds to an interval ranging from 3.162 to 31.62 ounces or tons. This explains why the class limits used in Figures 10 and 11 are equal to 3.162 multiplied by a power of 10. Contouring was done on the basis of a semiquantitative assumption because weights for density of points and weights of (P+R) values for single points were summed in a qualitative way. For example a deposit of $\log_{10}$ (P+R) = 6, was counted as 6 occurrences located at a single point; and a deposit with $\log_{10}$ (P+R) = 3, counted as 3 occurrences, etc. when contouring a single density figure of say 5, can be obtained in more than one manner since various deposit sizes and numbers of single occurrences in combination give this density value. On Figures 10 and 11 weighted density contours are shown for gold and copper occurrences. Only contours 1, 5, and 10 were traced. Dots of different radii are shown on the maps, to represent the different sizes of deposits as determined from $\log_{10}$ (P+R) (productions plus reserves obtained from available published data up to and including 1968). In this way the relationships between clustering of occurrences and sizes of producers, was expressed and a different set of contour lines was produced.

Several things should be kept in mind when inspecting these contours: (1) they represent a compromise between two different types of data, i.e., densities of points, and values of $\log_{10}$ (P+R) expressed as densities over nonmeasurable areas (points); (2) contour 1 will always be a closed line containing points, contour 5 will be a closed line which may not surround points with weights 1, 2, 3, or 4. Contour 10, which expresses fairly high densities or sizes, may or may not surround one or more producers, since the latter all have values less than 10 and range in size from 1 to 7 for gold deposits and from 1 to 6 for copper deposits.

In the weighted density contour maps, gold and copper occurrences tend to cluster more strongly around producers, and clusters tend to be of greater density when the size of the producers increases. This is particularly evident for the main area of gold deposits in the vicinity of Timmins, Kirkland Lake, Noranda, and Val d'Or, and also for the main area of copper deposits around Noranda and Val d'Or. These facts may be explained in part because of an increased amount of exploration around major discoveries, and partly because of an actual higher concentration of mineral occurrences in particular areas.

The weighted contour maps for gold and copper occurrences will be used later to correlate the distribution of the mineral deposits with various types of geological information.

Comparison of methods of classification of deposits by size

Ore deposit of any type may vary greatly in size and value. In general the classifications that are in use now to express the size of deposits do not make use of a scale with regular intervals between the classes.

A scheme for worldwide classification of ore deposits was proposed by Laffitte and Rouveyrol (1964) to express by means of circular dots of appropriate radii both the sizes of the deposits and their relative world percentage. For the Metallogenetic Map of North America, Leech (pers. comm.) proposed a simple division into three classes, small, medium, and large. Neither classification schemes is applicable for our purpose of contouring the deposits according to their size: the former because of the more complicated size relationships between classes of deposits, and the latter because the contours may be too generalized with only three classes.

A common logarithmic scale was therefore chosen, which besides being very simple, keeps the values of the classes small and suitable for contouring. The classes for the sizes of gold and copper deposits according to Laffitte and Rouveyrol (1964) and Leech (pers. comm.) are compared in Figure 9 with the classes used in this report for the weighted contouring of gold and copper deposits. The original data for production and reserves are expressed as troy ounces of gold and short tons for copper. The class limits in metric tons of the two other classifications are plotted for comparison as numbers of troy ounces and short tons. By comparing Figure 9 with Figures 10 and 11, it is apparent that most of the deposits plotted in this study belong in the lower classes of both classification schemes.

Correlation Of Gold and Copper Occurrences With Geology and Fracture Pattern

Gold

By comparing the unweighted density contours of gold occurrences of Figure 7, with the geology of the Abitibi area (Fig. 2), it is apparent that the gold occurrences are distributed in volcanic-sedimentary belts. Moreover the distribution of occurrences in several areas seems to coincide with the strike lines of known faults or fracture zones, and lineaments which are expressed in the drainage pattern. These two features may have parallel or subparallel trends, or may intersect at high angles. The continuous distribution of narrow maxima of density of gold occurrences along the Cadillac-Bouzan Fault and the clustering along the Porcupine-Destor Fault, north of Noranda (cf. Figs. 4 and 10) is remarkable. Densities of points alone, suggest several distribution maxima in the Timmins-Kirkland Lake area along north-, northwest-, easterly-, east-northeast-, and northeast-trending lines.

These relationships are even more apparent in Figure 10 where the weighted density contours of gold deposits are superimposed on the fracture pattern compiled for the Abitibi area. It is evident that a significant belt of gold deposits coincides in location with the Cadillac-Bouzan Fault in the southeastern part of the area. This fracture zone roughly follows a narrow belt of sedimentary rocks, lying in a critical zone between sedimentary and volcanic rocks (Latulippe, 1966; see also Fig. 2) and the above belt of gold

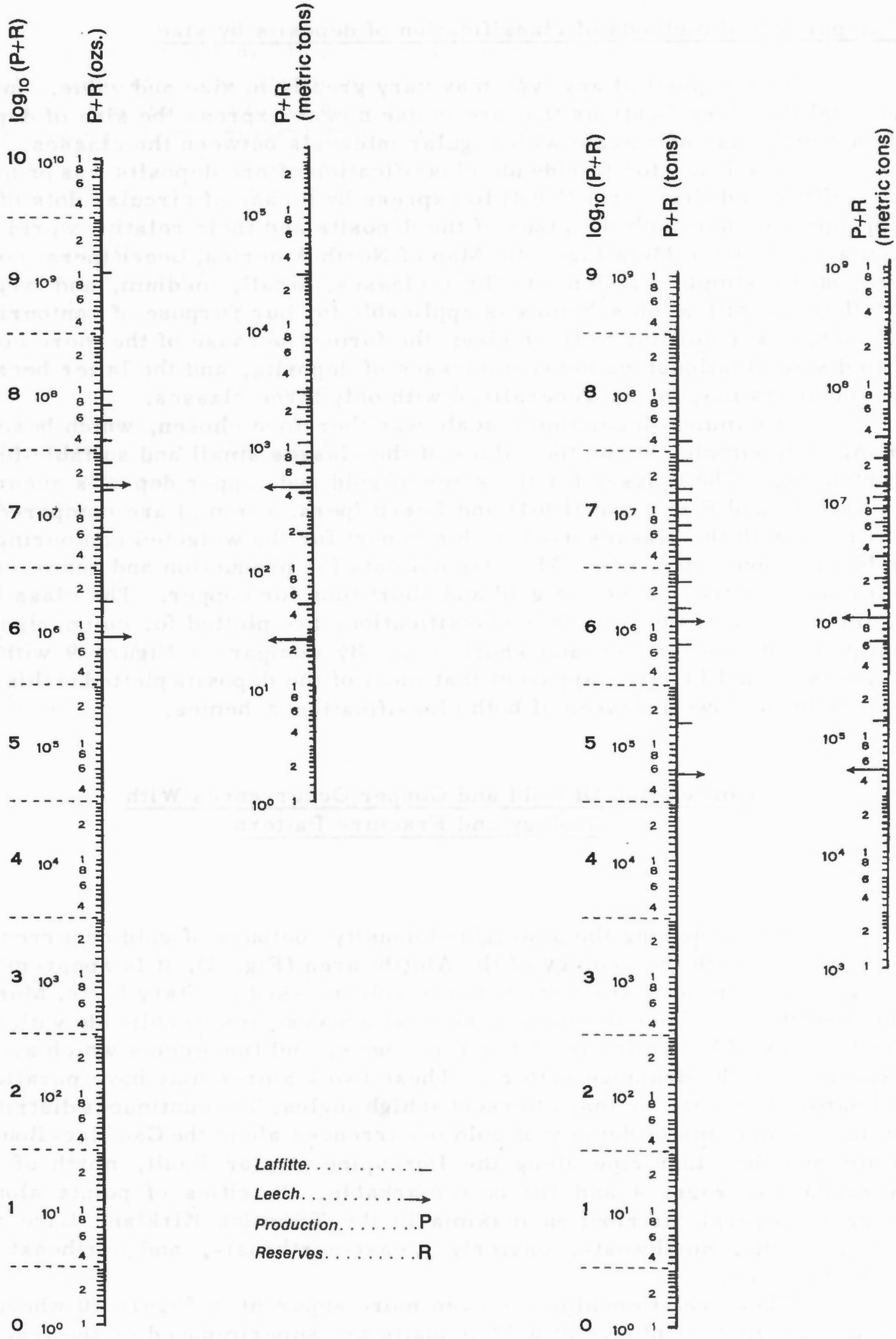

Figure 9. Comparison of the classifications of gold and copper deposits by size as used by Laffitte and Rouveyrol (1964) and Leech (pers. comm.) and the classification used in the present paper for the weighted density contours shown in Figures 10 and 11.

deposits gives at the same time an impression of lithological control. North of the east-striking Cadillac-Bouzan Fault, the strong concentration of gold deposits in the Noranda cluster of ore deposits occurs in volcanic rocks that are intruded by several mafic rocks and where fractures with various strike directions intersect, northeast- and northwest-striking faults. The orebody of Vauze Mines Ltd., as previously mentioned was discovered at the intersection of these fracture sets. Two remarkable clusters of gold deposits are located west-southwest of Noranda on the Larder Lake Break, along the western extension of the Cadillac-Bouzan Fault (Thomson, 1943), and on the northeast-striking Kirkland Lake Break which are referred to as the Larder Lake and Kirkland Lake areas, respectively.

Farther to the southwest around Matachewan clusters of ore deposits occur at the intersection of at least three sets of faults. One of them is the northwest-striking Montreal River Main Fault which is intersected by a number of north-striking faults and diabase dykes (Fig. 14). A third set of fractures in the Matachewan area is represented by east-northeast-striking faults and lineaments which may represent an extension of the Larder Lake Break (see Figs. 10 and 11, and Lovell, 1967b).

The Timmins-Porcupine cluster of gold deposits is one of the most significant in the Abitibi area and is shown in Figure 10, and in detail in Figure 12. It is located at the intersection of three main sets of faults: the easterly trending Destor-Porcupine Fault the north-trending Mattagami River Fault system, and the northwest-trending Montreal River Fault system.

A comparison between Figures 4, 7, and 10 suggests that the regional strike of the east-northeast-trending Abitibi diabase dykes, may represent a possible trend that coincides with the distribution of gold occurrences.

Copper

The unweighted density contours of copper occurrences (Fig. 8), do not show as continuous a distribution along the curved east-trending lines as that observed for gold (Fig. 7), but are localized at particular places along these lines. However, the distribution of occurrences and density maxima along particular directions, mainly the north, northwest and northeast trends observed in Figure 8, are even more evident for copper than for gold.

Moving from east to west in the Abitibi area (see Fig. 11), the first main cluster of copper deposits occurs near Val d'Or, close to the Cadillac-Bouzan Fault. Farther west lies the Noranda cluster of copper deposits, the most important in the Abitibi area. It is located in an area of volcanic rocks, intruded by several mafic intrusions, and intersected by several sets of fractures. Geological features of the area indicate the proximity of an ancient volcanic centre according to Roscoe (1965). A few small deposits of copper also occur to the south and east of Kirkland Lake. Some concentrations of copper occur in the Matachewan gold area where fractures of three different sets intersect (see Fig. 13).

Some large concentrations of copper in the Timmins area appear to be related to specific structural features in a broader structurally favourable area. For instance the fault pattern north of Timmins (Kirwan, 1969; Figs. 4, 11, and 12) shows several wedge-shaped blocks formed by the intersection of north-northwest and northwest-striking fractures. The large Kidd Creek base metal deposit appears to occur at one of these fault intersections.

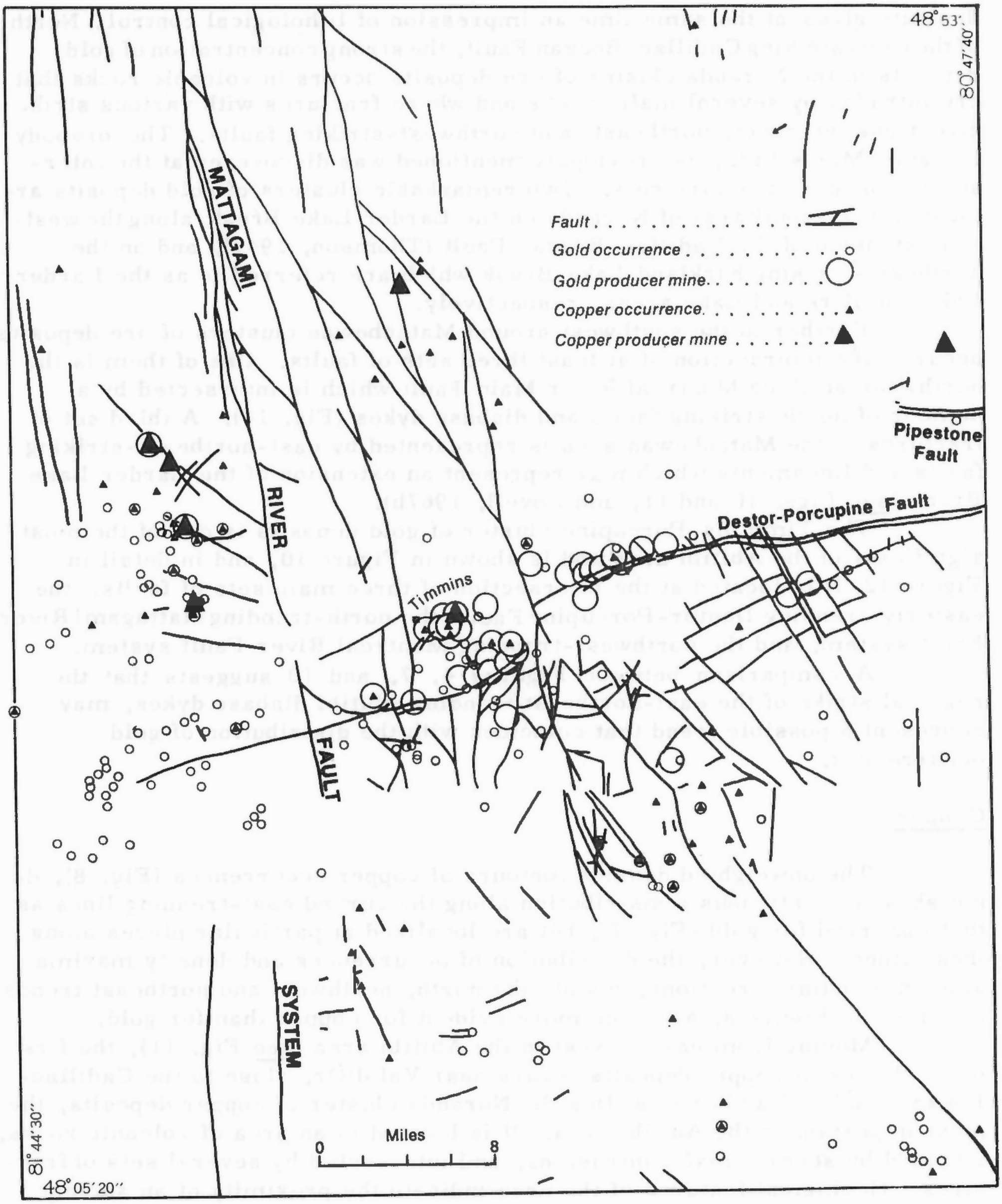

Figure 12. Concentration of gold and copper deposits in the Timmins-Porcupine ore field, and significant intersection of east, north, and northwest sets of faults.

According to Kirwan (1968) this deposit appears to be related to a centre of volcanism nearby.

West of Timmins (Kamiskotia area) Pyke and Middleton (1970) relate four copper deposits to a major centre of volcanic activity. According to them a source rock for the copper ore-bearing solutions might be an intrusion at the base of the volcanic pile. An alternate source, considered to be less likely by them, might be a phase of the gabbroic complex that intrudes the lower part of the volcanic sequence. An association of basic intrusions with base metal deposits was observed by H. D. B. Wilson (1953, 1967) in several areas of the Canadian Shield, including the Timmins area. According to Wilson (1967) the suggested relationship of ore to basic intrusions and to volcanic rhyolite rocks, which may appear to be a contradiction, can be understood if all these features are related to one differentiation process in which both ore minerals and rhyolite may be end products of a basic magma which fed material to the volcanic centre. Clusters of basic intrusions and clusters of the more massive rhyolite domes may all be produced around a volcanic centre.

Finally, comparing Figures 7 and 10 and Figures 8 and 11, we observe that some trends appear to be common for both the distribution patterns of gold and copper occurrences. Gold occurrences, however, show some additional trends in their distribution. For example in the Val d'Or district, gold orebodies occur in all rock types: volcanic, sedimentary and intrusive, but only in competent members (Latulippe, 1966). These and other observations may suggest more than one period of mineralization for gold, which could be in part contemporaneous with and in part later than copper. Some evidence that the gold mineralization in several parts of the Abitibi area may be later than copper mineralization, was presented by Price (1948), Dugas (1966), and Latulippe (1966). Campbell and Charlesworth (1965) ascribe greater mobility to the gold-bearing hydrothermal solutions in the Canadian Shield with respect to more viscous agents depositing the massive sulphides.

Recommendations for Prospecting in the Canadian Shield

Correlation of some of the prominent types of geological structure which occur in Superior Province (Fig. 14) are repeated in other parts of the Canadian Shield (Fig. 1). The relationship of ore districts to the intersection of east-striking deep-seated fracture systems which occur at intervals of about 100 miles is one of the main observations made in this study, and it is believed that other fractures of this set may occur at the same interval in other parts of the Shield. These east-striking fractures are intersected by several other important sets such as the north- and the northwest-trending sets of fractures in the Superior Province, south of Hudson Bay. Clusters of orebodies at Noranda and around Cobalt near the Hudson Bay Paleolineament lead to the prediction that the areas marked 3, 4, 5, and 6, at other places where the Hudson Bay Paleolineament is believed to be intersected by east-trending fractures may be favourable ground for prospecting.

Even though there are good indications for the existence of east-trending lineaments spaced at 100-mile intervals in the Arctic area, we cannot expect to find this specific interval between east-striking fractures in all the other parts of the Shield. Block movements and several other deformational factors may have distorted the original fracture pattern even if it was more or less regular at the time when it originated. The segmentation of the Hudson Bay Paleolineament as seen in Figure 1, shows that the pattern of deep-seated fractures was distorted by later deformation processes. Nevertheless, it would be very instructive to extend the pattern of deep-seated fractures over the whole Canadian Shield, to study possible distortion of it caused by later deformation and to try to relate the distribution of ore deposits to it in the whole Shield. Such a study may also contribute to a better understanding of some of the basic problems of structural geology in the Shield, and especially to the study of structural relationships between its provinces.

Recommendations for Prospecting in the Superior Province

Evidence has been given to show that a net of mutually intersecting east- and north-striking deep-seated fractures, undoubtedly combined with fractures of other sets, exists in the Superior Province south of Hudson Bay (Fig. 14). The pattern of east-trending trajectories (Fig. 14) coincides in general with the position of east-trending fractures suggested by Kalliokoski (1968) and it is noteworthy that these two interpretations of structure were derived through fully independent approaches.

The distribution of endogenous ore deposits is closely related to this fracture pattern (Fig. 14). Important ore deposits and ore districts occur in seven out of fifteen structurally comparable areas. More intense prospecting is therefore recommended in the seven areas where deposits are known and to extend prospecting to the other eight areas. Considering what has already been discovered along the north-trending trajectories, the following seem to be most promising among the other eight areas mentioned. First the area around the intersection of ±0 trajectory of the north-trending set and the +1 trajectory of the east-trending set, because the Noranda and the Cobalt ore district occur along this north-trending lineament. The second promising area is located around the intersection of -1 lineament of the north-trending set and +1 trajectory of the east-trending set, because a part of the Sudbury district and some part of the Timmins-Porcupine district ore deposits occur along the projection of this north-trending -1 trajectory.

Recommendations for Prospecting in the Abitibi Area

The ore deposits are generally grouped along major fractures and their intersections (Figs.4, 10, and 11). They show preferential relationships to some of the host rocks and their position in the sequence of geological events.

Gold

Ridler's study (1970) suggested that all the gold occurrences of the Abitibi area may not belong to the same genetic type and prospecting methods may therefore differ. Genetic groupings for all of the 1,300 gold occurrences considered in the study cannot be made on the basis of data available. Therefore all gold and copper deposits of the Abitibi area have been grouped together. Their distribution as a whole is related to the fracture pattern (Fig. 10). The clustering of gold deposits at or near intersections of major faults leads to several suggestions for future prospecting and three examples are presented for consideration:

(1) Regardless of the explanation given for the genesis of the Kirkland Lake gold deposits they appear to be located along the western extension of the Cadillac-Bouzan Fault (see Figs. 4 and 10). Projecting the Larder

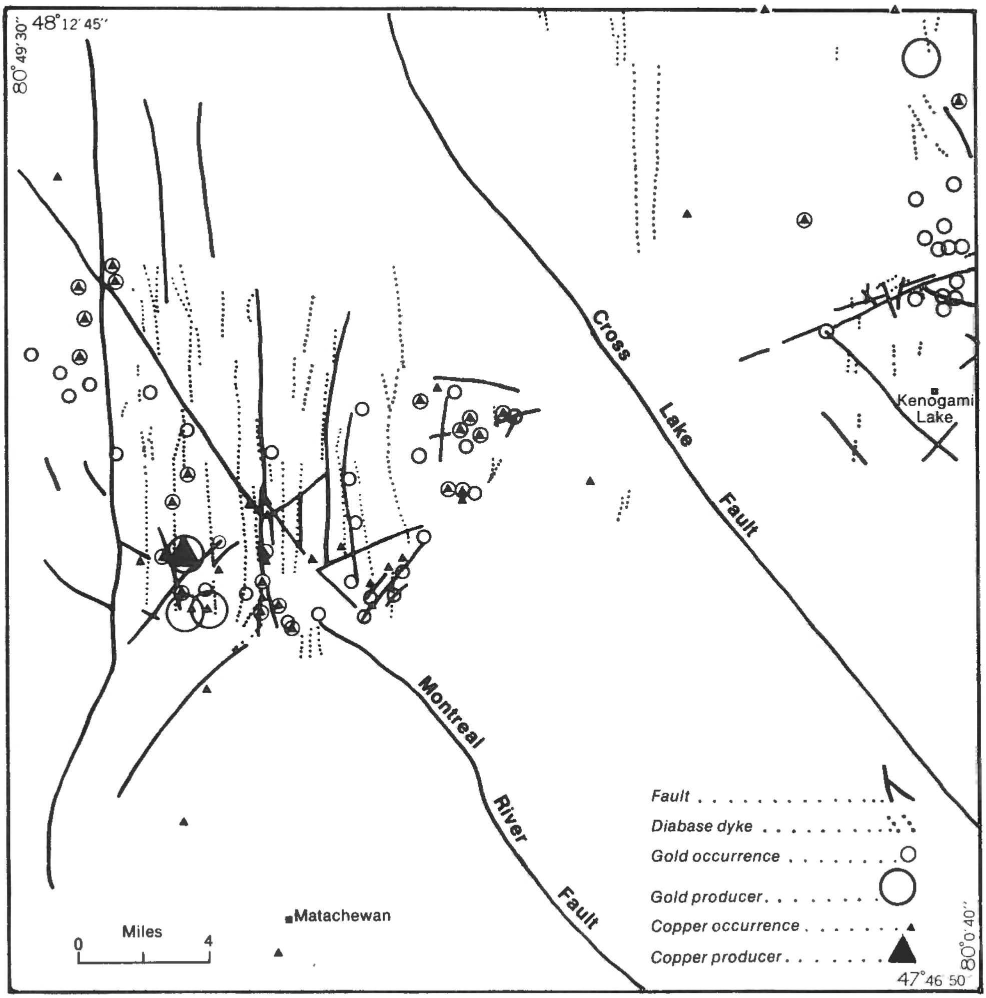

Figure 13. The Matachewan cluster of gold and copper deposits, and significant fractures.

(1) (cont.) Lake Break to the southwest (Fig. 10) leads to the prominent Matachewan cluster of ore deposits which are at the intersection of the northwest-striking Montreal River Main Fault with a set of north-striking faults and diabase dykes (Figs. 10, 4, and 13). Traces of west-southwest-striking faults are visible here which may represent a western extension of fracture systems related to the Larder Lake Break and the Cadillac-Bouzan Fault. The whole pattern of Figure 10 suggests that a similar intersection of the west-southwest fractures with the Cross Lake Fault can be expected. The well-known Cobalt Camp with important silver-cobalt ore is located along the Cross Lake Fault, and suggests that areas should be prospected at the intersections of the Cross Lake Fault with southwest- to west-southwest-striking faults which lie between Kirkland Lake and Matachewan.

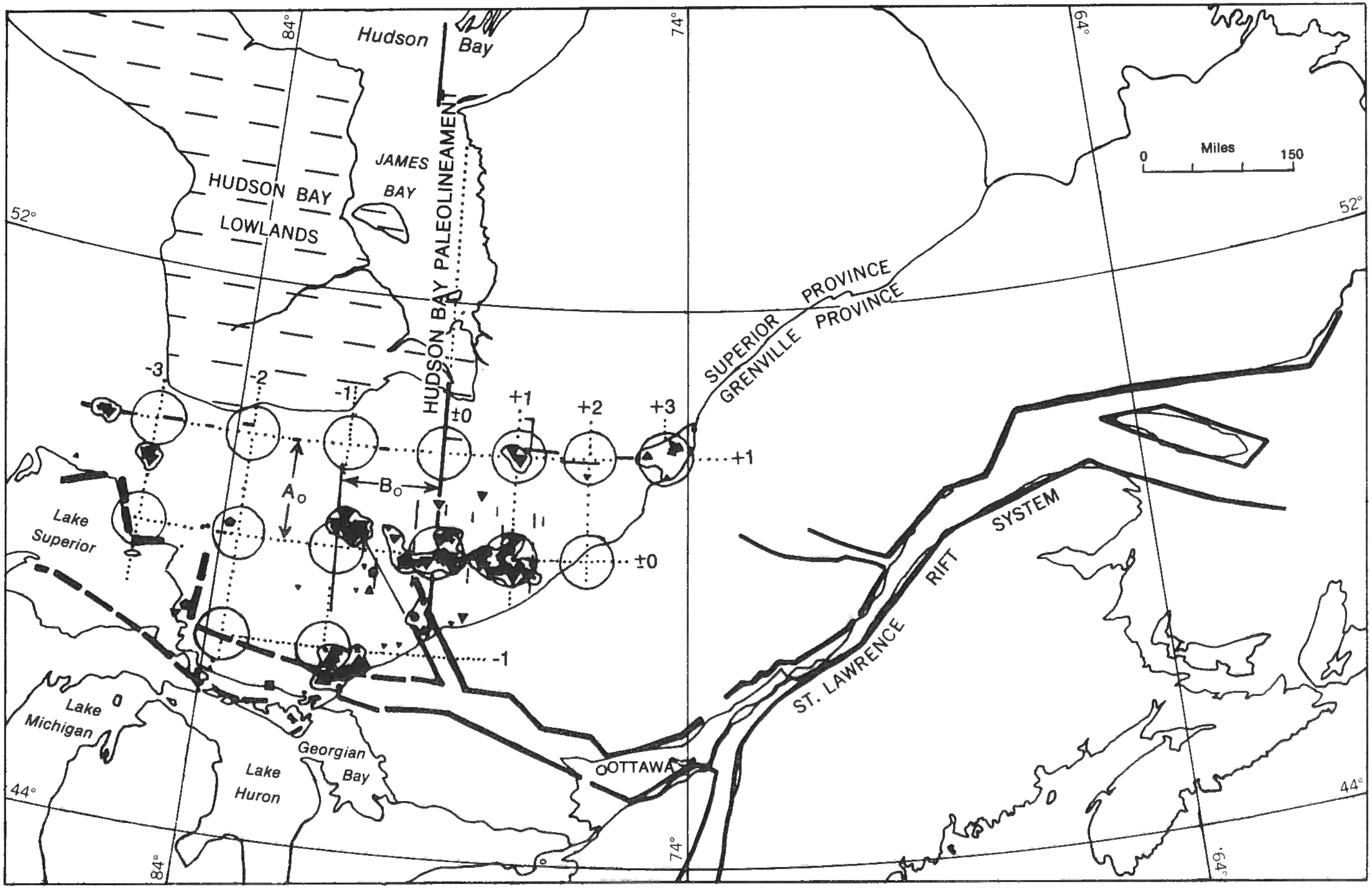

Figure 14. Empirical prospecting net for the Superior Province south of Hudson Bay. The location and size of endogenous deposits, simplified after Whitmore et al. (1969).

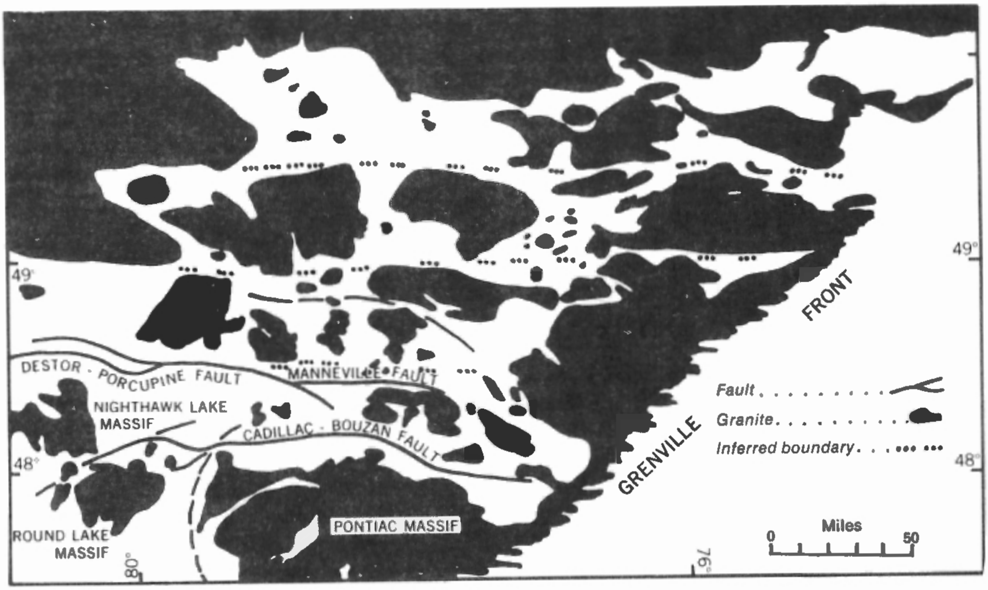

Figure 15. Structural control by east-striking faults of granitic rocks and their preferential localization of the cores of structural blocks ("massifs"), Superior Province, Canada. (Adapted from Kalliokoski, 1968).

(2) Another interesting area for prospecting lies at the intersection of the Destor-Porcupine Fault, and northwest-striking faults that represent the northwestern extension of the Cross Lake Fault.

(3) A belt of gold occurrences and mines extends northwestward from the Kirkland Lake area and runs parallel to the Montreal River Main Fault and the Cross Lake Fault. Its distance from the Cross Lake Fault is similar to the spacing between the Montreal River Main Fault and the Cross Lake Fault. It is possible that this belt of gold deposits defined by the density contours may follow another fault of the same strike that lies east of the Cross Lake Fault. More intensive prospecting is recommended in the area where this belt intersects the Destor-Porcupine Fault.

Several other guides for prospecting can be deduced from Figures 4 and 10.

Copper

Comparison of the distribution pattern of copper occurrences with the main fracture pattern (Fig. 11) gives further ideas about possible extensions of the mineral distribution patterns.

A study of the relationship between the distribution of volcanic centres and the fracture pattern may also help in prospecting for copper. The pattern of the distribution of volcanic centres may also be studied on different scales, for example, Figure 14 can assist on the scale of the Superior

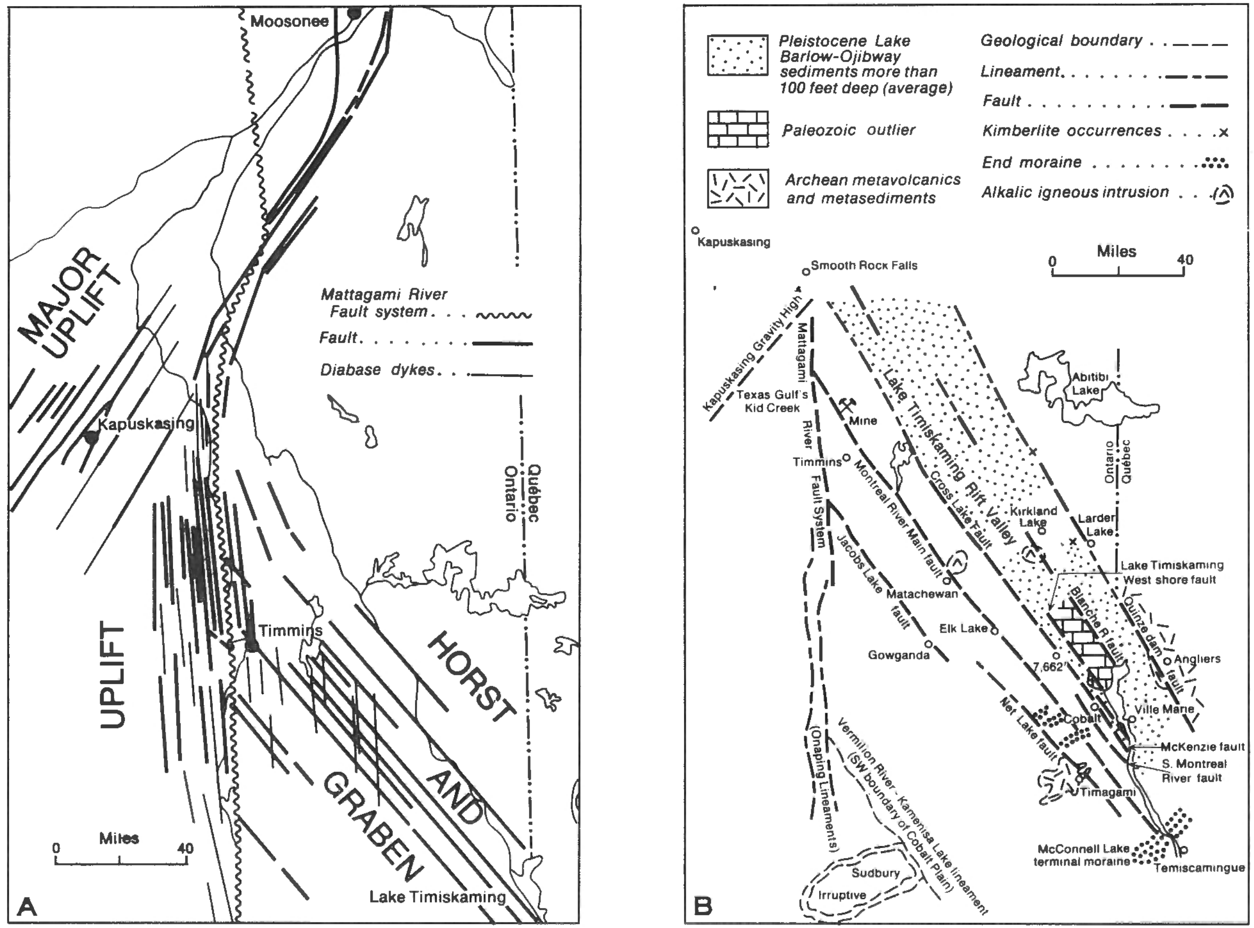

Figure 16. Comparison between the structural interpretations of part of the Abitibi area: A, by Kirwan (1969); B, Lovell and Caine (1970).

Province and Figure 4 on the scale of the Abitibi area. It should be emphasized that some of the significant fractures, well expressed in the Abitibi area, extend beyond, and may be used in the neighbouring areas. As example is given by the northwest-trending faults which have been the subject of two recent studies (see Fig. 16).

The results and prospecting predictions presented in this paper have been achieved by geological methods. The principle of equidistances was applied in the study of regularities in the distribution of fractures and mineral occurrences. The regularities have been studied on different scales which prevented the authors from overlooking some regularity which would be well visible on one scale but hardly recognizable on another. Nevertheless, the essentially empirical approach cannot eliminate the possibility that some regularity still exists, but its recognition is beyond the possibilities of the method.

An attempt was made to study the same region by statistical methods. The 1,333 occurrences of gold and 709 of copper sufficiently substantiated their treatment by harmonic analyses. A regularity in the distribution of the gold and copper occurrences was derived and will be the subject of a separate paper by F.P. Agterberg and A. Fabbri, in which the features of the equidistant distribution derived in the present paper will be compared with results obtained by harmonic analysis.

The statistical study may also be applied to objects other than the location of mineral occurrences, for instance to the periodicities in the distribution of fractures, to the drainage patterns, as well as to specific problems like the preferential relation of some mineralization to specific sets of fractures. The results obtained to date are sufficiently encouraging to recommend the application of statistical analysis to other areas of the Canadian Shield, as an extension of the geological method.

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APPENDIX

TABLE I

PRESENT AND PAST GOLD PRODUCERS IN THE ABITIBI AREA

Ontario

1. Renabie Mines Ltd.
2. Jerome Gold Mines Ltd.
3. Kam-Kotia Porcupine Mines Ltd.
4. Canadian Jamieson Mines Ltd.
5. New Hope Porcupine Mines (De Santis Mine) Ltd.
6. Kenilworth Mines (Naybob Mine) Ltd.
7. Nakhodas Mining Co. (Faymar Mine) Ltd.
8. Vipond Mine (Hollinger Consolidated Gold Mines Ltd.).
9. Crown Mine (Hollinger Consolidated Gold Mines Ltd.).
10. Moneta Porcupine Mines Ltd.
11. Consolidated Gillies Lake Mines Ltd.
12. Hollinger Consolidated Gold Mines Limited.
13. McIntyre Porcupine Mines Ltd.
14. Schumacher Mine (Hollinger Consolidated Gold Mines Ltd.).
15. Coniarum Mine (Westfield Minerals Ltd.).
16. Davidson Tisdale Mines Ltd.
17. Dome Mines Ltd.
18. Preston Mines Ltd.
19. Delnite Mines Ltd.
20. Aunor Gold Mines Ltd.
21. Buffalo Ankerite Gold Mines Limited.
22. Fuller Property (Edwards Claim).
23. Tisdale Ankerite Mines Ltd.
24. Porcupine Pet Mine (Preston Mines Ltd.).
25. Cincinnati-Porcupine Mines Ltd.
26. Paymaster Consolidated Mines Ltd.
27. Gold City Porcupine Mines (Porcupine Lake Mine) Ltd.
28. Banner Porcupine Mines (Scottish Ontario Mine) Ltd.
29. Broulan Reef Mines (Porcupine Reef Mine) Ltd.
30. Hallnor Mines Ltd.
31. Broulan Porcupine Mine (Broulan Reef Mines Ltd.).
32. Pamour Porcupine Mines Ltd.
33. Hoyle Mining Co. Ltd.
34. Hugh-Pam Porcupine Mines Ltd.
35. Bonwhit Mine (Broulan Reef Mines Ltd.).
36. Bonetal Mine (Broulan Reef Mines Ltd.).
37. Goldhawk Porcupine Mine.
38. Porcupine Peninsular Mine (Hydra Explorations Ltd.).
39. M. & M. Porcupine Gold Mines Ltd.
40. Ashley Gold Mining Corp. Ltd.
41. Stairs Exploration & Mining Co. Ltd.
42. Ronda Gold Mines Ltd.
43. Tyranite Mines Ltd.
44. Young Davidson Mines Ltd.
45. Matachewan Consolidated Mines Ltd.
46. Ryan Lake Mine (Min-Ore Mines Ltd.).
47. Ethel Copper Mines Ltd.
48. Hill Mine (Argyll Gold Mines Ltd.).
49. Blue Quartz Gold Mine (Amalgamated Goldfields Corp. Ltd.).
50. Aljo Mines Ltd.
51. Munro Croesus Mines Ltd.
52. Ross Mine (Hollinger Consolidated Gold Mines Ltd.).
53. Buffonta Mines Ltd.
54. Coin Lake Gold Mines Ltd.
55. Harker Gold Mines Ltd.
56. Bourkes Mine (Davidor Mines Ltd.).
57. Golden Summit Mines Ltd.
58. Baldwin Kirkland Gold Mines Ltd.
59. Golden Gate Mine (Gateford Mines Ltd.).
60. Trout Creek Mine (Sathram Gold Mines Ltd.).
61. Tech-Hughes Gold Mines Ltd.
62. Macassa Mines Ltd.

Table I (cont.)

63. Kirkland Lake Gold Mine (Kirkland Minerals Corp. Ltd.)
64. Wright-Hargreaves Mines Ltd.
65. Lake Shore Mines Ltd.
66. Sylvanite Gold Mines Ltd.
67. Toburn Mine (Associated Arcadia Nickel Corp. Ltd.).
68. Kirkland Townsite Gold Mines Ltd.
69. Ontario Kirkland Gold Mines Ltd. (Hudson Rand Gold Mines Ltd.).
70. Bidgood Mine (Bidcop Mines Ltd.).
71. Moffat-Hall Gold Mines Ltd.
72. Morris Kirkland Gold Mines Ltd.
73. Upper Canada Mines Ltd.
74. Queenston Gold Mines Ltd.
75. Argonaut Mine (Lake Beaverhouse Mines Ltd.).
76. Omega Mine (Lomega Gold Mines Ltd.).
77. Cheminis Mine (Amalgamated Larder Mines Ltd.).
78. Barber Larder Mine (Amalgamated Larder Mines Ltd.).
79. Fernland Mine (Amalgamated Larder Mines Ltd.).
80. Canadian Associated Goldfields Mining Co. Ltd.
81. Raven-River Mine (Can-Erin Mines Ltd.).
82. Kerr-Addison Gold Mines (Kerr-Addison Mines) Ltd.
83. Chesterville Mine (Kerr-Addison Gold Mines Ltd.).
84. Martin-Bird Gold Mines Ltd.
85. Cathroy-Larder Mine (Mirado Nickel Mines Ltd.).
86. Gold Hill Mines Ltd. (Kordol Expl. Ltd.).
87. Barry-Hollinger Mines Ltd.

Quebec

88. Normetal Mining Corp. Ltd.
89. Beattie-Duquesne Mines Ltd.
90. Lyndhurst Mining Co. Ltd.
91. Duquette Mining Co. Ltd.
92. Mobrun Copper Ltd.
93. Inmont Copper Mines Ltd. (Robb-Montbray Mines Ltd.).
94. Eldrich Mines Ltd.
95. Quesabe Mines Ltd.
96. Halliwell Gold Mines Ltd.
97. Wingait Gold Mines Ltd.
98. Lake Wasa Mining Corp.
99. Aldermac Copper Corp.
100. Arntfield Gold Mines.
101. Francoeur Mines Ltd. (Shaft No.8).
102. Francoeur Mines Ltd. (Shafts Nos. 1 and 2).
103. Francoeur Mines Ltd. (Shaft No.3).
104. Vauze Mines Ltd. (B1 and B2).
105. Lake Dufault Mines Ltd.
106. East Waite Mine (Waite Amulet Mines Ltd.-Noranda Mines Ltd.).
107. Old Waite Mine (Waite Amulet Mines Ltd.-Noranda Mines Ltd.).
108. Amulet F Mine (Waite Amulet Mines Ltd.-Noranda Mines Ltd.).
109. N.W. Amulet Mine, Waite Dufault Mines Ltd. (Bedford Hill Mines Ltd.-Waite Amulet Mines Ltd.).
110. Amulet C Mine (Waite Amulet Mines Ltd.-Noranda Mines Ltd.).
111. Amulet A and Lower A (A, Waite Amulet Mines Ltd.; Lower A, Lake Dufault Mines Ltd.).
112. Elder Mines Ltd.
113. Anglo Rouyn Mines Ltd. (Pontiac Rouyn Mines Ltd.).
114. New Marlon Gold Mines Ltd.
115. Powell Rouyn Gold Mines Ltd.
116. Chadbourne Mine (Noranda Mines Ltd.).
117. New Senator Rouyn Ltd.
118. Stadacona Mines Ltd.
119. Granada Gold Mines Ltd.
120. Donalda Mines Ltd.
121. Quemont Mining Corp. Ltd.
122. Horne Mine (Noranda Mines Ltd.).
123. West MacDonald Mines Ltd.
124. Delbridge No. 2 Mine (Delbridge Mines Ltd.-D'Eldona Gold Mines Ltd.).
125. McWatters Gold Mines Ltd.
126. New Rouyn Merger Mines Ltd.
127. New Rouyn Merger Mines Ltd.

Table I (cont.)

128. Heva Gold Mines Ltd.
129. Hosco Gold Mines Ltd.
130. Mooshla Gold Mines Ltd.
131. New Mic-Mac Mines Ltd.
132. Dumagami Mines Ltd.
133. New Alger Mines Ltd. (Thompson Cadillac Mines).
134. O'Brien Gold Mines Ltd.
135. Kewagama Gold Mines (Que.) Ltd.
136. Consolidated Central Cadillac Mines Ltd.
137. Wood Cadillac Mines Ltd.
138. Pandora Gold Ltd.
139. Lapa Cadillac Gold Mines Ltd.
140. Pan Canadian Gold Mines Ltd. (West Malartic Mines Ltd.).
141. West Malartic Mines Ltd.
142. West Malartic Mines Ltd.
143. Barnat Mines Ltd.
144. Canadian Malartic Gold Mines Ltd.
145. East Malartic Mines Ltd.
146. Malartic Hygrade Gold Mines Ltd.
147. Camflo Mattagami Mines Ltd.
148. Norlartic Mines Ltd. (Norbenite Malartic Mines Ltd.).
149. Marban Gold Mines Ltd. (Marbenor Malartic Mines Ltd.).
150. Malartic Gold Fields -No. 1 Mine.
151. Malartic Gold Fields -No. 2 Mine.
152. Clarnor Property (Little Long Lac Gold Mines Ltd.).
153. Kiena Gold Mines Ltd.
154. Shawkey Gold Mines Ltd.
155. Provincial Mining School (Gale Gold Mines Ltd.).
156. Siscoe Gold Mines Ltd.
157. Sullivan Consolidated Mines Ltd.
158. Greene Stabell Mines Ltd.
159. Sigma Mines (Quebec) Ltd.
160. Lamaque Gold Mines Ltd.
161. Aumaque Gold Mines Ltd.
162. East Sullivan Mines Ltd.
163. Manitou-Barvue Mines Ltd. (Golden-Manitou Mines Ltd.).
164. New Formaque Mines Ltd.
165. Quebec Manitou Mines Ltd.
166. Dunraine Mines Ltd. (Rainville Mines Ltd.).
167. Dunraine Mines Ltd. (Rainville Copper Mines Ltd.).
168. Simkar Claims (Louvicourt Gold Fields Ltd.).
169. Akasaba Gold Mines Ltd. (Obaska Lake Mines Ltd.).
170. Vicour Gold Mines Ltd.
171. Bevcon Gold Mines Ltd. (Bevcourt Gold Mines Ltd. -Jowsey-Wyeth Claims).
172. Courvan Mining Co. Ltd. (Cournor Mining Co. Ltd. -Treadwell-Yukon Mines Ltd. -Bussières Mining Co. Ltd.).
173. Perron Gold Mines Ltd.
174. Courvan Mining Co. Ltd. (Beaufor Group).
175. Chimo Gold Mines Ltd. (Quemartic Mines Ltd.).
176. Tiblemont Cons. Gold Mines Ltd. (Tiblemont Island Mining Co. Ltd.).
177. Cons. Magador (Vendome Mines Ltd., Can. Shield Mining Corp.).
178. Bargold Mines Ltd. (Bartec Mining Co. Ltd. -Groslouis Claims).
179. Claverny Gold Mines Ltd.

TABLE II

PRESENT AND PAST COPPER PRODUCERS IN THE ABITIBI AREA

Ontario

1. Kam-Kotia Mines Ltd.
2. Jameland Mines Ltd.
3. Canadian Jamieson Mines Ltd.
4. United Oblaski Mining Company Ltd. (Genex, Mordey Prospect).
5. Ecstall Mining Ltd., Kidd Creek Mine (Texas Gulf Sulphur Company).
6. McIntyre Porcupine Mines Ltd.
7. Noranda Mines Ltd., Alexo Mine.
8. Munro Copper Mines Ltd., Centre Hill Mine.
9. Winnie Lake Mine.
10. Dane Copper Mine.
11. Lake Beaverhouse Mines Ltd. (Upper Beaver).
12. Amity Mine.
13. Patterson Mine .
14. Trethewey-Ossian Mine.
15. Ryan Lake Mine (Min-Ore Mines Ltd., Pax International Mines Ltd.).
16. Ethel Copper Prospect (Ethel Copper Mines Ltd.).
17. Siscoe Metals of Ontario Ltd. -Miller Lake-O'Brien.

Quebec

18. Normetal Mining Corp. Ltd.
19. Duvan Copper Co. Ltd.
20. Lyndhurst Mining Co. Ltd.
21. Hunter Mine (Beattie-Duquesne Mines Ltd.).
22. New Formaque Mines Ltd.
23. Trinity Chibougamau Mines Ltd. (North Trinity Mining Corp. Ltd.).
24. Belfort Mines Ltd. (Roymont Mines Ltd.).
25. Cons. Magador (Vendome Mines Ltd., Can. Shield Mining Corp.).
26. Barvallée Mines Ltd.
27. Zulapa Mining Corp. Ltd.
28. Abitibi Copper Mines Ltd. (Abitibi Metals Mines Ltd.).
29. Quebec Manitou Mines Ltd.
30. Dunraine Mines Ltd. (Rainville Copper Mines Ltd.).
31. Manitou-Barvue Mines Ltd. (Golden-Manitou Mines Ltd.).
32. East Sullivan Mines Ltd.
33. Greene Stabell Mines Ltd.
34. Dumagami Mines Ltd.
35. New Mic-Mac Mines Ltd.
36. Mobrun Copper Ltd.
37. South Dufault Mines Ltd.
38. Delbridge No. 2 Mine, Delbridge Mines Ltd. (D'Eldona Gold Mines Ltd.).
39. Quemont Mining Corp. Ltd.
40. Horne Mine, Noranda Mines Ltd.
41. Joliet Quebec Mines Ltd.
42. Norbec Copper Mines Ltd.
43. Vauze Mines Ltd. (B1 and B2).
44. Lake Dufault Mines Ltd.
45. East Waite Mine (Waite Amulet Mines Ltd. -Noranda Mines Ltd.).
46. Old Waite Mine (Waite Amulet Mines Ltd. -Noranda Mines Ltd.).
47. Waite Dufault Mines Ltd., N. W. Amulet Mine (Bedford Hill Mines Ltd. -Waite Amulet Mines Ltd.).
48. Amulet F Mine (Waite Amulet Mines Ltd. -Noranda Mines Ltd.).
49. Amulet C Mine (Waite Amulet Mines Ltd. -Noranda Mines Ltd.).
50. Amulet A and Lower A (A, Waite Amulet Mines Ltd.; Lower A, Lake Dufault Mines Ltd.).
51. Inmont Copper Mines Ltd. (Robb-Montbray Mines Ltd.).
52. Halliwell Gold Mines Ltd.
53. Aldermac Mine (Aldermac Copper Corp. Ltd. -West Wasa Mines Ltd.).
54. O'Leary-Malartic Mines Ltd.
55. Valray Explorations Ltd.