Geology of Canadian Gold Deposits

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Foreword

The Geology Division of CIM held a symposium at Val d'Or, Quebec in September 1980 featuring gold deposits of the Abitibi Greenstone Belt from Val d'Or to Timmins and including some other gold deposits in Canada. The objective was the presentation of current descriptions of the deposits with thoughts on their genesis, and techniques used in exploration for gold. Most of the papers presented were submitted for publication, edited and arranged in this Special Volume. Three papers which had not been presented were obtained to round out the content.

It is the intent of this volume to begin to fill the gap in the literature on Canadian gold deposits that exists between the CIM's Jubilee Volume, published in 1948, and the present. Some of the papers in this special volume are comprehensive and some are first descriptions of deposits; no attempt has been made to achieve consensus on genesis. It is our view that the papers will remain worthwhile references and encourage publication of data coming from a renewed interest in this most valuable and interesting commodity.

This Special Volume is the first in a series of proceedings from symposia on special topics organized by the Geology Division of CIM.

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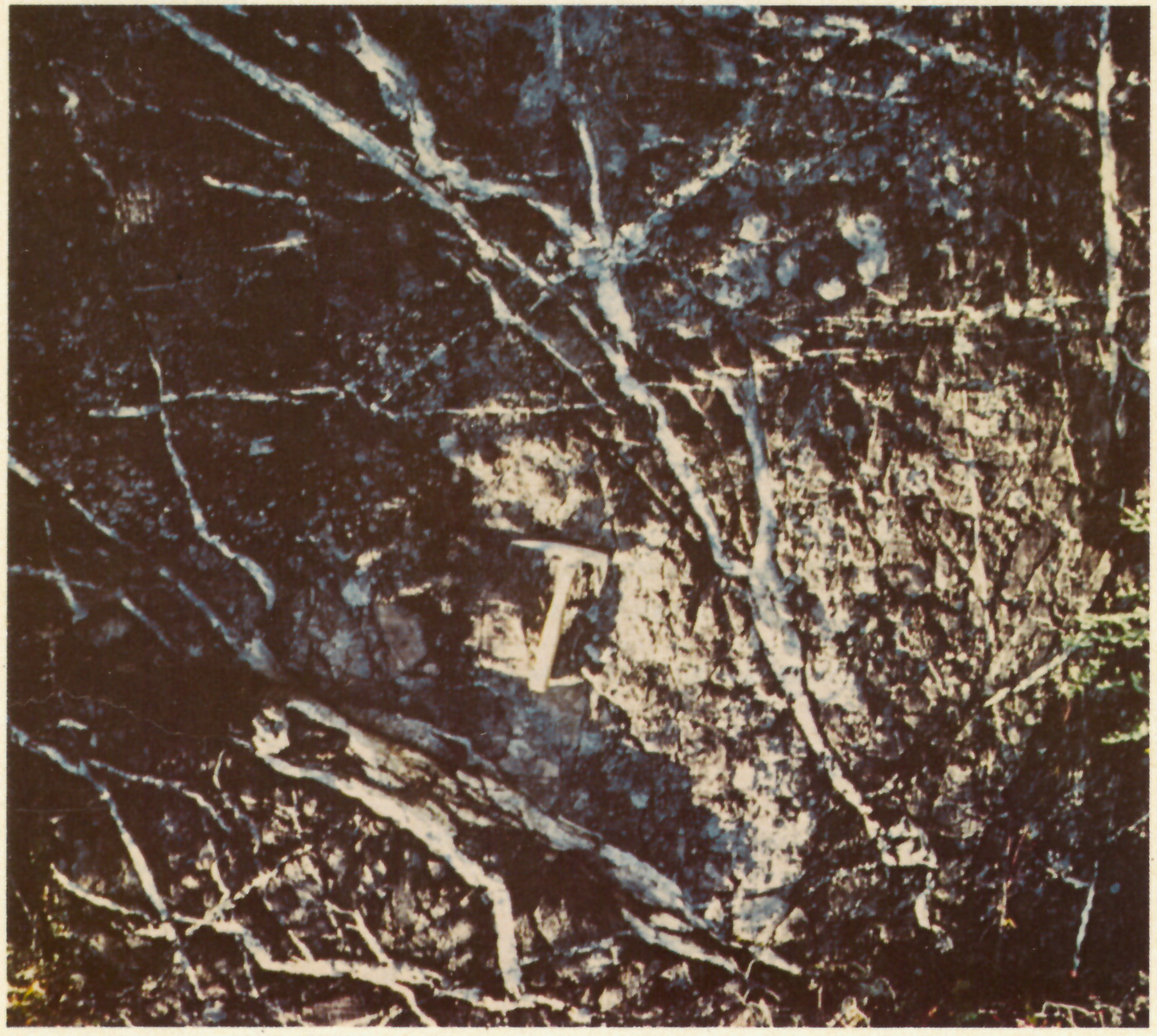

The vein system at the Kerr-Addision Mine, as observed in outcrop near an old tailings disposal area.

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Gold Deposits: A Review of Their Geological and Geochemical Setting

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Introduction

Two general types of auriferous deposits are recognized—lode (vein) deposits and placers. The enigmatic quartz-pebble conglomerate deposits, the largest known auriferous concentrations on earth, have generally been classified as modified placers, but some geologists have considered them to be of hydrothermal origin akin to lode deposits.

The text that follows deals only briefly with the general geochemistry of gold and with the geological and geochemical setting of its varied deposits. Details should be sought in the writer's monograph on the subject (Boyle, 1979). The classification of the auriferous deposits is that used in the work just cited; other classifications are possible, but it is thought that the present classification is as objective as can be devised and is relatively independent of speculative genetic theories.

General Geochemistry of Gold

Gold is a member of Group IB of the periodic table, which includes copper, silver and gold. In its chemical reactions gold resembles silver in some respects, but its chemical character is markedly more noble. The principal oxidation states of gold are +1 (aurous) and +3 (auric). These states are unknown as aquo-ions in solutions, the element being present mainly in complexes of the type $[Au(CN)_2]^-$, $[AuCl_2]^-$, $[Au(OH)_4]^-$ and $[AuCl_4]^-$. There is only one naturally occurring isotope of gold: ^{197}Au.

In nature, gold occurs predominantly in the native state or as a major constituent of various alloys containing mainly silver, copper or platinum metals. Several gold and gold-silver tellurides are known, of which the most common are sylvanite, calaverite, petzite, krennerite and nagyagite. The antimonide, aurostibite, $AuSb_2$, occurs in some auriferous deposits, and there is also a selenide, fischesserite. Ag_3AuSe_2, a sulphide, uytenbogaardtite, Ag_3AuS_2, and a bismuthide, maldonite, Au_2Bi, which is fairly well differentiated. The principal ore minerals of gold are the native metal, aurostibite and the various tellurides.

The abundance of gold in the upper lithosphere is about 0.005 ppm and the Au/Ag ratio is about 0.1. The average gold content of igneous-type rocks in parts per million is—ultramafic (0.004), gabbro-basalt (0.007). diorite-andesite (0.005) and granite-rhyolite (0.003). The average gold content of sedimentary rocks in parts per million is—sandstone and conglomerate (0.03), mormal shale (0.004) and limestone (0.003). Certain graphitic shales, sulphide schists, phosphorites, and some types of sandstones and conglomerates may contain up to 2 ppm Au or more.

The average gold content of soils is 0.005 ppm, and the average for natural fresh waters is 0.00003 ppm. Sea and ocean waters contain an average of 0.000012 ppm Au. Gold is a trace constituent of many plants and animals. Some coals are slightly enriched in gold, with 0.05 to 0.1 ppm Au in the ash.

Auriferous Deposits

Gold is won both from deposits mined essentially for the element and as a by-product of the mining and treatment of nickel, copper, zinc, lead and silver ores. Eight types of deposits, exploited mainly for gold, are listed below. Brief comments about the possible origin of some of the types are appended.

(1) Auriferous porphyry dykes, sills and stocks; auriferous coarse-grained granitic bodies, aplites and pegmatites:

The indigenous gold content of these granitic rocks is invariably low, of the order of 0.003 ppm. Certain quartz-feldspar porphyry dykes and stocks with indigenous pyrite and pyrrhotite may contain up to 0.10 ppm Au and 1 ppm Ag, principally in the sulphide minerals. Porphyritic, aplitic and granitic bodies of this type are common in Precambrian, mainly Archean, terranes and in younger rocks throughout the world. Most are of an intrusive nature, probably the rheomorphic products of deep-seated granitization. None so far known are of economic value, although many are probably the sources of the gold, silver and other metals secondarily concentrated in the fractures, faults and shear zones in the porphyry bodies themselves and in their nearby host rocks (see type 6A below).

(2) Auriferous skarn-type gold deposits:

Gold is a frequent constituent of skarn deposits, in which it is commonly more abundant than the literature would indicate. Most skarn deposits yield gold as a by-product of copper and lead-zinc mining, but there are a number of these deposits that are greatly enriched in gold and silver and are mined essentially for the two precious metals.

The general features of skarn deposits are well known and need not be described in detail here. Most of the deposits occur in highly metamorphosed terranes, particularly those containing carbonate rocks or carbonate-bearing pelites and in which there has been much granitization and injection of granitic rocks. Some deposits occur near the contacts of granitic bodies and have long been called 'contact metamorphic'; others are developed in favourable reactive beds or zones some distance from granitic contacts. The deposits contain a characteristic suite of early-developed Ca-Mg-Fe silicate and oxide minerals and a lower-temperature, generally later, suite of silicate, carbonate, sulphide and arsenide minerals. The gold minerals include native gold and various tellurides. Most of the skarn deposits worked essentially for gold contain much pyrite and/or arsenopyrite.

The elements most frequently enriched with gold in skarn deposits are Fe, S, Cu, Ag, Zn, Pb, Mo, As, Bi and Te. There is commonly a positive correlation between Au and Cu in some skarn deposits. Tungsten is a common trace element in gold-bearing skarn deposits. The element belongs to the early phase of skarnification, whereas gold tends to be precipitated late in the mineralization processes. The two elements may, therefore, be negatively correlated, for it is common to find skarn deposits that are rich in tungsten (scheelite) practically devoid of gold and vice versa.

Auriferous skarn deposits occur at widespread points in the Canadian Cordillera, particularly in the Hedley district of

British Columbia, where the Nickel Plate and French mines worked arsenopyrite-pyrite orebodies in skarn developed in Triassic limestone and limy argillites. In the Canadian Shield, auriferous skarn deposits occur mainly in the Grenville Province, examples being the lead-zinc-silver-gold ores of the Tetreault Mine near Quebec and the New Calumet Mine northwest of Ottawa.

(3) Gold-silver and silver-gold veins, stockworks, lodes, mineralized pipes and irregular silicified bodies, in fractures, faults, shear zones, sheeted zones and breccia zones essentially in volcanic terranes:

Representatives of this type of deposit are widespread throughout the folded and relatively flat-lying volcanic terranes of the earth. The deposits occur in rocks of all ages, but the largest number occur in those of Precambrian and Tertiary age.

The favourable host rocks are commonly basalts, andesites, latites, trachytes and rhyolites. In Precambrian rocks, such assemblages are usually referred to as 'greenstones'. Many deposits occur in tuffs, agglomerates and sediments interbedded with the volcanic flows, particularly in banded iron-formations. In the older terranes, the rocks are generally regionally metamorphosed and have the characteristic regional metamorphic facies outward from igneous or granitized centres. The younger rocks generally show the effects of chloritization (propylitization) over broad areas, but locally some of the andesites and rhyolites may be relatively fresh.

In the older rocks, the deposits are veins, lodes, stockworks, pipes and irregular mineralized masses generally in extensive fracture and shear-zone systems. Some occur in drag folds. The deposits in the younger rocks are usually confined to fissures, fractures, faults and brecciated zones that cut the volcanic rocks of calderas and generally have a limited horizontal and vertical extent. Others, however, are associated with fracture and fault systems that extend for many miles across volcanic sequences and their associated intrusive granitoids.

The mineralization of these particular deposits is characterized essentially by quartz, carbonate minerals, pyrite, arsenopyrite, base-metal sulphide minerals and a variety of sulphosalt minerals. The principal gold minerals are the native metal and various tellurides; aurostibite occurs in some deposits. Characteristic types of wall-rock alteration are generally developed adjacent to and in the vicinity of nearly all deposits in this class. In the old Precambrian rocks, the most common types of alteration are chloritization, carbonatization, sericitization, pyritization, arsenopyritization and silicification. In the younger rocks, propylitization (chloritization and pyritization) is especially characteristic and there may also be a development of adularization, silicification, kaolinization, sericitization and more rarely alunitization.

The elements commonly concentrated in this class of deposits include Cu, Ag, Zn, Cd, Hg, B, Tl, Pb, As, Sb, V, Se, Te, S, Mo, W, Mn, Fe, (Co), (Ni), CO_2 and SiO_2; less commonly Ba, Sr, U, Th, Sn, Cr and F. Hg and Sb are particularly characteristic of the younger deposits. The source of these elements is probably the volcanic rocks within which the deposits are enclosed. Interbedded sediments may also have made a major contribution of elements to some of the deposits. Tertiary and younger gold-silver and silver-gold base-metal deposits in relatively flat-lying volcanic rocks such as andesites and dacites may have derived many of their elements from underlying older rocks in the basement complexes. The quartz in these deposits originated mainly as a result of chloritization and carbonatization of the wall rocks of the deposits. As the silicate minerals in the volcanic and associated rocks were hydrated and carbonated, the released silica migrated into nearby dilatant zones, where it crystallized as quartz. The mechanisms of formation of these types of deposits by granitization, metamorphic secretion and wall-rock alteration processes are discussed at length by the writer (Boyle, 1955, 1961, 1976, 1979).

(4) Auriferous veins, lodes, sheeted zones and saddle reefs in faults, fractures, bedding-plane discontinuities and shears, drag folds, crushed zones and openings on anticlines essentially in sedimentary terranes; also replacement tabular and irregular bodies developed near faults and fractures in chemically favourable beds:

These deposits are widespread throughout the world and have produced a large amount of gold and silver. They are developed predominantly in sequences of shale, sandstone and greywacke dominantly of marine origin. Such sequences are invariably folded, generally in a complex manner, metamorphosed, granitized and invaded by granitic rocks, forming extensive areas of slate, argillite, quartzite, greywacke and their metamorphic equivalents. Near the granitic bodies, various types (kyanite, andalusite, cordierite) of quartz-mica schists and hornfels are developed, and these grade imperceptibly into relatively unmetamorphosed slates, argillites, quartzites and greywackes marked by the development of sericite, chlorite and other low-grade metamorphic minerals. Most of the gold deposits are developed in the lower-grade facies. A few economic deposits occur in the granitic batholiths and stocks that invade the greywacke-slate sequences.

The principal gangue mineral in these deposits is quartz; feldspar, mica, chlorite and minerals such as rutile are subordinate. Among the metallic minerals, pyrite and arsenopyrite are much the commonest, but galena, chalcopyrite, sphalerite and pyrrhotite also occur. Molybdenite, bismuth minerals and tungsten minerals are local. Stibnite occurs in abundance in a few deposits, but is relatively rare in most deposits. Acanthite, tetrahedrite-tennantite and other sulphosalts are not common in these deposits. Carbonate minerals, mainly calcite and ankerite, are common, but not abundant. The valuable ore minerals are native gold, generally low in silver, auriferous pyrite and auriferous arsenopyrite. Telluride minerals are relatively rare, and aurostibite is an uncommon mineral in these deposits.

A few deposits in this category are tabular or irregular replacement (disseminated) bodies developed in carbonate rocks or calcareous argillites and shales. The principal minerals in these deposits are quartz, fluorite, pyrrhotite, pyrite, arsenopyrite, sphalerite, galena, chalcopyrite and stibnite.

As a general rule, wall-rock alteration associated with these deposits is minimal, and the quartz veins, saddle reefs and irregular masses are frozen against the slate, argillite or greywacke wall rocks. In places, thin zones of mild chloritization, sericitization and carbonatization are present. Some veins are marked by thick black zones (up to 15 cm) of tourmalinized rock. Disseminated pyrite and arsenopyrite are common in the wall rocks of most of these deposits. This pyrite and arsenopyrite is usually auriferous.

The elements exhibiting a high frequency of occurrence in this type of gold deposit include Cu, Ag, Mg, Ca, Zn, Cd, (Hg), B, (In), (Tl), Si, Pb, As, Sb, (Bi), S, (Se), (Te), (Mo), W, (F), Mn, Fe, (Co) and (Ni). Those in parentheses, have a low to very low frequency of occurrence.

The sedimentary rock sequences in which these deposits occur are marked by extensive development of shales, argillites and slates, all containing abundant pyrite. These rocks are invariably enriched in all of the elements contained in the auriferous deposits. In addition, the clastic sediments in the sequence including conglomerate, greywacke and sandstone, commonly have higher than normal amounts of gold, probably of detrital origin. These, together with the black pyritiferous sediments, are probably the source beds for the elements in the auriferous deposits. As the various structures developed in the sedimentary sequences, especially along fault and fracture systems and on the noses of anticlines (saddle reefs), their dilatancy induced the diffusive flow of silica, gold and other elements into these sites, where they were partitioned into the assemblage of minerals we now observe in the veins and lodes. In places, chemically receptive rocks precipitated quartz, gold and other minerals from diffusion currents transporting gold and gangue elements through the rocks.

Deposits in essentially sedimentary terranes are widespread throughout the world. In Canada, examples occur in the Yellowknife Supergroup in the Yellowknife district, Northwest Territories (Ptarmigan, Thompson-Lundmark and Camlaren mines), in the Paleozoic Cariboo Group at Wells, British Columbia (Cariboo Gold Quartz Mine), widespread in the Ordovician Meguma Group of Nova Scotia, and elsewhere.

(5) Gold-silver and silver-gold veins, lodes, stockworks and silicified zones in a complex geological environment, comprising sedimentary volcanic and various igneous intrusive and granitized rocks:

Deposits in this category combine nearly all the epigenetic features described in category (3) and (4). The origin of their metallic and other components may lie in the combined group or groups of rocks in which they occur, particularly interbedded sedimentary and volcanic rock sequences. The deposits have a widespread distribution throughout the world in rocks ranging in age from Precambrian (Archean) to Tertiary. Examples in Canada include the Precambrian deposits in the Kirkland Lake and Little Long Lac-Sturgeon River districts of Ontario and in the Jurassic volcanics of the Rossland gold-copper camp in the West Kootenay district of British Columbia.

(6) Disseminated and stockwork gold-silver deposits in igneous, volcanic and sedimentary rocks:

(A) Disseminated and stockwork gold-silver deposits in igneous bodies.

(B) Disseminated gold-silver and silver-gold occurrences in volcanic flows and associated volcaniclastic rocks.

(C) Disseminated gold-silver deposits in volcaniclastic and sedimentary beds:

(1) deposits in tuffaceous rocks and iron formations;

(2) deposits in chemically favourable sedimentary beds.

The principal economic element in these deposits is gold, with small amounts of silver. A few deposits yield the base metals, but they are generally not known as base-metal deposits. The grade of the deposits is highly variable. Most are relatively low grade (under 15.5 g Au/tonne), but are characterized by large tonnages. The elements commonly concentrated in these deposits, omitting those in the common gangue minerals such as quartz, silicate and carbonate minerals, are: Cu, Ag, Au, (Ba), (Sr), Zn, Cd, Hg, B, (Sn), Pb, As, Sb, Bi, V, S, Se, Te, Mo, W, (F), Fe, Co and Ni. Those in parentheses are infrequent or occur only in certain deposits.

The deposits in category (A) occur in igneous plugs, stocks, dykes and sills that have been intensively fractured or shattered and infiltrated by quartz, pyrite, arsenopyrite, gold and other minerals. Most of the deposits are stockworks or diffuse irregular impregnations. The alteration processes vary with the types of host rock. In granitic (felsic) rocks, sericitization, silicification, feldspathization (development of albite, adularia, etc.) and pyritization are predominant; in intermediate and mafic rocks, carbonatization, sericitization, serpentinization and pyritization prevail. Alunitization may occur in both felsic and mafic rocks in places. Deposits of this type are common in Canada, particularly in the Canadian Shield and Cordillera. Examples are: the Howey and Hasaga mines at Red Lake, Ontario, in an Archean quartz porphyry dyke; the Matchewan Consolidated and Young Davidson mines in Archean syenite plugs and dykes in the Matachewan district of Ontario; and the Camflo Mine in an Archean porphyritic monzonite stock near Malartic, Quebec.

The source of the gold and other elements in stockworks and veins in igneous bodies is problematical. In many cases, the source was probably the meta-volcanic and meta-sedimentary rocks invaded by the stocks and dykes, the only part played by the igneous rocks being a structural one; in other words, these more competent rocks provided the dilatant zones into which the gold and its associated elements were drawn from the invaded country rocks. In some cases, the igneous bodies may have contained sufficient gold and associated elements, which on redistribution and concentration during shearing, fracturing and alteration formed the orebodies.

It should be emphasized in closing this subsection that gold deposits in igneous bodies are common, especially in those intrusive into greenstone (meta-volcanic) and meta-sedimentary belts. Albitites, albite porphyrites, quartz-feldspar porphyries, fine-grained granites and syenites, and aplites should receive detailed attention during prospecting, especially where these rocks are pyritized, sericitized or otherwise altered.

The disseminated gold-silver occurrences in volcanic flows and associated volcaniclastic rocks in Category (B) are relatively common, but commercial deposits of this type have not been worked. Most occurrences are very low grade, commonly less than 0.01 oz Au/ton (0.3 ppm). Silver contents are higher in places, averaging in some cases 3.5 oz Ag/ton (120 ppm).

The disseminated occurrences in Category (B) are in reality large irregular and diffuse zones of alteration manifest mainly in rhyolites, andesites, basalts and their associated volcaniclastic rocks. These zones of alteration constitute silicification, sericitization, epidotization, argillization or alunitization, commonly associated with pyritization and carbonatization. In the mafic and intermediate rocks, the effects are commonly collectively called propylitization. Large volumes of the volcanic country rocks are affected, giving them a bleached and altered aspect. Locally diffuse silicified zones, quartz veins, alunite veins, and pyrite veins and segregations ramify through the altered rocks.

Occurrences and deposits in Category (B) can be expected in all metamorphosed volcanic and sedimentary terranes and rocks in or associated with volcanic caldera, especially those that have a high degree of propylitization. The occurrences rich in pyrite and/or arsenopyrite, and containing higher than normal amounts of Hg, B, Sb, Se, Te and Mo, appear in most cases to contain the most gold and silver. These altered and mineralized zones require detailed sampling and analysis before any conclusions can be drawn as to their commercial value.

The disseminated gold-silver deposits in volcaniclastic and sedimentary beds in category (C) are usually conformable with the sedimentary and volcaniclastic beds, although in some cases their limits may infringe irregularly on overlying or underlying rocks. Some are large and of relatively high grade; others are commonly too low grade or not of sufficient tonnage to merit attention.

Two general categories of these deposits can be recognized: (1) those developed in tuffaceous rocks and iron-formations within volcanic and sedimentary terranes; and (2) those resulting from extensive infiltration or replacement of chemically favourable beds, particularly carbonate rocks in calcareous pelites. The first is especially common in Precambrian terranes, although there is no reason why they should not occur in rocks of younger age; however, examples of the latter are rare to date. The second can apparently occur in rocks of any age.

Gold deposits in tuffaceous and other volcaniclastic rocks and in iron-formations in volcanic and sedimentary terranes are particularly common in the greenstone and associated sedimentary belts of the Canadian Shield and in other similar rocks throughout the world. Orebodies in tuffaceous rocks are generally large-tonnage, irregular disseminated bodies containing essentially pyrite, pyrrhotite and arsenopyrite, with much secondary fine-grained quartz. The gold is usually free or in a finely divided state in the sulphide and arsenide minerals. A typical example of this type of deposit is the Madsen Mine in Archean tuff at Red Lake, Ontario. Auriferous deposits in iron-formations are of two types—disseminated bodies similar to those just described, and zones of quartz veins or stockworks traversing the rocks of the iron-formations. These contain essentially quartz with pyrite, pyrrhotite and arsenopyrite; the gold is generally present in the native state. Examples of deposits in iron-formations are the Central Patricia Mine and the Pickle Crow Mine in the Archean Crow River greenstone belt of northern Ontario.

Interflow sediments in volcanic terranes and the sulphide, carbonaceous sulphide and certain oxide facies of iron-formations, especially those of Archean age, have indigenous (sedimentary) enrichments of gold, silver and various other metals (Boyle, 1968, 1976). During metamorphism and tectonic activity, these metals were redistributed and concentrated in orebodies more or less conformable with the iron-formations and interflow sediments, where shearing, dragfolding and dilatancy took place along the beds, and in disconformable or cross-cutting orebodies where fractures, faults, shears and other dilatant structures are developed across the iron-formations and interflow sedimentary rocks.

Gold deposits resulting from extensive infiltration or replacement of chemically favourable beds (Category 2) are developed principally in calcareous and dolomitic pelites and psammites and thin-bedded carbonate rocks invaded by granitic stocks and porphyry dykes and sills; a few occur in porous sandstones. Most deposits are characterized by one or more of silicification, argillization, pyritization and arsenopyritization, and introductions of elements such as Au, Ag, Hg, B, Sb, Se, Te and the base metals. The gold is usually disseminated through the altered rocks in a very finely divided form ($<50\mu$) and is generally, although not always, rich in silver.

Deposits of this type have a widespread distribution throughout the world and are commonly referred to as Carlin-type because of their occurrence in Silurian silty limestone and dolomitic siltstone in the Carlin - Gold Acres District of Nevada. In Canada, deposits of the Carlin type can be expected principally in the Cordillera, an example being the Cinola (Specogna) deposit on the Queen Charlotte Islands, British Columbia. There are reasons for suspecting that such gold deposits should also occur in the auriferous regions of the Canadian Shield and Appalachians, where favourable beds are present.

(7) Gold deposits in quartz-pebble conglomerates and quartzites:

These constitute the largest known auriferous deposits, producing some 58 per cent of the annual gold production of the world, mainly from the Witwatersrand in South Africa. Smaller deposits occur in the Tarkwaian of Ghana and at Jacobina in Brazil. All these deposits are of Precambrian age, and all contain gold principally in the native state in the matrix of the conglomerates and quartzites. Associated minerals are mainly pyrite in the Rand and Jacobina deposits and hematite and ilmenite in the Tarkwaian orebodies. The Rand deposits also produce considerable quantities of uranium and small amounts of platinum minerals.

Auriferous deposits of this kind are unknown in Canada, although occurrences of gold in quartz-pebble conglomerates and quartzites in the Canadian Shield are widespread, examples being certain beds in the Blind River - Elliot Lake uraniferous quartz-pebble conglomerates and quartzites, similar beds in the Montgomery Lake - Padlei District of the Northwest Territories and in the Sakami Formation in Northern Quebec, and quartz-pebble conglomerates in the Nonacho Lake District of the Northwest Territories.

The origin of the auriferous and uraniferous quartz-pebble conglomerate deposits is debatable. Some geologists advocate a hydrothermal genesis; others consider the auriferous and uraniferous quartz-pebble conglomerates and quartzites to be modified placers. The latter appears to be the more probable at the present state of geological and geochemical investigations.

(8) Eluvial and alluvial placers:

Elluvial placers result from the mechanical and chemical concentration of gold in the weathered residuum overlying or near auriferous deposits; alluvial placers orginate in a similar manner, the gold being concentrated in streaks in stream, river, and beach gravels and sands. Native gold is the principal economic mineral in most of these deposits and is generally associated with a number of heavy minerals, such as magnetite, ilmenite, cassiterite, scheelite, barite and zircon. Some auriferous placers also contain recoverable amounts of platinum metals.

Placer gold deposits are widespread in British Columbia and Yukon and have been worked extensively in the Klondike District of the Yukon, the Cariboo District of British Columbia and elsewhere. In eastern Canada, ancient (probably Tertiary) stream placers have been productive in the basin of the Chaudière River in Quebec. These particular occurrences in a glaciated terrane suggest that other auriferous placers may lie at the bottom of deep valleys infilled with glacial debris in the auriferous belts of the Canadian Shield and Appalachians. Especially favourable valleys are those where the direction of glaciation has been nearly perpendicular to the trend of the depressions.

(9) Miscellaneous sources:

Gold is won as a by-product of many types of polymetallic deposits, including those producing nickel, cobalt, copper, lead, zinc, silver and uranium. Chief among these are the massive and disseminated Ni-Cu sulphide deposits associated with mafic igneous rocks, the massive Cu-Zn-Pb deposits in volcanic and sedimentary terranes, the porphyry copper deposits and certain types of pitchblende deposits (e.g. Jabiluka, Australia).

Summary

The general types of lode (vein) gold and auriferous placer deposits have been described, together with some brief notes on their origins.

The quartz-pebble conglomerate deposits currently provide the bulk of the world's production of gold, some 58 per cent. The other deposits, mainly the vein and disseminated types, eluvial and alluvial placers and the various polymetallic veins, lodes, massive bodies and stockworks (by-product gold), now provide the remaining 42 per cent of the production.

The epigenetic vein, lode, stockwork and disseminated types of gold deposits probably originated mainly by metamorphic secretion processes, the source rocks of the gold and its associated elements being mainly in the enclosing volcanic and/or sedimentary rock sequences. Modern gold placers are of sedimentary origin, the gold being winnowed into pay streaks as the result of both chemical (accretion) and physical (gravity) processes operating during weathering and subsequent sedimentation. The auriferous quartz-pebble conglomerate deposits probably originated as placers, the gold and many of its associated elements having undergone radical chemical reworking during subsequent diagenetic and metamorphic events.

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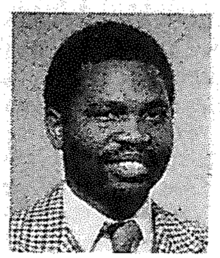


Samuel O. Akande received his B.Sc. degree in geology from the University of Ibadan, Nigeria in 1973. He was a geologist in the Geological Survey of Nigeria from 1973 to 1975. Mr. Akande was awarded a Nigerian Postgraduate Scholarship in 1975 to study the geology of ore deposits at the University of Western Ontario, London, Ontario, where he received an M.Sc. in 1977. He worked during the summers on exploration projects for Newmont Exploration of Canada Limited and Esso Minerals of Canada Limited. He is a Member of the CIM and is currently studying for his Ph.D. degree at Dalhousie University, Halifax.

R.W. Boyle

Dr. R.W. Boyle is a special projects officer with the Resource Geophysics and Geochemistry Division of the Geological Survey of Canada. A native of Wallaceburg, Ontario, he received his Ph.D. from the University of Toronto in 1953 and since then has been a member of the Geological Survey and former head of its Geochemistry Division.

Dr. Boyle's geochemical and geological work has taken him to many parts of Canada and has included research on the gold deposits at Yellowknife, the lead-zinc-silver deposits of Keno and Galena Hills, Yukon, the barite-sulphide deposits of Walton, Nova Scotia, and the sulphide deposits at Bathurst, New Brunswick, for all of which he has authored or co-authored significant monographs. In addition, he has carried out geochemical prospecting research in Yukon, Northwest Territories, Nova Scotia, New Brunswick and at Cobalt, Ontario. For his study on the geochemistry of gold, Dr. Boyle visited and worked in many parts of the world, including Bulgaria, Eire, Fiji, Finland, Great Britain, Greece, Japan, New Zealand, Norway, Sweden, and the U.S.A. and U.S.S.R.

Dr. Boyle is a Fellow of the Royal Society of Canada, the Royal Canadian Geographical Society and the Geological Association of Canada, and a member of several national and international professional societies. In 1966, he received the Barlow Medal of The Canadian Institute of Mining and Metallurgy, and in 1971 the Willet G. Miller Medal of the Royal Society of Canada and the Public Service of Canada Merit Award. During the second world war, he served overseas as an artillery officer with the Royal Canadian Artillery.

R.A. Cameron

Bob Cameron, an economic geologist and geophysicist, received a B.Sc. from Dalhousie University in 1948, an M.A.Sc. in mining geology from the University of Toronto in 1953 and a Ph.D. from McGill University in 1956. His early experience included nine seasons of summer field work with survey parties in Labrador, Nova Scotia, Quebec and Saskatchewan. He was then employed successively as a lecturer at the Department of Geology of the University of New Brunswick, as a geologist with Imperial Oil Ltd., Edmonton, Alberta, as a geologist with Malartic Gold Fields Ltd., Halet, Quebec, as chief geologist of East Malartic Mines Ltd., Norrie, Quebec, as area geologist with McIntyre Porcupine Mines Ltd., Val d'Or, Quebec, as field manager of the Atlantic Development Board potash development project and as Assistant Professor in the Department of Mineral Engineering at the Technical University of Nova Scotia.

Dr. Cameron is now Associate Professor in the Department of Geology of Laurentian University, Sudbury, Ontario. He is a member of the CIM and the Association of Professional Engineers of Ontario, and a Fellow of the Geological Association of Canada, and he is the author or co-author of some 10 publications or reports.

N. Champigny

Normand Champigny, born in Montreal, Quebec, completed his B.A.Sc. degree at Ecole Polytechnique in 1979. He subsequently obtained his M.A.Sc. in 1981 from the University of British Columbia. His thesis consisted of a geological evaluation of the Cinola gold deposit. He is currently working with International Geosystems Corporation, in the field of computer applications to mineral exploration and development data.

W.B. Coker

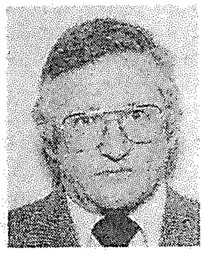
William B. Coker was born in Brandon, Manitoba, and graduated from Carleton University in 1971 with an Honours B.Sc. degree in geology. Specializing in geochemistry, he received his Ph.D. degree from Queen's University in 1974. He has been involved in both base metal and uranium exploration in eastern Canada with Phelps Dodge Corporation of Canada Ltd., SOQUEM and Rio Tinto Canadian Exploration Co. Ltd., where he was employed as a geologist-geochemist on graduation from Queen's University in 1974. From 1975 until 1981, he was employed in the Geochemistry Section of the Geological Survey of Canada as an applied geochemist working on uranium and base metal geochemistry in the southern portion of the Canadian Shield. Research interests lay in the study of chemical limnology and base metal and uranium geochemistry of lakes and surrounding catchment basins as applied to the interpretation of geochemical data for mineral exploration.

In 1981, Dr. Coker joined Gulf Minerals Canada Limited, where he was employed as senior geochemist. He is now with Kidd Creek Mines Ltd. in Toronto.

P. Cregheur

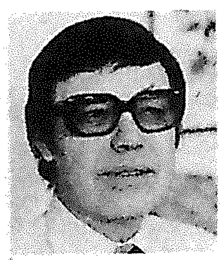
Paul Cregheur was born in Noranda, Quebec, and worked from 1963 to 1966 as a mine geologist with Falconbridge Copper Limited at their Opemiska Division. He then worked with Rio Algom Mines Limited to 1975 as a mine geologist at the Poirier Mine. From 1975 to 1976, Paul worked as a geologist with SEREM Canada Limited in Northwest Quebec and then to 1977 with Selco Mining Company on their Selbaie project. He joined Mining Corporation Limited in 1977 as a project geologist dealing with property evaluation in Canada and the U.S.A., becoming involved with the Chadbourne project in 1979.

J.H. Crocket



James H. Crocket earned a B.Sc. in geology from the University of New Brunswick (1955), a B.Sc. in research from Oxford University (1957) and a Ph.D. in geochemistry from M.I.T. (1961). He is currently a professor of geology at McMaster University in Hamilton and is actively involved in the teaching of economic geology. Much of his research has focussed on the geochemistry and economic geology of the noble metals and, together with his graduate students, he has carried out studies in the Red Lake, Timmins and Kirkland Lake gold camps, the Sudbury Irruptive and the base metal sulphide deposits of Eastern Canada. He has also been involved in the development of neutron activation analysis as an analytical tool for noble-metal analysis. Dr. Crocket is a Fellow of the Geological Association of Canada and a member of the Geochemical Society.

J.F. Davies

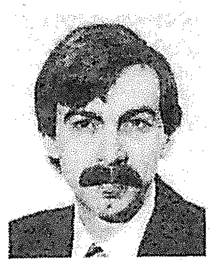


J.F. Davies, economic geologist, obtained a B.Sc. from the University of Manitoba in 1946, an M.Sc. from the same institution in 1948 and a Ph.D. from the University of Toronto in 1963. Currently Professor of Geology at Laurentian University, Sudbury, and a consultant on lithium, uranium, base metal and industrial mineral deposits, Dr. Davies earlier worked as Precambrian geologist and then as chief geologist of the Manitoba Department of Mines, with emphasis on gold, base metal and pegmatite mineral deposits. A Member of the CIM, he was awarded the Institute's Barlow Memorial Medal in 1965. He is also a Fellow of the Mineralogical Association of Canada and the Geological Association of Canada, and a member of the Association of Professional Engineers of Manitoba and the Society of Economic Geologists.

Jean Descarreaux

Jean Descarreaux received an honours B.Sc. and M.Sc. in geology from the University of Montreal and a Ph.D. degree from Université Laval in 1973. He has previously worked as a mining geologist in mineral exploration, and geological mapping and research. Since 1972, Dr. Descarreaux has been working as an independant consultant and contractor in exploration (geology and geochemistry) and mining geology. He has mainly worked in northwestern Canada, in the United States and in other countries world wide. Dr. Descarreaux has been a pioneer in the lithogeochemical prospecting technique for volcanogenic deposits, using variations in the major elements. He has published several articles on many subjects since the beginning of his career. Dr. Descarreaux is very active in the principal Canadian mining associations.

R.N.W. DiLabio

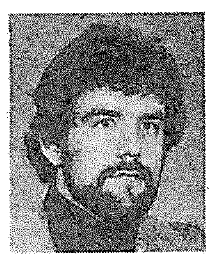


Ron DiLabio was born and raised in the Ottawa Valley. He graduated from Carleton University in 1971 with an Honours B.Sc. in geology and received a Ph.D. from the University of Western Ontario in 1976. Since then, he has been employed by the Geological Survey of Canada as a research scientist. His main research and publications have been on arctic glacial dispersal and the geo chemistry of till in the tundra, boreal forest and at present-day glaciers. He has also studied metal uptake by plants and peat in glaciated terrain.

R. Doucet

Roger Doucet is currently chief exploration geologist, Province of Quebec, for Long Lac Mineral Exploration Ltd. Mr. Doucet was born in the Lac St-Jean region of Quebec and graduated with a B.Sc. degree in geology from the University of Ottawa in 1972. Before joining Long Lac Mineral Exploration Ltd. in 1975, Mr. Doucet gained experience with the Quebec Ministry of Energy and Resources, SEREM and Amax. He also assisted SOQUEM with the discovery of the Silver Stack (Mine Doyon) mine in 1974. In 1975, as resident geologist with Long Lac's exploration group, he was directly involved with the discovery of the Bousquet gold deposit adjacent to Mine Doyon, in northwestern Quebec. Mr. Doucet has served as Chairman of the Harricana Branch of the CIM and for two years as District Councillor for CIM District 2. He is currently vice-chairman of the Quebec Prospectors Association and a member of the Association des Géologues du Québec.

D. Duff

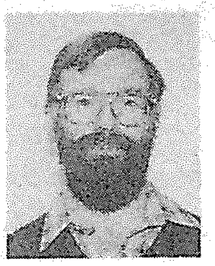


Damien Duff, born in Dublin, Republic of Ireland, graduated with an Honours degree in geology from University College, Dublin, in 1978. Subsequently, he attended Laurentian University in Sudbury, Ontario, from where he expects to graduate with a Master's degree in economic geology. Mr. Duff has been employed as a mine geologist with Pamour Porcupine Mines, Limited since last May, and he is currently working at that company's Timmins underground project (old Hollinger Mine). He also spent seven months as mine geologist at the Ross Mine in Holtyre.

Joe Fox

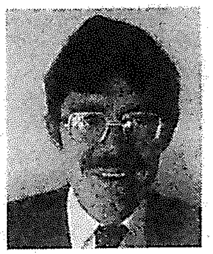
Joe Fox was born in Montreal, and graduated from McGill University with a B.Sc. in geology in 1968 and an M.Sc. in petrology in 1970. He went on to complete a Ph.D. in petrology at Cambridge University in England. Between 1974 and 1978, he worked at the Saskatchewan Research Council, developing petrological and geochemical techniques as applied to base and precious metal exploration. Between 1978 and 1980, he was project geologist responsible for base and precious metal projects at the Saskatchewan Mining Development Corporation. He is currently employed as senior geologist at Teck Explorations Limited.

J.A. Fyon



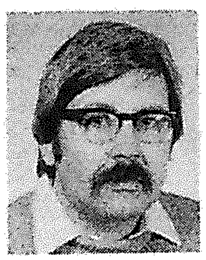
Andy Fyon was born in Montreal, Quebec and graduated with an Honours B.Sc. in geological engineering from Queen's University, Kingston, Ontario, in 1976. He obtained his M.Sc. in geology from McMaster University in 1980 and is currently working toward a Ph.D. in geology at the same institution. Between 1971 and 1977 he worked, summer and full time, in various capacities in the British Columbia mining industry and was engaged in mineral exploration in Ontario. In 1977, Mr. Fyon began his postgraduate thesis work in the Timmins area under the auspices of the Ontario Geological Survey and McMaster University. He is a member of the CIM, the Geological Association of Canada, Mineral Deposits Section, and the Prospectors and Developers Association.

R. Goldie



Raymond Goldie received a Ph.D. in geology from Queen's University, Kingston, Ontario in 1976, and a diploma in Business Administration from the University of Toronto in 1978. He has worked as an exploration geologist in New Zealand and Canada and is currently employed by Greenshields Inc. in Toronto as a mining investment analyst.

M.C. Graves

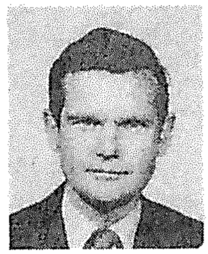


Milton C. Graves was born in Lewiston, Idaho. He obtained his B.Sc. from the University of Idaho College of Mines in 1972. After working briefly in petroleum exploration for Amoco Production Co. in Denver, Colorado, he came to graduate school in Halifax. The recipient of a Killam Scholarship at Dalhousie University, he completed his M.Sc. on gold mineralization in southern Nova Scotia in 1976. Since then, he has divided his time between research toward a Ph.D. at Dalhousie on aspects of the (post-Acadian Orogeny) metallogenic evolution of the Canadian Appalachians and working as a geologist in eastern Canada in a variety of geological environments, including coal.

Jayanta Guha

Currently employed as a professor at the University of Quebec at Chicoutimi, Quebec, Jayanta Guha received a Doctorate in economic geology from Jadavpur University, Calcutta, India, in 1967. He moved to Canada in 1968 and worked at the Ecole Polytechnique, Montreal, as a research associate. He has also worked in various capacities in the field of exploration and mining geology.

R.W. Hodder



Robert W. Hodder was born in Ottawa, Ontario, and is a graduate of Queen's University and the University of California at Berkeley. He worked as an exploration geologist for twelve years before joining the faculty of the Department of Geology at the University of Western Ontario in 1970.

R.W. Hutchinson

Richard William Hutchinson was born in London, Ontario, where he attended school. He obtained a B.Sc. in geology in 1950 from the University of Western Ontario, followed by an M.Sc. and later a Ph.D. from the University of Wisconsin. He also obtained a diploma in a middle management course at the University of Pittsburgh in 1963.

Dr. Hutchinson spent the summers of 1947 to 1953 carrying out field work for several Canadian mining companies and government surveys. In 1953, he joined Union Carbide Ore Company, working in Portuguese East Africa. From 1954 to 1964, he was with American Metal Co. Ltd. and American Metal Climax Inc., in New Brunswick, Quebec, Ontario and New York State.

Dr. Hutchinson has been Professor of Mineral Deposits Geology at the University of Western Ontario since 1964. From then until 1970 he also served as consulting geologist for Callahan Mining Corporation. Since 1974, he has been retained as a consulting geologist by Chevron Resources Co., and has worked periodically as a consultant to the UNDP-UNRF. He is currently president-elect of the Society of Economic geologists.

His current research interests and investigations involve metallogenic relationships in mineral deposits geology, as well as the geology and origin of massive pyritic base metal ores and the evolution of these deposits through geologic time.

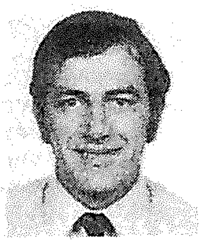
W.O. Karvinen

William O. Karvinen was born in Sudbury, Ontario. He obtained B.Sc. and Ph.D. degrees from Queen's University in 1968 and 1974 respectively, and graduated with an M.Sc. from the University of British Columbia in 1970. After graduation, he served briefly as a research scientist with the Geological Survey of Canada in Ottawa and then joined the Ontario Ministry of Natural Resources as a regional geologist in Timmins in 1974. He moved to Sudbury in 1977 as resident geologist with M.N.R., and in 1978 he established W.O. Karvinen & Associates Ltd., a consulting and mineral exploration firm. He has been president of the firm since its inception. Dr. Karvinen is a Member of the CIM and a Fellow of the Geological Association of Canada.

R. Kerrich

R. Kerrich received a Ph.D. from Imperial College, U.K., in 1975, subsequently entering the University of Western Ontario as a NATO Postdoctoral Fellow. Dr. Kerrich is currently an Associate Professor at Western, with research interests including interactions between chemical and mechanical factors in rock deformation, and the geochemistry of ore deposits.

P.J. MacGeehan

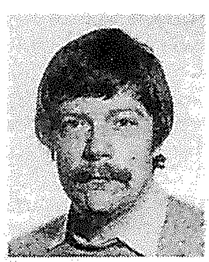


Patrick MacGeehan was born in Bristol, U.K., but grew up in Montreal, Quebec, and in southern England. He obtained a B.Sc. honours geology degree from Bristol University in 1969, and then worked for several years in exploration in Australia before completing an M.Sc. in mineral exploration at McGill University in 1974, and a Ph.D. in 1979, documenting the relationship between massive sulphide mineralization and sub-seafloor geothermal activity in the Matagami district. Between 1978 and 1980, he was a research associate at Queen's University, Kingston, investigating the genesis of gold mineralization in the Red Lake district, Ontario. He is now engaged in a 2-year consulting contract with Western Mining Corporation Ltd., based in Kalgoorlie, West Australia.

C. Mongeau

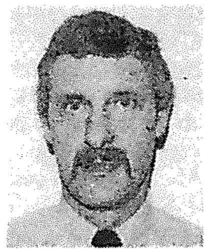
Claude Mongeau is the area chief mining geologist, Province of Quebec, for Little Long Lac Gold Mines Ltd. Mr. Mongeau was born in Montreal, Quebec, and attended Ecole Polytechnique de Montréal, obtaining a B.Sc. in geological engineering in 1974. While attending university, he had summer employment with the Quebec Ministry of Energy and Resources and worked in the Grenville Province, the Labrador trough and the Abitibi greenstone belt. He also gained experience as project geologist with the Brossard Mining Group, Val d'Or, Quebec, from 1974 to 1977. He began employment with Little Long Lac Gold Mines Ltd. during 1977 in the engineering department at the East Malartic Mine, Quebec, and he became mine geologist at the Bousquet Mine when underground development commenced in 1978.

J.H. Morris



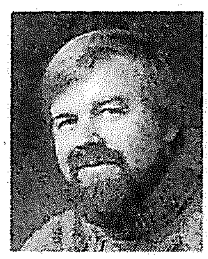
John H. Morris obtained a B.A. in 1970 from Trinity College, Dublin, Ireland (majoring in geology), an M.Sc. in 1974 from the University of Waterloo, Ontario (economic geology course and thesis) and a Ph.D. in 1979 from Trinity College in Dublin. His Doctorate comprised a primarily structural-stratigraphic-sedimentological synthesis of an area of Lower Paleozoic rocks in central Ireland. From 1969 to 1973, his summers were spent on exploration programs, mainly for uranium and base metals, in Quebec, Ontario and Saskatchewan with Canadian Johns-Manville Co. Ltd. and later with Derry, Michener and Booth, with one year as a mine geologist at the Upper Beaver Mine in Ontario. In 1979-80, he was a temporary lecturer in geology at University College, Dublin. Dr. Morris is currently with the Geological Survey of Ireland carrying out research on various economic geology projects, to date primarily dealing with gold-antimony and base metal vein mineralization in a Lower Paleozoic greywacke terrain.

J. Pirie



James Pirie graduated with an Honours B.Sc. in geology from Aberdeen University, Scotland, in 1966 and a Ph.D. from Queen's University, Kingston, Ontario, in 1971. After working in mineral exploration for Phelps Dodge in Ontario, B.C. and the U.K., he joined the Ontario Geological Survey in 1975. During his employment at O.G.S., he spent four field seasons carrying out detailed geological mapping in the eastern half of the Red Lake greenstone belt. Since 1979, he has been Ontario district exploration geologist for Esso Minerals Canada.

F.R. Ploeger



F.R. Ploeger graduated from Queen's University in 1973 with a degree in geological engineering. Following graduation, he joined the Ontario Geological Survey, Ministry of Natural Resources, as a resource geologist at Kirkland Lake. In 1980, Mr. Pleoger began work on an M.Sc. degree at McMaster University and a special study of the gold deposits of Kirkland Lake for the Mineral Deposits Section of the Ontario Geological Survey.

R.G. Roberts

R. Gwilym Roberts is an Associate Professor in the Department of Earth Sciences, University of Waterloo. After graduating from Cambridge University (1957), he worked for three years as an exploration geologist in Zambia, Zimbabwe and Malawi. He obtained his M.Sc. and Ph.D (1966) degrees in economic geology from McGill University. Since graduating from McGill, he has worked for several mineral exploration companies in the Precambrian Shield areas of Canada and southern Africa. His research interests centre on Archean volcanogenic massive sulphide deposits and gold deposits.

Dean S. Rogers

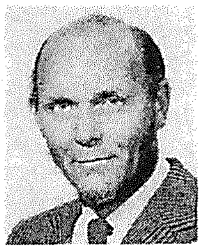
Mr. Rogers is currently the chief geologist at the Dome Mine, a position he has held for the past 10 years. Previous to returning to the Dome in 1972, he spent a total of three years in exploration in the Blind River, Lynn Lake and Red Lake areas before his first underground geology position at H.G. Young Mines. The next ten years were spent in mining geology related positions at Broulan Reef, Dome, Eagle Gold and Preissac Molybdenite mines.

He is a graduate of Queen's University and is a member of the Advisory Board of the Haileybury School of Mines and a member of The Canadian Institute of Mining and Metallurgy.

K. Shen

Shen Kun is an ore microscopist from the Peoples Republic of China who recently completed a 2-year sojourn as Visiting Scholar in the Department of Geological Sciences, University of British Columbia, Vancouver. Mr. Shen's research activities during the past 2 years have centred on fluid inclusion studies of several important deposits in the Canadian Cordillera. He has recently returned to China to take up a new position in the laboratory of the Geological Department of Shandang Province, Jinan.

A.J. Sinclair

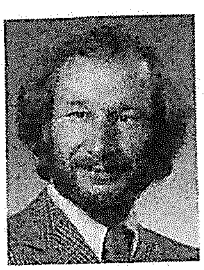


Alastair J. Sinclair graduated in geological engineering from the University of Toronto. He subsequently obtained graduate degrees from the Universities of Toronto (M.A.Sc.) and British Columbia (Ph.D). Since 1964, Dr. Sinclair has taught in the Department of Geological Sciences at the University of British Columbia, where he is now Professor and Director of Geological Engineering. His research interests include regional metallogeny, genetic models of ore deposits, lead isotope studies and geostatistics, and he has acted as consultant to the mineral industry on geological and geostatistical topics.

W.D. Sinclair

Dave Sinclair graduated from the University of Toronto with a B.Sc. (honours) geology degree in 1966 and then worked for one year in northwestern Ontario for Noranda Exploration Company Ltd. He subsequently obtained an M.S. degree from the University of Wisconsin in 1970 and a Ph.D. in 1973. From 1973 to 1977, he was employed by the Department of Indian and Northern Affairs in Whitehorse, Yukon as a district geologist and was acting regional geologist in 1976-77. Since 1977, he has been working for the Geological Survey of Canada, specializing in the geology of copper and molybdenum and related deposits.

V. Sopuck



Vladimir Sopuck graduated from the University of Manitoba with a B.Sc. in 1969 and an M.Sc. in structural geology in 1971. Before attending Queen's University, he worked for several years as a base metals exploration geologist with Anaconda American Brass Ltd. and Barringer Research Ltd. In 1977, he received a Ph.D in geochemistry from Queen's University, where he concentrated on the application of lithogeochemistry in the search for volcanogenic massive sulphide deposits. Since 1977, he had been employed with the Saskatchewan Research Council, where his research included the study of uranium dispersion in lake sediments, tills and the Athabasca sandstone overlying unconformity-type uranium deposits. He is now a geochemist with the Saskatchewan Mining Development Corporation in Saskatoon.

Marcel Vallée

Marcel Vallée was born in Quebec City and obtained a BScA in geological engineering from Université Laval in 1956. From 1956 to 1962, he worked as a geologist with the Development Division of the Iron Ore Company of Canada in Schefferville, Québec. From 1962 to 1967, he occupied the post of chief geologist with the St. Lawrence Columbium and Metals Corporation at Oka, Québec, in charge of mine geology and outside exploration programs. He joined SOQUEM in 1967 as geologist and project manager and was in particular involved with the discovery and development of the columbian deposits of Niobec in the St-Honoré Carbonatite. As chief development geologist of SOQUEM, he is supervising the development and mining geology programs of SOQUEM and its subsidiaries, including mine exploration programes. Mr. Vallée was awarded the Barlow Metal of the CIM for 1967.

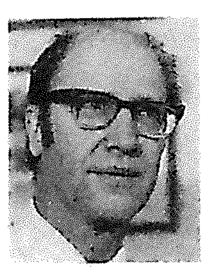
R.I. Valliant

Robert Valliant was born in Ottawa, Ontario and attended the University of Waterloo, obtaining an Honours B.Sc. degree in geology in 1977. He is currently at the University of Western Ontario, where he is completing a Ph.D. thesis about the geology of the Bousquet Mine. He has worked for Long Lac Mineral Exploration Ltd. since 1977 on various projects in Ontario and Quebec. Prior to working for Long Lac, Mr. Valliant spent field seasons with Hudson's Bay Mining and Smelting Co., Ltd., Gulf Canada, Hudson's Bay Oil and Gas Ltd., Chevron and Shell Canada Resources Ltd. at various locations in Canada.

S.D. Walker

Stephen Walker was born in Baden, West Germany. After spending a year at the Haileybury School of Mines, he returned and finished an honours B.Sc. at Dalhousie University in 1979. He completed an M.Sc. program and thesis on the Chadbourne mine at the University of Western Ontario in 1981, and is currently employed with Noranda Exploration Company Limited, Noranda, Quebec. Mr. Walker is a member of the CIM and GAC, and an associate member of the S.E.G.

R.E. Whitehead



R.E. Whitehead, economic geologist and geochemist, received a B.Sc. from Mount Allison University in 1970 and a Ph.D. from the University of New Brunswick in 1973. He has been Associate Professor of Economic Geology and Geochemistry at Laurentian University since 1974. He had earlier worked at Pamour Porcupine Gold Mines Ltd. and at Heath Steele Mines Ltd., and was a field geologist for Heath Steele Exploration and Noranda Exploration Ltd. Dr. Whitehead is a member of the CIM and of the Society of Economic Geologists.

M. Zentilli

Marcos Zentilli was born in Santiago, Chile. After graduating with a B.Sc. from Universidad de Chile in 1963, he specialized in mineral deposits geology in Munich, Germany. He worked six years for Instituto de Investigaciones Geologicas, mainly as resident geologist in Atacama, Chile, and then moved to Canada, where he obtained his Ph.D. from Queen's University in 1974. In 1972, he worked for Geophysical Engineering Ltd. in Newfoundland, and in 1973 he joined Dalhousie University, where he teaches economic geology. His research interests have included the regional metallogenic evolution of the Central Andes, mineral deposits of Nova Scotia and volcanic-hydrothermal processes in eastern Iceland.