Geoscience Canada

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Volume 28, Number 3, September 2001

URI: https://id.erudit.org/iderudit/geocan28_3art02

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Publisher(s)

The Geological Association of Canada

ISSN

0315-0941 (print)
1911-4850 (digital)

Explore this journal

Cite this article

Hutchinson, R. W. (2001). Prospecting and Exploration Through the Ages: Enduring Fundamentals but Changing Technologies. *Geoscience Canada*, *28*(3), 119–126.

Article abstract

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Prospecting and Exploration Through the Ages: Enduring Fundamentals but Changing Technologies

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SUMMARY

The fundamentals that drive prospecting and exploration, *i.e.*, the search for useful mineral materials by investigating observed abnormalities, have not changed significantly through the millennia. The variety of minerals sought and the approaches used in the search, however, have increased exponentially, especially in the last century, owing to advances in many fields of science and technology, all accompanying immense growth, diversification, global expansion, and integration of the world's mineral industry. The focus of these activities has shifted continually and progressively westward from Mesopotamia through the Mediterranean basin and northwestern Europe to the Americas, then southward to Africa and Australia, but always toward little-explored or unexplored regions. Significantly, the focus of world political influence has accompanied this westward shift through time. Mineral wealth, derived through prospecting and exploration, is an essential basis of modern living standards and global power, an overlooked, ignored, or even forgotten relationship that merits careful reconsideration by today's public, idealists, and politicians.

RÉSUMÉ

Les principes fondamentaux régissant la prospection et l'exploration, *i.e.*, la quête de minéraux utiles par l'étude d'anomalies, n'ont pas changé notablement au cours du dernier millénaire. Cependant, et la variété des minéraux recherchés et les approches adoptées se sont multipliés de manière exponentielle, particulièrement au cours du dernier siècle, suite aux développements scientifiques et technologiques dans plusieurs domaines, ces derniers entraînant des vagues immenses de développements, de diversifications, d'expansion globale et d'intégration de l'industrie minérale mondiale. L'intérêt de ces activités d'exploration s'est continuellement et progressivement déplacé d'Est en Ouest, passant de la Mésopotamie au bassin de la Méditerranée et au nord-est de l'Europe vers les Amériques, puis vers le sud, vers l'Afrique et l'Australie, toujours vers des régions peu ou pas explorées. Fait intéressant, historiquement, les préoccupations politiques mondiales ont suivi ce même parcours vers l'Ouest. La richesse minérale découlant de la prospection et de l'exploration constitue une assise essentielle des niveaux de vie modernes et des pouvoirs globaux – relation de cause à effet qui est trop souvent négligée, ignorée ou même oubliée par le grand public, les idéalistes et les politiciens.

INTRODUCTION

Organizers of the "Mining Millennium 2000" joint meeting of the Prospectors and Developers Association of Canada (PDAC) and the Canadian Institute of Mining and Metallurgy (CIM), held in Toronto in March 2000, requested a retrospective overview of global prospecting and exploration during the past thousand years. As an aging participant in these activities for 50 years, the writer facetiously suggested that a mere 1000 years of hindsight seemed too limited from his perspective! The organizers replied in kind by broadening their invitation to include the beginning of his career as indicated in the above title.

It seems relevant to begin such an overview by considering when, why, and how prospecting and exploration began, and how have they evolved through time. Archeology establishes unquestionably that these activities began long before commencement of the last millennium. Since appearing on earth, *Homo sapiens* has sought useful and more effective mineral materials to make tools and weapons, although innate curiosity and increasing desire for profit have been additional, related incentives. Early in the first volume of his *History of the English Speaking Peoples,* Winston Churchill (1956) commented that Britain's earliest Stone Age inhabitants had round skulls and, like Australia's native peoples today, used hard, durable flint for cutting tools, axes, and arrowheads. They were, however, subjugated by later "long-skulled" people who made heavier, more durable and effective bronze weapons but who were, in turn, similarly treated by Iron Agers. Churchill succinctly concluded that "for smashing skulls, whether long-headed or round, iron is best." Sadly, smashing skulls remains an important use for modern mineral materials. Clearly then, the fundamental motivation for prospecting and exploration has not changed through several thousand years. We still seek useful mineral materials, albeit in vastly greater diversity.

It is further relevant to ask "how did prehistoric peoples explore?" Once again, not so differently it appears, from the way we explore today, for they too chased anomalies! Like the diversity of minerals sought, however, the technology of anomaly recognition and definition has expanded exponentially: the importance of anomalies in prospecting and exploration has always been fundamental. Prehistoric peoples surely noted the unusual and therefore distinctive characteristics of certain minerals: flint's hardness and durability; gold's weight and spectacular, durable lustre; heavy cassiterite; copper's attractive blue-green oxides; sulphur's yellow and cinnabar's brilliant red colours. Their innate curiosity about these unusual features led to investigation of how, why, and where minerals originated, and to the search for them. In this way primitive mankind very early became basic scientists, investigating the "how and why," applied metallurgists extracting the metals, and thus prospectors-explorers.

Prehistoric peoples learned early that salt seasoned and preserved food. They found salt in Eritrea's Danakil Desert and in Israel's Dead Sea where, according to the Old Testament, Lot's wife misbehaved and turned into a pillar of salt, presumably like those in Eritrea (Fig. 1). Copper, readily identified from its colours in oxidized outcrops, was smelted as early as 5000 B.C., at a thoroughly studied archeological site at Timna in the Israel Negev near Eilat (Poss, 1975, plate 48) where copper has also been mined during recent decades. Copper was combined with tin, won and smelted from placer cassiterite, to make the vessels and tools of the Bronze Age throughout the near- and mid-eastern world in the 4th and 3rd pre-Christian millennia, but the geographic source of this abundant tin remains uncertain and conjectural, one of archeology's unsolved enigmas (Raymond, 1984, p. 33). Gold, then as now the most highly prized of all, and probably the first found, initially went almost exclusively to the powerful and affluent to signify wealth and power, and for decorative and religious purposes. Gold's use in coinage developed somewhat later, about 700 B.C., in Lydia. It was widely won from placers and lodes. The ancient Greek legend of Jason and the Golden Fleece is almost certainly an allegorical account of a gold prospecting expedition to the eastern Black Sea coast, where fine gold was apparently won by washing auriferous stream sediment through lamb's fleece (Bernstein, 2000, p. 15-16, 30).

HISTORICAL REVIEW

Prospecting, exploration and mining spread from beginnings in the prehistoric mid- and near-eastern Old World first into Egypt and the eastern Mediterranean, then throughout the entire Roman world, and thence to include northern Europe by the middle ages. Subsequently, using many of the same methods and approaches, these activities were carried to the New World of the American and southern continents during the Age of Discovery, five centuries ago.

The Old World

The earliest prehistoric prospecting and mining activities were widespread throughout Mesopotamia and Anatolia (modern day Turkey) where Hittites first learned to extract and use the much more abundant and still harder, thus more available and durable, iron, and in so doing became the dominant power of the region in the mid-third millennium B.C. (Raymond, 1984, p. 60). Two thousand years of successive Babylonian, Egyptian, Assyrian, and Persian empires were then followed by Phoenician, ancient Greek, Carthaginian, Macedonian and Roman prospectors, who explored westward throughout the Mediterranean basin. Republican, then Imperial Rome may be credited with the first government-promoted, systematic regional exploration, which significantly funded the Roman aristocracy and, through it, global power and aggrandizement.

Silver, won from cupellation of argentiferous galena at Laurium, south of Athens, where archeological evidence shows that mining began about 3500-3000 B.C., funded the Athenian fleet's victory over the Persian flotilla at Salamis in 480 B.C. (Kakavoyannis, 1988, p. 44-45; Raymond, 1984). The oldest known mining documents, also from Laurium, are marble slab inscriptions. One (Fig. 2), now in charge of the Acropolis Trustee, Museum of the Ancient Agora in Athens, concerns a mortgage on a mining property. Romans prospected and explored from Anatolia in the east to Cornwall in the northwest using many time-honoured methods such as surface stripping, pitting, trenching, and "divining," as well as currently used indicators. They are known to have "grubstaked" local prospectors who were sent to seek out mineralized outcroppings and auriferous placers. Gossan prospecting is not new! Gossans or "eisen huts" in later European terminology, were indicators not only to Romans but to their predecessor Egyptian and Phoenician explorers. This "live" gossan (Fig. 3) remains visible on outcrops above the now mined out, 20 million tons of *ca.* 4.0% Cu ore body at Mavrovouni in Cyprus. It must surely have attracted the attention of earliest prospectors, perhaps leading to the copper mining which, according to archeological evidence, had begun by

Figure 1 Bedded halite capped by bed of less soluble gypsum, forming "pillars" due to erosional dissolution, Danikil area, Eritrea (from Holwerda and Hutchinson, 1968).

Figure 2 Slab from Ancient Laurium describing a mortgage of a mining property at Laurium. Acropolis Trustee, Museum of Ancient Agora, Athens, Greece.

about 2500 B.C. (Bear, 1963). The presence of Roman workings or utensils in all but one of some 50 massive sulphide bodies in Cyprus testifies to the remarkable efficiency of these early explorers (G. Constantinou, Geological Survey Dept., Cyprus, personal communication).

Prospector Godfrey Gunther, waiting in a Brooklyn, New York library for a young lady, by chance came across historical writings that led him, in 1912, to sites of ancient copper mining in the (then) Egyptian Negev, in east-central Turkey near Ergani Maden where copper is still mined today, and finally to Cyprus (Lavender, 1962). In Cyprus, these reddish and earlier Pheonician slags higher on the hill slope and a topographically lower, million-ton heap of black Roman slags at modern day Skouriotissa (Fig. 4; skourios is Greek for "slag") were Gunther's key indicator to re-discovery of the great Skouriotissa and Mavrovouni orebodies on behalf of Seeley Mudd and Cyprus Mines Corporation. Production from these major orebodies laid the foundations of that great but, sadly, recently disappeared company. Radiocarbon dating indicates an age range of about 100-400 A.D. from the base to top "stratigraphic levels" within the million-ton Roman slag heaps (G. Constantinou, personal communication). Similar slags are widespread along Turkey's Black Sea coast and elsewhere in the middle east where they identify sites of ancient mining, perhaps not all of them yet thoroughly prospected and explored. Secondary enrichment too, was well known to Roman prospectors and explorers. Narrow underground staircases (Fig. 5) extended downward to the water table where gold-enriched attapulgitic-palygorskitic clays were especially sought. These enrichments, termed "devil's mud" by Cypriot miners because of their extreme acidity, greatly aided Cyprus Mines Corporation in maintaining production during the depression of the mid-1930s, when copper sold for 5-6 cents per pound.

Figure 3 Gossan above mined-out Mavrovouni orebody showing "live, hematitic-limonitic colours," near Skouriotissa, Cyprus.

Figure 4 Ancient Phoenician (reddish and right, below centre) and younger Roman (black and left, below centre) slags at Skouriotissa in Cyprus.

Prospecting, exploration, and mining throughout the Roman Empire and its successor Eastern Roman Empire continued for one thousand years. Too widespread and diverse to consider in detail, many of the best-known examples are located in Spain, which became Rome's greatest treasure house after Scipio's defeat of Hannibal at the battle of Zama in 202 B.C., and her final conquest of Carthage in 146 B.C., where Julius Caesar, as governor, acquired his personal fortune (Poss, 1975, p. 116). Roman workings succeeded Carthaginian ones at the La Union lead-zinc deposit east of modern-day Cartagena in southeastern-most Spain, at Rio Tinto (Raymond, 1984, p. 86) in what we know as the Iberian Pyrite Belt and elsewhere throughout the Iberian Peninsula. Extensive Roman hydraulic placer workings recovered gold at Las Medulas northwest of Ponferrada in Spain (Hacar *et al,* 1999), and at Tresminas near Vila Pouca de Aguilar in Portugal. Total recovery of gold by Romans in Iberia has been estimated at 1800 tonnes (F. Barriga, personal communication).

Although undocumented, an ancient Latin request reportedly sought mining of "hydrargentum"; *i.e.,* "watersilver, Hg or mercury," at Almaden, this for an empress's spectacular fountain in Rome. If she showered in it she must, indeed, have been a spectacular empress, but might not have survived as well as steel balls floating in a tank at modern Almaden (Fig. 6)! But a millennium and a half later, control of Almaden's mercury fostered Spain's rise to world power through global regulation of gold recovery, supply, and trading. Amalgamation remains important in gold extraction, especially in underdeveloped regions of the world, where it is a serious pollutant and environmental hazard.

After the fall of Rome and the Western Empire in the 4th century A.D., prospecting and exploration declined during the Dark Ages. Many ancient mines were abandoned. Activities then shifted westward, as they do today, to less-explored areas in central and northern Europe. The famous Rammelsberg copper-silver-lead deposit was discovered *ca.* 938 A.D. (Poss, 1975, p. 133) and, beginning shortly thereafter, was mined continually for more than a thousand years, finally closing only in 1988. So rich in silver were the narrow polymetallic veins (Fig. 7) of the Erzgebirge, the "ore mountains" of Saxony and Bohemia, discovered *ca.* 1170 A.D., that regional currencies of this part of central Europe were based for centuries on silver, rather than gold as elsewhere (Poss, 1975, p. 133-136; Raymond, 1984, p. 98). Silver's regional pre-eminence was commemorated in the form of a famous and priceless, medieval silver table, sadly now disappeared. A photo of it may be seen in an old Czech restaurant in the town of Gottesgab (T. Seifert, Freiberg, Saxony, personal communication). In this region George Bauer, better known by his Latin name as Georgius Agricola, some 400 years later in the 16th century became interested in the great deposits of the region, and wrote *De Re Metallica* (see Hoover and Hoover, 1950). Immensely rewarding prospecting and exploration here (Fig. 8) ultimately led to the founding, in 1765, of the western world's first Mining Academy at Freiberg in Saxony. It is still a world centre for studies of ore deposits, and is where Abraham Gotlieb Werner in 1769-1771 espoused what may be considered the earliest "Neptunist" or marine genetic hypotheses for the origin of ores and rocks. Some Erzgebirge ores also yielded gold, others lithium, tin, molybdenum, tungsten and, interestingly, a mineral termed "kupfernickel" or "devil's copper" because, although resembling sulphides of copper, it yielded none, only a worthless and unrecognized new element, nickel! Similar silver-rich veins were soon discovered at Konigsberg in Norway. Then, much later but dearer to Canadian hearts, also in 1899 in northern Ontario, prompting that first great claim-staking "rush" that truly initiated Canada's mining industry, and

Figure 5 Old downward-accessing Roman stairway exposed in wall of modern pit, near Troulli, southeastern Cyprus.

Figure 6 Steel balls floating in tank of native mercury, Almaden, Spain.

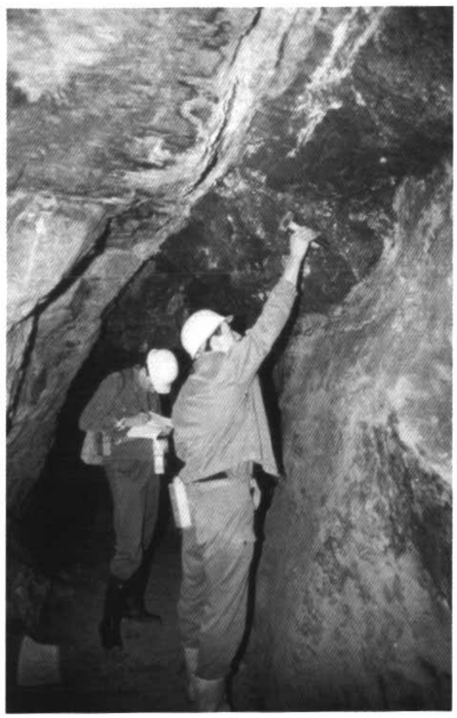

Figure 7 Narrow, very high-grade polymetallic Pb-Zn-Ag vein, Reiche Zeche Mine Wilhelm Stehender, Freiberg District, in the Saxonian Erzgebirge, Germany (photo by T. Seifert, Freiberg).

where they sang that

...little song about Cobalt.
If you don't live there it's your fault,
Oh you Cobalt,
where the wintry breezes blow,
Where all the silver comes from,
you can live a life and then some.
Oh you Cobalt,
you're the best old town I know!

In Scandinavia, copper mining began at Falun in central Sweden by *ca.* 1000 A.D., on rich volcanogenic massive sulphide (VMS) outcrops famous in Swedish as Stora Kopparberg or "the great copper mountain." As at Rammelsberg, mining continued at Falun for more than one thousand years, contributing significantly to Sweden's world power status between 1600 and 1730. In 1637 three small pits there collapsed into the warren of underground workings that by then had penetrated to depths of 1000 feet, forming the famous "Great Pit," 325 feet deep and 1000 feet in diameter (Rydberg, 1975), still to be seen on modern surface tours at Falun. And swords of finest Swedish steel from the rich Grangesberg and Kiruna iron ores had become world favoured for the skewering of medieval midriffs. Some earliest innovations in prospecting and exploration too, were Swedish. Daniel Tilas traced boulders in glacial overburden to their source outcrops in Finland and published his account of the work (Tilas, 1739-1740). This was clearly the forerunner of modern basal till methods, till sampling for diamond indicator minerals, and other types of deposits.

The New World

With European colonization of the "New World" about five centuries ago, prospecting and exploration again moved westward to unexplored regions. Iron Age Spaniards, Portuguese, French, and English readily cracked the skulls of Bronze and Stone Age indigenous peoples who, like prehistoric peoples in Asia Minor, valued, but did not otherwise extensively use, the soft metals, gold, silver, and copper. The Europeans were, in fact, significantly motivated by the lure of mineral discovery. Pizarro collected his demanded room full of gold ransom, containing about 5 tons, but neglected to return Atahualpa to the Incas. Instead, Atahualpa was tried, convicted on various charges, and executed (Bernstein, 2000, p. 126). Champlain's earliest voyages sought copper in the Triassic red beds of the Bay of Fundy, Canada. Native peoples told the newcomers of native copper in both Michigan and the Canadian Arctic, the latter prompting Samuel Hearne's two unsuccessful and third successful traverses overland from Hudson Bay westward across the Northwest Territories to the Coppermine River in 1769-1772 (Hearne, 1795). Most of the great mining districts of the Americas were discovered by surface prospectors and explorers in these little known terranes, seeking the same ancient surficial indicators of colour, gossans, and secondary enrichments, and using the same old proven approaches of panning streams for heavy minerals, and shallow trenching. Moreover, significant surface discoveries as recently as 1980 at Red Dog in Alaska (Koehler and Tikkanen, 1988) and 1994 at Voisey's Bay in Labrador (Naldrett *et al.,* 1996) attest to the continuing importance of surface prospecting and regional exploration.

A–Twig. B–Trench.

Figure 8 Drawing depicting late-16th century prospecting and exploration in the Erzgebirge, from translation of Agricola's *De Re Metallica*, Hoover and Hoover, 1950, p. 40.

The Present

Understandably, however, the role of these approaches is necessarily diminishing. With global population now more than six billion (United Nations' estimate, mid-1999) there remain few places on the earth where *Homo sapiens* has not walked, observed, prospected, and explored, sometimes knocking a few skulls just to keep in practice. In the last two centuries, roads, railroads, then aircraft have opened remote and formerly inaccessible regions to prospecting and exploration, as did float-equipped aircraft to the entire Canadian Precambrian Shield after World War I. The contrast is immense between modern explorationists, who reach the most remote areas of the globe in 24 hours, and A.P. Low who, just over 100 years ago (Alcock, 1947, frontispiece), required months to access Lake Mistassini and Labrador from Ottawa by canoe, where he first discovered the great iron ranges. Sometimes, however, the old means of access remain more reliable (Fig.9)! Early, landmark regional and district mapping by the Geological Survey of Canada and other international and regional governments, immensely aided prospecting and exploration during the last century. This and later mapping provide the solid building blocks on which modern activities depend.

Post-World War II generations

have witnessed exponential growth and improvements in prospecting and exploration technology dating almost entirely to the last century, and mainly to its last five decades. The driving force has been the huge growth in world population, with commensurate expansion of demand for mineral materials in ever-greater abundance and diversity. These improvements stem from research and resulting new knowledge in all fields of science, and their applications to prospecting and exploration have been landmark, although far too broad and diverse to consider here in historical context. In summary, however, improvements in prospecting and exploration technology include vastly improved understanding of the orgin and distribution, both in space and through 4 billion years of Earth's evolution, of all types of ore deposits. These improvements also include increasingly diverse, reliable, sensitive, and accurate geophysical, geochemical, global positioning, and remote sensing exploration approaches and systems. Finally, the Internet age permits ever-more effective processing, global exchange, and communication of data, concepts, and ideas.

The writer as a young man, for example, shown in a *Toronto Star* photo (Fig.10) with well-known prospector Joe Rankin knowingly testing a sample of uranium ore with a geiger counter at the 1949 PDAC meeting, well recalls the impact on prospecting and exploration of radioactivity. In truth, neither Joe nor I knew much about this newly desirable element; only that it was the best skull smasher yet! The new exploration approaches "look" both at the surface and below it to increasing depths, and with ever-increasing sensitivity and resolution, thus identifying anomalies of increasing diversity that were formerly unknown, invisible to, or beyond the reach of surficial exploration. Increasingly, the prospector is becoming a diversified explorer. An outstanding example was the discovery in 1977 of the huge Neves Corvo polymetallic massive base metal sulphide deposit 350 m beneath a strong positive gravity anomaly in southern Portugal (de Carvalho, 1988). A first drill hole was bottomed too soon at 275 m due to misunderstood geological relationships, leaving the anomaly unexplained. Four years later, persistence and reinter-

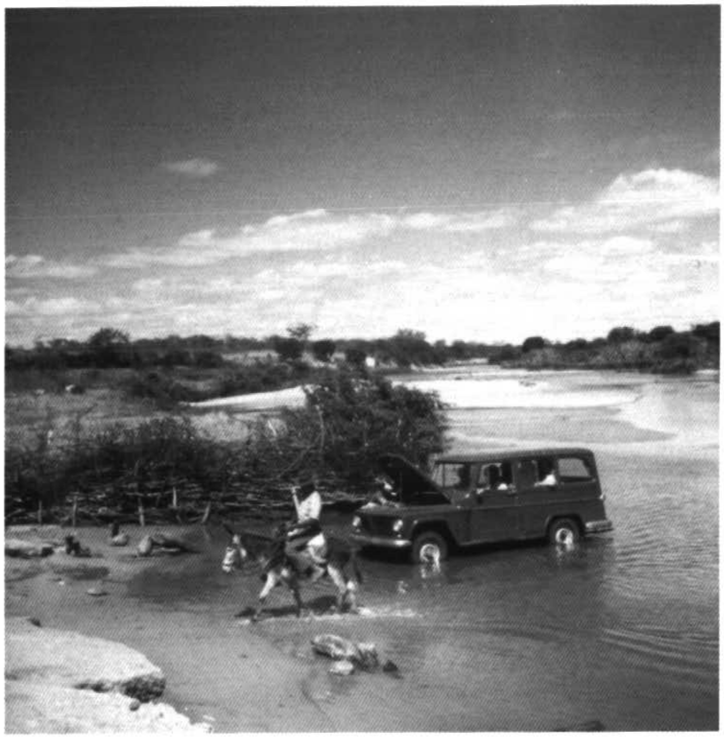

Figure 9 Jeep, stalled in stream; local donkey-mounted prospector has no problem. Near Boquira Mine, western Bahia State, Brazil.

14 Tues., March 8, 1949

RADIO-ACTIVE

JOE RANKIN, veteran uranium prospector, explains the "ins" and outs" o Geiger counter work to Dick Hutchinson, University of Western Ontari geology student

Figure 10 *Toronto Star* photo of author and prospector Joe Rankin of Prospector's Airways, at Prospectors and Developers Association of Canada meeting, 8 March 1949.

pretation paid off when a second hole intersected 50 m of zinc-lead-silver sulphides, and a third soon after intersected 15 m of very rich copper ore.

The Future

Have these innovations resulted in an improved record of more or richer discoveries at lower cost? Although virtually impossible to evaluate accurately and objectively, the discovery record over the last five decades (Tables 1 and 2; Hutchinson, in review) suggests that regional exploration and prospecting in under-explored but geologically favourable regions, together with simple good luck, have been at least as equally rewarding as the advanced exploration technology, although the increasing importance of geophysical and geochemical exploration methods is evident.

Where will *Homo sapiens* seek to satisfy society's ever-greater and more diverse mineral needs? As always through the millennia, he will turn to little or unexplored regions. This is already underway. The shallow sea floor yields diamonds off the Namibian coast (Gurney *et al.*, 1991). The deep ocean floor has widespread, nickel-rich manganese nodules (Scott, 2001). Trial mining has extracted base metals from the Red Sea deeps, and the rights to base metals and gold have been granted by Papua New Guinea at sites of hydrothermal discharge in the Manus Basin (Scott, 2001). And sub-sea floor deposits of methane hydrate attract the energy industry. Finally, the National Aeronautics and Space Administration (NASA) of the United States has recently funded studies of lunar helium resources (Cameron and Kulcinski, 1992), and an iron deposit is suspected on Mars (Lane *et al.*, 2000). Zubrin (1996, p. xvi) also pointed out that deuterium, then worth $10,000 per kilogram here on Earth, was five times more abundant on Mars, and discussed possible recovery of huge tonnages of nickel, cobalt, and the platinum group metals from metallic asteroids in the asteroid belt between Mars and Jupiter (Zubrin, 1996). The moon and Mars are no longer totally inaccessible! Clearly, tomorrow's prospectors must become exploration technologists.

Table 1 Tabulation of some important districts discovered in the last five decades, identifying their main* discovery approach (*others may have contributed).

Major Districts	Type	Approximate Discovery Date	Main Discovery Approach
Labrador, PQ	Fe	1945-1946	review old data
Bathurst, NB	VMS Zn-Pb	1951	happenstance
Mattagami Lake, PQ	VMS Zn-Cu	1956	geophysics
Viburnum Trend, MO	MVT Pb-Zn	1956	geology
Hamersley, W. Australia	Fe	1962	review old data
NWT-YT	sedex Zn-Pb	1962	regional exploration
Ireland	carb. Zn-Pb	1964	regional exploration
Kambalda, W. Australia	Ni	1964	happenstance
Carajas, Brazil	Fe	1968	regional exploration
Carlin, NV	Au	1970	geology-geochemistry
NW Cape Providence, Republic of South Africa	sedex Zn-Pb-Cu	1972	regional exploration
Saskatchewan	U	1980	regional exploration
Lac de Gras	diamond	1991	geology

Table 2 Tabulation of some important deposits discovered in the last five decades, identifying their main* discovery approaches (*others may have contributed).

Important Deposits	Type	Approximate Discovery Date	Main Discovery Approach
Allard Lake, PQ	Ti-Fe	1948	geophysics
many, worldwide	VMS Cu-Zn-Pb	1953-1998	geophysics
Henderson	Mo	1964	geology
Olympic Dam	Cu-Fe-U-Au	1977	happenstance
Red Dog	sedex Zn-Pb	1980	regional exploration
Yilgarn, W. Australia	Au lodes	1980-1992	review old data
Hemlo, ON	Au	1982	review old data
several, western South America	cu-porph	1982-1996	regional exploration
Lisheen, Ireland	carb. Zn-Pb	1992	geology
Voisey's Bay, NF	Ni-Cu-Co	1993	happenstance
Cannington, Australia	sedex Zn-Pb	1994	geophysics
Pogo, YT	Au	1996	geochemistry

ACKNOWLEDGMENTS

Many friends and colleagues have contributed to this paper over the years through discussions and comments about its various aspects. Special thanks are due to Bruce Bouley, who assisted both in this way and with preparation of illustrative figures. Panayiotis Perlikos in Athens contributed both data and photos of ancient work at Laurium, while Fernando Barriga and Jorge Relvas in Lisbon provided information about Roman hydraulic gold mining in Portugal and Spain. Ulrich Schwarz-Schampera and Thomas Seifert of the Institut fur Mineralogie at the Technical University of Freiberg, Germany, provided information about the history and deposits of the Erzgebirge, and Steve Hickock and Alexis Dreimanis at the University of Western Ontario are thanked for information about the early work of Daniel Tilas. Jo Kalliokoski of Michigan Technological University accompanied the writer to the site of a recently unearthed 20-ton glacial erratic of native copper north of Haughton, Michigan, clearly demonstrating how native North American peoples knew about its presence. In many places herein the content is the writer's summary or synthesis of more detailed and longer passages in the excellent books by Bernstein, Poss, and Raymond cited in the text and references. Thanks are also due to journal reviewers Patricia Dillon and John Hansuld and *Geoscience Canada* editor Roger Macqueen, whose helpful suggestions improved both the content and flow of the paper. David Sargent digitized the illustrations at the Geological Survey of Canada, Calgary.

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Accepted as revised 1 June 2001