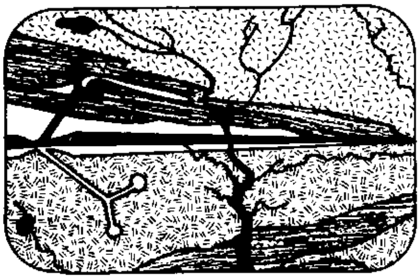

4. Predictive Metallogeny: A Two-Edged Sword

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Introduction

The ability to predict the location of undiscovered mineral deposits and, further, to have some inkling of their type, size and grade is the ultimate aspiration of the economic geologist. Like many ultimate goals, it is at present beyond our reach. It is vitally important that this should be recognized at the outset of any discussion of predictive metallogeny. By pretending otherwise we not only delude ourselves, but can seriously mislead non-geologists, such as politicians, economic planners and the owners of mineral rights who depend on our council for their guidance.

In discussing predictive metallogeny my viewpoint is that of the profit-motivated private sector of the Canadian mineral exploration industry. In addition to Canadian experience, I will draw upon experience in the United States and other parts of the world, experience gained over a period of twenty years of mineral search. During that time, I have been fortunate enough to have been associated, directly or indirectly, with two highly successful applications of predictive metallogeny, and with several other "technical successes" in which mineral deposits were found which were not immediately mineable. Please note the distinction between "successful" and "technically successful" used here, as the distinction is the key to the viewpoint of the mining company. According to this viewpoint, it is of little value to find mineral resources unless they can be exploited profitably within a reasonable time frame, usually twenty years or less.

Mining Company Exploration Procedures

There is little unanimity or conformity in the approaches of various mining companies to mineral exploration. Nonetheless, companies tend to fall into certain broad categories. For example, companies may be *active* or *passive*. Active companies initiate exploration, passive ones allow entrepreneurs or other companies to bring proposals and properties to them. Among the active companies, some are oriented towards the *acquisition* of prospects at various stages of development, whereas others pursue a *grassroots* approach, developing their own concepts and pursuing them in the hope of finding previously unrecognized deposits. Most of the more successful companies employ a mix of the acquisition and grassroots approaches. Some companies direct their efforts towards a single commodity or a single geographic area, others seek a wide range of targets and pursue their objectives throughout the politically and economically favourable parts of the world.

Whatever the approach, the driving force is the desire to make a profit. Exploration is a tool to achieve corporate objectives. When the objectives have been attained, or when it is clearly demonstrated that they cannot be attained economically, exploration stops. Much of what I have just said is elementary and self-evident, but it bears repeating in the hope of avoiding the misundertandings that can arise between the government, academic and industrial factions of our economic geology community. For example, in his letter confirming my invitation to sit on this panel, Atholl Sutherland Brown, speaking for the Committee of Provincial Geologists, identified the subject of predictive metallogeny as one needing more open discussion and more systematic and innovative approaches. Granted. However, he went on to say "We believe that there is a large amount of *ad hocery* in the business of designing exploration programs". My dictionary defines *ad hoc* as "arranged for a purpose", or "special". My point is that an exploration program mounted by a private company will always be *ad hoc*, in that it is designed to achieve a specific, profit-motivated corporate purpose, usually within a restricted time-and-expenditure frame. Accepting this fact, one is led to conclude that long-range, systematic studies aimed at elucidating the origin and distribution of mineral deposits are outside the normal realm of the mining companies, and clearly become the responsibility of the government agencies and other research organizations which have the consistency of policy and funding to carry them out, and the obligation to publish their findings. However, to be most effective, the groups charged with carrying out metallogenic studies must maintain close contact with the exploration industry, which is the crucible within which long experience, daily exposure to new data and the motivation of profit are fused to form new exploration concepts and techniques.

Two Success Stories

I would like to describe two successful exploration programs which represent ideal applications of predictive metallogeny to the search for ore. They are Amax's long campaign which culminated in the discovery of the Henderson, Crested Butte and other molybdenum deposits, and Texasgulf's Canadian Shield program which led to the discovery of the Kidd Creek orebody.

The Amax example, seen from the perspective of hindsight, was a classic exploration exercise. The description which follows is very general and is derived from my own experience as a brief participant in the program some twenty years ago.

At some time in the mid-fifties, the American Metal Climax Company, then, as now, the world's predominant producer of molybdenum, decided that the market outlook for their product required a major effort to locate new reserves for future exploitation. A team of experienced geologists was charged with compiling data on all known molybdenum deposits. From this compilation arose several important conclusions. One of these conclusions was that only the Climax-type molybdenum deposit was worth looking for. This conclusion eliminated the pegmatite, skarn and other deposit types from consideration, and enabled the company to focus its attention in one direction.

From careful study of deposits of the Climax type, a set of parameters was derived, including the following:

1. the gross tectonic-petrologic environment of the desired deposits
2. the age and composition of the associated plutons
3. the specific localizing structural environment
4. the nature of the alteration imposed upon the host rocks

In today's parlance, they developed a "conceptual model", although that term was not in use at the time.

Armed with the model, amply funded and backed up by corporate persistence, Amax geologists pursued their objective from Alaska to southern Chile, with a side trip to Greenland. In the course of the program the original exploration parameters were modified and new exploration techniques were developed, particularly in geochemistry. Over the years, geologists came and went, thus gradually spreading the newly developed technology throughout the industry.

When success finally came, it was in Amax's own backyard, the Colorado Mineral belt. Roughly ten years had passed since the inception of the program before the first significant drill intersection was obtained from the Henderson orebody, and a further ten years passed before Crested Butte was found. These two magnificent discoveries, each with immense reserves of high-grade ore, are a fitting reward for the high-risk, long-term investment of corporate resources.

My second example also was stimulated by a corporate policy. Prior to 1950, Texasgulf had been essentially a sulphur company, with little activity outside the gulf coast of the United States. Early attempts to diversify were largely sporadic and poorly funded. They did, however, lead to the accumulation of a body of imaginative people, as well as data and experience concerning massive sulphide deposits. From these ingredients, a concept arose concerning the genetic and spatial relationships between rhyolitic volcanic rocks and the concordant, base metal-bearing massive sulphide deposits. In 1957, the decision was made to apply this concept to that part of the Canadian Precambrian Shield which lies between Chibougamau and Flin Flon. The implementation of the project was facilitated by two events: one was a strong corporate drive towards diversification, the other was the recent development of the airborne electromagnetic method. The first factor ensured the support of head office and adequate funding; the second provided a rapid and effective means of evaluating the large number of prospective environments identified by geological compilation and field work.

In November of 1963 the program culminated in the discovery of the Kidd Creek orebody north of Timmins, Ontario.

These two successful exploration programs or, more specifically, the proposals which were put forward at the start of each program, were exercises in predictive metallogeny. In each case all available data were compiled before field work was undertaken, a conceptual model was developed and selected areas were investigated in the field to identify prospective environments. Some other important features of the process were as follows:

1. In developing a conceptual model to guide the search, full advantage was taken of the backlog of experience and data available because of the sponsoring company's earlier involvement in mining and exploration.
2. From the outset, an economic model was also in place, in that the target was an orebody, which must be mineable under a specific set of parameters which prevailed at a given time for an individual company.
3. The studies which led to the programs were *qualitative*, rather than *quantitative*. The sponsoring companies and their staff who developed the programs knew better than to try to quantify the expected results.
4. The geographic scope of the projects was dictated by geology alone, not by any political boundaries.
5. The participants understood the risk involved in their investment; they knew that there was no assurance of success, and they had the resources to carry the programs to completion.

It is instructive to compare the foregoing characteristics of the two successful company exploration programs with the characteristics of many of the exercises in predictive metallogeny carried out by government or academic organizations in recent years.

1. *Motivation*. Most predictive metallogeny exercises, or resource appraisals, are carried out at the instigation of political or economic planners, who have little understanding of the capabilities or the limitations of economic geology.
2. *Staff*. The individuals who do the work, although they may be skilled scientists, commonly have little background in the applied aspects of geology.
3. *Data base*. Many evaluations are based on published geological maps which have been made by geologists who are relatively uninterested in mineral deposits and who are not trained to recognize the peripheral indications of hidden mineral deposits. In most Canadian provinces, the compilers of metallogenic maps commonly pay little attention to the assessment files with their wealth of data of economic mineral occurrences.
4. *Misuse of data*. Many attempts are made to produce quantitative data, usually on the basis of questionable statistical assumptions, or the equally dubious concensus of a group of "experts" on the region involved or the deposit type sought. The "quantitative" data from such studies, taken out of context and used by economic planners or "simplified" by the media, can be very misleading. Bad economic planning and misuse of public funds can result from the improper use of so-called quantitative resource appraisals.

Conclusions

The past 20 years has been a period of growth in the use of various forms of predictive natural resource assessment in North America. Controversy has surrounded many of the applications of the technique, usually being sparked by violent differences of opinion between private industry and the agencies responsible for the studies. An example which caused public consternation was the Club of Rome's ridiculous misinterpretation of geological data to derive a doom and gloom scenario for the world's near-term supply of metals. Another instance, which should have revealed to all the weakness of our predictive skills, is the continuing controversy over the extent of hydrocarbon resources. Still another massive difference of opinion arose in the United States about a year ago, when very negative federal government findings on domestic phosphate rock resources were totally rejected by spokesmen for the mining industry. The federal study had assumed that consumption would accelerate, but that there would be no technological advances to permit the increasing of reserves by material not mineable at present. No justification was given for the obviously false assumption that exploration, mining and processing technology, which have improved fairly steadily over the past twenty or thirty years, would suddenly become stagnant.

The fundamental conflict between the academic approach to predictive metallogeny and that of the exploration geologist is displayed dramatically in a brief but spirited exchange of Letters to the Editor generated by DeVerle P. Harris' paper entitled *A subjective probability appraisal of metal endowment of Northern Sonora, Mexico* (1973). To attempt here a summary of the paper and the discussion it provoked is not feasible. Suffice it to say that the author's work "yielded an expectation of approximately 2600 tons of metal per square mile" in this study area, and led him to estimate that roughly one-quarter of this could be found and mined profitably under the economic conditions of the time. The paper was written in 1973; in hindsight, one wonders what part of the expected metal would have been mineable three years later, in 1976, under the drastically different economic conditions that prevailed then. Not surprisingly, Sobel, an experienced economic geologist with a fair amount of field time in Sonora, vigorously and not too politely disputed both Harris' methods and his findings. He offered his own conclusion as to how the study could be summed up: "Ten experienced geologists feel that a good chance exists to find new mineral deposits in Sonora; the choice sites to explore are close to known deposits." The correspondence ends with the author's reply to the criticism, in which he defends his position with the interesting statement "it matters not that the task is a dirty one, that the phenomenon of mineral occurrence is not completely understood, or that information is often too meagre to give high or even moderate reliability to estimates. Mineral resources appraisals often must be made in spite of these obstacles". Accepting that there is a general and increasing need for mineral resource appraisals is not difficult; accepting that they must be quantitative is more difficult, in view of the very problems expressed by Harris. The weaknesses in the basic data and assumptions used can be expressed properly when the communication is in the form of a scientific paper exchanged between consenting adult earth scientists. The problem arises when the quantitative conclusions are taken out of context by members of the communications media, politicians or bureaucrats, and unknowingly used in an improper manner. Such misuse, as noted earlier, can lead to unwise expenditure of public or private funds, unfair taxation and unrealistic mining laws.

To close on a more positive note, a few words about the various approaches to predictive metallogeny. The one which currently appeals most to me is the type presented in recent Geological Survey of Canada resource assessment studies for various parts of northern Canada. As described in a recent paper by Findlay and Sangster (delivered at the Annual Meeting, CIMM, Quebec City, 1982), the reports are subjective geological assessments that present areas or packages of rocks "in terms of their perceived potential to contain undiscovered mineral deposits". The ratings are essentially qualitative, and are derived by matching the geological characteristics of selected terrains with the diagnostic features of the conceptual models of various mineral deposits. The appraisals are documented abundantly so that the user can see clearly how the rating was determined. Findlay and Sangster note that the asessments are "broadly equivalent to the initial compilation stage of many exploration programs", which probably explains why they are so acceptable to me!

References

Findlay, D.C. and D.F. Sangster, 1982, Recent G.S.C. Resource Assessment Studies and Their Potential as Mineral Exploration Guides: preprint of paper presented at Annual Meeting of CIMM, Quebec City, May 1982.

Harris, DeVerle P., 1973, A subjective probability appraisal of metal endowment of Northern Sonora, Mexico: Economic Geology, v. 68, p. 222-242. See also p. 1344-1346 of same volume, including discussion by Harvey L. Sobel and author's reply.

Invited Discussions

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I will try to present the view of an exploration geologist about predictive metallogeny, what in the old days we used to call "having a nose for ore".

The panellists have outlined various methods: empirical, qualitative methods using subjective judgement with or without mathematical computations, quantitative methods with objective judgement. Predictions are done by a variety of people, ranging from those closest to the scene, i.e., field geologists, to exploration managers, pure scientists, mathematicians and even astrologers. Predictions are commonly based on an analysis of a control area and an effort to apply it to the area that is being assessed. By analyzing the total geological picture, ore deposit models and frequency distributions, one sets probabilities of occurrence in this and that area.

To me, predictive metallogeny has two major levels. When it is applied to a mature mining district that has a good data base obviously the events are more predictable and you have more confidence. It is like finding blueberries in a blueberry patch: you know you're in a patch and even can tell after some time what size, quality and shape the berries will have. The real rub comes when you go into an unknown area where there is a poor data base and events are less predictable. But this is where predictive metallogeny really has to reach, this is where it is most important to be able to answer the question, "are we in elephant country?". And the second level is the "exploration surprise factor". Quite often in the field when you least expect it you find yourself on candid camera. No one said there was going to be ore there, but by God it's there! Anyway, reviewing the past 30 years of Precambrian discoveries, I can think of 10 or 12 camps, Manitouwadge, Snow Lake, Thompson, Elliot Lake, Kidd Creek, Detour Lake, Athabasca Basin—I won't name them all—about which who cannot say that, despite all the data present at the time, they were surprised when these discoveries were made; and made by others!

Let's take Case 1, the uneven endowment factor. Timmins: a pre-1964 major gold district, over a quarter of Canadian Precambrian gold production, 50 years of history, 2 or 3 minor copper-zinc deposits. Now who in all honesty would have predicted to his exploration management that he needed certain funds because he knew there was going to be a world-class copper-zinc-silver deposit just 10 miles out of town? The Kidd Creek deposit in itself is equal to all the production of the the gold mines in the Timmins area.

This fantastic deposit is 25 times larger than the average Precambrian deposit. It is even three times larger than the largest known Precambrian deposit. Mathematically, you cannot predict an event like that because of its uneven endowment factor and you have no control over it. Now you can draw contours around it mathematically and as you move in closer to the bull's eye you come in second, because you'd have homed in on Kamkotia which is about 6 million tons. Eighteen years have passed since that discovery and nothing of any consequence in massive sulphides has been found there. Who will care to predict the next discovery— its size, grade and location?

Case number 2 exemplifies the surprise factor— geological surprise. The Athabasca basin, pre-1968, consisted in essence of the Beaverlodge deposit, a classic vein model type deposit with a 25-year history. Despite the uranium exploration going on around Uranium City, the unconformity model was developed, with Cluff Lake, Key Lake, etc. Unknown to the geologists or the mathematicians or anyone else, there happened to have been a change of ore deposit habitat. The ore locale changed. The ore was in the area but it wasn't in the veins anymore. So how can you predict that quantitatively?

From the viewpoint of exploration, I am inclined towards the use of a qualitative method, subjective approach and, to coin a phrase, "simple intuitive method", and to review areas in terms of their having or not having a tendency toward containing either a high, medium or low probability of discovery of the type you are looking for. When you are working in a mature district where there is abundant data you can afford the luxury of a semi-quantitative or perhaps even a quantitative approach. In a very restricted area, where perhaps 20 discoveries have been made over 30-50 years, and the geometry, the ore deposit size, shape and grade and the frequency distribution are known, then you can perhaps afford the luxury of calculating to one decimal place, but I wouldn't go beyond that.

Also, I am inclined toward using predictions expressed in relative terms and not necessarily in absolute terms. That is where the trouble begins, when you become absolute.

In closing, I believe that predictive metallogeny is really an art and not necessarily a science. The artistic aspect is that of predicting with reasonale accuracy from minimum data and in minimum time. And to quote Niels Bohr, "Prediction is a very difficult business, gentlemen, especially when dealing with the future".