Geophysical developments and mine discoveries in the 20th century

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In 1999, Colin Barnett reviewed the progress of geophysical developments in the 20th century. Undeniably, major advances have taken place and are still taking place in parameters measured, accuracy, speed and data volume, display, and analytical software. This leads to the question: "How has all this progress affected the rate and efficiency of discovering ore deposits?"

This subject has been addressed by others. Bob Horn, in a provocative paper in Pathways '98, concluded that although luck has contributed to the discovery of many of the world's important deposits, technology has indeed resulted in greater exploration success and efficiency. After examining the development of geophysical methods over the century, I also conclude that technology has impacted significantly on the pace of mine discoveries. But it is also apparent that the cost of discovering a new mine has increased almost 10-fold since 1975, in spite of improvements in technology. This paper shall attempt to explain, in part, why the rate of mine discoveries has fallen steadily over the past 20 years while exploration activity remains at record levels.

Geophysical advances and exploration success. The progression of geophysical developments in the 20th century, as graphically (and subjectively) portrayed in Figure 1, illustrates a shift from new and better methods to an improved use of the data they generate. According to this overview, *data analysis, modeling, and integration* are the only areas of significant development since 1985, and these have slowed in the past five years. It is my view that geologic input is needed at this stage to focus and exploit these three important fields of study. Most geophysicists agree that we are now collecting data faster (and with greater accuracy) than we can properly absorb it.

Figure 2 shows dollars spent on exploration annually in Canada, in five year increments, from 1950 to 1998. These numbers are based on information developed by National Resources Canada. Comparable figures are not available for the United States or for the world in general. Except where stated otherwise, these and all other dollar figures in this paper are in Canadian dollars, corrected to 1998 in accordance with the Statistics Canada CPI (consumer price index).

Comparing this graph with Figure 1, we see that exploration peaked shortly after geophysical methods and data processing technology reached their period of maximum development. We can conjecture that the need for new technology to assist exploration to some extent drove (financed?) the major developments of the 1950s, '60s, and early '70s. *Could the availability of new exploration methods have also stimulated exploration?* The drop in exploration after 1985 could be correlated with the relative decline in technology development.

Figure 3 is a histogram of worldwide ore deposit discoveries compiled from lists by Horn (1998), Derry (1970 and 1976), and other sources (e.g., personal communication with Ken Witherly). Comparing this chart with Figure 1, we see that discoveries made with the aid of geophysics mirror rather closely developments in geophysical methods.

Perhaps the best measure of exploration success is cost per mine discovery. To arrive at global expenditures, available numbers for worldwide exploration expenditures in the 1990s

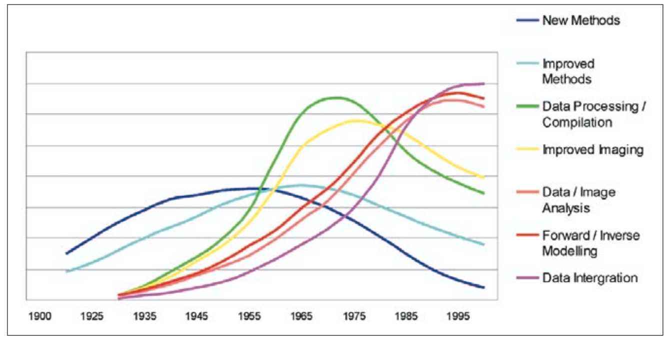

Figure 1. Rate of development of geophysical methods.

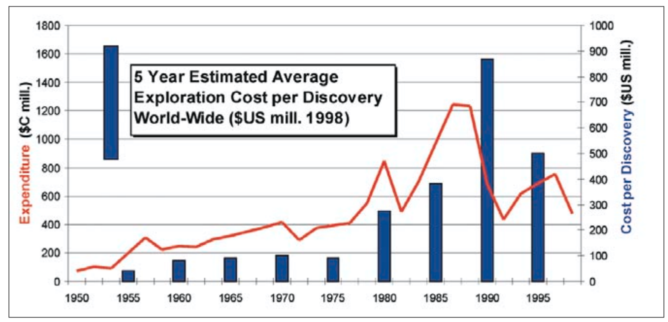

Figure 2. Two-year average annual expenditure on exploration in Canada.

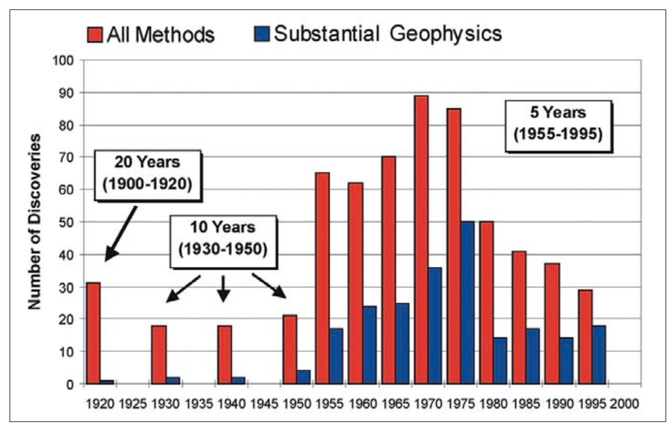

Figure 3. Number of worldwide mine discoveries.

by companies with budgets $4 million and over have been compared with expenditures in Canada over the same period. By extrapolation it is possible to imagine that worldwide exploration was roughly four and five times the Canadian level in 1950 and 1970, respectively. Using these figures, the exploration cost per discovery worldwide (total worldwide exploration divided by the number of mines discovered, in a five-year period) is found to increase (Figure 2) from $US 80 million in the 1950-1975 period to an average of $505 million since 1975. Figure 2 also demonstrates an unexpected correlation between the scale of exploration and the cost per discovery. It would seem that the more you spend the less bang you get for your buck. Finally, it may be significant that the years of highest cost per discovery are years when geophysics contributed the least (Figure 1).

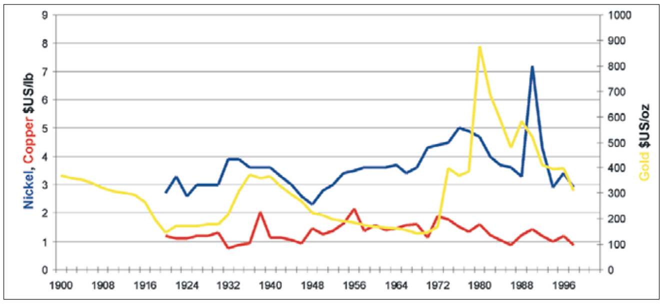

Figure 4. *Two-year average annual metal prices ($US 1998).*

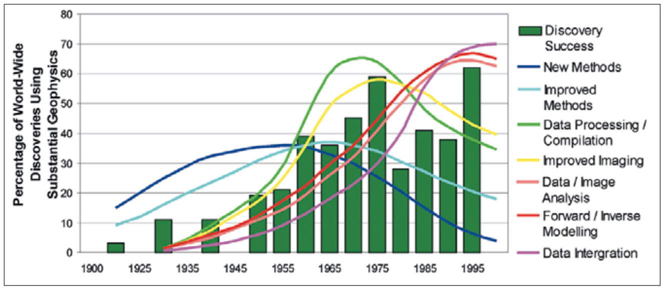

Figure 5. *Rate of development and discovery success for various geophysical methods.*

Impact of metal prices. Cranstone (1982) deals in depth with the difficulty of arriving at meaningful estimates of the cost of finding minable ore, chief of which is metal prices. Not only does the price affect the value of the ore found but, just as significantly, it affects the tonnage of minable reserves. And in some cases a small fluctuation in the price of the metal will create or eliminate a deposit. Metal prices are strongly affected by the demand for minerals, and are therefore closely linked to exploration level. Accordingly, at times of high metal prices one would expect a high level of exploration, accompanied by a corresponding increase in the discovery rate, both in terms of orebodies found and the value of the ore.

In an effort to unravel the true economic effect of new exploration technology, I have tracked (Figure 4) the price (in 1998 US dollars) of gold, nickel, and copper in the period 1920-1998 for which discovery statistics are available. However, in comparing these curves with Figure 1, we find little direct correlation between exploration activity and metal prices, except for the short period between 1980 and 1990 when gold exploration responded to soaring prices and the introduction of "flow-through" shares. The steady growth of activity and the peak in discovery rate in the period 1950-1975 actually saw a decline in the gold price and a relatively flat copper price (although nickel rose almost 50%). Furthermore, the assumption that an increase in prices would reduce the cost per discovery seems to have little, if any, validity. Cost per discovery, instead of dropping in response to better economics in 1980-1990, rose to almost 20 times the level of the pre-1975 period.

The conclusion is that the high rate of methodology development prior to 1975 had much more impact than metal prices on the high discovery rate and low discovery cost in those years.

New and improved methods. A review of methodology development and corresponding mine discovery rates (Figure 5) reveals some interesting facts:

1) Geophysical mine discoveries peaked in 1970-1975 at the same time that the most important improvements in methodology were taking place.
2) Discoveries in general and geophysical discoveries in particular jumped sharply after 1950, coinciding with the introduction of IP, airborne EM, spectrometry, and the proton precession magnetometer. In fact 152 of the 222 geophysical discoveries recorded in this century took place between 1950 and 1975.

There is no doubt that to a very large extent geophysical activity and corresponding discoveries took place in waves following the introduction of new methods. Discoveries in the 1920s and 1930s were mainly by electrical resistivity, gravity, ground magnetics and spontaneous polarization (SP), methods introduced during the same period. Following the appearance of the airborne magnetometer in 1945, a huge wave of aeromagnetic surveying led to discoveries of iron, asbestos, nickel, and rare earth metals in North America, Australia, South Africa, and the Soviet Union—e.g, Horn (1998) and deWet (1957).

The advent of airborne EM (AEM) in 1948-1950 led to the discovery of nine base-metal deposits before the decade was out. By 1975 airborne frequency domain and transient EM scored a total of 63 deposits, or 41% of the 152 deposits credited to geophysics between 1950 and 1975. The estimated average worldwide exploration cost per discovery in this period (Figure 3) was a mere $90 million in 1998 dollars.

Induced polarization (IP), also introduced in 1948-1950, heralded a worldwide search for porphyry coppers and other disseminated sulphide deposits that had so far resisted exploration by other methods.

Data processing, compilation, imaging. Referring again to Figure 5, note a very close correlation between peaks in the data processing, compilation, and imaging curves, and the success rate of geophysical methods. Huge strides were being made during 1965-1980 in the rapid, high-density acquisition and presentation of data.

Computers were taught to handle the entire process, resulting in almost real-time digital images of enormous resolution and sophistication. A 10-fold reduction in sampling time of many instruments, together with expansion of bandwidth, resulted in 100-fold and greater increases in data quantity, which allowed geophysicists to resolve weaker and more subtle anomalies.

But although the geophysical success rate may have benefited from these developments, the mine discovering rate dropped drastically (Figure 3) after 1975, and it was clear that advances in acquisition and data processing alone would not meet exploration needs in an ever more hostile geologic environment. Something new had to be done to deal with the backlog of overflowing data banks and underinterpreted images.

Interpretation—image analysis, inverse modeling, and integration. It is a fact that early textbooks devoted very little space to interpretation, emphasizing instead the theory and practice of data acquisition. Methodology was the theme of most geophysical papers and conference proceedings until the late 1950s. AEM surveys were conducted for a decade without the aid of quantitative interpretation tools. The need for quantitative analysis of the huge volume of aeromagnetic data collected in the 1940s and 1950s led to the development of graphical tools. In the late 1960s computer analysis was introduced. Grant and West's (1965) *Interpretation Theory in Applied Geophysics* was an important milestone, heralding a flood of developments in data analysis and forward modeling. As shown in Figure 1, this momentum has gathered steam throughout the 1970s and '80s, possibly peaking in the 1990s with the advent of fast, efficient methods of data inversion and source parameter mapping.

The most serious roadblock to the geophysicist remains the difficulty inherent in conceiving realistic geologic models upon which to base a data acquisition, processing, and interpretation strategy.

Many of us base our interpretation strategy on looking for geophysical aberrations—i.e., features in an image or profile that look unusual or do not seem to fit what we think the geology should look like. Here, we come to the most significant roadblock, and the one we must address most urgently if exploration is to be successful in the next century: *What does the environment of an orebody look like?*

It is my opinion that in the current drive to harness computing tools (e.g., expert systems) to develop our models and correlation, we have overlooked the power of the human brain and its almost fathomless memory banks. These are not easy to access. However, it is perfectly clear that human interaction is essential at all stages of data integration, regardless of how well the model appears to be defined. Maybe, human experience (instinct?) is the *luck factor* identified by Horn. If so, the challenge of the next century will be to work this powerful tool into the integration process.

Postscript. This paper was initially prepared in 1999 and contains statistics up to the year 1998. Subsequent years in the 20th century saw a continuing drop in mineral exploration activity, reaching a current (2002) level of 2400 million (year 2000 $US) worldwide and about $300 million in Canada. No information is readily available on mine discoveries, but I suspect that that number has also continued to drop. The relative success of geophysics is anyone's guess. Certainly geophysics is continuing to find kimberlite-hosted diamond deposits, and a number of massive nickel sulphide deposits have been located with on-time pulse EM systems. It is too early to say whether improvements in computer-based data integration and target recognition systems are paying off, since so little grassroots work is being carried out. If exploration continues to decline, the world will be out of metals before 2010. The relative success of geophysics will then be of academic interest only.

Suggested reading. "The geophysical curve of time, 1900-1999" by Barnett (presented at the Janus I SEG Symposium, 1999 GSA Annual Meeting). "An analysis of ore discovery cost and rates of ore discovery in Canada over the period 1948 to 1977" by Cranstone (1982 doctoral dissertation, Harvard). "Exploration expenditure, discovery rate and methods" by Derry (*Canadian Mining and Metallurgy Bulletin*, 1970. "The trend in mining exploration expenditures in Canada" by Derry (*Canadian Mining and Metallurgy Bulletin*, 1976). *Methods and Case Histories in Mining Geophysics* by de Wet (Mercury Press Company, Montreal, 1957). "Exploration success—luck or skill?" by Horn and Brisbois (in *Pathways '98, British Columbia and Yukon Chamber of Mines*, 1998). "Experimental and field data for the dual-frequency phase-shift method of airborne electromagnetic prospecting" by Paterson (GEOPHYSICS, 1961). "Statistical methods for interpreting aeromagnetic data" by Spector and Grant (GEOPHYSICS, 1970). TLE

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