CANADIAN MINING GEOPHYSICS — 1974*†

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ABSTRACT

Mining geophysics in Canada is currently suffering one of the low periods of its traditionally cyclic activity. In terms of constant dollars, current level of activity is about 1/3rd of the peak reached in 1968, and roughly equal to the previous low in 1963. Total mining exploration in Canada has followed a similar pattern. Canadian metal mining production however has continued to rise, and has a real value of approximately 2.5 times the 1963 production. It is estimated that at the current rate of mine discovery, Canada is producing between 3 and 5 times as much as it is finding.

With the exception of Australia, overseas activity continues to increase, though Canadian firms are receiving a decreasing proportion of the market for instruments and services.

The current recession, with its unfortunate effects on the mining geophysics profession, is blamed chiefly on recent government policy with respect to the Canadian mining industry. Unrealistic taxation has removed the incentive for capital expenditure, particularly on exploration. Increasing government interference in areas such as foreign ownership, export and processing controls, etc., has further dampened investor and mining company interest.

Canada has a unique position in the world in mining geophysics, standing first in terms of instrumentation, methods, and services. Most of this record stems from the private sector which, despite its technical successes, has a poor record of job security and business profitability.

The hope is expressed that with the shift from the private to the public sector that is taking place in Canada, adequate incentives will be found to maintain an interest in exploration and a desire to continue the development of geophysical instrumentation and techniques.

INTRODUCTION

In February, 1961, a conference was held in Calgary, sponsored by C.S.E.G. and three other local sections of S.E.G. The topic of the conference was Exploration Geophysics — Today and Tomorrow. I was given the responsibility of looking at the mining industry, examining its health, and forecasting its prospects. In reading over the text of that paper I find that I am a better geophysicist than a fortune teller. My diagnosis was not far off the mark, and if the treatment I prescribed had been followed the forecast might have worked out better. But I took an unrealistic view of the role that government would play in the following years.

Some of you will remember that in 1961 we were in a period of low activity in mining geophysics, following an unprecedented boom in the late 1950's. Annual expenditure in Canada was down to $2½ million from a peak of almost $4 million 5 years earlier.

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N.B. Figures 4 to 10 inclusive are photographs of geophysical equipment and were not available for publication.

The smaller exploration companies were being squeezed out by new controls on stock promotions. The government was taking a bigger and bigger piece of company profits and wages were increasing faster than metal prices. Sounds familiar doesn't it?

Despite the problems one *had* to be optimistic in 1961 because there were many things going for us:

1. We had the best developed mining geophysical technology in the world.

2. Geophysics had discovered mineable orebodies in the preceeding 5 years at a cost of less than $1 million per mine.

3. Discovery rate by all methods in Canada was only a small fraction of production, leading to inevitable metal shortages if the trend were to continue.

4. Important new geophysical methods were being developed that could significantly increase the discovery rate if properly applied.

It is thirteen years since that conference and we find ourselves in an almost identical situation. We in Canada are suffering from the biggest mining exploration depression in history. The small exploration companies are not being threatened now — they are virtually extinct. Governments, both provincial and federal, have settled on policies of public ownership (meaning control without incentive or experience, earnings without risk, expenditure without accountability). Foreign owned resource companies are being discouraged on the shaky premise (presumably) that the revenue and employment accruing from their activities are less useful than those derived from similar Canadian-owned operations. Incentives for investment have been almost totally removed, environmental controls have been instituted out of all proportion to the dangers that exist, and labour has been encouraged to believe that unemployment is an acceptable alternative to hard work. These and other pressures have served to reduce expenditure in mining geophysics to a level (in 1961 dollars) comparable to that prevailing 13 years ago, despite an annual production rate that is almost *six times as large.*

For the remainder of this paper, I am going to look at some of the factors that have led to the current situation. I will list the main things we have going for us and try to anticipate future developments, both technical and economic. As far as the political scene is concerned I draw no conclusions but fear the worst. As Hillaire Belloc put it:

Here richly, with ridiculous display,

The Politician's corpse was laid away.

While all of his acquaintance sneered and slanged,

I wept; for I had longed to see him hanged.

HISTORY

A brief history of mining geophysics in Canada follows:

Before 1950: We experienced the first stirrings of modern mining geophysics. Early pioneers in Canada including Thomas Edison, Lachlan Gilchrist and Hans Lundberg; and later, Arthur Brant, Tuzo Wilson, Norm Keevil, Stan Davidson and Sherwin Kelly. Emphasis was on magnetic, self-potential and resistivity techniques.

1950-1959: Major developments started in 1950 with activity by McPhar and INCO, and culminated in fifteen discoveries by mining geophysics in the years 1955-1959. Canada produced well-known personalities such as Seigel, Grant, Morley, Collett, Wait, Ward, West, Becker, Faessler, Wagg, Hutchison, Smellie, McLachlan, Robinson, Cartier, Clarke, Salt, Mousuf, Reford, Baldwin, Ruddock, Strangway, Hood, Barringer, and many others.

The decade was notable for developments in ground and airborne EM, which methods accounted for most of the mine discoveries.

1960-Present: EM developments, a peculiarly Canadian field, continued, and methods proliferated. Discoveries continued but at a lower rate. Costs escalated but economic pressure on the industry kept prices down. Many contracting companies went under; others merged or were bought out. Induced polarization achieved its first suc-

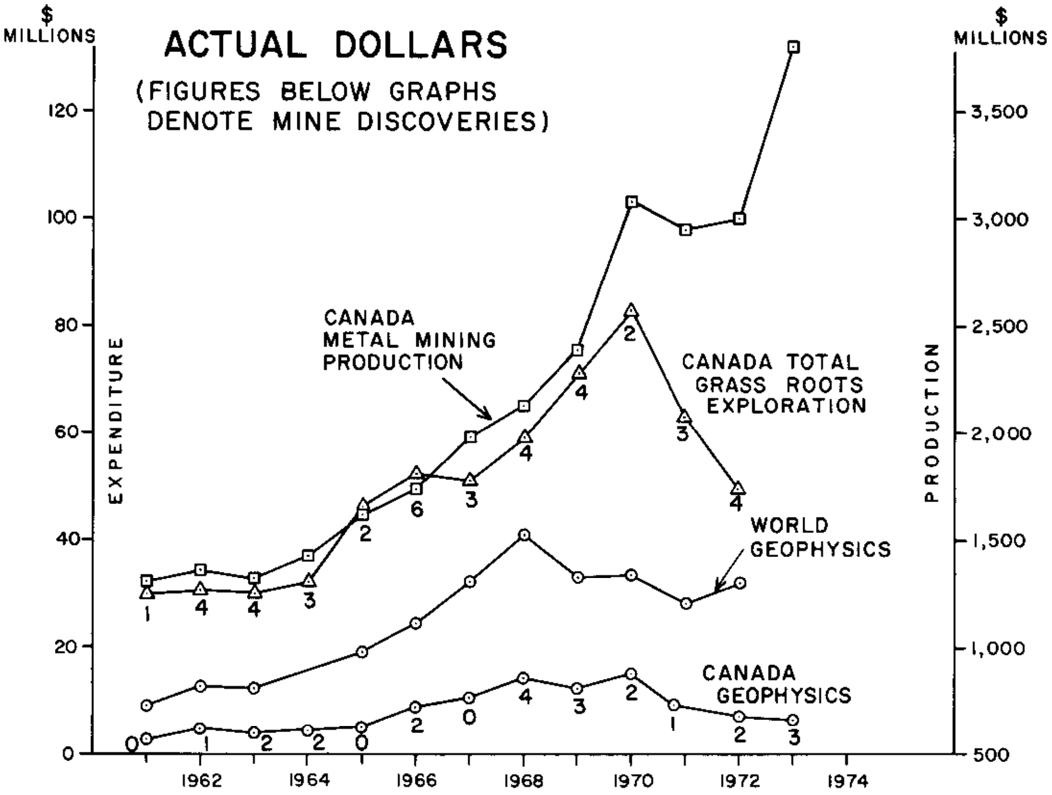


Fig. 1.

cesses at Pine Point and in the Highland Valley. By 1969 IP accounted for one-third of all ground geophysical expenditure in Canada.

Figures 1 and 2 show the level of industry activity in Canada and worldwide in the years 1961 to 1973, compared with Canadian metallic mineral production. Figures are shown in actual dollars (Fig. 1) and constant, 1961, dollars (Fig. 2).

With the exception of the period since 1970, total mineral exploration is seen to be keeping pace with production, at an average annual growth rate of about 15% in actual dollars, 11.5% in 1961 dollars. Discovery rate, however, has remained relatively constant, with geophysics accounting for an increasing proportion of new mines. Mine discoveries are indicated but unfortunately we have no accurate information on the value. It would appear however that the average value of ore discovered annually in the period 1967-1971, at today's metal prices, is somewhere in the vicinity of $300 to $500 million. This compares with an annual production rate of between five and ten times that figure.

Despite the increasing gap between discovery and production, and despite the ever improving success rate by geophysical methods, it is evident that geophysical expenditure has not kept pace with either production or money spent on other methods. In fact, in 1961 dollars, we are precisely where we were 13 years ago in terms of geophysical activity. The same is true, but to a much lesser extent, for worldwide geophysics, the Canadian and Australian contributions being largely to blame for the reduction in level.

It is quite apparent that the last three years have been difficult ones for the Canadian exploration industry as a whole, and mining geophysics in particular. Before examining the causes and effects, let us look

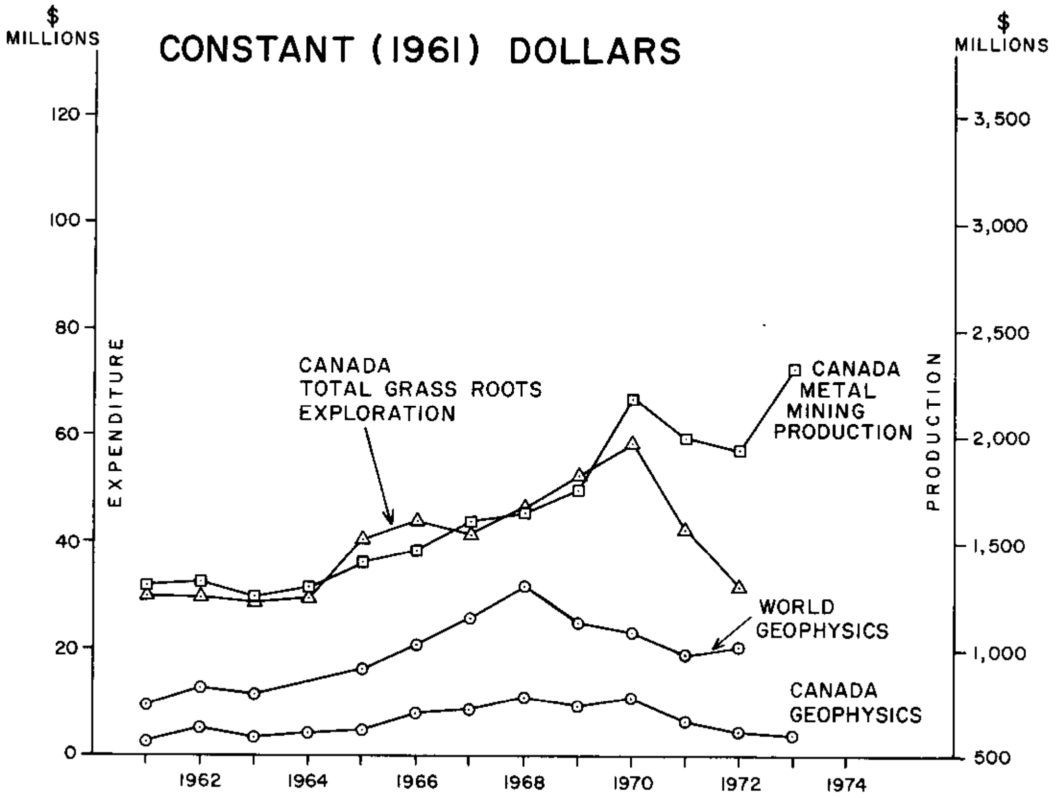


Fig. 2.

at a few facts about mining geophysics in Canada.

Facts about Mining Geophysics in Canada

1. *Research*

According to a review recently carried out by Dr. Harold Seigel, President of Scintrex Limited, between $1.5 and $2 million is spent annually on research and development by the Canadian mining geophysical industry. For an industry that earns a gross of about $18 million, including instruments and foreign contracts, this is an incredibly high figure, and probably unequalled by any other industry in the world. It is all the more remarkable when one considers that with few if any exceptions the companies doing the research have been losing money heavily in recent years.

Considering however that geophysical methods have been responsible for at least $150 to $250 million worth of new ore per year in Canada, a research expenditure of only 1% of that amount is quite modest.

Government funding of industrial research has helped greatly in recent years. Without this support it is doubtful whether Canadian firms could have survived the last few years without a major sacrifice of technological progress.

By way of comparison, the government also spent $2 million in 1973 to assist Indian and Eskimo people to "conduct research into land claims and treaty rights".

2. *Innovation*

The level of innovation in mining geophysics is extremely high. With few exceptions (fluxgate magnetometers for example), instruments are obsolete within two to three years after market introduction. It is quite common for equipment in use on a project to be of a type that was not even invented five years previously. Whereas in the 1950's and early 1960's it was usual for geophysicists to design their own equipment, this role is now commonly assumed by electronic design engineers working to geophysical specifications. This has led to a much higher level of equipment performance and reliability, and most current instruments may be truthfully referred to as "state of the art".

3. *Foreign Business*

Dr. Seigel (Fig. 3) estimates that in 1973 Canadian mining geophysical firms carried out roughly equal amounts of airborne geophysics in Canada and abroad (about $5 million), but that in ground geophysics, the overseas volume was almost twice as great as the domestic ($2.1 vs $1.2 million). Exports of geophysical instruments were 50% greater than domestic sales. Altogether 53% of the $18 million Canadian mining geophysics business was outside Canada. This is an extraordinarily high figure as compared with most service or manufacturing businesses.

4. *Employment*

It is estimated that at the present time, there are roughly 210 geophysicists permanently employed in mining exploration in Canada. This is an increase of approximately 150% over 1961, and implies a current level of expenditure in Canada of only $30,000 per geophysicist. When one considers that this figure includes not only salaries of geophysicists but wages for field technicians and helpers, draftsmen and other office workers, field expenses, depreciation and maintenance of field equipment, airborne survey costs including aircraft and fuel (375,000 line mi. total in 1972), and all associated office rents and overheads, one can readily appreciate that geophysicists are not paid very well. To the best of my knowledge there has never been a survey of geophysical salaries, but I would guess that in Canada the average mining geophysicist is 35 years old, has 1.5 university degrees (or an average of five years at university), spends 30% of his time away from home, gets 3 weeks' annual vacation (always in the winter) and earns between $14,000 and $16,000 a year. He has had 1.5 marriages; he can order beer in 4 languages and his life expectancy is about 65 yrs. I have never known a retired mining geophysicist.

The majority of mining geophysicists have little job security and poor prospects for advancement.

By contrast, the average engineer of the same age and experience in government service earns $17,000 - $19,000, has unlimited job security, far better working conditions and liberal fringe benefits.

ESTIMATED 1973 BUSINESS BY CANADIAN

MINING GEOPHYSICAL COMPANIES

	Domestic	Foreign	Total
Aerial Survey	5.4 (30.0%)	4.8 (27.0%)	10.2 (57%)
Ground Survey	1.2 (6.7%)	2.1 (11.7%)	3.3 (18%)
Instrument Sales & Rentals	1.9 (10.6%)	2.6 (14.5%)	4.5 (25%)
TOTALS	8.1 (47.0%)	9.5 (53.0%)	18.0 (100%)

After H.O. Seigel - Feb. 1974

Fig. 3.

5. *Share of the Market*

Despite the negative factors (or maybe because of them) Canada still enjoys a pre-eminent position in world mining geophysics. Dr. Seigel estimates that in 1973 Canadian firms carried out 40% of the world airborne survey work and 26% of the ground survey work. They probably supply at least 75% of the world's mining geophysical instruments, excluding the Soviet Union. Quite a record for a nation of only 20 million people. Mining geophysics may well be the only industry in which Canada dominates the world market.

RECENT TECHNICAL DEVELOPMENTS AND TRENDS

Equipment Miniaturization and Reliability

Significant improvement has been made in the last 13 years towards the miniaturization of both airborne and ground equipment, accompanied by greatly improved reliability. This has come about, as stated earlier, largely as a result of a shift towards use of professional electronic design engineers under geophysical direction. Previously, geophysicists frequently did the design themselves and too often had to accompany the equipment in the field in order to keep it working. Space age electronic developments have, of course, made an important contribution.

With miniaturization and improved reliability have come changes in operating style and procedure. There is less need now for skilled electronic technicians in the field. Instruments tend to be of modular construction and operators are equipped with spare modules. There is an increasing tendency towards redundancy in field equipment as the cost of this is generally less than the cost of delays due to breakdowns.

Examples of typical, modern ground instrumentation are shown in Figures 4, 5 and 6. The Geonics VLF-EM system in Figure 4 is not new but it is a good example of the trend towards smaller, more mobile and more rugged equipment. Figure 5 illustrates the Barringer GM 122, one of the new family of 1 gamma proton precession magnetometers. The cost of these is now comparable to that of the older, fluxgate instruments and they have important advantages for many applications. Figure 6 shows the Exploranium GRS400, a hand-held gamma ray spectrometer. This unit is capable of performing a versatile role that would have required instrumentation many times as large only five years ago; and a role that could not have been performed by any equipment 13 years ago.

Airborne EM

Whereas the most popular airborne systems today are improved versions of ones that were flying in the early 1960's, there have been quite recent improvements that have significantly affected their performance. Chief of these is increased bandwidth. The towed bird quadrature systems operating in 1961 employed only two frequencies. The new 3-frequency McPhar F-500 system (Figure 7), based on the same principle, covers a bandwidth from 340 to 3,450 Hz. Two additional frequencies are to be added soon. The Scintrex Tridem system (Figure 8), based on the earlier Rio-Mullard wingtip design, operates at three frequencies in the bandwidth 500 to 8,000 Hz. The Mark VI INPUT system, by improved signal processing, has increased the sampling period of the transient voltage, which is equivalent to increasing its bandwidth. Barringer now operates multi-mode AEM equipment from a helicopter that effectively covers the range from 900 Hz. to more than 1 MHz.

Increasing bandwidth increases the aperture within which conductors can be detected; by adding frequencies, one also improves the potential for better interpretability.

Another important improvement in airborne EM has been in the area of signal to noise ratio. In most modern systems the noise level has been decreased by a factor of at least 4 to 5, without loss of resolution. In fact, the time constant has also been reduced in some cases.

Multi-Parameter Sensing and Digital Recording

In 1961 I reported a trend toward the use of a combination of techniques in both airborne and ground exploration. This has continued, particularly since the advent of portable digital acquisition systems. It is common now for airborne systems, even in aircraft as small as a Britten-Norman Islander, or a helicopter, to record simultaneously magnetic, EM and radiometric data, together with altimeter, camera and intervalometer. Figure 9 illustrates such a system installed in an Islander by Barringer Research Limited for Canadian operations. Included are, from top to bottom, a magnetometer, chart recorder, VLF E-phase and Radio phase, LF and Broadcast Band EM channels, and magnetic tape recorder — a total of about 30 channels of information.

Figure 10 shows a Barringer-equipped Alouette II helicopter with magnetometer, electrical and magnetic component VLF sensors, a broadcast band EM sensor, Exploranium gamma ray spectrometer and a variety of ancillary gear.

Processing of such a wide variety of information would not be practical without real time digital recording although analog recording of at least the main channels is still important for monitoring and preliminary interpretation purposes. The importance of multi-parameter sensing stems from the fact that it is seldom possible to recognize a mineral deposit from its signature in one parameter only. Used in combination it is possible to assign priorities to targets on a logical basis. A recent development which will further increase the power of multi-parameter sensing is airborne bio-geochemistry. The Barringer Airtrace system senses and records continuously a variety of metallic and other elements that are believed to concentrate in the atmosphere in the form of minute particles, largely by a process of transpiration from surface vegetation. Whatever the mechanism, it seems possible that one may be able to recognize mineral deposits by relative concentration of these elementary particles. The method would be even more effective when used in conjunction with magnetic, EM and other geophysical techniques.

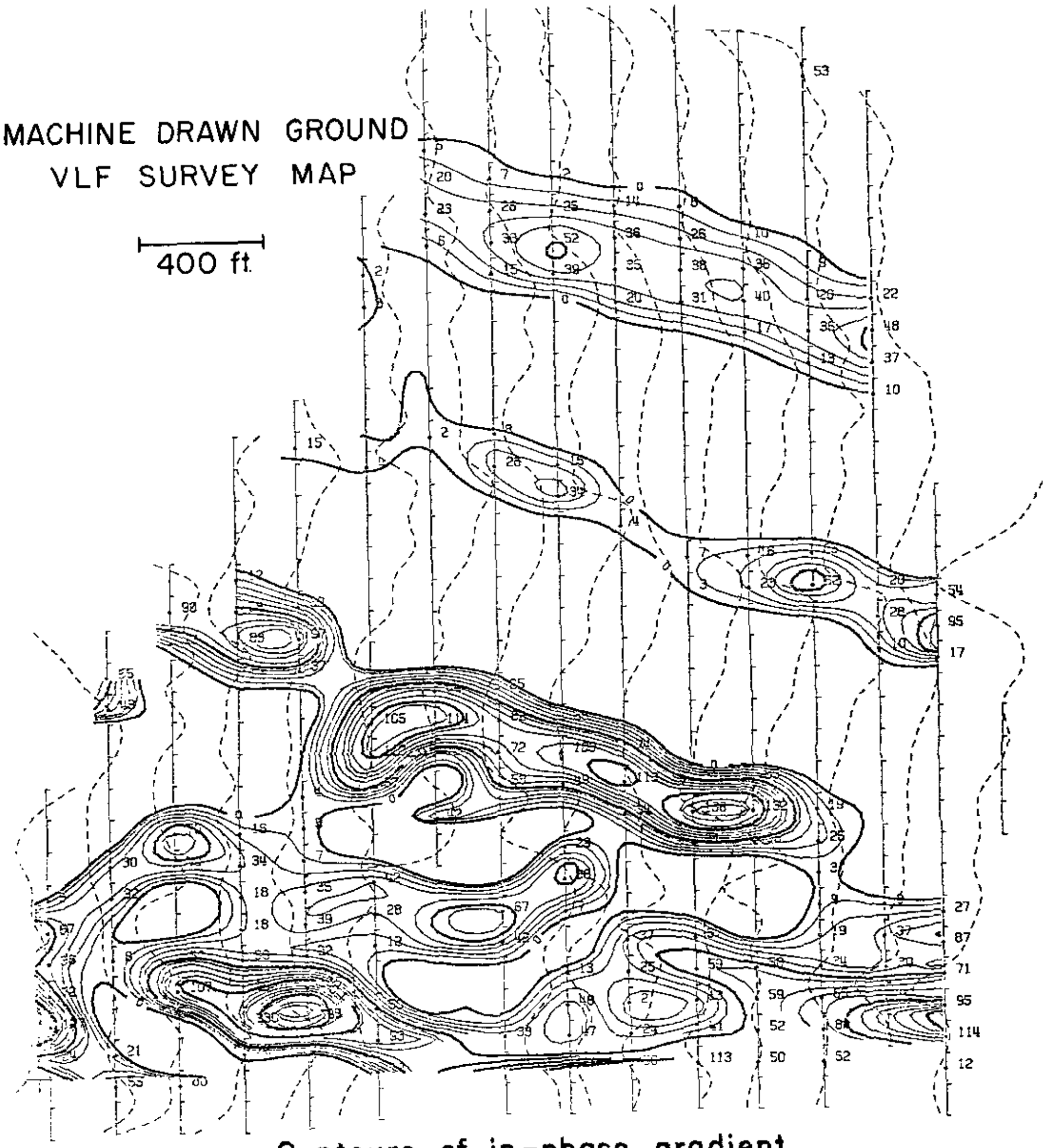
Computer Processing and Machine Plotting

Major advances have been made in the computer processing and machine plotting of both airborne and ground geophysical data. Cost and therefore popularity of these methods increased sharply with the advent of real time digital acquisition equipment, removing the necessity for laborious and costly manual digitization. I would guess that almost 50% of airborne geophysical survey data is now collected digitally and processed by computer. Machine contouring accounts for a still higher percentage. Manual steps are still necessary, particularly in the recovery and analysis of aircraft position.

Ground geophysical data are processed manually in most cases unless some form of analytical computation is required. We have found that manual procedures are still less expensive than mechanical for routine plotting and contouring. Where filtering, gradient calculation or some other process is desirable, this can sometimes be done cheaper by computer, followed by machine plotting and contouring. An example of a computer/machine plotter VLF-EM survey map is shown in Figure 11. The cost of preparing such a map from raw field data is in the range $10 to $15 per line mile.

Computer-Assisted Interpretation Methods

Significant improvements have been made in the use of computers for interpreting gravity, magnetic, electrical and I.P. data. In addition to working our libraries of type curves for all these methods and developing interpretation aids such as nomograms and phasor diagrams, important progress has been made in inversion techniques. By this process the computer defines a physical model that best fits the observed geophysical data, rather than generating theoretical anomalies which have to be matched and adjusted by a process of trial and error. The method has been used effectively for resistivity, EM and gravity. A form of inversion referred to as magnetic susceptibility mapping has recently been developed by Paterson, Grant & Watson Limited and is illustrated in Figures 12 to 15. Figure 12 shows a published aeromagnetic map in the Sturgeon Lake area of Northern Ontario. The magnetic data, digitized and gridded at an appropriate interval (in this case 1/8 mile), is used to calculate the susceptibility of an equal number of vertical prisms (Figure 13) whose upper edges form the ground surface. The susceptibilities are contoured to produce a magnetic susceptibility



Contours of in-phase gradient.
Profiles of quadrature response.

Fig. 11.

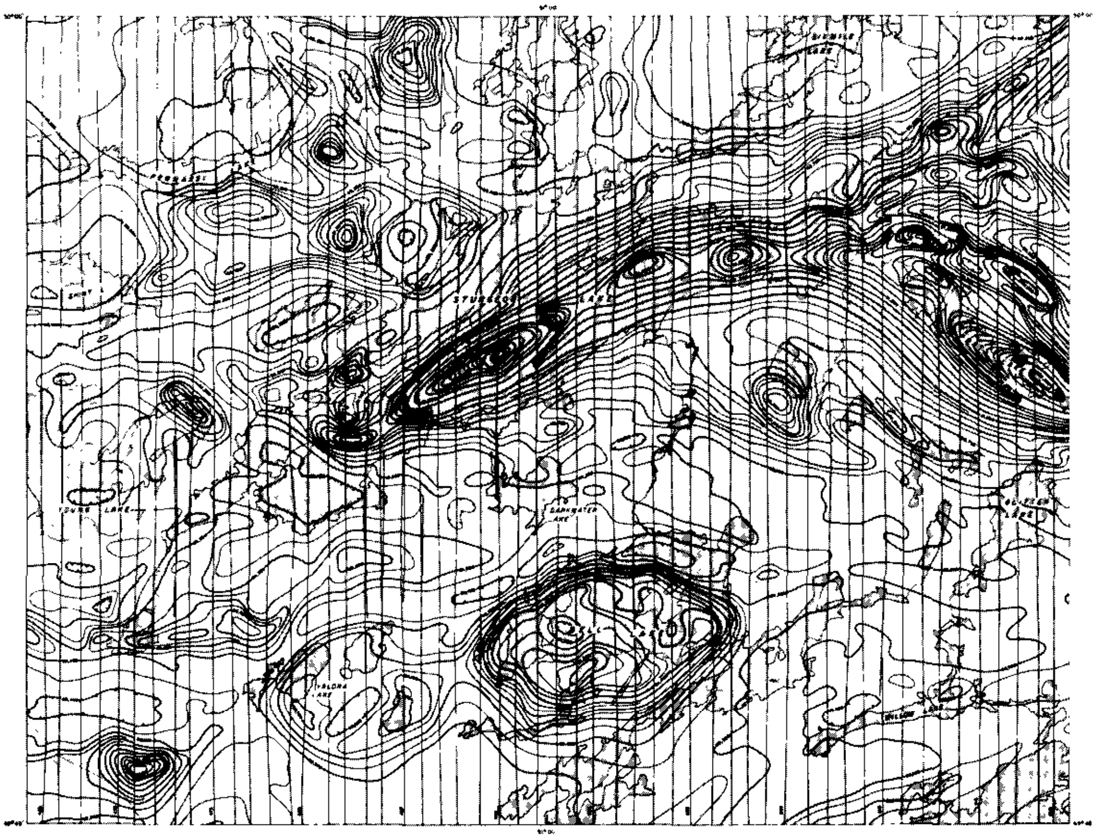


Fig. 12.

map as seen in Figure 14. Areas of equal susceptibilty are then zoned mechanically and correlated with available geological data to produce an interpretation map, as shown in Figure 15. The process is quite different from filtering in that the end product is a physical property map of the ground rather than an anomaly map which is dependent on source size and configuration, aircraft height, magnetic latitude and other variables. Unfortunately for magnetics, lithologic classifications are based primarily on silica rather than magnetite content. In very few cases is the zoned susceptibility map directly interpretable in terms of lithology. However, we are finding increasingly that the magnetic zoning reveals secondary phenomena associated with alteration and metamorphism that interpreted in conjunction with the known geology can be even more important from an exploration point of view. What one looks for in this case are magnetic zones that fail to conform with the simple geological model. One such zone is quite evident in Figures 14 and 15, and is believed to represent a zone of intense alteration that may be related to the four copper-zinc orebodies located along it.

Studies on the EM Effects of Finite Host Rock and Overburden Conductivity

Traditionally, interpretation of airborne and ground EM data has been based on the assumption of a free space condition, i.e., the host rock and overburden have zero

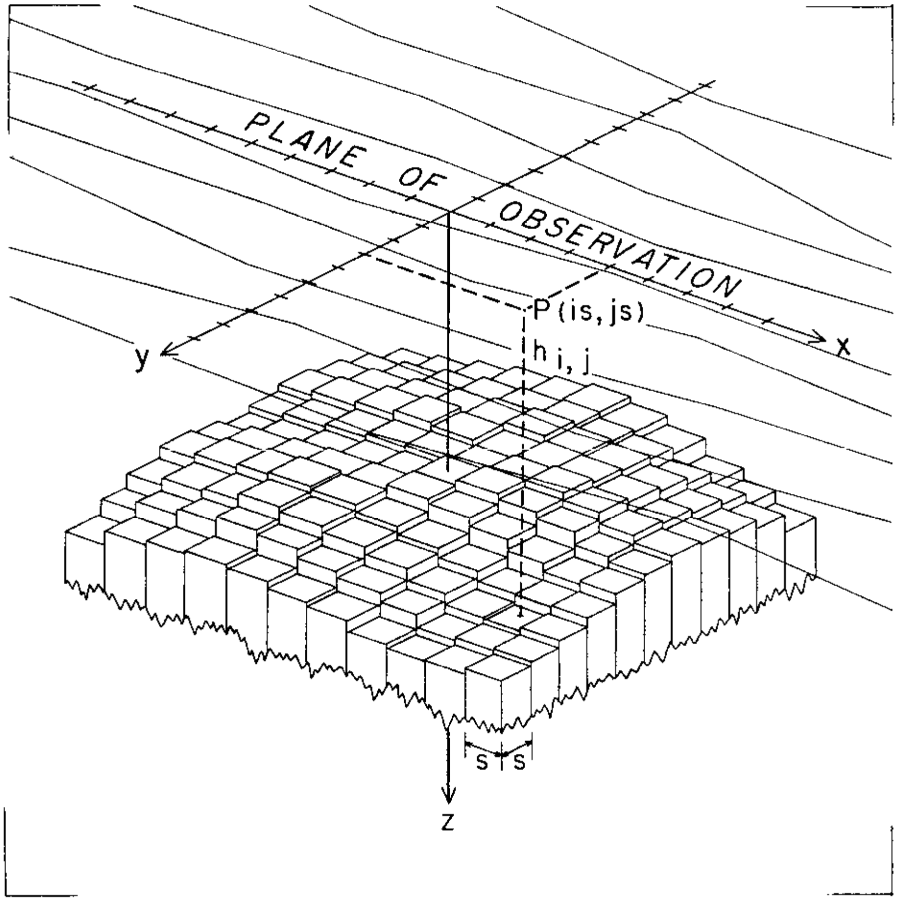


Fig. 13.

conductivity. This approximation has worked well in certain parts of the Canadian Shield but its shortcomings have been observed increasingly in areas of younger rock and/or heavy overburden. Studies at the University of Toronto and at several centres in India have been aimed at determining the effects of changes in host rock and overburden conductivity. The effects are complex and different for each EM system, but progress has been sufficient to permit us to make a qualitative compensation in some cases. Figure 16 is the result of recent studies in India for a horizontal loop system over a dipping sheet conductor. The EM response is seen to increase rapidly as the host rock conductivity increases. The quadrature component is the one most strongly effected.

Economic and Political Factors

It is evident from the facts we have listed about the mining geophysical industry that to support the level of innovation necessary on so small a sales volume, high profit margins and long term stability are required. Unfortunately, because of the violent cycles in exploration activity, neither of these conditions exist. With the exception of a short period around 1968 to 1970, the Canadian Mining geophysics industry has been in a condition of serious oversupply. This has caused a downward pressure on prices, and losses have inevitably occurred. The record

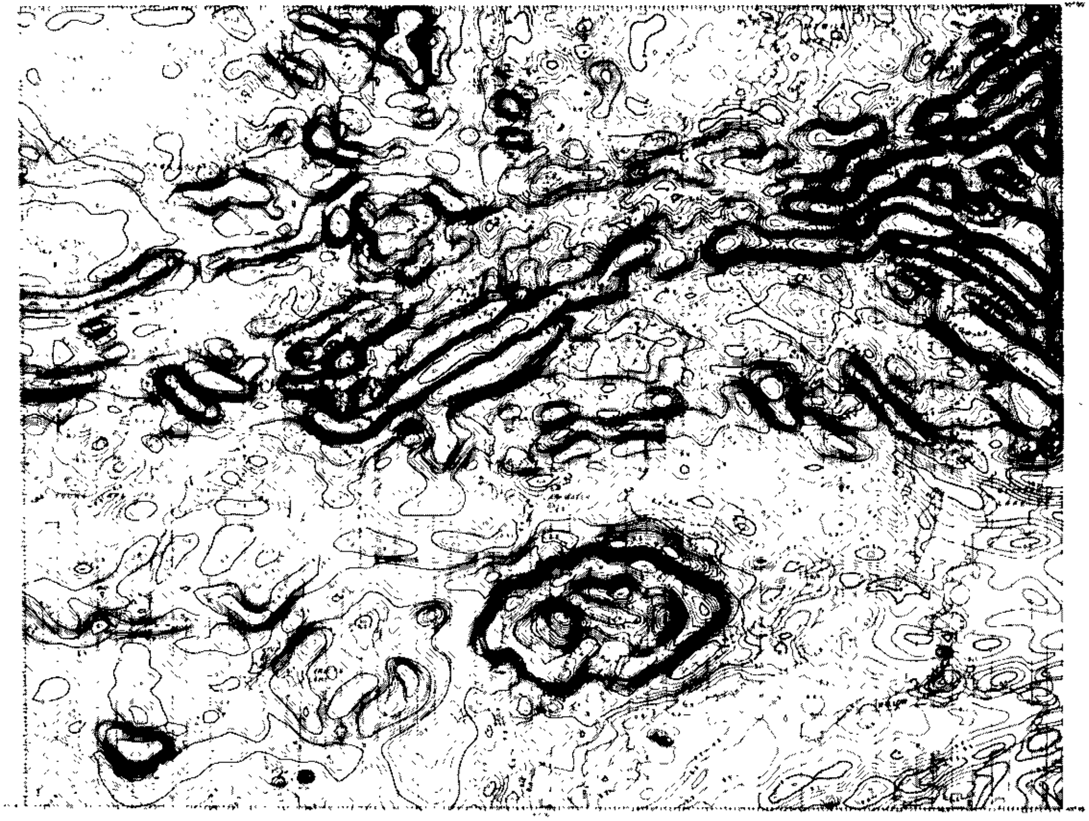


Fig. 14.

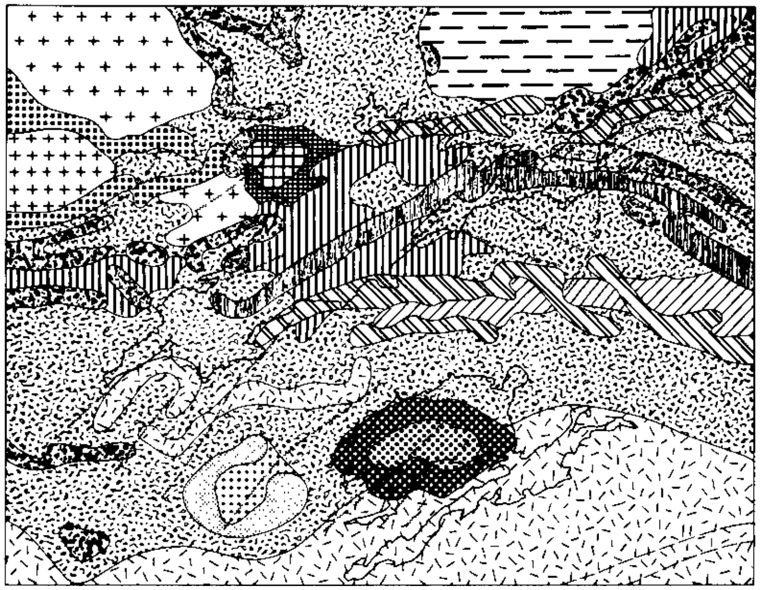
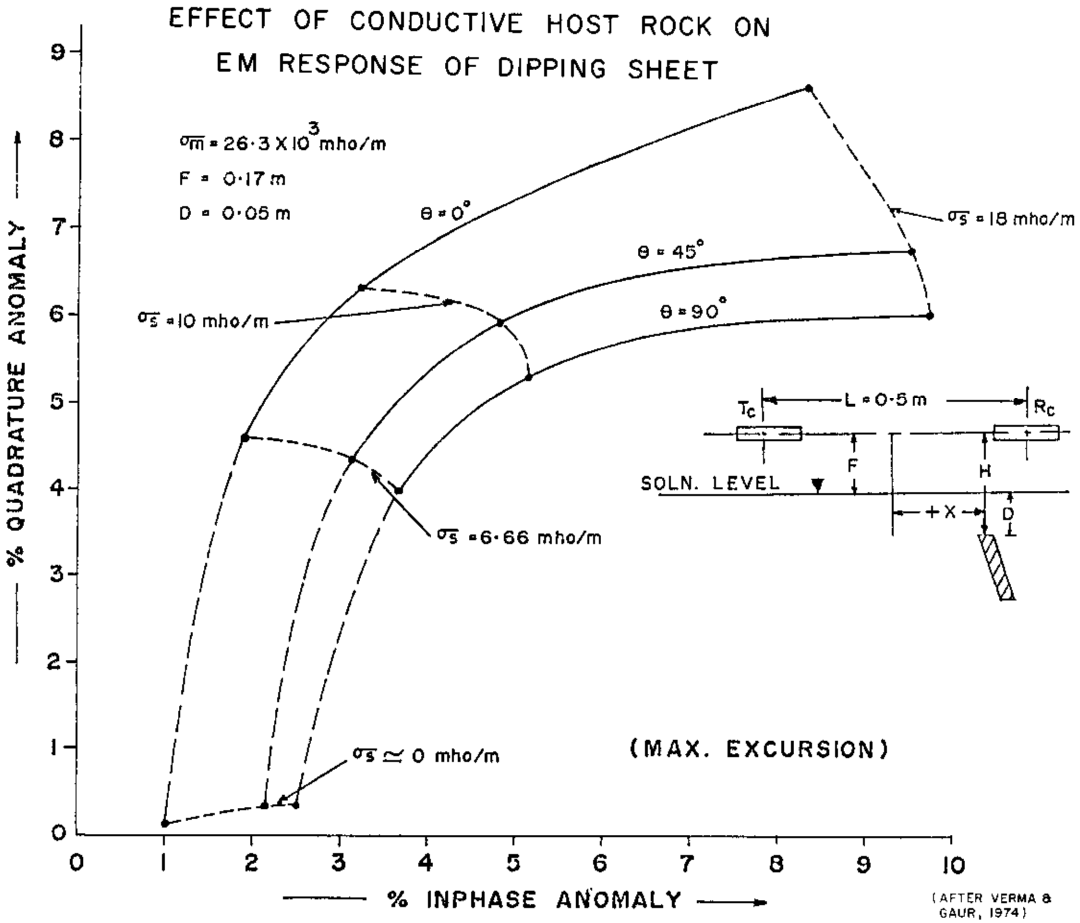


Fig. 15.



(AFTER VERMA & GAUR, 1974)

Fig. 16.

of profitability for the industry has been poor, even when averaged over longer periods. In terms of 1961 dollars, geophysical survey prices have remained constant or have actually decreased. The same is true of instruments. As you know, this has not been the case in the petroleum industry, where average survey prices have probably tripled during the same period. There has been a welcome trend recently towards consolidation among survey contractors, together with an increased involvement by larger and more sophisticated financing groups. Already this appears to have had the effect of reducing price cutting and improving business performance. It is clear, however, that higher prices are necessary as a hedge against the fluctuations in business level that seem to be an inevitable part of the Canadian mining economy.

We ask ourselves constantly why, when there is such an obvious need for the discovery and development of our natural resources, exploration should suffer these wild fluctuations and fall so far behind the level required to meet the country's minimum need. A popular explanation is that exploration is uneconomic. Spokesmen in industry and government alike have questioned whether exploration really pays for itself. They point to the main sources of major mining company profits and explain that these were not the result of sophisticated exploration, but were stumbled over many years ago. More than one major producer has quit exploration on these tenuous grounds.

Fortunately, this view is not held by the majority of metal mining companies. Nor will it stand up to critical examination. In Canada, an average annual expenditure of $65 million over the past five years has resulted directly in the discovery of 3.5 new mines per year, for an average cost of around $18.5 million per mine. If one assumes a dollar value of between $300 and $500 million dollars for the metallic ore discovered annually during the same period, one finds that the cost of exploration works out at around 16% of the gross value. This figure is probably much too high if one considers the additions to reserves that inevitably occur after the initial mine discovery. (If one assumes that discovery is actually equal to production, one can argue that it costs only 2% of the value of ore discovered, to maintain supply). If one compares this exploration cost with that of petroleum, it is apparent that, though not insignificant, it is not a major factor in the economic equation. I think I am right in saying that in the case of petroleum, exploration cost is seldom less than 50% of the well-head value ,and in areas like the Arctic Islands, it is very much higher.

The major determinable factor in the economics of metal mining is the cost of mine development. In 1973 this amounted to a total of about $850 million dollars in Canada. Dividends paid by mining companies during the same period were around $312 million dollars. Return on invested capital in the mining industry is probably lower than in any of the other major industries, despite the very much higher risk.

A still more significant factor in the economic equation is the tax taken by various levels of government. If we leave aside the truly absurd legislation proposed in British Columbia, we still find that the government share of the *gross* value of ore produced in Canada is approximately 15%. Under new legislation proposed for Ontario, a Conservative province, the total government take could easily be as high as 25% of gross.

It is important to keep these factors in perspective when considering the reasons for the low level of exploration. For example, Ontario recently introduced a cost-sharing scheme whereby the provincial government paid 1/3rd of exploration costs in designated areas. I understand that acceptance of this program has been disappointing. A moderate easing of the restrictions on junior mining company financing has led to increased exploration activity and discovery by such companies. But in contrast to the 1950's and early 1960's, discoveries have not resulted in large gains in the prices of company stock. The reason for both of these phenomena is that new ore deposits, particularly small ones, are of little value if they cannot be developed and mined profitably. Under tax legislation existing in the 1950's one could be fairly certain that a few million tons of high grade copper-zinc ore would be a profitable venture. Now, with metal prices more than twice as high, you have to take a very different view. The truth is that mining companies are unwilling to invest even the small amount that is necessary to discover mines if they cannot be reasonably assured of a satisfactory overall rate of return on investment in the long run. It is not the funds necessary for the exploration, but the subsequent capital cost, that is the deciding factor.

In view of this and the concern expressed by *most* federal and provincial spokesmen at the serious drop in Canadian exploration, it seems incredible that the return on investment is being further, deliberately eroded by increasingly severe taxation. One cannot help but feel that the industry is like the unfortunate Alice in Wonderland where the rules of the game are constantly changing and the reward for success is "Off with her head".

Prognosis

It is hard to see how the immediate future in Canadian mining geophysics can be other than upward, though the improvement is likely to be slow.

As we have seen, the main contributing factor to our current exploration predicament has been the inexorable trend of government towards the management and control of mineral resources. Though this trend is bound to continue, I believe that the main impact on exploration activity has already been felt. We are entering now a new era of mineral exploration and development calling for much greater cooperation between government and industry. Suitable alternatives to the practices of past years must be found.

With the increasing awareness at all levels of the critical shortfall in mineral discovery level, solutions will inevitably be forthcoming. The current renewal of interest in uranium and coal as energy sources is already having its effect. Airborne gamma ray spectrometer surveying is up sharply, and it is in keeping with the trend we have observed that government will be funding the major portion of this work. I would anticipate that more than $10 million will be spent on such surveys in Canada over the next three years, of which the government's share will be at least $6 million.

According to Mr. Jack Austin, Deputy Minister of Energy, Mines and Resources, by the year 2,000, to maintain its world market position, Canadian copper production will have to rise 4 to 5 times, nickel output must double, iron ore triple, and zinc almost triple from 1970 levels. He also points that the mineral industry fits perfectly the long-term Canadian public interest because it is capital-intensive in nature. I estimate that a ten-fold increase in exploration activity would barely meet Mr. Austin's objectives.

Clearly, industry must find ways of participating with government in the exploration and development of new deposits. One avenue will be through Provincially or Federally owned mining companies such as the Quebec corporation SOQUEM (Société Quebec Exploration Minière), which has already participated successfully in mine developments. Another avenue will be through greater government participation in surveys and mapping, including direct exploration surveys such as the recent INPUT programs in Quebec. These have also resulted in mine discoveries. If this approach is to be successful, however, it must be followed by financial support or participation in the mine development stage.

The Canadian government is aware of industry's expertise and current over-capacity in mining geophysics and is exploiting it increasingly in aid programs to underdeveloped countries. This form of aid is vitally needed, but more effective means are required for translating the results into mineral discoveries and from mineral discoveries into producing mines. Canadian exploration technology provides a leverage in this area that can be invaluable to mining companies operating overseas.

Despite these hopeful notes, there are some serious short-term problems that must be solved if the industry is to enjoy a healthy recovery. Chief of these is the training and recruitment problem. Enrollment in university geophysics courses is down drastically and unsatisfactory employment conditions have discouraged the few graduates from entering mining exploration. A number of practicing geophysicists have left the industry because satisfactory employment could not be found. This is a tap that cannot be turned on whenever the need is felt. A rapid growth in demand and vastly improved employment conditions are urgently required if the centres of excellence in university and industry are to survive over the next few years. Already much of the priceless momentum built up by the industry over the past 25 years has been lost.

Finally, whatever formula we develop for working with government in mineral exploration, adequate incentive must be provided for initiative and perseverance, two qualities essential for success in exploration. In the past it has been partly the romance but chiefly the pot of gold that has wrung the incredible efforts from the pioneers, scientific and business alike. Still greater risks and greater efforts will be required if Mr. Austin's production levels are to be achieved. Finding suitable incentives may well be the toughest problem facing the industry in the next 25 years.