Articles

Earth Science in Canada from a User's Viewpoint

John M. Hamilton
Cominco Ltd.
700-409 Granville Street
Vancouver, British Columbia V6C 1T2

Address of the retiring President of the Geological Association of Canada Delivered at the Annual Meeting, Montreal, Quebec May 15, 1989

In this address, I shall look briefly at research activity in Canada compared with elsewhere, and at recent funding patterns for research in earth science here. We'll review Canada's earth science enrollments and present work force. I'll touch briefly on Canada's economy and the resource sector's contribution to it. Then I'll focus on the mineral industry, in which I am employed, and look at disturbing trends in the country's deteriorating reserve base and exploration experience. Finally I'll come back to research and to why and how I think all of us, but perhaps particularly industry people should change their perception of the role research could and should play in Canada's resource sector in future.

Being president of a national organization tends to expand one's perspective. Fortunately a large number of overviews and studies pertinent to Canadian geoscience and its scientists became available during the year, many of these for the first time. It is with gratitude that I shall be drawing on the results of some of these during this address.

I'll start by citing a 20-page article published recently in *Nature* (Palca and Anderson, 1988). The subject was the role science will play in Canada's future prosperity, and whether the government understands scientific enterprise. It deserves a thorough airing. On a per capita basis as shown by the bars in Figure 1, Canada spends about half as much on research and development as do the world's leading R and D countries which are the USA, Japan and West Germany. As shown by the line graph, we also have about half as many people, about 30 per 10,000 in the labour force, doing R and D. Canada's efforts on a per capita basis are similar to Italy's in both respects. At least the research people Canada does have are, on average, receiving funding comparable with those in the USA, Japan and West Germany though Canada's total effort is comparatively small.

Canada's government R and D people receive a fraction of gross domestic product that is normal by world standards. However, government support for extramural research in Canada is quite small by world standards, so per capita government expenditures on R and D are only about half that of the USA, Japan and West Germany (Anderson, 1989). Industry itself in Canada spends only about one third as much on R and D as does industry in those leading nations (Anderson, 1989), significantly compounding the problem. Most federal support for university research is administered by three granting councils, of which the Natural Sciences and Engineering Research Council (NSERC) is the largest, administering almost 60%.

The Canadian Geoscience Council commissioned an in-depth study of R and D efforts in earth science to be done by the Centre for Resource Studies at Queen's, and the draft report was tabled recently (Wojciechowski, 1988). Most federal funding for R and D in earth science is done through Energy, Mines and Resources, with a significant additional contribution through NSERC (Figure 2). These are augmented somewhat by what is scored as a small contribution from industry, although industry's exploration costs generally are not included in

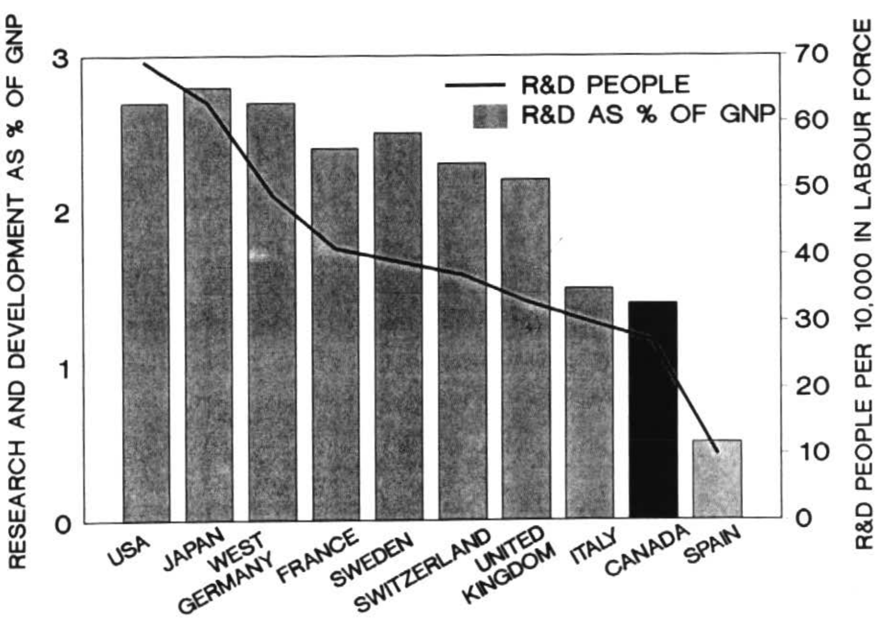


Figure 1 *Research and development; comparison of financial and human resources in 10 OECD countries. Source: Palca and Anderson (1988).*

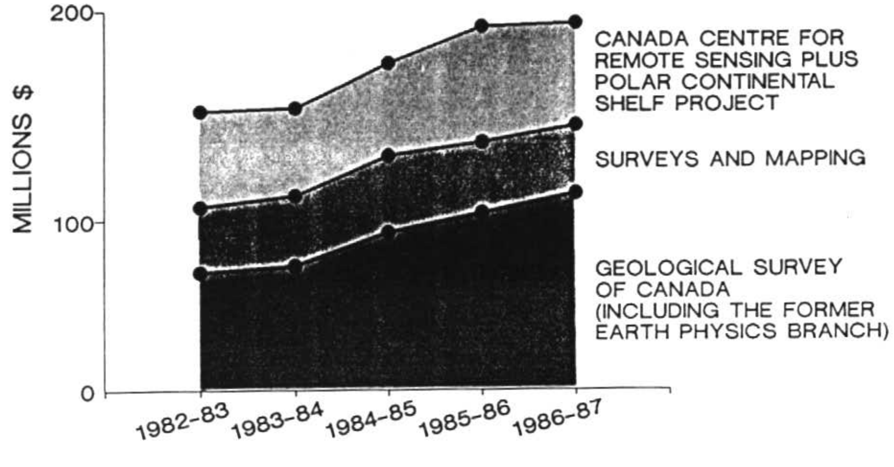
national totals. I'll discuss this omission later, as it seems at least in part unjustified.

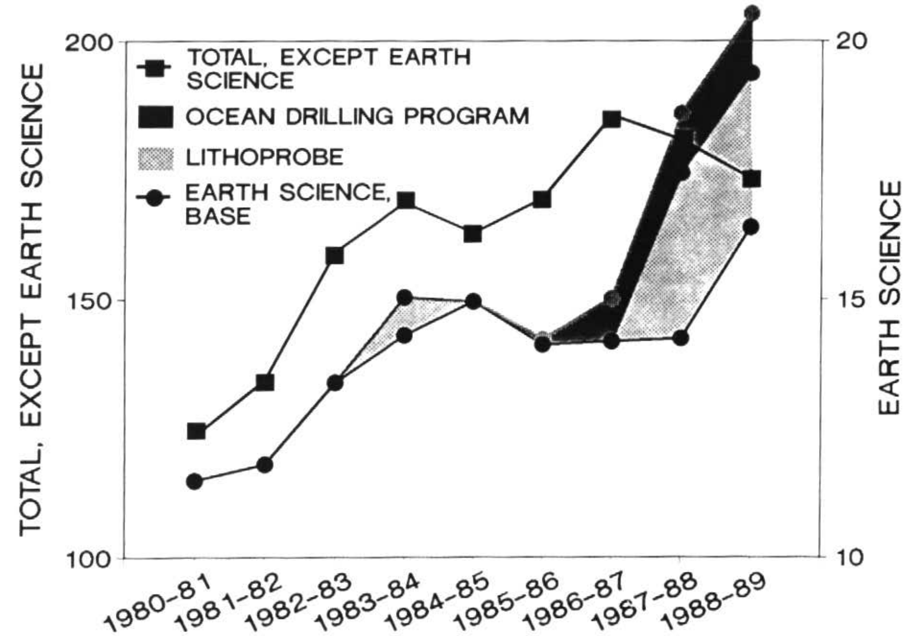
Since 1981, total Energy, Mines and Resources funding for science and technology has increased about 27% after adjusting for inflation, to total about 193 million dollars in 1986–87. Research and development costs were about two-thirds of that amount, with related scientific activities taking up the remainder. The Geological Survey of Canada's budget, including the former Earth Physics Branch, increased 49% to about 113 million in 1987 dollars, with fully 73% of that going to research and development. However, a significant part of that increase arose due to programs not in the A-Base budget, such as the very important Mineral Development Agreements with the provinces. The A-Base budget for the Survey increased slightly during the period after adjusting for inflation, partly due to implementation of the Frontier Geoscience Program designed to better understand the 60% increase in Canada's landmass that came with the new 200-mile offshore limit. Funding for this program was recently designated part of the A-Base budget, which otherwise had been declining alarmingly.

NSERC grants (in 1988 dollars) since 1980 are depicted in Figure 3. The upper graph is the total except earth science, referenced to the left-hand axis, which has generally risen slowly after adjusting for inflation. The equivalent line for earth science is at the bottom, referenced to the right-hand axis. It has also risen in inflation-adjusted dollars, and averages about 8% of NSERC's grants. Also shown are significant additional grants for Canada's megaprojects in earth science, Lithoprobe and the Ocean Drilling Program.

I've often heard earth science faculty members praise NSERC's grant awarding mechanism, which is notable because it is based almost exclusively on peer review. However, for many university scientists, it is the only source of research funding, and is regarded as woefully inadequate by them. NSERC would agree, and tabled a draft strategic plan (Anon., 1988) which proposed doubling its budget over the five years to 1992–93, on a before-inflation basis. There seems no doubt that NSERC's university research community could effectively employ such expanded financial resources. There is doubt that government can afford such a doubling.

Now I'll review Canada's geoscientific community briefly. The American Geological Institute reports important results (Figures 4





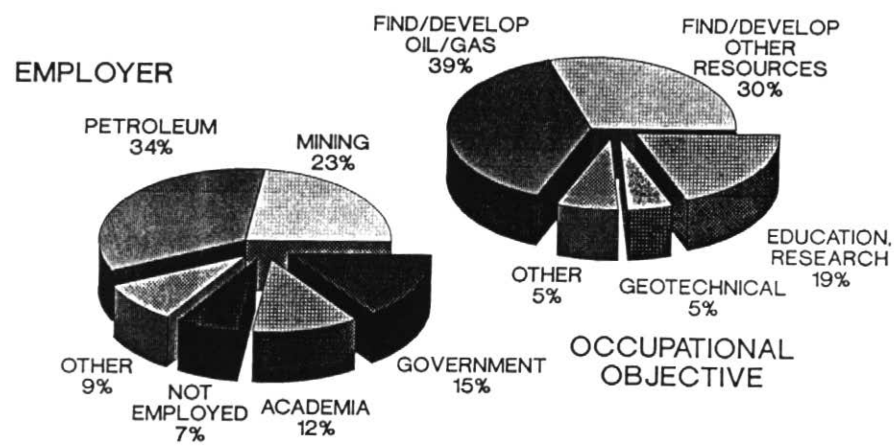
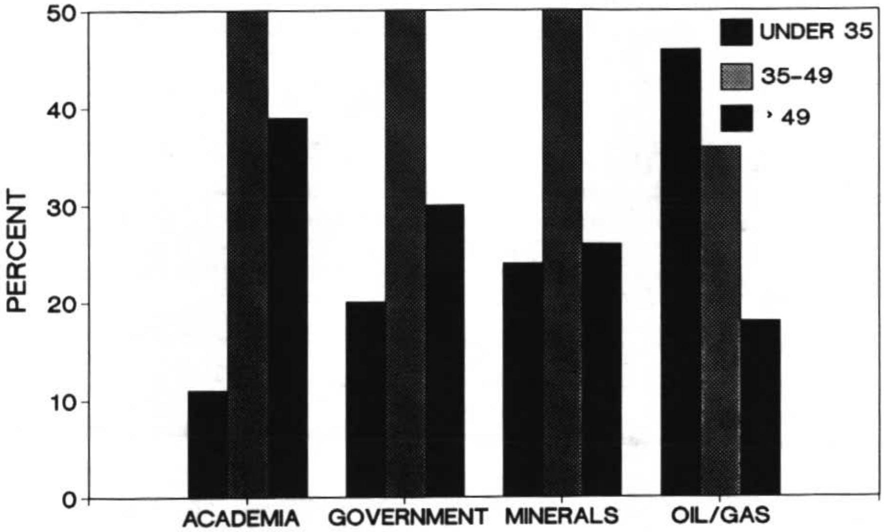
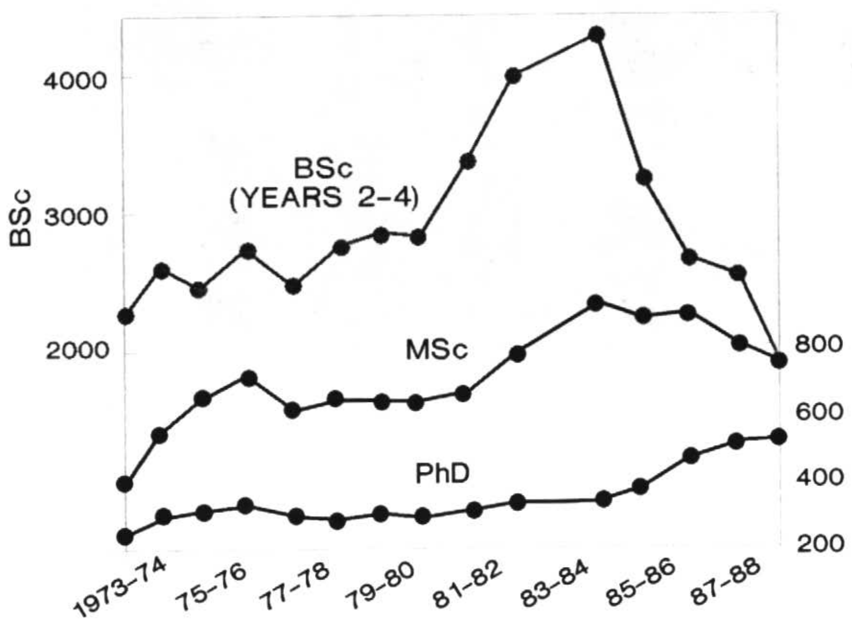


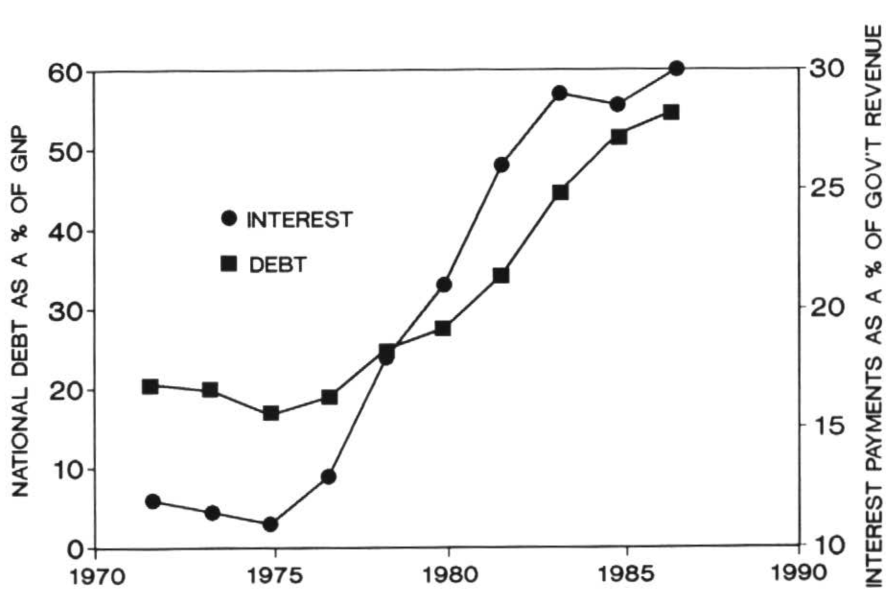
Figure 2 *(upper)* *Energy, Mines and Resources Canada expenditures, inflation adjusted. Source: Wojciechowski (1988).*

Figure 3 *(middle)* *NSERC funding in 1988 $. (scale = millions). Source: J.E. Halliwell and M.A. Taylor (NSERC, personal communication, 1989).*

Figure 4 *(lower)* *Canada's Earth Science community. Source: Claudy and Kauffman (1988).*







and 5) from about 2700 returns (a 47% response rate) in the Canadian Section of its first North American Survey of Geoscientists (Claudy and Kauffman, 1988), and closer to home, GAC got a 75% response to its first membership questionnaire. About a third of AGI's Canadian respondents belong to GAC. As shown on the left-hand part of Figure 4, our petroleum and mineral industries employ about 57% of Canada's 15,000 geoscientists; government at 15% and academia at 12% are the other employers of significance. However, almost 70% of Canadian respondents cited finding and developing oil, gas or mineral resources as their occupational objective, because some in government and academia share that objective with their colleagues in industry.

As shown in Figure 5, the average age of practising earth scientists is rising. This is particularly true of Canada's university faculty, but also is true in government and the mineral industry. The oil and gas industry has Canada's youngest demographic profile in earth science. The most debilitating result of aging geoscientists, at least in government and the mineral industry, is a tendency for some highly qualified people to try to limit their field work. This leads to a lower level of development of fundamental field data.

University enrollments have been on a roller coaster (Figure 6)(Ghent, 1989). A 50% rise in undergraduate enrollment between 1983 and 1985 strained education resources, and also produced subsequent bulges in post-graduate enrollments. Since 1985, however, undergraduate enrollment has fallen just as steeply, in response to low commodity prices which had curtailed private-sector hiring. This has already affected MSc enrollments and PhD enrollments will likely follow suit. Since the early 1980s, there has been a roughly 25% rise in university enrollments in Canada (Anderson, 1989), but earth sciences are not attracting their fair share. In fact, this year's BSc enrollments are down alarmingly from last year's low level.

Let's set all this against Canada's economy, which has been strong during the last few years, and for instance grew about 150% in the decade ending in 1987 (Taylor, 1989). However, the national debt hangs heavy, having grown by more than 250% during the same decade. Figure 7 shows how national debt has climbed, and how its interest cost has climbed faster. Today, federal government debt is more than $11,000 per capita and provincial and civic debt push the total to over $20,000. Stated another way, the

Figure 5 (*upper*) *Age profiles of earth scientists by sector. Source: Claudy and Kauffman (1988).*

Figure 6 (*middle*) *Enrollments in earth science. Source: Ghent (1989).*

Figure 7 (*lower*) *Canada's national debt. Source: Vancouver Sun, April 8, 1989, p. D5.*

sole breadwinner for a family of four can be thought of as entering the housing market already shouldering an $80,000 mortgage imposed by three levels of government. Interest on this debt consumes about a third of all direct and indirect taxes each of us pay. A rapidly growing part of these interest payments flows to foreign lenders. Our debt has risen rapidly in bad times, but also in good times during the last decade. To quote Alan Taylor of the Royal Bank of Canada, "We must stop objecting to tax increases for deficit reduction — and stop asking for increases in spending programs."

How the resource sector impacts on Canada's gross domestic product is shown in Figure 8. As has been pointed out (Woodall, 1984), one has to adjust national statistics, to compensate for classifying contributions from things like smelting and refining with manufacturing, and here I use results from Wojciechowski (1988). The resource sector's contribution fell from about 25% of Canada's GDP in 1975 to about 19% five years later, and has been fairly constant since. Agriculture's contribution is slightly larger than those of minerals, petroleum and forestry, which are about equal. However, according to Energy, Mines and Resources (1988), as shown in Figure 9, the per capita inflation-adjusted value of raw mineral commodities produced in Canada recently fell about 32%, from about $1,800 in the 1979-85 period to $1,350 since then. This change results largely from low commodity prices, but as the Federal Associate Deputy Minister warned late last year (Perron, 1988) many in government have been lured into thinking that "mining is a sunset industry", and the industry shouldn't take government support for granted.

Is mining a sunset industry? A look at trends in Canada's reserve base over the last few years certainly does give one pause (Figure 10). Cranstone and Lemieux (1988) have pointed out that Canada's lead and zinc reserves (Figure 10a,b) each have fallen about 27% since 1975. Reserves of copper fell about 18% (Figure 10c) while gold reserves (Figure 10d, lower right), rose quickly. Of course, Hemlo and subsequent discoveries financed by flow through shares have caused this boost in reserves for gold, so it would be easy to assume that a similar effort aimed at base metals would have a similar impact. We shall return to this point.

Cranstone and Lemieux (1988) also predicted the effect declining metal reserves would have on Canadian mineral production. Figure 11 shows metal production for lead, zinc and copper from presently existing facilities processing known reserves, between now and 2005. They forecast a comparatively small increment to the base supply, which comes from presently undeveloped and hence marginal deposits. A significant looming supply shortfall depends in part upon rate of forecast growth in use. It will occur unless new orebodies of significant size are found and developed in Canada soon. For zinc, Canada's "looming" supply shortfall has started.

Is an assumption warranted that base metal reserves in Canada are likely to be increased quickly like gold, through application of funds and existing exploration technology? Mackenzie and Bilodeau (1989) recently reviewed exploration expenditures and subsequent discoveries in Canada since World War II. Their findings, which I believe are very important, have been summarized in Figure 12. In the upper left histogram, we have exploration expenditures adjusted for inflation, broken into five periods since 1945. Base metal expenditures are shown by the left-hand of the pair of bars for each eight-year period. Such expenditures peaked in the early to mid-70s. Expenditures for gold exploration rose slowly to 1977 and quickly since. Note that for gold in this and the other three histograms, data for the most recent

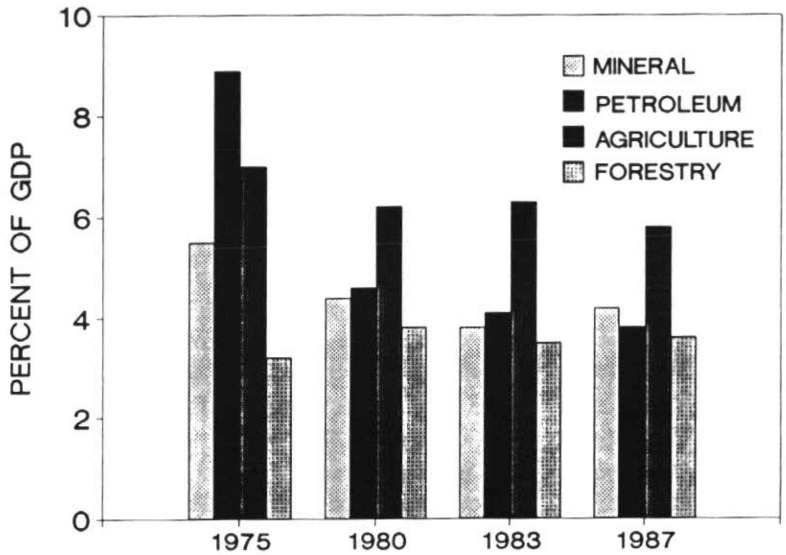


Figure 8 *Contribution of the resource sectors to gross domestic product (GDP). Source: Wojciechowski (1988).*

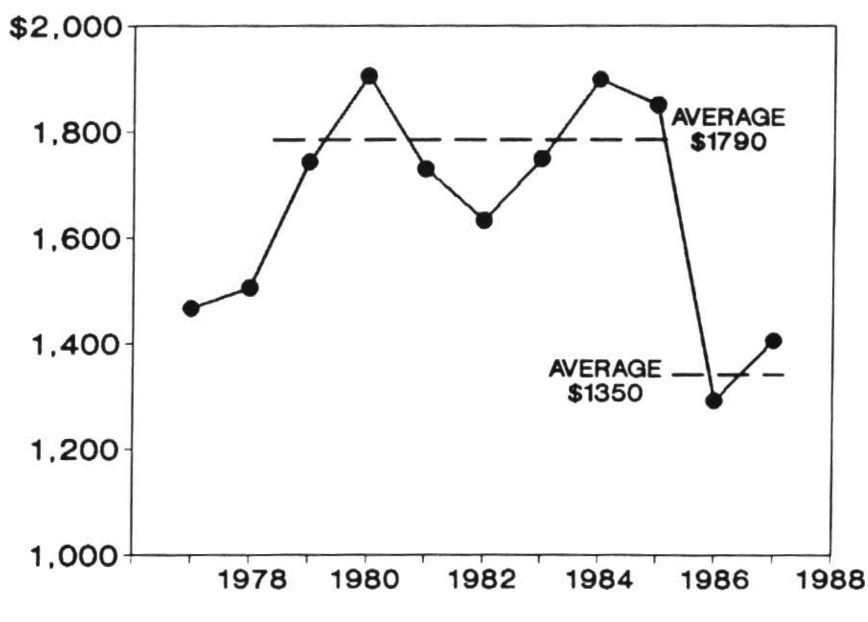


Figure 9 *Mineral production of Canada in dollars (1987$) per capita. Source: inset table, EMR Map 900A, 38th edition.*

eight years are broken down into two periods of four years each, using their detailed data. The upper right histogram shows number of discoveries per period, which peaked for base metals in the mid-60s and for gold in the 1978–82 period. Mackenzie and Bilodeau also derived cost per discovery, shown in the lower left, which has risen alarmingly for base metals after adjusting for inflation. The cost per gold discovery also rose, to double historical norms, but not until the most recent four-year period they examined.

The average rate of return on investment in exploration is shown in the lower right and is now distinctly unsatisfactory for both base metals and gold.

There is something wrong here. On the one hand we have, in the absence of exploration success, a looming gap of alarming proportions in Canada's ability to contribute to world metal supplies. On the other hand, we have an alarming deterioration in the economic attractiveness of doing mineral exploration in Canada, even for gold.

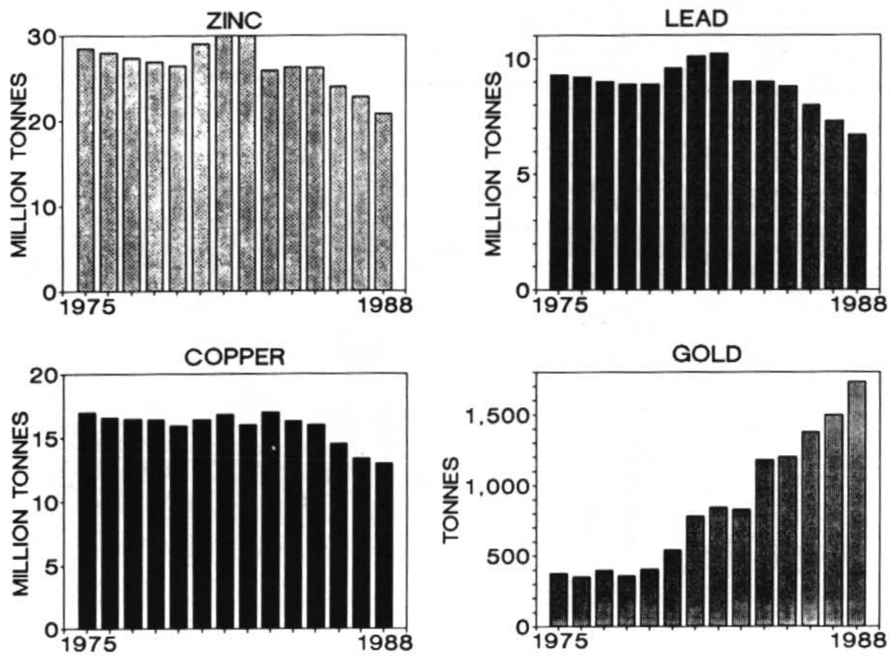


Figure 10 *Metal reserves in Canada, 1975-88. After Cranstone and Lemieux (1988, figures 1, 2 and 3).*

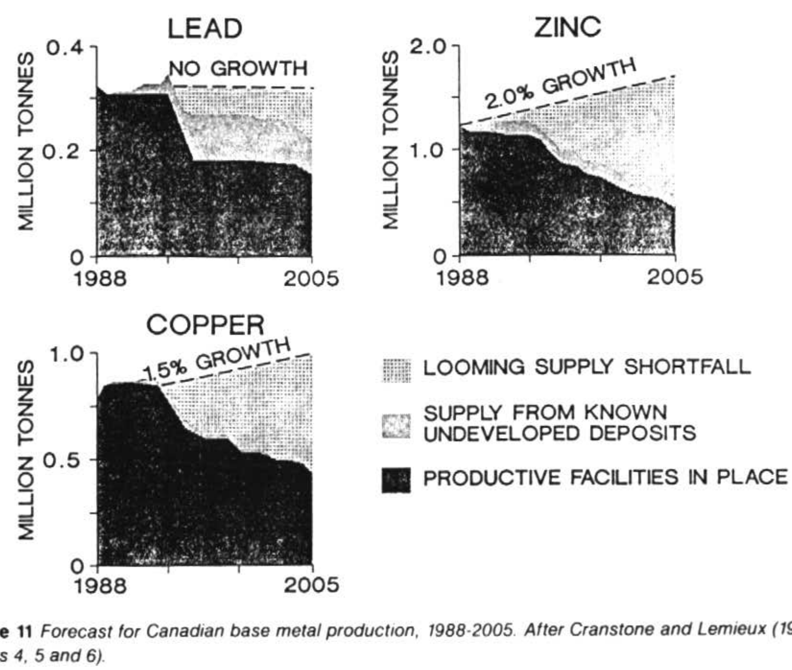


Figure 11 *Forecast for Canadian base metal production, 1988-2005. After Cranstone and Lemieux (1988, figures 4, 5 and 6).*

One possibility is that we have largely discovered Canada's mineral endowment; explorers are going to a nearly dry well. According to this theory, it's all downhill from here; mining *is* a sunset industry. Zwartendyk (1987) has considered this important question rather carefully in an excellent paper. Zwartendyk finds that, while our knowledge of Canada's mineral endowment is indeed sketchy, there is little evidence to support the contention that we have seriously depleted it. For instance, as has been pointed out (Martin and Jen, 1988), average grade being mined has not fallen since 1940, except where new technology such as big equipment or heap leach techniques turn what was waste into ore. Their data are shown in Figure 13. Also, discovery of large and/or rich deposits like Cigar Lake and notably Hemlo on the Trans-Canada Highway are evidence that the endowment doesn't yield its secrets in any orderly sequence of size or grade, and that excellent deposits occur in unexpected places.

I want to summarize these points, and suggest what I think they are telling us. Before doing so, I should tell you more about the corporate culture I inhabit. Table 1 lists 26 mines developed or being developed by Cominco and its associated companies. Four of these properties, as noted, were purchased from others who had already delineated small reserves, although in each of those cases we went on to discover the bulk of reserves. Cominco and its associates discovered the other 22 orebodies, often with significant use of data provided by government agencies. In seven cases government assistance was of indirect, but noticeable, value; in three other cases the discovery outcrops were encountered and reported on by people who were employed by government (Gray, 1938; Tailleur, 1970; Jolliffe, 1987). Cominco and its associates found the other 12 orebodies. Hence, for 10 out of 22 of these mines, government data contributed noticeably to discovery. That figure rises to 9 out of 17, or more than half of the mines discovered in Canada, USA and Australia, where effective government activity in earth science prevailed during the period. Our five biggest discoveries of that period are Valley Copper, Red Dog, Pine Point, Polaris and Hellyer; government activity contributed directly or indirectly to discovery of three of these.

Cominco sustains itself by discovery to a somewhat greater extent than is true for mining companies as a whole. In that sense Cominco is unusual. Of course, government activity has contributed directly or indirectly to numerous other discoveries, at least in Canada, so I doubt if our experience, of government contributing to more than half of discoveries, is unusual. We are deeply cognizant of the impact government scientists have made and could keep making on the discovery process. That is one of the reasons Cominco people are more active than normal in the affairs of earth science.

Now I'll summarize, predict and suggest. First, in Canada we've elected a series of governments at all levels who have spent us into the poorhouse. In living beyond society's financial means we've polluted our own and our children's financial environment at least as much as the natural one. If successful democracies are populated by informed, intelligent electorates and Canada remains successful, it will only be because we start electing governments that cut expenditures and raise taxes so annual surpluses are available to pay down debt. We probably should stop looking to government to continue supporting greater than inflationary rises in research funding, either intramurally or at universities. Dollars for greater than inflationary rises in earth science research will have to come from other sources.

Second, about 70% of our earth science community cites discovery of resources as their career objective. These scientists are aging. Let's strenuously resist the tendency for some earth scientists to change from field work to office studies long before they retire from the workforce. Surely much of the truth is, and always was, in the field, and ineffective geoscience organizations don't deserve continued support from their backers, be they shareholders or taxpayers.

Statistics suggest that Canada as a nation has half as many people doing research and development per capita as do the world's leading R and D countries, but those people are as well funded per capita. Further, in the university environment at least, NSERC's allocation mechanism attracts praise. But in Canada government funding of research and development is below par and industry's contribution is even worse. On the other hand, a large part of Canada's earth science community do exploration, and the science I see in my own and some other organizations, albeit applied and unpublished, is as worthy of being called research as is much of the work done by government and university scientists. Earth science in Canada might be one of the few sciences in which a significant fraction of industry's employees are actively engaged in research.

Historically, Canada has successfully contributed a notable share of earth resources, and we've done it in a competitive environment. This activity has generated a significant part of the nation's product, one which we can ill afford to start foregoing now. In the last 10 years however, the number of discoveries hasn't justified the exploration costs, and a decrease in Canada's future earnings from earth resources is looming ever nearer unless significant new deposits are found and developed soon.

I can imagine a world without oil and gas, because I believe fission or fusion or both will succeed that energy source. I have difficulty imagining society returning to existence without metals. For instance, despite fibre optics and miniaturization of electronic devices the world uses more copper each year. Better technology helps us find and exploit metal deposits as well as use metal more wisely. Earth science has plenty to offer at the front end of that process. For most metals, we are still a long way from the time when recycling is cheaper than primary production. If Canada is going to avoid foregoing the contribution minerals make to our economy then, among other things, we need to get more effective at locating some of the rest of Canada's mineral endowment.

Orebodies, even ones large enough to sustain large integrated mining corporations, are very small targets, much smaller and more elusive than oil and gas fields. Most orebodies that are sticking out of the ground have been found, and so have some of the ones lying under thin mantles of drift or barren rock. The clear challenge facing the mineral industry is to search using better technology because undoubtedly better search techniques will prove that our endowment is by no means exhausted.

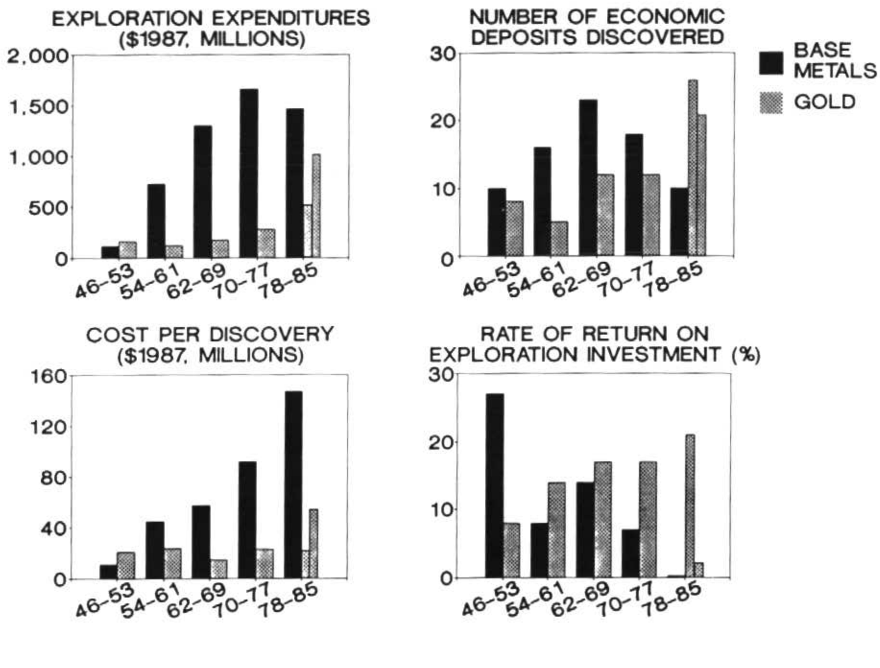


Figure 12 *After Mackenzie and Bilodeau (1989, pages 10, 12, 15 and 18).*

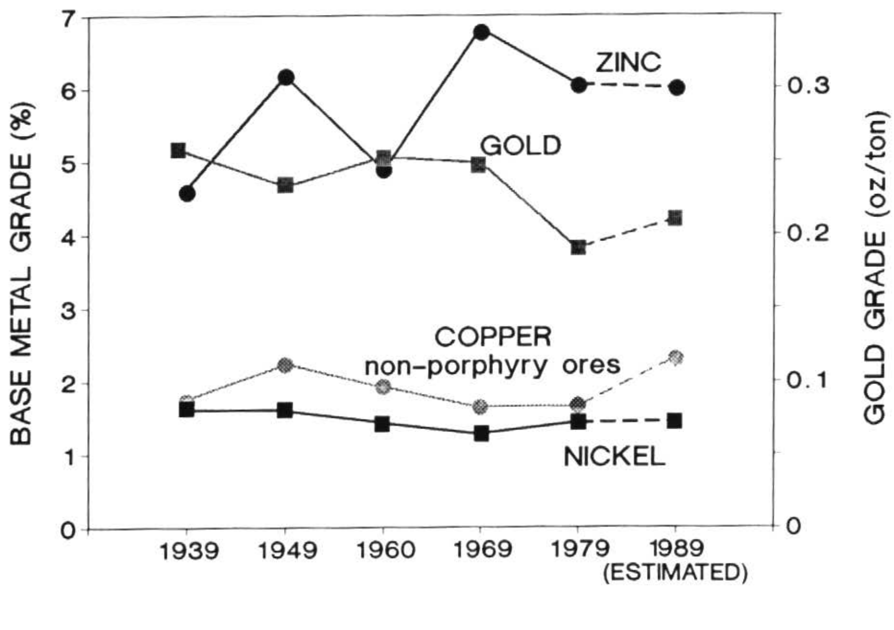


Figure 13 *Canadian mine production grades, 1939-1989. Source: Zwartendyk (1987), as drawn from Martin and Jen (1988).*

One answer that must have come to your mind long ago is to ask the mineral industry to contribute a lot more than it has been to university research. There needs to be a significant change in attitude before that will happen, and I can speak knowledgably about industry's present perspective on this point. I've been tangentially or directly associated with at least seven joint research projects with university people, and generally financial support was provided by Cominco. Two of these projects are in progress. Of the other five, four were distinctly unsatisfactory experiences from Cominco's point of view, for one reason or another. Our general experience is an apparent lack of understanding of industry's imperatives or a lack of caring about the well-being of its scientists, or both, on the part of university researchers. I gather from talking with colleagues in industry that our experience is by no means unique. On the other hand, many university earth scientists have acquired a similarly dim view of their colleagues in industry. In much of the country, scientists in the mineral industry and in geology departments constitute two solitudes, and this should change.

Cominco's best experience, for the record, was our help with funding UTEM development by Yves Lamontagne under Gordon West about 13 years ago (Lamontagne, 1975). UTEM is an acronym for University of Toronto Electromagnetometer. We went on to put a few hundred thousand dollars into Lamontagne's fledgling company, on a non-equity basis, in order to ensure availability of field-worthy equipment. The equipment our funding ensured contributed directly to discovery in 1983 of the magnificent Hellyer deposit in Tasmania. I'm sure that other carefully selected research ventures of scientific merit can be identified that will attract industry support.

There are some reasons for optimism. At a broad level, the Universities of Toronto and of British Columbia as well as McGill in Montreal have all recently engaged in successful fund-raising campaigns with industry. A joint industry-university research initiative in earth science is presently emerging in Vancouver. University-government earth science research consortia also exist, such as the Derry Laboratory in Ottawa. The Centre for Resource Studies at Queen's University attracts some funds from both industry and government. Other examples could be cited.

But there are other things we should be considering in this country. Two programs in Australia are worthy of our serious consideration. Australia spends no more on research than Canada, on a per capita basis. Australia also has a significant mineral resources sector, and it does more research in the minerals area.

The Australian Mineral Industrial Research Association (AMIRA) was founded thirty years ago. Seventy member companies now contribute about four million dollars annually for research. Such a level of funding is about 25% of NSERC's current earth science base. At AMIRA, a board of directors establishes policy and priorities, and six research co-ordinators in the secretariat identify researchers and facilities on the one hand, and industry sponsorship of individual projects on the other hand. All research is contracted out. The result is R and D that is fully funded by potential users, generally short term and applied, and widely regarded as very cost effective.

Several earth science departments in Australia permit people to get post-graduate degrees with minimal attendance requirements, of the order of two months per year. Most work is done by correspondence, and of course a thesis is required. The university scientists involved get a virtual pipeline into industry's problems, so they can frame proposals that are much more attractive to industry. The result of these and other programs is that, by my reckoning, Australia's mineral deposit earth science has gone from being not as advanced as Canada's, to being at least as good and in many ways better, over the last few decades.

The advice I have for government agencies is very simple. Much of this country isn't mapped in anything like the detail required to be of direct use to the mineral industry. The GSC built its reputation largely on provision of high-quality mapping, albeit much of it at a scale of 1:250,000. Mapping to contemporary standards, at a scale of 1:50,000 is a highly valued starting point for industry's exploration work. A great deal of the northern part of this country lacks such mapping, so a huge job remains to be done. Doing it should prove highly rewarding for the people of Canada. Only government can do it because individual companies are constrained by competitors' claim holdings. Government mapping activity has contributed to about half of Cominco's recent discoveries and, if sustained, would be a critical catalyst for ore discoveries in Canada in future.

Figure 14 may help reinforce my suggestions to the mineral industry. In 1986, the federal government revealed how it saw increases in university research being financed between then and 1991 (Minister of

Table 1 Mines developed or being developed by Cominco and its associated companies.

Year	Name	Country	Commodity	Note
1914	Sullivan	Canada	Pb, Zn, Ag	1
1928	Montana Phosphate	USA	P_2O_5	2
1938	Con	Canada	Au	3
1940	Pinchi	Canada	Hg	3
1951	Tulsequah	Canada	Cu, Zn, Ag, Pb, Au	1
1952	Bluebell	Canada	Zn, Pb, Ag, Cu	2
1955	H.B.	Canada	Zn, Pb	2
1963	Wedge	Canada	Zn, Pb, Ag	4
1965	Pine Point	Canada	Pb, Zn	1
1968	Magmont	USA	Pb, Zn	1
1969	Vade (Vanscoy)	Canada	K_2O	4
1973	Black Angel	Greenland	Zn, Pb, Ag	4
1977	Rubiales	Spain	Zn, Pb, Ag	1
1978	Hondeklip	Namibia	Diamonds	1
1981	Que River	Australia	Zn, Pb, Ag	4
1982	Polaris	Canada	Zn, Pb	4
1983	Valley Copper	Canada	Cu	4
1984	Buckhorn	USA	Au	2
1986	Troya	Spain	Zn, Pb	1
1987	Bardoc	Australia	Au	1
1987	Hellyer	Australia	Zn, Pb, Ag	1
1989	Marte	Chile	Au	1
1989	Red Dog	USA	Zn, Pb, Ag	3
1989	Ajax Monte Carlo	Canada	Cu	4
1989	Stratmat	Canada	Zn, Pb, Ag	1
1991(?)	Snip	Canada	Au	1

NOTES:
1. Discovered by Cominco and its associated companies.
2. Purchased, Cominco went on to discover bulk of reserves.
3. Persons encountered and reported on the discovery outcrops while working for government.
4. Discovered by Cominco and its associated companies, government assistance was of indirect, but noticeable, value.

Supply and Services Canada, 1986). There is no adjustment for inflation in Figure 14, so NSERC's base budget is actually falling in buying power unless the amounts available in principle for matching are in fact matched by industry.

In the mineral industry, we have been effective explorationists without, as a group, contributing much to extramural research, except perhaps in the technology service sector. We have also matured as an industry and, perhaps, that brings some responsibility. Initiate more dialogue with your peers in university. Get a list of thesis titles at the university near you and visit students working on problems of interest. Lobby your local department to follow the Australian example of post-graduate programs with much reduced attendance requirements and much increased home study. This kind of close industry-university liaison can flourish without breadwinners foregoing salaries or companies putting up with commonly naive graduate students. Agree to lend your opinions to steering groups, and peddle whatever influence you can bring to bear. And finally, if the time arrives when an industry research consortium, patterned perhaps on AMIRA, becomes a reality in this country, support it. Changes in attitudes take time to achieve, but there is an incentive now for all parties to facilitate a much increased level of co-operative research into exploration earth science.

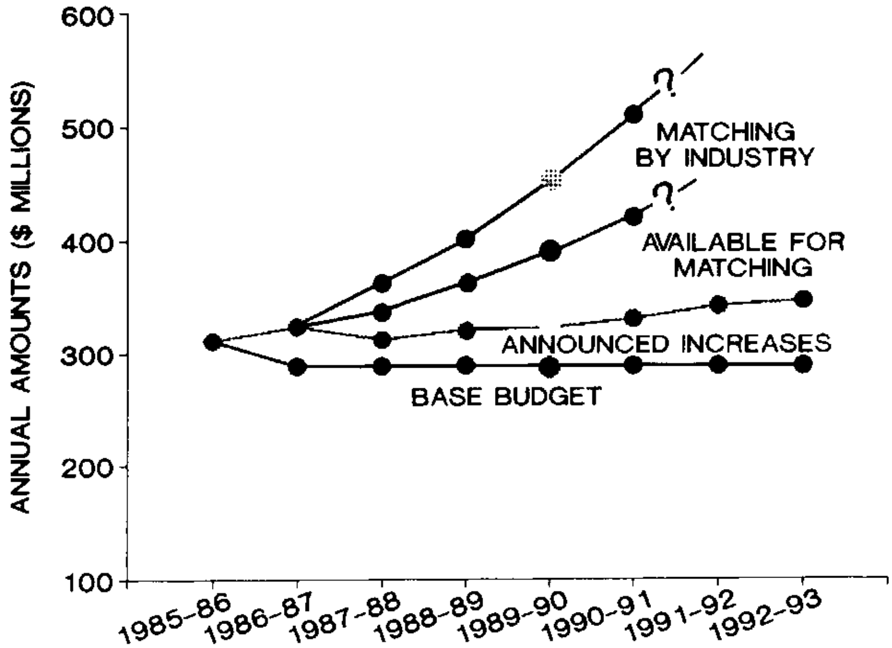


Figure 14 *The anticipated effect of matching policy rules on NSERC budgets. Source: Minister of Supply and Services Canada (1986) and J. E. Halliwell (personal communication, 1989).*

Acknowledgements

Cominco is acknowledged for recognizing the importance of supporting scientific organizations in principle and me in particular during my year as President. My family's endorsement is also deeply appreciated. J. Bartlett capably prepared original slides and the graphic derivatives which appear herein. J. Douglass typed the manuscript and also provided valued support throughout the year.

References

Anderson, E.V., 1989, Canada grapples with its science and technology policy: Chemical and Engineering News, March 6, p. 7-13.

Anon., 1988, 12 years to 2000: Draft discussion paper: Natural Sciences and Engineering Research Council of Canada, February, 19 p.

Claudy, N. and Kauffman, M.E., 1988, North American survey of geoscientists, Canadian section: American Geological Institute, p. 75-115.

Cranstone, D.A. and Lemieux, A., 1988, Base metals: today's exploration challenge: presented at Congrès Annuel de l'Association des prospecteurs du Québec, Val d'Or, September, reprint, 16 p.

Energy, Mines and Resources Canada (EMR), 1988, Principal mineral areas of Canada, and Inset Table, Mineral production of Canada: Map 900A, 38th edition.

Ghent, E.D., 1989, (compiler), Annual survey of enrollments, degrees granted and faculty strength: report by the Canadian Council of Chairmen of Earth Science Departments to the Canadian Geoscience Council.

Gray, J.A., 1938, Preliminary report, East half, Fort Fraser map-area, B.C.: Canada Department of Mines and Resources, Paper 38-14, 14 p.

Jolliffe, A.W., 1987, Discovery of the 1930's: the Con mine at Yellowknife, in Padgham, W.A., ed., Yellowknife Field Guide, Mineral Deposits Division of GAC and the Yellowknife Geoworkshop Committee, p. 5-10.

Lamontagne, Y., 1975, Applications of wideband, time-domain EM measurements in mineral exploration, Unpublished Ph.D. thesis, University of Toronto.

Mackenzie, B.W. and Bilodeau, L., 1989, Trends in exploration performance: the search for base metals and gold in Canada: presented at Prospectors and Developers Association of Canada, March, reprint, 19 p.

Martin, H.L. and Jen, L-S., 1988, Are ore grades declining? The Canadian experience, 1939-1989, *in* Tilton, J.E., Eggert, R.G. and Landsberg, H.H., eds., World Mineral Exploration, Trends and Economic Issues: Resources for the Future, Inc., Johns Hopkins University Press, Washington, D.C., p. 419-444.

Minister of Supply and Services Canada, 1986, Strengthening the private sector/university research partnership, the matching policy rules: pamphlet, catalogue number ST31-22/1986, 18 p.

Palca, J. and Anderson A., 1988, Science in Canada, Canada's changing times: Nature, v. 333, p. 717-736.

Perron, P.O., 1988, The Federal Government and the Ontario minerals industry: address to Ontario Geological Survey Forum, December 12, reprint, 12 p.

Tailleur, I.L., 1970, Lead, zinc and barite-bearing samples from the Western Brooks Range, Alaska: United States Geological Survey Open-File report 445, 16 p.

Taylor, A.R., 1989, Chairman's message to shareholders, Royal Bank of Canada, Annual Meeting, January 13.

Wojciechowski, M.J., 1988, Research and development in the earth sciences: Centre for Resources Studies, Queen's University, study commissioned by the Canadian Geoscience Council, 86 p. Note: Accompanying background studies entitled "R&D trends in earth sciences in Australia (46 p.), Canada (204 p.), Finland (44 p.), Sweden (50 p.) and the United Kingdom (39 p.)" are part of this reference.

Woodall, R., 1984, Success in mineral exploration: confidence in prosperity: Geoscience Canada, v. 11, p. 83-90.

Zwartendyk, J., 1987, Prospects for the Canadian mineral endowment: Centre for Resource Studies, Queen's University, reprint, 14 p.

Accepted 10 July 1989.