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Résumé de l'article

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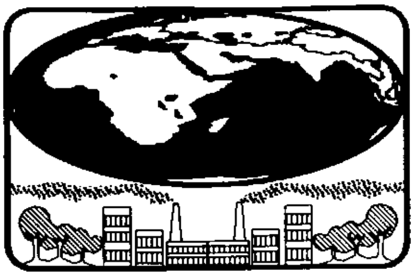

Changing Earth Sciences [1]

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Summary
Canada's economic dependence on natural resources has declined — minerals, oil and gas, forestry, trapping, fishing and agriculture contribute proportionately much less to the Gross Domestic Product than they did 30 years ago. Advanced materials, advanced crops and service industries appear to be replacing our traditional bases.

Are earth scientists still needed?
They are certainly needed from a nationalistic Canadian perspective. Canada's mineable reserves of copper, lead, zinc and nickel are declining, and new discoveries are needed if the nation is to maintain its international market share in the 1990s. The nation must be wealthy if we are to play our proper part in tackling the really important global tasks — saving and then managing the planet properly.

Planetary peoples are becoming conscious of planetary abuse, and want solutions to the many global problems. Some solutions must come from good science and technology. The problems are difficult, and need creative, motivated individuals, working within a framework suited to the task. New organizational structures or ways of working are needed — the problems cross all scientific, technological and political boundaries, and the vertically integrated organizational relationships with which scientists and technologists have become familiar may be inadequate.

The planet's peoples don't have the luxury of time to wait for solutions to appear. Shouldn't earth scientists more than ever contribute to society? Urgently?

Canada's Economic Dependence on Natural Resources has Declined
Wilson Sarty of Nova Scotia made wooden snowshoes and he told Peter Barss how he would start a pair.

> "It's more to makin' snowshoes than meets the eye. It doesn't look much work, but it's really quite a job. I make 'em right from scratch. The best frame you can get is to go into the woods to cut your own wood — ash, oak — a good hard wood. You pick out your tree that you think will make a good pair of snowshoes ... "

Alex Hiltz made spoons, working in wood like his father before him.

> "My old father, anything he could make out of wood — make himself — he never bought. Never paid a cent for anything that he could go out in the woods an' make. He'd go an' try to find the perfect piece o' wood or somethin' that was near enough to it. An' then he'd whittle it up ... "

Many craftsmen and women like Sarty and Hiltz are described in the beautifully illustrated book by Peter Barss and Joleen Gordon: *Older Ways: Traditional Nova Scotian Craftsmen*. All of them skilfully adapted a natural material to a practical use. That natural approach is passing. With "modern" materials we "start with a need and then develop a material to meet it, atom by atom", and so optical fibres are replacing copper in cables (Clark and Flemings, 1986). *The Globe and Mail* reported in February 1989 that Haley Industries of Haley, Ontario had increased its interests in the company Advance Composite Technology Inc. of Denver, "which has developed a high-speed filament-winding process that can make composite aircraft parts in many shapes from carbon, graphite and Kevlar". Changes like this are among the reasons for the decline in Canada's primary resource industries as the nation's engines of growth. Kevlar, carbon and graphite are a long way from Sarty and Hiltz and their snowshoes and spoons.

Canada's natural resources — agriculture, fishing, minerals, oil and gas, forestry and trapping — contributed 16.4% to the Gross Domestic Product in 1961. They contributed only 9.8% in 1987. Although minerals, crude oil and gas increased their total contributions to the economy between 1961 and 1987 by 50%, the economy as a whole grew much more, 300% (Figure 1).

Are Advanced Materials, Advanced Crops and Service Industries the New Engines of Growth?
Locomotives' weight-to-power ratio fell from 1000 kilograms per horsepower in 1810 to rather less than 20 in 1980 (Larson *et al.*, 1986; the splendid mix of units is theirs). Glass is displacing copper as a conductor, and this provides new business for a variety of individuals. For example, Bedford Institute of Oceanography now provides advice and fields questions on routes for new fibre-optic cables offshore, which are replacing the old ones made of copper. Again, advances in technology allow us now to specify the properties we want, and the material can then be designed and made.

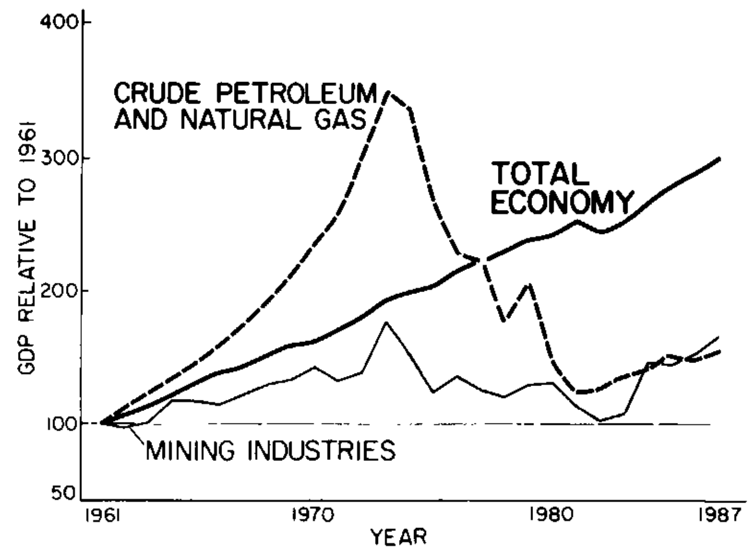

Figure 1 *Mineral resources are not now as relatively important to the nation's economy as before. The figure shows the change in Gross Domestic Product at factor cost (heavy solid line) and the change in contributions to the Gross Domestic Product at factor cost from Crude Petroleum and Natural Gas (dashed line), and the Mining Industries (light line) since 1961. The contributions have been indexed to 1961 (fixed at 100). The estimates were made in 1981 fixed dollars, with intermediate costs subtracted so that estimates of GDP at factor cost are shown. Actual intermediate costs are available and were used from 1981 onwards, but only estimates were available before then. Mining Industries include: gold mines, other metal mines, iron mines, asbestos mines, non-metal mines except coal and asbestos, salt mines, and coal mines. Services Related to Mineral Extraction are not included in Mining Industries nor in Crude Petroleum and Natural Gas. (The Gross Domestic Product at factor cost is: the output of the mine or mill production multiplied by the base year price, less the intermediate costs such as the costs of production and ore or concentrate). Source: Statistics Canada Catalogue 15-001; Input-Output Division. The figure was provided by Jan Zwartendyk, Mineral Policy Sector, Energy Mines and Resources, Ottawa.*

[1] Geological Survey of Canada Contribution No 51588

Service industries are different from traditional industries. Compare those of governments, communication, transportation, public utilities, and finance with manufacturing, mining, construction, agriculture, forestry and fisheries. Employment in service industries is more stable than in manufacturing industries, wages are high where the value added is high, and productivity is high (see Quinn *et al.*, 1987). Service industries are becoming ever more important to the economy.

Are earth scientists still needed by the nation?

Earth Scientists are Needed to Solve National and Global Problems

Canadian reserves of copper, lead, zinc and nickel have decreased in the last few years, and Canadian production of copper, lead and zinc will decline in the 1990s unless some major discoveries are made very soon (Figure 2; Cranston and Lemieux, 1988). Not only has there been a relative decline in the contribution to the economy from the mineral, oil and gas industries, but the pattern of contributions has shifted too. Efforts in mineral exploration in the last few years have been successfully directed toward gold, for example (Zwartendyk, 1987).

We should not be surprised at the changes in our mineral industry. B.J. Skinner (1977) wondered some years ago if Canada could not be compared with any mineral "camp", a big camp, of course, but a camp when all is said and done, evolving, falling, rising again ... with all the natural changes flowing from new concepts, new methods and different economics in the mineral industry.

Changes are restricted neither to Canada, nor to minerals. In the USA, the relative contribution of coal to energy consumption reached a peak in the early part of this century, and the contributions of oil and gas are declining now (Classen and Girifulco, 1986). The green revolution has produced new crops with strange names and remarkable properties — buffalo gourd, a fruit of a trailing vine, crambe, a cabbage, and jojoba and kenaf. PEI potatoes don't sound so exotic. Products from these new crops (I don't mean the potatoes, delicious though they are) contribute to soaps, detergents, lubricants and cosmetics, and to the feedstocks for hydrocarbons and rubber (Hinman, 1986).

Earth scientists are certainly needed to solve the problems of declining reserves and changing circumstances. If Canadians neither exploit primary resources as before, nor inventively add value in new industries based on knowledge, the country will be poor. From a global perspective this may seem to be a narrow, nationalistic view, but we cannot contribute to solving the planet's environmental problems from a weak economic base.

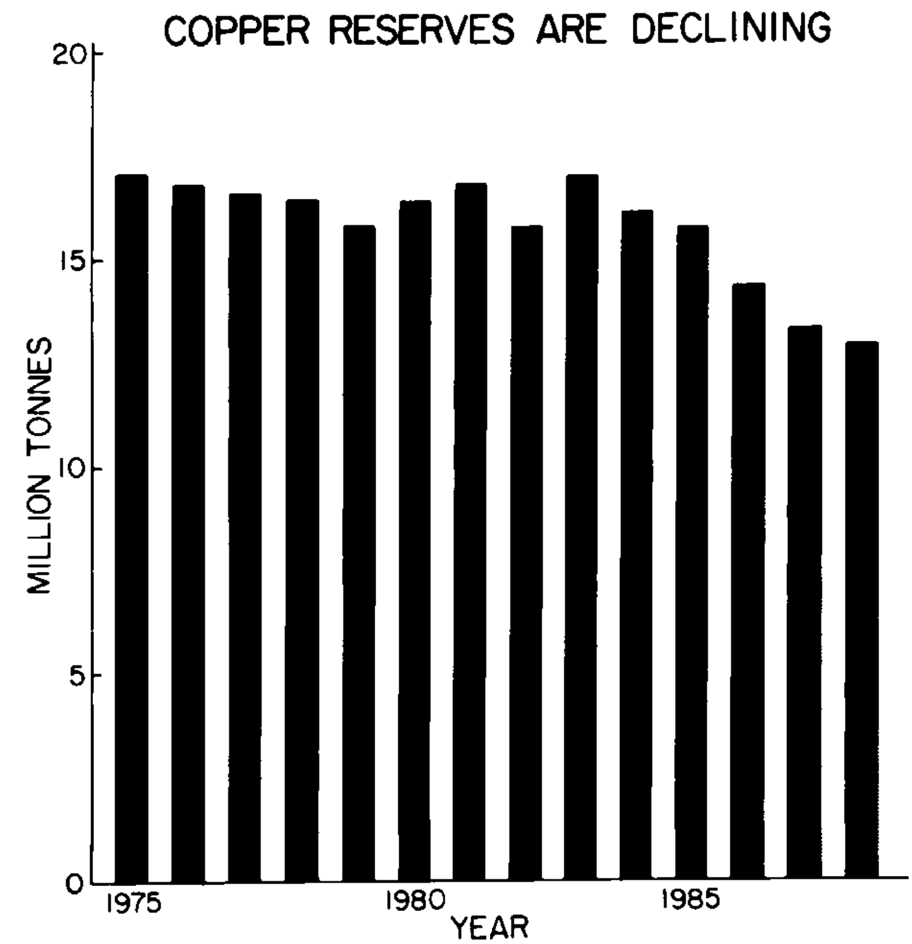

Figure 2 *Canadian copper production in the 1990s will decrease, unless some major discoveries are made soon. The figure shows reserves of copper in proven and probable ore at Canadian mines, and has been redrawn from Cranston and Lemieux (1988, fig 1).*

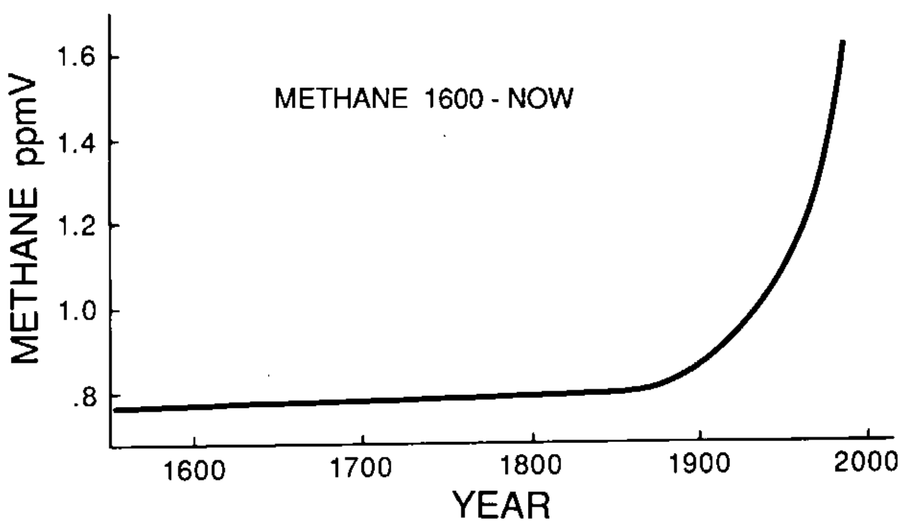

Figure 3 *Un-natural global change? Methane in the atmosphere has been increasing rapidly for about the past two hundred years, and appears to be higher now than at any time in the past 150,000 years (Pearman and Fraser, 1988; Raynaud* et al., *1988).*
The figure has been redrawn schematically from the figure in Pearman and Fraser (1988, p. 489). The concentration of methane now is about 1680 parts per billion by volume; interglacial and pre-industrial levels from ice cores are typically 620-650 and values for the end of the last-but-one glaciation are about 340 parts per billion by volume (Raynaud et al., *1988).*

Old Global Problems now Overwhelm Us

You could be hanged for burning coal as fuel in England in the thirteenth century. The family encyclopedia tells me that "It was burned so inefficiently in those early days, giving off smoke and what were considered poisonous odours, that a great deal of prejudice developed against its use". (Speare, 1960). No one learned from the English king with his drastic penalty.

The earth beneath skies darkened by industrial fumes has less sunlight, and less sunlight means rickets — the childrens' disease of softening bones. More than half the poorest children of the city of Leeds in England had rickets in 1902, but most Canadians only know the disease now by association with descriptive phrases like "ricketty chair". The London skies of English painters turned muddy yellow-brown over the last few centuries. Britain's Clean Air Act of 1956 contained particles, and so sunlight increased, but the Act did not contain SO_2, so acid rain still eats British buildings (Lamb, 1982).

Scripp's Institute of Oceanography had to start sampling the air over Hawaii before the world generally appreciated the potential dangers of CO_2. David Suzuki has pointed out that Canada would be a better place now if we had only acted earlier on Ursula Franklin's Science Council Report of 1978, where strategies of stewardship were all laid out (Franklin, 1978).

Canadians live well, and spend lots of energy in the process: as a result we "exhale" nationally FOUR times the world's average of CO_2 per head. Look at the warning on cigarette packages: what a pity that Health and Welfare Canada does not warn us that the potential damage to others on the globe increases with the amount of CO_2 exhaled!

Evidence of our planetary abuse comes in many forms. Both carbon dioxide and methane are increasing in the atmosphere (Figure 3). Bubbles in ice cores suggest that high concentrations of these greenhouse gases coincided with relatively high atmospheric temperatures in the last 160,000 years, and low levels with low temperatures (Figure 4, and note the caption)(Barnola *et al.*, 1987; Pearman and Fraser, 1988; Raynaud *et al.*, 1988). Carbon dioxide concentrations in the present and previous inter-glacial were in the range 260-280 parts per million by volume. The present concentration of CO_2 is 350 parts per million by volume, higher than at any time since the last inter-glacial.

Atmospheric gases can't be seen, but more visible evidence of abuse is everywhere. The Ecology Action Centre in Halifax tells its readers in its latest newsletter that the sludge on the bottom of Halifax Harbour has been called "black mayonnaise" for a decade now. The CBC's "As It Happens" has interviewed a Massachusetts' Senator who described children making sandcastles on Boston beaches with sewer-borne tampons, and the Senator himself had jogged along a Boston beach, not in sand but in human ... "faeces" is the word I must use here.

We have to have political action, and we are at least seeing budding political appreciation. The Montreal ozone accord has been signed, if not ratified. Ontario first, then Canada, acted firmly on ozone as I was writing, February 1989, and Mrs. Thatcher spoke in favour of nature in September 1988. Canada acted as host last year to an influential conference on our Changing Atmosphere (Morgan, 1988). A new US Administration may be sympathetic to working with us to solve both nations' problems from acid rain. *The Economist* of London illustrated with a green front cover in October 1988 the political change in environmental colour, the Paris monthly *Le Monde Diplomatique* devoted its issue of October 1988 to our ransacked globe, "La Planète Mise à Sac", and the *Bridgewater Bulletin* in Nova Scotia reports weekly in its "Forum on Pollution". Would you buy property on the LaHave River if the beaches were closed to swimming because of Bridgewater's wretched sewers?

Perhaps earth scientists are needed after all, to help solve these global problems?

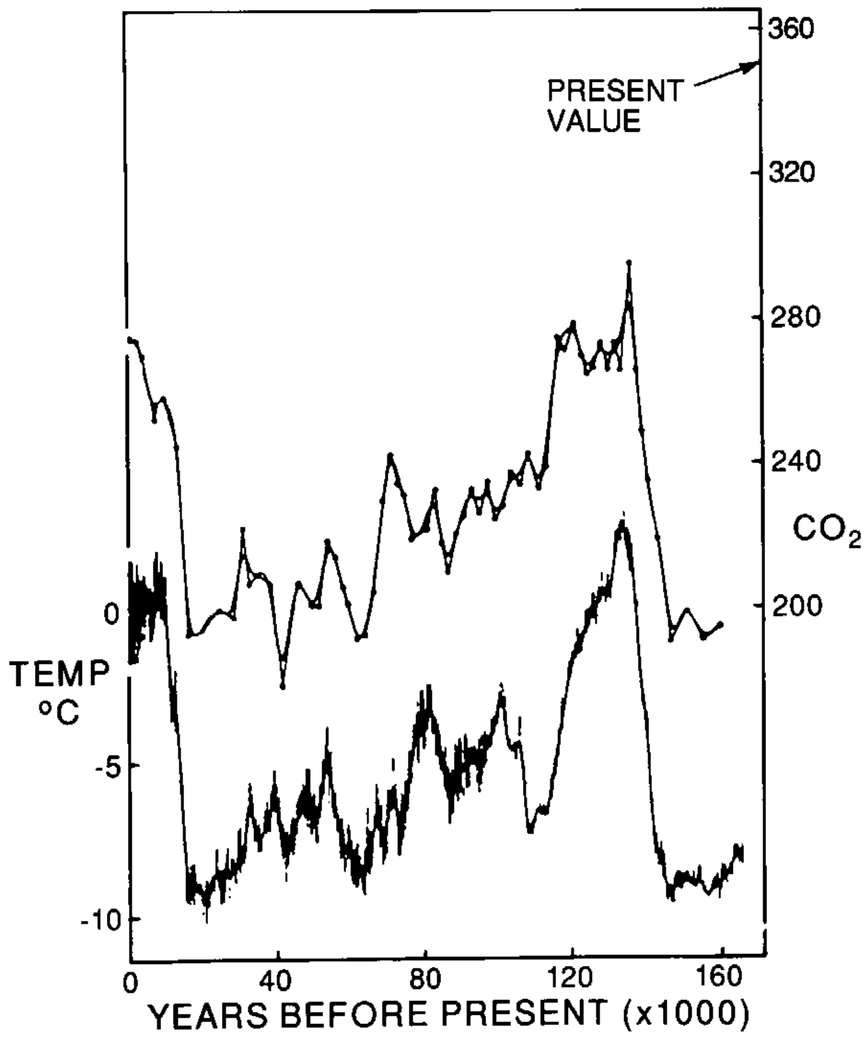

Figure 4 *Un-natural global change? Carbon dioxide in the atmosphere now may be much higher than at any time during the last 160,000 years. The evidence from the Russian Antarctic Vostok ice core suggests that high concentrations of carbon dioxide in the atmosphere were associated with high atmospheric temperatures and low concentrations with low temperatures during the last 160,000 years. The present concentration of carbon dioxide is 350 parts per million by volume (arrow).*

This figure has been redrawn from figure 2 of Barnola et al. *(1987, p. 410). Carbon dioxide concentrations in air bubbles in the ice were measured; temperatures were estimated from the ratio of deuterium (H^{2+}) to hydrogen (H^+); ages follow the scale of Lorius* et al. *(1985), not accepted by everyone (see e.g., Sundquist, 1987). The reader is warned that interpretations of ice core isotopic data (and indeed of isotopic data from marine sediments) is in a state of flux: see e.g., Craig (1988) and Petit* et al. *(1988). The atmospheric concentration of CO_2 now is about 350 parts per million by volume (Hengeveld, personal communication, 1989); the values typical of an interglacial (like the one we are now in, but before industrial contamination) are 260-280, and of a glacial period 190-200 (Anon., 1987; Barnola* et al.*, 1988). Note that values in the period 200 AD to 1800 AD (younger than the youngest air bubbles reported by Barnola* et al.*, 1987) apparently ranged from about 230 to about 310, with a mean value of about 280 parts per million by volume (Anon., 1987; Webster, 1985).*

Global Problems demand Creative Scientific and Technological Solutions

No one can escape. The sewer-borne problems of the St. Lawrence, of Halifax Harbour, of Bridgewater's LaHave River, and ... and ... and .... are simply local manifestations of our global nightmare. Any global rise in sea level — if there is a global rise in sea level — will affect Third World nations at least as much as us.

Some solutions are certainly political, and as a public servant I can't write about them. Taxes in Boston for better sewers will soon be as high as the normal property taxes, said the Senator from Massachusetts on CBC Radio. Taxes are political. But many solutions are scientific or technological.

If fossil fuels have to be burned for energy, shouldn't the most efficient be used in terms of CO_2 emitted? If coal is used, geologists must find coal with little sulphur, or technologists must extract the sulphur and other harmful elements before they escape. If we are to burn nuclear fuel we must use reactors which are acceptably safe, and develop ways to package and store their wastes for very long periods of time. Perhaps we have to develop a new code of ethics for mineral exploration: a deposit is not economic until we know what to do with the wastes which will be generated when it is extracted ... ? Perhaps we need a code of ethics for chemists: a new plastic is not economic until we know what to do with the wastes which will be generated when it is manufactured and used ... ?

An illustration of the mix of talents and approaches needed comes from one aspect of the carbon dioxide problem — how much produced industrially can the oceans absorb? Part of the answer will come in understanding the oceans' biological productivity. Carbon from the atmosphere is fixed by ocean plants in photosynthesis in the ocean's photic zone. How much sinks from this surface layer into the deep ocean, and is in this way removed from the ocean-atmosphere system for long periods of time? (see *e.g.*, Platt *et al.*, 1989). This problem illustrates the difficulty of formulating working models of the earth, which we need if we are to manage it properly in the years to come. Platt *et al.* tell us at the beginning of their paper:

> "Notwithstanding that it is the principal source of organic carbon for the support of the entire marine ecosystem, the magnitude of primary production in the ocean is still disputed to within a factor of 10."

Problems like these surely matter. If you were empress or emperor of the world and had to feed 5 to 10 billion people wouldn't you want to know about the physical environment of your home? How otherwise could you formulate your strategies for feeding, clothing, sheltering and succouring your children everywhere? Wouldn't you need to know if the oceans and atmospheres have surprises in store, as many studying the last de-glaciation warn us to beware? (See *e.g.*, Broecker, 1987; Lewis *et al.*, 1988). Problems like these are difficult to solve. Creative, talented earth scientists are needed. Can they be motivated to tackle the problems?

The Individual is at the Cutting Edge of Creativity

The soul of intellectual enterprise is the creative individual, finding joy in discovery.

Stephen Gould, the paleontologist, says it well. He is speaking of his work on the snail *Cerion* which provides:

> " ... insight into what may be the most difficult and important problem in evolutionary theory: How can new and complex forms (not merely single features of obvious adaptive benefit) arise if each requires thousands of separate changes, and if intermediate stages make little sense as functioning organisms?"

Gould tells us:

> "I chose *Cerion* because I thought it might illuminate these large and woolly issues. Yet, although they lurk always in the back of my mind, they are not the source of my daily joy Little predictions affirmed or small guesses proved wrong and exchanged for more interesting ideas are the food of continual satisfaction. *Cerion*, or any good field project, provides unending stimulation, so long as little puzzles remain as intensely absorbing, fascinating, and frustrating as big questions."

He describes the thrill of discovery — a prediction confirmed:

> "I wanted to shout for joy. Then I thought, 'But who can I tell; who cares?' And I answered myself, 'I don't have to tell anyone. We have just seen and understood something that no one has ever seen and understood before. What more does a man need?" (Gould, 1987, p. 182-183).

The British Nobel Medallist P.B. Medawar never aged in spirit, and wrote of the joy of daily re-birth only two years before he died:

> "No working scientist ever thinks of himself as old, and so long as health, the rules of retirement, and fortune allow him to continue with research, he enjoys the young scientist's privilege of feeling himself born anew every morning." (Medawar, 1986, p. 179).

Many Canadians must listen to the CBC radio programme "Quirks and Quarks". We heard in September 1988 of the discovery of "sighted" shrimps near hot ocean-floor hydrothermal vents.

Cindy van Dover, Wood's Hole Oceanographic Institution, and her colleagues Ete Szuts, Steven Chamberlain and Joe Cann showed that a shrimp recovered from the Mid-Atlantic Ridge was not sightless, as the water depths demanded, but could "see" (Van Dover *et al.*, 1989; Pelli and Chamberlain, 1989). They discovered organs which are primitive light-receptors with reflective backings, connected to optic nerves leading to its brain, and found this out by asking questions not posed by others. It would have been simple to have argued that the shrimp could not see because the water was so deep, and no light could penetrate from the sky, and so let us choose another problem. They asked instead: "What are these organs? Are they eyes?" — a falsifiable hypothesis. This led to the discovery of the shrimps' light-sensitive receptors, and so to the next simple question: "What do they look at?" As a result, John Delaney of the University of Washington and his colleagues used the submersible ALVIN on the Juan de Fuca Ridge to look for light associated with hot vents on the sea floor. They saw nothing with their *eyes*, but were equipped with a video-camera sensitive to wavelengths approaching the *infrared*, and on this they saw a glow from the waters of the vent.

Perhaps the shrimps' sensors which Van Dover and her colleagues discovered tell them when they are on the point of being cooked in hot vent water, on the point of becoming an exotic dish, *crevette à l'évent*. This ability must be an evolutionary advantage.

Isn't this a case example of good science? A bright, creative individual, curious, sharp, and laterally thinking, chose to work in a potentially fruitful field with other smart people. The linear thinking, the straight line thoughts, would perhaps have been: " ... deep water ... dark ... no light ... no eyes ... curious ... abandon ... on to next feature". And an advance would have been lost.

Bell Labs, the research arm of AT&T, played a role in all this. The video-camera was fitted with the charge-coupled device invented some years before by Willard Boyle and George Smith of Bell Laboratories, and a scientist from Bell Labs pointed out to Van Dover that the device would be sensitive enough for the work on the Juan de Fuca Ridge.

Are these attitudes of curiousity and caring of Gould, Medawar, Van Dover and her colleagues not those which all creative individuals must have? Three C's creative, curious, caring. And must have every day, if discoveries are to flow freely?

Luck often plays a part. Russell Ohl of Bell Labs discovered the principle behind solar cells when one New Jersey day a fan chopped the light between a bench lamp and a cylinder of silicon hooked up to an oscilloscope. Ohl saw that the voltage measured by the oscilloscope mimicked the oscillations of the fan (Bernstein, 1984, p. 74). Again, a graduate student poured much more mixture than a recipe demanded, and so discovered conducting plastics (Kaner and MacDiarmid, 1988). But "lucky scientists are usually talented, as well as lucky. P.B. Medawar wrote (1979): "Pasteur is well known to have said that fortune favours the prepared mind, and Fontenelle observed, 'These strokes of good fortune are only for those who play well!' "

The global problems I have mentioned were discovered by creative curious individuals simply wondering and caring about the Earth. We need such people. The problems are difficult to solve because the Earth is complex, and so much is poorly understood.

We need such people to help solve the problems they discovered. Directed programs of applied research would surely not be enough to discover the solutions? Programs restricted geographically would surely not be adequate?

Problems afflicting the whole world obviously cannot be solved within national boundaries, nor by nations working alone. We have to be part of a global community solving global problems, and plugged into the global knowledge network.

We want creative, talented individuals all over the world to work towards the common good. Management must see that the conditions are right.

The Field has to be Right for the Employer, and for the Scientist

Employers care about "bottom lines" which are seldom "understanding". They don't usually want the discoveries for their own sakes. AT&T, the owner of Bell Laboratories, wanted a successor to the vacuum tube to improve and develop their trans-continental networks of telephone lines. Nobel Prizes and confirmation of the Big Bang were surely bonuses? I quote Jeremy Bernstein from his account of Bell Labs (Bernstein, 1984, p. 73):

> "By the early 1930s engineers at Bell Labs realized that the practical limit to vacuum-tube technology had been reached ... they were still unreliable, expensive, and bulky; and some sort of solid-state device would have to replace them."

What did management do?

> "In the mid-1930s a program in solid-state physics was inaugurated, and in barely a decade it produced, among other things, the transistor. One of its remarkable side effects was an accidental discovery made in 1940 by Russell Ohl".

I have mentioned him already — he discovered the principle behind the solar cell.

But who started this program in solid-state physics?

Some Nobel Prize Winners become household names — Dirac, Feynman, Alvarez ... . Nobel Prize Winners in physics from Bell Labs include Shockley, Bardeen and Bratain for the transistor, and Penzias and Wilson for cosmic background radiation. Who remembers that in 1936 (Bernstein, p. 85):

> " ... Mervin J Kelly, who was then the director of research at Bell Labs, began to hire what would now be known as solid-state physicists. He assembled a small group ... Their job was to learn about the physics of the solid state, in general, with the vague hope that whatever came out of their effort might be useful for communications and, in particular, for the telephone business. What came out of it, among other things, was the transistor."

Kelly saw the direction, and hired the Nobel Prize winners. Is this not a lesson for good management? See that the best decisions are made on the general fields to enter, then hire the best, and leave them alone. The trick is, of course, deciding on the field to enter. The British did the same sort of thing at the same time, only their guru was Lindemann, later Lord Cherwell and an adviser to Sir Winston Churchill. The physicist Mott writes in his autobiography:

> "In 1936 he [Lindemann] and others were concerned at this country's neglect of fundamental work on the behaviour of electrons in metals, and persuaded the Council that something ought to be done about it. My predecessor Lennard-Jones was told that he would receive the necessary funds if he would undertake to devote some of his time to the subject. This was hardly to be refused ..." (Mott, 1986, p. 46).

Central agencies in two strong scientific nations followed good advice and promoted solid state physics for corporate ends. Management at Bell Labs found the right field to enter, and then motivated creative individuals to solve the organization's problems.

Management must see that the right fields are chosen.

Global Problems may be too Complicated for Vertically Integrated Organizations

Global problems are not so different in principle from the problem of finding the replacement to the vacuum-tube amplifier. Bell Labs' parent AT&T was vertically integrated, with units ranging from pure research to the manufacture of telephone sets, but the solution to the problem of the vacuum tube was not a "straight line" problem at all, because the source of the solution could only be hazarded. Many teams across many disciplines contributed to the solution to the discovery of the transistor, the solution to a particular problem, and contributed to the many serendipitous discoveries made on the way. Bernstein (1984) tells us that Bell Labs demanded cross-talk between individuals, and theoreticians and experimentalists were made to work together.

"Vertical" organizations dominate our lives. Government Departments of Forestry, of Mines, of Tourism ... . University Departments of Physics, of Chemistry, of Geology ... . Organizations like these resemble "integrated" oil companies, devoted to one end, and superb at dealing with a single piece of business. In the case of the oil company, the single end is the profitable, socially responsible marketing of hydrocarbons, and all the right structures will be in place for exploration, acquisition of land, exploitation, refining, transportation, marketing and so on. But what if the business ceases to be singular, and becomes complex, a mélange of issues?

The vertically integrated organization is not very well set up to do business outside its mainstream, and other sorts of organizations may be needed. Our global problems are complex, and we have few organizations established to cope with them.

Society's problems are "horizontal" — they are issues which cut across all the "vertically" integrated departments and companies, states, provinces and nations. A nation's energy policy in fact depends as much on its environmental and conservation policies as it does on technical capabilities or on endowment in oil, gas and hydro. The sources of the methane increasing in the atmosphere may be livestock and insects, rice fields and natural wetlands, biomass burning, land fills, gas and coal fields, and methane hydrates. The relative sizes of these potential sources are surely not well known, and finding out will demand competence in many disciplines. Don't we need to learn to cope with horizontal problems? Will geology departments whose graduates cannot cope with physics, chemistry, biology and mathematics survive in their professional lives? Will industry survive without well trained, broadly trained graduates in the century to come? Perhaps global problems demand the devotion of all the world's best scientists and technologists from across all fields.

Management has to see that the organization is right.

Time is Short: We need Talents at the Cutting Edge

We don't have much time, do we? Until now we could luxuriously wait for new paradigms to overwhelm conservatism afraid of drifting continents or of an expanding universe. We have had time to invent transistors to replace vacuum tubes, time to replace hand-pumps by windmills by steam engines by .... We have always had time to wait for ideas gestating to burst at their ripe moment. Until now.

The traditional motivation of the first-class scientist is the excitement of discovery, and good managers make sure that the needs of the organization and the individual coincide. Individuals solving scientific problems receive Nobel Prizes and other rewards to celebrate their talent. The owners of companies which employ them become rich. The contributions to the national and international "good" enrich all society. Perhaps now we need proper rewards for scientists and technologists and managers who use their creative talents to see that the world survives? The task of good management is still to see that the needs of the organization and the individual coincide. And must surely be done now?

Conclusions

Good scientists and engineers of all sorts are needed to bring good science and good technology to Canadian and to global problems, now. The problems include the traditional and important economic problems to which scientists and technologists have always had to devote attention. Canada must be able to afford to contribute to solving the potentially life-threatening problems involving the whole planet.

The problems demand the best basic science, the most imaginative technology, and extraordinary management. The problems are global, and the solutions will be found by working globally, not parochially. The solutions to the problems demand a scientifically literate population which can understand, and well-trained talented people doing the work. Education is extraordinarily important. Canadians from all sectors of science and technology will have to work together.

The problems are difficult — they demand attention and co-operation from all creative, curious and caring individuals in whatever estate of science or technology we may be. The Earth was full of surprises in its natural state before our race began the great geophysical experiment, and the Earth may be full of other unexpected un-natural surprises on account of our messing with the atmosphere, the biosphere and the oceans. We don't yet know how the Earth works, so we cannot forecast what will happen.

Our minds have been enlarged through the works of individual creative scientists, mathematicians and technologists. Can we not find ways to channel this talent into saving the world so that our children and our grandchildren can still share the world's physical beauty, and still share our species' intellectual glory? Don't smart earth scientists have more than ever to contribute to society? Urgently?

Acknowledgements
Jan Zwartendyk and Donald Cranstone of the Mineral Policy Sector of the Department of Energy, Mines and Resources, Ottawa were very helpful in providing advice, information and figures related to the mineral and petroleum industries. Cindy Van Dover kindly described the exciting discoveries she and her colleagues were making when I phoned. Jennifer Bates, Ward Neale and Chris Findlay carefully read early drafts, and Chris Barnes pointed out that we do not now have the luxury of time. Comments and suggestions from David Sinclair and David Ross were helpful. The hospitality of the Department of Oceanography at Dalhousie University during the winter of 1988-89 has been warm, and is appreciated.

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