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Government geoscience to support mineral exploration: *public policy rationale and impact*

PREPARED FOR

Prospectors and Developers Association of Canada

BY

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The Prospectors and Developers Association of Canada (PDAC) is a national association that exists to protect and promote the interests of the Canadian mineral exploration sector and to ensure a robust mining industry in Canada. The association encourages the highest standards of technical, environmental, safety and social practices throughout Canada and internationally.

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Introduction

The geoscience knowledge provided by federal, provincial and territorial governments as a public good is widely acknowledged to be one of Canada's competitive advantages in attracting mineral exploration and to have contributed to this country's standing as a leading mineral producer. Nevertheless, total geological survey expenditures are now less than 60 percent of 1980s levels in inflation-adjusted terms. As governments move into deficit in the wake of the recent recession, survey budgets will likely come under renewed pressure. This paper reviews the public policy rationale for government geoscience and its impact on mineral exploration, and concludes that a more robust public effort will be needed as part of a strategy to deal with deceasing rates and increasing costs of mineral discovery.

Public policy rationale

Governments need geoscience information to formulate and implement public policies in such areas as resource development, environmental protection, public health and safety, land use, and infrastructure planning. Governments can choose among a variety of institutional arrangements to satisfy their requirements for geoscience. These include units within government ministries; agencies which operate at arms length but remain accountable to ministers; and reliance on non-governmental sources. Each option involves trade-offs in terms of accountability, credibility, effectiveness, and efficiency. Most governments in Canada, as elsewhere, have established geological survey organizations to meet their geoscience needs, and the majority of these are integral parts of government departments.

Most mineral resources in Canada are public assets and governments have determined that the responsible development of these resources is in the public interest. Moreover, because much of the geoscience information that underpins exploration has the economic characteristics of a public good, the provision of public geoscience to stimulate exploration is a key element of federal, provincial and territorial mining strategies.

The role of government geoscience in mineral exploration

Mineral exploration and development differ from most other economic activities in three important respects: the location is constrained by geology; the long duration means that the time cost of exploration greatly exceeds the nominal cost; and the high risk means that companies must spend several times the average discovery cost to have a reasonable probability of success. Government geoscience mitigates each of these challenges. First, it attracts exploration investment by allowing industry to identify areas of favourable mineral potential. Second, public geoscience increases exploration efficiency by making it unnecessary for individual companies to duplicate common information or to spend money on non-prospective ground. Third, it increases exploration effectiveness by providing key information inputs to risk-based decision-making. By reducing exploration costs and risk, public geoscience not only improves returns on private investment but also increases revenues accruing to governments as royalties and taxes.

Telling the performance story

Government provision of public geoscience is predicated on the expectation that it will lead to more and better mineral exploration, which results in discoveries, development and production, and ultimately in economic prosperity. In progressing from the outputs of government surveys through exploration and development to production and economic development, the extent to which results can be attributed to government action diminishes. This, together with the long time frame and high risk of exploration, discovery and development, makes rigorous and accurate cost benefit analysis of government geoscience very difficult. The preferred approach is to develop a credible performance story demonstrating the cause and effect relationship at each step in the process.

There is ample evidence that government geoscience stimulates private sector exploration. Program evaluations suggest that 6 of 10 mapping projects will have immediate impact in terms of claim staking or new exploration activity. The incremental exploration expenditures resulting from new public geoscience are more difficult to quantify and depend on location and timing in the business cycle of government action. Nevertheless, the often cited rule-of-thumb that $1 in government spending results in $5 in private sector exploration appears to be a reasonable expectation over the medium term.

Mineral industry users of geoscience data are almost unanimous in their view that government geoscience increases exploration efficiency and effectiveness, but there have been few efforts to quantify these impacts. Surveys of diverse user groups suggest efficiency improvements of 5 to 20 percent, but the impact could well be greater in the early stages of mineral exploration. The impact on exploration effectiveness is even more difficult to quantify. Anecdotal evidence suggests that government geoscience has contributed to many discoveries, but this does not reflect the contribution of public geoscience to the quality of day-to-day decision-making in exploration. Quantitative measurement of the impact of public geoscience on the effectiveness of exploration and in reducing discovery risk would be a fruitful area for further research.

The magnitude of tax revenues from mining is one indicator of society's return on government investment in public geoscience. The Mining Association of Canada estimated that revenues accruing to Canadian governments from 2004 to 2008 from mining as royalties, corporate and individual income taxes averaged $5.5 billion/year. Federal, provincial and territorial geological survey expenditures to promote exploration averaged $80 million over the same period, or just 1.5 percent of revenues.

How much government geoscience is enough?

Governments seek to sustain or increase mineral production in existing mining camps and to promote new economic development, especially in areas with few other potential sources of prosperity. Economic analyses have shown that the provision of public geoscience can be one of the most effective policies to promote mineral development. Although the amount of public geoscience necessary to achieve this goal is not readily predicted, the evidence suggests that the level of expenditures in Canada has been insufficient in recent years. Mineral discovery rates have decreased over the past three decades and discovery costs have increased. This has contributed to declining production and reserves of several important metals.

Government spending on geological surveys has decreased substantially over the same period. Despite recent increases, average annual expenditures during the 2000s were much less than during the 1980s, both in constant dollar terms and as a percentage of the value of mineral production. Canada's federal, provincial and territorial governments collectively spent $1.9 billion less on their geological surveys than would have been the case had budgets been sustained at 1980s levels and adjusted for inflation.

While it might be tempting to attribute decreased exploration success to lower geoscience expenditures, correlation does not necessary equate to causation. Public geoscience is only one of many factors that influence exploration success. Reducing the costs and risks of discovery will require new technologies, improved exploration management practices, and enhanced geoscience knowledge, including public geoscience.

This study does not prescribe an optimal level of government geoscience expenditure. Rather, it suggests that this be determined through a Canada-wide assessment of public geoscience needs in the context of a broader dialogue about improving exploration performance. This assessment should not only evaluate the adequacy of "conventional" regional map coverage, but also anticipate the requirements for public geoscience that will promote the effectiveness of deep exploration.

1. Introduction

Background and purpose of study

Geoscience provided by governments as a public good has long played an important role in fostering a competitive investment climate for mineral exploration. The information generated by Canada's federal, provincial and territorial geological surveys is widely acknowledged to be among the best in the world and to have contributed to this country's standing as a leading mineral producer. Nevertheless, government expenditures on geoscience to promote mineral exploration decreased significantly during the 1990s, in the face of ballooning government budget deficits. Along with across-the-board budget cuts, the federal-provincial Mineral Development Agreements, which had funded a significant amount of exploration-related geoscience for more than a decade, were allowed to lapse.

Concerned by the impact of reduced budgets on Canada's ability to attract exploration investment, the Prospectors and Developers Association of Canada (PDAC) became a strong advocate for geoscience and played a crucial role in reversing the decline in geological survey spending. Notwithstanding subsequent budget increases, however, government geoscience expenditures remain much lower in inflation-adjusted terms than during the 1980s. Moreover, they are likely to come under renewed pressure in the face of government deficits resulting from the recent recession. Given that PDAC believes that a sustained public geoscience effort will be essential to future exploration success, it commissioned this review of the public policy rationale for government geoscience and, in particular, the evidence that it does indeed accomplish its objectives.

Governments are constantly evaluating priorities, reviewing existing programs, considering new initiatives, and re-allocating resources accordingly. This self-examination is particularly intense during periods of deficit spending. These program reviews typically address a series of questions, including:

- Is the program needed?
- Is the program an appropriate role for government?
- How is the service best delivered?
- What level of service is both necessary and affordable?

This report is loosely structured around these four questions. Chapter 2 outlines the public policy rationale for government geoscience in broad terms: why is it needed and why should government play a role? Chapter 3 reviews the origins of geological surveys and, in particular, budget trends and developments in service delivery over the past three decades. Chapter 4 describes how government geoscience contributes to successful mineral exploration. Chapter 5 – "Telling the Performance Story" – reviews the evidence that government geoscience has the desired impact on exploration success and, by extension, on government policy goals. Chapter 6 addresses the last of the four questions – how much government geoscience is enough and why is a more robust effort needed now?

Terminology – government geoscience, public geoscience, geological surveys

"**Geoscience**" is used in this report to refer broadly to geological, geophysical and geochemical data, information and knowledge. It may exist in a variety of forms ranging from conventional maps and reports to electronic files to the tacit knowledge residing in the heads of experts. It includes exploration assessment files as well as collections of rocks and other geological materials (*e.g.*, as in drill core repositories maintained by some agencies).

Although often used interchangeably, the terms "**government geoscience**" and "**public geoscience**" have specific and distinct meanings in this paper. The former includes all the geoscience knowledge acquired by or on behalf of government agencies whereas "public geoscience" includes only that made available as "a public good". The characteristics of public goods are reviewed in a subsequent section, but suffice it to say that geoscience knowledge that is made available without restriction and at nominal or no cost falls into this category.

The term "**geological survey**" is used here in the generic sense to denote a government organization whose principal *raison d'être* is the collection and dissemination of geoscience information, whether or not the words appear in its formal name. Government organizations other than geological surveys occasionally collect geoscience information for specific purposes. For the most part, this report deals with Canada's federal, provincial and territorial geological surveys as a collectivity. This is especially the case in the discussion of expenditure trends: spending may have increased in certain jurisdictions whilst cumulative spending was decreasing, and vice versa. Similarly, specific observations may apply more to some jurisdictions than to others.

The words "**data**", "**information**" and "**knowledge**" have distinct meanings for the information scientist. They represent a hierarchy of increasing analysis and interpretation. Geological surveys produce all three. For example, observations made by a geologist on an outcrop are data, the geological map resulting from assimilation of these data is information, and an interpretation of the map in terms of plate tectonics is knowledge. Although important in certain contexts (see, for example, Reedman *et al.*, 2002, p.8), the distinction is not made in this paper, except where indicated.

2. Public policy rationale for government geoscience

Introduction

Most countries have a government geological survey or equivalent organization[1]. Moreover, federations such as Canada, the United States, Australia and Germany generally have surveys at both the national and state or provincial levels. Price (1986) succinctly expressed the underlying reason for this:

“To govern, governments need information”

Governments use geoscience knowledge to meet two broad objectives:

- To inform policy decisions bearing on natural resources, environment, health and safety, trade, and national security, among other issues. The principal clients for information are within the government and, in this respect, geoscience is similar to other policy advice, which may or may not be accessible to those outside government.
- As a means to implement policies on a similar range of issues. In this case, the target audience for the geoscience is outside of government – in industry, in civil society, and the general public. This geoscience knowledge may or may not be provided as a public good; the distinction is important and will be examined in some detail below.

This chapter examines this dual role of government geoscience. First, however, it is appropriate to define what is meant by “public policy”. According to one widely quoted definition, it is *“a course of action or inaction chosen by public authorities to address a given problem or interrelated set of problems”* (Pal, 1992). The reference to inaction is not facetious; sometimes government’s best option is to do nothing. Drechsler (1982, p.34) put it more simply: *“public policy is whatever a government chooses to do or not to do”*.

Policy-making in government proceeds on several levels. Legislation and regulation lie at one end of the spectrum. In both cases, the process provides opportunities for public input and debate. Decisions within a Minister’s mandated authorities, which are set out in existing legislation, are at the other end of the spectrum. In the middle are major new policies and expenditures, which require cabinet approval. These are subject to a formal and often protracted process involving interdepartmental consultation and ultimately a Memorandum to Cabinet.

At its core, a policy is a decision. Policy analysis involves weighing the economic, environmental, and social consequences of the various options available to address a particular issue. Sound policy analysis is based on a diverse array of knowledge including, in some cases, geoscience.

Government geoscience for policy formation

Geoscience is most frequently brought to bear on policies concerning natural resources, not only their development, but also issues related to technology, trade and taxation. Government geoscientists are also called upon to provide advice on questions of public health and safety, particularly with respect to natural hazards, as well as national defence and sovereignty. Input on environmental issues such as climate change, environmental impact assessment and toxic substances has become increasingly important. Some examples of the most common geoscience-policy linkages are described below, but this is not an exhaustive list. Although the importance of these issues varies among jurisdictions and over time, most geological surveys in Canada have had some involvement in most of these areas.

Resource Development

Geoscientific understanding of resource endowment influences a government’s position on resource development as part of an overall industrial policy. For example, does resource potential justify government action to promote development? Action might include tax provisions, building public infrastructure, regional development initiatives, investment promotion, and so on. Are the potential benefits worth the expenditure of taxpayer dollars and political capital?

[1] The database maintained by EuroGeoSurveys currently lists more than 150 national geological surveys.

Resource endowment is also a consideration in the geopolitical context. Strategic resources are those for which domestic sources are insufficient to meet a country's needs in the event of an international crisis. Geological surveys are periodically asked to address the adequacy of the country's resources to meet domestic needs in the event of disruption of foreign sources. This was the case after the oil shocks of the 1960s, 1970s and 1980s. Because Canada is a major exporter of energy and minerals, Canadians are perhaps less concerned about resource adequacy than are citizens of countries that are major commodity importers. The United States Geological Survey, in particular, is well known for its ongoing assessment of global mineral and energy resources.

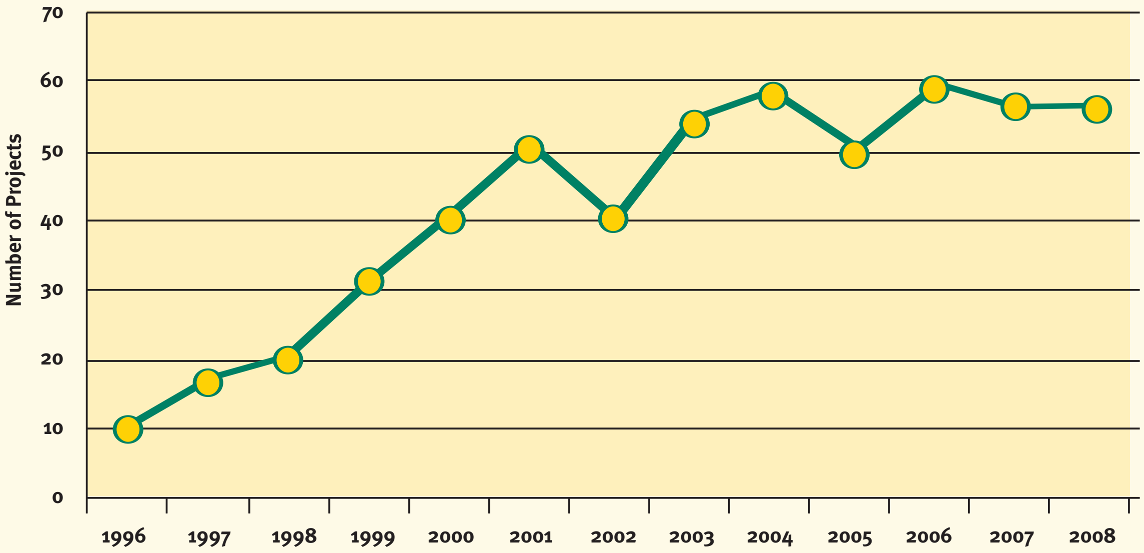
Land use

Governments seek to balance the economic, environmental and social considerations in making land use decisions. Geoscience is especially important in decisions to set aside land for parks and other protected areas. A longstanding example is the federal Mineral and Energy Resource Assessment (MERA) process, which is mandated by the National Parks Policy and the National Marine Parks Policy. Ministers consider the resource assessments made by government geoscientists in deciding park locations and boundaries. Several provinces and territories have undertaken major resource assessments to support land use designations including, for example, Ontario (Lands for Life), British Columbia (CORE), Saskatchewan (Representative Areas Network), and Yukon (Protected Areas Strategy). Resource assessment is only one application of geoscience in land use planning. In New Brunswick, for example, the Geological Surveys Branch produces geological maps of major municipalities for urban planning purposes, and provides advice to coastal communities about shoreline erosion.

Exhibit 1: Geoscience input to federal environmental assessment

- Demand for geoscience input to environmental assessment of major projects has grown substantially since the implementation of the Canadian Environmental Assessment Act in 1995.
- In 2008-2009, a typical year:
  - Input to 56 assessments, including 18 mining projects, 9 infrastructure projects, 9 nuclear projects, 7 oil and gas projects, 7 power generation projects, 3 water supply projects, 1 urban waste project, and 2 others.
  - Examples include La Romaine and Lower Churchill hydroelectric projects, Prosperity and Mt. Milligan mines, Bruce nuclear plant, and Mackenzie Valley gas pipeline.
  - More than 180 requests for geoscience input from 14 different federal departments and agencies.
  - Involved 37 scientists for periods ranging from a few hours to several months.

Growth in GSC environmental assessment activity



Aboriginal land claim negotiations

The settlement of land claims has been a pre-occupation of governments and aboriginal groups in Canada since the mid-1970s. Unsettled comprehensive and specific claims number in the hundreds. Geological surveys in most Canadian jurisdictions have been called upon to provide advice on resource values, which are often a key consideration in negotiations.

Environmental impact assessment

Environmental assessments of major engineering projects are required by both federal and provincial jurisdictions, and geoscience advice is required to adequately review proponents' submissions. The involvement of government surveys in this issue has grown significantly over the past fifteen years. Exhibit 1 illustrates the amount and scope of environmental assessment activities in the Geological Survey of Canada.

Safety and Health

Natural hazards pose a threat to both people and infrastructure. Geological natural hazards include earthquakes, tsunamis, landslides, volcanic eruptions, and magnetic storms. Government geoscientists often play a lead role in hazard assessment and are called upon to provide advice on mitigation measures (*e.g.*, building codes, zoning) as well as on emergency response plans. Understanding the hazard posed by exposure to naturally occurring toxic substances is one example of the application of geoscience in the area of public health.

Water

The quantity and quality of water resources may well become the most prominent resource issue of the 21st century. Canadians have historically been somewhat complacent about their freshwater resources, fuelled in part by the misleading perception that a quarter to a half of the global endowment occurs here. Notwithstanding the fact that 30 percent of the Canadian population relies on subterranean sources for potable water, the volume and vulnerability Canada's groundwater resources remain poorly understood. Geoscience plays a vital role in understanding groundwater supplies and most of Canada's geological surveys have experienced a growing demand for input to government decision-making.

Climate change

There is an international consensus that the climate is warming and that human activity has made a significant contribution to this trend. Geoscience played an important role in elucidating prehistoric climatic variations, which has helped calibrate models of recent and future climate trends. Going forward, geoscience information on a local, regional and national scale will be required to allow Canadians to adapt to the changing climate. For example, the Geological Survey of Newfoundland and Labrador provides a long-term perspective on sea level changes and the NWT Geoscience Office is building capacity to address permafrost issues. Geoscience will also underpin the success of carbon sequestration, an important mitigation strategy.

Government geoscience in policy implementation

Although geoscience is used to implement policies in most of the areas described above, this section focuses on mineral resource development. Most mineral resource rights in Canada are vested in the Crown, which implies a duty of stewardship. Governments in Canada, without exception, have determined that the responsible development of mineral resources is in the public interest. The reasons for this are straightforward. Mining creates wealth. Ownership of most mineral resources is vested in the Crown, meaning that society has a stake in the economic rents that accrue. More importantly, the mineral industry is a source of employment, capital investment, export earnings, and tax revenues. Some salient statistics are given in Exhibit 2. Distributional benefits are an important consideration; that is, exploration and production offer opportunities for economic development in rural and remote parts of the country and to aboriginal Canadians. Notwithstanding the fact that most exploration and mining occur far from major urban centres, these also benefit considerably from the mineral industry. This is indicated, for example, by the importance of mineral commodities to the transportation sector, and of mining to the equity markets.

Exhibit 2: Contribution of mining to the Canadian economy

Contribution to GDP	**$40.3 billion**
Contribution to Exports	**$75.2 billion**
Capital Expenditures	**$8.9 billion**
Exploration Expenditures	**$2 billion**
Foreign Direct Investment in Canada	**$40 billion**
Total Tax Revenues to Governments	**$5.5 billion**
Royalties and Equivalent	**$1.3 billion**
Federal Share of Total Tax Revenues	**54%**
Rail Freight Revenues	**55%**
Volume of Shipments Through Canadian Ports	**70%**
TSX Share of Worldwide Mining Equity Transactions	**81%**
Employment	**358,800**
Number of Mining Communities Across Canada	**115**

Annual values averaged over 5 years (2004 – 2008). Data include metallic and non-metallic minerals, but exclude oil sands mining. Royalties are also included in total tax revenues.

Source: Mining Association of Canada Facts and Figures, 2009.

The mineral policy statements of the federal, provincial and territorial governments acknowledge the importance of exploration to sustaining mining's contribution to the economy. Furthermore, they almost always underline the role of geoscience information in exploration and make commitments to maintain or enhance the public geoscience knowledge base.

The role of government geoscience in mineral exploration is discussed in detail in subsequent chapters of this report. In brief, public geoscience information is one of the principal enablers of exploration – the first stage in mineral development. It is used by industry to decide where to explore, and reduces both the cost and risk of exploration.

Readers are referred to Hogan (2003) for an excellent analysis of the economic rationale for public geological surveys. Although focused on Australia, much of the review applies equally to Canada. She explored several factors, including (p.22):

> *...the public good attributes of basic geoscientific information; the high risks associated particularly with the early stage of mineral exploration, and risk averse private investors; economies of scale in regional mapping and information dissemination; potential land access difficulties for private explorers; and the presence of information externalities.*

In Canada, as in most western democracies, government geoscience aimed at promoting mineral exploration and development is provided as a public good. As the notion of public good is among the principal justifications for government's role in this area, it is worth understanding what underlies it.

Geoscience as a public good

The term "public good" is used in two ways. In the vernacular, it is often synonymous with "the public interest", or the well being of the general public. In the field of economics, however, it has a more specific meaning,[2] and it is this meaning that is used here. In layperson's terms, public goods are "*goods or services which, if they are provided at all, are open to use by all members of society*".[3]

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[2] The concept of public goods is a topic of longstanding in the economic literature, including the iconic treatises of Adam Smith (1776) and John Stuart Mill (1848). Samuelson (1954) is generally credited with formulating the theoretical and mathematical basis.

[3] *Oxford Dictionary of Economics (2002).*

In the language of economics, two characteristics distinguish public from private goods: *non-rival consumption* and *non-excludability*. The former means that one person's consumption of a good or service does not decrease its availability to anyone else. Non-excludability means that preventing someone from using the good is impossible, inefficient, or undesirable. Note that although no one can be excluded from using a public good, it is not necessary that everyone take advantage of the opportunity to benefit from it.

The lighthouse was used as an example of a pure public good by Mill (1848), and is still frequently cited today.[4] The cost of providing the light is fixed regardless of the number of ships using it for navigation. Use by one ship does not reduce the amount of light available to others (non-rival), and there is no practical way to exclude certain ships from observing the light (non-excludable). A good or service need not be intrinsically non-excludable to be provided as a public good. Using another example from the field of navigation, GPS signals could be encoded and provided on a subscription basis, much like satellite television signals. However, governments have determined that the public interest is better served by providing unrestricted access.

Knowledge is generally considered to be a public good. It is inherently non-rival: once it is generated, one person's use does not decrease its utility to others. Although knowledge is typically non-excludable, there are situations where it is held in secret or where its use is limited by patent protection or copyright. Because exclusion is possible in some cases, knowledge is sometimes described as an *impure public good*.

Public goods are said to be a result of market failure; the market would not normally provide them since the economic return would not justify the investment. Governments are not the only source of public goods. They may be provided privately by not-for-profit, charitable or even commercial enterprises, but this approach is prone to *under supply.* Moreover, when funding is based on voluntary subscription, costs are not equitably distributed among users; economists call this the *free-rider problem*. Accordingly, public goods are commonly provided by governments (Stiglitz, 1999, p.320):

> *National public goods provide one of the central rationales of national collective action and for the role of government. Efficiency requires public provision and, to avoid the free-rider problem, provision must be supported by compulsory taxation.*

In concluding this general discussion of public goods, it is worth underlining a number of points. Government may *provide* a public good, but not necessarily *produce* it; service delivery may be contracted-out to the private sector. Not all government services are public goods. There are some that are neither non-rival nor non-excludable for which the market is unable to meet the desired level of service. This sometimes occurs when the service is a *natural monopoly*. In such cases, government may decide that it is in the public interest to provide it on a quasi-commercial basis. Examples include public transit and postal services. Finally, not all public goods are "pure", but have some characteristics of private goods. Some are subject to what economists call *congestion*. For example, roads and bridges may be non-rival most of the time, but decidedly not so at rush hour. User fees are sometimes invoked to mitigate congestion of public goods.

We turn now from the general consideration of public goods to the specific case of government geoscience and, in particular, that aimed at promoting mineral exploration and development. Herfindahl (1969, p.2) was among the first to discuss geoscience in this context, concluding that it had the characteristics of a public good and can be provided "*only and better by government*". Bernknopf *et al.* (1993) provided a rigorous analysis of government geoscience as a public good, albeit in the context of land use and engineering decision-making. Doggett *et al.* (1996), Hogan (2003), and Bernknopf *et al* (2007) have extended the arguments to government geoscience in support of mineral exploration.

Geoscience serves a wide variety of public and private interests. Apart from mineral exploration, applications include identifying adequate supplies of clean water, civil engineering projects, land use planning, environmental impact assessment, public health and safety, and national sovereignty. Experience has shown that the market cannot be relied upon to supply all of the geoscience information required for these and other applications, indicating a need for public provision of some of it.

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[4] Another example of a public good used by Mill, relevant in the current context, was "a voyage of geographical or scientific exploration", which could embrace geological survey activity.

Where should the line be drawn between public and private provision? Bernknopf *et al.* (1993) argue that the distinction between general and specific geoscience information is important in this respect. General information is that which will potentially find a large number of users and therefore is appropriately provided as a public good. They argue that specific information, which is potentially of value to only a single user, should probably be provided privately, even though it may have the economic characteristics of a public good (i.e., non-rival, non-excludable). However, as Herfindal (1967) noted, this is offset to some extent by *information externalities*. For example, information about a specific mineral deposit, although principally of interest to its owner, would likely be useful to other firms exploring for similar deposits.

In concluding this discussion, it is important to understand the fact that geoscience information has the economic characteristics of a public good is not the only argument for its provision by government. As noted by Hogan (2003, p. 2),

> *The public provision of basic geoscientific information increases private mineral exploration activity by reducing both the costs and risks of private explorers in the selection of areas for more detailed exploration.*

Thus, public geoscience is just one of the measures that governments use to promote mineral exploration and development. The fact that it is a public good and addresses a number of other needs means that it is one of the most effective.

Conclusion

This chapter began with the observation that governments need geoscience information to formulate and implement a broad range of public policies in such areas as resource development, environmental protection, land use and infrastructure planning, and public health and safety. In respect to the first of these areas, federal, provincial and territorial governments in Canada have, without exception, determined that responsible mineral development is in the public interest, and most have included the provision of public geoscience to stimulate exploration as a key element of their mining strategies.

Governments can choose among a variety of institutional arrangements to satisfy their requirements for geoscience. These include units that are integral parts of government ministries; agencies or crown corporations, which remain accountable to ministers but operate somewhat at arms length; and reliance on non-governmental sources. Each option involves trade-offs in terms of accountability, credibility, cost, and efficiency.[5] Most governments in Canada, as elsewhere, have established geological survey organizations to meet their geoscience needs, and the majority of these are integral parts of government departments.

Policy development, in particular, benefits from close linkages between scientific, economic and social expertise. Consultants could be retained to provide advice on specific questions, and organizations such as the Council of Canadian Academies might be asked to provide opinions on major scientific issues. Either of these approaches may be appropriate alternatives to in-house capacity in certain circumstances. However, there are potential disadvantages in terms of timeliness, breadth of expertise, security, and perceived conflicts of interest, and governments have generally concluded that it is important to maintain some level of in-house expertise to support the iterative process of policy development.

In-house expertise also helps mitigate the “unknown unknowns”[6] often encountered in policy formation, wherein a government may not recognize the need for, or relevance of, geoscience input to a given question. When a geological survey is an integral part of a government department, as opposed to being in an arms-length relationship, it has a role in the policy process of the government as a whole. Because legislation and other cabinet level policy decisions are subject to broad interdepartmental consultation, an integral geological survey helps ensure that a geoscience perspective is brought to bear. One relevant example is the federal Toxic Substances Management Policy (Environment Canada, 1994) which, by virtue of involvement of scientists from the Geological Survey of Canada, explicitly prescribes different approaches for naturally occurring and synthetic substances. This was not only a rational decision; it has had significant implications for the mineral industry.

5. Jarvis (1968) provides a concise and web-accessible summary of factors influencing institutional arrangements for government science. Although focused on scientific input to regulation, the considerations apply generally. See, in particular, “The Science Establishment” section and Annex 1 of his report.
6. From the widely quoted comment by U.S. Secretary of Defence Donald Rumsfeld in a press briefing on 12 February 2002: “Reports that say that something hasn’t happened are always interesting to me, because as we know, there are “known knowns”; there are things we know we know. We also know there are “known unknowns”; that is to say we know there are some things we do not know. But there are also “unknown unknowns” – the ones we don’t know we don’t know.”

Geological surveys have also proven effective in delivering public geoscience to implement policies, including those to promote mineral resource development. While the public good characteristics of geoscience argue for government *provision*, in and of themselves they do not require government *production*, which could be outsourced. However, government surveys offer a number of advantages. Overarching among these is the fact that a national or regional geoscience knowledge base is not merely a compilation of observations and facts. It embodies the interpretation and synthesis of a large amount of diverse data and information. A coherent knowledge base requires that scientific and technical standards are consistent over space and time, which is promoted by a continuity of expertise. Moreover, the analysis and synthesis of data and information benefits from the critical mass of expertise resident in a geological survey.

The distinction among “data”, “information”, and “knowledge” noted at the outset of this paper is relevant here. If the government geoscience required for exploration comprised only “data”, its production could be contracted-out. Indeed, geological surveys in Canada routinely outsource most geophysical and geochemical surveys and other data-gathering activities. Exploration, however, relies heavily on information and knowledge expressed as geological maps, regional syntheses and other products that involve a significant amount of analysis and interpretation, as well as on the expertise of government scientists. Moreover, government geoscientists are governed by strict conflict-of-interest guidelines, which means that company geologists may discuss their exploration ideas without compromising their competitive advantage.

3. Government geoscience: origins and recent developments

Introduction

The introduction to this paper listed a series of questions that governments often consider when defining their program portfolio. The previous chapter addressed the first of these – whether the geoscience information is needed and whether its provision is an appropriate role of government. It was observed that governments in most countries have found that geoscience is required for the development and implementation of public policy, and have established geological surveys to help ensure an adequate knowledge base. Further, the fact that geoscience has the attributes of a pubic good is an important argument for government involvement. This chapter addresses issues about the means of program delivery and, in particular, the impact of "re-engineering" efforts over the last two decades. First, however, it is instructive to review the origins of government geoscience, which can be traced back more than 200 years.

Origins of government geoscience

Geology emerged as a modern science towards the end of the 18th century, in the midst of the Industrial Revolution. Early geological investigations were largely the domain of academics and skilled amateurs. However, there was a burgeoning demand for coal, iron and other mineral commodities, and it was not long before governments saw the benefits of acquiring and disseminating geological information as a means to promote economic development (Zaslow, 1975).

In Britain, the Board of Agriculture began to issue maps with geological information in 1794 and, in 1811, produced the first geological memoir. Perhaps spurred on by the publication in 1815 of William Smith's now-famous geological map of England, in the 1820s, the Board of Ordnance asked its surveyors to add geological observations to topographic maps. The need for dedicated geological expertise became apparent and the Ordnance Geological Survey was established in 1835. This became the British Geological Survey, the world's first national survey organization.

The earliest publicly funded geological surveys in the United States were also aimed at promoting agriculture (Rabbitt, 1989). These were initiated in New York in 1820 and North Carolina in 1823. Although predicated on agriculture, the statewide survey of North Carolina also described a number of gold deposits. New discoveries in 1825 underlined the relevance of geological surveys to mining exploration, and several states followed North Carolina's lead. These early efforts were rudimentary and of short duration. The first continuing geological survey organization was established in New York State in 1836. By 1869, geological surveys were ongoing in thirty states (Socolow, 1988; Socolow and Fakundiny, 1992). In 1834, Congress appropriated funds for the construction of a geological map of the United States, but the project was soon aborted. Although the United States Geological Survey (USGS) was not established until 1879, the federal government funded geological assessments of mineral potential of public lands as early as 1839.

The geological initiatives of governments in Britain and the United States were not lost on government and business leaders in British North America, which lagged somewhat in economic development. Short-lived surveys were commissioned by the legislatures of New Brunswick (1838-43) and Newfoundland (1839-40). A number of attempts in both Upper and Lower Canada to launch geological surveys came to naught, in part because of the political unrest that ultimately led to the union of the two provinces in 1841. It is noteworthy that among the earliest actions of the government of the new province was the appropriation of funds for what would become the Geological Survey of Canada.

The government engaged William Logan to lead the Canadian survey in 1842. Logan combined an understanding of science, commerce, and politics with unimpeachable personal integrity and impartiality, making him an inspired choice. He and his small staff did much to promote the development of a mining industry in Canada. Moreover, Logan would likely have had little time for arguments about basic versus applied research. As he told a select committee of the provincial legislature in 1854 (as quoted by Lang, 1968, p.555):

> *The object of the Survey is to ascertain the mineral resources of the country, and this is kept steadily in view. Whatever new scientific facts have resulted from it, have come in the course of what I conceive to be economic researches carried on in a scientific way ...thus economics leads to science, and science to economics.*

At the time of Confederation in 1867, mineral resources came under provincial jurisdiction. The responsibility for geological surveying was not defined in the British North America Act of 1867, but it was understood that the Geological Survey of Canada would address this need throughout the founding provinces (Zaslow, 1975). This became explicit in the terms of union of Manitoba (1870), British Columbia (1871), Prince Edward Island (1873), and Newfoundland (1949), but not those of Alberta (1905) or Saskatchewan (1905).

As early as 1868, Logan anticipated that the provinces would need their own geological capacity and proposed a division of labour (Zaslow, 1975). Logan's intuition proved correct; geological work was initiated by the Bureaus of Mines in Ontario in 1891 and British Columbia in 1895. There are now geological surveys in every province, except Prince Edward Island, and in all three Territories.

The early geological surveys began as time-limited activities. Indeed, the very name "survey" connotes a finite project rather than a continuing activity. However, it is noteworthy that the early surveys generally evolved into permanent organizations. Governments have found that they need ready access to geological knowledge on an ongoing basis. This reflects not only the dynamic nature of scientific knowledge but also the increasing breadth of applications of geoscience.

Although most geological surveys were initiated in order to promote development of mineral and energy resources, many have seen their mandates broadened and, in some cases, the original objectives have receded in importance. In the USGS, for example, the current budgets for water resources and geological hazards exceed those for energy and mineral resources combined. Given the nature of the challenges facing society, there is every reason to believe that governments will have an increasing need for geoscience information.

Reinventing government geoscience

In the 1980s and 1990s, governments around the world sought ways to become more efficient, effective and economical. This was variously driven by ideology, a widespread loss of confidence in government, and rising public debt. In the United Kingdom, Margaret Thatcher was elected in 1979 with a mandate to reduce government intervention in the economy and promote market solutions. Ronald Reagan, in his first inaugural address in 1981, famously said "*In this present crisis, government is not the solution to our problem; government is the problem*". The book *Reinventing Government* (Osborne and Gaebler, 1992), which espoused "entrepreneurial government", was a virtual blueprint for reforms by the Clinton administration in the United States (Gore, 1993) and influenced developments in Canada, both federally and provincially (Aucoin, 1995).

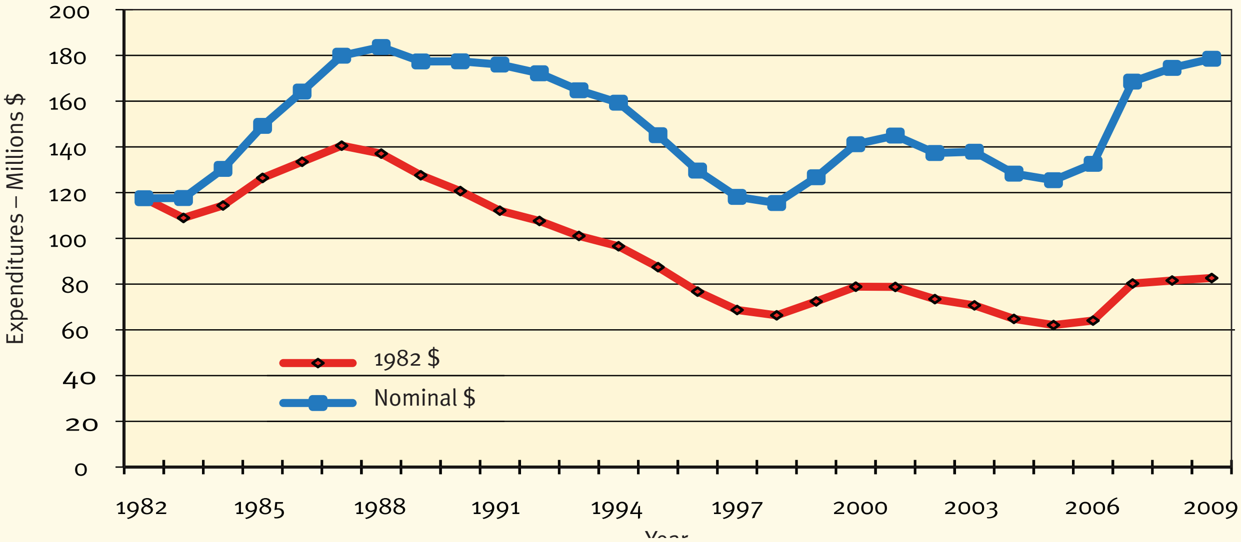
"Steering not rowing" became a common mantra. Thus, the role of government was to provide policy direction, regulation and enforcement. Governments examined their activities with a view to withdrawing from those that were more appropriate to the private and voluntary sectors, and looked at the feasibility of "alternative service delivery" for those functions that it did retain.

Geological surveys, like much of government, were impacted in three principal ways: significant budget reductions, experiments with entrepreneurship and alternative service delivery, and introduction of a results-based management culture. A related and important development for surveys in Canada in the 1990s was the clarification and codification of the roles and responsibilities of the federal and provincial/territorial surveys. A brief summary follows.

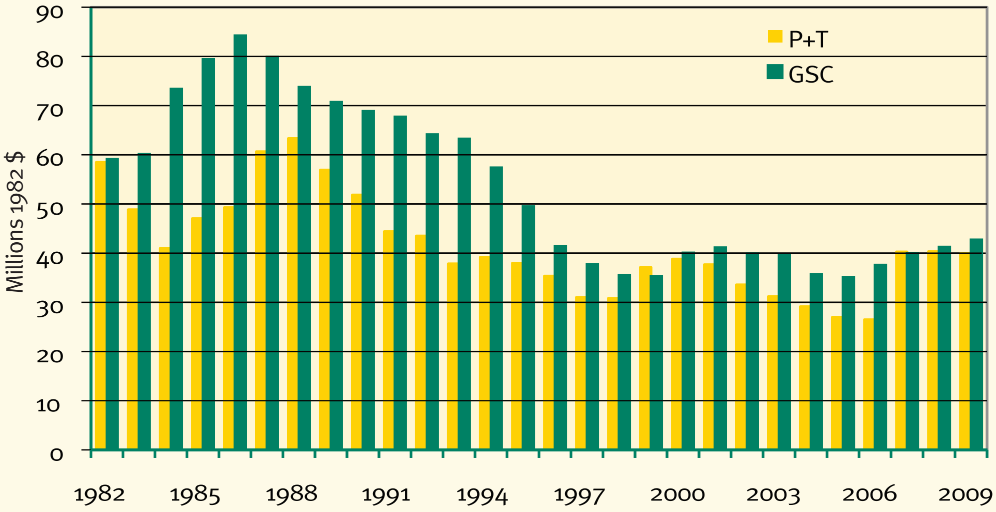
Budget reductions

The variation of the total expenditures of Canada's federal, provincial and territorial geological surveys since 1982 is illustrated in Exhibit 3. It is important to note the amounts refer to all survey expenditures, rather than just those directly relevant to mineral exploration. Although some provincial surveys devote significant parts of their budgets to energy and environmental geoscience, the weighted average of minerals-related mapping and research is more than 90 percent. The proportion is much lower in the GSC, however, ranging from 25 to 45 percent during the period in question. This means that minerals-related activities have generally accounted for 50 to 60 percent of total government survey spending.

Exhibit 3: Variation of federal, provincial and territorial geological survey expenditures, 1982-2009



(a) Total federal, provincial and territorial survey expenditures in nominal and constant 1982 dollars. Approximately 50 to 60 percent of total spending is directly relevant to mineral exploration: the balance is directed to areas such as energy, water resources, natural hazards and the environment.



(b) Variation in GSC and total provincial and territorial expenditures in constant dollars.

The increase of survey funding in the mid-1980s reflects several initiatives, including the federal-provincial-territorial Mineral Development Agreements and, in the GSC, the energy-related Frontier Geoscience Program. After peaking in 1988, nominal annual expenditures decreased by 37 percent over the following 10 years. The steep decline between 1995 and 1999 reflects two factors in particular: the end of the Mineral Development Agreements and the impact of the federal Program Review process on the GSC. The downward trend reversed in 2000, a result in part of effective advocacy by industry and mining communities. The federal and Ontario governments provided incremental funds for the Targeted Geoscience Initiative and Operation Treasure Hunt, respectively, and Nunavut Territory was established with a new geological survey organization. Most jurisdictions have further increased geological survey budgets since 2006, to the point that total expenditures in 2009 were about the same in nominal dollars as they were in the peak year of 1988.

Although the increase in geological survey budgets over the past decade is a positive development from the perspective of the exploration industry, expenditures remain substantially less than the 1980s in inflation-adjusted terms. Because of year-to-year fluctuations, it is more instructive to look at spending by decade than to compare specific years. Thus, average annual expenditures, in 2009 dollars, decreased from $272 million in the 1980s to $197 million in the 1990s to $160 million in the 2000s. Put another way, over the past twenty years, Canada's federal, provincial and territorial governments have collectively spent $1.9 billion less on geoscience than would have been the case if the budgets had been sustained at 1980s levels and adjusted for inflation. We will return to the question of what constitutes an appropriate level of geological survey expenditures in Chapter 6.

In addition to budget reductions, funding uncertainties have been a significant concern for some geological surveys. The federal government, in particular, has tended to favour "sunset programs" with relatively short funding commitments of perhaps two, three or five years. Although this makes it easier to terminate ineffective programs, it poses problems for planning and executing systematic mapping programs, and is a significant hindrance to recruiting and retaining highly qualified staff. It also consumes an inordinate amount of senior management time in justifying program renewal.

The Quebec government is addressing the problem of budget stability through an innovative approach introduced in 2009. It has established *Le Fonds du patrimoine minier* (Mining Heritage Fund), which is financed by royalties from mineral production. The Fund will be used to promote mineral development, including the acquisition of geoscience knowledge, and research on exploration, mining and site restoration technologies. An explicit objective of the approach is to ensure stable funding of Géologie Québec over at least the next ten years (MNRF, 2009).

Alternative Service Delivery

Another focus of the re-inventing government movement is what is known in government circles as *alternative service delivery*. The point of departure is the determination that a particular service is indeed an appropriate and necessary role of government. The question then becomes whether it should be delivered through the traditional departmental structure, or whether other institutional arrangements are preferable. These other arrangements run the gamut from special agencies within government, to crown corporations, to public-private partnerships ("P3"), to reliance on arms-length, not-for-profit organizations.

Most Canadian geological surveys are integral parts of government departments. The exception is the Alberta Geological Survey, which was established as part of the Alberta Research Council in 1921 and moved to the Energy Research and Conservation Board, a quasi-judicial independent government agency, in 1995. British Columbia has adopted a double-barrelled approach to providing public geoscience. The BC Geological Survey, which dates back to 1895, is part of the Ministry of Energy, Mines and Petroleum Resources. The government also funds public geoscience through periodic grants to Geoscience BC, a not-for-profit, industry-directed corporation established in 2005.[7]

Canada's Mines Ministers appointed an industry-government task force in 1997 to examine alternative funding arrangements for government geoscience. As part of its investigation, the working group reviewed organizational arrangements in other countries (Ward *et al.*, 1998). It found that the majority of surveys operate within government departments, as in Canada, although there were some noteworthy exceptions.

The United Kingdom was well ahead of the re-engineering curve. The British Geological Survey became part of the Natural Environment Research Council in 1965 and, beginning in 1973, was funded primarily by contracts from other government departments. Predictably, geological mapping and other core activities shrank to almost nothing, leading the government to question the need for BGS. Finally, in 1990, on the recommendation of a Commission of Inquiry, the government restored sufficient appropriation funding to allow BGS to conduct a core science program, including mapping (Cook, 1996). This budget amounts to about 60% of BGS funding and the balance comes mainly from cost recoverable activities or "commissioned research".

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7. The compilation of geological survey expenditures in the preceding section and the Appendix include neither the funds provided to Geoscience BC by the provincial government nor the energy geoscience expenditures of the BC Resource Development Branch. These additional amounts are significant in the context of the province, but do not materially change the observations with respect to Canada-wide spending patterns.

In 1992, the New Zealand Geological Survey became part of the Institute of Geological and Nuclear Sciences, one of nine crown agencies that operate as quasi-commercial entities. Geological mapping and minerals geoscience is part of the Public Good Science and Technology Program, which has been funded by competitive contracts from the Foundation of Research, Science and Technology (the New Zealand equivalent of NSERC). It was decided recently, however, that in order to promote more stable funding, budgets would be allocated to large, long term programs through negotiation rather than a competitive process (IGNS, 2008).

The experiences in the United Kingdom and New Zealand underline the public good characteristics of the kinds of government geoscience information of greatest use to mineral exploration. The Canadian task force (Ward *et al.*, 998, p.92, 99) concluded that,

> *Alternative organizational models that might be applicable to Canada's geological surveys differ primarily in their input in to the development of government policy and their financial and managerial independence from government.*
>
> *Where a government chooses to situate its geological survey in the spectrum from line unit to not-for-profit enterprise will reflect the degree to which it would like the organization to operate at arms length. If a model affording greater autonomy is associated with an expectation of significant revenue generation from external sources, there will likely be a cost in terms of the organization's credibility in providing scientific input to policy decisions. On the other hand, greater autonomy from the constraints under which the public service operates could result in increased operating efficiency and "more bang for the buck". The choice of organizational model in itself does not change the underlying requirements of a geological survey.*

The task force did not address the accountability of government-funded external organizations, which has been an issue in respect to certain arrangements implemented by the federal government to fund scientific research. The interested reader is referred to various reports of the Auditor General for Canada (*e.g.*, OAG, 2002).

Jarvis (1968) observed, in certain circumstances, gains in efficiency attained through alternative service delivery might be offset by reduced effectiveness. For example, although it might be less expensive to outsource geological mapping, experience has shown that it is less likely to provide an optimal product. Moreover, contracting-out contributes little to the critical mass of expertise residing in a geological survey, which is a source of tacit knowledge valued by industry, government and civil society. There are also potential conflict-of-interest issues. As one observer told the author, "industry geologists value the opportunity to discuss the exploration implications of regional geology with survey staff, but are less likely to do so if they think [the contractor] may be working for the competition six months from now".

Results based management

The requirement to demonstrate the efficiency and effectiveness of government programs led to an increased emphasis on performance measurement. More fundamental, however, was the shift in focus to assessing results in terms of *outcomes* rather than *outputs*. Previously, the performance of a geological survey program was judged primarily on whether maps and reports were produced on time and on budget. With the advent of *value for money evaluation*, the focus became the measurable impact on various public policy objectives; for example, the level of mineral exploration activity or improvements in seismic hazard mitigation. Most governments in Canada now employ some form of Results Based Management. This is relevant to the present study because the results based approach is fundamental to making the case for public geoscience to government decision makers. This will be discussed in considerable detail in Chapter 5.

Government Geoscience – a shared responsibility

The fact that Canada has both federal and provincial geological surveys also came in for scrutiny during the 1990s. From one point of view, the fact that the ownership of resources is vested in the provincial crown means that the federal government should not deliver resource-related geoscience in the provinces. An opposing perspective is that notwithstanding provincial ownership, the federal government has a significant stake in resource development. Not only does it receive more than half of the tax revenue accruing from mining, but resources also loom large in many federal policy areas. Accordingly, in about 1994, the Intergovernmental Working Group on the Mining Industry was asked to advise whether or not the federal survey should continue to play a role in minerals-related geoscience in the provinces. It concluded that the GSC did have an important part to play but that it would be beneficial to formally define the respective roles and responsibilities of the federal, provincial and territorial survey organizations. This culminated in the Intergovernmental Geoscience Accord (IGA), first signed by Ministers in 1996 and subsequently renewed twice.[8] The roles and responsibilities as defined in the IGA are as follows:

> *2.1 The Geological Survey of Canada carries out national geoscience programs to define the geology and resources of Canada. These programs are typically thematically based, and national or broadly regional in scope and significance. They are operated across Canada, and include aspects of fundamental research, technology development and information transfer not contained in the programs of all of the provincial and territorial survey organizations. In addition to its activities on land, the GSC operates marine and coastal studies that are unique among the geological survey organizations. The GSC also has a lead role in representing Canada in international geoscience activities.*
>
> *2.2 The provincial and territorial geological survey organizations carry out programs specific to the economic development and resource management of their own jurisdictions. These programs are carried out at a scale appropriate to addressing provincial or territorial responsibilities, and are geographically limited to the jurisdiction over resources, environment and land of the province or territory. They contribute to a systematic description of the geology of the provinces and territories, including their mineral and energy endowment. Provincial and territorial programs are largely directed toward sustainable economic development and are closely linked to the local needs of clients. They are also related to provincial and territorial land use and social issues.*

The IGA also sets out principles and mechanisms of cooperation. It establishes a framework for joint priority setting and program planning.

Although precipitated by a federal policy decision, the fact that the IGA gained broad acceptance was undoubtedly influenced by a trend towards more effective collaboration among surveys that had been underway for some time. This began in the mid-1980s with the Mineral Development Agreements and blossomed with joint delivery of programs such as NATMAP and EXTECH. It should be added that these same programs also promoted closer working relationships with university geoscientists. The IGA and the spirit of cooperation that it engendered have been sustained for 15 years – a positive outcome by any measure.

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8. The original IGA may be viewed in the Provincial Geologists Journal, v.14, pp. 33-40. http://www.cpgeologists.ca/PDF/PGJ_1996_V14.pdf (Accessed 4 May 2009).

Conclusion

Governments in Canada and elsewhere have relied on geological surveys to support the development and implementation of public policy for more than 170 years. Although most surveys were established to promote the development of mineral and energy resources, most have seen their mandates broadened to address a range of issues. The fact that government surveys have weathered political and economic storms speaks to both the continuing societal relevance of geoscience and their ability to adapt to changing needs.

Geological surveys were not immune from the efforts to “reinvent government” that occurred in most western countries in the 1980s and 1990s. Some experimented with alternative service delivery and revenue generation, but in most jurisdictions, the provision of geoscience as a public good continues to be recognized as a core mandate. The advent of results-based management, with its focus on public policy goals and users’ needs, was a positive development, as was the rationalization of the roles of Canada’s federal, provincial and territorial surveys embodied in the Intergovernmental Geoscience Accord.

Budget reductions are a lasting legacy of this period for Canadian surveys. After a protracted period of decline, total survey expenditures have returned to the levels of the mid-1980s in nominal dollars. However, in inflation-adjusted terms, substantially less is being spent than in previous decades. Average annual expenditures in the 2000s were 19 percent lower in constant dollars than in the 1990s and 41percent lower than in the 1980s.

4. Role of government geoscience in mineral exploration

Introduction

Resources are the lifeblood of mineral production. Reserves at operating mines will ultimately be depleted and will need to be replaced if humankind's demand for minerals is to be met. Although an individual mining company may choose to sustain production through merger or acquisition, all ore reserves are ultimately the result of successful exploration. Moreover, given its strategic position at the beginning of the mineral supply chain, the efficiency and effectiveness of exploration is a key determinant of the ultimate return on investment in mining (Mackenzie, 1987).

The exploration sector has traditionally been viewed as comprising senior companies – producers able to finance exploration from revenues – and juniors, which lacking production revenues, finance exploration from equity. The industry has evolved in recent years to become a little more complicated than this. In his profile of the North American mining industry, MacDonald (2002) describes a production system comprising giant and major firms, intermediates and expansionary juniors, junior firms and "junior juniors". The goal of a majority of junior companies is to find and bring deposits to a point that they can be dealt to a major company. Only a minority of juniors aspire to become producers in their own right.

Junior companies are nevertheless very important in the mineral production system. In recent years, they have accounted for an increasing share of exploration spending in Canada, peaking at 67 percent of the total in 2007. They also account for a disproportionate share of grassroots discoveries. Data from Natural Resources Canada and Harper (2003) suggest that during the 1980s and 90s, junior companies accounted for about 35 percent of exploration expenditures and 60 percent of discoveries. Periodic surges in junior exploration spending in Canada have been encouraged by the availability of flow-through share financing. Furthermore, industry consolidation has altered the "value proposition" of exploration for very large companies, for which even a major discovery has a marginal impact on shareholder value (Goodyear, 2006). It has also been encouraged by the impact of changing economics of exploration on senior companies, described in more detail below. Similarly, from the perspective of some medium and large companies, the acquisition of promising prospects or discoveries represents a more rapid and less risky strategy than exploration to build reserves (Seigel *et al.*, 2002).

This chapter begins with a look at historical trends in exploration spending in Canada. This is followed by a description of the mineral exploration process and, in particular, how government geoscience promotes successful exploration. It concludes with a consideration of discovery risk and the economics of exploration.

Mineral exploration expenditures

Metal prices are arguably the principal driver of global exploration expenditures. They tend to rise and fall together, with exploration generally lagging slightly (Eggert, 1987). The correlation of Canadian exploration expenditures and metal prices is illustrated in Exhibit 4a. The fact that exploration increased in advance of metal prices in the mid-1980s likely reflects changes to flow-through share tax provisions introduced in 1983.[9] The flow-through mechanism is particularly important to the junior sector, and the juniors' share of exploration tends to increase disproportionately during the up-cycles. This effect was particularly dramatic during the recent exploration boom (Exhibit 4b), probably reflecting the increase in the price of gold, in particular.

Exploration spending reached unprecedented levels in 2007-08. Notwithstanding record spending, however, it may have given "less bang for the buck", because exploration costs have outpaced broader inflation indices (Metals Economics Group, 2009). The 16-year hiatus between major exploration peaks corresponds to the time it took for the metal price index to return to 1988 levels. Real metal prices were depressed during the interim, the MPI moving counter to the CPI more often than not.

While total exploration spending is driven by commodity prices, the share directed to a given jurisdiction reflects the attractiveness of its investment climate, including the perceived mineral potential (*e.g.*, Jara *et al.*, 2008). Canada has been among the principal destinations for investment in mineral exploration for as long as records have been kept. It led from 1981-91, Australia ranked first from 1992-2001, and Canada regained the lead in 2002. In recent years, Canada has accounted for almost 20 percent of global expenditures.

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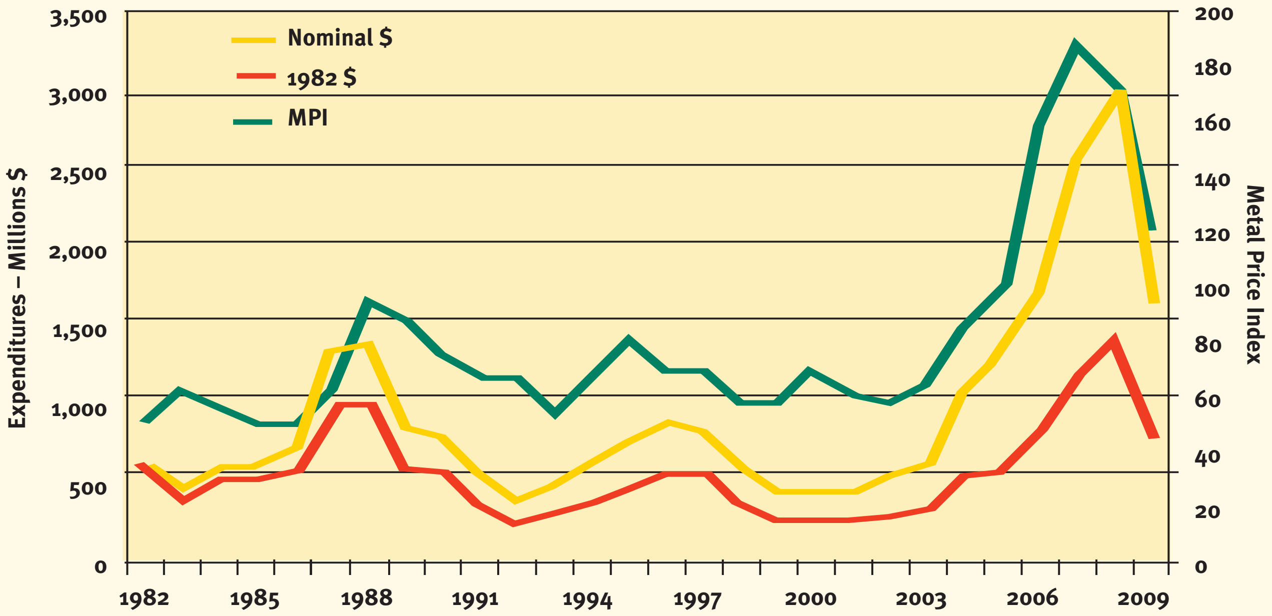
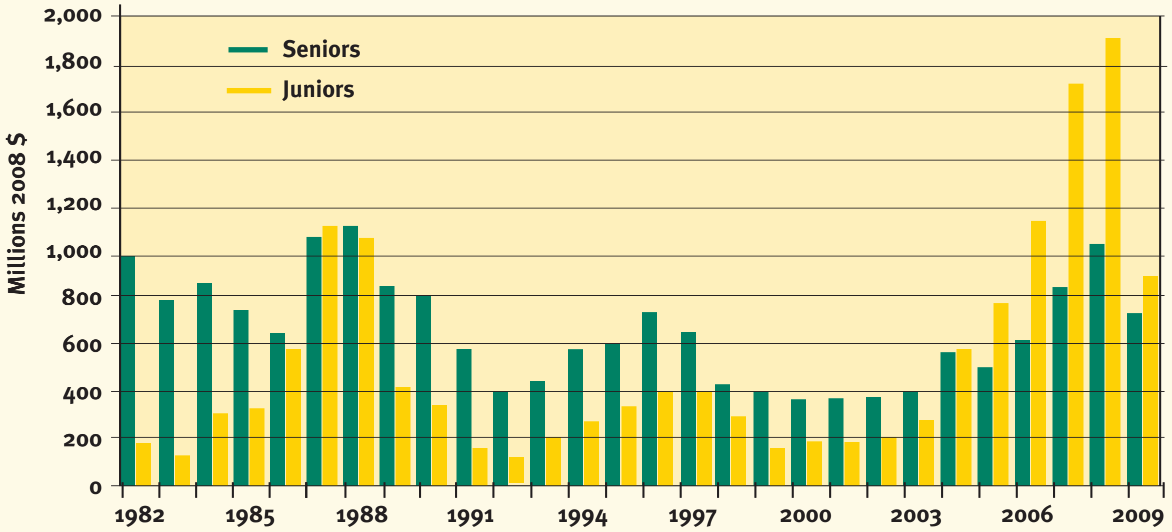
9. In an effort to stimulate exploration, in addition to new flow-through provisions, governments enhanced their geoscience efforts in 1984 through federal-provincial Mineral Development Agreements, which were a major funding source of minerals-related government geoscience for the following 10 years.

Exhibit 4: Canadian mineral exploration expenditures, 1982-2009[10]



a) Variation of exploration and deposit appraisal expenditures and Metal Price Index

b) Exploration spending by senior and junior companies.



Exploration is not only cyclical in terms of total expenditures but also episodic with respect to the commodities sought. In Canada, base metals were the principal target in the post World War II years until about 1984, when they were surpassed by precious metals (specifically gold). Gold has led the "hit parade" in every subsequent year except 1992. Apart for the occasional flurry of interest in uranium, base and precious metals had dominated the picture, generally accounting for 85 to 95 percent of exploration. This changed with the discovery of diamonds in the Northwest Territories in 1992, and diamond exploration expenditures rivalled those for base metals, and exceeded them from 2001 through 2004. Diamond exploration tapered-off somewhat since 2005, while interest in other commodities surged. Uranium exploration enjoyed an upsurge in the 1970s and again in 2007-08.

[10] Expenditures include fieldwork and overhead, but not engineering, economic, pre-production feasibility studies, environment and land access costs from Natural Resources Canada, constant dollar amounts calculated using CPI from Bank of Canada. Averaged monthly data from International Monetary Fund used for MPI.

The Mineral Exploration Process

Mineral exploration may be characterized as a multistage information gathering process. The goal of each stage is to discriminate between areas of greater and lesser mineral potential, thereby reducing the area to be explored in the subsequent more expensive stage. Although terminology varies, five stages are generally recognized: planning, reconnaissance exploration, detailed exploration, discovery, and deposit appraisal (Exhibit 5).

Exhibit 5: Stages of mineral exploration

M	Stage	Industry	Government Geoscience
Grassroots Exploration	Planning (EX-1)	Exploration Strategy: Select commodity (ies), deposit type, areas optimizing political, economic and discovery risk	Regional geoscience information is essential to evaluating mineral potential. Mineral deposit models are integral to exploration strategy.
	Reconnaissance Exploration (EX-2)	Identify targets (geophysical, geochemical, mineralogical anomalies) over a wide area and select most promising for follow-up	Regional geological, geophysical and geochemical maps, data, and expert knowledge increase exploration efficiency, as do reports of previous exploration held in public assessment files.
	Detailed Exploration • Target delineation (EX-3)	Ground acquisition Confirm location and characteristics of targets	Public releases of new information in areas of current interest often lead to staking rushes
	• Target testing (EX-4)	Investigate cause of anomalies by drilling or trenching	District/camp-scale geoscience information and deposit models, assist in defining specific targets and interpreting new discoveries.
	Discovery and Delimitation (EX-5)	Confirm existence of a mineral deposit of potential economic interest. Delimit sufficient indicated resources to justify deposit appraisal	Provides results of exploration technology research that leads to efficient application of exploration techniques. Expert knowledge assists industry in analysis and interpretation of data.
Late Exploration	Mineral Deposit Definition (DA-1)	Define deposit size and shape, internal distribution of grade and mineralogy. Acquire all data required for engineering and cost estimation.	
	Project Engineering (DA-2)	Determine design, schedule, capital and operating costs of potential mining operation.	Public geoscience, particularly surficial and hydrogeology maps and data can support infrastructure planning and geotechnical engineering.
	Project Economics (DA-3)	Evaluate economic, financial, environmental, and socio-political dimensions of potential mining operation.	
	Feasibility Study. Production Decision (DA-4)	Validate geological, engineering and economic analyses. Obtain permits and financing.	Input to government review environmental impact assessment
Mine Site	Mine Complex Development (MCD)	Construction of processing plant, infrastructure and mine on time, on budget and in accordance with regulatory requirements.	
	Mine Production (MP)		

The stage definitions are consistent with those in the *Generalized Model of Mineral Resource Development* (Cranstone *et al.*, 1994:10). Column M lists the definitions used by the Metals Economics Group. The geoscience role is after Ward et al. (1998), with modifications.

These stages are often episodic and may involve more than one firm. For example, grassroots exploration by a junior company may turn-up a target, but testing might be suspended due to a downturn in metal prices. A different firm might revisit the prospect at the beginning of the next upward cycle. If this company makes a discovery, it may well enter into an arrangement with a senior company, which would undertake deposit appraisal. It has been estimated that a typical mining property passes through the hands of seven different firms.

Government geoscience can influence each stage of mineral exploration and development. Discussion of the role of government geoscience typically focuses on regional maps, reports and data. While these products are arguably the most useful to the explorationist, other forms of information are also important. One of these is the tacit knowledge about regional geology, mineral deposits and exploration technology that resides in the heads of government geoscientists. This information is transferred through thousands of interactions during office visits, field trips, "open house" meetings, telephone conversations, trade shows and conventions. Government geoscientists also make important contributions to the peer-reviewed scientific literature and to the development of exploration technologies. Industry values the role geological surveys play in training the next generation of geoscientists, particularly by providing university students with practical experience through summer employment on field parties. One of the unfortunate consequences of the reduction of geological survey budgets in the 1990s was a disproportionate decrease in student employment.

Planning stage

Once a company has decided to invest in mineral exploration, the next step is to determine what to look for and where. This is variously called the planning, conceptual, generative, or design stage of exploration. Although it may involve brief visits to areas of potential interest, it is largely an office exercise.

What to explore for is less problematic than where to look. Senior companies typically seek to sustain or increase production of their current inventory of commodities, but may also want to diversify their portfolio. Juniors, on the other hand, are more likely to focus on "hot" commodities, because this makes it easier to raise venture capital and to realize returns from exploration success.

Having identified commodities of interest, a company may also specify deposit characteristics such as the minimum size and grade that would be required to meet the firm's strategic objectives. Major companies, for example, outside of their current mining establishments, may gear their search to world class deposits, that is, those that would rank in the top 10 percent of all deposits in terms of contained metal (Singer, 1995).

In any case, the selection of one or more mineral deposit types having the desired economic characteristics is an important early step in the planning stage. This selection is based on a review of mineral deposit models that describe the characteristics of relevant deposit types – geological setting, composition, morphology, size and grade, *etc*. The development of mineral deposit models is by no means the exclusive purview of government geoscientists. The contributions of scientists in academia and industry to the understanding of mineral deposits are as great or greater. However, it is noteworthy that the most widely cited compilations of models were produced by geological surveys (*e.g.*, Eckstrand, 1984; Cox and Singer, 1986; Kirkham *et al.*, 1993; Eckstrand *et al.*, 1995; Lefebure and Ray, 1995; Goodfellow, 2007). One reason for this is that deposit models are essential to the mineral resources assessment role that is central to the mandate of geological surveys (Chapter 3, above).

The next step is to identify regions with good geological potential to host the target deposit type. Perception of mineral potential is shaped by two kinds of information: regional geological knowledge and the presence of known mineral deposits. The relative importance of these two factors depends on circumstances. In "greenfields" exploration, regional geological information may be the only indicator of mineral potential, and given that this is provided largely by geological surveys, government geoscience is clearly critical to exploration planning. Decisions to explore in "brownfield" areas are undoubtedly driven by the presence of economic deposits, but regional geological information enters into the assessment of opportunities in such areas.

The decision on where to explore is based on the evaluation of a variety of risk factors (Otto, 2006), which may be grouped into three main categories:

- Political or Country Risk – This includes not only the political stability of the jurisdiction in question but also the existence of a stable and reasonable regulatory framework governing mineral title, taxation, environmental protection, labour, and so on.
- Economic Risk – The greatest economic risk derives from uncertainty about commodity prices, especially in relation to the cost of inputs to production. However, many economic factors are dependent on location. These include the availability of labour and infrastructure, physical geography, climate and other factors that will determine the costs of exploration, development and production.
- Discovery Risk[11] – The greatest risk in exploration is that it will not succeed in finding an economic mineral deposit. This comprises two components: the probability that a deposit having the desired characteristics exists in the area in question and the probability that it can be discovered. The latter depends on the availability of both reliable geoscience information and appropriate exploration technologies for the target deposit type in the particular area.

The first component of discovery risk, the probability of occurrence of an economic deposit, is often described as mineral or geological potential. This is typically the most important single factor influencing exploration investment. For example, in the annual survey of mining companies by the Fraser Institute, respondents are asked to rate the relative importance of mineral potential and policy considerations. *"In most years, the split was nearly exactly 60 percent mineral potential and 40 percent policy"* (Fraser Institute, 2009, p. 25). As the survey's authors observe, this probably does not apply in the extreme. Policies that make it impossible to develop a deposit would trump outstanding mineral potential, and highly favorable investment policies will be of little import if the probability of exploration success is negligible.

A company's decision on where to invest is also influenced by the quality and accessibility of government geological information that will be required for the subsequent stages of exploration. Again, the Fraser Institute survey indicates whether the "quality of the geological database" encourages or inhibits investment in various jurisdictions, but does not say how important this is relative to other factors. An examination of recent surveys suggests that a poor geological database would rarely be the sole reason for a company's decision to not invest in a particular jurisdiction. On the other hand, in only 21 of the 71 jurisdictions considered was the geological database seen to encourage investment by more than 50% of respondents. These included all seven Australian states/territories, nine of twelve Canadian jurisdictions, two American states, Finland, Sweden and Norway.

The quality of the geological knowledge base speaks to the second dimension of discovery risk, which is the probability that a deposit can be discovered, given that it exists. Public geoscience information can be used to predict the utility of various exploration technologies, a critical component of an exploration strategy. For example, the nature and thickness of overburden may dictate the usefulness of various geophysical and geochemical methods. The foregoing considerations define what may be described as the company's exploration model (see also Henley and Berger, 1993). An exploration model is based on three kinds of geoscience knowledge: a mineral deposit model describing the characteristics of the target deposit type, knowledge of the geology of the region(s) of interest, and an array of exploration technologies (Exhibit 6).

Reconnaissance stage

The result of the planning stage of exploration is the identification of one or more areas that meet the company's geological, political and economic criteria. These will likely be regional in scope, encompassing thousands of square kilometres. This reconnaissance stage typically involves broad scale geological, geophysical or geochemical surveys, examination of known mineral occurrences, and reviewing the records of any previous exploration. Its goal is to identify exploration targets that will be tested by detailed exploration and drilling. Targets may be geophysical or geochemical anomalies, mineralogical anomalies (*e.g.*, a mineral occurrence or indicator minerals), or definitive geological setting. Once targets have been identified, the next step is to select smaller areas for detailed exploration and secure the exploration rights, if this has not already been done.

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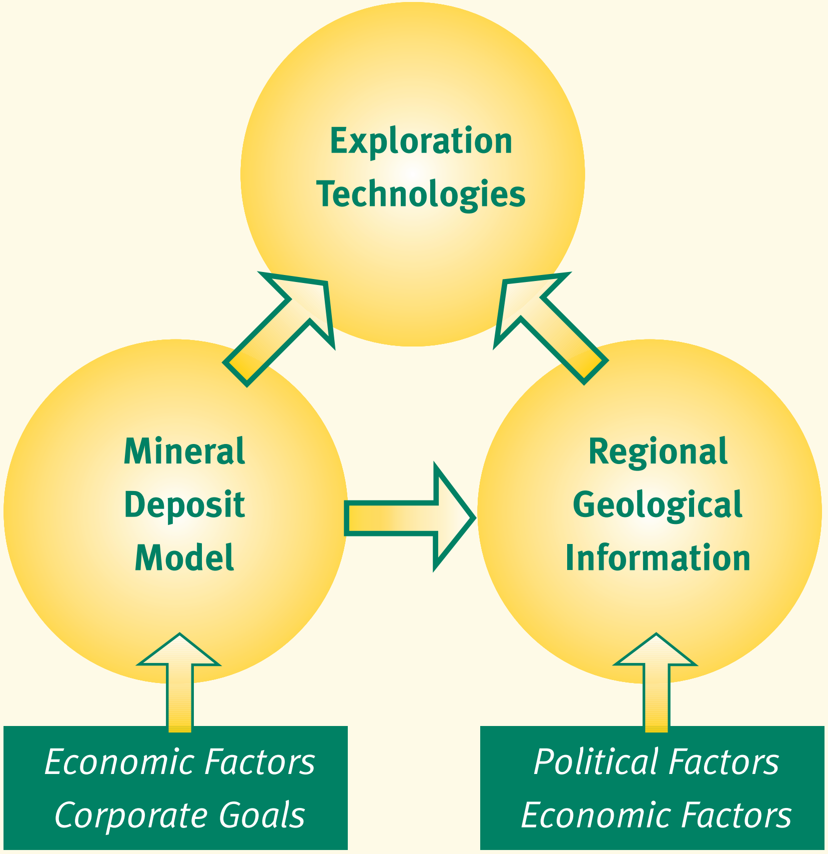
[11] Discovery risk is sometimes described as "geological risk", particularly in the context of oil and gas exploration. However, in the mining context, "geological risk" generally refers to the uncertainty in deposit size, grade, etc. that impact its economic viability (e.g., Mackenzie, 1989).

Exhibit 6: **Essential elements of an exploration model**



The deposit model incorporates the essential attributes of the type of mineral deposit that the exploration program seeks to discover. The deposit type, in turn, would have been selected in part because it has economic characteristics that satisfy corporate goals. Exploration is targeted on areas with good mineral potential, based on regional geological information and the deposit model, and which an acceptable level of political and economic risk. Consideration of the deposit model and regional geology suggests which exploration technologies are likely to be effective.

At the reconnaissance stage, government geoscience maps provide a framework that allows companies to focus their efforts on areas of greatest potential within the region in question. Regional mapping is both expensive and time-consuming. If this information were not provided by government, it is unlikely that companies would do the mapping themselves. Rather, they would direct their exploration investment to areas where adequate regional scale coverage was available. The discovery of the Kidd Creek deposit (Exhibit 7) is a good example of the interplay of a mineral deposit model and government geoscience in exploration success.

Another valuable public good provided by government is the documentation of previous exploration in the form of assessment reports that companies are required to submit as a condition of retaining their exploration rights. Downing and Mackenzie (1979) have underlined the importance of the government's role in capturing exploration information and making it accessible.

Exhibit 7: Role of government geoscience in the discovery of the Kidd Creek Deposit

The discovery of the giant Kidd Creek massive sulphide deposit near Timmins, Ontario is illustrative of both model-driven exploration and the role played by public geoscience in the planning and reconnaissance stages of exploration. The story began in the early-1950's when the Texas Gulf Sulphur Company, the largest producer of sulphur in the U.S., decided to explore for massive base metal sulphide deposits (Miller, 1976; Bleeker and Hester, 1999).

The key elements of its deposit model were that such deposits were to be found in 'eugeosynclinal' volcanic sequences, hosted by fragmental rhyolitic rocks. The company was also ahead of the curve in recognizing these deposits as synvolcanic, a view that was just emerging in the literature. It was known that the deposits were electrically conductive, meaning that airborne electromagnetic surveying was an important technology. TGS had developed a helicopter borne system, which would be used in the program. The first Canadian efforts were in the Appalachians, in southern Quebec and New Brunswick. Geologist Leo Miller was hired to undertake the Canadian Shield project in 1957. His first step was to undertake a 4-mile to 1-inch compilation of the geology of the Abitibi Belt between Chapleau and Chibougamau, which would have been based on information from the Ontario and Quebec geological surveys as well as from the GSC. Based on this compilation, the area in Kidd Township was identified as the highest priority. The company was drawn to the area by an OGS map, which showed two outcrops that suggested the contact between rhyolitic fragmentals and mafic volcanics (Berry, 1941). In his visits to the site in the summer of 1958, Miller observed sulphide mineralization in the rhyolites, within a large magnetic anomaly. Although not specified, the information about the magnetics almost certainly came from a government aeromagnetic survey program. The company flew its own airborne survey in 1959, which indicated a strong conductor. However, this lay on patented ground and it was not until 1963, when the company finally acquired the mineral rights, that the anomaly could be accurately delineated by ground geophysics and tested by drilling. The first drill hole intersected massive sulphide. In 1996, past production and proven reserves totalled 138.7 million tons averaging 2.35% copper, 6.50% zinc, 0.23% lead and 89 g/t silver.

Although Kidd Creek is commonly regarded as a geophysical discovery, geological insight arguably played as important a role. The target of the discovery drill hole was undoubtedly a geophysical anomaly. However, as Miller (1976) noted, the initial airborne anomaly did not result from a regional geophysical survey, but rather was focused on a small area delineated by geological observations. Moreover, the same airborne anomaly was known to INCO (and possibly other companies) but was not followed up because of a lack of a coincident magnetic anomaly (Bleeker and Hester, 1999).

Detailed stage

Detailed or property scale exploration generally begins once a company has acquired exclusive exploration rights to an area. It will generally conduct detailed geological, geophysical and geochemical surveys (i.e., scales larger than 1:10,000). Although the firm would likely already have identified one or more targets on the property, detailed surveys are required to precisely locate the target on the ground and, indeed, may well turn up additional anomalies. Once targets have been delineated, they are ranked and tested. Testing generally involves drilling to determine whether an anomaly is the result of a mineral deposit.

Although companies generally do their own property-scale mapping, government geoscience can nevertheless play a role at the detailed stage. Government maps provide a framework for property mapping as well as for correlation between exploration properties (including those of other companies). This is especially the case in established mining districts, where relatively detailed government maps are often available (*e.g.*, 1:20,000).

Discovery and initial delineation stage

The discovery of a mineral deposit is obviously an important milestone in the exploration process, but it is one that is reached in perhaps only one in a hundred exploration projects. "Discovery" in this context applies only to potentially economic mineral deposits, and so the fact that a discovery has occurred is only knowable in hindsight. For example, according to Cranstone (1982, p.38), "Discovery refers to a mineral deposit sufficiently attractive to have warranted the expenditure necessary to establish its tonnage and grade." He added that discovery typically involves drilling, in which case the moment of discovery was the point at which "drilling intersected mineralization recognised within a short period of time to be part of an economically interesting deposit".

Thus, the discovery stage includes not only the "Eureka moment" when, for example, a drill hole intersected massive sulphides, but also the subsequent period during which the approximate size and grade of the deposit is determined through additional drilling. The completion of this initial deposit delineation marks the end of the exploration phase for the purposes of the federal-provincial/territorial compilation of mineral exploration expenditures (*e.g.*, Exhibit 5). However, references to the amount of exploration spending in Canada normally include both the exploration and deposit appraisal stages.

Deposit appraisal stage

The goal of deposit appraisal, also called advanced or late exploration, is to determine the size and grade of the deposit and, in particular, whether it is economically exploitable. This stage involves engineering studies of the physical plant and infrastructure, environmental permitting, and assessing the economics of a potential operation. It culminates in a feasibility study and a decision whether or not to develop a mine.

At the deposit appraisal stage, public geoscience may be of use in geotechnical engineering studies and environmental impact assessment. Examples include identification of sources of aggregates for construction, assessing slope stability, permafrost and other terrain hazards that impact on infrastructure, and understanding sources and vulnerability of groundwater. The impact can be substantial. In an example from northeastern British Columbia, surficial geological mapping by the provincial government identified new gravel resources. It is estimated that as a result of this $1.3 million program, the province and the oil and gas industry have saved $76 million in road construction costs (A. Hicklin, pers. comm). Uncertainty and delays in environmental permitting are sometimes identified by industry as disincentives for mineral exploration. In any case, the availability of public geoscience information can accelerate the process and reduce costs.

A risky business

Mineral exploration has long been recognized as a risky proposition. None other than Adam Smith (1776, ¶ IV.7.18)[12] characterized it as a lottery:

> *Of all those expensive and uncertain projects, however, which bring bankruptcy upon the greater part of the people who engage in them, there is none, perhaps, more perfectly ruinous than the search after new silver and gold mines. It is perhaps the most disadvantageous lottery in the world...*

Exploration has changed considerably since Smith's time. Modern mineral exploration is an application of the scientific method. It begins with a question (where is an economic mineral deposit likely to occur?), formulates a hypothesis (the exploration model), and tests the hypothesis through experiment (geoscience surveying and drilling).

Nevertheless, discovery risk remains a significant consideration. The probability of exploration success varies according to region and commodity, but is universally very low. A common rule of thumb is that 1 in 10 projects will progress from the reconnaissance to the detailed stage, 1 in 10 projects at the target testing stage will result in a discovery, and 1 in 10 discoveries will turn out to be an economic deposit. In other words, only one grassroots exploration project in a thousand will result in an economic deposit.

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[12] Given the many editions of Smith's work, the reference is to book-chapter-paragraph, rather than page.

Discovery risk is exacerbated by the natural variation in the quality of economic deposits – what MacKenzie (1989) termed "geological risk". Boldy (1977) analysed the distribution of size and grade of volcanogenic base metal deposits in the Canadian Shield and concluded that if the probability of a given target being an economic deposit were 0.01, the odds against it being both economic and in the upper decile of the deposit size range would be 1500:1. This has important implications, given the importance of major deposits in terms of profitability and share of total production.

Burn (1984) described the probability of exploration success (P_S) as the product of three components: the probability that the area being explored contains at least one deposit (P_1), the probability that exploration is sufficiently thorough to find the deposit (P_2), and the probability that the deposit meets the firm's minimum economic requirements (P_3). Thus,

$$P_S = P_1 \times P_2 \times P_3$$

Slichter (1960) was the first to apply the statistical concept of "gambler's ruin" to mineral exploration. This is the possibility that a firm would exhaust its capital before it made a discovery. It might also be framed in terms of the expenditures rising to a point that exploration does not yield an acceptable rate of return.

If exploration were merely a lottery, the only way to ensure success would be to investigate a very large number of prospects. The number of targets (n) that must be tested to be reasonably assured of at least one economic discovery, is given by

$$n = \log (1-P_d)/\log (1-p_s)$$

where P_d is the probability of making at least one discovery and p_s is the probability that any single prospect is an economic deposit (Singer and Kouda, 1999). For example, if $p_s = 0.01$, 229 targets would need to be tested in order to have a 90% probability of success. Mackenzie (1989), using a similar formulation, concluded that in order to have a 90 percent probability of discovering at least one economic deposit, a company would have to have to spend 2.3 times the average discovery cost. This has important implications for the economics of exploration. With discovery costs on the order of $100 million, a company requires very deep pockets to be assured of success.

Singer and Kouda (1999) observed that joint venturing is one strategy used by industry to mitigate the risk of gambler's ruin. Of course, the trade-off for spreading the risk among several companies is the dilution of the rewards for success. Another strategy is to increase the probability of success by focusing exploration on deposits of particular types and grade-tonnage characteristics. Such considerations are an integral part of most exploration models.

Unlike in a game of chance, the probability of success can be modified in light of geological evidence gathered as exploration proceeds. The probability is increased by the presence of positive indicators based on the relevant mineral deposit model. For example, according to the account of the Kidd Creek discovery (Exhibit 7), the presence of fragmental rhyolitic rocks and anomalous electrical conductivity were key success factors suggested by the company's preferred model.

Exploration geologists have employed such reasoning in a qualitative way for decades, and it is amenable to quantification and simulation through the application of Bayesian statistics.[13] Since the introduction of PROSPECTOR™ (Duda *et al.*, 1978), a variety of expert systems have been developed to support decision-making in mineral exploration (*e.g.*, Stanley, 1994; Chinn and Ascough, 1997) and mineral potential mapping (*e.g.*, Bonham-Carter, 1994; Wright and Bonham-Carter, 1996; Scott and Dimitrakopoulos, 2001).

The notion that risk is something to be managed rather than avoided or endured has gained currency in many areas of endeavour, including resource exploration. Gouveia *et al.* (2003) drew a parallel between the apparent decrease in the discovery rate of major deposits in the 1990s and a similar decline in success of oil and natural gas exploration in the previous decade. The improved energy exploration performance in the late 1990s has been attributed in large part to adoption of rigorous discovery risk management practices (*e.g.*, Rose, 1999). Gouveia *et al.* advocated a similar approach in mineral exploration, and progress has been made in developing decision support systems integrating financial and geological models (*e.g.*, Lord *et al.*, 2003, Guj, 2008, Kreuzer *et al.*, 2008).

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[13] Bayes' Theorem is a mathematical relationship that allows the prior probability of an event to be modified on the basis of new observations.

Government geoscience plays a central role in mitigating discovery risk in the early stages of exploration by helping industry focus exploration on the areas of greatest mineral potential. As exploration proceeds, public geoscience information can be helpful in ranking targets. At the point of ground acquisition, a company will likely use geological maps to determine the boundaries of its claim block.

The economics of mineral exploration

The economics of mineral exploration has been described by Mackenzie (1981, 1989), Eggert (1987), and Harris (1990), among others. A detailed summary is not necessary here, but some key concepts are important in evaluating the role of government geoscience. These include, in particular, the implications of expected value, the time cost of money, return on investment, and economic rents.

Mackenzie (1980) set out a framework to determine the economic value of exploration that results in discovery of a large number of deposits over the long term. Accordingly, the expected value of exploration (EV) is given by

$$EV = R - E$$

where R is the average return of an economic deposit, (i.e., revenue – production costs), and E is the average discovery cost *(i.e.*, total exploration expenditures/number of economic deposits found).[14] In order to properly assess the value of exploration, revenues and costs must be compared on a net present value (NPV) basis at some given time, for example, at the beginning of exploration.

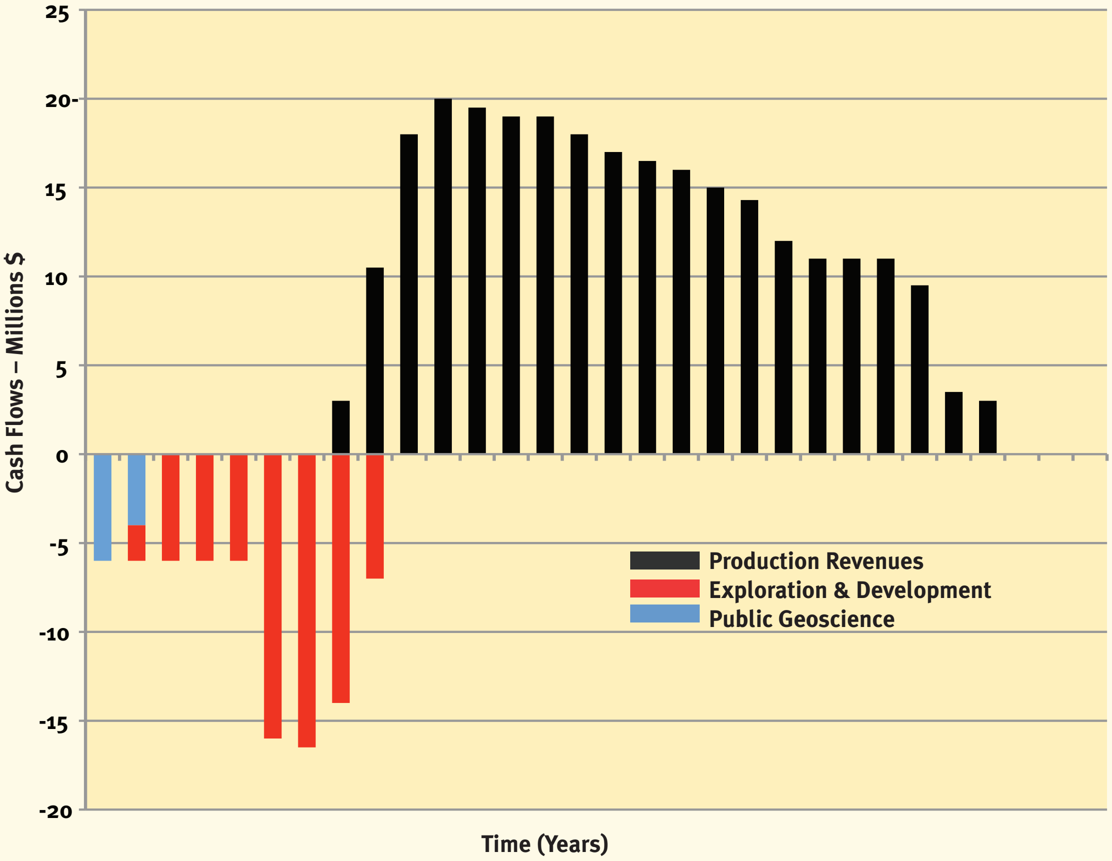
The duration of the exploration process is highly variable, but it is not unusual that ten or more years elapse from the planning stage through the initial delineation of an economic deposit. Development and permitting can add several more years, meaning that a company initiating exploration may not see any return on its investment for 15 years or more. For this reason, the time cost of money, a critical consideration in any investment decision, is especially important in assessing the potential return to mineral exploration. Mackenzie (1987) observed that the time-adjusted cost of exploration is typically several times the direct cost.

Mackenzie (1989) cites several case studies of the value of exploration for various commodities in different regions and geological settings. One particularly interesting example, also described by Woodall (1984), is the comparison of the value of base metal exploration in Canada (1946-77) and Australia (1955-78). It showed that the expected value of an economic base metal discovery in Canada was about twice what it would be in Australia. Even more sobering, from the Australian viewpoint, was the fact that without the success of one company, Western Mining Corporation, the cumulative net present value of Australian discoveries was negative. Mackenzie (1989, p.17) attributed the company's advantage to *"superior geological concepts, exploration technology, and organizational motivation and efficiency"*. This Australian case study underlines the fact that exploration success is not random; some companies are more able than others to mitigate discovery risk.

Mackenzie *et al.* (1988) analyzed the economic return of base metal and gold deposits discovered in Newfoundland in the period 1946 to 1985 (Exhibit 8). To demonstrate the potential impact of public geoscience, they postulated that a $10 million expenditure on geological mapping would relieve industry of costs it would otherwise incur at the beginning of exploration, effectively reducing the length of the process. The result of this intervention was to increase the EV from $22 million to $33 million and the rate of return from 12 to 15 percent. Mackenzie *et al.* evaluated other forms of government support to mining in the same way (direct cash assistance to exploration, support for mine development, production assistance, end-of-mine life assistance) and concluded that geological database development provided the greatest return. Moreover, alone among the policy options investigated, it has the potential to benefit many companies (and to increase the return from multiple discoveries).

[14] In other contexts, discovery costs are sometimes expressed as the exploration expenditures per unit metal found (e.g., oz. of gold, lb. of copper).

Exhibit 8: **Time distribution of cash flow for an economic deposit in Newfoundland, illustrating the impact of public geoscience on the return on investment (after Mackenzie *et al.*, 1988)**



The model assumed that government geoscience reduced the average discovery cost of economic deposits by $10 million, increasing the expected value of the deposit from $22 to $33 million and rate of return of private investment from 12 to 15 percent.

Government geoscience also increases the return to society for the private use of public mineral resources. This return is sometimes described in terms of society's share of *resource rents*.[15] Economic rent is the amount of revenue in excess of the cash and sunk costs of production, including a "normal" return on capital invested. The fact that mining generates rent is largely a consequence of the variable quality of mineral deposits – that is, the "geological risk" described above. Production costs are a function of a deposit's location and quality (size, grade, amenability to processing, *etc.*). Revenues, on the other hand, are determined by commodity prices, which are largely a function of global supply and demand. Natural geological variability has a profound impact on the profitability of individual deposits and, in principle, on the direct benefits that accrue to society through royalties and other taxes. This concept is illustrated in Exhibit 9. By reducing exploration costs, public geoscience increases the potential resource rents realized when a deposit is put into production (*e.g.*, Hogan, 2003).

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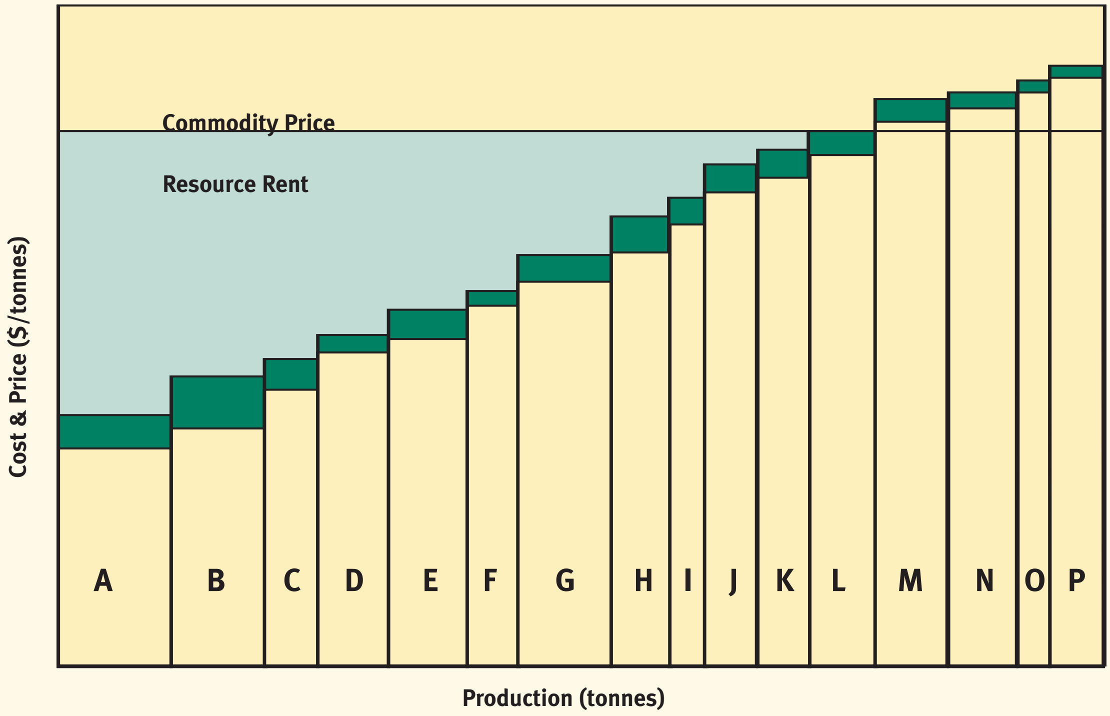
15. Otto et al. (2006, p.20-30) provide an excellent description of resource rents in the context of mining royalties.

Exhibit 9: Government geoscience increases resource rents: conceptual model



The vertical bars represent a series of mineral deposits of a given commodity arranged in order of increasing total production cost, which includes sunk costs of exploration and development, operating costs, and an acceptable return on invested capital. Differences in production costs among deposits reflect both natural variability in geological quality and relative operating efficiencies. Sometimes deposits at the upper end of the cost league (e.g., M, N, O, P) may stay in production pending an increase in commodity prices or cost-cutting measures, as long as they are meeting their operating costs. The light green area represents resource rent. The dark green shading illustrates the impact of public geoscience in terms of reduced exploration costs and, potentially, increased rents. See also, Brosio (2006), Hogan (2003).

Conclusion

Three characteristics, in particular, distinguish mineral exploration and development from most other economic activities: location, long time frame, and high risk. The location of mining activity is constrained by geology. Unlike a manufacturing plant, for example, the siting of which is influenced by proximity to markets, labour, and infrastructure, a mineral deposit must be mined where it is discovered. Exploration is similar to research in terms of long duration and lack of certainty that it will succeed. It is not unusual for 10 to 20 years to elapse between the beginning of exploration and the realization of revenues from production. This means that the time cost of exploration may be several times the nominal cost (Mackenzie, 1987) and have a significant impact on the profitability of a mine. The low probability that any given exploration project will result in the discovery of an economic deposit, let alone one of superior quality, requires the investment of many times the average discovery cost to have a reasonable likelihood of success.

Public geoscience mitigates each of these exploration challenges. It attracts exploration investment by allowing industry to identify areas of favourable mineral potential. It increases exploration efficiency by making it unnecessary for individual companies to duplicate common information or to spend money on non-prospective ground. It increases exploration effectiveness by providing key information inputs to risk-based decision-making. By reducing exploration costs and risk, public geoscience not only improves returns on private investment but also increases revenues accruing to governments as royalties and taxes.

The quality of public geoscience information provided by government is generally recognized as one of the important determinants of the investment climate for exploration and development. Geoscience attracts exploration investment to particular jurisdictions by allowing industry to identify areas of favourable mineral potential. Proponents of government geoscience tend to emphasize this role and, in particular, the extent to which public geoscience stimulates private exploration expenditures. While this approach is valid, one should not lose sight of the fact that public geoscience improves the efficiency (reduces the cost) and effectiveness (reduces the risk) of exploration. This is the underlying reason that it enhances the investment climate.

5. Telling the performance story

Introduction

The public policy rationale for government investment in geoscience is the promotion of various social benefits. In the case of geoscience undertaken to support mineral exploration, these benefits are usually framed in terms of economic development, particularly in rural and remote regions of the country. They may include elements of job creation, sustaining resource-based communities, security of supply, increased competitiveness, improved productivity, and so on. In an ideal world, it would be possible to determine the net present value of these social benefits, attribute a portion of the value to public geoscience, and thereby conclude whether the government's investment was justified; in other words, to undertake a rigorous cost benefit analysis. This is very difficult in practice.[16]

Apart from anecdotal information about the role of government geoscience in specific exploration plays or discoveries, most systematic documentation of its impact comes from evaluations done by or for various governments. Program evaluations may be qualitative or quantitative, and may be based on information from a variety of sources, ranging from a simple review of program files, to expert opinion, to surveys of the intended beneficiaries of the program, to rigorous cost benefit analysis. The interested reader is referred to a manual published by the federal Treasury Board Secretariat (1998), available online, which provides a good summary of the language and methodology of evaluation.

There are a number of complicating factors in the evaluation of government geoscience:

(1) The *reach* of public geoscience is broad and it is virtually impossible to identify all of the actual and potential users. It is safe to assume that any companies holding exploration licenses or claims in a given area have used available government maps or reports, but there is no way of knowing how many other firms have reviewed this same information in the planning or reconnaissance stages of exploration. Similarly, the reach extends beyond the exploration community to those involved in land use studies, academic research, engineering projects and so on.

(2) The impacts of public geoscience accrue over an extended *timeframe*. There are two dimensions to this. First, because geoscience knowledge has a long "shelf-life", it may well influence exploration decisions 20 or more years into the future. Second, exploration itself is a protracted process; the time from the beginning of exploration to discovery to mineral production is often 10 to 20 years. Program evaluations are typically carried out upon completion of the program, when the realization of outcomes is just beginning. A better appreciation of program impacts could be developed 5 to 10 years following completion.

(3) *Attribution* is a problem in the evaluation of many government programs and it certainly obtains in government geoscience. Outcomes are often indirect; government action plays a supporting, enabling or catalytic role, but is only partly responsible for the outcomes. For example, is a spike in exploration activity due to geoscience, rising metal prices, tax incentives, resolution of land use issues, or a combination of these? If the latter, what portion is attributable to geoscience? Ideally, program results should be evaluated against a counterfactual; that is, compared to what would have happened without the program. This is generally difficult to assess in regional geoscience programs.

The title of this chapter – *Telling the Performance Story* – was inspired by a publication of the Office of the Auditor General of Canada, which highlights the difficulties of measuring the outcomes of government programs against numerical targets (Mayne, 2003). It suggests that a better approach is to tell "a credible performance story" based on an understanding of the cause and effect relationships between program activities and the desired outcomes.

The causal relationship in the present context is straightforward. The premise is that government geoscience promotes the discovery of economic mineral deposits, which, in turn, fuel economic growth. Geoscience achieves this by increasing the amount, lowering the cost, and reducing the risk of private sector mineral exploration. In this chapter, we will review the evidence supporting this hypothesis. The difficulty here, as for many areas of government programming, is not in determining whether the desired impact has occurred, but rather to what extent can the result be attributed to government action. As Mayne (2003, p.15) observed:

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16. Although Cost Benefit Analysis is widely used in government and civil society, the writer is aware of only a handful of rigorous CBAs of regional geoscience programs (e.g., Bernknopf et al., 1993; Bullock and Clinch, 2001; Reedman et al., 2002; Scott et al., 2002). These are referenced below as appropriate.

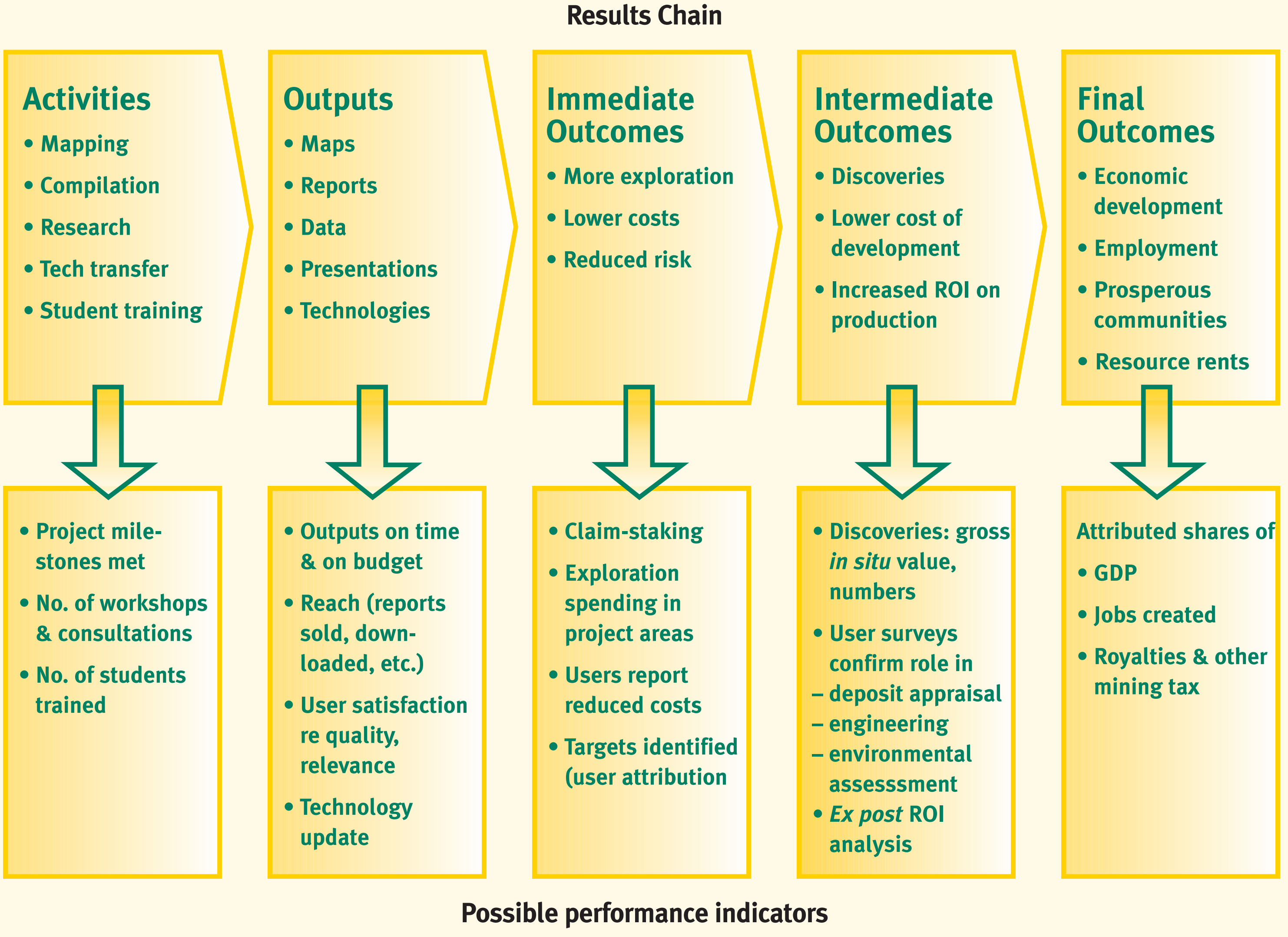
> *It is likely that no single piece of evidence gathered will on its own be enough to build a credible case concerning a result achieved or a contribution made by a program... It is the totality of the evidence gathered – some of it strong, some of it perhaps rather weak – that builds a credible performance story.*

The logic model

A logic model is a useful way to illustrate the cause and effect relationship between government action and desired results tool in telling a performance story. The model may be presented in various formats, but a simple *results chain* will suffice here (Exhibit 10). This shows the progression from geological survey activities at the front end to the public policy objectives that the program seeks to advance. Thus, the *outputs* of geoscience programs – maps, data, reports, and so on – result in *immediate outcomes*, which are increases in the amount, efficiency and effectiveness of exploration. Each of these, in turn, increases the likelihood of achieving the *intermediate outcome*s – discovery, development, and production.

Governments and industry seek different *final outcomes*. Whereas companies are driven by the need to generate profits and increase shareholder value, governments seek to achieve their public policy goals. As discussed above, the ultimate goal of geoscience to promote mineral exploration from a government's perspective is typically stated in terms of economic development. Governments also seek to capture a portion of resource rents through royalties and other mining taxes to compensate society for the private use of public mineral resources.

Exhibit 10: A logic model for a government geoscience program to stimulate mineral exploration



Results Chain

Activities	Outputs	Immediate Outcomes	Intermediate Outcomes	Final Outcomes
• Mapping • Compilation • Research • Tech transfer • Student training	• Maps • Reports • Data • Presentations • Technologies	• More exploration • Lower costs • Reduced risk	• Discoveries • Lower cost of development • Increased ROI on production	• Economic development • Employment • Prosperous communities • Resource rents
• Project milestones met • No. of workshops & consultations • No. of students trained	• Outputs on time & on budget • Reach (reports sold, downloaded, etc.) • User satisfaction re quality, relevance • Technology update	• Claim-staking • Exploration spending in project areas • Users report reduced costs • Targets identified (user attribution	• Discoveries: gross *in situ* value, numbers • User surveys confirm role in – deposit appraisal – engineering – environmental assesssment • *Ex post* ROI analysis	Attributed shares of • GDP • Jobs created • Royalties & other mining tax

Possible performance indicators

There are also subsidiary immediate and intermediate outcomes. These include the increase in the number of trained professionals as a result of career oriented summer employment of university students and stimulating the exploration services industry.[17] In the mid-term, public geoscience can reduce the costs of environmental impact assessment and engineering studies required for mineral development.

In this model, mineral exploration is not an end in itself but a means to an end. It is worth noting, however, that exploration provides economic benefits on an ongoing basis. Although individual exploration projects may be of short duration, the benefits that accrue to northern communities that act as hubs of regional exploration activities can last for decades. Moreover, exploration has given rise to a robust services sector. This industry, which comprises mostly small and medium sized enterprises, serves the global exploration market and is a source of export earnings.

Having defined the outputs and outcomes, it is then necessary to select performance indicators; that is, the evidence that causal relationship expressed by the logic model is valid and that the magnitude of the impact justifies the investment of public money. Some of the indicators that have been used in the evaluation of geoscience programs are shown in Exhibit 10 and reviewed in the following sections.

In this regard, it is important to understand the difference between performance indicators, outcomes and quantifiable benefits. For example, the discovery of an economic deposit is defined as an intermediate outcome. Although it is an essential step on the path from exploration to wealth creation, in and of itself, a discovery affords no benefit to society. Similarly, gross *in situ* value is often used as an indicator of the value of a mineral discovery. However, to determine the potential benefit, one would need to know the cash flow characteristics of the deposit, the royalty and taxation regime, and so on, and compare these to the cost of the program on a net present value basis.

Outputs, outcomes and performance indicators

Activities and outputs

Before the widespread adoption of results-based management, evaluation of government geoscience generally emphasized outputs – the maps, reports, data and so on that are the direct results of programs – rather than outcomes. The quantity and timeliness of outputs are readily measured against pre-defined targets. Peer review and client surveys provide assessments of scientific quality and relevance to user requirements. Moreover, geological surveys in Canada make extensive use of external advisory committees on an ongoing basis, at both the corporate and program levels, to ensure that their activities are aligned to industry needs.

This is not to say that outputs are not important – they matter. Indeed, from the perspective of many stakeholders, outputs are all that matter. The point is that unless activities are undertaken with an understanding of the desired outcomes, the outputs may not be the most appropriate. For example, geological mapping undertaken to solve some fundamental tectonic problem may differ in location, scale and style from that required to promote mineral exploration. Geological surveys need to balance their portfolio of activities to address their various mandates.

The material reviewed for the present study indicates that government surveys in Canada generally receive high marks for quality, relevance and timeliness of their outputs. This was not always the case. Although scientific quality has rarely been an issue for Canada's surveys, there was a time 15 or 20 years ago when some were criticized for what were perceived as undue delays in the release of data, maps and reports. Technological advances have mitigated many of these concerns. Digital capture of data in the field, rapid analysis in the laboratory, desktop publishing and cartography, and distribution of published outputs through the Internet mean that value-added information can be made available to clients very quickly.

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[17] Porter and the Monitor Company (1992) highlighted the contributions of government geoscience in making Canada a world leader in geophysical contracting. These included transfer of technology developed in government labs, contracting of public geoscience surveys (especially helpful during the downturns in the exploration cycles), and showcasing Canadian capabilities in international development assistance projects.

The annual survey of mining companies undertaken by The Fraser Institute gives an indication of how Canadian government geoscience outputs are perceived in a global context. Respondents are asked to rate jurisdictions on the extent to which the quality, scale and ease of access of the geological database upon which investment decisions are based. The 2008-09 survey polled 658 companies for their opinions on 71 jurisdictions (12 Canadian provinces and territories, 14 American states, 7 Australian territories and states, and 38 countries). If jurisdictions are ranked on the percentage of respondents who perceived that the geological database encouraged investment, the top quartile comprised 8 from Canada, all 7 Australian states and territories, and two European countries (Finland and Sweden). Quebec was ranked first globally in this category by a significant margin. Nunavut and the Northwest Territories received the lowest ratings among Canadian jurisdictions, which presumably reflect the more limited coverage of these vast areas, rather than the quality or accessibility of the information.

These results support the long held position of industry groups such as the Prospectors and Developers Association of Canada and the Mining Association of Canada that the public geoscience knowledge provided by Canada's geological survey organizations is among the best in the world and affords a competitive advantage in attracting investment in exploration. However, this is not a reason for complacency. Canada's average ranking appears to have declined relative to Australia and some other jurisdictions.

Immediate outcome – increased level of exploration

Several different performance indicators have been used to measure the impact of geoscience on the amount of exploration, including claim staking, observed exploration activity, and actual expenditures in project areas. For example, Swindon (1993) determined that 94 percent of exploration expenditures in Newfoundland and Labrador during the period 1981-1991 occurred in areas for which there were relatively recent geological maps. He cautioned that government mapping had focused on areas of perceived high mineral potential, but also demonstrated direct linkages between mapping and exploration in several case studies.

The evaluations of federal-provincial/territorial Mineral Development Agreements, undertaken from 1984 to1996, are relevant. Although now somewhat dated, these studies are interesting because they review a large number of diverse geoscience projects (265) spanning much of the country. Most of these evaluations were conducted in the final year of the relevant program, before all of the resultant maps and reports had been released, and therefore reflect only the immediate, partial impact on exploration. The results indicate that 58 percent of projects stimulated new exploration (Exhibit 11). A more recent evaluation of the Targeted Geoscience Initiative had the same result: 11 of 19 projects, or 58 percent, had stimulated new private sector exploration expenditures during the life of the program (Boulton, 2003).

Exhibit 11: Federal-provincial-territorial mineral development agreements Proportion of geoscience projects resulting immediate exploration stimulation

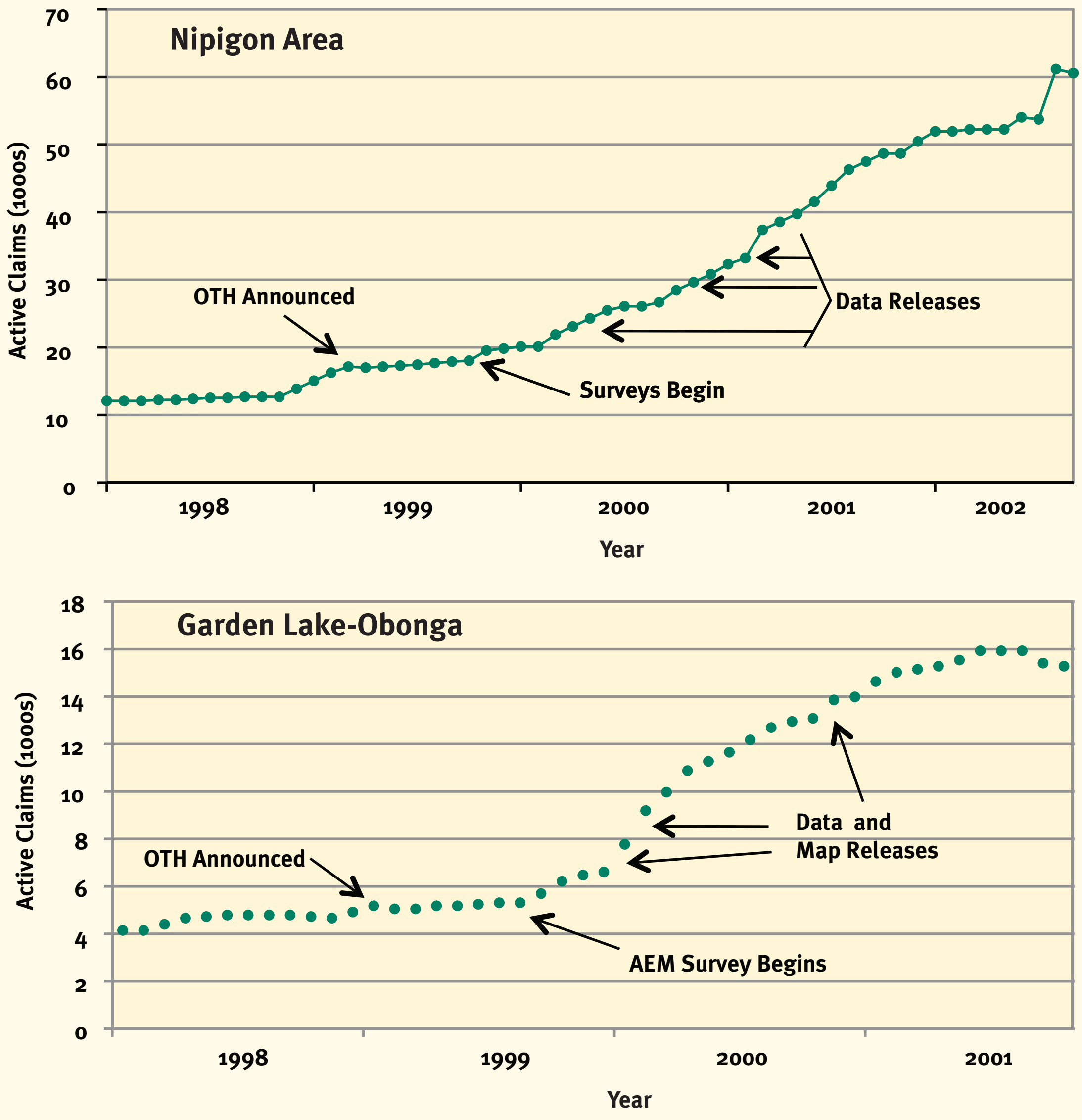
Jurisdiction	Geoscience Projects	Resulting inExploration	Percent	Reference
Newfoundland (1984-89)	31	16	52	Goss Gilroy (1990)
Nova Scotia (1984-89)	25	10	40	Goss Gilroy (1990)
New Brunswick (1984-89)	24	17	71	Goss Gilroy (1990)
Ontario (1985-90)	55	32	58	Goss Gilroy (1991)
Manitoba (1984-89)	33	24	73	Goss Gilroy (1990)
Saskatchewan (1984-89)	16	9	56	Goss Gilroy (1990)
British Columbia (1985-90)	20	11	55	Ference (1990b)*
NWT (1987-91)	18	13	72	Ference (1990a)*
British Columbia (1991-95)	20	13	65	Marek (1995)
NWT (1991-96)	23	9	39	Goss Gilroy (1995)*
Totals	265	154	58	

*Numbers inferred from project summaries

Although claim staking is not necessarily followed by work on the ground, it is nevertheless a useful indicator of exploration activity. Day (1995) used a GIS-based statistical approach to demonstrate a strong correlation between the density of exploration permits and “second pass” government mapping in Queensland, Australia. He noted that private exploration increased when government mapping began, that exploration remained high in the mapped areas, and increased over time where mapping enhanced the mineral potential.

The Ontario Geological Survey monitored claim staking in project areas during Operation Treasure Hunt (Churchill *et al.*, 2000, 2001; Fyon *et al.*, 2002). The number of active claims increased by 200 percent in the Schreiber area, 275 percent in Garden Lake-Obonga, and 500 percent in Nipigon. Claim staking sometimes anticipates the release of geoscience results, especially certain types of geochemical and geophysical surveys that provide direct indication of exploration targets (Exhibit 12). Staking does not necessarily lead to increased exploration, but in Nipigon, at least, industry follow-up was substantial – $6.4 million by the end of the program.

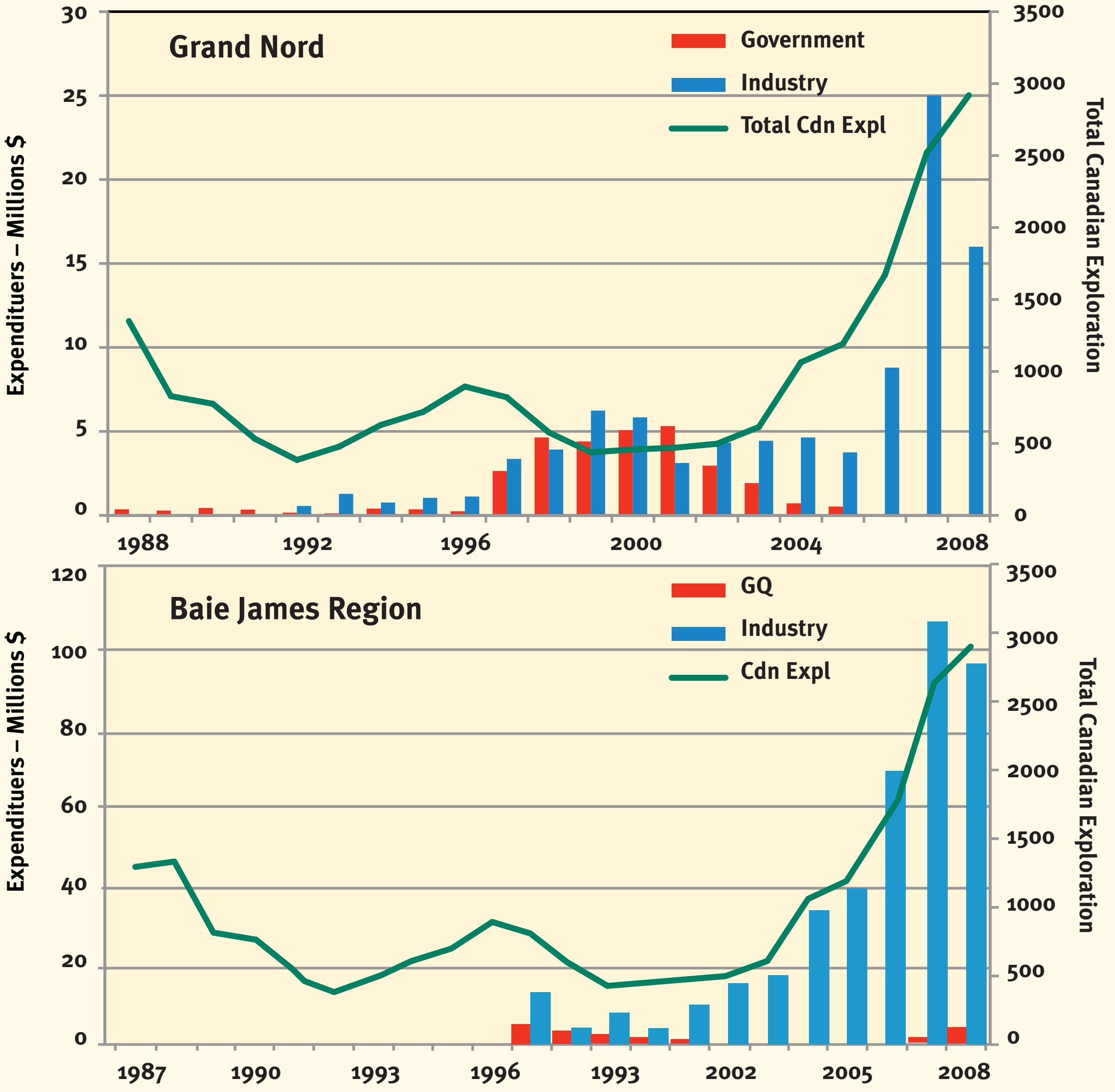
Exhibit 12: **Increase in the number of active mining claims in the Lake Nipigon and Garden Lake-Obonga regions, beinning with the announcement of Operation Treasure Hunt and continuing with releases of geochemical and geophysical data** **(Churchill *et al.*, 2001; Fyon, *et al.*, 2002).**



While it is relatively easy to determine whether a given geoscience project has stimulated new exploration in the short term, measuring the incremental increase in exploration expenditures is sometimes difficult. For example, in the MDA evaluations described above, industry representatives responding to client surveys often reported increased exploration spending but declined to give dollar amounts. However, there are many straightforward examples where virtually no exploration had occurred in a given area for many years, but was initiated upon the release of new map or report.

A case study of the Grand Nord (far north) region Québec is important in this respect because it encompasses a large area, the attribution to government geoscience is clear, and it spans a business cycle (LeClair et al., 2006; Maurice et al., 2009). The region comprises 350,000 km2 in the northeastern Superior Province, about 20 percent of the landmass of Québec. It had been mapped on a reconnaissance basis (1:1M) in the 1950s and 60s, but had attracted little exploration by virtue of its isolation and low perceived mineral potential. The perception changed in 1991-92 when GSC mapping of a 100 km wide transect revealed the presence of prospective volcano-sedimentary rocks ("greenstone belts"). This stimulated nearly $5 million in private sector exploration over the following 5 years – a multiplier of about 2. In 1997, Géologie Québec embarked on a 10-year program 1:250K geological mapping and related surveys, with complementary work by the GSC. By the end of 2008, three years after the completion of the program, private sector exploration had totalled $92.9 million compared to cumulative government expenditures of $40.7 million, a ratio of 2.3:1. This multiplier will undoubtedly increase as exploration proceeds over the next 3 to 5 years. The pattern of public and private expenditures is illustrated in Exhibit 13a. It is significant that mineral exploration in the area increased in the late 1990s, at a time when total exploration spending in Canada was declining.

Exhibit 13: Government geoscience and private sector exploration expenditures in the Grand Nord and Baie James regions of Northern Quebec (after Maurice *et al.*, 2009).



Another case study from Québec provides a good example of the difficulties of attribution. Exploration companies were already active in the James Bay region when Géologie Québec (GQ) initiated its "Near North" program in 1995 (Maurice et al., 2009). Private sector activity continued over the following six years, during which GQ produced 34 maps at a scale of 1:50,000 and 4 at 1:250,000. Thus, a modern geoscience information base for the region was in place for the next upswing in exploration activity, beginning in 2001. Industry expenditures from 1997 to 2008 totalled $422 million, compared with a $22 million investment in government geoscience – a ratio of 19:1. The increase in industry spending in the region between the trough in 2000 and the peak in 2007 was 21-times, much more than the Canadian average of 5-times. The discovery of the Éléonore gold deposit in 2004 by Virginia Gold Mines was arguably a major impetus to increased exploration spending. However, because exploration began increasing in the James Bay region much more rapidly than in the rest of Canada in 2001, it is reasonable to conclude that the new government geoscience played an important role in attracting investment.

Boulton (1999) undertook an evaluation on behalf of Natural Resources Canada to support the business case for the Targeted Geoscience Initiative (TGI) in the 2000 federal budget. The report concluded (p.23) that:

> *Every $1 million of government investment to enhance the geoscience knowledge base will likely stimulate $5 millions of private sector exploration expenditures, which, in turn, will result in discovery of new resources with an average in situ value of $125 millions.*

This conclusion has been widely cited and, because the report is unpublished, it is important to examine the underlying arguments. The 5:1 ratio between public sector and private sector investment was derived from 13 previous studies, 10 from Canada and 3 from Australia. The earlier work reflected different evaluation methods and assumptions, and indicated multipliers in the range of 1 to 7. Boulton's analysis applied to the "medium-term", which he defined as 5 to 7 years following program completion. However, because only two of the previous evaluations post-dated the programs in question, rather than averaging the results, he provided a best estimate of medium term impacts.

A number of subsequent studies appear to support Boulton's conclusions (Exhibit 14). In Australia, the federal, state and territorial governments launched a series of mineral exploration initiatives in the early 1990s, each of which included an important component of geoscience (Lambert, 1998). Dugmore (2003, p.4) summarized the results of these initiatives and found that *"for every $1 spent by government on exploration initiatives, between $2.70 and $9 is spent by industry on exploration"*. Reedman et al. (2002), in their excellent review of the policy rationale for geoscience in support of international development, describe a number of mineral exploration case studies in Asia, Africa and South America. Maurice et al. (2009) analysed the impact of two major mapping programs in Québec, as well as a smaller but very effective mineral potential assessment initiative.

As well as these *ex post* assessments, estimates of the impact of government geoscience on the level of exploration spending have been derived from model-based cost-benefit analyses. In their pioneering study of the societal value of geological maps, Bernknopf *et al.* (1993) estimated the reduction in economic loss resulting from land use decisions based on upgraded versus older map data. Using a similar approach, Bernknopf et al. (2007) applied mineral potential and economic modelling to evaluate the impact of second-generation geological mapping of southern Baffin Island. They projected that the new maps, which cost $1.86 million to produce, would stimulate between $2.28 and $15.21 million in private sector exploration, under various assumptions. This indicates a multiplier in the range 1.2 to 8.2, which is similar to those inferred from retrospective evaluations.

In order to isolate the effect of government information, Scott *et al.* (2002) undertook a statistical analysis of company spending intentions in Queensland, contained in confidential exploration permit applications. They found that the older and upgraded government geoscience data accounted for 5 and 10 percent, respectively, of proposed exploration expenditures. Assuming that exploration began in the second year of the 10-year mapping program and continued for five years after its completion, their model suggests the multiplier would be 1.8, or 1.5 on a net present value basis.

On balance, the evidence indicates that the "rule of thumb" that $1 spent on government geoscience will stimulate $5 in private sector exploration is reasonable, as long as its limits are understood. Program scope is important; an individual mapping project is not guaranteed to stimulate exploration, but a portfolio of suitable projects will include some "winners". The data reviewed here suggest that about 60 percent of projects have immediate impact. Commenting on the Australian experience, Jaques (*pers. comm.*) observed that the magnitude of industry response is influenced by both the timing and location of government geoscience activities. Uptake tends to be greater when exploration is booming than during a trough in the business cycle. The response in remote areas may be restrained, at least until there is a discovery or other positive result from exploration (the Grand Nord case study, above, exemplifies this).

Exhibit 14: Examples of exploration expenditures stimulated by government geoscience

Case Study Description	Program period	Program cost	Exploration period	Exploration expenditure	Ratio	Reference
Canada-British Columbia MDA*	1985-1990	C$6.7M	1985-1990	C$5.6M	0.83	Ferrence et al. (1990)
Canada-Northwest Territories EDA*	1991-1996	C$7.8M	1992-1995	C$14.1M	1.8	Goss Gilroy (1995)
Pickle Lake, Ontario*	1972-1973	C$0.75M	1982-1984	C$5.5M	7.3	Fyon & Churchill (1998)
EXTECH II (Bathurst, New Brunswick)*	1994-1999	C$6.5M	1994-1999 1994-2009	C$12.5M C$37.5M	1.9 7.7	Fraser Services (1999)
Discovery 2000, NSW, Australia*	1994-1999	A$17.5M	1996	A23.1M	1.3	
Discovery 2000, NSW, Australia	1994-1999	A$35M	ns	A$150	5	DPIR, 2008
South Australia Exploration Initiative*	1992-1996	A$23.5M	ns		5	Dugmore (2003)
VIMP, Victoria, Australia	1994-2005	A$29.5	ns		9	Dugmore (2003)
Proyecto Precambrico: Eastern Bolivia	1976-1983 ~1990	US$4.9 M US$1 M	1987-1999	>US$40	>7	Reedman et al. (2002)
Geological & Geochemical Mapping, Sumatra	1975-1994	US$8M	1992-1996	US$68M	8.5	Reedman et al. (2002)
Midlands Goldfield, Zimbabwe	1989-1992	US$2M	1996-1998	US$5M	2.5	Reedman et al. (2002)
Grand Nord, Québec	1987-2005	C$40.7M	1987-2008	C$92.9M	2.3	Leclair et al (2006); Maurice et al., (2009)
Baie James, Québec	1997-2001 2007-2008	C$22M	1997-2008	C$421.9M	19	Maurice et al., (2009)
Mineral Potential Assessments, Québec	2005-2006	C$0.2M	2006-2008	C$2.5M	12	Maurice et al., (2009)
Lake Nipigon, Ontario	2000-2002	C$2.2M	2000-2002	C$6.4M	2.9	Fyon et al. (2002)
Separation Rapids, Ontario	1992-2001	C$0.8M	1996-2001	C$4.8M	6.0	Churchill et al. (2001)
East Bull Lake, Ontario	1971-2001	C$0.8M	1986-2001	C$12.4M	15	Churchill et al. (2001)
Discover Abitibi, Ontario	2002-2005	C$12.5M	2004-2007	C$29.5M	2.4	Boulton (2006)

* Case studies also cited by Boulton (1999). Several other sources used by Boulton but based on different assumptions are not included here.

It is worth repeating a point made above. In the context of program evaluation, increased exploration expenditures are an outcome of government geoscience and the spending ratio is a performance indicator. The amount of increased exploration is not a benefit *per se* in the sense of a cost-benefit analysis.

Immediate outcome – reduced cost of exploration

Government geoscience not only increases total exploration expenditures, it reduces the cost of individual exploration projects or programs. In other words, it increases the efficiency of private sector exploration. Public geoscience contributes to the overall efficiency of mineral exploration by reducing the duplication of effort by individual companies. The premise is that if regional geological maps, for example, were not provided by the government, companies would need to do their own mapping. Regional mapping is both expensive and time consuming, and in practice, it is more likely that companies would direct their exploration to areas with adequate public information. The more important contribution to efficiency is in allowing companies to focus their efforts on areas of higher potential, allowing them to identify targets more quickly and at lower cost.

Although the relationship between the availability of government geoscience information and exploration efficiency is widely acknowledged, there have been only a few attempts to quantify the impact in a systematic way. For example, most of the evaluations of the geoscience programs conducted under the Mineral Development Agreements (Exhibit 11) simply asked users whether the results had improved the efficiency and effectiveness without defining what this meant in practical terms. Not surprisingly, the responses were strongly positive (100% in one case).

A more useful approach in *ex post* surveys is to ask users to estimate savings in operational costs or time attributable to the availability of public geoscience. The author is unaware of any such surveys that focused exclusively on mineral industry users, but two broad studies of diverse user groups are of particular interest.

Bhagwat and Ipe (2000) evaluated the economic benefits of geological mapping in Kentucky. The entire state was mapped at a scale of 1:24,000 during the period 1960-78 by the state geological survey and USGS. When the mapping was initiated, it was intended primarily to promote exploration and development of coal, industrial minerals, oil and gas. The study showed that while these remained important, groundwater exploration had become the most important single application. In addition, the maps were widely used for transportation planning, waste disposal siting, and industrial permitting. Respondents to the user survey estimated that the maps had resulted in an average saving of 17% in project costs. Using map sales, the authors extrapolated these figures to yield a total value of the mapping program of $2.25 to $3.35 billion, or 25- to 39-times the $90 million cost of the program (all in 1999$). The high benefit to cost ratio may reflect the fact that the study was conducted 20 years after the completion of the mapping program.

García-Cortés *et al.* (2005)[18] used a similar methodology to evaluate geological mapping in Spain. The entire country was mapped at a scale of 1:50,000 during the period 1971 to 2003. They evaluated the impact of the mapping program in terms of cost reductions accruing to users, and concluded that the program, which cost €122 M, had resulted in savings of €2,200 M to the Spanish economy through 2004, a benefit to cost ratio of 18:1. Like the Kentucky study, mineral industry users constituted a minority of those surveyed, and therefore the results should be extrapolated with caution (although the savings might be even greater in exploration).

Immediate outcome – improved effectiveness – reduced discovery risk

"Effectiveness" is a measure of the success of a given activity. The success of mineral exploration is ultimately measured in terms of discoveries. Increasing the effectiveness of exploration is tantamount to decreasing discovery risk. Bailly (1981) defined exploration effectiveness as the ratio of the value of deposits discovered to exploration expenditures, that is, the discovery cost. This ratio may be calculated at the level of an individual company, a region, a country or the industry as a whole. Leveille and Doggett (2006) equated exploration effectiveness to the ratio of net reserve replacements to metal produced. While these are a reasonable definitions of the overall effectiveness of exploration, they are not very useful for individual projects or programs or, indeed, for gauging the impact of government geological surveys.

Lord *et al.* (2001) proposed an alternative approach to quantifying exploration effectiveness. They related effectiveness to the probability of a project advancing to the subsequent stage of exploration. In particular, they calculated the expected value of a project[19] (ev) at each exploration stage:

$$ev = p_s \text{ x } TV - C$$

where TV is the threshold value, the minimum acceptable NPV that a company has defined for a particular exploration program. In this case, p_s and C are, respectively, the probability of advancing the project to the next stage of exploration and the cost of doing so. The latter probability, in turn, is based on the presence or absence of critical geological features derived from the mineral deposit model:

$$p_s = p_1 \text{ x } p_2 \text{ x } p_3 \ldots\ldots p_n$$

The p_i terms are assigned values between 0 and 1, based on the degree of certainty that critical processes occurred. Lord *et al.* selected critical features on the basis of a genetic or process model, but the concept could apply equally to features suggested by a descriptive model.

Although Lord *et al.* did not explicitly consider public geoscience input to the probability function, there is no fundamental reason why, in some cases, one or more of the pi terms could not be deduced from public geoscience information. In the event, it would offer a conceptual framework to quantify the impact of government geoscience on exploration effectiveness and may be an avenue worthy of further research.

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[18] As reported by Regueiro & Rodríguez (2008).

[19] Note that the expected value of a discovery (ev) differs from the expected value of an economic discovery (EV), defined in chapter 4.

In the meantime, target identification may provide a practical indicator of the contribution of government geoscience to reducing exploration risk. In the discussion of discovery risk in Chapter 4, it was observed that in order to be reasonably assured of discovering an economic deposit, a company would need to test a large number of targets.

Scott *et al.* (2002) surveyed exploration companies to determine the impact of the new geological maps in Queensland on perceptions of mineral potential. Respondents were asked to estimate the number of potential targets that would be generated using upgraded instead of existing maps. The mean response was that the new information would yield 2.8-times as many.

Bernknopf *et al.* (2007) suggested a model-based approach to quantify the impact of public geoscience on exploration efficiency and effectiveness. They defined efficiency as the number of targets found per unit area searched, and productivity as the number found for a given exploration effort. Applying a hypothetical decision model to two generations of geological maps, geological criteria were used to delineate "favourability domains" for specific types of mineral deposit types on both the old and new maps. The number of targets per unit area was inferred from known occurrences and by analogy with similar terranes. The model was based on the assumption that exploration will be directed at areas where there is the greatest perceived likelihood of finding targets. The difference in the resultant decisions was calculated in economic terms, which equates to the benefit accruing from the enhanced geological information.

The model was applied in two case studies: the mature Flin Flon district of Manitoba-Saskatchewan, and the relatively little-explored southern part of Baffin Island. In the Baffin example, the model suggested a 40 percent increase in the number of targets identified for a given exploration effort. The Flin Flon case examined a number of scenarios, which typically indicated an increase of up to 60 percent in the number of targets.

Intermediate outcome – discoveries

Two different approaches have been used to quantify the contribution of government geoscience to mineral discoveries for evaluation purposes. The first uses case studies and the second is based on the assumption that the value of discoveries is a function of exploration expenditures, which can be related in turn to the amount spent on geoscience.

Although the role of government geoscience in stimulating and guiding exploration is widely acknowledged, its contribution to mineral discoveries is not well documented. Discovery case histories only occasionally describe what role government geoscience may have played. This omission is perhaps not surprising given the long time between the beginning of exploration and discovery, and the fact that the mineral rights may have been held by several corporate entities in the interim.

In the description of the mineral exploration process in the preceding chapter, it was noted that the term "discovery", as used in the context of national exploration statistics, refers to potentially economic mineral deposits. For the purposes of evaluating the impact of government geoscience, however, discoveries of significant prospects are also useful as a performance indicator. Some examples of discoveries of mineral deposits and significant prospects, in which a role of government geoscience has been acknowledged, are listed in Exhibit 15.

Lang (unpublished, reported by Duke, 1992) reviewed 37 discoveries of mines or mineral districts involving the Geological Survey of Canada from 1842 to 1968. He calculated the value of production and reserves of these deposits to be $42 billion, as compared to cumulative GSC expenditures of $96 million over the same period. Applying an attribution factor (typically 1 to 5 percent) to each discovery, Lang concluded that the value of the GSC contribution totalled $680 million, or seven times its expenditures.

Doggett *et al.* (1996) analyzed the costs and benefits of the National Geochemical Reconnaissance (NGR), the GSC's systematic regional stream and lake sediment survey program. The goal of the program is to elucidate the regional variations in the chemical composition of surficial materials, which provides a baseline for various applications including, in particular, mineral exploration and environmental assessment. Doggett *et al.* determined that the total cost of the program (1973-1995) had been $41.8 M (1996$). In the benefits column, they estimated both the gross in situ value and the revenues that would accrue from two discoveries for which a significant NGR role had been acknowledged: Brewery Creek (gold) and Kudz ze Kayah (base metals), both in Yukon. Applying an attribution factor of 5 percent, they concluded that the projected revenues would exceed the total cost of the NGR program by a factor of 2.

At least five additional discoveries have been made in the Finlayson Lake belt since Kudz ze Kayah was found in 1993. The most significant of these, Wolverine, is expected to begin production in 2010. Although the NGR was not directly implicated in these follow-on discoveries, the program arguably should receive some attribution by virtue of having attracted exploration to the belt in the first place. Other discoveries in which the NGR played a direct role include the Clarence Stream gold deposits in New Brunswick and the Strange Lake rare element deposit in Labrador.

Exhibit 15: Examples of discoveries of deposits and significant prospects in which government geoscience played a role (since 1970)

NUNAVUT
Meliadine District (gold)
Committee Bay (gold)

NORTHWEST TERRITORIES
Ekati (diamonds)
Sue-Dianne, Nico (copper, gold)

YUKON
Kudz Ze Kayah (base metals)
Brewery Creek (gold)
Lucky Joe extension (copper, gold)

BRITISH COLUMBIA
Joss'alun (copper)
LJ (zinc-lead)
Fran (gold)

ALBERTA
Buffalo Hills (diamonds)
Zama Lake (Pb-Zn)
Marguerite River (U)

Saskatchewan
Fort à la Corne (diamonds)
Contact Lake (gold)

Manitoba
Photo Lake (base metals)
Lalor Lake (base metals)
Eden Lake (rare earths)
Little Stull Lake (gold)
Monument Bay (gold)

ONTARIO
Pickle Lake (gold)
Separation Rapids (lithium)
Cargill Township (phosphate)

QUEBEC
Canadian Malartic (gold)
Troïlus (copper-gold)
Sept-Îles (apatite)
Lac St-Jean (wollastonite)

NEW BRUNSWICK
Camel Back (base metals)
Clarence Stream (gold)
Sussex (potash)

NOVA SCOTIA
East Kempville (tin)
Murchyville (gypsum)
McLeod Quarry (marble)

NEWFOUNDLAND AND LABRADOR
Strange Lake (rare earths)
Voisey's Bay (nickel)
Central Mineral Belt (uranium)

The case study approach tends to focus on discoveries in which government geoscience played a direct role in identifying targets for follow up exploration (*e.g.*, mineral occurrences, geochemical or geophysical anomalies). However, direct target identification is not normally the objective of government surveys. Rather, their role is to assist the private sector to identify targets as, for example, in the Kidd Creek discovery described above (Exhibit 7). In other words, this approach uses exceptions to prove the rule. Limiting the accounting to those cases where there is an acknowledged direct relationship understates the total contribution.

Having concluded that each $1 in government geoscience resulted in $5 in exploration, Boulton (1999) used two different methods to estimate the 25:1 ratio between exploration expenditures and the value of discoveries. The first was to divide total exploration expenditures by average discovery costs, giving ratios in the range of 16:1 to 31:1. The second method used the ratio of production revenue to exploration expenditures over a 9-year period, which gave multipliers from 23.5 to 27.2, depending upon assumptions. Lambert (1999) reached essentially the same conclusion based on the Australian experience. He found that every $1 spent by government on pre-competitive geoscience led to discovery of in ground resources worth $100 to $150. Calculated in these ways, the value of discoveries is not an independent performance indicator. However, it does provide a "rule of thumb" estimate of what might be anticipated as an outcome of government geoscience and, as such, is useful for communication purposes.

Bullock and Clinch (2001) undertook an *ex ante* cost benefit analysis of RESI, a major geophysical and geochemical program in Ireland. They estimated the value of benefits in a wide range of applications including mineral development, land management, water supplies, and environmental protection. These amounted to a benefit-cost ratio of 5:1 on a net present value basis. Mineral development accounted for the largest share of benefits, albeit based on a much higher attribution factor than other studies.

Final outcomes

There is no question that mineral production continues to make an important contribution to the Canadian economy. The final outcomes that past governments have sought from their investments in geoscience are being realized. In the foregoing, we reviewed evidence that supports the notion that geoscience promotes exploration and discovery, which are prerequisites for production and economic development. However, the provision of public geoscience is only one of many government policies that have influenced this outcome. The question is whether policy makers can be confident that the cost of geoscience justifies the benefits. The answer depends upon what proportion of the benefits may be attributed to geoscience.

Swan (1997) proposed that government geoscience be evaluated in terms of its contribution to the value of mineral production. He considered government geoscience to be a factor of production and that the value of its contribution to mineral output is proportional to its cost. For example, in 1995, the total cost of mineral exploration, development and production was C$11.2 billion, *including* federal and provincial government geoscience spending (C$ 155.7 million). Thus, the cost of government geoscience represented 1.4 percent of total costs. Applying this percentage to the value of mineral output (C$12.2 billion) indicates a value of geoscience of C$ 169.5 million, or a net benefit of 8.8 percent. This approach does not relate production to the specific geoscience expenditures that contributed to the discoveries of deposits being mined at the time, which were obviously incurred many years earlier. Rather, exploration-development-production is regarded, in effect, as a steady state system. It assumes that the existing level of government geoscience effort and private sector exploration is what is required to sustain current production. One might argue that Swan's assumption that the contribution of government geoscience to the value of production should be adjusted upward to account for private sector exploration stimulated by government expenditures. In any case, it is interesting that the share of production value proposed by Swan is within the range of attribution factors commonly used by others (1 to 5 percent).

The economic impact of geoscience has also been evaluated in terms of economic or resource rents (see chapter 4, above). Economic rent is the excess of revenue over the total cost of production, which includes not only the cash costs of extraction, but also the sunk costs of exploration and development, and a "normal" return on capital. It is a return to the resource that is available for sharing between the industry (as profits) and government (as royalties and other taxes). The availability of public geoscience decreases exploration costs, thereby increasing economic rents. According to Hogan (2003, p.35):

> *In broad terms, the public geological surveys may be considered to be cost effective if the cost of the surveys does not exceed the benefits, as measured by the gain in economic rent.*

Hogan did not address attribution, apart from observing that in Australia, royalties from mining were A$925 million in 2000 – many times the A$75 million spent on government surveys. In their model-based analysis of the value of upgraded geoscience information in Queensland, Scott et al. (2002) used royalty revenues as an indicator of the return to society for its investment in public geoscience. They concluded that the resulting increased royalty revenues equate to a benefit/cost ratio of 4.7:1 on a net present value basis. However, it should be noted that royalties are not the only means whereby governments capture rents. Because rent represents "surplus" revenue, income taxes also serve this purpose in part.

The Mining Association of Canada has estimated that from 2004 through 2008, annual tax revenues to Canadian governments from mining averaged $5.5 billion, including $1.3 billion in royalties (Exhibit 2). Total spending by federal, provincial and territorial geological surveys averaged $146 million over this period (Appendix A). It was estimated above that approximately 55 percent of survey expenditures are relevant to mineral exploration. This amount ($80 million) is equivalent to just 1.5 percent of total government revenues from mining.

Conclusion

In order to justify the expenditure of tax dollars on public geoscience to policy makers, it is important to establish the cause and effect relationship between government actions and achieving public policy goals. The premise is that government geoscience maps, reports, etc. (outputs) lead to more and better exploration (immediate outcomes), which results in discoveries, development and production (intermediate outcomes), and ultimately to economic development (final outcome). In the progression from outputs to outcomes, the extent to which results can be attributed to government action diminishes. Together with the extended time frame of exploration, discovery and development, this makes rigorous cost benefit analysis of government geoscience very difficult. The preferred approach is to develop a credible performance story at each step in the results chain.

There is ample evidence that government geoscience stimulates private sector exploration. Program evaluations suggest that 6 out of 10 mapping projects will have immediate impact in terms of claim staking or new exploration activity. The proportion should increase in the years following project completion. User surveys typically assign a high attribution factor (30 to 100 percent) to government geoscience in these cases. Incremental exploration expenditures are more difficult to quantify and depend on the location and timing in the business cycle of government action. However, the often cited rule-of-thumb that $1 in government spending results in $5 in private sector exploration is a reasonable expectation over the medium term.

Although it is widely acknowledged that the availability of public geoscience information reduces the cost of mineral exploration, there have been few systematic efforts to quantify these outcomes. Surveys of diverse user groups indicate efficiency improvements of 5 to 20 percent, but much higher percentages may obtain in the early stages of mineral exploration. Similarly, industry respondents to user surveys often say that government geoscience has increased exploration effectiveness, but this impact is difficult to quantify. Anecdotal evidence suggests that government geoscience has contributed to many discoveries – the most obvious indicator of effective exploration. While this is a useful performance indicator, it does not reflect the role of public geoscience information on the quality of day-to-day decision-making in exploration. How to measure the impact of public geoscience on increasing the effectiveness of exploration and reducing discovery risk in quantitative terms would be a fruitful area for further research.

6. How much government geoscience is enough?

Introduction

Federal, provincial and territorial governments in Canada have generally included public geoscience as an important element of their mining policies or strategies. Governments seek to sustain or increase mineral production in existing mining districts and to promote new economic development, especially in rural and remote areas, and they understand the role played by geoscience in stimulating investment in exploration. The question facing policy makers is not whether to fund government geological surveys but rather to determine a level of funding that both achieves its public policy goals and is affordable. In doing this, they must consider geoscience in relation to other public policy priorities. There are opportunity costs; funding geoscience means that a government must forego or delay other priorities. In this respect, geoscience suffers from a perception that although it may be important, the need is not urgent. Given that final outcomes are realized over the long term, government decision makers need to be convinced that there are real consequences to delaying the acquisition of new geoscience information.

Geoscience information required for mineral exploration

Governments provide geoscience as a public good to address a broad range of public policy goals, some of which were described in Chapter 2. The information required for mineral exploration is a subset of the total body of geoscience knowledge and has specific characteristics. The utility of the public geoscience knowledge base for a given application may be judged on five factors: relevance, scale, coverage, currency, and format.

Relevance

Four broad categories of public geoscience information are fundamental to mineral exploration: bedrock geology, surficial geology, geophysics and geochemistry. Each of these comprises a number of subcategories. For example, geophysics includes aeromagnetic, electromagnetic (AEM), and airborne gamma ray spectrometry (AGRS). Geochemistry includes stream and lake sediments, tills, and rocks. Generally speaking, industry places the highest priority on bedrock geology and aeromagnetic data. Drainage sediment geochemistry and AGRS are also very useful in specific geological terranes, and the increase in diamond exploration in Canada since the early 1990s has created a demand for kimberlite indicator mineral (KIM) surveys.

Scale

Because much of the geoscience information used in mineral exploration is in the form of maps or geospatial data, it is convenient to discuss needs in terms of scale. Larger scale implies greater density of observations, better spatial resolution, and better positional accuracy. Mineral exploration uses geoscience information collected at a variety of scales. Generally speaking, exploration requires progressively more detailed maps and data as it proceeds from the reconnaissance stage to target identification and discovery. A number of standard scales are in common use by geological surveys. Regional geological maps are generally published at scales of 1:100,000 or 1:250,000 with the latter being the minimum useful scale for exploration. Common scales for more detailed mapping include 1:50,000 and 1:20,000.[20] Scales as large as 1:10,000 are used for systematic mapping in some jurisdictions (*e.g.*, United Kingdom), but this is not common.

Coverage

The third measure of the utility of the geoscience knowledge base is the extent of coverage, generally expressed as the percentage of the area of a given jurisdiction for which adequate geoscience information is available. For example, Ward et al. (1999) estimated that adequate bedrock geological map coverage at a scale of at least 1:250,000 existed for only 65 percent of Canada's landmass.

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20. 'Regional' and 'detail' scales are defined differently in different jurisdictions and contexts. For example, Barnes and Lisle (2004) describe 1:250,000 geological maps as 'reconnaissance", 1:100,000, 1:50,000 and 1:20,000 as 'regional', and any scale larger than 1:10,000 as 'detail'.

Currency

In most jurisdictions, the body of public geoscience knowledge that influences investment decisions has been built over several decades. Once generated, regional geoscience information is useful to the exploration industry for many years. Indeed, there are cases where the impact of the information occurred long after it was released. The discovery of Kidd Creek described in Chapter 4 is one example. Another is the discovery of diamond deposits at Fort à la Corne, Saskatchewan in 1988, which was directly attributable to aeromagnetic maps published by the GSC in 1968, but largely ignored for 20 years. Although regional geoscience information has a long "shelf life", it is rendered less useful over time by scientific and technological advances. This being the case, does geoscience information have a "best before date"? While there is no hard and fast rule, many geologists would agree that after 20 to 30 years, the utility of information is much reduced. For example, a guideline of the Ministry of Northern Development and Mines of Ontario stipulates a 20-year mapping cycle for areas of significant mineral potential (OAGO, 2005).

Format

Advances in information technology over the past twenty years have had an enormous impact on the dissemination of geoscience information. In the past, information was distributed primarily as traditional paper products (maps, reports, etc.). Today, most geological surveys produce (and clients expect) information in digital form and make it available on CD and over the Internet. This allows users to produce custom products to meet their particular needs and to integrate different kinds of data using GIS-based systems. A fundamental requirement of this new approach is adherence to data models or interchange standards.

How much government geoscience is enough?

The facile answer to this question is "enough to ensure an adequate level of mineral exploration and discovery". However, this gives little guidance in terms of an optimal level of expenditures for geological surveys. One approach is to compare expenditures among similar jurisdictions, normalized to population, area, mineral production, or GDP. For example, Dugmore (2003) did this for the Australian states and territories, and the Committee of Provincial Geologists in Canada has included such figures in its annual compilations of survey budgets. While such comparisons are interesting, they do not address the fundamental question, which is the optimal level of funding.[21]

A better approach is to assess the state of knowledge relative to user-defined needs. Geological surveys in Canada consult regularly with the exploration industry and other user groups in order to establish priorities. However, such consultations are generally aimed at an appropriate allocation of existing budgets rather than establishing an optimal level.

Ten years ago, the Intergovernmental Working Group on the Mining Industry appointed an industry-led task force to undertake a rigorous review of the state of geoscience map coverage and to recommend the amount that would be required to sustain the competitive advantage afforded by Canada's public geoscience (Ward et al., 1999). The task force evaluated the existing coverage for four types of geoscience maps at the regional and detailed scales: bedrock geology, surficial geology, aeromagnetic data and drainage sediment geochemistry. It compared this to established priorities in each jurisdiction, and estimated the shortfall between existing geological survey budgets and the cost of meeting the mapping priorities over a ten-year period.

The goals identified by the task force were not overly ambitious, especially when compared to coverage in some other mining jurisdictions. It saw the completion of the first generation bedrock and surficial geological mapping of the country as a basic requirement. It found that adequate bedrock geology maps at the minimum scale considered acceptable for exploration (1:250,000) existed for only 65 percent of the Canadian landmass. Furthermore, the task force recommended that governments aim to achieve more detailed bedrock geological map coverage (*e.g.*, 1:50,000) of at least those areas with existing infrastructure or established mineral potential. This would have required about 22 percent of the incremental funding. Although aeromagnetic coverage existed for 80 percent of Canada, almost half of these surveys were more than 30 years old, had collected analogue rather than digital data, and had less than optimum position control. The task force recommended completing aeromagnetic coverage and re-flying 50 percent of the older surveys with modern technology. Finally, it called for completing the drainage sediment geochemical coverage for those parts of the country amenable to the method and suggested that this would require about 10 percent of the incremental funding.

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21. Interestingly, in 1999/2000, the base year in Dugmore (2003), average geological survey spending per unit area by Canadian provinces and territories was almost exactly equal to that of the Australian states and Northern Territory – C$6.30 per sq. km. (excluding federal survey expenditures in each country).

The task force concluded that the cost of achieving these goals was $674 million. The total annual expenditure by federal, provincial and territorial surveys to the four types of geoscience mapping was then $31.1 million,[22] indicating a cumulative incremental budget requirement of $363 million over ten years.

Governments did respond to the task force report and to calls by the mineral industry for enhanced geoscience funding. There were some specific programs – for example, Operation Treasure Hunt in Ontario and the federal Targeted Geoscience Initiative – and there was an overall increase in geological survey budgets from 1999 through 2002 (Exhibit 3). Total expenditures declined in mid-decade, and then increased again significantly during the recent exploration boom. The net effect was that over the last ten years, average annual expenditures were $20 million higher than in 1999 in nominal terms. This is about two-thirds the increase recommended by the task force, although it is not known how much was directed to the four types of mapping on which the calculation was based. In constant 2008 dollars, however, average annual expenditures were $13 million lower, and it is likely that the gap in mapping coverage has not narrowed appreciably beyond what was anticipated under existing budgets at the time.

Did the lack of a robust response to the task force recommendations have consequences? On the one hand, Canada remains a leading destination for investment in mineral exploration. Indeed, it regained first place in exploration spending from Australia in 2002. On the other hand, as noted in Chapter 5, Canada appears to have lost some ground to Australia and other countries in terms of the perception of the "quality of its geological data base" as measured in the annual surveys by the Fraser Institute. The more important question is whether mineral exploration has been as effective as it would have been with more and better public geoscience information. This issue will be examined in the next section.

The GEM Program announced by the federal government in 2008 will substantially improve regional geoscience coverage in the three territories, where the need is arguably the greatest. Program managers estimate that only 30 percent of the combined area of Nunavut, NWT and Yukon has adequate regional geological map coverage. Under GEM, conventional, "boots on the ground" mapping will fill 40 percent of the gap. The balance, in areas believed to have lower mineral potential, will be addressed through a combination of Remote Predictive Mapping (Schetselaar et al., 2006) and selective "ground-truthing". Up to 25 percent of federal funds for GEM will be allocated to projects "south of 60", undertaken in partnership with the provinces. Although a moot point, it is interesting to speculate whether more discoveries would have been made during the recent exploration boom if the large gaps in regional coverage in northern Canada had been addressed earlier.

Why now?

From the end of the Second World War until relatively recently, there was little concern about industry's ability to sustain mineral production through successful exploration. This view is changing, however, with a growing body of evidence that exploration has become less effective in recent decades. Blain (2000) analyzed the record of mineral discoveries in the western world over a fifty-year period.[23] He found that the pattern varies with commodity and deposit type, but that the overall discovery rate increased through the 1950s and 1960s, peaked in the late 1970s and then decreased during the 1980s and 1990s. Goodyear (2006) reported that discovery rates for base metal deposits had continued to decline at the beginning of this century, despite an upward trend in exploration spending (Exhibit 16). This trend is notwithstanding favourable circumstances. In a keynote address to the Society of Economic Geologists, M.A. Etheridge (2004)[24] observed:

> *Discovery rates, especially of world-class deposits, have fallen significantly over the past 15-20 years, despite increased exploration expenditure, a wide range of new science and technology, and unparalleled access to virtually all parts of the globe*

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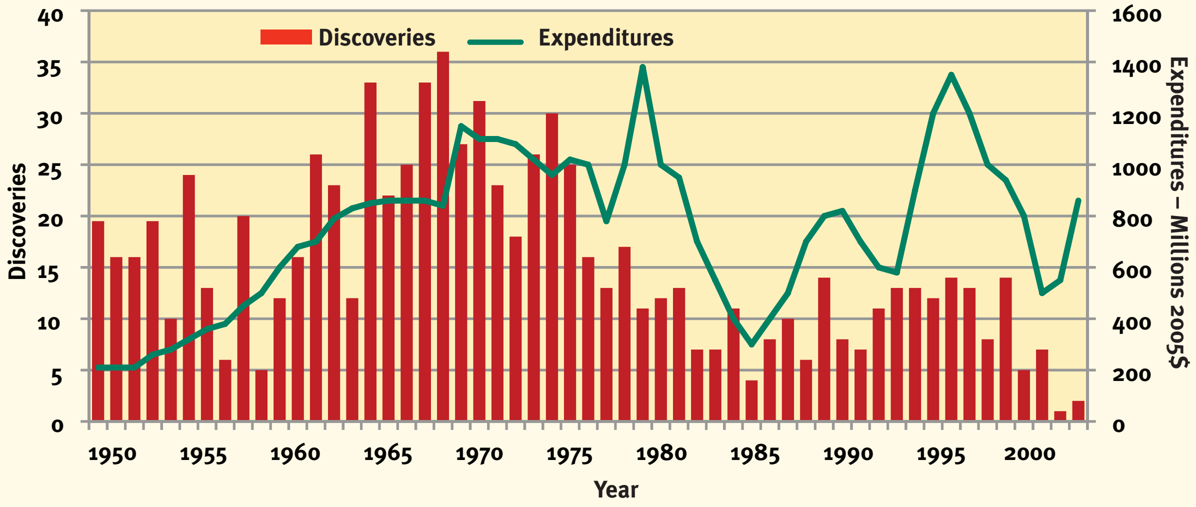
[22] Note that the $31.1 million allocated to the specified types of mapping represented 28% of total survey budgets.

[23] The most frequently cited source of discovery rates and costs is an internal company database maintained by BHP Billiton Ltd. The papers by Blain (2000) and Goodyear (2006) each used this source, whereas Schodde (2003) used data from Western Mining Corp.

[24] As quoted by Williams (http://www.ga.gov.au/image_cache/GA7003.pdf)

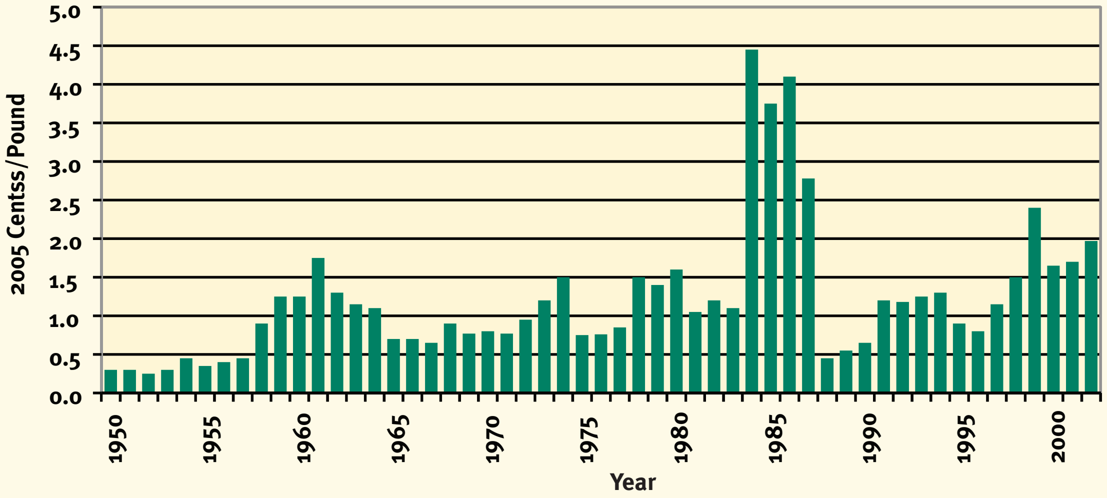
Exhibit 16: Base metal exploration, discoveries and discovery costs, 1950-2004

(after Goodyear, 2006)



(a) Global base metal exploration expenditures and number of major discoveries (i.e., > 100 kT copper equivalent).

(b) Discovery costs (per pound copper equivalent).



An implication of declining discovery rates and increasing exploration expenditures is that discovery costs have increased. Schodde (2003) concluded that the cost of discovering a major gold or base metal deposit had increased by a factor two to three over the preceding two decades.[25] Similarly, Goodyear (2006) reported that unit finding costs for base metals had doubled in the previous 30 years. He examined the exploration performance of 48 major companies in terms of the cost of discovery of a "Tier 1" deposit during the period 1992-2004. The median cost for the entire population was $918 million (2005 US$), whereas the median for companies in the top quartile was $300 million. Thus, the industry is highly differentiated in terms of exploration success. This is not a new phenomenon and may reflect good luck, good management or a combination of the two (*e.g.*, Boldy, 1977; Woodall, 1984).

These trends should be interpreted with caution. For one thing, reserve additions do not come only from newly discovered deposits. They can result from exploration in or near existing mines or simply an increase in commodity price. For example, Leveille and Doggett (2006) concluded that the global copper industry has been very successful in replacing reserves and that the cost of doing so has varied little over the last 30 years.

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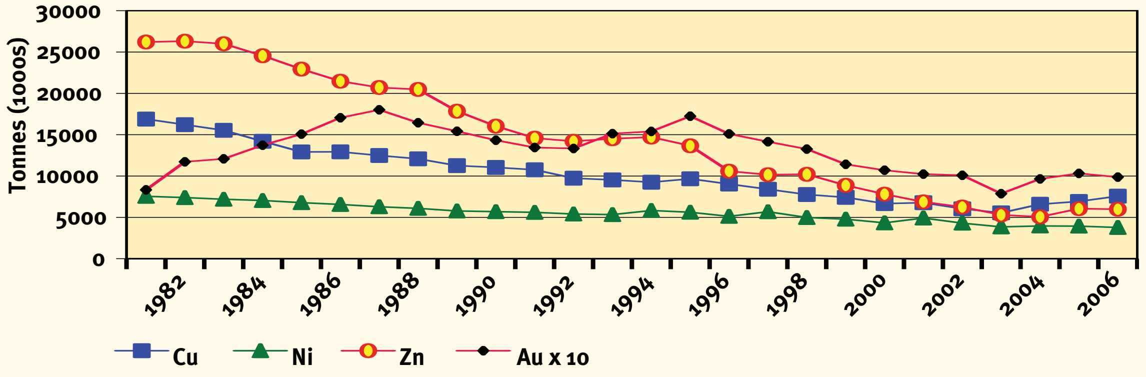
[25] Schodde (2003) defined a major deposit as one having an in situ value of >US$1 billion. Goodyear (2006) defined a Tier 1 (= 'world class') deposit as one having a Net Present Value >US$250 million.

These observations with respect to western world exploration appear to apply equally to Canada. Cranstone *et al.* (1993) analyzed exploration performance in three-year increments from 1946 to 1990. Their data suggested that despite periodic downturns, there was not a strong downward trend in the total value of metals discovered. However, exploration expenditures increased steadily over the period, resulting in a pronounced upward trend in discovery costs. Canadian exploration appears to have become more productive in the mid-1990s, at least in terms of the number deposits discovered (Cranstone, 2002; Drake, 2006). Highlighting the greenfields discoveries were several major diamond deposits in the Northwest Territories, nickel-copper at Voisey's Bay in Labrador and the Rankin Belt in Quebec, and the Finlayson Lake base metal district in Yukon.

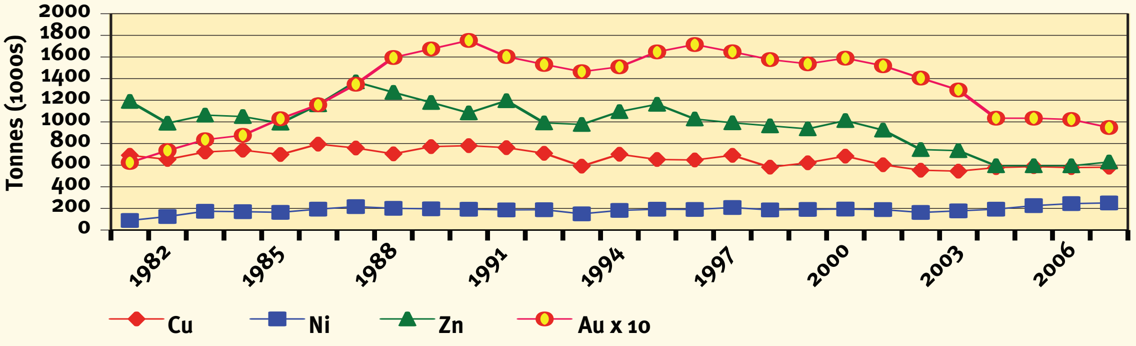
Harper (2003) documented 920 discoveries made in Canada between 1970 and 2002, which resulted in 209 producing deposits. Although he observed a direct correlation between exploration expenditures and the number of discoveries, the gross value of discoveries was inversely correlated. When aggregated by decade, the number of discoveries in the 1990s was 70 percent below that of the 1980s, and 50 percent less than during the 1970s. Moreover, when diamonds were excluded, the value of Canadian discoveries continued to decline during the 1990s. In summary, it is likely that discovery costs have continued to trend upward as has been the case elsewhere.

Trends in Canadian production and reserves are also instructive (Exhibit 17). Reserve data should be interpreted with caution, as they do not generally represent the amount of metal remaining in producing deposits. First, due to the time cost of exploration, companies will normally prove-up only enough reserves to sustain production for a certain number of years, say 10 or 15. Second, reserves will vary with metal prices and production costs; sub-economic resources may move to the reserve category as prices increase and reserves may be removed from the inventory if prices decline or costs increase.

Exhibit 17: Canadian production and reserves of four metals



Canadian reserves (above) and production (below) of copper, nickel, zinc and gold.
Note that gold values are multiplied by 10. Data Source: Natural Resources Canada.



The slight increase in copper and gold reserves since 2005 probably reflects commodity prices. In any case, Canadian reserves of base metals have declined significantly over the past 30 years – more than 50 percent for copper and nickel, and 80 percent in the case of zinc. Production of copper has declined about 20 percent since the 1980s, whereas that of nickel has actually increased by 30 percent. Zinc production is about half of what it was 20 years ago, and the fact that reserves have not been replaced may be a matter of concern. The trend for gold has been quite different; both reserves and production increased dramatically in the 1980s. Reserves peaked in 1988 and again in 1996, and have subsequently returned to the levels of the early 1980s. Gold production peaked in 1992 and 1998, and has since declined. It will be interesting to see if this trend is reversed as a result of recent price increases.

A number of reasons have been suggested for the apparent decline in exploration performance. Blain (2000) concluded that it reflected both economic and geological factors: the decrease in real metal prices, which raised the threshold for economic viability, and the increasing exploration maturity of prospective areas. Gouveia *et al.* (2003) drew a parallel between the deterioration in the rate of discovery of major deposits in the 1990s and a similar decline in success of oil and natural gas exploration in the preceding decade. Improved energy exploration performance in the late 1990s has been attributed in large part to industry's adoption of rigorous management of discovery risk (*e.g.*, Rose, 1999). They advocated a similar approach in mineral exploration, and progress has been made in the development of decision support systems that integrate financial and geological models (*e.g.*, Lord *et al.*, 2003, Guj, 2008, Kreuzer *et al.*, 2008).

According to Goodyear (2006, p.2), the decline in exploration success

> *... most probably reflects the diminishing number of deposits in the world available to be relatively-easily discovered by surface-prospecting techniques. The implication is that most of the important discoveries of the future will be at depth...*

Most deposits discovered to date in greenfields areas occur at or near the surface, and there is little doubt that as a region becomes more thoroughly explored, the likelihood of discovering a deposit that was missed in previous exploration diminishes. New rounds of discoveries may result from the introduction of new technology, new conceptual understanding of mineral deposits, enhanced geological knowledge, or a combination of these (i.e., a new exploration model). For example, the flurry of massive base metal sulphide discoveries in the mid-1950s and 1960s was stimulated by both new geophysical technology and new understanding of ore genesis. Similarly, the discovery of major diamond deposits in northern Canada in the 1990s resulted in large part from new understanding of kimberlite indicator minerals, glacial dispersal and ice flow directions.

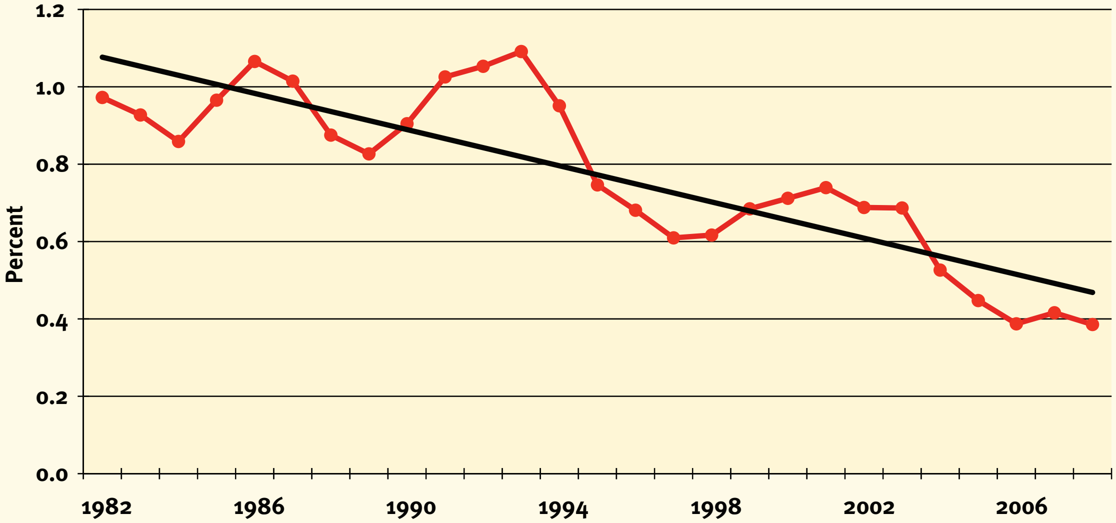
Large areas of Canada remain relatively unexplored. The fact that 30 percent or more of the landmass lacks adequate regional geological maps suggests that opportunities remain for near-surface greenfields discoveries. Completion of first generation regional geoscience mapping would accelerate such discoveries and should be a priority. Ultimately, however, exploration will necessarily have to focus on deeper targets, and this will require geological surveys to provide different kinds of public geoscience.

Williams (2004) suggested that successful exploration at depth would require a paradigm shift on the part of industry, academia and government surveys. It would rely on predictive rather than analogy-based exploration models, integrative geoscience and technology, and a more rigorous approach to risk management. Geological surveys would need to place a greater emphasis on mapping the third and fourth dimensions (depth and time), especially in frontier areas. He also saw a need for surveys to focus more on mapping "mineral systems" (Wyborn *et al.*, 1994), rather than conventional lithostratigraphy.

Canadian surveys, working in partnership with industry and academia, have already made important contributions in these areas. The 1980s and 1990s saw the elucidation of the deep structure of mineral belts through novel applications of geophysical methods in the LITHOPROBE program. Simultaneously, the development of high precision geochronology helped unravel the history of both Precambrian and Phanerozoic terranes. The EXTECH program, initiated in Manitoba's Snow Lake district in 1990 embodied a mineral systems approach (although it was not called that).[26] The results of the Snow Lake EXTECH project have contributed to two discoveries: Photo Lake in 1994 and Lalor Lake in 2007. The latter is the largest deposit discovered in the camp to date. More recently, the third phase of the Targeted Geoscience Initiative (TGI 3) included a "DeepSearch" component to develop 3D mineral system mapping techniques in established mining camps. Unfortunately, these initiatives have either finished or will end soon.[27]

[26] Subsequent EXTECH projects were undertaken in Bathurst, New Brunswick, Yellowknife, NWT and the Athabasca Basin, Saskatchewan-Alberta.
[27] A two year renewal of TGI was announced in the federal budget on March 3, 2010.

Exhibit 18: **Total geological survey expenditures as a percentage of the value of Canadian mineral production, 1982-2008**



Calculated using the total production value of metals, non-metals, construction materials and coal tabulated by Natural Resources Canada and total federal, provincial and territorial survey expenditures tabulated by the National Geological Surveys Committee. Black line is least squares trend. Geological survey spending to promote mineral exploration typically amount to 50 to 60 percent of total expenditures.

It was observed in Chapter 3 that the total government geoscience expenditures in Canada have declined significantly over the past two decades. Average annual spending during the 2000s was 41 percent less than in the 1980s in constant dollar terms. Survey expenditures have also decreased as a proportion of the value of mineral production during this period (Exhibit 18). While there is no intrinsically correct percentage, the downward trend is striking.

Conclusion

By and large, governments in Canada understand that public geoscience plays an important role in promoting private mineral exploration and development. The question facing government decision makers is how much public expenditure is required to sustain production in existing mining districts and to stimulate new economic development, especially in rural and remote areas. The evidence suggests that exploration has become less effective over the past 20 to 30 years. The number and value of discoveries have declined, and discovery costs have increased. Canadian production and reserves of several metals have declined.

To their credit, Canadian governments have responded to industry concerns by making significant investments in public geoscience over the last decade and, in particular, since 2007. However, in inflation-adjusted terms, average expenditures during the last decade remained 19 percent below 1990s levels and 41 percent of those in the 1980s. While it might be tempting to correlate decreased exploration success with lower public geoscience expenditures, public geoscience is only one of several determinants of exploration performance. Moreover, the increase in discovery costs appears to be a global phenomenon, which Williams (2008) described as a “mineral discovery crisis”.

Mineral exploration is subject to something akin to the law of diminishing returns. This economic principle holds that the increase of output due to an increase of an input factor decreases with each additional increment of input, other factors being constant. A classic example is a cornfield where the inputs are land, seed, fertilizer and labor. Increasing any one of these may boost corn production, but at a certain point production will begin to level off unless other inputs are increased as well. In the case of exploration, input factors would again include land and labor (or effort, as measured by expenditures), but also technology and geoscience knowledge. Simply increasing exploration expenditures will not be sufficient to sustain production over the long term. This will require more technology, improved exploration management practices, and increased knowledge, including public geoscience.

The state of regional geoscience knowledge varies greatly across Canada. On average, Canadian jurisdictions receive high marks for the quality of their geoscience in industry surveys. However, this hides the fact that significant areas have not yet been mapped at the minimum scale deemed necessary for exploration and that Canada lags behind many other developed countries in the extent of more detailed mapping.

Geoscience information is, in a sense, a depleting resource. It is gradually rendered less useful by advances in both scientific understanding and the technologies used in mapping and exploration. As a rule-of-thumb, geoscience information has a “shelf life” of 20 to 30 years. Moreover, as a particular area matures from an exploration perspective, there is a need for more detailed geoscience information. As Ward et al. (1999, p.85) observed:

> *… it is important to understand that the geoscience mapping of the Canadian landmass will never be ‘finished’. Moreover, barring an enormous infusion of funds, it is unlikely that the geoscience knowledge pertaining to Canada’s immense landmass could ever be made ‘complete’ at any given point in time: it will always be a work in progress.*

This chapter has not given a precise answer to the question with which it began – how much government geoscience is enough? The observation that geoscience expenditures and the effectiveness of exploration have both declined significantly over the last 25 years suggests that a more robust effort is required. Determining the optimal level of investment in government geoscience warrants a Canada-wide needs assessment. Most provincial and territorial surveys have developed a good understanding of the needs of the exploration industry on the basis of advice from advisory committees. However, it has been ten years since these requirements were compiled for the country as a whole (i.e., Ward *et al.*, 1999). The next assessment should not only evaluate the needs for “conventional” regional geoscience information, but should also anticipate the requirements for public geoscience that will promote the effectiveness of deep exploration.

7. Conclusion

Public policy rationale for government geoscience

This paper began by paraphrasing four questions often posed by governments about their programs, particularly at times of spending restraint, and has attempted to address them in respect to government geoscience in the subsequent chapters.

1. Is the program needed?

Governments around the world continue to need geoscience information to support both the formulation and implementation of policies bearing on resource development, land use, environmental stewardship, public health and safety, among other issues. The demand for geoscientific input into public policy decisions is unlikely to diminish in the foreseeable future. Mineral and energy resources underpin a significant part of the Canadian economy and growing demand from China and other emerging economies suggests that these will continue to fuel economic prosperity for some time to come. Increasing concerns about such issues as adequate supplies of groundwater, the threat posed by natural hazards, and the impact of climate change will likely require greater involvement by government geoscientists.

Public geoscience supports mineral exploration in three important ways: it attracts exploration investment by allowing industry to identify areas of favourable mineral potential; it increases exploration efficiency by making it unnecessary for individual companies to duplicate common information or to spend money on non-prospective ground; and it increases exploration effectiveness by providing key information inputs to risk-based decision-making. By reducing exploration costs and risk, public geoscience can have a significant impact on the returns on private investment in mineral exploration and development.

2. Is it the role of government?

Three considerations underpin government's role in providing geoscience in support of mineral exploration. First, most mineral resources in Canada are public assets and this confers a duty of stewardship upon governments. Second, governments in Canada have determined that the responsible development of mineral resources is in the public interest. They understand that geoscience promotes successful exploration and most have included the availability of public geoscience as a key element of their mining strategies. Third, geoscience information has the economic characteristics of a public good, which argues for government provision.

In common with most federations, the provision of public geoscience in Canada is a responsibility shared among federal, provincial and territorial governments. With respect to geoscience to promote mineral exploration, although most mineral rights are vested in the provincial crown, the federal government has a significant stake in resource development. For example, more than half the taxes and royalties from mining typically accrue to the federal government. The Intergovernmental Geoscience Accord, first signed in 1996, defines the roles and responsibilities of the two orders of government and establishes principles and mechanisms of cooperation. Among other benefits, there are economies of scale to be realized from not duplicating specialized expertise and capacities that reside in the federal survey in provincial and territorial organizations.

3. How is the service best delivered?

Governments can choose among a variety of institutional arrangements to satisfy their requirements for geoscience. These include units within government ministries; agencies or crown corporations, which remain accountable to ministers but operate somewhat at arms length; and reliance on non-governmental sources. Each option involves trade-offs in terms of accountability, credibility, effectiveness, and efficiency. Most governments in Canada, as elsewhere, have established geological survey organizations to meet their geoscience needs, and the majority of these are integral parts of government departments. This arrangement has the advantage of facilitating scientific input to policy decisions, having clear lines of accountability, and minimizing perceived conflicts of interest. Some countries have placed their geological surveys in quasi-commercial corporations with the expectation that a large part of their budgets would be derived from revenue generation. It is noteworthy, however, these surveys have reverted to traditional mechanisms to fund regional geological mapping and similar public goods.

Some governments have looked to partnerships with the private sector to reduce the financial burden on taxpayers by sharing costs. Although there are opportunities for such partnerships, they are not always consistent with the core public good mission of government surveys. The GSC, in particular among Canadian surveys, experimented with industry partnerships in the 1990s. These had the objective of stimulating technology transfer as well as mitigating budget reductions. Although these partnership projects were successful for the most part, the approach posed a number of problems. One was that private companies understandably expect a period of privileged access to survey results as a *quid pro quo* for providing funding. Another was that entering into a contractual relationship with a company created a potential conflict between public and private interests. Because of these concerns, the GSC has largely abandoned this approach.

4. What level of service is necessary and affordable?

This is the "sixty-four dollar question" in respect to government geoscience to which there is no easy answer. Most government policy makers see the provision of geoscience as a legitimate and important role of government, and understand the benefits of cooperation among federal, provincial and territorial surveys. They also appreciate the impact of government geoscience on private sector mineral exploration. The challenge for those seeking to sustain or increase investment in public geoscience is to demonstrate not only that a particular level of expenditure is required to achieve a government's public policy goals but also that there are consequences to delaying investment.

Government geoscience expenditures have decreased significantly in inflation-adjusted terms over the past three decades. Average annual expenditures during the 2000s were only 59 percent of the average of the 1980s, after adjusting for inflation. Spending relative to the value of mineral production has dropped by a similar percentage. Canadian production and reserves of several metals have also declined over the past 30 years, and discovery costs have increased. Although public geoscience is only one of several determinants of exploration success, it is a significant factor in reducing both cost and risk. A more robust government effort will almost certainly be required to improve exploration performance. This report does not prescribe an optimal level of government geoscience expenditure, apart from concluding that the current effort is insufficient. Rather, it suggests that this be determined as part a broader dialogue about the geoscience requirements of the next generation of mineral exploration.

Impact of government geoscience

Government provision of public geoscience is predicated on the expectation that it will lead to more and better mineral exploration, which results in discoveries, development and production, and ultimately in economic development. There have been very few rigorous cost benefit analyses of government geoscience programs aimed at promoting mineral exploration and development. This is understandable. Assumptions about the duration of exploration, the probability of discovery, and the share of results attributable to government geoscience are highly uncertain, making credible estimation of the net present value of benefits exceedingly difficult. The preferred approach is to demonstrate the cause and effect relationship at each step stage in the exploration process – in other words, to tell a compelling performance story.

The literature reviewed in the course of this study provides ample evidence that government geoscience stimulates private sector exploration. Program evaluations suggest that 6 of 10 mapping projects will have immediate impact in terms of claim staking or new exploration activity. The incremental exploration expenditures resulting from new public geoscience are more difficult to quantify and depend on location and timing of government action in the business cycle. Nevertheless, the often cited rule-of-thumb that $1 in government spending results in $5 in private sector exploration appears to be a reasonable expectation over the medium term.

A majority of industry respondents to user surveys agree that the availability of government geoscience increases the efficiency and effectiveness of exploration. There have been few attempts to quantify these increases, probably because of a lack of commonly accepted performance indicators. The few estimates that have been made suggest cost reductions of 5 to 20 percent and increases of 40 to 280 percent in the number of exploration targets identified.

The evidence for a government geoscience contribution to discoveries – the ultimate indicator of exploration success – is largely anecdotal. The examples cited most frequently are those where a government survey directly identified a geophysical or geochemical anomaly or a mineral occurrence. The contribution of public geoscience information to the quality of day-to-day decision-making in exploration that led to a discovery is rarely documented. The role of government geoscience in the discovery of the world-class Kidd Creek deposit described in this report is a good example of this.

The importance of exploration and discovery from the government perspective is that it results in positive outcomes for society as a whole. The magnitude of tax revenues from mining is one indicator of society's return on government investment in public geoscience. The Mining Association of Canada estimated that revenues accruing to Canadian governments from 2004 to 2008 from mining as royalties, corporate and individual income taxes averaged $5.5 billion/year. Geological survey expenditures on geoscience to promote exploration averaged $80 million over the same period, or just 1.5 percent of revenues. Of course, public geoscience is only one means whereby governments promote mineral exploration and development. The comparison is nevertheless instructive.

Recommendations

1. The PDAC should continue its advocacy for public geoscience with a renewed sense of urgency in light of increasing discovery costs and anticipated pressures on government program spending.
2. The case for government geoscience should emphasize its role in reducing the cost and risk of exploration, which underlies its contribution to a more competitive investment climate.
3. Government surveys should document their impact on a more systematic basis, paying more attention to the extent to which public geoscience increases exploration efficiency and effectiveness.
4. Research should be pursued on quantifying the impact of public geoscience in terms of reduced discovery risk.
5. Industry and government should jointly assess the scope and kinds of public geoscience that will be required to promote successful exploration over the next 10 to 20 years.
6. A more robust government geoscience effort should be an important element of a Canadian discovery strategy.

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Appendix: Statistical Tables

Canadian mineral production and exploration expenses, 1982-2009

Year	Production Value (millions)	Exploration Spending (millions)	Seniors % of Total	Metal Price Index 2005=100	Consumer Price Index 2008=1
1982	$12,088	$576	85	49.7	2.00
1983	$12,689	$472	85	58.6	1.96
1984	$15,184	$617	74	52.6	1.88
1985	$15,454	$589	70	47.7	1.81
1986	$15,409	$698	53	47.9	1.74
1987	$17,729	$1,300	49	60.0	1.67
1988	$20,986	$1,350	51	92.5	1.60
1989	$21,456	$828	67	84.6	1.53
1990	$19,612	$775	70	74.2	1.45
1991	$17,162	$532	79	62.8	1.37
1992	$16,352	$385	78	61.0	1.35
1993	$15,098	$477	70	52.7	1.32
1994	$16,754	$628	69	62.6	1.32
1995	$19,443	$718	64	76.0	1.29
1996	$19,041	$895	65	66.4	1.27
1997	$19,382	$820	63	67.9	1.25
1998	$18,721	$576	59	55.6	1.24
1999	$18,511	$438	73	55.4	1.22
2000	$19,835	$458	67	62.7	1.19
2001	$19,604	$470	67	56.3	1.16
2002	$19,960	$497	65	54.3	1.14
2003	$20,078	$614	59	60.7	1.09
2004	$24,382	$1,063	49	81.7	1.08
2005	$28,036	$1,191	39	100.0	1.06
2006	$34,233	$1,670	35	156.2	1.04
2007	$40,522	$2,521	33	183.3	1.01
2008	$45,278	$2,919	35	168.7	1.00
2009	na	$1,638	45	116.7	0.99

Production and spending in nominal dollars from Natural Resources Canada. Production includes metals, non-metals, construction materials and coal. Exploration includes fieldwork and overhead, but not engineering, economic, pre-production feasibility studies, environment and land access costs. Metal Price Index – average monthly values from International Monetary Fund. Consumer Price Index from Bank of Canada.

Government Geological Survey Expenditures in Canada, 1982-2009 ($ millions)

FY	NFLD	NB	NS	QUE	ONT	MAN	SASK	ALTA	BC	YT	NWT	NU	P+T	GSC	Total
1982-83	3.0	1.5	5.4	13.0	17.6	2.0	2.1	9.0	3.1	0.7	1.1	0.0	58.5	59.1	117.6
1983-84	2.4	1.1	4.7	18.2	15.9	1.8	2.1	1.7	3.0	0.7	1.2	0.0	52.8	64.9	117.7
1984-85	4.1	1.2	4.2	11.0	14.0	3.3	2.3	1.2	3.4	0.7	1.3	0.0	46.7	83.6	130.4
1985-86	5.1	1.3	4.0	12.7	15.8	3.5	2.2	4.7	4.1	0.8	1.3	0.0	55.5	93.7	149.2
1986-87	5.9	1.3	5.3	13.5	13.2	3.2	2.6	7.4	5.7	1.1	1.4	0.0	60.6	103.6	164.2
1987-88	5.5	2.3	5.6	20.8	18.1	3.5	3.2	9.0	6.6	1.5	1.5	0.0	77.6	102.3	179.9
1988-89	4.7	2.8	5.8	20.7	21.3	3.3	3.7	9.6	8.8	1.5	2.6	0.0	84.8	98.8	183.7
1989-90	5.1	2.0	4.2	20.9	19.9	3.5	3.8	8.4	7.3	1.5	2.5	0.0	79.1	98.3	177.4
1990-91	4.8	2.3	3.8	17.3	19.9	3.6	4.4	8.6	7.8	1.8	1.9	0.0	76.2	101.2	177.4
1991-92	5.9	2.4	3.5	16.3	18.9	3.9	4.1	4.5	7.5	0.7	2.0	0.0	69.7	106.3	176.0
1992-93	5.4	2.2	3.3	14.8	18.9	3.9	4.0	4.7	7.0	2.6	2.8	0.0	69.6	102.6	172.2
1993-94	4.9	2.3	2.9	13.4	14.5	3.2	4.4	4.4	6.1	2.7	2.9	0.0	61.7	103.1	164.7
1994-95	3.9	3.4	3.4	17.0	14.5	4.3	2.3	3.9	6.5	3.3	2.2	0.0	64.7	94.7	159.3
1995-96	3.9	3.2	2.5	17.9	13.5	3.8	2.4	3.2	6.9	3.2	2.5	0.0	63.0	82.1	145.1
1996-97	3.5	2.8	2.5	17.6	13.5	3.7	2.5	2.5	6.5	2.5	2.3	0.0	59.7	69.9	129.7
1997-98	3.3	2.8	2.5	15.4	11.1	3.7	2.5	2.7	4.4	2.3	2.9	0.0	53.3	64.8	118.1
1998-99	3.2	2.9	2.5	16.6	11.0	3.9	2.5	2.1	4.1	2.6	2.3	0.0	53.6	61.8	115.5
1999-00	3.6	2.8	2.5	16.6	21.0	4.0	2.4	2.1	4.2	2.7	2.4	0.7	64.9	61.8	126.7
2000-01	3.5	2.2	2.0	16.2	20.1	4.3	2.9	5.2	4.0	3.1	2.7	3.4	69.5	71.7	141.2
2001-02	3.7	2.6	1.9	14.4	21.1	4.4	3.6	6.1	3.0	3.0	3.0	2.6	69.3	75.7	145.0
2002-03	3.5	2.4	2.0	13.2	14.6	4.5	3.9	6.0	3.0	4.1	3.0	2.5	62.8	74.6	137.3
2003-04	3.6	2.5	1.9	12.3	11.1	5.3	4.2	5.7	2.9	4.2	4.6	2.6	60.8	77.1	137.9
2004-05	3.6	2.4	2.0	7.3	12.8	4.7	3.7	5.6	3.3	4.7	5.1	2.6	57.7	70.6	128.3
2005-06	3.6	2.4	2.1	2.3	14.4	4.2	3.2	5.5	3.7	5.2	5.5	2.6	54.5	70.9	125.4
2006-07	4.0	2.5	2.0	3.4	13.5	4.2	3.3	5.9	3.2	4.5	5.4	3.0	54.8	77.8	132.6
2007-08	5.1	5.3	2.2	16.5	18.5	4.6	5.0	6.1	4.1	5.6	6.3	5.3	84.5	84.0	168.5
2008-09	5.1	3.3	2.4	16.9	18.8	4.9	5.8	7.5	4.0	5.9	6.5	5.3	86.3	88.3	174.6
2009-10	5.7	2.3	2.5	18.8	19.2	4.7	4.5	9.1	2.8	5.9	6.4	4.5	86.3	92.3	178.5

*Geological survey expenditures in nominal dollars. GSC expenditures include those of the Earth Physics Branch. Government fiscal year is April 1 through March 31. Sources – Committee of Provincial and Territorial Geologists and Geological Survey of Canada.

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