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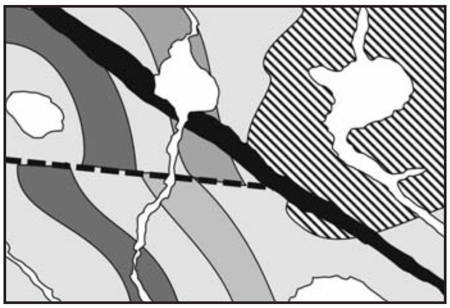

NATMAP – Canada's National Geoscience Mapping Program: 1991 – 2003

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SUMMARY
The National Geoscience Mapping Program (NATMAP) was developed by the Geological Survey of Canada (GSC) in 1991 to support Canada's natural resources industry by filling gaps in the fundamental geoscience database, and to respond to emerging environmental and societal issues. The 12-year, multi-million dollar program operated through close collaboration between the GSC and the provincial and territorial geoscience agencies; it also incorporated participation from universities and some support from industry. Projects ranged from mapping and assessing the surficial geology of the Oak Ridges Moraine in Greater Toronto, documenting the geological framework of the Slave Province in the Northwest Territories, to research on the evolution of oil and gas in the Magdalen Basin off Canada's east coast. The program, whose thirteen projects included components in nine provinces and three territories, came to a successful end in 2003. Now, almost twenty years after fieldwork began on the first of the NATMAP projects, impacts of this major contribution to Canada's geoscience realm have been recognized from several perspectives.

As expected, a wealth of new, high-quality geoscience knowledge was acquired for various areas across Canada, knowledge that became and remained readily accessible. Early socio-economic impacts from applying this knowledge can now be recognized and documented. In addition, NATMAP's legacy must also include recognition of how it led to establishing an important and effective framework under which cooperative and collaborative geoscience is designed and conducted by GSC and provincial and territorial geoscience agencies, and also how the organization of NATMAP became the first step in the evolution of the way in which the GSC plans and undertakes the whole of its geoscience program in response to meeting the varied geoscience needs of Canadians. Perhaps a final testament to the success of NATMAP resides with many of this country's young geologists, now following professional careers in the public and private sectors, who received invaluable training as student participants in one or another of the NATMAP projects.

SOMMAIRE
Le Programme national de cartographie scientifique (*NATMAP*) a été développé en 1991 par la Commission géologique du Canada (CGC) en appui à l'industrie des richesses naturelles en comblant les lacunes de la base de données géoscientifiques, et pour être en mesure de répondre aux problèmes sociaux et environnementaux émergeants. Ce programme de plusieurs millions de dollars étalé sur 12 ans a été mise en œuvre en étroite collaboration entre la CGC, les services géoscientifiques des provinces et des territoires; il y a également eu participation d'universités ainsi qu'une certaine collaboration du secteur privé de l'industrie. Les projets allaient de la cartographie et de l'étude de la géologie des dépôts meubles de la moraine d'Oak Ridge dans la région du Grand Toronto, à la documentation de la structure géologique de la Province des Esclaves dans les Territoires du Nord-Ouest, à la recherche sur l'évolution du pétrole et du gaz dans le bassin de la Madeleine au large de la côte Est du Canada. Ce programme dont les treize projets comportaient des composantes dans neuf provinces et trois territoires s'est terminé avec succès en 2003. Maintenant, près de vingt ans après le début des premiers travaux de terrain des premiers projets, les retombées dans le domaine géoscientifique sont reconnues et ce de différents point de vue. Comme il fallait s'y attendre, une abondance de nouvelles connaissances géoscientifiques de haute qualité ont été ainsi acquises de diverses régions du Canada et sont désormais disponibles. On peut déjà mesurer et documenter les premières retombées socio-économiques découlant de l'application de ces connaissances. C'est aussi *NATMAP* qui a permis l'édification d'un important et efficace réseau de collaboration et de coopération permettant la planification et la réalisation de projets géoscientifiques menés par la CGC et les services géoscientifiques des provinces et des territoires. Il faut aussi reconnaître comment l'organisation de *NATMAP* a été la première

étape de l'élaboration de la façon dont la CGC planifie et défini l'ensemble de sa programmation géoscientifique afin de répondre aux divers besoins géoscientifiques de la population. Finalement, un dernier aspect des retombées positives de *NATMAP* sont tous ces jeunes géoscientifiques au pays qui poursuivent une carrière dans le domaine et qui ont été formés par leur participation en tant qu'étudiants aux projets de *NATMAP*.

INTRODUCTION

Geological Mapping in Canada

Planning and conducting a wide range of public and private sector undertakings requires specific knowledge of the bedrock of a given region and/or its overlying, unconsolidated deposits. As Vodden (1992) stated,

> "*A comprehensive knowledge of the geoscience of the Canadian landmass and its offshore is fundamental to economic development, public safety, environmental protection and national sovereignty*."

This understanding was echoed by the Intergovernmental Working Group on the Mineral Industry (1999) which concluded,

> "*Geoscience knowledge, provided by governments as a public good, is the basis upon which the private sector plans and conducts its activities. The mining industry has identified this publicly accessible geoscience knowledge as one of Canada's key advantages in attracting investment in the increasingly competitive global mineral exploration market*."

The source of this knowledge, whether to aid in the exploration for mineral deposits, determination of terrain stability for construction projects or for assessment of the supply and security of an important groundwater source has been, for almost two centuries, a geological map portraying the various bedrock and/or surficial units and their distribution at the present erosion surface.

This country's first geological maps were based on the 1843 field studies of Sir William Logan, the first director of the newly founded Geological Survey of Canada (GSC), and his associate Alexander Murray, and covered areas of New Brunswick and the Gaspé Peninsula, and the region between Lake Erie and Lake Huron, respectively. These investigations supported the mandate of the GSC to determine whether Britain's new Province of Canada would furnish the coal and mineral resources required to support its settlement and development. In the years following, adjacent and intervening areas were systematically mapped by Logan and his GSC colleagues, gradually piecing together the broad geological framework of eastern Canada and its natural resource potential and resulting in the publication of the *Geology of Canada* (Logan 1863). One prominent reviewer of this comprehensive report – Sir William Dawson – recognized not only the scientific importance of Logan's work, but also the value of public geoscience knowledge when he wrote,

> "*The practical man has all that is known of what our country produces in every description of mineral wealth; and thus has a reliable guide to mining enterprise, and a protection against imposture*" (Dawson 1864).

And, with remarkable insight into the longer term legacy of geological maps and reports, he remarked that,

> "*even in the case of new discoveries of useful minerals which may be made, or may be claimed to be made after the publication of this Report, it gives the means of testing their probable nature and values, as compared with those previously known*."

Logan, himself, had earlier proclaimed on the economic value of public geological surveys in an anonymous article on the history of the fledgling GSC published in 1851. According to Smith (1999),

> ". . . . *Logan was a master in generating public awareness of the benefits of geological surveys in Canada*."

Despite its gradually evolving mandate over 168 years, geological mapping to provide the fundamental geoscience knowledge in unmapped or under-mapped regions, to encourage and support resource development, has remained at the core of GSC's mandate and activities. In the decades following the various stages of Confederation, the geoscience agencies (geological surveys) of Canada's provincial and territorial governments have joined and shared in this role with their own particular focus. These complementary roles were eventually formally defined in the first Intergovernmental Geoscience Accord (National Geological Surveys Committee 1996) as follows:

> "*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 or significance*."
> Whereas, "*The provincial and territorial geological survey organizations carry out programs . . . at a scale appropriate to addressing provincial or territorial responsibilities . . . largely directed towards sustainable development and are closely linked to the needs of local clients*."

The most recent Intergovernmental Geoscience Accord – IGA3 2007 – generally restates these distinctions, but acknowledges that the GSC's programs are typically thematic in nature and are intended to provide a comprehensive geoscience knowledge base to also address public safety and environmental protection, rather than simply defining the nation's geology and its resources, while the work of the provinces and territories is increasingly used to address land use and public health and safety issues.

Periodically – about every twenty-five years – the Geological Survey of Canada produces an updated geology map of the entire country, working with the provinces and territories to incorporate new geoscience data for all regions of Canada. The most recent compilation, published in 1996, just as for the 1968 version, seems to indicate that all of Canada has been geologically mapped – there are no gaps or blank spots – leading to the possible supposition that geological mapping of this country has been completed. From one standpoint, this is true. There are few areas of Canada where at least a 'regional-scale' investigation of the *bedrock* geology has not been carried out and maps published. But there are still large areas of Canada lacking even regional documentation of the *surficial* geology, and similar gaps exist with regional *surficial geochemical* mapping and *geophysical* mapping. However, a geological map of a given area produced even as recently as twenty years ago could likely now be considered obsolete, or at least incomplete, in terms of the level of information it furnishes for current day ventures and decision making. As well, there are significant areas in Canada's northern territories where the existing 1:250 000 scale maps were compiled three and four decades ago, from observations and samples taken no closer than tens of kilometres apart, simply to provide a first-order portrayal of the nature and structure of the region's bedrock. While such reconnaissance maps and their accompanying reports were initially suitable to construct and depict the broad geological framework of Canada's north, they have proven inadequate in offering the level of knowledge required to undertake cost-effective resource exploration in this remote region. For example, in Nunavut, where reconnaissance geological maps cover most of the territory, fully one third of the terrain is considered inadequately mapped to aid this new Territory in effectively managing its land and resources.

The scale of mapping is not the only factor limiting the current-day usefulness of a geological map. Technologies and concepts that are an integral part of today's mapping 'toolbox', and which contribute a critical level of understanding of the nature and evolutionary history of a region's geology, were unavailable twenty years ago, or in the early stages of development. While it is still absolutely critical that the fundamental geoscience knowledge of an area be obtained by a skilled geologist on the ground, this knowledge is now routinely supplemented by a range of other information gained from airborne and satellite measurements and observations, and sophisticated laboratory studies. Mapping Canada's geology must be an ongoing process, with revisions incorporated as new tools and understandings are brought to the task and as the more remote regions gain new importance in the search for natural resources.

This does not mean that terrains must be entirely remapped to bring them up to current standards. Today's geological map is no longer simply a graphic representation of bedrock and surficial deposits, but might be better defined as a geospatial distribution of thematic geoscience information. Geoscience information that, besides the standard nomenclature and 2-D portrayal of the various rock types and structural elements, could include knowledge of chemical, magnetic, gravitational and radiometric properties of the rocks and their precise age of formation, all tied to specific and accurate geographical localities. These several components constitute a digital geoscience database, from which one or more knowledge 'layers' can be extracted, combined, correlated and extended into adjacent terrains to provide a more complete picture of the geology and geological history of the area in question, and provide the means for assessing its economic potential. Whereas the basis for new or revised maps can simply be gathering data at more closely-spaced geological outcrops over targeted parts of an area previously mapped in reconnaissance fashion, such as for many of the northern map areas, a 'new' map can also be developed through the addition of another data 'layer' for a newly acquired geological parameter — geochemistry, for example – to an otherwise complete and adequate geological map. This new generation of digital, interactive, GIS-based maps also allows the users to add and merge their own specific data to assist their interpretations and help guide their ventures. It should be noted that, while maps of bedrock and surficial deposits and their structural elements are still the principal products of geological mapping and were largely the focus of the NATMAP program, they are not the only category of geological maps. There is an increasing variety of maps that document specific geoscience properties to either augment knowledge of the physico-chemical nature of the rocks on the 'traditional' maps, or to delineate structural parameters whose existence could be supportive of, or hazardous to, environmental and development issues. Typical examples of the former group are maps of a region's geochemical or magnetic signatures, while maps of terrain stability as influenced by landslide potential or permafrost degradation typify the latter.

The Value of Geological Maps

Although geological maps support an expanding range of uses, including environmental impact assessments, hazard evaluation and urban land-use planning for groundwater and aggregate resources, their primary value in Canada remains in providing the fundamental knowledge of a region's bedrock to direct mineral resource exploration. In a large and incompletely explored country like Canada, it is beyond the scope of even the major exploration companies to undertake the mapping of any sizeable region and well beyond the competitive nature of their business to make this information generally available. As a result, here and in many other countries, this task is carried out by publicly funded geoscience agencies (geological surveys) that provide the knowledge as a public good in support of the nation's resource-based sector of the economy. And, as is necessary with expenditures from the public purse, the questions related to public funding of geological mapping must be asked on a recurring basis. Is the information being used? Must the information be periodically updated? Is it the right information in the right format? Is there a strategy in selecting the areas being mapped or remapped? And, most importantly, are the exploration expenditures stemming from the new geoscience, and thus the contribution to the nation's economy, meaningfully greater than the cost of providing the new maps?

For over a century, the members of Canada's mineral exploration industry have recognized the value of geological maps produced by Canada's federal, provincial and territorial geoscience agencies. Having reviewed the scientific output of the GSC and its use in 1982, the resultant report of the Canadian Geoscience Council (Coope et al. 1983) concluded that a geological map was considered by all users as the single most useful type of product and that this product is irreplaceable. A similar review of the work of the Ontario Geological Survey (OGS) a year later reached the same conclusion. The Prospectors and Developers Association of Canada (PDAC) has, on several occasions, publicly acknowledged the key role that Canada's government geological surveys play in attracting mineral exploration by providing the up-to-date, comprehensive geoscience information and knowledge required by the mineral industry, and the competitive advantage that this knowledge base provides.

A number of additional studies to assess the value of geological mapping have been carried out in the recent past, requesting qualitative responses by the users of the geoscience information on their satisfaction with the maps and related products. Without exception, those users in the mineral exploration industry continue to indicate that geological maps, in their modern guises, remain an important factor in planning their exploration activities. A study in Australia, for example, concluded that "the modest expenditure by governments on pre-competitive geoscience has been very important to Australia's development. It has greatly stimulated private investment by reducing the commercial risk in mineral exploration and greatly improving the overall efficiency of exploration" (Lambert 1999).

Some studies have attempted a more quantitative analysis. It is generally accepted that the ultimate impact of a geological map likely will not be realized for a decade or more after its publication, so an evaluation of its usefulness in the few years immediately after its release would be incomplete, and perhaps misleading. In the USA, Kentucky is the only state that has completed and published maps for all its quadrangles, at a cost of US$90 million, and seen at least two decades of map use. Analysis of responses by users of these maps in several fields, including exploration, indicated,

> "*the value of geologic maps to the users was at least 25 to 38 times higher than the cost of the mapping program*" (Bhagwat and Ipe 2000).

Focusing specifically on the value of public geoscience to the resource exploration industries in Canada, a somewhat more involved study by Boulton (1999) found that

> "*every $1 million of government investment to enhance the geoscience knowledge base will likely stimulate $5 million of private sector exploration expenditures...*" ,

a more modest, but still appreciable, factor of 5:1. He extended this analysis to conclude that this initial $1 million investment resulted, perhaps years or decades later, in the discovery of new resources with an average *in situ* value of $125 million.

A more recent study by Bernknopf et al. (2007) incorporated efficiency, productivity, effectiveness and risk considerations of the exploration industry users to analyse the value of government geological map information for mineral exploration. Their analysis was founded on exploration in the Flin Flon Belt of Manitoba and Saskatchewan and the South Baffin Island area of Nunavut, a mature mining district and a frontier region, respectively, and both mapped by the GSC. A calculation of the economic value of exploration activities resulting from publication of the updated Baffin Island maps ranges from $2.28 to $15.21 million. And, when compared to the $1.86 million for the cost of the mapping, results in a multiplier effect of 8 to 1. Just as importantly, the study concluded that,

> "*updated and finer resolution maps provide more detailed and accurate information than older coarser resolution maps when used as a guide for mineral exploration*",

and that use of the upgraded geological maps

> "*provided more exploration options, reduced exploration risk and improved efficiency and productivi*ty"

– a confirmation of the need to periodically remap a region using the newest technologies and concepts and focusing on more promising areas delineated in the earlier mapping.

In an even more recent review (Maurice et al. 2009), Géologie Québec tracked the evolution of investments by the mineral industry in two large, underexplored regions where that agency had conducted major mapping projects. In northern Québec, covered by the Far North program, exploration expenditures increased almost continually from virtually zero in 1988, at the outset of the mapping program, to over $25 million annually by 2007. A more dramatic experience was documented over the ten-year span of the Baie-James region program, during which time industry expenditures rose annually from less than $20 million in 1997 to nearly $100 million.

From a mutual understanding of the regional priorities for upgrading geological 'maps', and by sharing local and regional expertise and employing specialized techniques and technologies to accomplish this, GSC and the provincial and territorial surveys are continuing to keep Canada's geoscience knowledge at the high level required for socio-economic growth. Canada's NATMAP program was a major contributor to this endeavour.

NATMAP — A MAJOR CHANGE IN GEOLOGICAL MAPPING

Prior to *ca.* 1974, Canada's federal and provincial public geoscience agencies generally carried out their geological mapping without collaborating on projects that overlapped or abutted their political jurisdictions, or taking advantage of expertise extant in another agency. Some provinces were wary of allowing the GSC to infringe on their territory, and GSC felt that the work carried out by some provincial surveys focused on the mineral industry and economic development, whereas it (the GSC) took a broader and longer term approach. Although individual scientists in GSC and the provincial surveys occasionally collaborated for specific and limited projects, the two spheres officially, and contentedly, worked independently.

Mineral exploration levels generally follow the changing world prices of metal commodities. Sharp increases in the prices of gold and silver between 1978 and 1980 were reflected in a dramatic rise in exploration expenditures in Canada in 1980 and 1981 (Cranstone 2002). However, with the almost immediate drop in the price for these precious metals in 1981, followed by the decrease in price of nearly all base metals a year later, exploration levels fell off steeply. To offset the decline in this sector of the economy, an exploration incentive was introduced to the Canadian income tax system for the period 1983 to 1988. This meant that both major and junior exploration companies could now be more speculative in their exploration activities by venturing into unknown or poorly explored regions. However, from a survey of its members, PDAC concluded that map coverage for these regions was not keeping up with industry needs and that the level of geological mapping by Canada's geological surveys had declined to a level inadequate to close the widening gap

(Andrews and Lawton 1988). The perceived problem was not unique to Canada; the U.S. Geological Survey had also recognized that "*current geologic mapping in the United States . . . is inadequate to meet current needs*" (USGS 1987), and the situation was similar in Australia (Lambert 1999).

The GSC acknowledged an apparent decline in traditional, systematic map coverage, but this had been paralleled by publication of more detailed, non-traditional maps and datasets resulting from various specialized research and surveys. Even though these latter products were becoming more important to the more sophisticated elements of the exploration community, the attention of the junior mining and exploration community was still focused on traditional and systematic areal geologic map coverage. The GSC recognized that the PDAC concern could provide a special opportunity to propose a national review of the current-day status plus the future requirements for geological mapping in Canada. Not only was the production of new maps apparently inadequate, the ever increasing volume and complexity of geoscience data and the expanding uses to which it was being applied demanded new ways of managing and distributing this knowledge. Therefore, in 1988, as part of a periodic review of the activities of the Geological Survey of Canada, the Canadian Geoscience Council (Mossop 1989) recommended that

> "*creation of a modern computerized database system that incorporates all relevant existing data should be one of the highest priorities of the GSC, in collaboration with provincial surveys and industry.*"

To address these issues, GSC management and scientists embarked on a series of internal, in-depth discussions on the modern concept of geological maps and data standardization to define and implement a new National Geoscience Mapping Program. The latest policies and practices for improving mapping in other countries facing the same problems of inadequate geological maps, most notably the United States, were examined as part of these discussions. The timing of this exercise, while driven by the CGC and PDAC concerns, was propitious for other reasons. The current phase of Canada's Mineral Development Agreements (MDAs) was drawing to a close, prompting the need to consider future mechanisms for geoscience program delivery in the provinces and territories. As well, the Geographic Information System (GIS) was emerging as a new and essential component of all geological field observations and data analysis locations permitting, better merging and comparison through computer technology of a variety of geoscience parameters over a map area.

The result of GSC's deliberations was an internal document in early 1989 outlining a potential GSC national mapping program to fill this 'map gap'. Later that year, as a result of discussions with other mapping agencies in Canada, GSC prepared a revised program "much broader in scope and potentially involving all mapping agencies in Canada, titled *Canada's National Geoscience Mapping Program (NATMAP)*." The revised NATMAP program was then presented to the Canadian geoscience community at a workshop in early 1990, attended by representatives of provincial/territorial geological surveys, industry, academia, other federal agencies and professional associations. Workshop participants reached substantive agreement on the concept of NATMAP as a cooperative, multidisciplinary program, and a number of important guiding principles were defined (St-Onge 1990). Principal among these were that NATMAP would:

1. Foster coordination of mapping activities among federal, provincial and territorial surveys and Canada's universities;
2. Employ all available and developing computer technologies for digital mapping and geoscience data management; and
3. Contribute to the development of the next generation of skilled field geologists by employing and training undergraduate and graduate students in the various mapping projects.

To help ensure adherence to these principles and other recommendations, NATMAP was to be controlled by a National Steering Committee (renamed National Coordination Committee in 1995) representing all the participating agencies.

The workshop participants recognized that development of these guiding principles was only the first step in addressing the growing demand for new geological maps; the next challenges would be to identify projects for an expanded mapping program and to confirm and allocate the resources to carry them out. These tasks were undertaken by the newly constituted NATMAP Coordinating Committee, led by GSC and provincial (Manitoba) co-chairs and composed of eleven representatives of the GSC, provincial surveys, industry and universities, served by a GSC-based Secretariat whose manager was seconded from the Ontario survey for two years.

The Steering Committee stressed to all potential participants that the NATMAP program was not a granting agency to provide total funding for a project. Rather, NATMAP would provide supplementary funding to expand and enhance mapping programs that were largely funded from other sources — the annual financial appropriations to the federal and provincial/territorial surveys by their respective governments, Natural Science and Engineering Research Council (NSERC) research grants, and provincial geoscience research funds. The NATMAP's fundamental principles were firmly enough established to allow the launch of two 'pilot' projects in the summer of 1991 — the Shield Margin NATMAP and the Slave Province NATMAP. Both areas were already the site of GSC geoscience projects whose goals were largely those of the NATMAP aim of enhancing Canada's geological map coverage and associated geoscience knowledge. The Steering Committee notionally identified a reallocation of $500 000 of GSC funding for this first set of GSC-led projects, divided almost equally between field operational costs and salary and laboratory support costs. The expectation was that this would be at least matched by other GSC funding related to the projects.

The new NATMAP Program was officially announced in a fan-fold pamphlet (NATMAP 1992) in early 1992, and widely disseminated to the Canadian geoscience community.

NATMAP elements were defined (in part) as follows:

- What is NATMAP? NATMAP is an initiative of the Geological Survey of Canada to increase the level of geoscience mapping in Canada. NATMAP encourages coordinated projects by all agencies with an interest in the geosciences to reduce operating expenses and duplication of effort, and produce integrated projects. NATMAP supports projects that maximize the application of computer technology. NATMAP will contribute to the development of the next generation of skilled field geologists in Canada by supporting projects that provide opportunities for students to obtain practical training in mapping disciplines.
- What makes a NATMAP project?: NATMAP projects must meet the following criteria:
  - i Projects must produce geoscientific maps as major outputs;
  - ii Projects should be multi-disciplinary. Mapping must be the principal component, but projects should incorporate other disciplines (e.g. geophysics, engineering geology, geochronology, hydrogeology, geochemistry, stratigraphy, paleontology, structural geology) as required;
  - iii Projects should be cooperative (i.e. involve more than one agency) and, where possible, should result in integrated products that combine the results of different agencies and different disciplines;
  - iv Projects should involve undergraduate and graduate students from Canadian universities in their field components; and
  - v Projects should capture new data in digital format.

Before 1990, GSC's mapping projects had been carried out by its several divisions, based on the expertise and responsibility of that Division: the crystalline rocks of the Precambrian Shield, the sedimentary rocks of the large sedimentary basins, the unconsolidated overlying deposits, or the geophysical parameters of bedrock or surficial deposits. Bedrock mapping projects were defined by a senior geologist, based on matching the training, experience and interests of the geologist to a particular region's scientific potential. The project's rationale was to furnish new data for an area that was unmapped or insufficiently mapped, a premise that served the nation well for the first century of the GSC's existence. Project proposals that stated objectives, methods, budgets, milestones and participants were remarkably brief and general and were usually approved and annually renewed with limited discussion. A regional mapping project would be carried out at 1:250 000 scale, moving the field operations each successive year to a new area within the map boundaries until completion, generally a three-year period. Prior to the field activities, little regard was paid to any existing maps, which were likely compiled 20 to 30 years earlier at a scale of 1:1 million, nor to the samples from these earlier efforts archived in the GSC sample repository. Although preliminary results were released every year, typically in the form of *Current Research* reports, no time for compiling and publishing the final maps and reports was formally built into the project plans. Commonly, these publications were not produced until several years afterwards. Bedrock mapping meant simply that – examinations on the outcrop and in the laboratory to produce a map and report on the distribution of a region's bedrock types and structural relationships. Projects did not include airborne geophysical or ground-based geochemical surveys that could help understand an area's mineral potential. The nature and extent of surficial deposits and the region's glacial landforms and history were similarly not considered in bedrock projects, except most often in a cursory way. Studies of these complementary geoscience elements were not ignored, but commonly were not undertaken for several years afterward, or over areas whose boundaries or mapping scale might not correspond to those of the bedrock map. As a result, clients who were interested in learning the total geoscience story of a region to help assess its mineral potential were obliged to assemble the several component maps and reports and to devise the relevant correlations and economic implications on their own before planning and executing an exploration venture.

Acceptance of the NATMAP concept, principles and practices meant a significant and necessary shift in how the GSC proposed, planned and carried out its major geoscience mapping projects. NATMAP projects had to have a defined, defensible and timely rationale. Each scientific endeavour would need to bring together all the tools and expertise necessary to provide the complete geoscience story. NATMAP projects were both multidisciplinary (geology, geophysics, geochemistry) and interdisciplinary, with the experts in each aspect integral to the project's planning and execution. Now, for example, airborne geophysics is routinely the first step in bedrock mapping, and its data and interpretation are essential in guiding the field mapping in following years. Projects would be GSC-led, but the requisite technical and academic expertise could be drawn from the appropriate source, whether GSC, provincial or territorial survey or university. The planning for each project would include both the research period plus the time to properly complete the scientific outputs. Milestones and budgets for each year of the 3- to 5-year duration would be detailed at the outset. Project proposals and the details of budgets, methods, timetables and expected outcomes and outputs would require review and approval by a panel whose members were drawn from appropriate facets of Canada's geoscience community. Progress would be assessed annually by the same panel to determine whether the project would proceed. Although these ideals and principles were not always realized during NATMAP, with modifications over the succeeding years these elements of relevance, accountability, collaboration and an interdisciplinary approach have largely become the standard requirement for all of GSC's scientific endeavours.

The NATMAP Projects

NATMAP projects were conceived and developed by GSC scientists, commonly with input from provincial/territorial colleagues who, in turn, sought guidance from their respective mineral industry associations on how their particular interests could be addressed by the acquisition of new geoscience

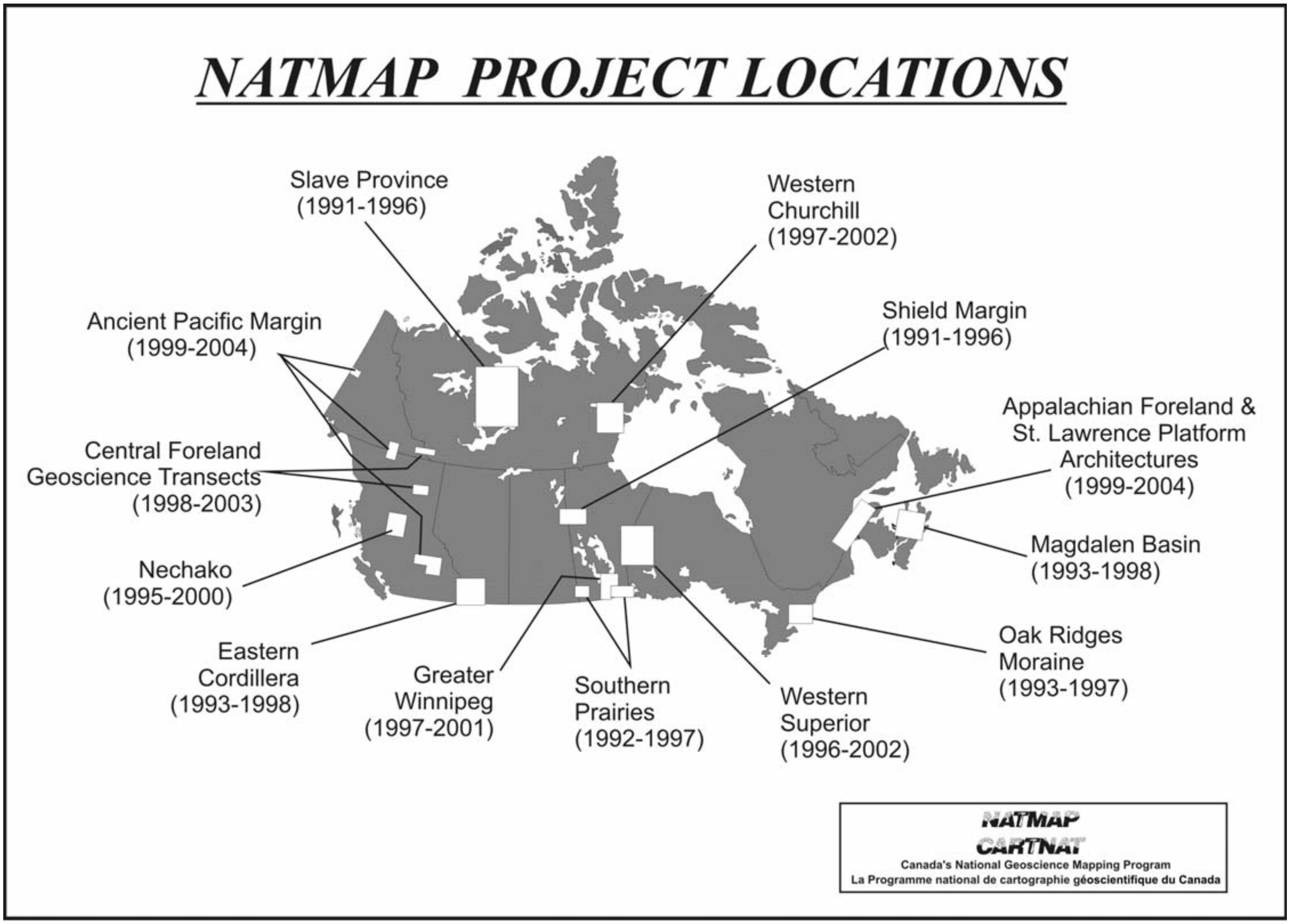

Figure 1. Locations of NATMAP projects.

knowledge. Thirteen projects were approved and undertaken under the NATMAP banner (at least four additional proposals did not receive approval). Despite more of the projects being located in the western half of Canada, their geographical distribution (Fig. 1; Table 1) is a validation of NATMAP as a 'national' mapping program. Although it could be argued that a large part of the NATMAP project areas would have been mapped by the GSC and provincial surveys anyway, regardless of the NATMAP program and funding, the NATMAP projects produced new geoscience knowledge for an area of roughly 1 million km^2, or an impressive 10% of Canada's landmass. The results of the individual NATMAP projects have been synthesized, archived, interpreted, published and communicated in a wide variety of forms and in countless scientific reports, maps, databases, theses, posters, field trips and oral presentations. Readers interested in the details of, or references to, the immense volume of new NATMAP geoscience knowledge, are advised to conduct a literature search using standard methods. A higher-level report on each NATMAP project (in press) summarizes:

i. The circumstances that suggested the need for particular geoscience knowledge;
ii. The constraints on the extant knowledge;
iii. The goals of the particular NATMAP project;
iv. Areas to be researched, necessary expertise, sharing of duties and techniques and technologies to be employed to achieve these goals; and
v. Significant new insights and implications from the new geoscience acquired.

THE SUCCESS AND LEGACY OF NATMAP

As was the intent, the primary legacy of NATMAP lies in the important advances in Canada's geoscience database and the interpreted knowledge made available within each of the thirteen project areas, advances that have been documented, portrayed, manipulated and communicated in a variety of ways for use by a range of stakeholders. By 2000, it was estimated that the program had resulted in the publication of more than 500 geological maps and more than 1500 reports. Similar products appearing in the three succeeding years of NATMAP, plus those completed and published in the few years afterward, increased the total NATMAP output by an additional 50%. Maps and potential economic implications were presented to the resource exploration sectors at industry conferences. Field trips, guided by

Table 1. NATMAP projects by years of operation

Project	Location	Years
Shield Margin	MB, SK	1991-1996
Slave Province	NT, NU*	1991-1996
Studies of the Surficial Geology of the Southern Canadian Prairies	SK, MB	1992-1998
Eastern Cordilleran Geologic Mapping in Southern Alberta	AB	1993-1998
Surficial Geology of the Oak Ridges Moraine & Greater Toronto Area	ON	1993-1998
Origin & Evolution of the Devonian to Carboniferous Magdelan Basin, Eastern Canada	NB, NS	1993-1998
Nechako Project, British Columbia	BC	1995-2000
Western Churchill	NT, NU**	1997-2002
Western Superior: Tectonic evolution, mineral potential of Archean continental & oceanic blocks	ON, MB	1996-2003
Geology of the Winnipeg Region	MB	1997-2001
Central Foreland Geoscience Transect	BC, YK, NT	1998-2003
Ancient Pacific Margin	BC, YT	1998-2003
Appalachian Foreland & St. Lawrence Platform Structures	QC, NB, NF	1999-2003

* While Nunavut Territory (NU) wasn't created until 1999, the Slave NATMAP project straddled what was to become the NT-NU boundary.
** Western Churchill NATMAP project area lies within NU; when the project was initiated, however, NU was still part of NT.

NATMAP geoscientists to significant, newly mapped areas, provided on-site interpretations for industry colleagues. Databases of geology, geochemistry and geochronology parameters, GIS-referenced to field localities, are accessible for application in a wide range of issues – economic, environmental, societal – i.e. any aspect in which geoscience can make a major contribution. The acquisition of large quantities of new geoscience data, and the requirement to make it easily accessible and applicable in the emerging digital data world, necessitated development of a range of new and readily usable techniques and tools for data acquisition, standardization, archiving, manipulation and dissemination, often specific to a particular project's needs. Many of these, or their derivatives, have become standard components of today's geoscience 'toolbox'.

Although one might wish to measure the 'success' of NATMAP in largely economic terms – increased spending on exploration and discovery of new ore bodies, and contributions to Canada's GNP from new mines brought into production – it is fully recognized both by those who compile the new maps and the industry users that the ultimate value of publicly funded, base-level geoscience lies in the longer term. As Dirk Templeman-Kluit, VP Exploration, Richfield Ventures Corp. has stated (personal communication), referring to the results of the Nechako NATMAP project, "NATMAP [projects] do not by themselves drive discoveries – economics plays a huge role. It is really the building of information that started generations before – the work to improve the database and to get it into the public domain – that allows timely economic decisions to capitalize on markets. NATMAP and all geological surveys deserve credit for improving the base data. That is the proper role – it is up to industry to take it to the next step and do the discovering." Similar examples can be cited from virtually all projects that focused on improving knowledge for resource exploration where incorporating the new NATMAP geoscience into exploration strategies has had immediate results:

- The Lucky Joe copper–gold occurrence in the Stewart River, Yukon region was recognized following staking and sampling of a significant geophysical signature revealed in airborne magnetic surveys as part of the Ancient Pacific Margin project.
- Known reserves at the Endako molybdenum mine, BC, were expanded by using Nechako project geoscience data, as it was released, to target new prospects; new claims were staked over a molybdenum anomaly discovered by the NATMAP geochemical survey data.
- New geoscience knowledge from the Central Foreland project (Alberta) contributed to resource exploration expenditures on the order of $400 million and the drilling of 48 new wells, including 17 successful gas producers between 1998 and 2006.
- New geological maps and structural cross sections from the Eastern Cordilleran project (Alberta) greatly assisted industry in developing and successfully exploring new plays for oil and gas; in the Triangle Zone, 55 new wells, at an average cost of $2.3 million, resulted in the discovery of 974 million m^3 of gas reserves.
- Till characterization data for the southeast Manitoba segment of the Southern Prairies project revealed gold, base metal and kimberlite anomalies, leading immediately to the largest claim-staking activity in the province's history, with a corresponding investment of $5–$10 million.
- Western Superior project results provided a westward correlation of geologic units of the Red Lake Belt, Ontario, leading to redoubled gold exploration investment, while southeastward correlation prompted new staking of 24 000 acres.
- Hydrocarbon exploration expenditures in Québec, virtually nil before the initiation of the Appalachian Forelands NATMAP project in 1999, reached a record $24 million in 2004, the final year of the project.

Not all of the thirteen NATMAP projects, however, were designed to acquire new understanding of a region's geology to aid the mineral and petroleum exploration industries.

In particular, the principal aim of the multi-faceted Oak Ridges Moraine project was to understand the geomorphology of this feature and, thereby, to aid in establishing principles and practices to preserve this critical source of groundwater for the greater Toronto region. As one result of this NATMAP project, the Oak Ridges Moraine Conservation Act was enacted by the Government of Ontario in 2001. Groundwater sustainability was similarly a major focus of the Greater Winnipeg project, but other components addressed human and natural influences on Lake Winnipeg evolution and a better understanding of Red River flooding from a long-term prospective. The principal success of these latter studies has been a dramatically increased awareness by various government, industrial and environmental communities of the need to incorporate geoscience in their planning.

The legacy of the NATMAP program extends beyond the new geoscience knowledge and how it has contributed to new economic ventures or environmental management practices. The federal–provincial geoscience collaboration that became a cornerstone of NATMAP's success and is commonplace, expected and valued today, required a major culture shift that was generally accepted by management of all organizations. The willingness at senior leadership levels to venture into collaborative projects translated into a changed culture of acceptance at the scientist level on both sides. In his report on the evaluation of the NATMAP program, Gartner (2000) partially quoted a respondent from a provincial survey, "*NATMAP stands out as the most cost-effective, pragmatic, inspirational and productive model for co-operation between geoscientists in Canada . . . . it has left a lasting legacy of goodwill between all who have shared the co-operative experience*."

The NATMAP program had its flaws and criticisms. As Gartner (2000) noted, the program lacked a "*strategic vision to determine mapping priorities for the future, say 5 to 10 years*". Also, according to Gartner, the original objectives stating that NATMAP should not undertake systematic regional geophysical or geochemical mapping, "*was interpreted to mean that geophysics and geochemistry should not be considered on NATMAP projects*." For some projects, parallel geophysical, geochemical and hydrogeological surveys in the same areas could be linked to the NATMAP project to augment and support the geological mapping efforts, although not in a true interdisciplinary sense.

The new geoscience knowledge gained under NATMAP was largely meant to assist the exploration industry in assessing economic potential in the regions mapped and formulating their exploration strategies. NATMAP consultation with industry stakeholders about what type of program or priorities they would like addressed, did not always translate into the areas or activities that industry considered the most useful at the time for their needs. As these consultations commonly occurred through the established provincial–territorial client networks, it was these agencies, not the GSC, who received the complaints of these companies. As well, there were some differing perceptions on how rapidly the NATMAP results were disseminated.

Nonetheless, the environment of cooperation generated largely under NATMAP has continued well beyond the original program. It has become an invaluable part of today's major geoscience programs carried out by the GSC and its provincial and territorial counterparts. As a prime example, the four phases of GSC's highly successful Targeted Geoscience Initiative (TGI), commenced in 2000 and re-funded into 2012, planned and carried out in collaboration with provincial surveys, universities and industry, were a direct result of the successful interaction realized under NATMAP.

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