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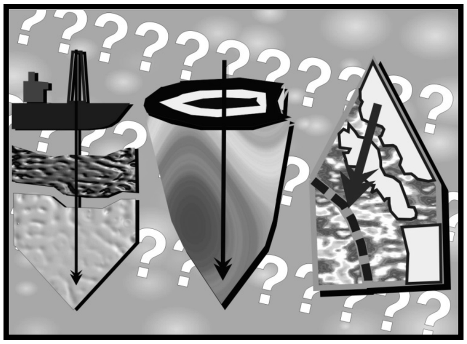

Brainstorming about the Future of Solid Earth Sciences in Canada

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(On behalf of the Ad-Hoc Strategic Planning Group - see appendix - with specific sections provided by others as indicated in the text)
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SUMMARY
This article is a synopsis of an informal meeting that was convened in Montreal last May to discuss strategic planning for the "Solid Earth Sciences" in Canada. Five possible approaches for developing a new research program are discussed and the lessons from LITHOPROBE are reviewed. This is followed by a brief overview of existing and emerging Solid Earth Science projects that are focussed on the Continental, Far North, Marine, and Planetary realms. There is also a section on future directions of federal and provincial geological surveys. Finally, at least two workshops are proposed to define and flesh out research themes, and identify funding pathways. One should deal with research in continental geology, perhaps using the "Taking the Pulse of Planet Earth" proposal as a starting point. A second should explore research opportunities for solid earth scientists in planetary science and attempt to develop funding links with the Canadian Space Agency.

SOMMAIRE
Le présent article est un compte rendu sommaire des débats d'une réunion informelle tenue à Montréal et portant sur la planification stratégique dans le domaine des « sciences de la Terre solides » au Canada. On y décrit cinq approches distinctes visant à mettre sur pied un nouveau programme de recherche, et on passe en revue les leçons tirées du programme Lithoprobe. Puis, on revient brièvement sur les projets émergeants en sciences de la Terre solides et qui portent sur les secteurs de recherche sur le continent, le grand nord, la mer et les planètes. Il y a aussi un segment discutant des orientations des services de levés géologiques fédéral et provinciaux. Finalement, on propose la création d'au moins deux ateliers de remue-méninges afin de définir en détails des thèmes de recherche et de cibler des processus de financement. Un premier atelier devra porter sur la recherche en géologie du continent, en prenant s'il y a lieu, comme point de départ, le projet « Prendre le pouls de la planète Terre ». Un deuxième atelier portera sur les possibilités de recherche intéressant les chercheurs des sciences de la Terre solide dans le domaine des sciences des planètes, et essaiera de définir des pistes de financement avec l'Agence spatiale canadienne.

1. INTRODUCTION
On May 18, 2004, an opportune meeting was convened at the Joint Assembly of the Canadian Geophysical Union, American Geophysical Union, and the Society of Exploration Geophysicists in Montreal, to discuss, in an informal atmosphere, strategic planning for the "Solid Earth Sciences" in Canada. This represents the purview of NSERC Grant Selection Committee 08 that is probably to be renamed "Earth and Planetary Sciences" (John Waldron, pers. comm., 2004).

Science funding in Canada and elsewhere is increasingly granted to large groups of researchers working around common themes. Solid Earth Sciences was one of the disciplines to first realise the benefits of this approach, through the LITHOPROBE project (1984-2004). LITHOPROBE combined novel applications of geophysical and geological techniques to understand the structure and evolution of Canada's lithosphere. With the conclusion of LITHOPROBE, and a growing number of Canadian earth scientists now studying climate change and hydrosphere-atmosphere processes, the Solid Earth Sciences appear to be at a cross-roads. Which research themes should solid earth scientists develop, and how should they link with the research of environmental earth scientists? About twenty earth scientists from across the country and two NSERC representatives (see Appendix) met to discuss these questions. Many others expressed interest but could not make it to Montreal. Among those present, three main issues came to the fore:

- Should the Solid Earth Sciences community develop a "big science" project (on the scale of LITHOPROBE) to focus its research agenda? Or should the community concentrate on a few, more moderate size projects?

- Which projects are currently ongoing or on the drawing board, and why have some been more successful than others in gaining funding (e.g., NEPTUNE, POLARIS, both largely funded through the Canadian Foundation for Innovation (CFI); the Sudbury deep drill hole, IODP, both still awaiting major funding).
- How can the Canadian earth science community better explain the importance of its research in the context of large-scale funding activities such as the NSERC reallocation process?

These issues, although independent, have some overlap in that they are constrained by similar dynamics in the larger earth science community, and indeed the greater science community in Canada. Hence, they tend to merge together when discussions are held on what direction Canadian Solid Earth Sciences should take.

A representative from NSERC (David Bowen) indicated that the NSERC reallocation process will continue, as it provides a useful way for science disciplines to formulate their priorities, and argue their merits to the wider scientific community. An announcement about the next reallocation exercise is expected in 2005. The Earth Sciences have lost NSERC funding in each of the past three reallocation exercises. Clearly, clarity has to emerge on how to articulate better the contribution of Canadian earth science to understanding fundamental Earth processes, and applying that knowledge to meet a variety of societal needs. A wide range of views seem to exist on the matter—from simply better organization and communication among researchers, to the need for earth scientists to develop a true community, defined by a shared sense of goals and priorities. It is felt that the views of those involved in past NSERC reallocations would be beneficial to any team to be assembled for the next Earth Sciences proposal.

There were several informal presentations at the Montreal meeting, focusing on general strategies for planning, lessons from LITHOPROBE, as well as more specific existing and possible new research themes. These are briefly reviewed below with input from some who could not attend the meeting. Two general conclusions were reached:

- It is essential that the next proposal for NSERC reallocation presents an exciting, forward looking, innovative, and broad, yet coherent, perspective of both the Solid and Environmental Earth Sciences, perhaps highlighting the best and brightest in our respective fields, and what their science could achieve for Canada in the next 5-10 years. At the same time, it is clear that any new project or proposal needs to be increasingly relevant with respect to current societal, environmental and economic concerns.
- It is equally important to pursue "niche proposals" not necessarily solely relying on direct NSERC funding. POLARIS, a geophysical instrument pool for deployment across the country to address innovative scientific questions (e.g., mapping mantle layering in the keel of the Slave craton; Snyder et al., 2004), is a good example. This has been mostly funded through the CFI. Similarly, funding for the NEPTUNE project, an ocean floor real-time monitoring array, came largely through CFI. Planetary science holds many untapped research themes for earth scientists, and potential funding through collaboration with the Canadian Space Agency.

2. GENERAL STRATEGIES FOR SOLID EARTH SCIENCES PROGRAM DEVELOPMENT

Generally, any successful research program or collection of projects requires careful trade offs between two end-member approaches: 1) broad, inclusive, but perhaps less specific and thus less "sexy" versus 2) highly specific, timely, and focussed on a "hot" issue. A third approach may aim to strike a balance between these two. Within this framework, and assuming a strong scientific rationale can be constructed for a research program, one or more of five different strategies may be adopted. Paul Sylvester described them and asked the group which would work best in the current funding landscape:

Approach 1: Build around the research of a small group of scientific leaders—everyone else is carried up by the rising tide of success. The question is whether there are leaders with the necessary balance of scientific expertise and strong organisational skills in Canadian Solid Earth Science? How do we assess and tap leadership potential in this context? Perhaps through a mechanism that utilizes large NSERC grantholders or Canada Research Chairs in Earth Science in a more co-ordinated fashion?

Approach 2: Build on the combined expertise of an existing sub-community in Canadian Solid Earth Sciences that is acknowledged for excellence. One obvious choice is Precambrian Geology, magmatic processes, geochronology, crust-mantle evolution, perhaps through the "Taking the Pulse of Planet Earth" proposal (Bleeker, 2004). The questions are whether peer reviewers will see this kind of proposal as exciting and new, or tried and true? Will it link with other disciplines in the earth sciences, particularly the environmental earth sciences, capturing interest broadly throughout the community?

Approach 3: Build on societal and governmental concerns in Canada. For instance, there appears to be growing interest amongst policy-makers in the nearshore marine environment, particularly with regard to the effects of climate change on coastal communities and fisheries, but also for the potential for offshore resource exploration. In this context, new integrated studies on geological processes occurring on the continental shelf would seem to be a ripe area for development. The same interests apply to the "Far North", but here on land as well as the offshore, largely because global warming is expected to degrade the permafrost. New technologies are increasingly important to societies, and earth scientists could help improve tools for certain advanced applications such as space-based remote sensing and mapping, and sampling in harsh environments, as on the seafloor or in the Far North. The question is how can "traditional" Solid Earth scientists participate in these activities? And do earth scientists need a "champion" in government (in cabinet) to push policy-based research agendas?

Approach 4: Build on the intrinsic scientific curiosity of the general population. One obvious choice is the small but growing Planetary Science discipline in Canada, as we are entering a "golden age" of exploration with eight orbiter and three lander missions to be launched to Mercury, Venus, Moon, Mars and asteroids before 2010. A Mars sample return is planned for ca. 2015. The question is what role can Canada play in a field dominated by the United States (NASA) and Europe (ESA)? Perhaps this can be achieved through technology development, as mentioned above. Another avenue might be Earth analogue studies, particularly focussing on the ancient rock record and the clues it holds to the development of plate tectonics and the origin of life. The recent move of Planetary Science to the Solid Earth Science committee at NSERC presents a timely opportunity to embrace this partnership through directed research. Clearly, a strategic link should be forged with the Canadian Space Agency (CSA), which, apparently, is eagerly looking for collaboration.

Approach 5: Build on practical industrial and economic interests in Canada. A strong earth science infrastructure in Canada has traditionally been justified on the basis of its direct relevance to the stability of a resource-based economy. Resources of particular interest are diamonds, nickel, base metals, gold and PGEs; and petroleum, particularly offshore, with a link to marine studies mentioned above. It is worth pointing out that many of Canada's major mining centres and smelter communities, from Bathurst (New Brunswick) through Sudbury and Timmins (Ontario) to Trail (British Columbia) are running out of local concentrate supplies or have already done so. This is a significant issue north of the 49th parallel, where the potential for job creation from exploration successes is real. It must be acknowledged, however, that there is a perception (in some quarters) of mining and oil production as environmentally unfriendly sunset industries. In this regard, resource-based research programs are perhaps more likely to be successful if combined with other approaches listed above.

No consensus was achieved at the meeting on which of these approaches (if any) was the most appropriate in guiding development of key research programs for the Canadian earth sciences. Opinions were particularly divided on the value of substantial industry support. Also, several participants thought that a focus on research "leaders" could be divisive. However, there was general agreement on some points:

- Any new research program should, in the first instance, be able to demonstrate "scientific excellence".
- Earth science research must capture the imagination of both scientists and the general public, and should include components that have relevance to societal and government concerns. As one participant, Penny King, summed it up – we should have a program that has an importance and excitement that can be conveyed to "our next door neighbour, over the back yard fence".
- New technologies have driven several successful earth and planetary science projects in the past and, if possible, should be a focus of future projects.

3. LESSONS FROM LITHOPROBE

LITHOPROBE, for more than two decades a premier flagship project of Canada's Solid Earth Sciences, is winding down. There is little question that it has been a successful "big science" project, bringing together earth scientists from across the country to work toward a common goal: to understand the large-scale architecture of the Canadian continental lithosphere. Although the project also has had its critics, the reasons for its general success can be clearly understood:

- First and foremost, proponents of LITHOPROBE had a grand vision (e.g., Keen, 1981; Clowes et al., 1984)—to understand the fundamental architecture of the Canadian crust and lithosphere from coast to coast, in three dimensions, and through time.
- Second, rapid advances in seismic reflection and deep-probing electromagnetic techniques, largely made possible by rapid growth in modern electronics and computing power, opened an entirely new observational window into the crystalline crust and, increasingly over the last decade, into the lithospheric mantle (e.g., Calvert et al., 1995; Cook et al., 1999).
- Third, the transect approach divided the overall project up into manageable chunks, linking regional expertise pertinent to particular transects with thematic expertise from across the country.
- Fourth, the Supporting Geoscience grant system assured "buy-in" from a multi-disciplinary science community, bringing together the best minds from different disciplines and organizations to work together on cross-sections through the Canadian lithosphere.
- And finally, competent leadership and management made it all happen.

Of course, favourable timing of these and other factors (e.g., funding sources and cycles; willingness and ability of the Geological Survey of Canada to be a significant partner; industry interest), all coming together at the right time, was critical. Some of these factors are unlikely to be repeated, but other favourable factors have emerged (CFI) or may emerge. This general recipe for success could be easily emulated by any future project. Initially, at a conceptual stage, the first two reasons for success—a grand vision and a powerful new observational window—are undoubtedly the most important for any new project.

4. A BRIEF OVERVIEW OF EXISTING AND EMERGING SOLID EARTH SCIENCE PROJECTS

Several existing or potential research programs and projects were discussed at the meeting and a selection of these is summarized below. Some are active projects, successfully funded, whereas others are mere visions or future opportunities. Collectively, they provide a sampling, albeit admittedly incomplete, of some of the present research directions in the Canadian Solid Earth Sciences. For convenience, we have grouped these programs and projects in terms of their general "realm":

- Continental (section 4.1)
  - "Taking the pulse of planet Earth" (proposed theme)
  - Deep scientific drilling, Sudbury (advanced proposal)
  - Deep probing geophysical studies, POLARIS (active project, funded largely through CFI)
- The "Far North" (section 4.2)
  - The upcoming International Polar Year, IPY 2007-2008 (upcoming event)
- Marine (section 4.3)
  - General overview
  - "Wiring the Juan de Fuca plate", Neptune (active project, funded through CFI)
  - Ocean drilling, IODP (active proj-

ect, modest Canadian participation)
- Space and planetary (section 4.4)
  - Developing strategic partnerships between Canada's solid earth and planetary science communities

As stated above, this brief list and the following summaries do not pretend to be complete. Clearly, geodynamical and modeling studies, and mineralogy and experimental petrology, fields in which Canada has considerable strengths and which have the potential to provide a broad theoretical and numerical framework to complement the observational disciplines, should be an integral part of any overall Solid Earth Science program.

A final part of this report (section 4.5) provides an update of where federal and provincial geological surveys are heading over the next decade.

4.1 Programs and projects in the continental realm

It is in this realm that the conclusion of LITHOPROBE is most strongly felt and where new initiatives are particularly needed. Several new and exciting projects are underway or on the drawing board.

4.1.1 "Taking the pulse of planet Earth" (Wouter Bleeker)

This proposal (Bleeker, 2004) aims to provide a comprehensive and multiparameter knowledge base of the complete record of mafic magmatism in and around Canada, and through international collaborations, around the world.

A complete record of mafic magmatism through time and space (spatial distribution, ages, periodicities, rates, volume estimates, estimated geochemical fluxes to atmosphere and hydrosphere, tectonic settings, sequence stratigraphic framework, structural trends, evolving major and trace element compositions, evolving isotopic ratios, paleomagnetic information, paleo-intensities, associated ore deposits, etc.) provides critical constraints on numerous first-order questions about the past and present evolution of our planet. ("Mafic magmatism" is used as a shorthand here, meaning to include all mantle-derived magmatic activity other than steady-state arc magmatism, i.e., all basalt (±komatiite)-dominated and (or) bimodal magmatism associated with divergent margins, or more generally extensional regimes, intraplate magmatic provinces, mantle plumes, anorogenic provinces, kimberlite and alkaline provinces; i.e., products of mantle processes other than steady-state subduction.) Many of such questions relate directly or indirectly to issues that are currently a focus of attention: global change, past climate extremes, complex Earth systems, geochemical fluxes, planetary evolution, geodynamics, core and mantle evolution, the geodynamo, mantle plumes, flood volcanism, extinction events, potential relationships with large impacts, and discovery of new strategic mineral resources.

At its core, the proposed project would have a large dating program, aiming to provide ca. 200-300 new high-precision ages of mafic magmatic events across Canada, adjacent regions, and landmasses suspected of being formerly connected to Canada and North America. As more precise and accurate ages are critical to virually every geoscientific question, this project should not only focus on just new dates but also on the development and application of new dating methods, e.g., accurate and precise dating of very young events, and the dating of associated sedimentary rocks. Canada has several well-regarded TIMS and LA-ICPMS labs, and one SHRIMP lab (at the Geological Survey of Canada) that could be fully engaged in this activity.

A Supporting Geoscience grant system, perhaps modeled on that of LITHOPROBE, will ensure that other aspects of the magmatic record receive equal attention (e.g., sequence stratigraphy, paleomagnetism, geochemistry, paleo-intensity studies, geophysical and geodynamic studies). Together, these data would trigger a quantum leap advance in paleogeographic reconstructions and, thus, in the understanding of the first-order rhythm of Earth evolution—the supercontinent cycle through time.

At a modest cost and building on many of our traditional strengths, from geochronology to geodynamics, and from igneous petrology and isotope geochemistry to Precambrian geology, this project could provide a central theme for the Solid Earth Sciences. Key innovations would be the scale and scope of investigations, integrating data from a large number of disciplines and around the globe into a holistic model of Earth evolution. The project would be timely in making optimum use of the next generation of analytical equipment now being acquired through CFI and other programs at various earth science departments across Canada. More so than LITHOPROBE, this project would look into the mantle and even the core, while trying to relate surface processes (e.g., basin development, geochemical signals, extinctions, etc.) to mantle-driven tectonic rhythms. There are clear synergies between this proposed project for the traditional continental realm and some of the other projects summarized below (e.g., the Sudbury deep hole, POLARIS, IODP, NEPTUNE, planetary science).

4.1.2 Deep scientific drilling—the Sudbury deep hole (James Mungall)

An initiative is underway to launch a major new project in the Sudbury area, to be carried out by a partnership of academic, industry, and government researchers. The goal of the project is to develop a holistic understanding of the formation and modification of one of Earth's largest impact basins, its differentiated melt sheet, and the associated mineral deposits (Therriault et al., 2002). A focus of the project will be a ca. 6-km-deep drillhole and associated multidisciplinary probing studies, funded in part by the International Continental Scientific Drilling Program (ICDP). The project group, called the Sudbury Integrated Geoscience Network (SIGNet), is being coordinated by James Mungall of the University of Toronto, and is currently preparing funding requests to NSERC, CFI, and ICDP. The primary product will be a state-of-the-art 3D model of the Sudbury Structure and its environs, containing data on composition, structure, age, mineral assemblages, and texture from within and around the Sudbury Basin. Secondary products will be detailed models of heat flow, impact crater dynamics, magma chamber dynamics, hydrothermal fluid flow, tectonic modification, and contemporary fluxes of heat and fluid flow within the Sudbury Structure.

4.1.3 Deep probing geophysical studies—POLARIS (David Snyder and David Eaton)

POLARIS (Portable Observatories for Lithospheric Analysis and Research

Investigating Seismicity) is a national research consortium using various geophysical instrument deployments (seismic, GPS and MT) to address long-standing geoscientific problems. POLARIS has a broad geographical base and has active participation and steering committee representation from six universities, two offices of the Geological Survey of Canada, and the power-generation and diamond-exploration industries. Currently, 71 observatories are deployed on the Slave craton, atop the Cascadia subduction zone around Vancouver Island, and across the Grenville orogen and Superior craton. Installation of the initial POLARIS infrastructure, including field instruments and two satellite communication hubs, has been completed, and additions will be made over time from new funding sources.

Funding for POLARIS has been obtained from different sources. The first 4-year phase of the consortium (2001-2005) has been funded through CFI, with matching provincial contributions from Ontario and British Columbia and substantial industry support. Through its Major Facilities Access program, NSERC is providing partial support for operations over the next two years. The Ontario Research and Development Challenge Fund has provided bridge funding for four new faculty positions at Ontario universities. Natural Resources Canada, the province of British Columbia and industry are also providing substantial support for the project.

Over the next few years the original scientific goals will be met. Episodic Tremor and Slip (ETS) on the Cascadia subduction zone beneath Vancouver Island is recorded by monitoring both small transient changes in surface displacements using continuous GPS measurements and the occurrence of distinct, non-earthquake-like tremors that accompany the transient displacements. These displacements and tremors occur surprisingly regularly beneath southern Vancouver Island and are thought to reflect the repeated relief of stress on the deep subducting plate interface. Seismometers in the southwestern B.C. POLARIS transect help to locate tremor sources with greater precision than previously possible. Eruptions of diamond-bearing kimberlite volcanoes 50-100 million years ago, in a region 250 km north of Yellowknife, originated at 200-500 km depths and plucked diamonds and other rock fragments out of the mantle during their ascent. These eruptions are thought to rise first as vertical sheets of magma, before separating into individual pipes. Precise age dating of clusters of eruptions, and structural fabric orientations derived from new seismic anisotropy estimates from POLARIS observatories, now substantiate these eruptive models and suggest that such eruptions may be triggered by changes in North American plate motion (e.g., Snyder et al., 2004). The third POLARIS array, located in southern Ontario, has resulted in more accurate "shake maps" that document the small magnitude ($M<4$) earthquakes that have been recorded by the enlarged array of sensors, but also provide better predictive tools for potentially larger earthquakes in this most densely populated part of Canada (Atkinson and Sonley, 2003).

Responses to the first request for proposals to redeploy the observatories, as described on the POLARIS website (www.polarisnet.ca) are being evaluated. Some observatories are expected to follow the similar USArray studies south of the border as they move from west to east across the continent.

4.2 Programs and projects in the "Far North"

No specific programs or projects were discussed at the meeting although there is a general recognition that societal and environmental pressures make the Far North an attractive target. It is also a priority of the Geological Survey of Canada, through its Northern Resource Development program. One example of successful collaborative research in Arctic Canada is the multinational scientific drilling of gas hydrates in Mallik (Dallimore et al., 2002), and discussions have started in Canada on a successor project focussed on associated permafrost studies (Dallimore and Schmitt, 2003). By its very nature (onshore environments, arctic islands, offshore shelf and Arctic Ocean, climate change, resources), this realm lends itself extremely well to interdisciplinary science. Similar comments may apply to Canada's extensive coastal environments in general. One timely opportunity for the "Far North" realm is the upcoming International Polar Year (IPY 2007-2008). A National IPY Committee and Secretariat, which will oversee the development of the Canadian Research Plan, is being assembled. Information on this activity is provided by the Canadian Polar Commission (www.polarcom.gc.ca).

4.3 Programs and projects in the marine realm

4.3.1 General overview (Jeremy Hall)

Canada's marine territory includes accessible natural laboratories for significantly advancing our understanding of:

- Earth processes associated with the creation and destruction of lithospheric plates;
- sedimentary basins and their mineral deposits that form at, or close to, plate margins;
- earthquake risk evaluation at the active plate margin on Canada's west coast;
- hydrocarbon potential and hazards posed by gas hydrates at shallow depth below the seabed along the continental edges; and
- paleoclimate and climate dynamics, derived from proxy data from ocean sediments.

These are substantial issues of science and economics, derivative from a huge area of Canadian territory. Canada's offshore, if we include the Great Lakes, is two-thirds the size of its landmass. Canada has the world's longest coastline. Our marine activities account for 5% of GDP. It is arguable that the provisions of Article 76 of the United Nations Convention of the Law of the Sea (UNCLOS) could permit Canada to extend seabed jurisdiction over additional regions of the Atlantic and Arctic Oceans equalling the area of the three prairie provinces.

Canadian marine geoscientists—distributed among academia and government—are addressing all the research themes listed, but with enhanced resources so much more momentum could be built. The total amount of ship time funding distributed by NSERC for all Canadian marine sciences is in the ball park of $3 million per year, enough for around 300 days (varies widely depending on vessel size, etc.). Recent investments by CFI have added strength to our research vessel fleet, including icebreaking capability for work in the

Arctic and new capabilities for the remotely operated vehicle ROPOS. Active experiments conducted from ships are a vital part of marine research, and Canadians are now using international collaborations to access resources needed to pursue research on (i) Earth system interactions, involving exchanges between oceans and atmosphere, and oceans and lithosphere, with implications for climate change; (ii) subduction zone structure and gas hydrates on the west coast; and (iii) the development of rifted margins and their sedimentary basins on the east coast.

Recently, the value of continuous recording of long time series of various ocean and seafloor characteristics has been recognised in awards from CFI for seabed observatories (Bonne Bay, Newfoundland; VENUS, in the Straits of Georgia; NEPTUNE, covering the whole of the Juan de Fuca plate, see below). New technologies drive innovation, and we can expect new discoveries from the operations of such seafloor observatories and the wider development of seabed imaging technologies (some of which may be funded to assist Canada's development of sovereignty under UNCLOS).

4.3.2 "Wiring the Juan de Fuca plate"—NEPTUNE (Christopher Barnes)

The NEPTUNE project will lay a 3,000 km network of powered fibre optic cable on the seabed over the Juan de Fuca tectonic plate, a 200,000 km^2 region in the northeast Pacific off the coasts of British Columbia, Washington and Oregon. This tectonic plate is the smallest of the dozen major plates that make up the planet's surface and through NEPTUNE offers real-time observations on a full range of Earth and ocean processes. The NEPTUNE cable network will feature 30 or more seafloor "laboratories," or nodes, spaced about 100 km apart. From these nodes, land-based scientists will control and monitor sampling instruments, video cameras and remotely operated vehicles as they collect data from the ocean surface to below the seafloor. Instruments will be interactive - scientists will instruct them to respond to events such as storms, plankton blooms, fish migrations, earthquakes, tsunamis, and underwater volcanic eruptions, as they happen.

In October 2003, full Canadian funding of $62.4 million for NEPTUNE Canada was awarded by CFI ($31.9M) and the British Columbia Knowledge Development Fund ($30.5M) to the University of Victoria (UVic), which leads a consortium of 12 Canadian universities from coast to coast. The United States will provide the other 70% of the NEPTUNE facility budget. Core staff based at UVic are being recruited, others under contract will be based elsewhere. NEPTUNE Canada funding includes a total of $13 million for an initial suite of observing systems to support the proposed Canadian research. These will be chosen through a new process involving competitive, peer-reviewed proposals, which are currently being evaluated. A report, describing recent workshops to review community experiments and propose specific systems and sites, is available on the web (www.neptunecanada.ca). UVic and NSF staff are developing a Memorandum of Understanding. NEPTUNE Canada is particularly interested in developing partnerships, including those with industry, which can attract additional funding and/or in-kind support.

Thus, with the receipt of funding for NEPTUNE Canada, a range of activities will occur over the next year: the NEPTUNE Canada office will be staffed; science workshops will consider the precise location of the observatory nodes, the detailed science experiments, sensor packages, and the needs for sensor/vehicle development; initial work on the location of a shore station, concurrent with the issuance of Requests for Qualifications and Proposals for the "wet plant" (cable/nodes); learning from the ongoing developments in the VENUS (www.venus.uvic.ca) and MARS test beds; and the initial design of the Data Management and Archive System. All of these require considerable dialogue with the scientific, engineering and local communities and with funding agencies, partners and industry.

4.3.3 Ocean drilling—IODP (Kathryn Gillis)

The Integrated Ocean Drilling Program (IODP) is a multi-year, multidisciplinary international program aimed at understanding the Earth systems that make up our planet. IODP is the advanced successor to the Deep Sea Drilling Project and the Ocean Drilling Program, funded by the US, Japan, and a European consortium (ECORD), which includes 14 European nations and Canada. IODP differs from its predecessors in that it will identify and support whatever type of drilling platform is required to best address highly ranked scientific questions. Platforms include an improved version of ODP's *JOIDES Resolution*; a riser-equipped drill-ship, under construction in Japan, with the ability to reach targets in deep water, on continental margins, and gas-prone regions; and mission-specific platforms such as jack-up rigs and ice-breakers.

Within the three broad IODP science themes of the Deep Biosphere, Environmental Change, and Solid Earth Cycles, the topics of particular interest to Canadian researchers include: climate dynamics; gas hydrates; seismogenic zones and seismic hazards; sedimentary basin formation; the deep biosphere and biotechnology; formation and evolution of the oceanic lithosphere; hydrothermal ore deposits; and mantle dynamics, the origin of mantle plumes and the formation of large igneous provinces. IODP will play a key role in observatory projects such as NEPTUNE, and has strong links with the International Continental Scientific Drilling Program.

In the first year of operations (June 2004–April 2005), IODP will recover critical cores for understanding global climate change from the Arctic (Eocene to present) and North Atlantic (Late Neogene-Quaternary), establish bore hole observatories in the Juan de Fuca plate to monitor plate-scale deformation, earthquakes and fluid flow, and examine the formation of oceanic core complexes. More information for these and future expeditions can be found on the ECORD website: (http://www.ecord.org/).

The current status and future plans for Canadian participation in IODP are as follows: Canada has recently joined IODP, in partnership with the European consortium. Our participation is currently limited to one year (2004/2005) and is funded through the NSERC–MFA program. Our contribution to IODP ($200,000) is modest, representing ~2 % of ECORD's participation fee. At this time there is no clear path to obtain longer term stable funding for participation in IODP. NSERC has stipulated that future proposals must show broader financial commitment from the community (e.g., government agencies, universities). Toward this end, the Canadian Consortium for Ocean Drilling (CCOD) has been established to facilitate participation in IODP and planning for long-term, stable funding. Membership in the CCOD is open to all Canadian universities, government agencies and industry groups with a commitment to Canada's participation in the IODP. More information about IODP or the CCOD is available from the Canadian IODP secretariat at the University of Victoria: CanIODP@uvic.ca.

4.4 Programs and projects in the realm of space and planetary science

4.4.1 Developing strategic partnerships between Canada's solid earth and planetary science communities (Paul Sylvester)

Canada has a small but diverse group of planetary scientists with expertise in meteoritics, impact processes, small bodies, planetary geology and astrobiology (www.unb.ca/passc/CSSC/index.html). The CSA supports and helps coordinate much of the planetary research. The CSA is a federal organization with a mandate to promote the use and development of space to meet Canada's social and economic needs. To achieve its goals, the CSA cooperates with other government departments, industries, universities, and international partners, particularly the United States National Aeronautics and Space Administration and the European Space Agency.

A dialogue is needed between planetary and earth scientists to determine how best to develop common research partnerships. One area with outstanding potential is Mars exploration, including preparation for a Mars sample return, a major focus of Canada's Space Plan. With tremendous ongoing international interest in Mars, fuelled by current and planned missions to the planet over the next decade, Canada's planetary science community has a wonderful opportunity to carve out a distinctly Canadian agenda for Mars research. The earth science community in Canada can help develop the Mars research agenda by bringing particular expertise to targeted areas of study. Developing these linkages is timely from a programmatic standpoint in that the funding of the planetary and solid earth science programs at NSERC will soon be administered by a common grant selection committee.

Perhaps the most fundamental Mars-related research question is whether, and if so when and how, life developed on the red planet. The same "when-and-how" questions remain unanswered for life on Earth, providing a common focus for study of the two planets. The answers to questions about early life on Earth are preserved in the oldest rocks, and Canadian earth scientists include some of the world's best Archean geologists and laboratories equipped to study Archean rocks. Mineralogical, chemical and isotopic fingerprinting of primitive biogenic activity on Earth could be developed in Canadian laboratories, and applied to early Archean rocks that have been well-mapped and described by Canadian geologists. Canada's geology includes some locations distinctly suited for such studies including the recently discovered Nuvvuagittuq sequence exposed in a relatively continuous outcrop on the east shore of Hudson Bay. Field tests of primitive biogenic signatures could also be undertaken in Canada's Far North, such as Devon Island, where the combination of cold and aridity mimics Mars-like conditions. This could build on existing, international bio-geologic research programs such as the NASA Haughton-Mars Project (www.marson-earth.org).

Canadian expertise in meteorite research, impact processes and robotics technology is related directly to early life questions. Meteorites derived from Mars and small bodies in the solar system may preserve distinctive biochemical signatures of early life. Impact events may initiate subsurface hydrothermal cycling necessary for critical biogenic processes. Development of a new generation of miniaturized instrumentation for chemical analysis and geochronology by robotic vehicles will be critical to the success of future missions to Mars.

4.5 Future directions of federal and provincial geological surveys (Simon Hanmer)

Faced with decreasing human and financial resources, Canadian geological surveys are finding it increasingly difficult to provide the level of geological mapping required by the end-users of public geoscience, with obvious negative consequences for collaborative research opportunities with the university sector. However, on the positive side, in order to reverse this trend, federal and provincial-territorial geological agencies are currently working together to launch *Cooperative Geological Mapping Strategies across Canada* (CGMS), a country-wide initiative for reinvestment by governments in public geoscience, in support of government issues and priorities for the next 10 years (Cherry and Itzkovitch, 2004). CGMS will therefore focus on improving and maintaining the quality of life of Canadians by providing a geoscientific knowledge base that will support and stimulate the environmentally responsible exploration and development of Canada's mineral and energy resources. The primary outcomes will focus on (i) a secure energy supply for Canada, (ii) the sustainable development of prosperous resource-dependent communities and regions, and (iii) new economic development opportunities in rural and remote areas, e.g., the North.

Underpinning the initiative are the concepts of innovative method development and innovative partnerships, with the potential to renew and strengthen opportunities for research collaboration among the geological surveys, university-based Earth Sciences and industry, both in the field and in the laboratory. New, innovative partnerships, including enhanced opportunities for the training of young Canadian geoscientists, are most likely to form under Approaches 3 and 5 (see Section 2). Note that industry support will be essential for the CGMS initiative to be taken seriously by governments across Canada.

While primarily resource-focussed, CGMS will be environmentally aware, emphasising societally responsible approaches to exploration and development in both the energy (e.g., non-conventional gas supply, underground CO_2 sequestration and groundwater issues related to hydrocarbon development) and the mineral sectors (e.g., mine life-cycle approach from discovery to recovery and remediation). In short, the prime objective of CGMS is to provide public geoscience for informed resource development policy and land-use decisions by governments, industry and Canadian society at large.

If CGMS is approved and funded, consultation with potential partners in industry and academia can commence as the implementation plan is being refined at the project level. CGMS will certainly not be a flagship component of academia's efforts in the upcoming NSERC reallocation exercise. However, the renewed partnerships it will entail can be presented as a tangible stepping stone, hopefully one of several, that can contribute in concrete terms to demonstrating the reinvigoration of university-based Canadian Earth Science, and the clear articulation of its relevance to Canadian society.

5. DISCUSSION AND CONCLUSIONS

The sheer diversity of current research activities in the Earth Sciences, compared to even 20 years ago and as clearly evident from even the incomplete survey presented here, suggests that a single, large, LITHOPROBE-type umbrella project should not necessarily be a goal of strategic planning activities.

Today, Environmental Earth Sciences, particularly climate change studies, occupy a large segment of the research base in the discipline. Marine science holds great potential, particularly through the development of new technologies for remote observations and measurements. Planetary science is an emerging field in Canada with potential links and overlaps with the Earth Sciences. Geological research in the Far North is primed for rapid development through the International Polar Year 2007-2008. Solid Earth scientists should embrace these changes and opportunities in the research landscape by defining a few key research themes, each of which can be justified in their own right in terms of scientific timeliness and quality, expertise, societal relevance and/or intellectual excitement and curiosity. Together these research themes could serve to encompass a large proportion of the existing research in the Solid Earth Sciences, and provide much-needed links to allied fields of environmental, marine and planetary science.

Appendix: Ad-Hoc Strategic Planning Group

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Perhaps a useful model is to think of the Earth Sciences in terms of several distinct but interconnected realms (the continents and deep time, the core and mantle, the shallow marine seabed, the Far North, the deep oceans, the atmosphere-hydrosphere-biosphere, terrestrial planets and small bodies, etc.) each requiring dedicated research themes that are complementary and collectively add up to a greater whole.

Planning workshops are required to define and flesh out some of these themes, and identify funding pathways. At least two workshops are proposed here. One should deal with research in continental geology, perhaps using the "Taking the Pulse of Planet Earth" proposal as a starting point. A second should explore research opportunities for solid earth scientists in planetary science and attempt to develop funding links with the Canadian Space Agency. A third might consider goals for scientific deep drilling in the continents and ocean basins, and develop strategies for supporting existing and new initiatives. Development of these themes would help provide the Solid Earth Science community with a strong, shared rationale for growth of our discipline over the next decade.

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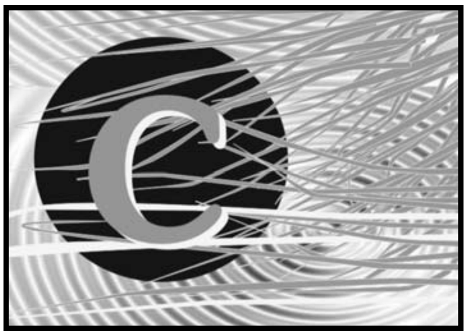

Celestial Climate Driver: A Perspective from Four Billion Years of the Carbon Cycle

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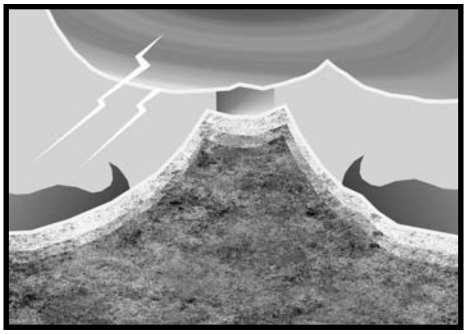
SUMMARY
The standard explanation for vagaries of our climate, championed by the IPCC (Intergovernmental Panel on Climate Change), is that greenhouse gases, particularly carbon dioxide, are its principal driver. Recently, an alternative model that the sun is the principal driver was revived by a host of empirical observations. Neither atmospheric carbon dioxide nor solar variability can alone explain the magnitude of the observed temperature increase over the last century of about 0.6°C. Therefore, an amplifier is required. In the general climate models (GCM), the bulk of the calculated temperature increase is attributed to "positive water vapour feedback". In the sun-driven alternative, it may be the cosmic ray flux (CRF), energetic particles that hit the atmosphere, potentially generating cloud condensation nuclei (CCN). Clouds then cool, act as a mirror and reflect the solar energy back into space. The intensity of CRF reaching the earth depends on the intensity of the solar (and terrestrial) magnetic field that acts as a shield against cosmic rays, and it is this shield that is, in turn, modulated by solar activity.

Cosmic rays, in addition to CCN, also generate the so-called cosmogenic nuclides, such as beryllium-10, carbon-14 and chlorine-36. These can serve as indirect proxies for solar activity and can be measured e.g., in ancient sediments, trees, and shells. Other proxies, such as oxygen and hydrogen isotopes can reflect past temperatures, carbon isotopes levels of carbon dioxide, boron isotopes the acidity of ancient oceans, etc. Comparison of temperature records from geological and instrumental archives with the trends for these proxies may enable us to decide which one of the two alternatives was, and potentially is, primarily responsible for climate variability. This, in turn, should enable us to devise appropriate countermeasures for amelioration of human impact on air quality and climate.

SOMMAIRE
Généralement, les raisons données pour expliquer les caprices de notre climat, les mêmes que celles avancées par le CICC (Comité intergouvernemental sur le changement climatique), veulent que ce soient les gaz à effet de serre, particulièrement le dioxyde de carbone, qui en soient le moteur principal. Récemment, une série d'observations empiriques ont ravivé l'intérêt pour un autre modèle voulant que ce soit le soleil qui en soit le moteur principal. Mais seuls, ni le dioxyde ce carbone ni les variations d'activité solaire ne permet d'expliquer la hausse de température observée au cours du siècle dernier, soit environ 0,6 °C. D'où la nécessité d'un facteur d'amplification. Dans les modèles climatiques généraux (GCM), le gros de l'accroissement calculé de température est dû à « la rétroaction positive de la vapeur d'eau ». Dans le modèle à moteur solaire, ce pourrait être le flux de rayonnement cosmique (FRC), ce pourrait être l'effet des particules énergiques qui en frappant l'atmosphère entraînent une génération possible de nucléus de condensation des nuages (NCN). Alors, les nuages se refroidissent et, comme un miroir, réfléchissent l'énergie solaire dans l'espace. L'intensité du FRC atteignant le sol dépend de l'intensité des champs magnétiques du soleil et de la Terre, lesquels agissent comme un bouclier à l'endroit des rayons cosmiques, le pouvoir de ce bouclier étant à son tour modulé par l'activité solaire. En plus d'entraîner la formation de NCN, les rayons cosmiques, génèrent aussi ce qu'on appelle des nucléides cosmogéniques, comme le béryllium-10, le carbone-14 et le chlore-36. Ces nucléides peuvent servir d'indicateurs indirects de l'activité solaire puisqu'on peut en mesurer la teneur dans des sédiments anciens, des arbres, et des coquilles, par exemple. D'autres indicateurs indirects comme les isotopes d'oxygène et d'hydrogène peuvent refléter les températures de jadis, les isotopes de carbone peuvent refléter les niveaux de dioxyde de carbone, les isotopes de bore peuvent refléter l'acidité des anciens océans, etc. La comparaison entre des registres de mesures de température directes et d'archives géologiques, avec les courbes de tendance de tels indicateurs indirects peut nous permettre de décider laquelle de deux options était et continue possiblement d'être la cause principale des varia-

tions climatiques. On pourrait alors décider de contre-mesures appropriées permettant d'atténuer l'impact des activités humaines sur la qualité de l'aire et sur le climat.

SERIES



Igneous Rock Associations 4. Oceanic Island Volcanism I Mineralogy and Petrology

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SUMMARY
Oceanic islands tend to occur at the young ends of hotspot trails because they record the passage of oceanic plates over rising convection cells (plumes) in the mantle, or the propagation of cracks in the lithosphere. Basaltic volcanism on oceanic islands is generally unexplosive and, although potentially destructive, poses less threat to human life than volcanism in other tectonic environments. However, the possibility of giant tsunamis from the catastrophic gravitational collapse of islands is of real concern for major cities surrounding the ocean basins.

Two series of magmas are recognized in oceanic islands. Tholeiites form at lower pressures than alkali basalts, from higher percentages of decompression melting. The former contain a low-Ca pyroxene and the latter can crystallize nepheline. Furthermore, minerals common to both series (chromite, olivine, augite, plagioclase, magnetite and ilmenite) are compositionally distinct reflecting fundamental chemical differences between the two magma series.

Mineral compositions vary as magmas evolve in sub-volcanic, lithospheric magma chambers by assimilation and differentiation. Magmas assimilate wall rocks in these chambers. Timescales for differentiation (mostly crystal fractionation) are generally less than a few thousand years. Early olivine, pyroxene, chromite and immiscible sulfide formation cause compatible elements (e.g., Ni, Co, Cr) to decline rapidly as differentiation proceeds. Plagioclase dramatically removes Sr at intermediate stages and alkali feldspars sequester Ba and Rb as late-stage trachytes and phonolites form in alkaline magmas. The high-field-strength elements are generally incompatible but locally decline reflecting apatite (P) and Fe-Ti oxide (Ti, Nb, Ta) removal. Studies of layering in individual lava flows suggest that rising volatiles may effect mass transfer of complexed ions during differentiation in magma chambers.

SOMMAIRE
Les îles océaniques se trouvent généralement à l'extrémité la plus jeune des traînées de points chauds parce qu'elles sont la marque du passage de plaques océaniques au-dessus de cellules de convection ascendantes (panaches) dans le manteau ou de la propagation de fissures de la lithosphère. En général, le volcanisme basaltique des îles océaniques n'est pas explosif, et bien qu'il puisse être destructeur, il présente moins de danger pour les humains que le volcanisme d'autres environnements tectoniques. Cependant, la formation possible de tsunamis géants provoqués par l'effondrement d'îles constitue un danger réel pour les grandes agglomérations situées au pourtour des basins océaniques.

On distingue deux séries magmatiques dans les matériaux constitutifs des îles océaniques. Les tholéiites qui se forment à des pressions plus faibles que les basaltes alcalins, et plus souvent sous des conditions de fusion par décompression, et les basaltes alcalins. Les premières contiennent un pyroxène à faible teneur en calcium et l'autre permet la cristallisation de la néphéline. De plus, les minéraux communs à ces deux séries (chromite, olivine, augite, plagioclase, magnétite et ilménite) ont des compositions distinctes qui reflètent les différences de composition chimique intrinsèques de ces deux séries magmatiques.

Les compositions minérales varient puisque les magmas changent de composition dans les chambres magmatiques lithosphériques pré-volcaniques par assimilation et différentiation. Les magmas absorbent les roches des murs d'enceinte dans ces chambres. Les échelles de temps de ces différentiations (principalement de fractionnement cristallin) s'étalent généralement sur quelques milliers d'années. D'abord, la formation d'olivine, de pyroxène, de chromite et de sulfures immiscibles entraîne un appauvrissement rapide du magma en éléments compatibles (Ni, Co, Cr par ex.). Puis, aux stades inter-

médiaires, la formation de plagioclases réduit considérablement la teneur en Sr et, aux stades finaux, la formation de feldspaths alcalins en extrait le Ba et le Rb alors que se forment les trachytes et les phonolites à partir de magmas alcalins. Les éléments les plus fortement polarisés sont généralement incompatibles mais, localement, leur teneur décline, reflétant ainsi la formation d'apatite (P) et d'oxydes de Fe-Ti (Ti, Nb, Ta). Les résultats d'études sur la formation en couche de coulées de laves indiquent que l'ascension gravitationnelle des volatils pourrait avoir un effet sur le transfert de masse d'ions complexes durant la différenciation dans les chambres magmatiques.