A new VSAT Broadband Digital Seismograph Array in Northern Ontario

by
I. Asudeh (Continental Geoscience Division, iasudeh@nrcan.gc.ca)
J. Adams (National Earthquake Hazards Program, jadams@nrcan.gc.ca)
Geological Survey of Canada
Natural Resources Canada
Ottawa, Ontario K1A 0Y3

In partnership with the
POLARIS Consortium
http://www.polarisnet.ca/

Project Funded By:
Industry Canada (The Federal Economic Development Initiative for Northern Ontario)
and
POLARIS Consortium

Objectives

1. Obtain new geophysical information about the Earth's lithosphere at key locations in Northern Ontario to assist the diamond exploration industry in Northern Ontario in the identification of diamondiferous kimberlite pipes .
2. Provide monitoring information for the safety of power dams and mine-tailings dams.
3. Enable rapid-ground motion warnings for critical facilities in northern Ontario, in partnership with POLARIS.
4. Assess the seismicity and seismic hazard of Northern Ontario, in order to provide seismological information for study of long-term nuclear waste disposal options and for other waste disposal initiatives.
5. Determine mining-related seismic activity in order to contribute to mine safety.
6. Provide outreach for Science North in Sudbury: Live seismograph and display.

Introduction

The establishment of POLARIS, a Consortium of Canadian Universities (Carleton University, University of Western Ontario, Queens University, University of British Columbia, University of Manitoba, University of Alberta), Natural Resources Canada's Geological Survey of Canada and Canadian Industry, has provided new and novel opportunities for geophysical research in Canada. The $9.9M POLARIS infrastructure, now at the start of its third year of operation, has already installed 50 new broadband digital seismographs in Southwestern Ontario, BC and the NWT. Plans are underway to install another 40 broadband digital seismographs and additional magnetotelluric and geodetic GPS instruments over the next two years. The primary focus of POLARIS research includes: (i)geophysical studies of deep earth structure as related to diamond exploration and lithospheric architecture, and (ii) measurements of earthquake ground motion for the evaluation and mitigation of earthquake hazards. See Appendix 1 for more details.

The POLARIS infrastructure is based on leading-edge satellite telemetry broadband digital seismographs manufactured, exclusively, by Nanometrics Inc. of Kanata, Ontario. These seismographs, called Libra systems, transmit near real-time data to a Data Acquisition Hub on the campus of the University of Western Ontario, in London Ontario, using a VSAT satellite telemetry system. POLARIS data are then ported over the Internet to the archiving facilities of the Geological Survey of Canada in Ottawa and are made available, free of charge, to all researchers. The key instruments of POLARIS infrastructure are therefore the Libra seismographs, Data Acquisition Hub and the VSAT satellite telemetry. In order to operate the VSAT, the POLARIS Consortium needs to lease satellite bandwidth from major satellite service providers.

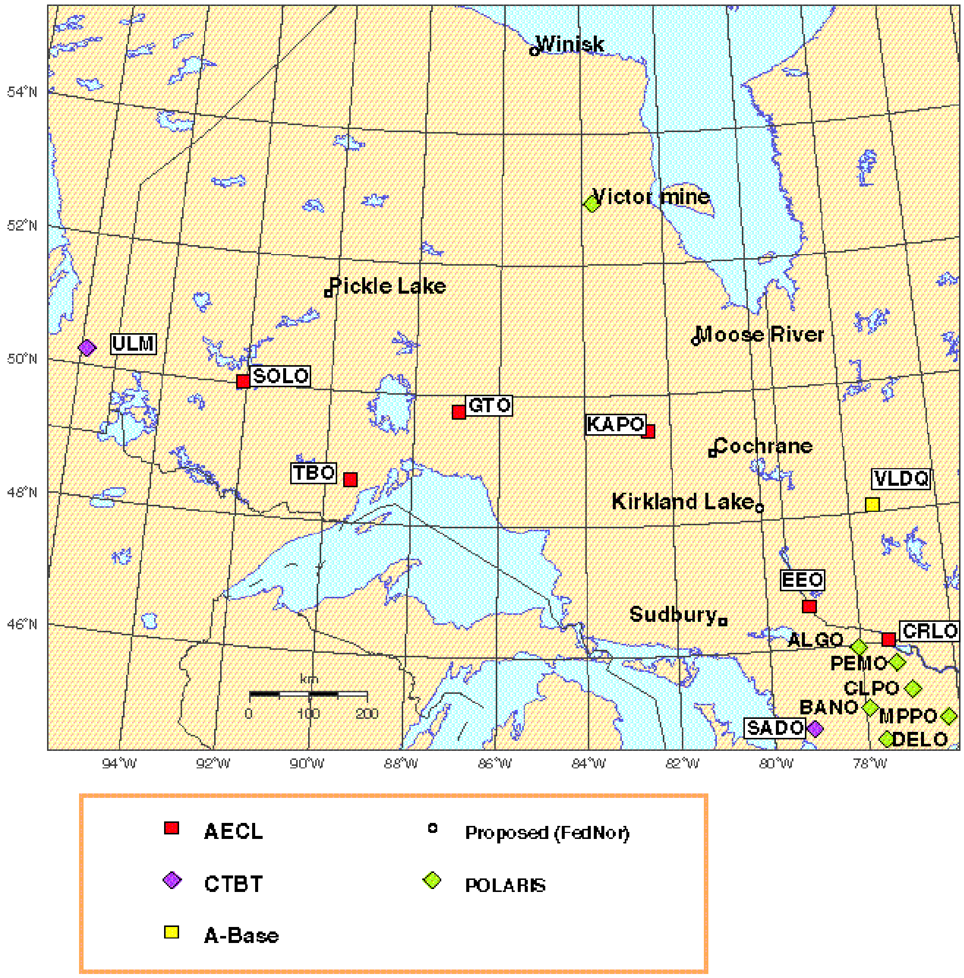
A single POLARIS broadband digital seismograph is already shipped to De Beers Victor diamond exploration mine, about 100 km west of Attawapiskat and will be operational in June 2003. Currently, this is the only POLARIS seismograph in Northern Ontario but, by design, and after the completion of at least four years of recording, some elements of the POLARIS NWT Array may be moved to Northern Ontario in an effort to concentrate on POLARIS research in this area.

The key objective of this project is to install another six POLARIS broadband digital seismographs in Northern Ontario in order to enable new research that will aid in diamond exploration in Northern Ontario and improve the assessment and mitigation of earthquake risk to major northern infrastructures (both current and proposed) and the people of Northern Ontario.

Work Plan

1. Purchase an array of six satellite telemetry Libra seismographs and a Data Acquisition Hub manufactured by Nanometrics Inc (identical to those currently used by the POLARIS Consortium) and the required satellite bandwidth for the operation of the Libra array for the first four years of operation. This acquisition, will be completed on March 31, 2003.
2. Install the Data Acquisition Hub in Ottawa, by June 1, 2003.
3. Start the process of finalizing the remote seismograph locations at remote Northern Ontario communities of Moose River, Pickle Lake, Winisk, and in mining areas near Cochrane and Kirkland Lake and at Science North in Sudbury. Complete this task by April 2003.
4. Start the process of remote site identification using satellite imagery, air photos and other maps and obtain remote site permits for the six remote seismograph locations. Complete this task by May 2003.
5. Start the installation of the six remote stations in early June 2003 and as soon as all the site permits are at hand. Complete the installation by July 2003.

Location Map



Benefits to Northern Ontario

In conjunction with the AECLR funded stations, POLARIS stations and other CNSN stations this will achieve the benefits listed below.

1. This project will enable deep earth studies related to diamond exploration in northern Ontario. POLARIS has already made much progress in NWT and will be able to apply this experience to developments in northern Ontario.
Benefit: improved understanding of kimberlite distribution and origins, leading to increased exploration/mining investment and future mines and jobs in the region.

2a. Improving the safety of power dams in Northern Ontario, an emerging issue because of a) continued operation of Ontario Power Generation dams, b) sale of existing dams to private owners, and c) upgrades of generating facilities to produce peak power to meet Ontario's short-term power deficit.
Benefit: improved safe operation of facilities, investment in existing, expanded and perhaps new facilities. [Government of Canada and Province of Ontario issue].

2b. Improving safety and economic efficiency of tailings dams in northern Ontario. There are many aging mine tailings facilities in the Sudbury region, and mine operators have an ongoing interest in evaluating the seismic safety of existing tailings dams, as well as the safety of proposed new tailings disposal projects that are required as mining continues. Improved seismological information is needed to make accurate hazard assessments, leading to cost-effective mitigation measures.

3. Enable the operators of critical facilities in northern Ontario to join the POLARIS rapid-ground-motion warning system. This system will provide accurate engineering information on the ground motions experienced at selected locations within minutes of the occurrence of an event, allowing timely mitigative measures to be taken by facility operators and emergency management personnel.
Benefit: rapid information on ground motions allows rapid engineering assessments of their impact, and enables rapid reaction so as to mitigate consequences.

4a. Quantifying low level seismicity and seismic hazard in Northern Ontario to aid in the siting of the future high level radioactive waste vault.
Benefit: New digital Libra seismographs to the north and south of the west-east line of existing AECLR-funded seismographs (Thunder Bay, Sioux Lookout, Geraldton, Kapuskasing, Eldee) would improve geographical coverage (perhaps allowing additional remote regions to be considered for the facility) and provide better data to ensure sensible siting and safe design of the facility. [A major policy role for the Government of Canada].

4b. Quantifying low level seismicity and seismic hazard in Northern Ontario to aid in the siting of garbage-disposal sites, such as the Adams Mine proposal for Toronto's garbage.
Benefit: environmentally safe design; population less concerned about the safety of the facility; jobs and investment in the north. [Mainly a Provincial issue, but Government of Canada was involved in the environmental review].

5. Responding to mining-related seismic activity (which remains to be a safety issue). Coverage in the mining area of Northern Ontario is much poorer now than during the 1980's when the Ontario-CANMET-GSC consortium had 3 stations monitoring the Sudbury basin for mining-related activity such as rockbursts, and poorer than in the early 1990's when CANMET operated 6 regional station in the Ontario-Quebec mining belt (all now closed). Mines often ask the GSC about larger events because it is important to them to get a reliable magnitude for such events (that usually exceed in-mine monitoring systems' capabilities). Mines will also be able to get relevant ground motion information more quickly, through the partnership between GSC and POLARIS.

Benefit: monitoring of/for mining industry, possibly leading to better mining practices and reduced casualties. [Has been a Government of Canada-Provincial Governments health and safety issue in the past]

6. Collaboration with Science North and, possibly other educational institutions of Northern Ontario. The Ontario-CANMET-GSC consortium operated out of Science North, and Science North would be interested to get a real-live seismograph or a live feed from a seismograph outside the city. The POLARIS infrastructure is Internet-ready and Internet-friendly. Displays of live seismic activity in Northern Ontario can be installed at some key schools or colleges in order to promote science and technology.
Benefits: enhanced tourism and education opportunities. [Government of Canada already playing a role in a static display at Science North]

7. Improve the current earthquake alert systems. The Government of Canada through the National Earthquake Hazards Program already provides rapid alerts, specifying earthquake magnitude, location and other rapidly-available information, to selected clients after potentially damaging earthquakes (for example alerts specify "Stop trains on this segment of track", "Inspect these dams", etc). As well as enabling specific ground-motion warnings to be made (point 3 above), the new stations will also allow improved rapid information on earthquake magnitudes and locations.
Benefit: rapid information on earthquakes large enough to have consequences for dams, rail track, etc and on large rockburst events, enables a broad range of responses to mitigate consequences.

Capability of Research Group

Continental Geoscience Division: (CGD) scientists have had leading contributions in the creation of Canada's Lithoprobe and POLARIS projects, both with strong components of deep crust and upper mantle explorations with linkage to diamond exploration and other mining activities. CGD has key contributions in design and technology transfer of geophysical instruments and in conducting both controlled-source investigation of many large scale transects in Canada, N America and overseas. CGD has designed the power sub-system for the POLARIS project and is leading the installation, operation and maintenance of the infrastructure.

National Earthquake Hazards Program: (NEHP) runs Canada's earthquake monitoring system. The new Northern Ontario VSAT array sponsored by FedNor would provide a data feed that could be directly processed in the NEHP's two automated datacentres, allowing real-time information to be rapidly used for immediate benefits. NEHP staff would monitor and quality control the data and use it to locate earthquakes and rockbusts. The data would be archived permanently. Web access allows all Canadians (primarily university researchers) to recover any of the data within minutes of it being recorded.

Partners: Professor David Eaton, the science leader of POLARIS Ontario has already been consulted and expressed his full support for this proposal. Professor Gail Atkinson, the President of POLARIS Consortium and Chair of POLARIS Steering Committee has already been consulted and expressed her full support for this proposal. NEHP already partners with Ontario Power Generation, AECL Research, and CN Rail to provide the coverage in Northern Ontario that will be enhanced by this proposal.

Acronyms and links

1. **FedNor** (The Federal Economic Development Initiative for Northern Ontario), http://strategis.ic.gc.ca/SSG/fn00800e.html
2. **POLARIS** (Portable Observatories for Lithospheric Analysis and Research Investigating Seismicity), www.polarisnet.ca
3. **GSC** (Geological Survey of Canada), http://www.nrcan.gc.ca/gsc/index_e.html
4. **CGD** (Continental Geoscience Division, GSC), http://gsc-cgd.nrcan.gc.ca/cgd/aboutcgd_e.html
5. **NEHP** (National Earthquake Hazards Program, GSC-Pacific Division, GSC), http://www.seismo.nrcan.gc.ca/index_e.php
6. **AECL** (Atomic Energy of Canada Limited), http://www.aecl.ca/index.asp

7. **Ontario Power Generation**, http://www.opg.com/default3.asp
8. **De Beers Canada** http://www.debeerscanada.com/index.html
9. **Victor Project** http://www.debeerscanada.com/files/attawapiskat/factsheet.html

Appendix 1.

Overview of POLARIS

POLARIS is a $9.9 million project hosted by Canadian universities - Carleton University, University of Western Ontario, University of B.C. and University of Manitoba – in partnership with the Geological Survey of Canada, with funding from the Canada Foundation for Innovation, provincial governments, and private industry (Ontario Power Generation, BHP). POLARIS is multi-institutional infrastructure comprised of mobile geophysical observatories that transmit data to research centres using a satellite-telemetry communications system. POLARIS is innovative in concept, state-of-the-art in design and flexible in configuration. POLARIS will fundamentally advance Canadian geoscience and promote innovative Canadian technology, by providing an order-of-magnitude improvement in our ability to "see" the Earth's interior. The improved imaging capability of POLARIS, combined with innovative interpretive techniques, holds the promise of breakthroughs in several geoscience disciplines. In the field of resource exploration, for example, POLARIS will facilitate development of Canada's emerging diamond industry. In the field of earthquake hazard, POLARIS will enable us to image earthquake faults, predict the severity of ground motions and provide rapid warning information on earthquake shaking.

The major components of POLARIS are a network of 90 seismograph and 30 magnetotelluric (MT) mobile field systems, complementary data-acquisition and satellite-communications equipment, and satellite downlink facilities. The seismograph network comprises three subarrays of 30 seismographs, to be deployed in Ontario, British Columbia, and the Northwest Territories over a period of four years (beginning in 2001). To date, eighteen seismograph stations have been deployed in the NWT, 18 stations in Ontario and 18 in B.C. The MT equipment will be utilized in two modes: (i) for lithospheric (less than 200 km beneath the Earth's surface) structure imaging, there will be short-term deployment at each seismograph location within the subarray; and (ii) for deep-mantle (to depths of 1000 km beneath the Earth's surface) imaging, or monitoring of the time variations of electrical conductivity associated with earthquakes, data will be recorded continuously at selected seismograph locations. Satellite downlink facilities are located at the University of Western Ontario, whereas internet access to POLARIS data, through the POLARIS website, is available anywhere. Data collected by POLARIS will be available to researchers all across Canada through the internet, in near-real time. Signals from seismograph stations installed to date can already be viewed and downloaded at www.polarisnet.ca.

The scientific research that will be conducted with POLARIS infrastructure has major economic benefits for Canada and our industrial partners. Our fledgling diamond industry is already adding millions of dollars to the national economy every year, with only one diamond mine active. Thus advances in our ability to find new diamond deposits would have economic implications in the multi-billion dollar range. Potential losses in the event of a large earthquake near a major urban centre in Canada could also be in the multi-billion dollar range, as demonstrated by the tragic losses in the last few years from earthquakes in Turkey, Japan, California, Taiwan and India. Earthquake losses are significantly reduced through knowledge of earthquake risk, which is a prerequisite for mitigation. Furthermore, the availability of ground-motion information in near-real time enables effective emergency response and improved engineering models of the earthquake response of structures.

Details of the Ontario Projects involving POLARIS

Through a proposal funded by the Ontario Research and Development Challenge Fund, a geophysical research network has been developed between Carleton, UWO and Queen's Universities, in collaboration with scientists from the Geological Survey of Canada. Our research will elucidate the structure, composition and physical state of the crust and upper mantle beneath Ontario, improving understanding of the dynamic processes that drive seismic hazards and create economic mineral resources in our province. The proposed research network capitalizes on the successful Canada Foundation for

Innovation (CFI) and Ontario Innovation Trust (OIT) proposal for the national infrastructure referred to as POLARIS (Portable Observatories for Lithospheric Analysis and Research Investigating Seismicity) (www.polarisnet.ca).

POLARIS is comprised of mobile observatories that use satellite telemetry to transmit geophysical data to research centres . Its major components are a network of 90 seismograph and 30 magnetotelluric (MT) mobile field systems, complementary data-acquisition and satellite-communications equipment, and satellite downlink facilities. Seismometers are sensitive devices that respond to ground movement. The analysis of these signals recorded by seismometers is used to characterize earthquake rupture processes and provide an image of the acoustic properties of the subsurface. MT field systems are used to image electrical properties of the subsurface. Acoustic and electric parameters are complementary; in combination, they form a powerful exploration tool. This new infrastructure will provide an order-of-magnitude improvement in our ability to see the Earth's interior, enabling us to image crustal faults, determine the severity of earthquake ground motions, and advance the techniques of mineral resource discovery.

CFI and OIT have provided capital funding for the purchase and initial deployment of the POLARIS infrastructure in Ontario, while the Ontario Research and Development Challenge Fund (ORDCF) has funded an integrative research network on the POLARIS platform, leading to exciting progress in related disciplines - geodynamics and tectonics, mineral exploration, seismic hazard evaluation and earthquake engineering. Scientific, social and commercial benefits will follow from the distinct but complementary research done at the three centres, which will be organised around the five themes described below. Brought together, this dynamic research network will firmly establish Ontario as an international centre for the analysis, interpretation and applications of the new generation of digital geophysical data.

Theme 1: Seismic Risk to Canada's Economic Core (CU, UWO, QU)

The seismic risk to southern Ontario is a significant social and economic issue in view of the population density and concentrations of critical facilities (eg. nuclear power plants, dams). Recent moderate earthquakes, such as the magnitude 3.9 earthquake on Nov. 26, 1999 in Lake Ontario near Toronto, the magnitude 5.2 earthquake on Jan. 1, 2000 near Temiskaming, Quebec, and the April 20, 2002 magnitude 5.0 earthquake in New York, have contributed to enhanced public concern. Much of this concern stems from uncertainties in the occurrence rates and spatial distributions of earthquakes, as well as uncertainties in the severity of the ground shaking they produce. Improved understanding of the architecture of the Precambrian basement in southern Ontario and the surrounding area is also required for a more complete picture of the earthquake hazards in this region.

The Ontario POLARIS array will include 30 seismographs installed in the southern Ontario region, roughly from Ottawa to Windsor and from Niagara to Georgian Bay, in conjunction with an MT study. This array will provide greatly improved definition of the spacial and depth distribution of earthquakes and their occurrence rates, as well as crucial information on generation and propagation of the seismic waves that cause damage to engineered structures. In addition, the seismograph and MT arrays will furnish data for three-dimensional mapping of the lithospheric architecture, and for identifying potential zones of crustal weakness.

Research activities at UWO will focus on characterizing regional earthquake source parameters, and determining what spatial relationships exist between contemporary seismicity and ancient structural elements in the underlying basement. In addition to the derivation of traditional source parameters (origin time, location and depth of focus, magnitude, fault-plane solution, spectra and seismic moment), other analytical methods will include full-waveform modeling, moment-tensor inversion and combined use of polarity and mode conversions. Applications of teleseismic shear-wave splitting, tomographic methods and surface wave analyses will increase fundmental knowledge of the deeper, broader-scale features. Integration of these results with processing and interpretation of crustal seismic-reflection profiles from the recently acquired Southern Ontario Seismic Survey will help to constrain the relation of seismicity with lithospheric structures.

Geological research at Queen's will combine what is learned about Ontario structures, ground movements and stresses from seismology with paleoseismicity and neotectonic data, which provide contraints with periods ranging from a day (historical-earthquake coseismic strain) to millions of years. Reactivation histories for displacements on ancient faults under varying stress conditions are of immediate significance for today's seismic hazard assessment. Beyond that, geodetic measurements will provide necessary constraints for geodynamic and structural/tectonic modelling, providing an improved physical basis for seismic hazard evaluation in the region.

A research focus at Carleton is the reduction of uncertainty in engineering ground motion parameters as used in design and retrofit of engineered structures. The POLARIS data will be used as a tool to develop time histories for input into engineering analyses. Such engineering time histories are typically simulated from knowledge of regional earthquake source and wave propagation characteristics. Limitations in this knowledge have led to large uncertainties in the earthquake shaking loads which engineered structures must withstand - typically greater than a factor of two and often as much as a factor of 10 in southern Ontario. This has important economic consequences for earthquake-resistant design and retrofit, particularly for major industrial facilities such as dams or nuclear power plants. Research at Carleton will develop a time-history construction methodology that represents a middle ground between simulated and real earthquake records for design. Earthquake engineers often prefer real records from past strong earthquakes to simulated records, because they include a greater range of earthquake phase and directivity effects. But real records from large earthquakes in Ontario, at appropriate distances for design, do not exist. By using the POLARIS data and integrated research results, we can develop a methodology to modify real earthquake recordings from small events to model the shaking that would occur during large earthquakes. This work will be performed in collaboration with earthquake engineers at Carleton (Dr. David Lau, Dr. Jag Humar) and UWO (Dr. Hesham El Naggar), who will use the time histories in their engineering research programs aimed at improvements in bridge and building design.

By integrating the advances made in earthquake sources, tectonics and ground motion propagation and modeling, quantitative reduction in uncertainty in seismic hazard estimates can be achieved.

Theme 2: Rapid Earthquake Warning Technology (CU)

With the POLARIS infrastructure, we will be receiving seismographic data from over 30 observatories and MT data from 2-5 observatories in Ontario in real-time (delay of only a few seconds), permitting development of Rapid-Warning technology for earthquake ground shaking. The TriNet project of southern California, supported by dense instrumentation and collaboration between government, universities and industry, has demonstrated that it is possible to provide reliable information on the distribution of the intensity of ground shaking within 10 minutes of the occurrence of an earthquake (Wald et al. in Earthquake Spectra, 1999). In the Aug. 1999 magnitude 7 earthquake in the California desert, rapid-warning information was available to stop trains before they travelled into areas where track damage was likely to have occurred. California utilities have formulated detailed earthquake-response plans, in which the response actions are keyed to the data provided by the shake maps. Future developments may even allow warnings to be issued several seconds in advance of the most severe portion of the seismic shaking, allowing automatic safe shutdown of critical systems, such as those in nuclear power plants for example. Real-time spatial analysis of earthquake ground motion in densely populated regions can provide crucial and timely information to emergency-response organizations and operators of critical industrial facilities, allowing them to prioritize their responses and take appropriate measures to reduce loss of life and mitigate damage.

We plan to develop the tools required to rapidly calculate maps of ground shaking within the Ontario array, including the calculation of response spectra at specific locations. With a concentration of stations in Ontario's economic core (Toronto area, the 401 corridor, and also the Ottawa area), we will be well-poised to develop the necessary technology to provide shaking estimates, within a few minutes of an event, for the locations of critical facilities. This would allow rapid assessment of potential damage, and facilitate timely responses to mitigate damage. A system to alert provincial, municipal and industrial subscribers (e.g., Province of Ontario, major urban cities, Ontario Power Generation, Bruce Nuclear) of an event and rapidly disseminate the information will also be developed. This technology is an ideal application for the satellite telemetry approach to data communications showcased in POLARIS. It is anticipated that this area of application will continue to grow in the future as a growing roster of sponsors subscribe to additional sites at or near selected critical facilities.

An additional innovation that we will be pursuing is the nature of electromagnetic (EM) signals generated by earthquake activity. As EM signals travel at the speed of light they reach the critical facilities in advance of the seismic signals that cause the devastation. If we can sense these extremely low amplitude signals within the noise, then potentially we can develop an early warning system with even greater advance warning. Although speculative, this avenue of investigation can be pursued with the equipment that will already be in place for more firmly-based lithospheric studies. At some of the seismograph sites (initially 2, but more will be installed as the project develops) we will be recording the low frequency (1 Hz sampling) EM signals and transmitting them to CU together with the seismic data. Analysis of the relationship between EM and seismic signals may hold long-term potential for improved rapid-warning technologies.

Theme 3. Geodetic Measurement of Crustal Strain and Deformation Processes (UWO, QU)

Permanent GPS arrays and campaign-style portable deployments are contributing a new, dynamic dimension to earthquake hazard studies in California, Japan and British Columbia. Recent advances in Global Positioning System (GPS) technology have enabled the precise measurement of crustal strain and horizontal deformation with sufficient accuracy (~ 1 mm per year) to map patterns of strain buildup prior to a large damaging earthquake, or crustal motions associated with postglacial adjustment. By making use of VSAT communications and data archival systems, GPS hardware can be incorporated directly into the POLARIS infrastructure at relatively low incremental cost (~ $50 K per site). Each GPS station will require the construction of a stable concrete or stainless steel monument, and integration of geodetic-quality dual-frequency GPS receiver into the data recording system. We propose to add GPS measuring systems into at least 3 of the POLARIS stations in Ontario (initially), in an array that will provide long baseline control along the Windsor - Ottawa axis, a tie into the Canadian Active Control System network station in Algonquin Park. These installations will be made in cooperation with GEOIDE, an NSERC network of centres of excellence project. Data from this array will be compared with results from other techniques (e.g., very long baseline interferometry) and recent numerical models of horizontal crustal deformation due to post-glacial adjustment. Ultimately, GPS data can be used to determine the total and residual crustal deformation fields, including dilation, rotation and maximum shear strain. These geodetic observations will enable us to highlight areas where crustal strain may be accumulating.

Theme 4. Integrated Analysis and Modeling of Continental Dynamics (QU, UWO)

A research focus at Queens and UWO will be the construction of models for the evolution and dynamics of the lithosphere which incorporate geological constraints as well as new experimental results from the POLARIS geophysical data. Such understanding is crucial in order to allow practical applications of the new data sets in seismic hazard mitigation and mineral resource discovery to develop from a solid theoretical foundation. The seismographic and magnetotelluric data made available by POLARIS will bring dramatic improvements in the clarity/resolution of lithospheric structures in the upper few hundred km of the Earth. The derived acoustic and electrical properties and their spatial variability will be combined with knowledge of surface geology and the properties and behaviour of rocks from low (upper-crustal) to high (upper-mantle) temperatures and pressures. Knowledge of in situ stress, historical seismicity and fault movements will also be incorporated. Geographic Information Systems (GIS) will be used to manage the differing databases. GPS recordings (Theme 3) are particularly significant, because contemporary velocities provide the constraint on crustal deformation required to calibrate lithosphere-scale geodynamic models. The lithosphere-scale models in turn will provide boundary conditions for the more focused, shallow crustal dynamical models that are of direct use in engineering-scale stress analyses. These latter models require the province to be meaningfully partitioned into structural domains (or elements), with which the mechanical responses to imposed tectonic boundary conditions can be explored. This geomechanical modelling will involve existing computer tools and potentially also existing analogue (scale-model) facilities. New high-performance computational facilities, such as the SHARC-net facility at UWO, will greatly facilitate this aspect of the research. This innovative multi-scale approach to mechanical analysis will form a vastly improved basis for understanding the complex dynamics of the region and fundamental linkages between regional geology and seismicity.

Theme 5. Deep Geophysical Tools for the Mineral Exploration Industry (CU, QU, UWO)

The resources demanded by an expanding global population must come from the discovery of new mineral deposits that are concealed in the subsurface. A fuller understanding of the entire lithosphere is necessary to improve exploration techniques. Current exploration involves geophysical methods such as electromagnetic surveying, combined with geological information on tectonic setting and history. It is the effective combination of different approaches that has enabled Ontario to be a world leader and global exporter of geological and geophysical exploration techniques for many decades. The application of seismic methods has not been common in mineral exploration to date, but the recent LITHOPROBE program has pioneered seismic reflection techniques in mining-camp-scale studies that have produced major advances. Teleseismic studies are used increasingly for area selection in diamond exploration to outline cool cratonic roots in which Precambrian diamonds may have survived to be transported to the surface by kimberlites. Thus the search for base metal, precious metal and diamond deposits will rely increasingly on the development of innovative subsurface exploration techniques.

Little is known about the deep lithosphere beneath the Grenville and Superior provinces of Ontario, but diamonds have been found in the latter, which may extend far southward for hundreds of km beneath the Grenville. Diamonds are stored in the high pressure, low temperature environment that exists in the roots of ancient cratons, at depths greater than about 120 km. A crucial parameter for diamond exploration is the thickness of the lithosphere. As the underlying asthenosphere contains 1-2% partially molten rock, it can be distinguished from its overlying solid lithosphere by the dramatic difference in seismic properties and electrical conductivity. Thus seismic tomography in combination with deep-probing MT studies can help delineate those parts of the lithosphere in which diamonds may have been stored.

The detailed information on seismic and MT properties being gathered by the POLARIS Slave array (NWT) in the diamondiferous Lac de Gras kimberlite field will be used to develop and calibrate techniques to aid in the search for diamonds in northern Ontario. Diamond exploration is ongoing in northern Ontario, but more geophysical information regarding lithospheric architecture is needed to improve current exploration methods. Additional POLARIS stations will be added in northern Ontario as more industrial funding becomes available with demonstration of the capabilities of new techniques. The research performed under this project will lead to improved mineral exploration strategies for northern Ontario.

Economic Benefits to Ontario

The proposed scientific research will have major economic benefits for Ontario. Earthquake losses are significantly reduced through knowledge of earthquake risk, which is a prerequisite for effective mitigation. Potential losses in the event of a large (M>6) earthquake near a major urban centre in Ontario would be in the multi-billion dollar range, as demonstrated by the tragic losses in the last few years from earthquakes in Central America, Turkey, Japan, Taiwan and California. Even moderate earthquakes, such as the events of magnitude 5 to 6 that typify the hazard in most of urban Ontario, often cause major financial losses. Moreover, as demonstrated by the catastrophic 2001 Gujarat, India earthquake, stable continental regions such as Ontario are not immune to large earthquakes. The India earthquake should serve as a wake-up call to regions of low-to-moderate seismicity that place a low priority on earthquake hazard mitigation. Improved knowledge of hazard has major benefits in terms of improved seismic design of valuable infrastructure such as bridges and buildings.

Data collected by POLARIS will be available to researchers in real time, enabling a rapid response to earthquakes, which greatly mitigates damage and losses. Earthquake rapid-warning technology is in high demand; this project will underpin the development of this technology in Ontario and facilitate its export. Mapping the architecture of the continental lithosphere with the improved imaging capability of POLARIS has direct applicability for targeting regional diamond exploration. Our fledgling diamond industry is already adding millions of dollars to the national economy every year, with only one diamond mine active. It is believed that northern Ontario also has economic diamond resources, some of which have already been discovered (eg. Athawapascat). Others are waiting to be discovered given the appropriate geophysical tools. Advances in our ability to find new diamond deposits have economic implications in the multi-billion dollar range. This project will build the integrative approach that is needed to realize these benefits within Ontario, and provide exportable mineral exploration technology.