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Chapter 4: Current Status and Predicted Developments and Trends in the Geoscience Technology

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CHAPTER 4

CURRENT STATUS AND PREDICTED DEVELOPMENTS AND TRENDS IN THE GEOSCIENCE TECHNOLOGY

Science depends on information – observations, measurements, and even speculations – are all based on the acquisition, processing, interpretation, and dissemination of information. Our ability to complete these basic functions is inextricably linked to the technology we have at hand. In many instances advances in this technology have led and even driven advances in understanding. Recent years have seen radical changes in the technology available to the earth scientist; they have presented tremendous opportunities as well as tremendous challenges to our community. They have provided us with unprecedented views (from microscale to megascale) of the workings of our planet, and they have allowed us, for the first time, to develop qualitative and even numerical models that begin to describe (albeit in a very simple manner) the complex "inter-workings" of the Earth System . In this section we will explore some of the recent technological developments available to the geoscience community and speculate on where these might lead us. It impossible to present a comprehensive discussion of such a broad subject; rather we will try, through selected examples, to set the scene for what the future of geoscience technology may hold.

4 (a) Data Acquisition

Remote-sensing from space

Our ability to gather information about the earth has changed over the past 100 years from what we were able to observe by walking about in the field to the remarkable images of the surface and subsurface provided by the range of remote-sensing techniques available. The vastly different observational vantage points provided by air- or space-borne sensors are ideally suited for the scale of some of the problems that we address in the earth sciences. In breaking our earthly bounds, we have, for the first time, gained a planetary perspective on the distribution of earth processes and features. Indeed, probably more than any single action or publication, the phenomenal images returned by early lunar orbiters of small round planet Earth adrift in the vastness of space, brought tremendous public awareness to the finite nature of our planet and its resources. It was with these images that a universal awareness of the "Earth System" was born.

The combination of space exploration and remote-sensing technology has, in the past few decades, progressed to the point that we now depend on space-borne sensors operating in the optical (e.g., Landsat, SPOT, NOAA GOES) and microwave (e.g., Seasat, SIR, ERS-1) spectrum for such wide-ranging tasks as weather prediction, mineral exploration, pollution studies, crop forecasting, ice forecasting, and commercial fishing. Although this field has progressed very rapidly, it is still in its infancy and will see tremendous activity in the future. Epitomizing this activity is the Earth Observing System (EOS), the space component of NASA's Mission to Planet Earth. (MTPE).

MTPE is an international earth-science program that uses space and ground-based measurement systems to provide a scientific basis for global change. The Earth Observing System will be a series of polar-orbiting and low-inclination satellites for long-term global observations of the land surface, biosphere, solid Earth, atmosphere, and oceans. The launch of the first EOS satellite (AM-1) is scheduled for 1998; with eight launches to follow through 2005. Canada will contribute to this program through the development of MOPITT, a 3-channel IR scanner which will be part of AM-1 and is designed to produce global measurements of carbon monoxide and methane in the lower atmosphere. Other instruments to be included on AM-1 are:

- CERES – two broadband scanners designed to measure the Earth's radiation budget through the measurement of both long- and short-wave radiation.

- MODIS – a 36-channel imaging spectrometer (250 m to 1 km resolution) that will look at the terrestrial surface; land cover; productivity; land and ocean temperatures; ocean color; cloud characteristics, aerosol concentrations and properties; atmospheric moisture and temperature and snow cover.

- MISR – 4-channel CCD arrays providing global observations of the directional characteristics of reflected light to learn about the Earth's surface, atmosphere, aerosols, and clouds.

- ASTER (Japan) – 3 scanners in different IR bands – 15 to 30 m resolution of vegetation, rock types, and soil properties.

Future satellites will include even more sophisticated sensors and will be capable of obtaining even higher resolution. The full suite of sensors is designed to provide near-continuous information on a wide range of variables (albedo; snow and ice cover; vegetation indices; surface temperature, fires, tectonic features, biophysical, and geochemical parameters – particularly for greenhouse gases; global carbon cycles; hydrological measurements, etc.). Through the long-term monitoring of the global distribution of these parameters, the fundamental basis for global change studies will be realized.

MTPE is clearly a project of vast magnitude with total program costs predicted to be more than $17 billion U.S. Canada, with the development of the MOPITT sensor and the planned launch of Radarsat, is presently a partner in MTPE but, as budgets get tighter, the continued Canadian contribution to such large-scale international programs is in jeopardy, with politicians questioning our ability to afford such participation. Given the critically important data that will be collected by MTPE, we must ask ourselves: can we afford not to participate?

Marine data acquisition

The remote-sensing systems described above will collect increasingly more detailed images of the atmosphere and the surface of both the land and the ocean. Still hidden from view, however, is the three-quarters of the Earth's surface that lies beneath the oceans. In parallel with the recent advancements in space-borne remote sensing has been the introduction of sophisticated new sonar technologies for mapping the seafloor. Evolving from the simple echo sounders developed during the Second World War, which collected sparsely spaced, relatively inaccurate bathymetric soundings, modern multibeam "swath" sonars can now produce highly accurate soundings across swath widths as great as 7.5 times the water depth. The most sophisticated of these systems can also collect acoustic backscatter information producing detailed acoustic images of the seafloor. The dense bathymetric data and detailed acoustic imagery produced by these systems, along with the ultra-precise positioning that can be achieved with new navigation techniques (to within centimetres), can be combined with sophisticated visualization software to produce representations of the seafloor that are on par with the terrestrial images produced by satellite remote sensing systems. Future developments of these systems will see increases in both resolution and aerial coverage. Most importantly, future systems will incorporate analytical techniques for the real-time classification of seafloor materials (analogous to space-borne thematic mappers) and for the direct identification of both species and biomass of fish and plankton. Although Canada has not been involved with the manufacture of these sonar systems, the Canadian Hydrographic Service has been at the forefront of developing advanced applications and platforms for their deployment. In addition, Canadian scientists have been world leaders in developing processing and visualization software for a range of ocean-mapping applications.

Along with the development of sophisticated sonar systems has been the evolution of a range of marine instrumentation providing increasingly more accurate measurements of biological, geochemical, and geophysical parameters. In particular, new generations of flourometers, transmissometers, and spectroradiometers are being developed to measure phytoplankton populations, turbidity, and light characteristics in the ocean (and thus provide ground truth for many space-borne sensors). Improved seismic sources and multichannel receivers will increase both the depth of subsurface profiling and the resolution possible; and tomographic techniques will be used to provide an increasingly more detailed picture of crustal and oceanic structure and to monitor global warming.

Whereas the techniques described above provide snapshot measurements of oceanographic parameters, the importance of time-series has now been realized, and the technology needed to collect these data sets being designed. Moored sensors and repeat cruises will monitor long-term fluxes and "seafloor observatories," areas of the seafloor where repeated intensive observations are made, are being developed. Canadians have been active participants in an observatory established on the Juan de Fuca Ridge where fluid circulation and metallogenesis are being studied through repeated visits to permanently instrumented Ocean Drilling Program boreholes. Work on seafloor observatories is best done from submersibles or remotely operated vehicles (ROVs). These platforms, when combined with new sensors and "telepresence" capabilities, will play an increasingly active role in deep-sea research and the exploration and exploitation of ocean resources. Canadian industry had been a world leader in the development of submersibles and ROVs, but the recent cutbacks in deep-sea research activities have left the Canadian submersibles and ROV's virtually unsupported.

The status of Canadian submersibles and ROVs is characteristic of a much more serious problem that is pervading Canadian oceanographic research – the rapidly decreasing availability of oceanographic research vessels. Despite Canada's obvious position as a Maritime nation, with an offshore that represents more than 30% of its territory, the Canadian oceanographic community, particularly the academic community, is finding itself with very limited access to research vessels, particularly for deep-sea research. Most of the ship's available to the Canadian oceanographic community are run by the Department of Fisheries and Oceans (DFO) which has retired a number of vessels as a consequence of a steady stream of budget cuts. While negotiations are currently underway to try to rationalize the use and availability of research vessels amongst DFO, the Coast Guard, the Canadian Navy, and NSERC has recently allocated limited funds to pay for shiptime use, for the most part the future of Canadian deep-sea research is bleak.

Land-based data acquisition

Traditional geologic field work has offered a two-dimensional view of the Earth's surface and an occasional two-dimensional glimpse of the near-subsurface through outcrops. The new frontier in geological mapping is the third dimension – depth (Price, 1994). Building on techniques originally developed for petroleum exploration, and prompted by a need to push mineral exploration to depths beyond 500 m, future exploration efforts will see multidisciplinary studies involving seismic reflection and refraction, gravity, and magnetics. The motivation is strong, as Canada is more reliant on its geological resources than any other developed country in the world; resource industries contribute almost $25 billion per year to Canada's positive trade balance (45% of total exports). Epitomizing this sort of effort has been the LITHOPROBE program, a highly successful collaborative project designed to answer fundamental questions on the nature and evolution of the outer shell of the Earth using a range of techniques, but focusing on developing state-of-the-art approaches to deep seismic profiling and processing. A project of this magnitude (approx. $50 M to date) could not easily have been done by an individual organization. LITHOPROBE has drawn together scientists from all sectors of the Canadian earth-science community and has produced results and technologies that, while initially designed for basic research goals, have found quick acceptance and usefulness in the industrial sector. The success of this project suggests that, when well planned and organized, large university-industry-government collaborative projects can make significant contributions to all sectors in a very cost effective manner.

There has also been a rapid development of drilling and borehole-logging techniques that are resulting in the greatly increased efficiency in both exploration and recovery. In particular, horizontal drilling has enabled the "mining" of hydrocarbon deposits. Most down-hole tools have been designed to evaluate siliclastic rocks in which porosity and fluid type are the critical parameters. New tools need to be developed that are capable of detailed resolution of permeability for the proper evaluation of carbonate reservoirs. Formation evaluation in carbonate and fractured reservoirs will be of critical importance in down-hole tool development. These developments will be required if exploration is to be successful in the Paleozoic carbonate-dominated portions of most basins where a significant amount of the remaining reservoirs are thought to occur.

Laboratory studies

The final area for data acquisition is in the laboratory. Here, developments in analytical tools (x-ray absorption spectroscopy and diffraction) will provide new insights into the structure and reactivity of mineral surfaces, and high pressure facilities will provide critically needed ground-truth data for deeply probing geophysical studies. Most important will be developments in stable-isotope and trace-element analytical techniques. In the coming decades, we will see detection limits of parts per trillion and spatial resolutions of a few microns as commonplace. Isotopic age determinations are revolutionizing our ability to date the geologic record. New dating techniques (which are allowing the determination of isotopic ratios to the precision of better than 0.002% in samples as small as a billionth of a gram) are adding a fourth dimension – time – to our geological and geophysical modelling efforts. Advanced dating techniques provide greater precision for sequence stratigraphy, the dating of mineralization events, and for environmental and global change studies. They also provide one of the only means of extracting temporal information from the first four-fifths of the Earth's history, The Precambrian, which lacks adequate fossils for precise biostratigraphy. Canada has been a world leader in the development of Accelerator Mass Spectrometry (the ISOTRACE laboratory at the University of Toronto), and the GSC has recently acquired a Sensitive High Resolution Ion Microprobe (SHRIMP). If support for these facilities can be maintained, Canada can remain competitive in the realm of precise dating technology. Precise, rapid, and relatively inexpensive analytical techniques, for example inductively coupled plasma mass spectrometry (ICP-MS), have the power to revolutionize our understanding of the distribution of low-level elements throughout the crust. Such analyses are also facilitating the rapid expansion of geochemical techniques in mineral exploration. A more detailed discussion of the Canadian perspective on the future of analytical facilities can be found in the NSERC Allocation Document (Appendix 1).

4 (b) Data processing and manipulation

The newly evolving technologies described above share a common characteristic – they all generate massive amounts of data. For example, a satellite-based SAR imager with 30-m resolution produces data at a rate of about 105 megabits per second. Even with subsampling and storage of only important scenes, many satellite imaging systems produce as much as 3 to 4 gigabits of data per day. A typical shallow-water swath sonar survey can generate hundreds of megabits of data per day, as can multichannel seismic surveys. We are, in fact, being inundated with data and we must look to other advances in technology to find the means to manage, process, and analyze these vast amounts of information. We will briefly explore two approaches to this problem – GIS systems and supercomputers – both of which will play increasingly important roles in the future of geoscience.

Geographical Information Systems

A Geographical Information System (GIS) is a computer-based system which can deal with virtually any type of information about features that can be referenced by geographical location. Such systems can handle both information about the location and the attributes of the data, and thus they provide, in addition to mapping capabilities, a relational database capability. This combination of capabilities provides the ability to spatially interrelate many types of information within a geographic frame of reference and to explore complex geospatial relationships in a highly organized and quantitative way. Geographic Information Systems (GIS) have, in essence, automated the map-making process, and in doing so, have added much of the additional functionality of database systems, statistical packages, and graphic display. A typical GIS will allow for the input of vast amounts of multidimensional data in a series of layers, each tied through a common geospatial reference. Thus one can accumulate information on surface lithology, subsurface characteristics, vegetation patterns, demographics, ground water properties, etc., all within a geospatial framework. These data can be combined or sorted in any manner desired and the complex interrelationships of the data revealed in a series of easily generated digital maps. This is exactly the type of analysis that earth scientists have been doing for years, but now it can be done quickly and precisely, in a matter of minutes (even in real-time in the field).

Future developments in GIS systems will involve the extension of relational database capabilities to "object-oriented" databases. In an object-oriented system, the nature of the features included in the database is no longer constrained to ASCII or floating point data lists. Such systems provide much greater flexibility and the ability to work in multi-dimensional spaces. In addition, future systems will become fully integrated with complex 3-D visualization (and perhaps virtual reality) capabilities. The price one pays for these advances is computational complexity, but these problems will be resolved as computer processing powers also increases. Canada can lay claim to the development of the first GIS systems and has maintained an active research program in this field. Because of their applicability to a wide range of tasks, GIS systems will be found in wide use and thus will grow relatively inexpensive. In the next few years GIS systems will become as commonly used by earth scientists as word processors are today; the key will be to make sure that our next generation of earth scientists is fully aware of their capabilities and trained in their use.

Supercomputing capabilities

The ultimate goal of much of our earth-science research is to gain enough knowledge about the Earth System to be able to predict its behavior in various circumstances and situations, in other words to produce viable models of the complex inter-workings. As quantitative models of earth processes are developed, they increasingly incorporate more and more components of the Earth System, with traditional subdiscipline boundaries collapsing. Global Circulation Models have begun to incorporate cloud physics and atmospheric chemistry; coupled ocean-atmosphere models are being developed which also include biospheric processes. The fundamental limitation of these models is computer speed; numerous simplifying assumptions (e.g., homogeneity, coarse spatial and temporal scales) are made to allow for computational viability.

Future models will involve simulations with more realistic inputs of atmospheric, hydrospheric, cryospheric, and biospheric components of the system (as well as their inter-relations) with improved spatial resolution and longer time integrations. Whereas improvements in modelling methodology will inevitably come along (e.g., the implementation of unstructured, multigrid, finite-element methods), it will be technological advances in computer capabilities that will probably result in the biggest advances in modelling. The increase in computational power needed is not insignificant – finite-element methods that deal with volumes work on the cube of the number of elements. Thus to increase the resolution of a model by ten fold requires a 1000-fold increase in computing power. Nonetheless computing power is increasing at a staggering rate with computing power per dollar doubling approximately every 1.5 to 2 years (i.e., a 1000-fold increase over 2 decades).

We will see multiple paths followed in computer acquisitions for geoscience research. Many laboratories will have large numbers of networked workstations capable of handling database and GIS issues. Those interested in more simplified models and complex 3-D visualization will need access to the next level of processors (about 200 Megaflop machines). Finally, those on the cutting edge of coupled ocean-atmosphere-hydrosphere Global Circulation Models will need access to the largest massively parallel machines. Today these are Gigaflop machines but, within a few years, machines generally should be available with Teraflop capabilities (one trillion floating point operations per second). If Canada is to play a role in this critical modelling research, the Canadian scientific community must have access to such machines.

Interpretation of data

The future will present us with massive amounts of data, but, with supercomputers and GIS systems (and their associated database management systems), we should have the means to process and analyze these data. We now explore one of the technologies that will aid us in the interpretation of these data. Our interpretive skills are inextricably linked to our experiences, many of which are visual. Thus the ability to visualize data inter-relationships can often greatly facilitate our understanding of complex processes or phenomena. This is particularly true in the earth sciences in which many of our insights have been based on observations and field relationships. In the last few years an array of sophisticated graphics and visualization applications have become available and fairly easy to use. Of particular interest to the Earth System scientist is a new generation of visualization applications that permit interactive explorations of complex multiparameter datasets in a natural and intuitive manner. When applied to topographic or bathymetric data these tools allow for the interactive exploration (often in stereo – a "virtual environment") of geospatial data (i.e., one can explore a 3-D ridge crest and see sediment type or biological patterns draped onto the surface). In the exploration sector, high-speed workstations integrating geologic, seismic, and other data sets, coupled with state-of-the art graphics, are beginning to present integrated 3-D images of the subsurface.

Future developments in this field will involve greater processing speed to allow for the handling of larger data sets in more a more efficient manner. Systems will become more portable allowing for interactive 3-D visualization in real-time or in the field (e.g., real-time 3-D display of a satellite image while field geologists are collecting data on the ground). Eventually the boundaries between the GIS and the visualization software will collapse, as will those between databases (see below). The earth scientist will have the ability to incorporate and update data sets from around the world, compare them to the output of various models, and visualize the results in a realistic virtual environment. Canadian scientists and engineers have made significant contributions to the interactive exploration of large-volume datasets but in order to maintain these activities, they must continue to have access to state-of-the-art graphics hardware.

Dissemination of data

It is clear, we hope, that the magnitude of the problems facing the geoscience community is such that progress will depend on collaborative efforts amongst multidisciplinary teams of researchers distributed around the globe. Facilitation of this process will require the ability to explore, retrieve, and supply data to databases residing world-wide on the Internet. With the growing access of the global community to the Internet we are seeing the development of the concept of distributed databases. Through the use of the World Wide Web, data sets on a particular topic (e.g., multibeam sonar data sets of ocean ridge crests) that reside on computers all around the world can be accessed with the stroke of a few keys from any computer on the Web.

Future developments will see the real-time transmission of massive data sets from point of acquisition to distributed data bases (this is already happening to a minor degree in the offshore petroleum industry). Modellers will be able to instantly update their verification data sets and interpreters to incorporate the latest information. Further down the road, we can certainly envision teams of researchers from around the world sharing a virtual environment – modellers all working together from their respective bases, or field scientists exploring real data together from their homes – a virtual field trip!

Coupled with these real-time data dissemination technologies will be electronic distribution of our more traditional mode of communication – journals, reports, core photos, thin sections etc. (either via CD-ROM or over the network). The increased efficiency and cost effectiveness of this mode of information transfer will be phenomenal, though unquestionably, issues of copyright and publication fees will need to be resolved.

4 (c) Discussion

This brief and certainly less than comprehensive speculation about what the future of geoscience technology may hold has several common themes. On the positive side, the potential of the new technologies to facilitate our goal of gaining a more complete understanding of the complex earth system is huge. On the negative side, however, many of these technologies will require very large commitments of research dollars. How can we reconcile these new technologies in a time of severe across-the-board cuts to research spending? The key will be in approaching these technological developments in the same way that we will approach earth system science – by sharing the burden in collaboration with the international community. We cannot, however, merely join these international research programs and reap their benefits. We must be able to come to the table with something to offer. Canada must recognize its strengths and provide sufficient support to ensure that Canadian expertise will be actively sought in the context of major international programs. If we can do this, we can then leverage our expenditures by gaining access to what the international community can provide.

Finally, we must remember that technology will never be an answer unto itself.

> *"The effectiveness of these new approaches is unlikely to be limited by technology. Rather, there is evidence that conceptual geological thinking will limit progress because geoscientists are becoming more reliant on the power of computers to produce spectacular geoscientific images and geological models, and are paying less attention to field geology and the importance of scientific intuition in the development of new geoscientific concepts. Geographical information systems offer a means of meeting the challenge but care must be taken to ensure those using these tools have a geoscientific background that is sufficiently strong to take full advantage of the technology." (Williams, N., 1994)*