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LITHOPROBE Workshop

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See table of contents

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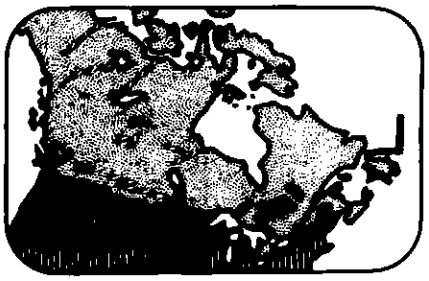

Lithoprobe Workshop

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LITHOPROBE is Canada's national project to study the nature and origin of the lithosphere, particularly the deeper parts of the continental lithosphere (CANDEL, Geoscience Canada, 1981, p. 117-125). Under the auspices of the LITHOPROBE Steering Committee (Chairman J.O. Wheeler, Geological Survey of Canada; as of March, 1984, Chairman – G.D. Garland, University of Toronto), about one hundred earth scientists from across the nation gathered at the University of Toronto, March 10-12, 1984. The purpose was to learn of lithospheric studies in Britain, West Germany, France and the U.S., and to informally assimilate, assess, debate and sharpen Canadian proposals being presented to the LITHOPROBE Steering Committee.

Plenary or full sessions included reports from abroad, proposed Canadian transects, deep crustal drilling, and workshop reports; smaller simultaneous sessions involved regional workshops and geophysically-oriented workshops. Phase one of LITHOPROBE is underway now (Clowes, in press, *Geoscience Canada*) through limited funding of about $1.2 million from NSERC and EMR; proposals and ideas now in the works, the subject of the Toronto meeting, are regarded as phase two and await funding on the order of $7 million per year for a five-year period. Even though phase two funding is not assured, a keen sense of curiosity, excitement, enthusiasm and comradeship characterized the meeting and proposals.

Overviews

The British Deep Geology Program, eloquently outlined by E. Ron Oxburgh, has two parts: deep seismic reflection, and fluid processes. Because costs at sea are only one tenth to one twentieth that of land-based surveys, all seismic reflection lines to date have been run at sea. About 1600 km were surveyed in 1983, with smaller line lengths surveyed since the program began in 1981. There is little structure observed to about six seconds, but below there are abundant discontinuous reflectors and two types of prominent inclined reflectors – those which start at the surface and go to the Moho, and those which start at depth and cut the Moho (thrusts? imbrications of "basement"?). All longer lines around Britain show these features. A disadvantage with sea-based lines is that reflectors can rarely be tied or traced to surface geology. Emphasis on fluid studies is to assess what is rising from the mantle and what is sinking from above, by the use of isotopes (^{3}He, etc.) and other techniques. Oxburgh noted that the program provided an excellent vehicle for coordinating studies of Britain; that the principle of extensive consultation beforehand, with only one or two people making the final technical decisions is working well; that small "piggy back" projects must not be shut out, but should be encouraged and funded; and that the 330,000 pounds a year spent on this work represents essentially a channelling of existing funds for earth science research but does not include subsidies from industry and universities.

West German lithoprobe-type activities, discussed by H.J. Behr, led to the discovery that the continental crust under much of Germany is relatively thin, only 20-30 km, and can be divided into three main crustal blocks, each with a specific geophysical signature. Reflection seismic work shows that all blocks have discontinuous reflectors within, and are bounded by more continuous reflectors which look surprisingly like overthrusts between the main blocks. Current plans are to drill through one of the boundaries between these blocks in south Germany, beginning in 1986. Present studies are aimed at locating the best place to drill a 2.5 km hole, with the possibility of extending it to a depth of 10 km.

Claude Jaupart of France reported that two years of seismic reflection profiling in the Paris Basin identified continuous reflectors at depth, some of which cut the Moho, forming step-like features (more overthrusts?). Additional reflection work is planned for the Massif Central, Aquitaine Basin, Pyrenees and Alps, and it is hoped that this will be followed up with a number of widely spaced shallow drill holes to depths of about one km. But the highlight of Jaupart's fine presentation was the exciting French-Chinese collaborative work carried out in Tibet and the northern Himalayas (*Nature* v. 307, no. 5946, 5-11 January 1984, p. 17-36). Seismic profiles identify a complex Moho topography, apparently resulting from multiple thrusting and large-scale, strike-slip faulting across a broad zone of suturing between the Indian and Eurasian plates. Once again, reflectors cut and displace the Moho, but in this case such complexities are mimicked by surface geology. Indeed, Jaupart's main message, echoed by other speakers, was that there may be much more evidence of horizontal transport within continents than any of us have expected. Jaupart speaks of continental mosaics made up of blocks bounded horizontally by sutures and zones of large lateral displacements, and vertically by interfingering slices of crust and mantle – an appealing view which is coming into prominence based on seismic reflection profiling to date.

Jack Oliver, Mr. COCORP U.S.A., brought us the American view. Very persuasively, Oliver sees the next great frontier as the geology of the continents, especially apart from or beneath the sedimentary basins. Deep seismic reflection profiling

applied to major tectonic problems outside petroleum basins was pioneered by Oliver and his colleagues. It has been remarkably successful because deep reflectors can be traced upward into surface features, such as has been done in Wyoming and the southern Appalachians, or can be interpreted to represent significant lithologic/structural changes, etc. About 5500 km of COCORP lines have been completed in the U.S.: presently a single crew works year-round at a cost of $3 million per year. The main finding, once again, is the presence of widespread, strong reflectors of variable continuity. A key aspect of the COCORP approach is that although seismic lines have been located to shed light on specific geologic problems, these traverses have always been considered as parts of a continent-wide study. Major problems revealed by the COCORP work include fluids and their influence on the brittle-ductile transition (where now? where in the past?) and where and what is the continental Moho (compositional or phase change), both now and in the past.

For Canada, Bill Fyfe emphasized the enormous potential we have for geoscience studies of the third dimension, with many kinds of continental crust and continental margins, three major Phanerozoic orogenic belts, and high quality surface geology. Despite the presence of widespread reflectors at depth, we really know very little about what is below approximately 5 km and, accordingly, Fyfe feels that our basic approach should be to throw every technique available at the third dimension. But not everywhere. What do we have that is unique? Fyfe suggested the Archean granite-greenstone problem, select areas of the Precambrian, such as the Kapuskasing Transect (noted below), and problems such as the presence (or absence?) of a subducting plate beneath Vancouver Island. In all this work, Fyfe stressed that fluids and fluid-rock interactions should be a prime consideration.

Canadian Transects

Ten proposed transects were presented for discussion. These ranged from detailed plans built on extensive studies already accomplished or underway through NSERC strategic grant or other funding and involving a large segment of the earth science community, to ideas for the future that are just beginning to take shape. When phase two of LITHOPROBE is funded, it is clear that proposals in the first category – broadly based, well-reasoned, and involving very wide support and interest – will be supported first. Later in the meeting the seismic workshop people, drawing on external reviews, recognized four transects as fitting this category. In no particular order, these are Kapuskasing, Abitibi, Southern Cordillera and Lithoprobe East (Newfoundland onshore/offshore). All of these are currently underway in some form, with two, Kapuskasing and Vancouver Island, currently receiving phase one LITHOPROBE support (Clowes, in press, *Geoscience Canada*).

Kapuskasing Transect is a proposal to continue study of a major Archean uplifted mass of high-grade gneisses that interrupts the continuity of the adjacent, and probably formerly continuous, Wawa and Abitibi greenstone belts. Structural interpretations support the concept that the Kapuskasing uplift exposes about two thirds of the thickness of the Superior Province, and thus it is of great interest to map the subsurface geometry and extent of this feature. Interested and active investigators number more than thirty-five and cover eight disciplines, including geology, geochronology, geochemistry, seismology, heat-flow and geomagnetism. The organization, oral presentation and written handout for this project could well serve as a model for those who contemplate seeking phase two LITHOPROBE support. In addition to being well conceived, the project is dynamic, exciting and innovative – an ideal research project and, interestingly enough, an outgrowth of a Queen's University Ph.D. thesis project by John Percival, now of the Geological Survey of Canada (and a major contributor to the planned transect).

The Abitibi Transect proposes to continue study of this, the largest greenstone belt in the world, particularly to shed light on the extent and nature of the belt at depth and the Cadillac shear zone within it. As noted by one participant, the Abitibi belt is the Canadian Shield equivalent of the Western Canada sedimentary basin. An NSERC strategic grant currently is supporting ten investigators from five organizations, with the general objective of geophysically identifying favourable zones for base and precious metal mineralization. This project is well underway, and although it stands on its own, it may be possible to extend it to include Grenville Front-Sudbury Basin relationships, the subject of a transect proposal at the conceptual stage of development.

The Southern Canadian Cordillera is the best known and most accessible part of the youngest mountain belt in Canada and is the focus of a series of proposed transects to identify the deep structure of displaced or suspect terranes, the nature of terrane boundaries, the westward extent of shield basement and a whole host of related problems posed by ten main investigators from five organizations. As noted by Clowes (1984), this project is also underway and offers great scope for new global concepts in continental accretion and the three-dimensional geometry of displaced terranes, to mention but two.

The Appalachian Orogen of Newfoundland, an area representing a complete Wilson cycle of ocean opening and closing, is proposed for transect study by a large group of investigators from maritime universities and EMR's Atlantic Geoscience Centre. Central questions include, What is the nature of the boundaries between the Humber, Dunnage, Gander and Avalon Zones? How much displacement affects the Dunnage Zone? What is the crustal structure beneath the Carboniferous basins, and of the Mesozoic rifted margins? And even, Are the Humber, Dunnage, Gander and Avalon Zones merely thin-skinned surface features with no continuity at depth (yes, Hank Williams posed this question)? We don't know the answers!

Other proposed transects appear to be of lesser priority at present because they lack key geological information, or wide support and/or involvement of the earth science community, or involve problems presently perceived to be of lesser scientific or economic significance than those noted above. Two transects were considered by the seismic workshop group to be at an early stage of development. One of these is a study of the Churchill-Superior Boundary zone near Thompson, Manitoba: is the Pikwitonei gneiss belt the upturned edge of the Archean Superior craton, and what is its relation to the Thompson nickel belt? A second early stage transect involves study of the nature and behaviour of the underlying craton in the evolution of the Phanerozoic-aged Williston Basin. Both proposals have merit, and undoubtedly will figure in future LITHOPROBE studies. Transect proposals suggested to be at a conceptual stage of development include northern Cordilleran transects along the Dempster and Canol roads, both interesting because of the great variety of geologic elements they traverse, but both needing more study; and the Athabasca Axis, a prominent low gravity linear feature extending from southern Alberta to Baker Lake (width? extent at depth? origin? economic significance?). Proponents of these transects also see them as considerations for the future.

Research Drilling

Jim Hall, an organizer and active participant in the Cyprus ophiolite study which utilizes diamond drilling and currently involves 120 scientists from 8 countries, shared his ideas on drilling with the group. Is drilling necessary, advantageous or unnecessary? What are the geological objectives, and can they be satisfied by means other than drilling? For example, is material needed that has not suffered surface effects? Or, are drill data needed

to reconstruct how the crust accumulated, deformed, etc. at depth? A question needing much thought is, how specific does the information obtained by drilling need to be? The value of drilling may depend on such factors as lateral variability, tectonic setting, etc., not obtainable on surface. Hall strongly advises that a project management team be set up, with a project director, site manager and scientific team, otherwise chaos can be expected on scientific, financial, sample shipment and analysis, and other fronts. Diamond drilling is feasible to 2 km easily, to 4 km with difficulty, and is well-suited to coring; oil field drilling is suited to deeper depths, but not well suited to coring. Drilling will be involved in more advanced stages of LITHOPROBE transects, and it is clear that the Cyprus team can be of great help in this.

Workshop Reports

Following individual, simultaneous sessions, each workshop leader reported to the reassembled group. The shield and cratonic basins group, led by Paul Hoffman, identified the following priorities: 1) nature of the lower crust (oblique exposures such as the Kapuskasing uplift expose approximately two thirds of the crust: What lies below?); 2) how much crustal shortening took place in zones of convergence (can we see asymmetrical steps in the Moho, "frozen in" since Precambrian time?); 3) how extensive is Archean crust beneath the widespread 1.8 Ga orogens? 4) what is the subsurface configuration and origin of Archean greenstone belts (gravitational collapse structures or asymmetrical because they are caught in convergent zones or bounded by diapiric granites?); 5) what can be learned about the development of intracratonic basins (does structure of the Moho parallel basin shape? Is there anything anomalous about the upper part of the crust beneath a cratonic basin?)

The Cordilleran group, chaired by Jim Monger, agreed that priorities are 1) Southern Canadian Cordillera; 2) Dempster Highway region, Yukon; 3) Canol Road, Yukon. Northwest Territories. The southern Cordillera can be viewed as a laboratory for study of the evolution of continental crust. One problem involves linking the various short transects, and the question of transect(s) in central British Columbia is not yet resolved (who, where and when). This will depend partly on results in the eastern Cordillera and Vancouver Island-Coast Mountains. There is an excellent opportunity forthcoming for co-operation with U.S. workers, as a COCORP line is planned for early completion in Oregon and the Cascades.

Hank Williams led the LITHOPROBE East discussions: the group agreed that Vibroseis (seismic reflection) on land is a first priority. The key question is how deep surface geology goes; most other questions that can be asked are secondary to this. The advantage of Newfoundland is that the geology is now well known, and the Taconic geology has not been obscured by deformation and sedimentation associated with younger periods of tectonism, as is the case in the southern Appalachians.

The seismic workshop organized by Ernie Kanasewich, drawing on external reviews, arrived at the tentative ranking of transect proposals noted above. The workshop people also observed that there will be a strong need for a national data processing centre, particularly for the seismic reflection work. Although Vibroseis is the favoured seismic reflection technique, there is a need for research on other techniques, for example, air gun on land, or shear-wave generating sources -- can these be perfected? Ian Gough's group discussed electrical and electromagnetic methods. Electrical conductivity work using natural (magnetotelluric) fields or controlled source methods are good indicators of fluids and partial melts, and should form part of most transects. Geoelectric profiling will be especially important in shield terrane. Ancillary techniques were examined by a group led by John Wheeler, who observed that the kinds of projects discussed are at once geological and geophysical. The key to real progress lies in melding of diverse fields and workers, and this is now happening increasingly.

Impressions

What are some of the central questions arising from the workshop? Perhaps the foremost one is, What's down there, or, how deep does surface geology go? What is the significance of the ubiquitous reflectors identified by high resolution, multichannel seismic reflection work (COCORP, COCRUST, etc.)? It is well to remember, as Fred Cook pointed out, that reflectors are geometric elements, not necessarily governed by lithology, metamorphic grade, fluid content, etc. Are we seeing evidence of horizontal transport at depth, as some believe? How has the lithosphere behaved over time? For example, homogeneous stretching in vogue by sedimentary basin modellers will provide a very different subsidence history from multiple necking or boundinage of the lithosphere.

Where do we go from here? Priority decisions already have been made by LITHOPROBE site selection committees and the Steering Committee. It is likely that all proposals have been enhanced by the interchange that took place at the Toronto workshop. Phase two proposals will require high level political commitment and approval: part of the purpose of the meeting was to provide a format for discussion and focusing of proposals. It would have been advantageous to have had more than the eight or so industry people present. More than twice as many industry people were invited, but many had other commitments. In future, it will be essential to enlist oil and mining industry help on matters such as seismic data processing and diamond drilling technology. Students were almost absent from this meeting. As an academic, I am struck by the marvellous opportunity we have to involve M.Sc. and Ph.D. thesis research in all phases of LITHOPROBE, and perhaps the teaching and learning aspects of LITHOPROBE studies should be more prominent in overtures to government and granting agencies. What a magnificent means for developing young minds and conducting world-class research at minimal cost!

Canada is blessed with an immense variety of geologic terranes, and therefore a unique opportunity in the field of third dimensional geology. Canada is known for its excellence in and a strong commitment to regional geology and geophysics, and for developing highly successful petroleum and metallic mineral exploration technology. A strong sense of the challenge before us pervaded the workshop: Can we now capitalize on this superb opportunity?