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Lithoprobe Phase IV: Multidisciplinary Studies of the Evolution of a Continent — A Progress Report

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Article abstract

LiTHOPROBE is Canada's major national geoscience research project which combines multidisciplinary studies of the Canadian landmass and surrounding off-shore margins to determine how the northern North American continent has formed over geological time from 4000 million years ago to the present. The project has been instrumental in establishing a new era of collaboration among geologists, geochemists and geophysicists from universities, government and industry. It has brought new and exciting results to the attention of students, politicians, the media and the general public through its public outreach-communications program. But first and fore-most, Lithoprobe is a scientific project. This article highlights the accomplishments of the scientific programs from all transects (study areas) during the period 1993-1996 and the subsequent enhancement of our understanding of the tectonic development of our continent.

Articles

LITHOPROBE Phase IV: Multidisciplinary Studies of the Evolution of a Continent — A Progress Report

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SUMMARY

LITHOPROBE is Canada's major national geoscience research project which combines multidisciplinary studies of the Canadian landmass and surrounding offshore margins to determine how the northern North American continent has formed over geological time from 4000 million years ago to the present. The project has been instrumental in establishing a new era of collaboration among geologists, geochemists and geophysicists from universities, government and industry. It has brought new and exciting results to the attention of students, politicians, the media and the general public through its public outreach-communications program. But first and foremost, LITHOPROBE is a scientific project. This article highlights the accomplishments of the scientific programs from all transects (study areas) during the period 1993-1996 and the subsequent enhancement of our understanding of the tectonic development of our continent.

RÉSUMÉ

LITHOPROBE est le plus important programme de recherches géoscientifiques du Canada. Il s'agit de recherches multidisciplinaires qui s'intéressent à la suite des événements qui ont mené à la formation de la portion septentrionnale du continent nord-américain au cours des dernières 4 000 millions d'années. Les projets de recherches qu'il comprend couvrent toutes les régions habitées du Canada sans oublier ses marges continentales offshores. Ce programme a joué un rôle clé dans l'établissement d'une nouvelle ère de collaboration entre les géologues, les géochimistes et les géophysiciens des universités, des services gouvernementaux et du secteur privé de l'industrie minérale. De plus, grâce à son programme de diffusion des résultats obtenus, les étudiants, les politiciens, les médias ainsi que le grand public ont pu prendre connaissance de données nouvelles fort intéressantes. Cela dit, LITHOPROBE est d'abord et avant tout un programme de recherches scientifiques. Le présent article souligne les principales réalisations des projets recherches menées sur tous les transects (régions étudiées) de 1993 à 1996 et montre comment les résultats obtenus ont amélioré notre compréhension des événements tectoniques qui ont modelé notre continent.

INTRODUCTION

Canada's vast geographic expanse and its diverse geological history provide an exceptional opportunity to investigate the evolution of the northern North American continent. LITHOPROBE, Canada's national, collaborative, multidisciplinary geoscience project, is responding to that opportunity. Its scientific program integrates modern geophysical, geological and geochemical concepts, methods and technology to extend to depth, and back in time, knowledge of the lithosphere in various key transects or study areas. Ten transects form the scientific bases of the project (Fig. 1). These transects extend across the country from Vancouver Island to Newfoundland and from the US border to the Arctic tundra, and represent 4000 million years of Earth history. The research is spearheaded by seismic reflection surveys, but the multidisciplinary approach is proving to be the foundation of comprehensive interpretations.

LITHOPROBE began in 1984-1985 with a preliminary scientific program on Vancouver Island and in the Kapuskasing region of Ontario funded by the Natural Sciences and Engineering Research Council (NSERC) Canada and the Geological Survey of Canada (GSC). The GSC maintained the project until 1987-1988 when NSERC and the GSC committed to continue funding for this pioneering project. LITHOPROBE is now in its twelfth year of activity and has achieved some remarkable results, a few of which will be highlighted below. During these years, additional funding and important contributions in kind have been provided by provincial-territorial geological surveys and by the mining and petroleum industry, when LITHOPROBE activities have been in their regions of interest. The LITHOPROBE Phase V Proposal for the period 1998-2003 is being prepared currently for submission to NSERC and the GSC. Phase V will bring the project to a planned and logical conclusion.

For the Canadian earth science community, LITHOPROBE has been more than a successful scientific project. It has spawned an atmosphere of scientific co-operation among geologists, geophysicists and geochemists who are working and learning together, thereby enhancing results beyond those that could be achieved through one subdiscipline. It has successfully fostered an unprecedented degree of co-operation among earth scientists in universities, federal and provincial geological surveys, and the mining and petroleum industries. It has demonstrated the applicability of the high-resolution seismic reflection technique to mineral exploration problems, particularly in mining regions where expensive infrastructure is already in place. It has pioneered the development of new instrumentation, particularly through efforts at the GSC, leading to technology that has been transferred to the private sector, which has sold and used the instruments nationally and internationally. It has enhanced the visibility and relevance of the earth sciences as a discipline through a co-ordinated effort of public education and media communication. It has actively involved more than 700 earth scientists, including more than 400 graduate students and research associates who have learned their specific skills in an environment of multidisciplinary collaboration. It has enhanced the international renown of Canadian earth science. LITHOPROBE has been supported by Canada and LITHOPROBE has benefited Canada.

Since LITHOPROBE is an established project approaching the final year of its five-year Phase IV program, Roger Macqueen, the newly appointed Editor of *Geoscience Canada*, asked me to prepare an article summarizing some of our recent achievements. As I had just prepared a summary of activities for the period 1993-1994 to 1995-1996 for an Annual Report to NSERC, I agreed. This article draws heavily on the NSERC annual report, which in turn draws on the many published and other results of the active scientists. It provides some selected highlights but cannot convey the extensive multidisciplinary scientific results contained in the ~400 LITHOPROBE publications which have been added to the previous ~420 publications listed in late 1992 at the time of preparation of the Phase IV Proposal (Clowes 1993). For a complete listing of publications and other information, I invite interested readers to explore our World-Wide Web site: http://www.geop.ubc.ca/Lithoprobe.

TRANSECT SCIENTIFIC ACTIVITIES 1993-1996

LITHOPROBE is foremost a scientific project and this article reflects that emphasis. Transects are discussed in the chronological order in which they have been active as part of the scientific program during Phase IV. Clowes *et al.* (1992) provide an earlier review of results prior to Phase IV. The LITHOPROBE Publication List, mentioned above, includes general LITHOPROBE articles as well as those specific to a transect. One of the outstanding general results has been the demonstration of prominent reflectivity at all depths within the crust and for crust of all geological ages (see Clowes *et al.*, 1996 for a discussion). The style and character of the reflections often indicate large-scale upper to mid-crustal brittle imbrication or lower crustal ductile flow, concepts which require revision of how we view lithospheric evolution and lead to models of processes which are consistent with the seismic images (*e.g.*, numerical modeling studies, Beaumont et al., 1994). The challenge of LITHOPROBE is to achieve new understanding of lithospheric evolution, including the origin and significance of these reflectors, through integration of geological, geophysical and geochemical studies. It is this exciting goal that has spawned the atmosphere of scientific co-operation noted above. The following highlights of results and interpretations to date for each transect provide a measure of how successfully this goal is being met.

Kapuskasing Structural Zone Transect

The Kapuskasing Structural Zone (KSZ) Transect is one of a number of transects

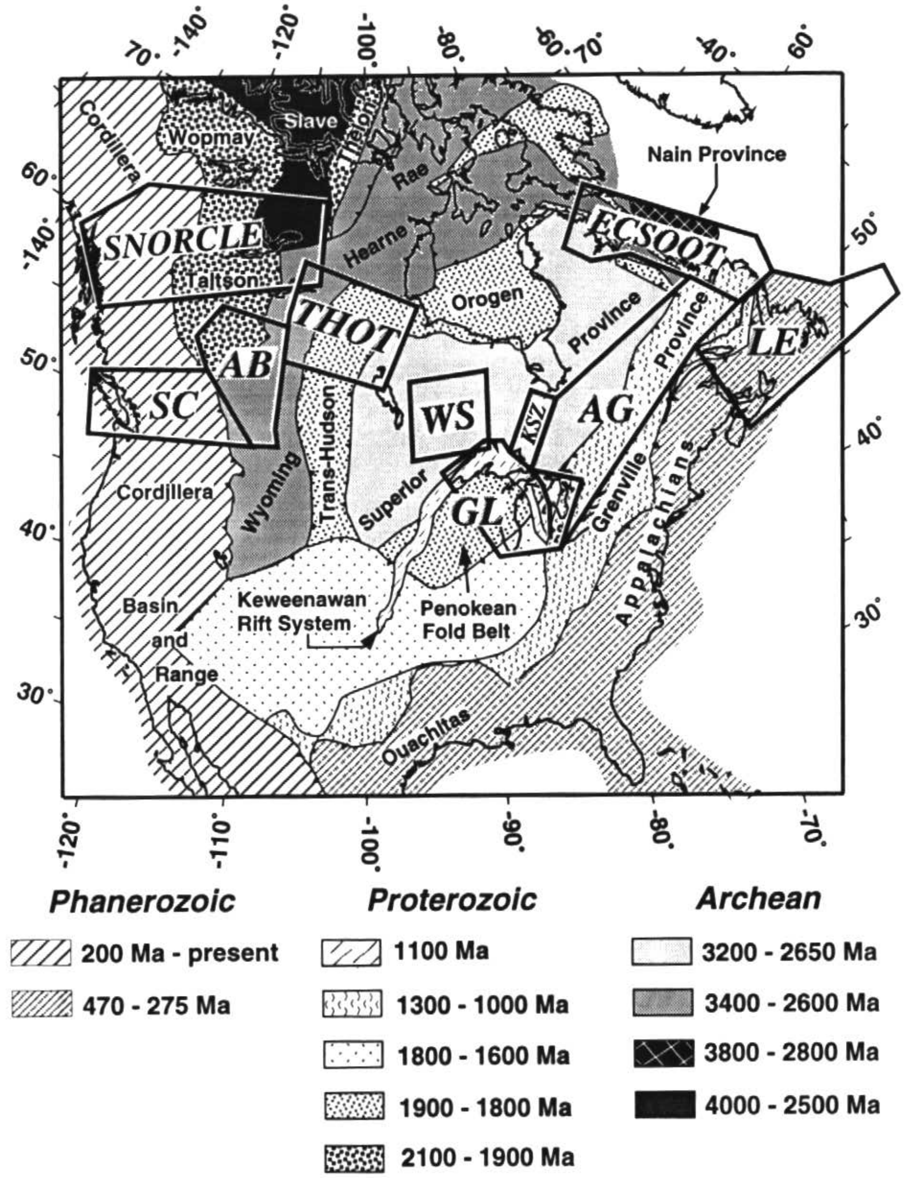

Figure 1 *Location of LITHOPROBE transects (study areas) on a simplified tectonic element map of North America. The transects are: SC - Southern Cordillera; AB - Alberta Basement; SNORCLE - Slave-Northern Cordillera Lithospheric Evolution; THOT - Trans-Hudson Orogen; WS - Western Superior; KSZ - Kapuskasing Structural Zone; GL - Great Lakes International Multidisciplinary Program on Crustal Evolution (GLIMPCE); AG - Abitibi-Grenville; LE - LITHOPROBE East; and ECSOOT - Eastern Canadian Shield Onshore-Offshore.*

which addresses a remarkable period of Archean continental growth from 2800 Ma to 2500 Ma when a large part of the North American craton, the Superior Province, formed and stabilized. Studies within the KSZ Transect also address the evolutionary history of the KSZ itself, a major uplift of deep crustal rocks now exposed at the surface and thus a "window" on the mid to lower crust. The transect scientific program culminated with the publication of a synthesis of results in the *Canadian Journal of Earth Sciences* (*CJES*; Percival, 1994). Since its recognition as a positive gravity anomaly in 1950, the KSZ has been enigmatic and interpreted in a variety of ways. LITHOPROBE results now provide one consistent interpretation, as briefly described below (from Percival and West, 1994).

Diverse geochronologic, geothermobarometric and geophysical studies provide a comprehensive 4-D (space and time) development of Archean (2750-2500 Ma) crustal evolution followed by Proterozoic (2500-1850 Ma) cooling and uplift. Supracrustal rocks of the KSZ (2750-2700 Ma) were buried by younger supracrustal rocks and intrusion of mid-crustal tonalites (2700-2660 Ma). Metamorphism began during this period and continued in response to magmatic heat and crustal collapse (2660-2625 Ma), followed by slow cooling and intermittent deformation (2625-2585 Ma). Subsequently, the Superior Province was eroded by 10 km on average, elevating Kapuskasing levels from ~30 km to ~20 km. Incipient breakup of the Superior craton (2500-2450 Ma) was recorded as new mineral growth at deep structural levels and by Matachewan dyke injection. Additional erosion of a few kilometres preceded intrusion of Kapuskasing dykes (2040 Ma) into the crustal section.

At ~1900 Ma, stresses caused by plate collisions at the Superior margin were transmitted into the interior in the form of right-lateral transpression along northeast-trending faults and northwest-over-southeast thrusting. These effects elevated Kapuskasing-level rocks from ~18 km to 3 km depths along the ~35° northwest-dipping Ivanhoe Lake fault zone, where 27 km of shortening through dominantly brittle deformation is implied (Fig. 2). Formation of a crustal root through ductile deformation accommodated shortening in the lower crust. Subsequently, northwest-dipping normal faults and a conjugate set of strike-slip faults broke the Kapuskasing structure into separate blocks with variable geometry. Isostatic rebound reduced topography on the root, producing several kilometres of uplift along steep structures not coincident with the Ivanhoe Lake fault, thereby completing the evolutionary story.

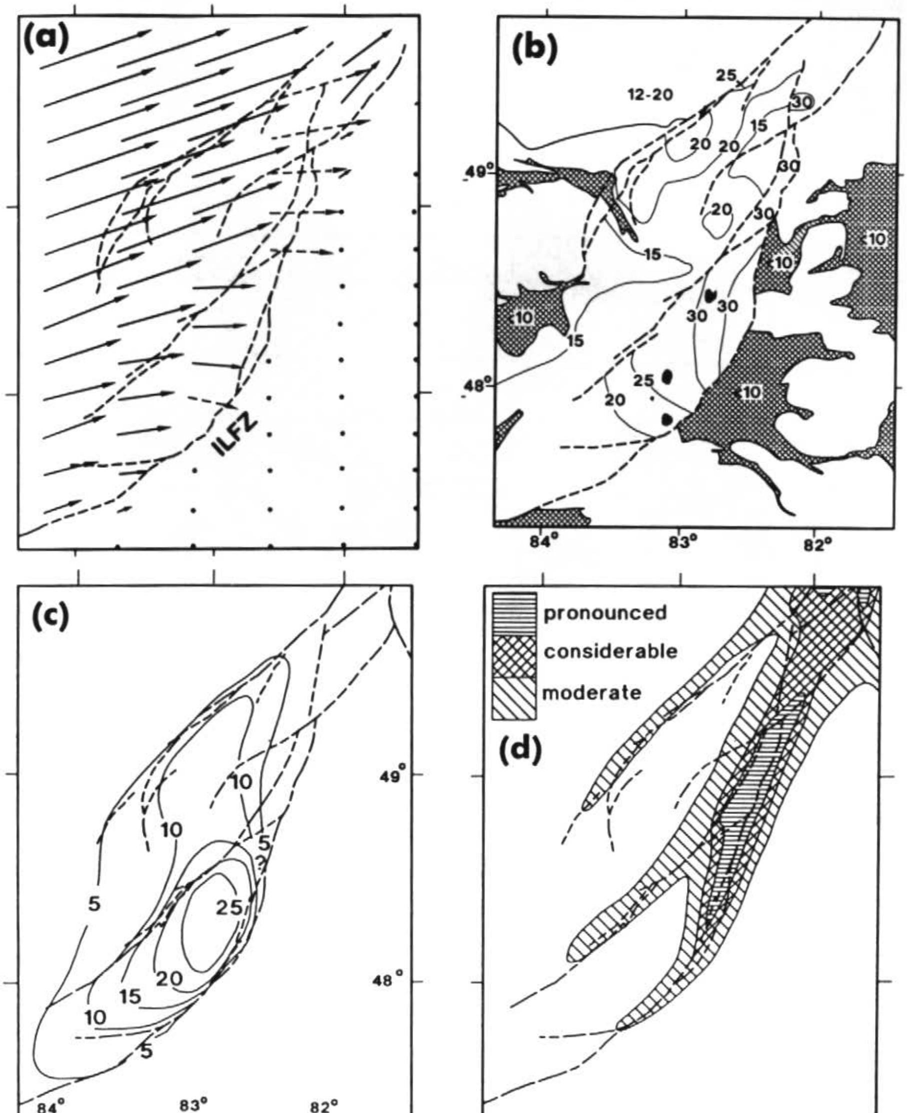

Figure 2 *Kapuskasing Structural Zone Transect. Maps showing interpreted horizontal and vertical displacements* **(a,b)** *and distribution of ductile and brittle thickening* **(c,d)** *in the Kapuskasing region. Dashed lines on each panel show bounding faults that outline the uplift structure.* **(a)** *Displacement vectors showing horizontal motion of northwestern block with respect to southeastern based on analysis of strain in the Matachewan dyke swarm. Arrow tail is pre-deformation position and head indicates present position. Dashed vectors are for material removed by erosion. ILFZ - Ivanhoe Lake fault zone.* **(b)** *Paleodepth contours (km) based on geobarometry; the map shows total amount of vertical uplift since ca. 2600 Ma.* **(c)** *Amount of ductile lower crustal thickening (km) based on erosion magnitude and refraction seismic estimate of Moho depression.* **(d)** *Qualitative estimates of brittle upper crustal thickening by thrust duplication. [Adapted from Percival and West 1994. Reprinted with permission from NRC Research Press.]*

Southern Cordillera Transect

The Canadian Cordillera is a major part of one of the great Phanerozoic mountain systems on Earth and is the birthplace of the concept of "terranes," which are now recognized as fundamental building blocks of the continent. The Southern Cordillera Transect seeks to understand the tectonic growth of western North America: how the process of lithospheric consumption is represented at the surface as continental outbuilding. The crust of southwestern Canada has grown westward by only about 500 km as a result of lithospheric accretionary processes during the past 185 m.y.

Yet during the same interval, about 13,000 km of oceanic lithosphere has been recycled into the sub-lithospheric mantle! And active research by the GSC and others continues within the present Cascadia subduction zone. While studies of the Canadian Cordillera continue both within LITHOPROBE (see SNORCLE Transect below) and beyond it, the scientific program of the Southern Cordillera Transect has been completed with the publication of a synthesis of results in *CJES* (Cook 1995a). Many new insights are contained within the series of papers, but here I will address only a few large-scale issues as discussed by Cook (1995b).

To address the issue of the small percentage of material accreted to the continental lithosphere relative to the amount available through convergence, Cook (1995b) pointed out that, as indicated by LITHOPROBE reflection data, upper and middle crustal contractional faults were probably accommodated within the lower crust by regional ductile detachment, analogous to the basal detachment at or near the basement surface beneath the thrust and fold belt. Gigantic, crustal-scale thrust sheets were tectonically delaminated from the subducted lithosphere along the tips of tectonic wedges. The crust of the easternmost accreted terranes was thrust over, or wedged into, North American strata. In the eastern Omineca belt, immediately west of the Foreland belt, the accreted rocks are confined to the upper crust and their structural characteristics are analogous to thrust and fold belt structures. These thin thrust sheets can be followed westward for about 250 km to the western Intermontane belt. They lie entirely within the crust and are underlain by westwardly thinning North American rocks. Tertiary extensional faults cut, and sometimes merge into, older compressional faults. At crustal scale, extension produced regional crustal stretching, as unroofed metamorphic core complexes preserve older structures. Further west, Coast belt terranes are either thrust over one another, or are interleaved along forward thrusts and backthrusts with vergence opposite to those in the belts to the east, reflecting a change in style of deformation related to subduction underthrusting.

With the exception of the transition near the Rocky Mountain Trench, the Moho is relatively flat and underlies crustal structures with as much as 20-25 km of structural relief. The Moho and lower crust appear to represent a zone of detachment for both compressional and extensional faults. Both the lower crust and Moho may have formed initially long before Mesozoic contraction began, and then acted as detachments during subsequent contraction and extension. The isotopic characteristics of both lower crustal and upper mantle rocks in the region support this interpretation, as Precambrian rocks are present in the deep crust and upper mantle throughout the Intermontane and Omineca belts.

Overall, the visible portion of the southern Canadian Cordillera is a result of plate divergence from the Mesoproterozoic to late Paleozoic, and plate convergence from the late Paleozoic to the Present (Fig. 3). Most of the present prominent regional geological characteristics resulted from plate interactions between about 85 Ma and 46 Ma. During mid-Cretaceous to Paleocene time, crustal rocks of the eastern accreted terranes were detached and probably rotated against the North American craton as oblique convergence between the Pacific plates and North America occurred. Once allochthonous crustal rocks became welded to the craton by the end of the Paleocene, convergence ceased in the Foreland and Omineca belts, and regional transtension ensued. Plate reorganization in Late Eocene time caused repositioning of some important strike-

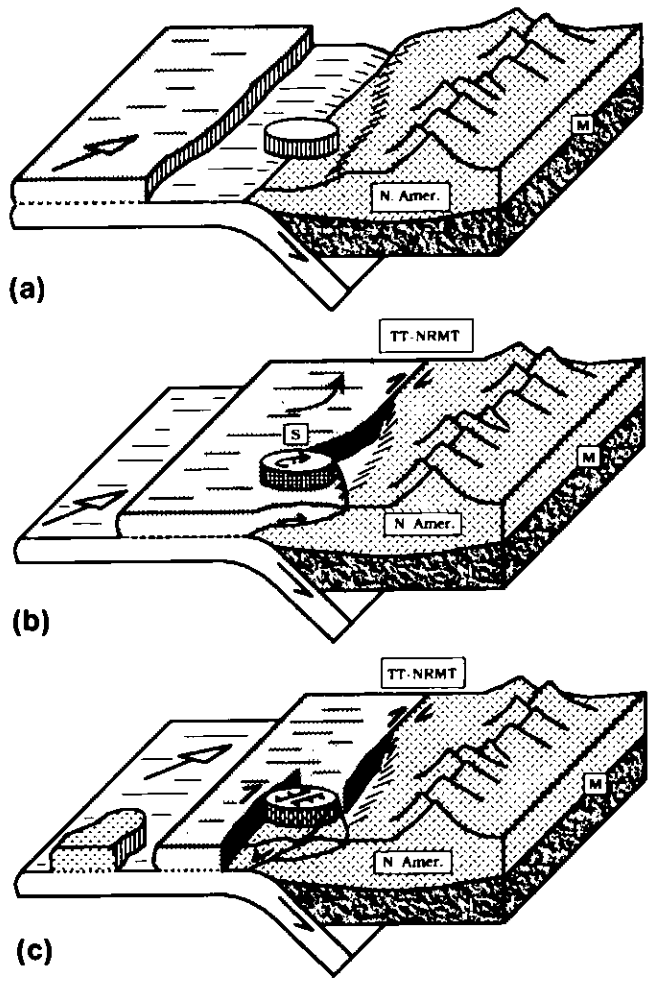

Figure 3 *Southern Cordillera Transect. Schematic model for the Mesozoic - Tertiary evolution of the southern Canadian Cordillera.* **(a)** *Approach of accreted terranes (Intermontane composite terrane) to western North America. Circular area represents material that may later undergo rotation.* **(b)** *Convergence of accreting rocks with North American margin. Detached rocks of the southern Intermontane, Omineca, and Foreland belts in between accreting rocks and the craton (disk) may have undergone rotation, while regions to the north underwent dextral strike slip. Note that rotation of disk is opposite to that of region west of Tintina - northern Rocky Mountain Trench (TT-NRMT). S - location of separation of rotating blocks.* **(c)** *Once the detached rocks welded to North America, relative motion between the obliquely converging plates was no longer accommodated by transpression, and regional transtension ensued. [From Cook 1995. Reprinted with permission from NRC Research Press.]*

slip faults and the initiation of Cascade volcanism at about 35 Ma. Active subduction continues to the present day below Vancouver Island.

LITHOPROBE East Transect

The LITHOPROBE East Transect has as its focus of study the creation and modification of the Appalachian orogen in and around Newfoundland, an example of a fundamental process in Earth evolution: the opening and closing of ocean basins. Transect studies have answered some old questions, raised some new ones, contributed to the development of new techniques, and created new economic opportunities. Preparation of a synthesis volume for *CJES* is in progress.

The timing of Appalachian orogenesis, and our understanding of how pieces of the orogen relate to each other, have been revised significantly over the lifetime of the LITHOPROBE East Transect. Ordovician collisional events in western and east-central Newfoundland, previously thought to be manifestations of a single Taconian orogeny, are now recognized to have occurred in widely separated areas, and so may not be tectonically related. In addition, high precision U-Pb geochronology has identified a major, and previously unrecognized, episode of Silurian tectonism named the Salinic orogeny. High-resolution industry seismic data from the Cabot Strait and geological correlations within western Newfoundland and Cape Breton Island have been used to identify major Silurian-to-Carboniferous along-strike movement in the orogen. This motion post-dates the across-strike amalgamation of the major Newfoundland tectonostratigraphic zones defined by differences in pre-Silurian geology. The collision of Laurentia and Gondwana through closure of the Iapetus Ocean is being shown to be a far more complex interaction than previously considered.

Although a minimum of several hundred kilometres of along-strike juxtaposition between sections of present-day Newfoundland now seems likely, and although electromagnetic and isotopic studies imply significant across-strike differences in the lower crust across the orogen, seismic reflectivity evidence for such differences is sparse. Tectonostratigraphic zone boundaries which are clearly recognized in surface geology cannot be traced into the deep subsurface, and crustal-scale reflectivity patterns are continuous across the entire width of the orogen except for upper crustal disruption in western Newfoundland. The simplest interpretation is that these crustal scale reflectivity patterns were developed late in the Paleozoic Appalachian cycle, thus obscuring whatever reflectivity patterns may have been associated with the earlier formed tectonostratigraphic zone boundaries recognized in surface geology. Inability to trace the crustal patterns to surface makes any interpretation of their age speculative. Such observations raise important concerns about the ability of seismic reflectivity patterns to constrain the early history of regions affected by multiple orogenic episodes.

Work originating with the LITHOPROBE East Transect has had significant economic impact, demonstrating that western Newfoundland is allochthonous on an unexpected scale, and that there exists a possibility for petroleum source and reservoir rocks in areas previously considered to be unprospective. These ideas were tested successfully by a joint Hunt Oil–PanCanadian Petroleum drillhole which struck oil on the Port-au-Port Peninsula. Although three subsequent wells were dry, suggesting that the play is more complicated than first supposed, several major and junior companies are actively exploring the entire length of the west coast of Newfoundland (Fig. 4). Related to these developments, new advances in multiple suppression are making it possible to improve the resolution of LITHOPROBE marine seismic data from the west and north of Newfoundland, to the point where it can contribute to interpretation of shallow structure and stratigraphy.

Abitibi–Grenville Transect

The Abitibi–Grenville Transect program is investigating the structure and evolution of the world's largest granite-greenstone belt, the mineral-rich Abitibi subprovince of the Archean Superior Province in Quebec and Ontario, and of the Mesoproterozoic Grenville Province along its extensive length from southwestern Ontario to southeastern Labrador. Although most of the major experiments associated with the transect are complete, the scientific program remains active and continues to provide new insights into the formation of such belts and their relation to mineral deposits and the development of the Grenville, probably the largest collisional orogen the world has ever seen. Here, I will highlight seismic reflection data recorded in the Abitibi–Opatica belts, which provide the first direct evidence for modern-style plate tectonics being active as long ago as the Late Archean (2600 Ma), and an interpretation of unusual high-pressure-temperature metamorphosed sedimentary rocks in the eastern Grenville Province which provide strong evidence of rapid, tectonically driven exhumation of the lower part of an overthickened crustal segment.

The primary objective of a reflection survey run across the northern Abitibi greenstone and Opatica gneiss belts was to test an orogenic model previously proposed for the Opatica belt and its juxtaposition with the Abitibi belt. Figure 5 shows the data and their interpretation. Calvert *et al.* (1995) interpreted the pronounced patterns of strong reflectivity observed at all crustal levels as being the image of a collisional event between the Opatica and Abitibi blocks. By combining the seismic interpretation with geological and geochronological data from other LITHOPROBE studies, they interpreted the collisional process in terms of a plate tectonic model. The pre-collision (pre-2693 Ma) Opatica crust originally was separated from the Abitibi crust by a north-dipping subduction zone. Early in the collision, the present-day northern volcanic zone greenstone belt was emplaced. At about the same time, the Abitibi margin was thrust beneath Opatica, displacing its lower crust to the north and creating the shallowly north-dipping crustal décollement observed in the seismic data. During the final stage of the collision, which produced the Opatica orogen, a lower plate beneath the décollement was thrust down into the upper mantle. Additional imbrication of the lower crust was accommodated by step-up shear zones in the overlying crust. These data and their interpretation provide the first direct evidence for modern-style plate tectonics being active in Late Archean time!

Other new interpretations come from supporting geoscience studies such as that of Indares (1995), whose metamorphic study of unusual high-pressure rocks provides compelling new evidence for burial and exhumation tectonics associated with the eastern Grenville Province. The metapelites studied by Indares (1995) occur in the parautochthonous Gagnon terrane (GT), a Grenvillian nappe and fold-thrust belt located in the region of the Manicouagan impact structure in southeastern Quebec, and consisting

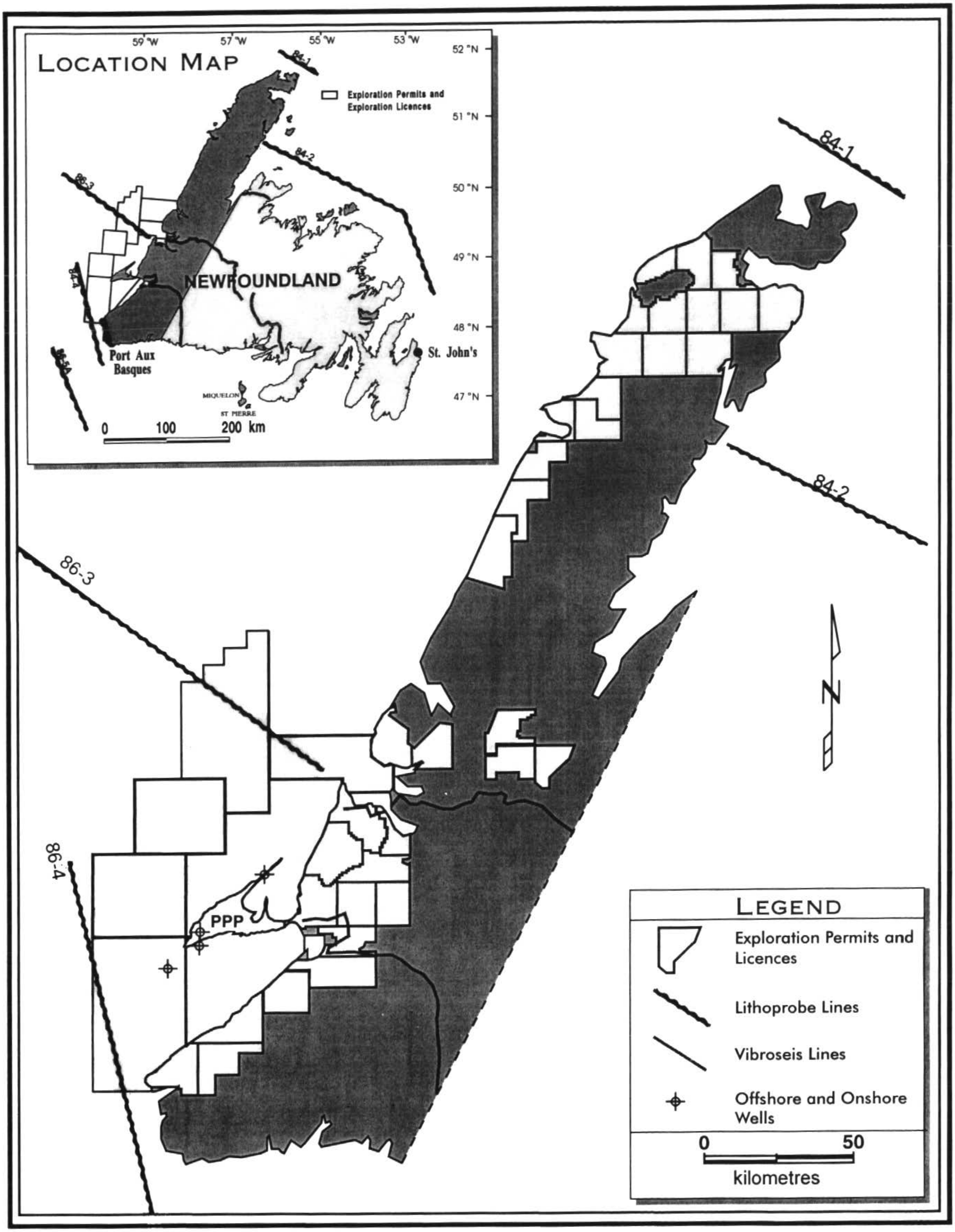

Figure 4 *LITHOPROBE East Transect. Map of western Newfoundland and offshore region showing extent of exploration permits and licenses for petroleum exploration; locations of LITHOPROBE seismic reflection profiles are superimposed. Inset is a general location map including locations of onshore ("vibroseis") and GSC offshore ("LITHOPROBE") reflection lines. Results from the LITHOPROBE East transect, particularly structural/stratigraphic interpretations (e.g., Waldron and Stockmal 1994), spurred exploration interest and eventual drilling of four wells on the Port au Port Peninsula (PPP). The first one struck oil but the others were dry. Activity is proceeding at a cautious pace as companies assess the complex geology of the area which has experienced extensive strike-slip motion from Silurian through Carboniferous time.*

primarily of a Paleoproterozoic continental margin sequence transported in a north-northwest direction toward the Grenville Front. To the southeast, the GT is tectonically overlain by the parauthochthonous Molson Lake terrane (MLT), composed mainly of granitic gneisses. Metamorphic grade increases from greenschist facies at the Grenville Front to eclogite facies in the southern part of the GT and in the MLT. The presence of high-pressure rocks in the southern GT indicates that parts of its southern edge were deeply buried, as were rocks of the MLT, prior to their incorporation in the hanging wall of the ramp and to their subsequent uplift and thrusting over adjacent parts of the GT to the north.

Indares' (1995) study deals with metapelites, from zones with eclogitic mafic rocks, containing large zoned garnet porphyroblasts several millimetres in diameter (Fig. 6a, b). Detailed analyses of the garnets and their internal zoning demonstrate a prograde pressure-temperature (P-T) path with high maximum pressure values (1600 MPa or ~60 km depth) and temperatures between the "wet" and "dry" melting of muscovite-bearing assemblages, followed by a pronounced retrograde profile indicating decompression and cooling along a steep P-T path (Fig. 6c). Such results suggest a relatively short time of residence at maximum depth and fast unloading rates, consistent with rapid, tectonically driven exhumation. The results provide additional support for the tectonic model of Rivers *et al.* (1993), which, following a crustal shortening event, has the deeply buried MLT (and now parts of the GT) of the Parautochthonous belt tectonically uplifted along a crustal-scale ramp and emplaced on the foreland to the northwest. More generally, they illustrate the incredible processes that have helped form the continent: collisions that bury sediments to depths as great as 60 km, thrusting that rapidly uplifts them 20 to 30 km, and erosion that exposes them at the present surface.

Trans-Hudson Orogen Transect

Investigations in the Trans-Hudson Orogen Transect (THOT) explore one of the major Paleoproterozoic orogenic belts of the world, marking a major episode of North American continental assembly involving collision and aggregation of Archean continental fragments and the creation of large volumes of new continental material. All of the major geophysical experiments have been completed, but interpretation of these data and the university supporting geoscience projects remain active. The NATMAP Shield Margin project, a collaborative study involving the GSC, Manitoba and Saskatchewan Geological Surveys, and university scientists, focusses on the southeastern quarter of the transect. It continues to be a major contributor to the overall THOT scientific program and exemplifies the collaborative nature of LITHOPROBE as a project. The multidisciplinary studies of LITHOPROBE and NATMAP have fundamentally altered our understanding of the structure and evolution of the Trans-Hudson Orogen. In the following, I present a few observations and summarize an inferred sequence of events.

One of the major achievements is an internal resolution of boundary relations between the Flin Flon–Snow Lake collage of volcanic terrains and granitic plutons, and the Kisseynew metasedi-

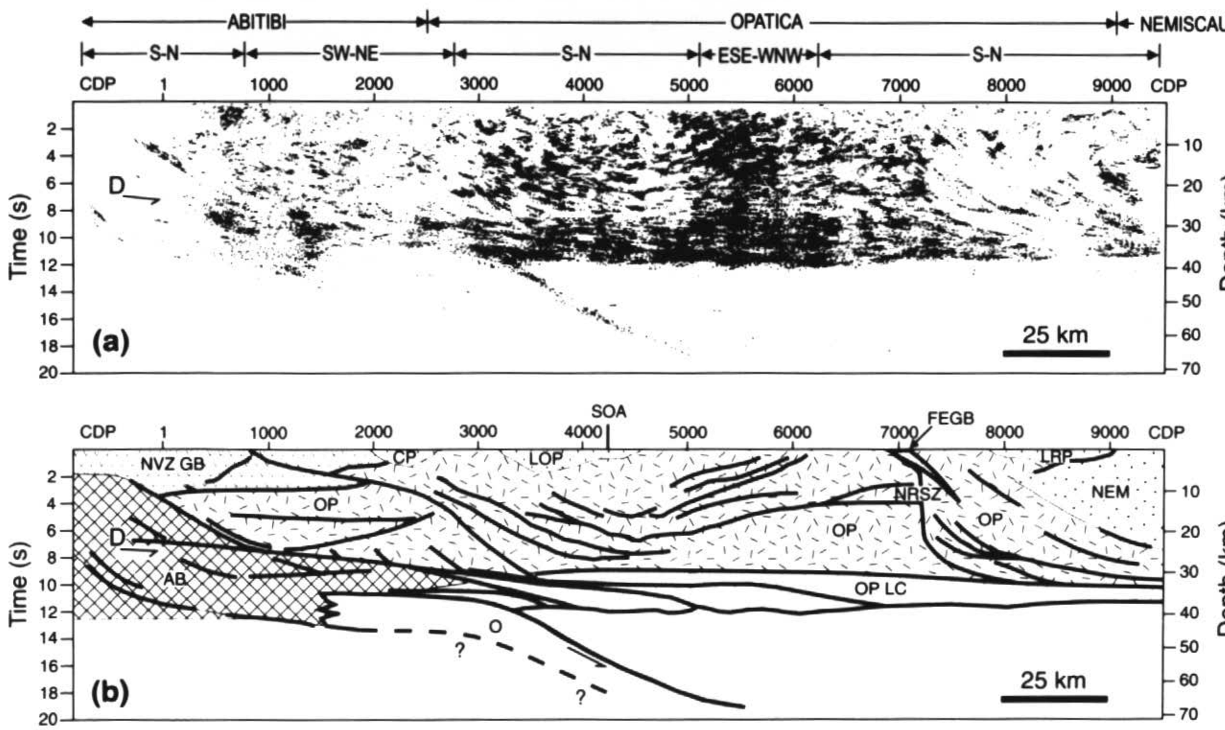

Figure 5 *Abitibi-Grenville Transect.* **(a)** *Coherency filtered, migrated data along line 48 across the northern Abitibi and Opatica belts; depth scale and display at 1:1 are approximate. Major changes in orientation of the seismic line are indicated.* **(b)** *Interpretation of the seismic section in* **(a)**. *The major crustal features are indicated: AB - Abitibi (subgreenstone) crust; CP - Canet pluton; D - a detachment zone; FEGB - Frotet-Evans greenstone belt; LOP - Lac Ouescapis pluton; LRP - Lac Rodayer pluton; NEM - Nemiscau crust; NRSZ - Nottaway River shear zone; NVZ GB - greenstone rocks that form part of the Abitibi northern volcanic zone; OP - Opatica crust; OPLC - Opatica lower crust consisting of strong subhorizontal reflectors; O - subcrustal unit, tentatively identified as an Archean oceanic slab. [From Calvert* et al., *1995. Reprinted with permission from* Nature, *v. 375, p. 673, 1995. Copyright © 1995, Macmillan Magazines Limited.]*

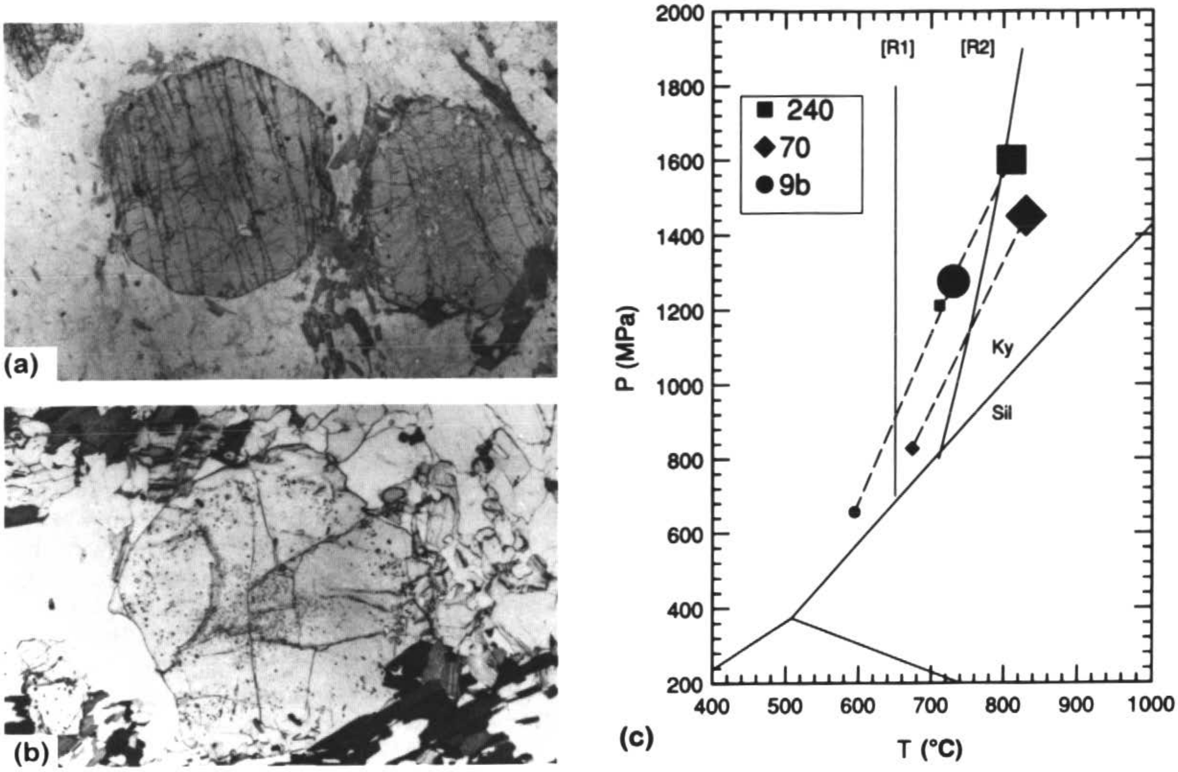

Figure 6 *Abitibi-Grenville Transect. Photomicrographs of typical garnet in metapelites:* **(a)** *sample 240;* **(b)** *sample 9; length of photographs: 6.4 mm.* **(c)** *Calculated maximum and retrograde P-T conditions and location of reactions (R1, R2) responsible for partial melting in the southern Gagnon terrane. Large symbols - P_M-T_M where M indicates maximum, values include four to six estimates per sample; small symbols - P_R-T_R where R indicates retrograde, minimum estimates. [Adapted from Indares 1995. Reprinted with permission from Blackwell Science.]*

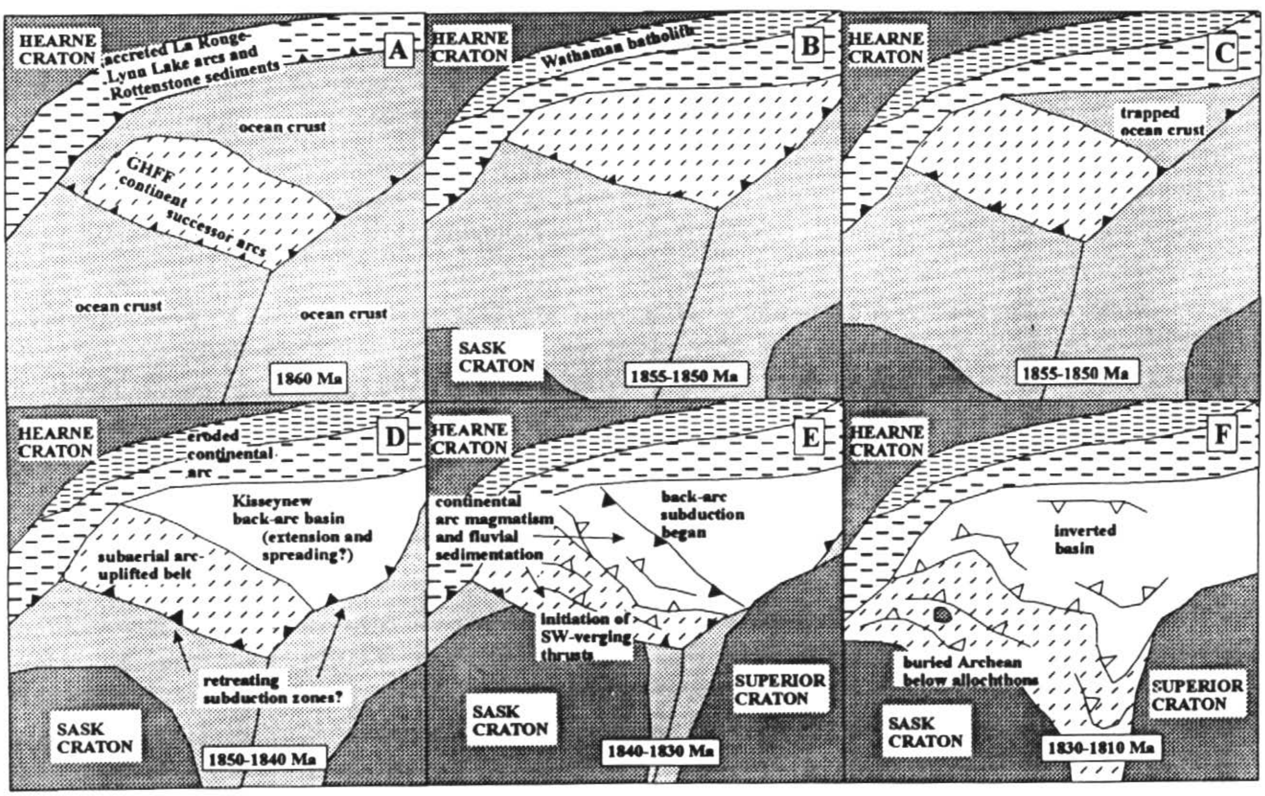

Figure 7 *Trans-Hudson Orogen Transect. Cartoon illustration for the evolutionary history in plan view of the THO in Saskatchewan and Manitoba in the interval 1860-1810 Ma. Note that B and C represent alternative scenarios for the same interval (1855-1850 Ma). Solid barbs - subduction zones, open barbs - thrust faults, GHFF - Glennie-Hanson-Flin Flon arc terranes. Note that cartoons are not to scale and no palinspastic restoration is intended. [From Ansdell et al., 1995. Reproduced with permission of the publisher, the Geological Society of America, Boulder, CO, USA. Copyright © 1995, The Geological Society of America, Inc. (GSA).]*

mentary domain (Ansdell *et al.*, 1995). A most significant "discovery" is the recognition and definition of the Sask craton, a previously unknown microcontinental Archean block that extends below a significant part of the THO and appears to be distinct from both the Superior craton to the east and the Hearne–Rae craton to the west (Lewry *et al.*, 1994). It is also the source of the microdiamonds that have been found in kimberlite pipes buried beneath Phanerozoic cover in southern Saskatchewan. A general, increased understanding of the crustal geometry and ages for the Reindeer Zone, the large internal part of the orogen, also has been achieved. These results, and others, have led to a representative scenario for the Paleoproterozoic geotectonic assembly of the THO; Fig. 7 illustrates one perspective for the interval 1860-1810 Ma. However, there are still many unsolved questions and a number of differing viewpoints on specific aspects of the evolutionary sequence in all regions of the orogen. (*e.g.*, Figs. 7B, 7C).

The period from 2450 Ma to 2100 Ma represents pre-rift continental development, followed by extension. About 2100 Ma, continental rifting was established. There is evidence for passive margin sedimentation from this time forward, to about 1860 Ma, on both sides of the developing Manikewan Ocean separating the two Archean cratons. As indicated by paleomagnetic studies (Symons, 1991), the ocean grew to one of Pacific size, up to 5000 km in maximum extent! A period of intra-oceanic tectonics, from about 1920 Ma to 1870 Ma, followed. Within this period, arc and back-arc magmatism with associated deposition of clastic sediments occurred, probably involving subduction and closure of the Manikewan Ocean. A present-day analog would be the southwest Pacific. About 1865 Ma, outboard collisional accretion of juvenile arcs, arc clastic basins, oceanic crust, oceanic plateaus and minor Archean slivers resulted in the formation of the juvenile Glennie-Hanson-Scimitar-Attiti-Flin Flon–Snow Lake protocontinent, a modern example of which might be the current and future evolution of the Philippines–Indonesia region. However, the collision of the Hearne passive margin and the La Ronge–Lynn Lake arcs, a Cordilleran-type collisional orogeny, didn't occur until about 1860 Ma. This was followed at about 1855 Ma by the emplacement of the Wathaman batholith, a calc-alkaline continental magmatic arc (Fig. 7).

During the period from 1850 Ma to 1830 Ma, successor arc volcanism and the generation of stitching plutons occurred throughout the Reindeer Zone. Various successor basin sediments were deposited and Kisseynew sediments were developed in an extensional back-arc basin setting. About 1835 Ma, the Archean Sask craton moved into and under the collage from the south, initiating the main southwest-vergent orogeny and fold-thrust tectonic imbrication and crustal thickening throughout much of the Reindeer Zone, which carried on until about 1805 Ma. From about 1810 Ma to 1800 Ma, there was a strong metamorphic overprint throughout much of the orogen. Terminal collision of the Superior craton occurred about 1800 Ma, generating transpressive structures in the Thompson Belt, the eastern boundary zone, and causing well-documented deformation throughout the internides of the Reindeer Zone. During the next 100 m.y., post-collisional tectonism took place, leading to the cessation of major activity in the THO. Late granites may have been derived partly from melting of the Sask craton. Uplift occurred, resulting in cooling and thermal equilibration. At about 1720 Ma, gold mineralization formed in the La Ronge domain. Shortly thereafter, the system ground to a halt.

Alberta Basement Transect

The Alberta Basement Transect (ABT) extends studies of the Archean and Paleoproterozoic lithosphere beneath the Western Canada Sedimentary Basin (WCSB), a westward-thickening prism of Phanerozoic strata deposited on the western extension of the Canadian Shield, recently shown to be a geologically heterogeneous crustal mosaic similar to its exposed counterpart. As well as an understanding of lithospheric evolution in the region, the transect seeks to answer a fundamental question of significant economic relevance: how has the ancient North American craton influenced or controlled the evolution of the overlying and much younger WCSB?

The first seismic reflection survey in the transect, Central Alberta Transect (CAT) took place in 1992. All other geophysical surveys were carried out during the past four years: seismic reflection in 1994, Peace River Arch Industry Seismic Experiment (PRAISE), and 1995, Southern Alberta Lithosphere Transect (SALT); magnetotelluric (MT) experiments occurring each year; and the 1995 Southern Alberta Refraction Experiment (SAREX)–Deep Probe refraction-wide-angle reflection program. Preliminary results from some of the earlier surveys have been published (Ross *et al.*, 1995; Boerner *et al.*, 1995; Eaton *et al.*, 1995). The supporting geoscience program is making substantive contributions to the transect objectives. Much of this effort is centred on understanding the history of the WCSB, Precambrian tectonics, and the possible interaction between the two. The annual transect workshops are large; typically there are 200-250 registrants, the majority representing the petroleum and mining industries. The multidisciplinary aspects of the transect and new, high-quality seismic reflection data contribute to the high level of interest in the scientific results. Here, I will comment on two unique experiments which probed hundreds of kilometers into the mantle, and summarize two preliminary results.

During the SALT 95 program, 830 km of new reflection data were acquired in the Southern Corridor of southern Alberta. The northernmost line tied with the 1992 CAT survey in the Loverna Block of the Hearne craton (see below). Another very high quality data set was acquired. A unique (and scientifically risky) experiment, the Vibroseis AUgmented Listen Time (VAULT) survey — an attempt to record reflections from within the upper mantle to depths of hundreds of kilometres — was run. Twelve large Vibroseis trucks, compared with the usual four, vibrated synchronously for 55 seconds with a subsequent listening time of 60 seconds. Almost 1000 channels along a 45 km spread recorded the signals in uncorrelated format, enabling processing that could extend the seismic section to 100 seconds two-way travel time (or about 400 km depth). Simultaneously, horizontal component data were recorded on a separate system, particularly to look for S-wave converted phases. The first results indicate exceptional reflectivity within the crust, good reflectivity in the mantle to about 20 seconds (~70 km), and relatively little coherent energy below that.

The other major 1995 seismic survey was the Southern Alberta Refraction Experiment (SAREX) and Deep Probe, an expanding refraction experiment designed to sample the upper mantle to depths of 400 km or more. The midpoints of the ray paths between sources and receivers were focussed on the Medicine

Hat Block in southeastern Alberta, a region of high-standing topography for about 1500 Ma. Both refraction experiments benefited from our continuing collaboration with US scientists from universities, the United States Geological Survey (USGS), and Incorporated Research Institutions for Seismology– Portable Array Seismic Studies of the Continental Lithosphere (IRIS/PASSCAL) consortium. In total, 756 portable seismographs were deployed at 1-2 km spacings for three separate deployments. Two instrument deployments covered a line from east of Edmonton to northern New Mexico. This was a true collaborative experiment as US scientists planned their expanding refraction spread to focus on the Phanerozoic southern Rockies of Colorado. Canadian shot points were located at the US border, Cold Lake, AB, Fort Mackay, AB, and Pine Point, NWT; US shot points were located in central Wyoming, southern Colorado, and southern New Mexico. This truly was a unique experiment of continental dimensions! The SAREX/ Deep Probe data sets show excellent propagation of Pn-related energy to offset distances greater than 1300 km. Pn is a seismic phase propagating as a refracted wave below Moho which normally is not observable beyond offsets of 400-500 km due to a lack of adequate energy. That the phase is observed prominently at much larger offsets and also shows a strong imbricated character suggest complex structures in the uppermost mantle. Analysis of the data continues.

The ABT reflection profiles provide high-quality data relating to the sedimentary section as well as the underlying crustal section. The CAT profile yielded a continuous seismic cross section across central Alberta (Fig. 8) from which new constraints are derived on the nature and extent of basement controls over Phanerozoic depositional and diagenetic processes in this part of the WCSB, as discussed by Eaton *et al.*, (1995). Three styles of basement influence that have distinct seismic expressions have been recognized: passive topographic effects, indicated by onlap, drape and infill of basin sediments over relief on the basal unconformity; faulting of the basement and overlying Cambrian strata; and abrupt lateral facies changes of uncertain origin, vertically overlying a deep-seated tectonic boundary. These examples from seismic profiles demonstrate clearly that basement structures have exerted subtle, but significant, influence over Phanerozoic paleogeography in this part of the WCSB. The most prominent basement high underlies the Leduc southern Alberta shelf margin on the western edge of the Precambrian Loverna Block. In the same region, the

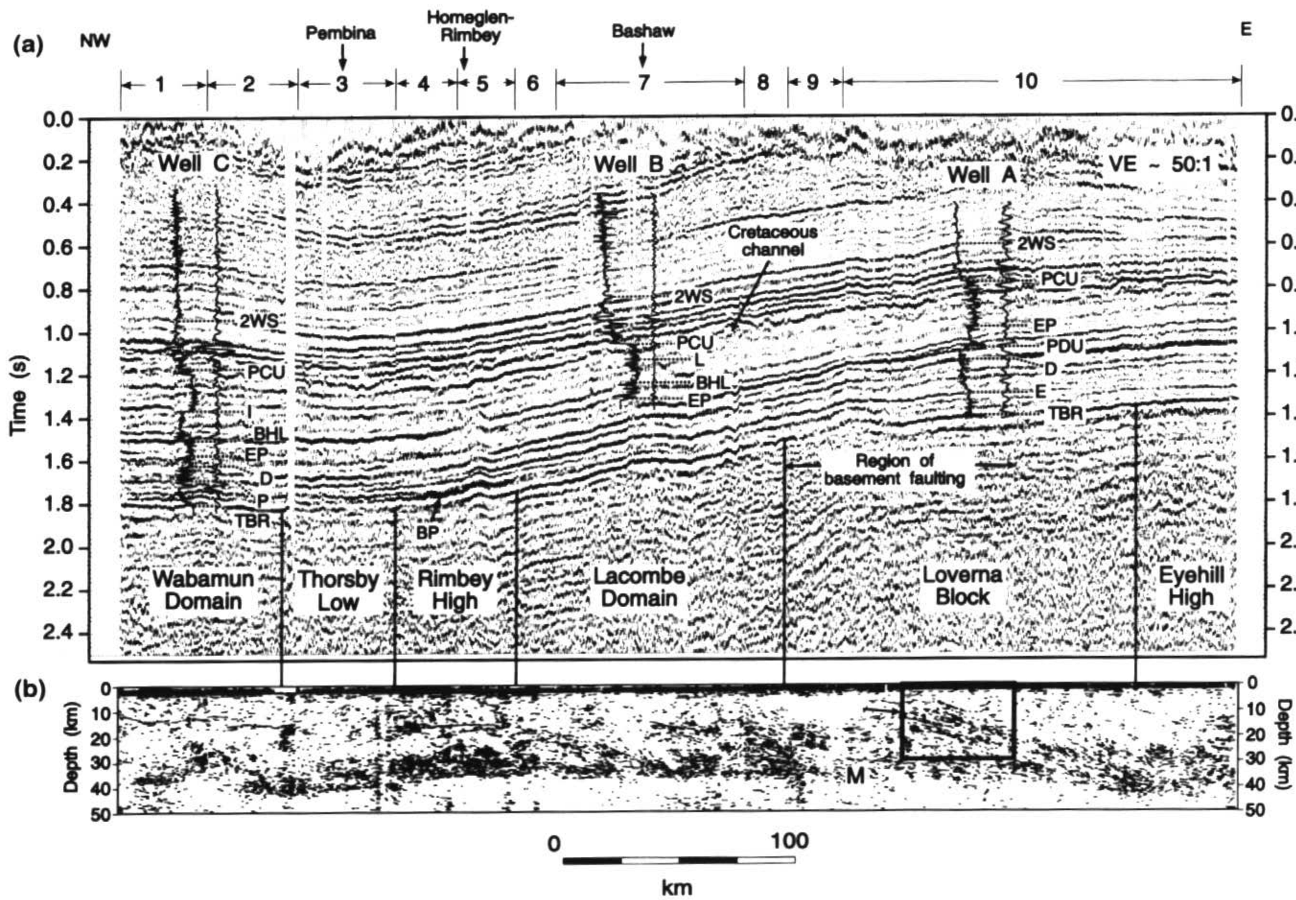

Figure 8 *Alberta Basement Transect.* **(a)** *Migrated data from the 1992 central Alberta corridor, showing line segments, stratigraphic correlation wells, some major producing fields (Pembina, Homeglen-Rimbey and Bashaw), basement domains and seismic marker horizons: 2WS - Second White Specks (Upper Cretaceous), PCU - pre-Cretaceous unconformity, I - Ireton (Upper Devonian), L - Leduc (Upper Devonian), BHL - Beaverhill Lake (Upper Devonian), EP - Elk Point (Middle Devonian), PDU - pre-Devonian unconformity, D - Deadwood (Upper Cambrian), P - Pika (Middle Cambrian), E - Earlie (Middle Cambrian), TBR - top-of-basement reflection and BP - basement precursor. Overall vertical exaggeration is ~ 50:1, but vertical exaggeration near the basement is ~ 40:1 (for an assumed average velocity of 5000 m/s).* **(b)** *Line drawing for the full 18 s of data (M - Moho). Box outlines imbricate thrust structures, part of the East Alberta orogen, which are shown in greater detail in Ross* et al. *(1995). [From Eaton* et al.*, 1995. Reprinted with permission from the Canadian Society of Petroleum Geologists.]*

basement surface is broken up by small vertical offsets along a number of faults that appear to extend upward to the top of the Middle Cambrian.

One of the most striking linear features of the WCSB is the Rimbey–Meadowbrook reef chain, which overlies the *ca.* 1825 Ma Rimbey magmatic arc. In plan view there is an imperfect alignment of the trend with the aeromagnetic fabric of the basement, suggesting that any basement control must have been indirect. However, juxtaposition of seismic images from opposite sides of the reef trend reveals a series of abrupt facies changes within Middle Cambrian to Middle Devonian strata that directly overly the Rimbey arc. Deep-seated controls over the orientation of the reef foundation, and possibly over coeval fluid-circulation patterns in the basin, could explain the coincidence of these elements in the seismic profile.

The full crustal segment of the 1992 profile (Fig. 8b) indicates that the subsurface extension of the Canadian Shield underwent significant Paleoproterozoic (~1800 Ma) crustal shortening, including the formation of a crustal scale orogenic belt referred to as the East Alberta orogen (Ross *et al.*, 1995). The scale and extent of the thrust structures are striking. The Moho is well imaged throughout the length of the reflection profile and is characterized by an abrupt loss in reflectivity. A postulated Moho step coincides with the subsurface extension of the Snowbird tectonic zone (Thorsby domain) and suggests that this structure may have accommodated substantial Paleoproterozoic displacement in the subsurface of Alberta.

Available age data suggest that the age of shortening in the East Alberta orogen was 1850-1780 Ma, coeval with the shortening in the adjacent Trans-Hudson orogen. The two regions can be linked on the basis of geochronologic data and appear to be part of a complex broad collisional orogen formed by the tectonic welding of the Superior, Hearne, and Rae provinces during assembly of the western Canadian Shield.

Eastern Canadian Shield Onshore-Offshore Transect

The Eastern Canadian Shield Onshore-Offshore Transect (ECSOOT) is investigating a critical part of the North American continent in the coastal region of Labrador and adjacent Quebec. This region contains portions of three Archean cratons (Nain, Rae and Superior provinces) and five Proterozoic orogenic belts: Eastern Churchill Province, including the New Quebec and Torngat orogens, Labrador orogen, and Makkovik and eastern Grenville provinces. Together these areas embrace a geological history ranging from 3800 Ma to 900 Ma and chronicle the construction of a significant part of northeastern North America.

One of the great successes of the ECSOOT scientific program has been the contributions from supporting geoscience studies, including work by university, GSC and Newfoundland Geological Survey Branch scientists. Much of this land-based research has been directed at unravelling the tectonic evolution of the Proterozoic orogens. A reflection seismic survey was completed in a single marine acquisition program in 1992. The survey comprised a northern line, covering the eastern part of the *ca.* 1900-1750 Ma southeastern Churchill Province (including the Torngat orogen and Rae Province) and extending south along the Labrador coast into the northern block of the Nain craton; and a southern line extending from the southern part of the Nain across the *ca.* 1900-1750 Ma Makkovik-Ketilidian orogen and the 1700-1000 Ma rocks of the Grenville Province (Hall *et al.*, 1995). The final geophysical component of the project, a combined marine-onshore seismic refraction–wide-angle reflection program, was completed in October 1996.

A joint Abitibi–Grenville–ECSOOT transect meeting focussing on the Grenville was held in Montreal in November 1994. The enhanced understanding of the development of this orogen and its complex variations along strike were demonstrated clearly. The principal theme of the March 1996 workshop was the Paleoproterozoic evolution of the northeastern Canadian Shield, including its extension into Greenland, but the meeting also included additional presentations on the Grenville Province. Six representatives from Denmark attended; their work on Greenland ties in well with the ECSOOT program in eastern Labrador. Strong links are developing between workers in the two study areas. These were enhanced further through the international conference "Proterozoic Evolution in the North Atlantic Realm" organized by the International Geological Correlation Project–LITHOPROBE ECSOOT–International Basement Tectonics Association and held 29 July-2 August 1996 in Goose Bay, Labrador. Although many projects are not yet complete, fundamental new understanding in some regions and confirmation of hypotheses in others already has been achieved. Some of the recent highlights for the three main study areas are summarized below.

Southeastern Churchill Province (SECP), including Torngat Orogen and Rae Province

Structural comparisons between the northern and southern parts of the Torngat Orogen indicate that the large (crustal-scale?) Abloviak shear zone, which is the major structure located along the Nain–Rae suture in the northern part of the orogen, is a much less significant feature in the south. This suggests that it is a relatively late feature that has modified an earlier collisional boundary; it does not define the suture *per se* and is probably not a fundamental, plate-bounding structure. The evolutionary history of the Torngat Orogen has to be reinterpreted in the light of new geochronological data. The *ca.* 1860 Ma event, previously believed to represent Nain–Rae collision, may be a less significant event related to collision of the Nain craton with the Tasiuyak arc-accretionary prism terrane (Fig. 9).

The results of the GSC Baffin project to the north indicate that much of the so-called Rae Province on south Baffin Island is likely to be juvenile Paleoproterozoic material of arc origin and not reworked Archean crust as previously inferred. Recent dating in the Lac Lomier complex of Torngat orogen, which is part of the "Rae Province" in Labrador and Quebec, has also revealed the presence of juvenile Paleoproterozoic crust that probably represents a southeastward extension of the Baffin Island material. The "Rae Province" in Labrador–Quebec, however, also contains many areas of dated Archean crust, the parentage of which is now open to debate. One possibility is that it represents an independent Archean block trapped in the interior of the SECP (Fig. 9c-i); alternatively, it might represent an extension of the Superior craton (Fig. 9c-ii). The implications of this latter interpretation are profound (*e.g.*, the mode of transport of domains onto and across the extended craton and the generation of batholiths).

Makkovik-Ketilidian Orogen

Recent work has focussed on the struc-

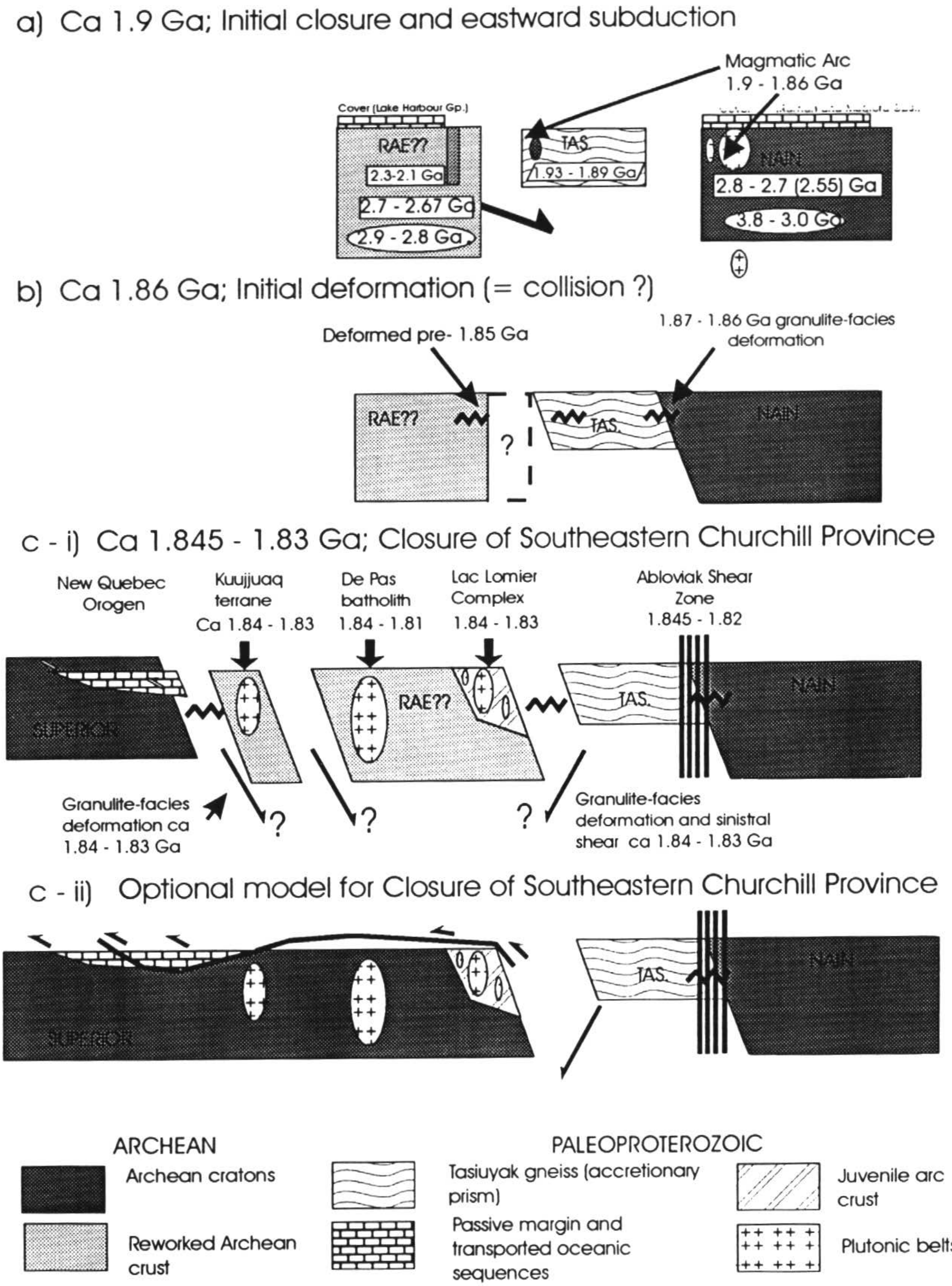

Figure 9 *ECSOOT Transect. Schematic models for the evolution of the Torngat Orogen in the context of the whole southeastern Churchill Province (SECP).* **(a)** *Early east-dipping subduction produces the Tasiuyak arc/accretionary prism complex located somewhere between the Archean Nain and Rae cratonic blocks.* **(b)** *An early structural-high grade metamorphic event ca. 1860 Ma is related to collision and accretion of the Nain and Tasiuyak complex. Final assembly of the SECP is inferred to have occurred between 1845 and 1830 Ma. Two options are suggested:* **(c-i)** *depicts the Archean rocks of the Rae Province as an independent crustal block;* **(c-ii)** *illustrates the alternative possibility that they represent an easterly extension of the Archean Superior Province. [Figure provided by Dick Wardle, pers. comm. 1996].*

tural evolution of the boundary zone that separates the reworked Archean crust (Nain craton) of the northern Makkovik-Ketilidian orogen from the juvenile Paleoproterozoic crust that comprises the remainder of the orogen. An early, east-directed thrusting event has been recognized that suggests a possible kinematic link to early collisional events in Torngat orogen. This was succeeded *ca.* 1870-1860 Ma by northwest-directed subduction and ensialic magmatic arc development, followed by northwest-directed thrusting of juvenile crust onto the Archean craton. Later stages of structural development were associated with *ca.* 1800 Ma dextral transpression along the boundary zone and finally with an important southeast-directed thrusting event (*ca.* 1780 Ma) that is probably responsible for the development of south-verging nappes in the Ketilidian part of the orogen. These nappes and their associated thrusts are believed to be imaged by the pervasive north-dipping reflectors on the offshore seismic profile and form the southern arm of a doubly-vergent collisional orogen.

Grenville Province

Work in the Long Range inlier of Newfoundland has confirmed earlier suspicions that this easternmost Grenvillian crust is of Mesoproterozoic (*ca.* 1500 Ma) age and part of the Pinware terrane. The extent and geometry of Mesoproterozoic structures related to development of the Pinware terrane, and to any accretion of juvenile crust, is also a major uncertainty requiring further work. Other activities have focussed on continued interpretation of the 1992 seismic line, in particular the origin of the doubly-vergent structure revealed by both onshore mapping and offshore seismic profiling in the easternmost Grenville Province.

Western Superior Transect

The Superior Province is the largest of several Archean cratons which form the nucleii of the North American continent. Its outstanding feature is an internal pattern of 100-200 km wide east-trending lithotectonic belts formed by an array of contrasting granite-greenstone, metaplutonic, and metasedimentary regions known as subprovinces. The Western Superior Transect (Fig. 1) is investigating the three-dimensional geometry and origin of this internal pattern (a first-order feature of Archean crust not addressed in other LITHOPROBE transects), testing a proposed tectonic model of terrane accretion, and investigating subsequent bulk deformation in this "classic" segment of the Canadian Shield. The scientific program began with university supporting geoscience, GSC and Ontario Geological Survey (OGS) efforts in 1994. The first major geophysical experiment, a refraction/wide-angle reflection experiment, took place in July 1996. Transect scientific activities will continue into Phase V of LITHOPROBE.

Slave-Northern Cordillera Lithospheric Evolution Transect

The Slave-Northern Cordillera Lithospheric Evolution (SNORCLE) Transect (Fig. 1) addresses structure and growth cycles of the continental lithosphere in a region of northwestern North America where the rock record spans 90% of Earth's history. Principal study objectives include 1) the formation of Early Archean crust and the evolution of cratons, 2) the Archean to Proterozoic transition and collisional suturing associated with Proterozoic orogens, 3) processes of ocean opening and the Proterozoic-Paleozoic rifted margin and miogeocline of North America, 4) growth of continents by terrane accretion, and 5) the deep architecture and Phanerozoic evolution of the Cordilleran orogen. Scientific activities within the transect were formally initiated in 1994-1995 with the first University Supporting Geoscience Projects awards. Excellent collaboration in the transect program arises from participation of scientists from the GSC, NWT Geology Division of the Department of Indian and Northern Development, Canada–Yukon Geoscience Office, and the BC Geological Survey. Co-operative ventures with industry are being developed on two fronts at present: diamond exploration companies active in the Slave Province, and petroleum companies in the southern NWT and northeastern BC. The first major geophysical experiments started in 1996: an MT experiment completed in October, and a seismic reflection survey scheduled for mid-October to December, both focussing on the Archean to Proterozoic corridor of the transect. Activities will continue into the Phase V program.

INDUSTRY PARTICIPATION 1993-1996

One of the most significant, and satisfying, aspects of LITHOPROBE has been the extent to which industry has become involved with the project since it was established. Such involvement includes direct contribution of funds, donation of data or other in-kind scientific support, participation in the planning and data interpretation, and advice through representative members on LITHOPROBE committees. Much of this involvement was documented in the Phase IV Proposal (Clowes 1993). Here, I mention the principal contributions since then to illustrate the continuing substantial involvement of industry in the project.

In the Northern Corridor (Peace River Arch region of current exploration interest) of the Alberta Basement Transect, the entire 1994 PRAISE multichannel reflection survey, comprising 630 km of high-quality data, was funded through the participation of 25 petroleum companies (which contributed a total of $625,000), GSC-Calgary, which redirected some of its budget to the survey, and GSC-Ottawa. For the SALT '95 program in the Southern Corridor (southern Alberta), LITHOPROBE secured the co-operation of eight companies which contributed $320,000 toward the total costs. In both surveys, acquisition parameters were adjusted to meet the requirements of industry while still providing the deep crustal data required by LITHOPROBE. Industry benefits from the availability of consistent, high-quality data on long lines, from which they can determine details of the regional framework of the Western Canada Sedimentary Basin to better understand development of the basin and to formulate their own exploration plans (*e.g.*, Fig. 8). In the Southern Corridor, PanCanadian Petroleum of Calgary in 1994 donated about 60 km of reflection data recorded to 13 seconds or 15 seconds along two east-west lines that tie with the LITHOPROBE SALT lines; the in-kind value of this donation is estimated at about $150,000.

During 1995, a consortium comprising three petroleum companies (which contributed a total of $150,000), the Saskatchewan Geological Survey, the GSC and NSERC LITHOPROBE interests funded a high-resolution aeromagnetic survey in southwestern Saskatchewan to help fill a prominent gap in publicly available coverage in a region of high basement interest on the part of the the companies and also of great importance to understanding tectonics within the Alberta Basement Transect.

In THOT, LITHOPROBE has achieved a

scientific first. With financial support of $150,000 from four uranium mining companies (CAMECO, Uranertz, Cogema and PNC Exploration), co-ordinated through the Saskatchewan Research Council, 32 km of very high resolution reflection data were acquired along the southeastern margin of the Athabasca Basin. The objective of the survey was to image the contact between the younger sandstone strata of the basin and the underlying crystalline basement (at depths from 0.5 km to 2 km) and to identify a number of fault and shear zones within the basement.

The scientific result of significance is that LITHOPROBE has demonstrated the value of high-resolution seismic reflection data to the uranium industry by identifying previously unknown sub-basins and basement faults along which fluids may have flowed in forming some of the uranium deposits. The companies are extremely pleased with the results and are expected to fund more detailed analyses of the data at the University of Saskatchewan. Also in THOT, mining companies active in the Thompson Belt have provided LITHOPROBE scientists with high-resolution magnetic and gravity data and basement drillcore samples from below the Phanerozoic sediments over the region just east of central Lake Winnipeg, along which a regional reflection survey was conducted in 1994. Such information is proving highly relevant to our interpretation of the data.

An exciting development is following from earlier LITHOPROBE high-resolution seismic reflection co-operative experiments with industry in the Abitibi–Grenville Transect. Independent of LITHOPROBE, but with the necessary participation of LITHOPROBE scientists from the GSC, INCO and Falconbridge carried out a full 3-D seismic reflection survey in the Sudbury region in the fall of 1995 to better define the structural environment at depth and, it is hoped, lead to the discovery of additional reserves. This project was carried out through a GSC Industry Partners Program. Noranda, with participation of seismologists from the GSC and École Polytechnique, ran a similar 3-D survey in the Matagami mining area in the spring of 1996. Such experiments represent commitments of major exploration budgets by these companies, and would not even have been considered without the pioneering efforts of LITHOPROBE. Also in the Abitibi-Grenville Transect, financial support in 1993 from INCO ($15,000) helped fund a high-resolution electromagnetic survey to further investigate the southern rim of the Sudbury structure.

PUBLIC OUTREACH–COMMUNICATIONS

Contemporaneous with its scientific progress and involvement with industry, LITHOPROBE has continued its efforts in public outreach–communications to ensure that the exciting and new results from this national project are brought to the attention of students, politicians, the media and the general public. Such exposure benefits sciences and engineering in general, the earth sciences specifically, and LITHOPROBE in particular. The outreach program is facilitated through a part-time Communications Adviser who reports to the Director.

Following the successful LITHOPROBE brochure, prepared in late 1991, a LITHOPROBE educational slide set, aimed at senior high school, college, and university students, was prepared and made available in 1994. The package includes 80 slides, accompanied by a 40-page narrative text and slide captions in both official languages, and is sold for $80.00 to recover some of the costs of production. About one third of the slides illustrate how earth scientists study the planet, while the remainder show scientific results current to early 1994 from the various transects. More than 120 sets have been distributed to date.

LITHOPROBE has been proactive in fostering articles related to the project in the print and electronic media. We have been particularly successful with the print media, with more than 50 articles published during the last four years, 27 of those in 1995-1996. The most significant development in the print media has been the publishing of a cover story on LITHOPROBE in the January-February 1996 issue of *Canadian Geographic* magazine, a story now being used as part of the outreach campaign. An unexpected bonus during 1995-1996 was the inclusion of a LITHOPROBE scientific discovery (Calvert *et al.*, 1995) in a series of stories on the ten Quebec scientific discoveries of the year in *Québec Science*, a francophone magazine. The scale and unique aspect of the Canadian–US collaborative Deep Probe experiment during the summer of 1995 engendered considerable coverage in newspapers from locations as disparate as Medicine Hat, Billings, Boston, Los Angeles and San Diego.

It is more difficult to achieve suitable access to the electronic media, but even here we have had reasonable success, the most notable an interview segment on the television program "@discovery.ca" broadcast on the Discovery Channel. Both the CTV and CBC outlets in Saskatoon carried stories in 1994 on THOT scientific activities and the CTV outlet in Calgary broadcast a story on the extended listen time (VAULT) experiment in Alberta in 1995. With an eye to the future, LITHOPROBE contracted professional video producers to film appropriate footage during the VAULT experiment in 1995 and activities associated with both the ECSOOT onshore-offshore seismic refraction and the SNORCLE reflection experiments in 1996. Efforts to encourage media presentation of LITHOPROBE results continue.

CONCLUDING COMMENTS

LITHOPROBE has met the challenges, and probably exceeded the expectations, of those who first formulated the concept in the early 1980s. The scientific program, dissemination of the results of the program in the scientific literature, communication of the relevant results to the media and the public, and the involvement of government and industrial participants have made a significant impact on the national and international solid earth science community. Indeed, EUROPROBE, an earth science project sponsored by the European Science Foundation, was established in 1992 and named to emulate LITHOPROBE. Our challenge now is to complete the scientific programs in all transects, synthesize the results to reveal the evolution of a continent, and bring the entire project to a successful conclusion in all its many aspects by the end of LITHOPROBE Phase V.

ACKNOWLEDGEMENTS

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