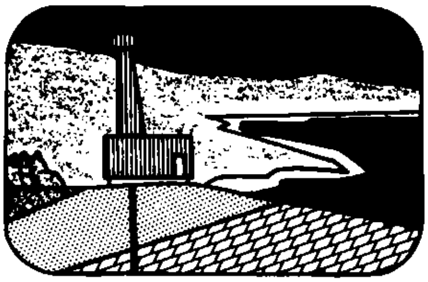
Conference Reports



The Kapuskasing Uplift and Lower Crustal Drilling Targets: a CCDP Workshop Report

J.A. Percival
Geological Survey of Canada
588 Booth Sreet
Ottawa, Ontario K1A 0E4

The first of a series of thematic workshops sponsored by the Canadian Continental Drilling Program (CCDP) was held at the University of Toronto, 18-19 February 1988. Widespread interest in problems of the lower crust is reflected in the profile of affiliations of the 50 participants: university (58%); government (26%); industry (16%). Discussion was focussed on opportunities presented by the Kapuskasing Uplift as a window on the lower crust of the Superior Province. Recent multidisciplinary LITHOPROBE investigations have served to clarify the third-dimensional geometry of the structure, at the same time identifying drilling targets of global significance.

To provide a context for the meeting, J.M. Hall (Dalhousie U; Chairman, CCDP steering commitee) briefly reviewed the evolution of the Program, ending with tangible goals expected for the present workshop.

J.A. Percival (Geological Survey of Canada (GSC); workshop convenor) provided an overview of the geology of the Kapuskasing Uplift. Evidence that an oblique crustal cross-section through typical Superior Province crust is exposed over a 100 km wide transect includes: (1) an increase in metamoprhic grade and pressure, from 2-3 kbar, greenschist-facies supracrustal rocks of the Michipicoten Belt, to 7-9 kbar granulite-facies gneisses of the Kapuskasing zone, suggesting a deepening level of exposure; (2) decreases in isotopic ages across the transect, interpreted to reflect progressively slower, static cooling with depth; (3) systematic structural rotations of dykes and gneisses; and (4) high seismic velocities at shallow depths in the Kapuskasing zone, equivalent to those present at greater depth in the surrounding region. Sub-Conrad discontinuity levels, metamorphosed at 25-30 km depth during the Archean, form the base of one or more slabs that were thrust southeastward along the Ivanhoe Lake fault about 2000 Ma ago.

Recent LITHOPROBE seismic results were reviewed by A.G. Green (GSC). Interpretations of the 1984 seismic refraction experiment by several groups show thick crust (up to 52 km) beneath part of the Kapuskasing zone, in contrast with regional 40-45 km values. High surface velocities beneath the Kapuskasing zone can be explained by uplift along a thrust rooted in the lower crust. Reflection profiles from the 1987 survey show abundant, near-surface vents. One strong band of reflections corresponds, in the preliminary interpretation, to the 37° NW-dipping Ivanhoe Lake fault and other short reflection segments may be related to lithological layering within the Kapuskasing gneisses.

J.T. Bursnall (U of Idaho) described the evolution of the Ivanhoe Lake fault in a relatively well-exposed area. Early, mylonitic decoupling structures, exposed rarely, are cut by widespread, small-scale mylonitic and cataclastic shear zones. Later open folding is associated with pseudotachylite generation, possible strike-slip displacement and late, NW-side-down normal faults. Although the fault zone is complex, there may be locations where a section unbroken by the later phases of faulting could be obtained.

J.A. Hanes (Queen's U) discussed the $^{40}Ar/^{39}Ar$ dating method, including laser spot dating of individual mineral grains. Useful constraints on cooling, dyke emplacement and uplift events in the Kapuskasing area have been obtained by conventional $^{40}Ar/^{39}Ar$ geochronology; laser probe work on fine-grained alteration minerals, obtained from drill cores through fault zones, could accurately define the age(s) of faulting and uplift, one of the outstanding problems of Kapuskasing geology. A possible link between late tectonic gold mineralization and late circulating deep crustal fluids could be examined through dating.

Oxide mineral evolution in Kapuskasing granulites was discussed by J.M. Hall. In comparison with oxides in unmetamorphosed igneous and low-grade metamorphic rocks, Kapuskasing ilmenite and magnetite are homogeneous and entirely recrystallized. Late-stage alteration to sphene, hematite and martite may record interaction with deep crustal fluids; to eliminate interference effects of surface alteration in determining the nature of the old fluids, core material is essential.

Potential drilling targets in the northern Kapuskasing Uplift were defined by A. Leclair (MDA, Ottawa). A review of the normal faulted geometry of the Groundhog River Block and its curious lack of an expected positive gravity anomaly suggest that a short hole in the Groundhog River area might reveal a thin (<1 km) sheet of granulite and resolve several enigmatic geological-geophysical features.

T.E. Krogh and L.M. Heaman (Royal Ontario Museum) reported on ongoing U-Pb zircon and sphene geochronology in the Kapuskasing zone. A pattern of complex, prolonged zircon and sphene growth, as revealed by a >100 million-year-range of ages within individual samples, probably records heating, cooling, dehydration/rehydration and deformational events at elevated temperatures. Interaction of fluids and melts between different crustal levels is inferred and could be defined within a short, continuous vertical drill section.

Gold mineralization and its relationship to igneous processes and the tonalite-trondhjemite-granodiorite (TTG) suite was reviewed by E.T.C. Spooner (U of Toronto), using examples of TTG-hosted deposits including the Renabie Mine near the Michipicoten Belt. Various geochemical parameters suggest a source of Au mineralizing fluids in

Geological Survey of Canada Contribution Number 53387

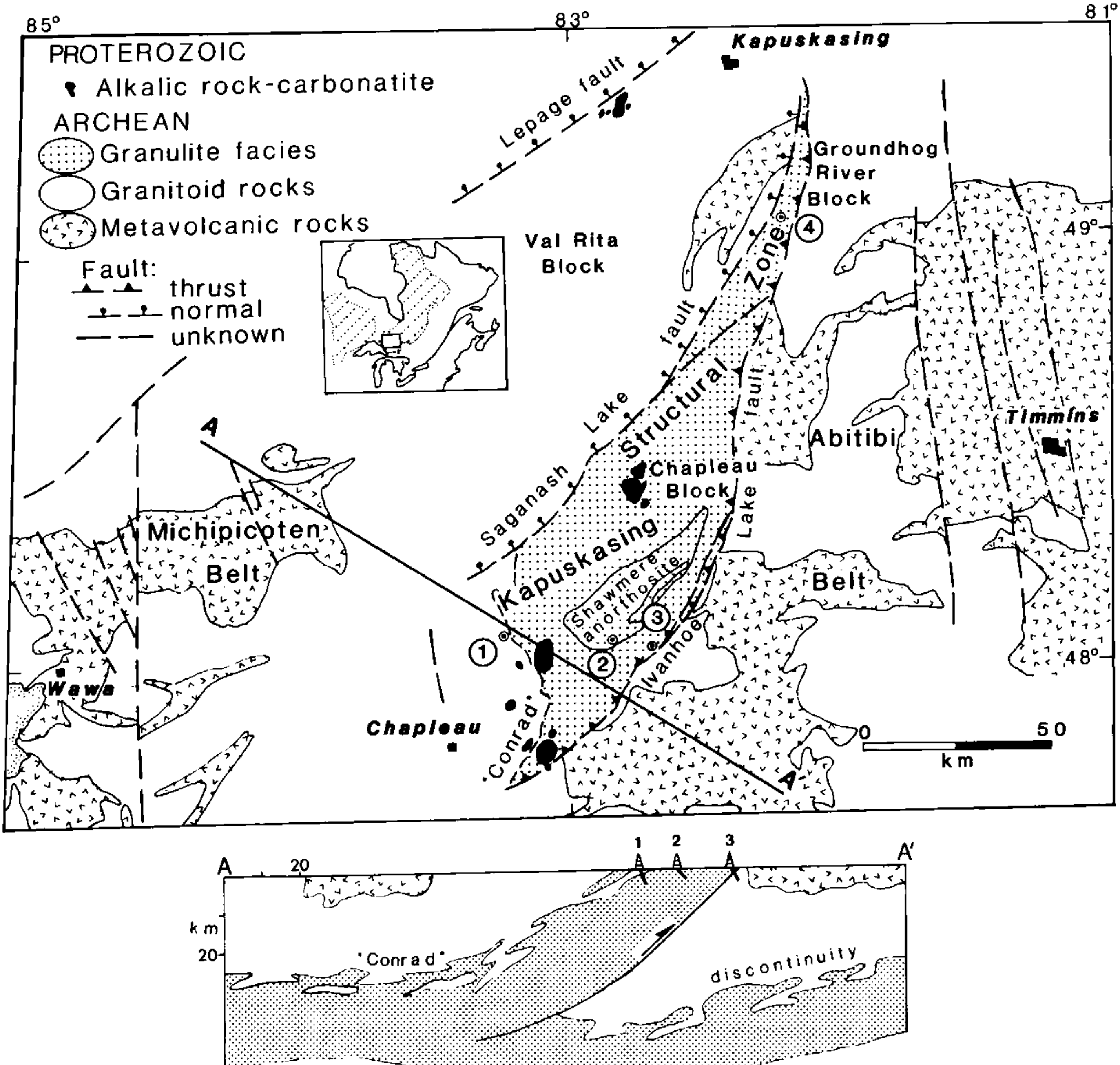
TTG intrusions, although spatial association with greenstone belts is apparent. To investigate this association, mine workings at Renabie could be utilized to sample a greenstone-TTG-Au deposit transect.

R.H. McNutt (McMaster U) and S.K. Frape (U of Waterloo) discussed generally the chemistry and isotopic composition of fluids and gases in the Canadian Shield. The fluids appear to be in isotopic equilibrium with the host rocks, suggesting significant residence time, possibly dating from the time of metamorphism. There may be two types of systems; those with long residence times, such as Sudbury, and those with more mobile fluids, such as Lac du Bonnet. Large volumes and high pressures characterize some systems. Drill holes would permit sampling of fluid cells at different levels.

Results of the late-1960s Kapuskasing geothermal experiment were reviewed by A.M. Jessop (Institute of Sedimentary and Petroleum Geology (ISPG, GSC), Calgary). Lower heat flow and heat production were recorded over the gravity high northwest of the Groundhog River block than over the adjacent terranes, consistent with the presence of high-grade rocks depleted in heat-producing elements. Improved understanding of the three-dimensional structure of the Kapuskasing area will permit new holes to be sited to address problems of heat flow from the lower crust.

M.J. Drury (GSC) reviewed the concept of heat flow provinces, with emphasis on the lower crustal contribution, which is not well known. Fluid circulation cells may account for some of the anomalous heat flow results from the Kola Superdeep hole, but they require a driving heat source, perhaps exothermal rehydration reactions. If hydrothermal cells are depth controlled, then progressive erosion should lead to a vertical pattern of progressively younger paleocirculation cells with depth.

Borehole EM techniques were reviewed by A.V. Dyck (Queen's U). Using an array of holes and various EM systems (EM induction; current channeling; borehole VLF), conductive horizons can be traced over considerable distances to map the subsurface geometry of folds and faults. Even weak conductors such as the Ivanhoe Lake fault might be resolvable. Other techniques, still in developmental stages, will be useful for core orientation.



Paleomagnetic uses of oriented drill core were explained by D.J. Dunlop, V. Costanzo and O. Ozdemir (U of Toronto). These include dating, determination of structural tilts or rotations, and examination of cooling, uplift and alteration/hydration history. Hypotheses developed during LITHOPROBE studies could be tested by drilling (1) into the Shawmere complex, to investigate the apparent changing inclination with depth relationship; and (2) a series of short holes across the Chapleau block to define tilt variations.

The power of vertical seismic profiling for imaging structures of variable orientation was demonstrated by W. Moon (U of Manitoba). Several 3-D source-receiver array combinations were used in examples of various targets. Advantages of VSP over conventional surface profiling methods include relatively low cost and elimination of the static problems often caused by overburden.

M.H. Salisbury (Dalhousie U) reviewed the evidence, from measured seismic velocities in the Kapuskasing transect, that an example of the Conrad discontinuity is exposed near Chapleau (supported by seismic refraction interpretations). The 12 km, 20+ year Kola hole aimed unsuccessfully at penetrating this surface. A well-placed, short (<2 km) hole near Chapleau could provide a continuous section through this elusive, poorly understood feature.

Rock fracture analysis, among other petrophysical tests, were advocated by T.J. Katsube (GSC) on Kapuskasing rocks. Porosity should be greater in uplifted, near-surface rocks than in equivalent horizons at depth as a result of tectonic unloading.

S.M. Wickham (U of Chicago), unable to attend the meeting, suggested that an oxygen isotope profile through the Kapuskasing transect would enable an assessment of the scale of fluid migration, and interaction. D.M. Shaw (McMaster U), similarly absent, advocated whole rock geochemical analyses to define lower crustal composition and fractionation processes.

A discussion of possible sites and targets was initiated by Hall with a review of the CCDP mandate: to encourage scientific drilling of world-class problems in Canada; to develop an agenda for a national drilling program; and to foster international contacts and collaboration.

Targets of immediate global significance are lower crustal reflectors, the non-reflective upper crust/reflective lower crust transition, and the Conrad discontinuity. A change in structural geometry from domal to subhorizontal occurs in gneisses at a similar crustal level. These features can be defined both geologically and geophysically based on existing reconnaissance data, however detailed work to locate appropriate sites is required. Therefore, a small number of judiciously placed, short (2 km) holes would provide continuous profiles through specific features which generally occur only in the deep crust, but are seismically traceable to the near-surface in the Kapuskasing Uplift. A better assessment of targets for drilling will be available when the seismic reflection data are more completely processed.

Verification of the geometry of the Ivanhoe Lake fault also has high priority as the validity of the lower crustal targets hinges critically on the geological and seismological interpretation of the Ivanhoe Lake fault as a thrust. Drilling a 2 km hole through Kapuskasing granulites and the Ivanhoe Lake fault into underlying low-grade rocks of the Abitibi Belt would not only provide the ultimate test of the interpretation but also supply material from the poorly exposed fault for study of reflection characteristics, physical rock properties, fault geometry, kinematics and age.

Similarly, in the northern Kapuskasing Uplift, the geological-geophysical model of a thin granulite sheet overlying granite could be tested with a short hole, at the same time providing material for the study of the enigmatic characteristics of the Groundhog River block.

Although the targets are well defined by surface mapping, seismic reflection profiling and other geophysical techniques, they cannot be continuously sampled owing to imperfect exposure (...5% in most areas). If fluids have played a role in the formation of some of the target features, then because of alteration and susceptibility to erosion these zones may not be exposed. Therefore they may be impossible to understand without core material. Also, direct sampling is essential to make correlations between specific seismic features, which generally cannot be traced closer than to within a few hundred metres of the surface, and their geological and physical characteristics.

By careful selection of sites for short holes to sample specific features of known geological context, drilling costs would be kept to a minimum. Furthermore, the risk factor in drilling near-surface features is much lower than for deeper targets of uncertain position. A significant contribution to the understanding of deep crustal features can be made without pushing the limits of drilling technology, by taking advantage of the well-studied, obliquely exposed cross-section in the Kapuskasing Uplift.

CCDP acknowledges with gratitude funding during its first year of operation from the Canadian Geological Foundation and Inco Ltd. Funding for the workshop was provided by the Natural Sciences and Engineering Research Council.

Accepted 23 March 1988.