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See table of contents

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Scientific Drilling in Sedimentary Basins: A CCDP Workshop Report

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Following the announcement of the Canadian Continental Drilling Program (CCDP) in May 1987, 29 conceptual proposals for drilling-based scientific investigations were received by the CCDP Steering Committee by the end of 1987, the deadline for submission of proposals for the first phase of CCDP operations. The proposals represented a wide range of geological problems in all parts of Canada. The Steering Committee reviewed the proposals and grouped them into themes, with the intention that each theme should be addressed at an open workshop, at which proponents could present their proposals in an environment designed to stimulate full discussion by all interested earth scientists. The first five workshops were on the Kapuskasing Structural Zone (KSZ); the Sudbury Structure; major faults; greenstone belts and associated granitoids; and the Algonquin Arch, Southern Ontario. Reports on each of these workshops, with abstracts, are available free of charge, while stocks remain, from the CCDP Planning Office. Summaries of these workshops have been, or will be, published in *Geoscience Canada*.

The sixth workshop was on the theme "Sedimentary Basins". Held in Calgary on 1-2 March 1989, it attracted 44 participants from industry, the universities and government agencies. The principal intention was to allow discussion of the proposals received before the first deadline, 31 December 1987. However, a number of new proposals were also presented.

The initial proposals, listed in order of receipt, were as follows. The first, from a large team headed by Laurence Vigrass of the University of Regina, was entitled "Additional Scientific Drilling at Exploration Wells (ASDEW)". It addressed the desirability of providing funds to industry to deepen wells being drilled by the oil and gas exploration industry into Precambrian basement underlying the WCSB. The second proposal was from Walter Jones, of the University of Alberta. Entitled "Thermal state of sedimentary basins", it proposed undertaking detailed heat flow studies of the deep sedimentary strata of the WCSB based on temperature and lithological information from the deeper wells in the basin. The third proposal was from John Wilson of the Alberta Geological Survey. It was concerned with the Steen River Structure of north-western Alberta.

The first speaker of the workshop was J.M. Hall (Dalhousie U), chairman of the CCDP Steering Committee, who brought participants up to date with developments of CCDP. He briefly reviewed the earlier workshops and outlined plans for the immediate future — the development of proposals beyond the conceptual stage. He particularly noted that of the approximately 100 holes proposed, 73% would be less than 2 km deep. He emphasised the contrast between possible CCDP projects and those of, for example the Federal Republic of Germany where a single ultra-deep hole (14 km) is planned.

A.R. Sweet (Geological Survey of Canada (GSC)) discussed a proposal for three boreholes intersecting the Cretaceous-Tertiary boundary in the WCSB. The programme would see multidisciplinary studies in three shallow (<300 m) boreholes in different parts of the WCSB, whose primary purpose would be the complete recovery of core spanning the K-T extinction boundary, at which many groups of organisms, plants and animals disappeared. It is now widely believed among earth scientists that the K-T extinction was the result of one or more meteorite impacts; Sweet cited the evidence of anomalously high iridium levels (typically 100-1000 times the background level worldwide) discovered initially in a marine section in Italy by Alvarez. Various other lines of evidence from the boundary, such as the presence of microspherules and shocked quartz, support this theory. Three sites were proposed: Turtle Mountain (Manitoba), Wood Mountain (Saskatchewan) and Cypress Hills (Alberta). The principal objectives would be to determine the exact position, physical characteristics and geochemistry of the K-T boundary, to document biotic changes prior to, at and following the boundary, and to attempt to determine over what time span the extinction occurred.

D. McIntyre (GSC) discussed a proposal to track biotic and climatic change through the Tertiary from boreholes in the Beaufort-Mackenzie Basin. Tertiary rocks of the Arctic contain paleoclimatic information and are therefore important indicators of global change. Two holes were proposed, one onshore and the second offshore, or on an artificial island constructed for hydrocarbon exploration purposes. Limited outcrop has permitted only a partial interpretation of conditions in the Paleogene, with very little data on the Oligocene. Core would enable much better resolution of climatic changes and also of geomagnetic reversals, knowledge of which is essential for detailed stratigraphic studies.

A proposal for drilling in the Old Crow Basin, Yukon Territory, was discussed by J.M. White (GSC). The Old Crow Basin is one of the few areas in Canada where a sedimentary basin could yield a record of nearly continuous Cenozoic subsidence. Palynological studies are predominantly from well cuttings, with the attendant problem that their exact source depth is not known; they do not, therefore, provide good biostratigraphic control. This problem would be overcome if continuous core were available. The Old Crow Basin contains about 600 m of Cenozoic sediment as suggested from seismics. The basin appears to be unglaciated, with little erosion, so that there would be minimal redistribution of fossils. A borehole from the Old Crow Basin would yield significant information on sediments and paleontology of a continental environment to provide a comparison with the more marine sections.

M. Bouchard (U de Montréal) presented a proposal to drill a meteorite impact structure, the Nouveau-Québec Crater, which may represent a small, complete sedimentary basin with an excellent Cenozoic stratigraphic record. The circular feature, with a diameter of 3 km, has a raised rim, and is the best preserved crater known on Earth. It contains a lake 267 m deep in the centre that has no contact with surrounding water bodies. A few centimetres of core of the uppermost part of the sedimentary column have been recovered; they suggest, based on extrapolation of the sedimentation rate and other geological evidence, an age of approximately 8 Ma for the crater. A cored borehole penetrating the sedimentary column and underlying basement would yield information both on climatic change, including a count of the number of continental glaciations, and on the nature of the crater as an impact structure.

A proposal for drilling in the Tertiary Sifton Basin in the northern Rocky Mountain Trench was presented by J.B.W. Wielens (Unocal Canada Exploration Ltd.). The Sifton Basin is probably a rifted structure. It contains a large alluvial fan and lake sediments, including sandstones and conglomerates. The sediments are in oner location breached by the 30-40 Ma old Mt. Balourdet batholith. Palynological studies indicate an upper Paleocene to lower Eocene sequence, formed in a warm, temperate climate, in anoxic water bodies. The lake sediments contain significant amounts of mature to under mature organic matter and are, therefore, potential source rocks for oil. Drilling

would give information on this and similar Rocky Mountain Trench basins and their sediments, and enhance our knowledge about their origin and processes of formation. The seismic lines required to determine a drilling location would give information on the deeper basin structure and the processes involved in the formation of the Rocky Mountain Trench. An organic maturity profile from the borehole would substantially increase our knowledge of the heat flux and of the paleogeothermal regime both horizontally and vertically.

S.K. Frape (U of Waterloo) provided an overview of the Southern Ontario/Algonquin Arch proposal, reported in detail in CCDP Report 89-2. The Algonquin Arch is a Precambrian structural high that, when periodically reactivated during the Phanerozoic, influenced sedimentation and structural development in southern Ontario. Proposed research areas include investigations of: the potential relationship between Paleozoic and Precambrian structures; patterns of fluid migration in the basin; potential rock-contaminant hydrogeochemical reactions; present subsurface stress conditions; the nature of the Grenville basement; the potential relationship between waters and gases found in Paleozoic strata with those in the underlying Precambrian basement; and the detailed effect of the Algonquin Arch on Paleozoic sedimentation.

J.S. Bell (GSC) discussed a proposal for a deep research well in the WCSB. The well would be continuously cored, with substantial sections of oriented core. The core would be used for biostratigraphy, paleoecology, sedimentology, geochemistry, petrography, radiometric age determinations, compressive and tensile strength measurements, density measurements, thermal conductivity measurements, heat generation measurements, seismic velocity measurements, and dynamic and static moduli measurements. Core logging would also be used for calibration of well logs. Borehole investigations would include open hole hydraulic fracturing, drill stem tests for permeability, hydraulic potential and fluid recovery, holographic stress measurement, vertical seismic profiling and leak-off tests. The overall aim would be to obtain a data suite sufficient to make the hole a reference well for the WCSB.

C. Hickson (GSC) discussed a proposed drilling programme in the Anahim Volcanic Belt of central British Columbia. Magnetotelluric soundings between the Rainbow Range and Ilgachuz Range suggest that the volcanic shields are underlain by a relatively shallow (1-2 km) conductive zone that can be interpreted as a completely covered deep sedimentary basin or an active hydrothermal zone. A 3-5 km borehole would identify the nature of the magnetotelluric anomaly. If it is an extension of the Nechako basin or a hidden Cretaceous or Tertiary basin it could have petroleum potential.

The proposal for additional scientific drilling at exploration wells was outlined by L.W. Vigrass (U of Regina). The proposal is aimed at deepening selected oil industry wells in the deeper parts of the WCSB, with the objective of collecting scientific information not otherwise available, both on the Precambrian basement and portions of the sedimentary column below current targets of the oil industry. There are five important areas of scientific interest: (1) geological history, *i.e.*, deciphering the nature of the Precambrian basement in terms of the development of mobile belts and continental accretion; (2) obtaining basement samples by coring approximately 100 m into basement; (3) examining heat generation in and heat flow from the basement with respect to, for example, intracratonic subsidence; (4) examining fluid flow in shallow basement and in the rocks immediately above basement; and (5) examining the relationship between Precambrian geology and the overlying Phanerozoic rocks.

The state of our understanding of Precambrian geology under the WCSB, particularly beneath the Williston Basin, was reviewed by J.F. Lewry (U of Regina). The Williston Basin lies across southern extensions of the Early Proterozoic Trans-Hudson Orogen, exposed in the shield to the north. Three orogenic zones are recognised: from east to west these are (a) the Churchill-Superior Boundary Zone, mainly comprising reworked Pikwitonei granulites of the contiguous Superior Craton; (b) the Reindeer Zone, a refolded imbricate thrust-nappe complex mainly comprising juvenile Early Proterozoic arc volcanics, plutons and volcanogenic clastics; and (c) the Cree Lake Zone, a broad zone of remobilised Archean basement and Early Proterozoic platform-miogeoclinal supracrustals. Southern extrapolation of orogenic zones is based mainly on aeromagnetic and gravity data. Present sparse basement core data, including U-Pb zircon ages and Sm-Nd isotopic data, impose few controls on geophysical data: more data, derived from drilling into basement, are badly needed.

In a complementary presentation, G.M. Ross (GSC) reviewed our knowledge of basement features with emphasis on the western part of the WCSB in Alberta. An integrated geochronological, and geophysical study has provided new insights into the crustal structure and timing of assembly of the components of the Canadian Shield buried in the Alberta subsurface. Extrapolation of the kinematic framework established for the exposed shield constrains the history of plate collisions to one in which the assembly of dated tectonic elements (2600-2100 Ma) was brought about by plate consumption along zones inferred to be magmatic arcs (2000-1800 Ma) and transcurrent shear zones. The study provides a framework for the selection of additional basement sampling areas in the Alberta part of the WCSB.

A proposal to drill the Steen River Structure of north-western Alberta was presented by J. Wilson (Alberta Geological Survey). The structure is roughly circular with a diameter of approximately 25 km. It consists of a central portion, uplifted about 1200 m above regional basement level, which brings basement to within 200 m of surface. Around this is a circular depression downwarped as much as 600 m below the regional level. The structure is known only from geophysics and drilling, but its shape and the presence of shock metamorphic features from the central uplift indicate an extraterrestrial origin. K-Ar and Rb-Sr dating of one sample of melt rock suggest an age of 95 Ma. The objectives of a drilling programme would be to determine the nature, tectonic history and age of the structure, to determine its hydrocarbon and mineral potential, and to determine its temperature history and the history of fluid flow patterns. The programme would see diamond drilling of the central uplift, to obtain a continuous core through the breccia and melt zone, and oilfield drilling of the surrounding Cretaceous rocks and of the syncline, to obtain core through problematical stratigraphic sections and of the downfaulted basement and possible major fault intersections.

C. Harper (Saskatchewan Department of Energy and Mines) discussed possible kimberlites in the WCSB. Unsubstantiated claims of diamond discoveries in north-central Saskatchewan were made in 1948 and 1961, and recently the presence of kimberlitic pipes in the Prince Albert area have been reported. Gas wells in the vicinity of the Sweetgrass Arch cluster of intrusions contain high levels of CO_2 in association with nitrogen, helium and other rare gases. Gas-rich inclusions in diamonds commonly contain high levels of CO_2 and nitrogen, and kimberlites themselves are commonly rich in carbonate. The questions were posed: is it a coincidence that marls have formed and are still forming at Sturgeon Lake, and can the presence of high levels of CO_2, nitrogen and other inert gases be used as an exploration guide in locating unexposed diatremes of kimberlitic affinity?

Our state of knowledge of heat generation in the basement underlying the WCSB was discussed by R.A. Burwash (U of Alberta). Heat generation of basement samples from analysis of radiogenic isotopes of uranium, thorium and potassium shows a wide range, between less than 0.02 and approximately 4 $\mu W \cdot m^{-3}$. Trend surface analysis has indicated an east-west belt of above average heat generation across the northern half of Alberta. There is a parallel weak and poorly defined trend in southern Alberta. A major problem is the uneven geographic distribution of data. Dating of basement samples indicates a Kenoran age from Nd-Sm and a Hudsonian age from Rb-Sr. The trend surface can probably be explained in terms of

Hudsonian metasomatism. Several data gaps might be addressed by appropriate locations for ASDEW or other basement tests.

A.M. Jessop (GSC) extended Burwash's presentation to examine the relationship between heat flow from the basement and heat generation within it. Conductive heat flow at the Earth's surface consists of a component from the mantle and a component from the crustal heat generation. Because of the large perturbation arising from moving fluids, heat flow measurements in the sediments are not reliable indicators of basement heat flow. Mean heat flow in the exposed Superior Province is approximately 42 $mW \cdot m^{-2}$. As the basement of the WCSB has been spared some 600 Ma of erosion of heat-producing upper crustal rocks, heat flow from it may be expected to be somewhat higher. Heat generation measurements of basement samples do provide a means for estimating basement heat flow, but for accurate determinations one must drill deep enough into basement to obtain a good measurement of thermal gradient. An advantage of estimating heat flow from heat generation is that as the decay constants of the radiogenic isotopes are known, heat flow can be extrapolated backwards in time to permit an assessment of thermal history of the basement, which is relevant to hydrocarbon maturation.

F.W. Jones (U of Alberta) discussed two heat flow anomalies in the WCSB: in the Hinton-Edson area of west-central Alberta and part of the Williston Basin of southern Saskatchewan, both of which have both heat flow and electrical conductivity anomalies. Both have been defined from analysis of bottom-hole temperature (BHT) data. The Hinton-Edson anomaly is on strike with the Miette Hot Springs, which suggests it arises from water movement. However, magneto-variational studies in the area suggest a zone of anomalously high crustal electrical conductivity in the area. The Williston Basin thermal anomaly is a linear feature extending north-south along the 103°W meridian, to the west of the North American Central Plains electrical conductivity anomaly. Recent magnetotelluric soundings have also indicated an anomalously high electrical conductivity with an anticlinal form coincident with the heat flow anomaly. Computer modelling of an anticlinal structure with anomalous heat generation and thermal conductivity values produces model heat flow profiles similar to the real one. Basement drilling to allow better measurement of heat flow would shed light on the nature of these two anomalies.

Two papers were concerned with studies that should be undertaken in any scientific drilling project. D.R. Schmitt (U of Alberta) reviewed methods of measuring crustal stress in boreholes. Techniques for measurement of stress at depth include hydraulic fracturing, in which a fracture is created by pressurising an interval of borehole; examination of borehole breakouts, which are caused by compressive shear failure of the borehole wall due to the concentration by the borehole of regional stresses; anelastic strain recovery, in which monitoring of core volume increase allows principal stress directions to be determined by comparing the creep recovery in all directions; differential strain analysis, in which the strain tensor as a function of pressure is measured; borehole guided wave polarisation, which uses the observation that horizontal particle motions recorded from vertical seismic profiling are polarised in the direction of the greatest horizontal principal stress; and borehole holography, in which a holographic camera is used to record a stress relief displacement field induced by drilling a small hole perpendicularly into the wall of the borehole. T.J. Katsube (GSC) reviewed petrophysical measurements on recovered core samples, to determine permeability and porosity and their variation with depth. Rocks from greater than 10 km depth could be quite permeable and electrically conductive, depending on their tectonic and stress history.

In the final presentation, M.J. Nusse (Touchstone International Inc.) described a proposal, independent of CCDP, for a neutral test well calibration facility. Currently the only public facility is in Houston, Texas, USA. A facility in the WCSB would provide a service for government agencies, service companies, educational companies and research and development companies. A site in central Alberta, south-east of Red Deer, is being considered.

After the formal presentations, participants broke into several working groups to plan the subsequent development of the various proposals. The CCDP Steering Committee anticipates that the proposals will be brought to a more mature stage for presentation at a national discussion meeting planned for 28-29 August 1989, in Ottawa, at which a plan for a first phase of scientific continental drilling in Canada will be suggested and discussed.

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The Industrial Associate Members of CCDP are currently: BP Canada, Bradley Bros. Ltd., Chevron Canada Resources, Esso Minerals Canada, Falconbridge Ltd., Heath and Sherwood Drilling (1986) Ltd., Inco Gold Co., JKS/Boyles Industries Inc., Longyear Canada Inc., Midwest Drilling, Newmont Exploration Ltd., Noranda Explorations Ltd., Petro-Canada Inc., Teck Explorations Ltd. and Tonto Drilling Company.

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