numerous shallow top values.

GLENDAY, KEITH S., and T. R. LENNOX,* Gulf Canada Resources Inc., Calgary, Alberta, Canada

The Gulf/AOSTRA Surmont Project—South Athabasca Oil Sands Deposit, Alberta, Canada

In September 1979, Gulf Canada Resources Inc. and the Alberta Oil Sands Technology and Research Authority entered into an agreement to determine the technical, economic and environmental feasibility of recovering bitumen from oil sands utilizing a system of horizontal wells and a steam recovery process. Two methods of access to the bitumen-bearing formation were to be considered: wells drilled from the surface and whipstocked to the horizontal, and wells drilled from tunnels located either above, within, or below the pay zone. It is believed that a horizontal well system is more cost effective, will have better recoveries, and have less environmental impact than a vertical well system.

The project site is located approximately 330 km (205 mi) northeast of Edmonton, Alberta, in the southern extent of the Athabasca oil sands deposit. The oil-bearing, Lower Cretaceous McMurray Formation occurs at a depth of 275 m and ranges in thickness from 64 to 87 m. Gross oil pays range in thickness from 25 to 43 m. At this location, the McMurray Formation is interpreted as having been deposited in a fluvial environment grading upward into a coastal plain and shallow-marine environment.

Due to the complex nature of the in-situ recovery process, it is essential that the geology of the oil-bearing sands is accurately interpreted with respect to channel and permeability trends. Other geological problems associated with the recovery process involve water supply and disposal. Steam recovery systems require large quantities of boiler quality water; hence, a reliable supply of relatively inexpensive water must be in place prior to pilot start-up. Also, owing to the large amounts of water produced, adequate underground disposal must also be available.

GONZALEZ, BENJAMIN R., Stephen F. Austin State Univ., Nacogdoches, TX (now with Gulf Oil Co., New Orleans, LA)

Facies Analysis of Pinnacle Reefs of Guelph Formation (Middle Silurian), Northern Michigan

Five facies were defined on the basis of a Q-mode cluster analysis of petrographic data derived from well core samples of five Guelph Formation pinnacle reefs. The five statistically significant facies are crinozoan facies, bryozoan facies, mixed skeletal facies, stromatoporoid-coral facies, and brachiopod facies. Additionally, empirical data were used to define an algal facies.

Pinnacle reefs initially formed as carbonate mud mounds when bryozoan and crinozoan "mud dwellers" baffled and trapped sediment. This mechanism allowed the mounds to grow upward into a zone near wave base. As mud-mound buildup reached wave base, an ecological regime suitable for the development of a stromatoporoid-coral reef was established.

Guelph Formation pinnacle reef growth ended after the deposition of an algal boundstone lithofacies. Crests of pinnacle reefs were at or close to sea level prior to a major sea regression marking the end of the Niagaran Series.

GOODMAN, EMERY D., Shell Oil Co., New Orleans, LA, and ROBERT EHRLICH, Univ. South Carolina, Columbia, SC

Dispersal and Provenance of Terrigenous Sand by Fourier Grain Shape Analysis, Northern Puerto Rico

The narrow, steep, north insular shelf of Puerto Rico contains terrigenous sands and silts derived from rivers originating in nearby mountains. This compact system provides an ideal setting for the study of sand sized sediment dispersal and provenance in coastal and nearshore environments using Fourier shape analysis.

Quartz sand shape on the north shelf reflects the lateral change in source-rock composition. The shelf can be divided into a western part containing dominantly angular quartz grains and an eastern part containing rounded abraded quartz sand. Rivers feeding the western shelf drain a significant body of granitic rock, whereas rivers to the east drain a quartz-poor, volcanic rock terrane. Rounded grains on the eastern shelf are mostly relict.

Quartz sand shapes do not change significantly with changing size either upstream or on the shelf. A size-shape dependence does exist in downstream, river mouth, and slope environments (fine sand is more angular than coarser sand) and on beaches (fine sand is more abraded than coarser sand).

It is significant that environments in which size-shape relationship exists are also sites of mixing between sands of different origins and transport histories. For example, samples studied from downstream and river mouth areas indicate mixing between fine-grained, angular fluvial sand, and coarser, smoother residual sand. Mixing occurs because fluvial sand is deposited on the shelf only when storm-induced flooding results in river-mouth bypassing.

This study suggests that investigations into the origin of size-shape relationships can aid in understanding climatically controlled, short-term changes in terrigenous output.

GORDY, PETER L., Shell Canada Resources Ltd., Calgary, Alberta, Canada

Hydrocarbon Accumulations in Overthrust Belt of Alberta

Estimated proved and probable ultimate reserves of marketable natural gas in Alberta are 80.5 tcf, of which approximately 10.5 tcf are in Paleozoic carbonate reservoirs that have been involved in thrust faulting in the Foothills belt of Alberta. Interpretation of exploration data in this belt has contributed significantly to our understanding of the geology of the southern Canadian Rocky Mountains as a whole.

The Precambrian basement is overlain by a westward-thickening prism of Paleozoic sedimentary deposits that contain important reservoirs in Upper Devonian and Mississippian carbonate rocks. Approximately 8% of the reserves are in the Upper Devonian and 87% in the Mississippian. There is close correlation between reserves found and facies trends within the Mississippian Rundle Group. A widespread organic-rich source rock, the Exshaw Formation, provided the major charge for both Mississippian and Devonian reservoirs. Jurassic marine shales overlie the Mississippian in the southern part of the belt and form an effective seal and possible source rock. In the northern part of the belt, the Mississippian is overlain by Triassic sedimentary rocks in which reservoirs are present. Cretaceous sandstones generally lack reservoir qualities and less than 5% of the reserves found to date are in the Cretaceous.

The Outer Foothills are characterized by closely spaced listric thrust faults that repeat the Mesozoic section. Some of the thrusts cut deep enough to carry a single or multiple thrust slices of Mississippian carbonate rocks. Trap capacity is governed by horizontal displacement, vertical uplift, convergences of allochthonous and autochthonous structural strike, and probable seal quality to the thrust planes. Approximately 18 significant gas-bearing structures containing 5 tcf marketable reserves have been discovered.

The surface geology of the Inner Foothills is characterized by outcrops of Paleozoic carbonate rocks and relatively undeformed Mesozoic strata. Usually two or more thrust sheets are stacked in a general anticlinal form and provide multiple objectives. To date, 14 gas-bearing structures have been discovered in this zone containing approximately 5.5 tcf of gas. The gas-bearing structures in the Waterton-Carbondale and Moose Mountain Panther River areas are typical. The gas-bearing post-lower Paleocene structures probably are related to the time of maturation of the major source rock and the west-to-east deformation of the southern Canadian Rocky Mountains. Despite the large areas of the Alberta Foothills belt in which exploration is restricted, it is estimated that 6 to 14 tcf of gas may still be found.

GRETENER, P. E., Univ. Calgary, Calgary, Alberta, Canada

On the Use of the Modified Lopatin Method

The modified Lopatin method (detailed description in AAPG Course Note Series 17) can provide quick estimates of the state of organic metamorphism. To do so, it is necessary to evaluate the thermal history of a potential source rock. Under favorable conditions, such as uniform burial in an environment of constant geothermal gradient, it is possible to approximate the actual thermal history by a linear temperature rise. For such simple situations, the method yields essentially instantaneous results without the help of any artificial aids. The method is equally applicable to more sophisticated models, but those require a careful analysis of the burial history and an evaluation of the possible changes of the terrestrial heat flow during the lifetime of a source rock.

Examples of the use of the method will be shown and the current limitations imposed by various uncertainties and approximations will be discussed.

GRIES, ROBBIE, AMAREX, Inc., Denver, CO

North-South Compression of Rocky Mountain Foreland Structures

Petroleum exploration beneath Precambrian on the flanks of Rocky Mountain foreland structures has revealed substantial throw on east-west-trending thrusts which has not been predicted by underthrust models of west-directed tangential compression. Recognizing this north-south compressional component in the foreland necessitates a new look at the forces that formed these structures.

Initial compression that developed foreland structures was dominantly from east to west and was caused by westward movement of the North American plate during the opening of the Atlantic Ocean in Late Cretaceous. Atlantic spreading progressed to the North Atlantic and Arctic Oceans in Late Cretaceous and early Tertiary. It is proposed that movement of the North American plate evolved from west to southwest to south, causing not only significant southwest and south movement on several foreland basement-involved thrusts, but also termination of movement in the detached Idaho-Wyoming-Utah thrust belt.

Major east-west-trending foreland structures include the Owl Creek Range, the south flank of the Wind River Range and the south flank of the Granite Mountains in Wyoming, the Uinta Mountains in Utah, and the north flank of North Park basin in Colorado. North-west-trending foreland thrusts, such as the southwest flanks of the Casper arch, and Gros Ventre and Wind rivers in Wyoming developed during the transition from east-west to north-south compression.

GRIFFITH, ROLAND LYLE, JR., Univ. Maryland, College Park, MD

Investigation of Beasman Prospect, Sykesville Mining District, Maryland, with a Proton Precession Magnetometer

The Sykesville copper-iron district is centrally located in the Piedmont upland of Maryland. Extending through the northeastern half of the district is the Monroe and Beasman prospect, where magnetite-quartz veins occur in steeply dipping faults or shear zones. To find the locations and configurations of the veins, traverses parallel and perpendicular to the strike of known localities of magnetite have been made using the proton precession magnetometer. A magnetic anomaly map with profiles will be developed and interpreted using the dipole system method and known geology of the area. Preliminary results suggest that the veins are discontinuous parallel to strike and dip toward the southeast.

GROVER, G., JR., Gulf Oil Exploration Co., Midland, TX, and J. F. READ, Virginia Polytechnic and State Univ., Blacksburg, VA

Near-Surface to Deeper Burial Cementation Patterns and Foreland Basin Evolution, Middle Ordovician Ramp Carbonates, Virginia

Middle Ordovician ramp carbonates, Virginia, were deposited in a subsiding foreland basin bordered by developing tectonic highlands. Ramp carbonates are largely occluded by nonferroan, clear rim, and equant cements which contain cathodoluminescent zones consisting of nonluminescent (oldest), bright and dull (youngest) cements. The zonation largely relates to increasingly reducing conditions of pore waters. Zoned cements in peritidal beds have complex zonations, pendant to pore-rimming fabrics, and are associated with vadose silt (which abuts all cement zones); these cements are vadose to shallow phreatic. Major cementation of subtidal facies occurred under burial conditions. Zoned burial cements have a simple zonation reflecting progressive burial (up to 3,000 m) of carbonates. Shallow burial nonluminescent cement formed from oxidizing, meteoric waters which expelled anoxic, connate marine waters; meteoric waters were carried by aquifers from tectonic upland recharge areas. Deeper burial, bright and dull cements formed at depths (2,000 to 3,000 m) and temperatures (75 to 135°C) associated with hydrocarbon emplacement during the Late Devonian or Mississippian. Final, clear dull cement fills tectonic fractures and was emplaced during late Paleozoic deformation. Deeper burial diagenesis appears to be genetically linked to late Paleozoic, Mississippi Valley-type mineralization. Zoned peritidal and burial cements are mainly confined to southeastern parts of the ramp, where cementation was influenced by meteoric waters from developing uplands on the southeastern margin of the foreland basin and carried northwest by aquifers. Cements in northwestern peritidal and subtidal ramp facies are dominated by nonzoned dull cements, where cementation was little influenced by upland-source meteoric waters. The close association of zoned cements and regional