tural analysis reveals the following paragenetic sequence: (1) calcareous fossils and ooids, (2) silica/pyrite, (3) chamosite, (4) siderite, and (5) hematite.

Petrographic evidence suggests a quiet water back-reef origin for the calcareous oolite. The first secondary minerals to form are pyrite and silica, the latter being mostly concentrated in foraminiferal tests. The mutually replacive relationship of silica and pyrite implies their cogenetic origin in a reducing barred environment. Abundant diagenetic chamosite formed next, replacing calcareous ooids and fossils in a still reducing but shallower environment. At this stage, dissolution of original carbonate sediments resulted in a high concentration of carbon dioxide in the basin facilitating precipitation of siderite. Hematite formed last in an oxidizing environment at the expense of earlier formed iron-bearing minerals. The abundance of pyrite/siderite and a corresponding scarcity of hematite in subsurface samples and the reverse relationship in outcrop samples imply oxidation of pyrite/siderite under surface conditions to produce hematite. The source of iron for the ferriferous minerals could be lateritization of emergent source rocks during a regressive phase. Fluvial supply either as hydrosols, colloidal suspension or adsorbed particles on clays would have concentrated the iron in a barred environment. Shelf-margin barriers in the form of shoals and reefs (for example, the El Guamo and Berlin limestones) prevented dilution and loss of the iron-bearing solution which on reaching sufficient concentration started precipitating different minerals under different Eh-pH conditions.

GIES, ROBERT M., Canadian Hunter Exploration Ltd., Calgary, Alberta, Canada

Origin, Migration, and Entrapment of Natural Gas in Alberta Deep Basin: Part 2

Gas entrapment in the Elmworth deep basin occurs under a variety of conditions. Typical trap types include (1) stratigraphic, (2) structural-stratigraphic, and (3) deep basin. The deep basin type of gas trap is the most important in terms of its large size and unconventional trapping conditions. The three main physical conditions associated with the deep basin type of gas trap are (1) an updip water/gas contact, (2) a downdip gas/water contact is generally absent, and (3) the original reservoir gas pressures are equal to, or less than, water pressures at the same depth based on extrapolation of water pressure gradients from the updip water saturated region.

The physical principles underlying this kind of gas entrapment, together with the intimate association of mature source rocks, constitute a fundamental relationship which is applicable to gas exploration in other sedimentary basins of the world.

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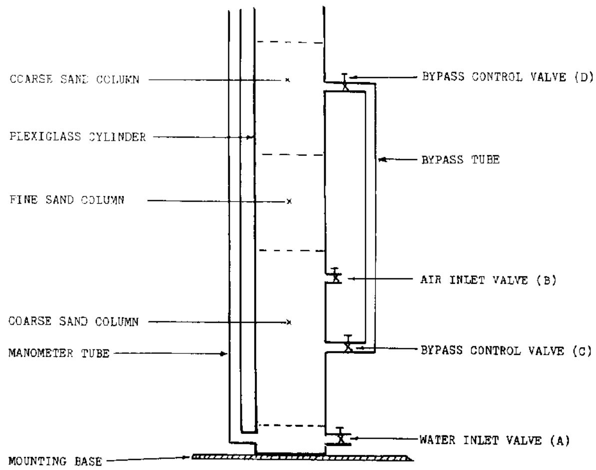
Basic Physical Principles of Conventional and Deep Basin Gas Entrapment

The model consists of a transparent plexiglass cylinder 2.5 in. (6.35 cm) in diameter and about 30 in. (76 cm) high mounted on a support stand. The cylinder contains a sand pack made of coarse, loose sand separated in the middle by 7 in. (17.8 cm) of loose fine sand. Permeability of the coarse sand is in excess of 1,000 darcys while that of the fine sand is several hundred darcys. The device was invented by me to study the behavior of gas and water flow through porous media and in particular to investigate the characteristics of conventional and deep basin types of gas traps.




The first demonstration represents the conventional trapping case. The second demonstration shows pressure/depth graphs for fluid phases to be identical with those found for the Elmworth deep basin gas traps, i.e., at the updip contact, the gas and water phase pressures are about equal as opposed to the conventional case where the gas pressure was much greater than the water pressure at the contact. Also, the downdip water column beneath the gas column is shown, in both cases, not to be in pressure continuity with the water column in the upper coarse sand column, even though there is a continuous water film wetting the sand grains through the gas-saturated coarse sand connecting the water-saturated fine sand with the water-saturated coarse sand below the gas column.

The fluid flow process through the depressured gas column from the upper water-saturated sands to the base of the gas accumulation will also be discussed.

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Reflection of Topography on Pre-Cretaceous Unconformity Through Overlying Section in Central Alberta

Topographic highs and lows on the Pre-Cretaceous unconformity of central Alberta are reflected as irregularities on the structure of overlying formations. These highs and lows are many times themselves reflections of changes in the deeper stratigraphy. In some places, the effects of large highs and lows can be seen directly on structure maps of Cretaceous formations. For example, the Leduc reef chain, which itself is up to 1,000 ft (305 m) below the unconformity, causes anomalies in the structure of all overlying formations and its effects can even be seen in the present-day topographic surface.

However, many irregularities on the unconformity are small and their effects are masked by the regional dip of the Alberta basin. Their effects also become more diffuse on the upper formations.

Trend surface analysis on the structure of the overlying formations removes the regional trend from the data, and these more subtle highs and lows can be recognized. They can be seen not only as differences between positive and negative residuals, but also as relative highs and lows within areas of positive and negative residuals.

Advantages of using residual maps of the structure of Cretaceous formations to locate highs and lows on the Pre-Cretaceous unconformity include: (1) showing that some structural and stratigraphic traps are a direct result of irregularities on the unconformity, and (2) despite limited well control to the unconformity, highs and lows can be mapped using the more 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