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Offshore World Petroleum Frontiers

The potential to find the large oil and gas fields of the future lies in the offshore frontiers. Exploration for petroleum in the coming decades must be concentrated on discovering commercial supplies of the hydrocarbons that lie untapped in these areas. New and better uses of geology, geophysics, petroleum engineering, and technology must be employed in all aspects of exploration, development, and production. Vital to accomplishing these tasks is an in-depth knowledge of the characteristics of basin areas and offshore frontier regions. New exploration strategies must be formulated for exploration in both moderate and harsh offshore areas. New technology for drilling and producing oil and gas, especially in Arctic regions and at greater depths globally than heretofore considered feasible, must also be advanced rapidly. As part of a unified exploration effort, each specialized discipline—whether geology, geophysics, or petroleum engineering—has to provide the bold and innovative thinking that will lead to the offshore discoveries of the oil and gas the world needs for future energy survival. This paper illustrates with slides the location of these promising offshore areas and the basins involved.

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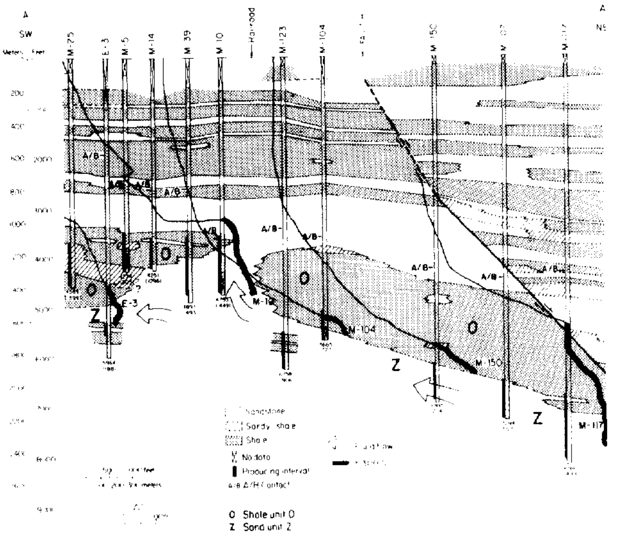
Geologic and Geothermal Fluid Flow Models of Cerro Prieto Field

A detailed hydrogeologic model of the liquid-dominated Cerro Prieto geothermal field in Mexico (located in Baja California about 35 km [22 mi] south of the U.S. border) has been developed to identify subsurface geothermal fluid flow paths. This was accomplished by integrating downhole temperature profiles and depth of production intervals with a geologic model derived from the interpretation of geophysical and lithologic well logs.

Two different methods were used to define the geologic model of the Cerro Prieto field. In the first, the lithology was divided into seven different formations based on correlatable groups of beds having distinct lithologic, structural, and fluid production characteristics. In the second method, the lithology was classified into three basic types of lithofacies: shales, sandy shales, and sands. Faults identified by the first method were incorporated into lithofacies sections.



Geothermal fluid flow paths were identified by integrating well temperature profiles and the depths of geothermal well production intervals with the lithofacies cross sections. Hot fluids are believed to enter the field at depths greater than 3,000 m (10,000 ft) from the east through a thick, porous sand unit, called Sand Unit Z, which dips gently to the east. This unit underlies a 450 to 600 m (1,500 to 2,000 ft) thick low porosity shale unit, named Shale Unit O, which acts as a local caprock. The fluids flow westward until they encounter a normal fault, Fault H, with downthrow to the southeast. The fluids then move up along this fault until they again encounter Sand Unit Z along the upthrown side of Fault H. Whereas most of the fluids continue to flow westward through Sand Unit Z, a small portion rise along Fault H, as evidenced by high temperatures found at shallow depths in the faulted region. The westward flow continues until it reaches a gap in the overlying Shale Unit O. There, some of the flow rises up and into the western Shale Unit O, which is sandier in this region, while the rest continues to flow westward through Sand Unit Z. Eventually, some of the geothermal fluids leak to the surface, whereas the rest mix with colder waters that surround the geothermal system. A number of cross sections detailing the subsurface movement of the geothermal fluids are shown.

This hydrogeologic model is consistent with other geologic, geophysical, geochemical, and reservoir engineering studies carried out at this field.

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Computer-Aided Exploration for Small Companies

Recent advances in computer hardware technology have created a trend of lower prices and higher performance. Today, both individuals and small companies can afford computer equipment for geoscience applications. The question is often asked, "What is necessary to initiate the use of computer technology to assist in the exploration process?" This paper reviews the hardware, software, and techniques involved in computer-aided exploration.

Basic hardware requirements for geoscience applications are a digitizing tablet for data capture, a processor and peripherals for data analysis, and a plotter for displaying results. Software is available for common applications such as digitizing, log analysis, and mapping. Nortex has purchased a digitizer and plotter and shares part of a computer with the business group.

Nortex has both purchased application programs and hired programmers to develop applications internally and maintain the present software. Applications include log digitizing and analysis, seismic data digitizing, mapping and retrieval from WHCS data, and trend surface and residual analysis.

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Larger Foraminifera as Depth Indicators in Carbonate Depositional Environments

Studies of living larger foraminifera have provided several breakthroughs pertinent to the use of their ancient analog in paleoenvironmental interpretation. The first of these insights is that modern larger foraminifera are nutritionally dependent upon algal symbionts and are morphologically adapted to house those symbionts. The second is that algal symbiosis is energetically highly advantageous under nutrient-deficient conditions such as those prevalent in well-developed modern coral reef environments. In addition, experimental evidence demonstrates that the availability of light and water turbulence in the environment influences shapes and sizes of modern foraminifera.

By analogy, assemblage composition, including the presence and abundance, or absence, of planktonic and smaller benthic species, along with shapes and size distributions of the larger foraminifera, can be used in paleodepth analysis and to supplement other petrographic evidence in carbonate facies interpretation.

Among the current limitations of the use of larger foraminifera as paleodepth indicators are the complications caused by taxonomic heterogeneity of both the larger foraminifera and their algal symbionts. Nevertheless, the potential for use of larger foraminifera in paleoenvironmental analysis is tremendous, as is the potential benefit of further studies of both modern and ancient assemblages of larger foraminifera.

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Facies Analysis and Petroleum Potential of Smackover Formation, Western and Northern Areas, East Texas Basin

The Smackover Formation (Upper Jurassic) in northeast Texas is a transgressive-regressive carbonate sequence which has been extensively dolomitized. The extent of dolomitization is directly related to the presence of the overlying Buckner anhydrite which has provided the magnesium-rich brines necessary for dolomitization.

The Smackover Formation is subdivided informally into a lower and upper member based on distinctive lithologic characteristics. The lower member, which rests conformably on the fluvial-deltaic sandstones of the Upper Jurassic Norphlet Formation, contains a laminated, organic carbonate mudstone facies that grades into an overlying locally fossiliferous, pelletal-micritic facies. The vertical sequence of facies indicates a transgression of the sea. They are interpreted to represent an inter-tidal mudflat to shallow-marine, low-energy platform or protected lagoonal environment. The upper member of the Smackover Formation consists mainly of broken skeletal debris and pelletal allochems in a micritic matrix. The sediments are better winnowed and better sorted upward in the sequence. Interbedded with and overlying the skeletal-pelletal facies is a clean well-sorted dolomitized oolitic-grainstone facies. This uppermost informal member marks the beginning of a progradational sequence which lasts throughout the remainder of Smackover deposition and continues through deposition of the evaporites and red beds of the overlying Buckner Formation.

Deposition of the Smackover Formation most closely resembles Holocene carbonate sedimentation in the southern Persian Gulf. Both areas are represented by a similar carbonate ramp depositional framework together with closely approximated salinity and climatic conditions.

Most of the Smackover production in northeast Texas occurs along the Mexia-Talco fault zone in the deeper gentle salt-related anticlines and salt-graben systems. Reservoir rocks are primarily leached and dolomitized oolitic grainstones and dolomite. Laminated organic carbonate mudstones which characterize the lower, transgressive phase of the Smackover Formation provide an excellent source rock for petroleum.

Exploration targets for the Smackover Formation are the areas where dolomitized oolitic and skeletal grainstones occur on top of structurally high areas such as over salt ridges or swells in the deeper portions of the basin. Along with this are those areas along the updip limit of the Smackover Formation in which the upper member has been leached and dolomitized and occurs in a stratigraphically favorable position.

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Aragonite Crusts and Pisolites Beneath Dolomitic Tepees, Lake MacLeod Evaporite Basin, Western Australia

Research currently being conducted by the Sedimentology and Marine Geology Group, under Brian W. Logan at the University of Western Australia, has recently concentrated on Lake MacLeod, a 2,000 km^2 (770 mi^2) coastal salina on the western coast of Australia. This work has shown that this evaporite basin, which is 3 to 4 m (10 to 13 ft) below sea level, is separated from the Indian Ocean by a topographic barrier, but seawater under hydrostatic head, seeps freely through the barrier and discharges from several vents and springs in a carbonate mud flat at the north end of the basin. From there, seawater flows slowly across the basin, evaporating and depositing carbonate, gypsum, and ephemeral halite. About 10 to 12 m (33 to 39 ft) of evaporites have been deposited in the past 5,300 years.

In July 1982, the authors visited the carbonate mud flats and discovered abundant aragonite pisolites and botryoidal-mammillary crusts of fibrous aragonite cement beneath "lily-pad" tepee slabs of cemented protodolomite. This protodolomite host-rock is well-lithified, intraclast, peloid packstone with abundant coarst fenestrae. Thick aragonite crusts cover both the undersides of "lily-pad" slabs and the lithified floors of tepees. Crusts covering the floors are more botryoidal and consist of both aragonite nubs and mounds (0.2 to 2.5 cm, 0.08 to 1 in., in diameter), and a few scattered, loose pisolites, several millimeters in diameter. Pisolites are composed of multi-generation fibrous layers of square-tipped aragonite rays surrounding peloid-intraclast nuclei. Thus, it seems that periodic deposition of a fine layer of carbonate mud, peloids, and intraclasts across the floor of a tepee is a prerequisite to pisolite growth.

Stable isotope analysis of the host rock and aragonite cements gave expected marine values ($\delta^{18}O = +0.25$ to $+1.14$ PDB and $\delta^{13}C = -0.18$ to $+0.16$ PDB) and reflect precipitation from ground water (marine composition) discharging from seeps in the carbonate mud flats.

The manner in which crusts, pisolites, and tepees occur at Lake MacLeod raises the possibility that they and their ancient counterparts from the Permian basin share a common origin. Perhaps Permian pisolites and aragonite crusts formed beneath cemented slabs of peritidal sediments in tepees bathed by marine water which seeped across exposed portions of the shelf crest.

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Depositional Environments in an Alluvial-Lacustrine System: Molluscan Paleoecology and Lithofacies Relations in Upper Part of Tongue River Member of Fort Union Formation, Powder River Basin, Wyoming

The upper part of the Tongue River Member of the Fort Union Formation (Paleocene) in the northern Powder River basin, Wyoming, contains assemblages of excellently preserved nonmarine mollusks which occur in laterally continuous outcrops of diverse lithologic sequences and sedimentary structures. These attributes offer a unique opportunity for interdisciplinary interpretation of depositional environments based on molluscan paleoecology and lithofacies relations. Taphonomic histories of mollusk assemblages as reflected by molluscan biofabric (size,