Evaluation of Atlantic Coastal Plain Geothermal Reservoirs Using Seismic Reflection Data

Ongoing studies of the moderate-temperature hydrogeothermal resource potential of the Atlantic coastal plain use seismic reflection data to evaluate potential reservoirs. Resource evaluation is dependent upon the determination of temperature and reservoir characteristics. The temperature of a potential reservoir can be estimated accurately if heat flow and thermal conductivity of the overlying sediments are known. Heat flow was determined in 51 shallow (300 m) exploratory holes. Equilibrium geothermal gradients in these holes indicate that thermal conductivity is a function of bulk composition, and can be characterized by the relative proportions of quartz sand, clay minerals, and water.

Seismic reflection data are being correlated with thermal conductivity of cores and cuttings from drill holes by making use of the relations between seismic velocity and bulk composition, and thermal conductivity and bulk composition. Seismic lines tied into drill holes allow interpretation of thermal conductivities between holes by correlating velocities to sedimentary units with known compositions and thermal conductivities. The seismic data are also being used to estimate the distribution and size of potential hydrothermal reservoirs by interpreting compositional differences between acquifers and aquitards.

Thus, the location, size, and temperature of potential hydrothermal reservoirs are estimated from seismic data. Preliminary results suggest that water at temperatures exceeding 60°C may occur in many areas in the eastern United States. Results of a deep test at Crisfield, Maryland, are encouraging. Brackish water at a temperature of 57°C was produced from an acquifer at a depth of 1.2 km. Further testing of the transmissibility of the deep aquifers beneath the Atlantic coastal plain is necessary.

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Origin and Evolution of Saline Formation Waters, Lower Cretaceous Carbonates, South-Central Texas

Systematic chemical variations exist in formation waters collected from a dip section through Lower Cretaceous rocks of south-central Texas. These chemical variations can be explained by an interactive water-rock diagenetic model.

Cyclic Lower Cretaceous shelf carbonates of the Edwards Group that dip into the Gulf Coast geosyncline act as an aquifer contained by basement beneath, and relatively impermeable Upper Cretaceous clays and chalks above. The hydrodynamic character of this carbonate system is strongly controlled by major fault systems which serve as pathways for the vertical movement of brines into the Lower Cretaceous section. Formation-water movement in this system has strong updip and upfault components.

The parent Na-Ca-Cl brine originates deep in the gulf basin, at temperatures between 200 and 250°C, by the reaction: halite + detrital plagiocalse + quartz + water $\rightarrow$ albite + brine. Other dissolved components originate by reaction of the fluid with the sedimentary phases, K-feldspar, calcite, dolomite, anhydrite, celestite, barite, and fluorite. Significant quantities of lead, zinc, and iron have been mobilized as well.

As the brine moves updip out of the overpressured deep gulf basin, encountering limestones of the Stuart City reef trend (the buried platform margin), small amounts of galena precipitate in late fractures. Updip and up-fault, the brine becomes progressively diluted with downward-moving meteoric water. On encountering significant quantities of dolomite in the backreef facies, the Ca-rich brine causes dedolomitization. Although thermochemical considerations suggest that small amounts of several authigenic phases should precipitate, they have yet to be found, except for minor amounts of calcite spar. As the brine evolves by dilution cooling, no systematic changes in any cation/Cl ratio occur, except for regular updip gain in magnesium as a result of progressive dedolomitization. The high-diluted formation water eventually discharges along faults as hot mineral water.

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Downward Vertical Fluid Flow in Subsurface: Implications at Kitty Field, Powder River Basin, Wyoming

Drill-stem test pressure data and subsurface geologic studies permit interpretation of fluid-potential relations in the Kitty field area of the Powder River basin. These relations provide substantiation of significant downward fluid flow from Mowry Shale source rocks to Muddy reservoirs in areas where maximum thicknesses of permeable sandstone are developed. Potentiometric contours indicate vertical flow becomes lateral and radiates outward from areas of high potential once confined to the Muddy aquifer system. Pressure distribution within individual reservoir beds is consistent with this interpretation. Vertical flow is presumably sustained by a combination of the following: (1) expulsion of bonded water during thermal alteration of mixed-layer clays in the Mowry Shale; (2) water generation associated with catagenesis and oil generation in the Mowry Shale; and (3) aquathermal pressuring at temperatures in excess of 200°F (94°C).

Local downward vertical flow of water at Kitty field may provide the means for hydrocarbon migration from Mowry source beds to Muddy reservoirs. Additionally, pressure gradients associated with this flow may be responsible for trapping approximately 75% of the total oil column in the field. Capillary pressures can account for a maximum of about 200 ft (61 m) of the total observed 835 ft (255 m) oil column. Calculations suggest that an additional 460 ft (140 m) of oil represents the minimum hydrodynamic column and that fluid-potential gradients necessary to trap the additional 175 ft (53 m) probably exist in the field.

The Muddy potentiometric surface implies a dynamic aquifer system of downdip inter-formational and vertical, cross-formational fluid flow. Early fluid migration is obscured by this present flow, but can be pressured to be updip toward the basin flanks in response to initial compaction processes. Post-Laramide (Eocene?) exposure of the Muddy aquifer resulted in recharge by meteoric waters. The interaction between meteoric downdip regional flow and local vertically downward flow at Kitty field suggests late accumulation of hydrocarbons.

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Imaging Beneath Complex Structure: Case History

Migration is recognized as the essential step in converting seismic data into a representation of the earth's subsurface structure. Ironically, conventional migration commonly fails where migration is needed most—when the data are recorded over complex structures. Processing field data shot in Central America and synthetic data derived for that section.

demonstrates that time migration actually degrades the image of the deep structure that lies below a complicated overburden.

In the Central American example, velocities increase nearly twofold across an arched and thrust-faulted interface. Wavefront distortion introduced by this feature gives rise to distorted reflections from depth. Even with interval velocity known perfectly, no velocity is proper for time migrating the data here; time migration is the wrong process because it does not honor Snell's law. Depth migration of the stacked data, however, produces a reasonable image of the deeper section. The depth migration, however, leaves artifacts that could be attributed to problems that are common in structurally complicated areas: (1) departures of the stacked section from the ideal, a zero-offset section, (2) incorrect specification of velocities, and (3) loss of energy transmitted through the complex zone.

For such an inhomogeneous velocity structure, shortcomings in CDP stacking are directly related to highly nonhyperbolic moveout. As with migration velocity, no proper stacking velocity can be developed for these data, even from the known interval-velocity model. Proper treatment of nonzero-offset reflection data could be accomplished by depth migration before stacking. Simple ray-theoretical correction of the complex moveouts, however, can produce a stack that is similar to the desired zero-offset section.

Overall, the choice of velocity model most strongly influences the results of depth migration. Processing the data with a range of plausible velocity models, however, leads to an important conclusion: although the velocities can never be known exactly, depth migration is essential for clarifying structure beneath complex overburden.

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Abnormally High-Pressured, Low-Permeability, Upper Cretaceous and Tertiary Gas Reservoirs, Northern Green River Basin, Wyoming

A large area of overpressured Upper Cretaceous and Tertiary rocks has been identified in the Green River basin of Wyoming. Source-rock, pressure, and temperature data from the El Paso Wagon Wheel No. 1 and Belco 3-28 Merna wells (originally proposed as nuclear stimulation sites) in the northern part of the basin reinforce previously reported conclusions regarding the cause of overpressuring: the generation of gas in low-permeability rocks. Pressure gradients in these wells exceed 0.8 psi/ft (18.1 kPa/m) and a maximum gradient of more than 0.9 psi/ft (20.4 kPa/m) may be present in the Merna well. If true, this would be the highest subsurface pressure gradient ever reported in the Rocky Mountain region.

Observations relevant to overpressuring in these wells include: (1) the coincidence of the onset of overpressuring and the top of the gas-saturated interval; (2) the source rocks of the gas are the interbedded coal and other carbonaceous lithologies; (3) the organic matter in the source rocks is predominantly a humic-type, capable of generating mainly gas; (4) the average total organic carbon content is about 2.0%; (5) the vitrinite reflectance at the top of overpressuring is 0.75 to 0.84 R_O, values that are consistent with the beginning of thermal gas generation; and (6) the low permeability (< 0.1 md), and stratigraphic and sedimentologic heterogeneity of the reservoirs provide an effective pressure seal.

Previously reported overpressuring mechanisms such as aquathermal pressuring, clay transformations, undercompaction, and dewatering of shales do not appear to be significant factors that contribute to overpressuring in this area.

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Can Hydrocarbon Migration be Recognized by Routine Geochemical Techniques?

Migration is the least understood step in the sequence of processes leading to the formation of a subsurface hydrocarbon accumulation. Hydrocarbons are redistributed by primary and secondary migration, which lead under ideal circumstances, to the formation of a reservoir accumulation. During geologic time, the reservoir accumulation may be destroyed by dissipation, that is, the leakage of hydrocarbons through the caprock (tertiary migration or dis-migration).

On the basis of case histories from geochemical analysis of exploration wells and of several shallow core holes, it is demonstrated that these hydrocarbon migration processes can be recognized by routine geochemical techniques. Certain changes with depth in light and heavy hydrocarbon composition reveal the extent and effectiveness of hydrocarbon migration. In particular, migration patterns become evident from a comparison of geochemical data of two adjacent exploration wells which penetrate the same stratigraphic sequence of interbedded source and reservoir rocks, but at different depth and maturation levels. Patterns of primary migration are evident also from regular compositional trends on either side of the contact between a source rock and a reservoir bed in a Jurassic-age sequence from Svalbard, Norway. Finally, geochemical evidence shows light hydrocarbons escaping from a gas reservoir by diffusion through the overlying seal. Based on recently determined diffusion rates for certain light hydrocarbons, one can estimate the hydrocarbon mass transport as a function of geologic time.

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A New Look for Gas in Forbes Formation, Sacramento Valley, California

The Forbes formation of Upper Cretaceous age consists of marine shale, siltstone, and interbedded sandstone, and lies stratigraphically between the younger Kione deltaic sandstone facies and the older Dobbins shale. On the west side of the Sacramento Valley, the Kione formation is truncated and the Forbes formation is overlain by the Capay (Eocene) and/or Tehama (post-Eocene) formations. In the Sacramento to Red Bluff area, the Forbes formation attains a thickness of up to 5,000 ft (1,524 m).

The importance of the Forbes formation as a source of gas production in the Sacramento Valley is well established. Gas was first produced from the Forbes formation near the south edge of the Marysville Buttes in 1953. The formation is now productive in over 20 fields in the Sacramento Valley with cumulative production to January 1, 1980, of 1.23 billion Mcfg.

The discovery and development of gas from the Forbes formation declined considerably in the late 1960s. As a result of new CDP seismic reflection profiling, however, drilling for gas from the Forbes formation has increased dramatically since 1978. Moreover, careful integration of modern seismic data with detailed subsurface stratigraphic mapping has resulted in new discoveries.

The Grimes gas field provides an example where these investigative techniques can be supplied.