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Abstracts

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Diagenetic Mineral Reactions Reveal Rates of Fluid Movement and Timing of Oil Emplacement

The San Joaquin basin of California is a young, rapidly buried basin in which feldspar alteration has major control over calcite cementation and porosity forming reactions in hydrocarbon reservoirs. The eastern part of the basin includes up to 3,658 m (12,000 ft) of Miocene and younger arkosic marine sand and shale. The Miocene sand is cemented by numerous thin bands of dolomite and calcite, which, as oxygen isotopic studies indicate, formed at burial temperatures between 20° and 90°C (68° and 194°F).

Strontium isotopic studies show that the calcium source for the calcite cements is plagioclase feldspar. Calcium in calcite cements forming at shallow burial depths and low temperatures (40°-70°C or 104°-158°F) was derived from plagioclase alteration reactions at deeper levels and higher temperatures (>80°C or 176°F) in the basin. Time-temperature burial plots indicate that minimum required flow rates from deep to shallow basin levels would have to be about 1 cm/yr (0.4 in./yr). In contrast to the low temperature cements, the calcium source for cements forming at deep burial depths and at high temperatures (70°-90°C or 158°-194°F) was plagioclase dissolving within the reservoir. In addition, aluminum released from the dissolving feldspar was precipitated as kaolinite in adjacent pore spaces. These diagenetic trends reflect increasingly restricted pore-water mobility during the basin history.

Strontium isotopic values in modern pore waters of the basin record increasing feldspar alteration with depth and suggest that present mixing of basin waters is restricted to subregions (10-15 mi or 16-24 km horizontally by 2 mi or 3 km vertically). Helium isotopes also suggest limited mobility of this gas on a scale similar to that of strontium.

Plagioclase dissolution (up to 5% of the rock volume) occurred just prior to the incoming of hydrocarbons, which suggests that acids associated with and perhaps moving in front of the hydrocarbons effectively created a substantial part of the reservoir porosity. Modern pore waters in the basin are rich in organic acids that may be responsible for the dissolution reactions.

The last calcite cements formed about 2-3 Ma, based on time-temperature burial plots. Thus, hydrocarbons filled the reservoirs (up to 500 million bbl) within less than 3 m.y. This short time for oil emplacement is surprising considering the low permeability of the reservoir rocks (1-10 md).

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Stratigraphy from Three-Dimensional Seismic Data

The interpretive benefits of three-dimensional seismic data are enormous because of the considerable improvements in subsurface resolution. In addition to the benefits for structural definition, the horizontal section can provide a display of ancient deposition and stratigraphy similar to that of modern deposition seen from an airplane window. On horizontal sections and horizon slices, we can observe directly the shape of offshore bars, meandering channels, delta-front channels, and crevasse splays, and also the extent of bed truncations at unconformity surfaces. Many of these features may be hydrocarbon reservoirs, and color display of modern well-processed three-dimensional seismic data considerably aids reservoir identification. Proper interactive use of three-dimensional data during appraisal and development permits the determination of downdip limits and the mapping of reservoir quality, especially porosity and net-pay thickness.

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Fluctuating Mesozoic and Cenozoic Sea Levels and Implications for Stratigraphy

Sequence stratigraphy encompasses depositional models of genetically related packages of sediments deposited during various phases of cycle of sea level change, i.e., from a lowstand to highstand to the subsequent lowstand. The application of these models to marine outcrops around the world and to subsurface data led to the construction of Mesozoic-Cenozoic sea level curves with greater event resolution than the earlier curves based on seismic data alone.

Construction of these better resolution curves begins with an outline of the principles of sequence-stratigraphic analysis and the reconstruction of the history of sea level change from outcrop and subsurface data for the past 250 Ma. Examples of marine sections from North America, Europe, and Asia can be used to illustrate sequence analysis of outcrop data and the integration of chronostratigraphy with sea level history.

Also important are the implications of sequence-stratigraphic methodology and the new cycle charts to various disciplines of stratigraphy, environmental reconstruction, and basin analysis. The relationship of unconformities along the continental margins to hiatuses and dissolution surfaces in the deep basins must also be explored, as well as the relevance of sequence-stratigraphic methodology to biofacies and source rock prediction.

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Development Geology of Giant Fields on Alaskan North Slope: Key to Successful Reservoir Management

The giant fields on the North Slope of Alaska (combined Permian-Triassic/Lisburne pools at Prudhoe Bay and the Kuparuk River field) produce approximately 2 million BOPD and contain about 30 billion bbl of oil in place. This production rate amounts to almost one-fourth of the United States daily production. Because the reservoirs in these fields are complex and the stakes in efficient field management so high, the development geology of these fields presents a great challenge.

The technical challenge of managing these fields lies in the fact that secondary and tertiary recovery projects have been initiated soon after start-up to ensure maximum recovery. Thus, the development geologist has to recommend primary development locations while formulating a reservoir description without knowing the full areal extent and heterogeneity of the reservoirs. To support the waterflood and enhanced oil recovery projects, permeability pathways and barriers have been identified using sedimentological, log, and engineering data. Because structure also plays an important role in controlling fluid pathways, the fault geometries, fracture patterns, and detailed structure are being mapped using two-dimensional and three-dimensional seismic, well, and log data.

The management challenge of development work in these fields is keeping communications channels open among the development geoscience group and the reservoir, production, operations, and drilling engineers. The development geologists must communicate in engineering language not only to be able to understand the problems engineers face but also to be able to explain geologic concerns and solutions in terms understandable to engineers. Therefore, the geologic work in these fields is conducted at two levels. At the basic scientific level, interpretations of regional settings, depositional environments, facies distribution, and diagenetic and porosity trends are being carried out. At the applied level, this knowledge is integrated with engineering plans and modeling studies for projects such as delineation and infill drilling, well completions, waterflood, and enhanced oil recovery.

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Generation, Migration, and Entrapment of Hydrocarbons on Southern Norwegian Shelf

The Southern Norwegian Shelf (56°-58° 30'N) has proved to be one of the most prolific hydrocarbon provinces in Europe. Recoverable reserves of about 4.8 billion bbl of oil plus oil equivalent are found predominantly in Upper Cretaceous and Danian-age chalk and Jurassic sandstones. The excellent quality of seismic data, moderate to dense well control, and the detailed geochemical evaluations of the Kimmeridge Clay, the principal source rock, make the Southern Norwegian Shelf an ideal area for hydrocarbon generation studies.

A geochemical analysis of the area contained five basic steps: (1) construction of a nine-layered three-dimensional grid summarizing the burial history of the sediments by using well control and seismic data, (2) calculation of geothermal gradients, (3) source rock analysis to investigate variations in thickness and richness of the Kimmeridge Clay study area, (4) maturation study based on the results of the three initial steps, and (5) volumetric analysis and prospect evaluation.

Major factors affecting hydrocarbon accumulations in the structural and stratigraphic closures of the study area include the amount of oil generated within the catchment areas of the various closures and, particularly in the case of the chalk fields, the level of hydrocarbon generation of the Kimmeridge Clay directly under the crest of the structure and presence of faults to act as conduits for vertical migration of hydrocarbons from the Upper Jurassic Kimmeridge Clay to the Upper Cretaceous Danian chalk. The expulsion and migration efficiency (hydrocarbons in place/hydrocarbons generated within the catchment area of individual closures) for tested closures average approximately 8% for the study area, with individual culminations having values as high as 40% or as low as 0%, based in part on the previously mentioned factors.

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Carbonate Sequence Stratigraphy and Controls on Carbonate Platform Development—Case Study from Permian of West Texas-New Mexico

Integration of seismic stratigraphic concepts with detailed field studies and geohistory analysis provides powerful interpretation leverage for deciphering the complex geologic history of carbonate platform-basin areas. Changes in carbonate productivity as well as platform growth and the resultant facies distribution are controlled most importantly by changes in relative sea level.

The structural history of the Permian basin during the Permian shows two subsidence cycles of 10-20 m.y. duration. These subsidence cycles were major factors in the long-term (10^6 - 10^7 m.y.) development of the Permian carbonate platforms. During periods of relatively rapid subsidence, aggradation was dominant; during periods of slow subsidence, major platform progradation occurred.

Superimposed on the long-term tectonic cycles is a series of third-order eustatic cycles (0.5-3 m.y.), which controlled development of 27 depositional sequences. Each sequence is composed of three depositional systems tracts: (1) a lower basin-restricted wedge interpreted to have been deposited during a relative fall and lowstand of sea level, (2) a transgressive systems tract of variable thickness, and (3) an upper, relatively thick, aggradational-to-progradational carbonate platform system, which includes significant allochthonous deposition in the basin and is interpreted to have been deposited during a relative highstand in sea level. The lowstand systems tracts are composed dominantly of quartz sandstone, commonly intercalated with carbonate debris beds at the toe of the slope. Sequence boundaries display erosional truncation (subaerial on platform or at platform margin, subaqueous on slope) and/or subaerial exposure. Erosion and debris deposition occurs both within and outside submarine-canyon feeder systems.

Two highstand depositional styles are differentiated here: (1) a keep-up system, which represents a relatively rapid rate of accumulation able to keep pace with periodic rises in sea level and displays a mounded-oblique stratal geometry at the platform margin, and (2) a catch-up system, which represents a relatively slow rate of accumulation and displays a sigmoid profile at the platform margin. Individual strata units of the platform margin and slope area of the catch-up carbonate system have a much longer sea-floor residence time and display significantly greater amounts of early submarine cement. The underlying transgressive systems tract tends to have a keep-up or give-up (i.e., thin, drowned) depositional style.

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Carbonate Platforms, Sequence Stratigraphy, and Sea Level

Besides tracing reflectors, the mapping of stratigraphic sequences marks a major advance in seismic interpretation. However, construction of sea level curves from sequence stratigraphy is complicated by other factors besides sea level influencing sequence geometry. One such factor is lithology. This point is examined by comparing siliciclastic systems and carbonate platforms.

During the Pleistocene, the siliciclastic sediment supply to the deep sea was at its maximum during glacial lowstands of sea level. Pleistocene carbonate platforms were exactly in antiphase to this rhythm. They produced and exported most sediment during interglacial highstands when the platforms were flooded ("highstand shedding"). In the Bahamas and other platforms, accumulation of both bank-derived fines and sandy turbidites is higher by a factor of 2 to 9 during the interglacials, and turbidites tend to cluster in these highstand intervals. Highstand turbidites also differ in composition from their lowstand counterparts. Turbidite abundance and composition together provide a faithful record of the Pleistocene sea level cycles not easily erased by diagenesis. Geometrically, platforms respond to sea level by forming highstand turbidite wedges and lowstand drapes of pelagic sediment—the opposite of siliciclastic systems.

Drowning unconformities are another example for the significance of lithologic change in sequence stratigraphy. Flanks of carbonate platforms are generally steeper than siliciclastic slopes. When carbonate platforms are drowned and buried by siliciclastics, an unconformity ensues because the clastics are unable to assume the steep carbonate slope angle or because they are shed from other directions than the carbonates. Examples of drowning unconformities include the Lower Cretaceous platforms off West Africa and off eastern North America as well as the middle Cretaceous unconformity in the Gulf of Mexico.

Highstand shedding and drowning unconformities of platforms illustrate that not all depositional systems respond alike to changes in sea level and that sequence boundaries may be caused by lithologic change. These lithologic turning points need not be related to sea level. In a very general way, sequence boundaries can be viewed as changes in the pattern of sediment input and dispersal in a basin. Sea level fluctuations are one way to induce such changes, but tectonic movements and environmental change represent important alternatives, demonstrated by the seismic stratigraphy of the deep Gulf of Mexico.

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Reservoir Description for Exploration and Development: What is Needed and When?

The biggest challenge for geologists, geophysicists, and petroleum engineers now and in the decades ahead is to significantly improve hydrocarbon recovery from all new and previously discovered reservoirs. Keystone of the methodology required to improve oil and gas production, as well as to evaluate and delineate new reserves, is a detailed reservoir description. This is a characterization of the reservoir and nonreservoir rock-fluid system that is appropriate in content and