Geology and Diagenesis of Belridge Diatomite and Brown Shale, San Joaquin Valley, California

The late Miocene to Pliocene argillaceous and siliceous shales of the upper Monterey Formation (the Brown Shale and overlying Belridge Diatomite) represent laterally continuous deposits of nearshore, diatom-rich muds and open marine, argillaceous, diatom-bearing muds on a developing shelf and growing anticline which flanked the San Joaquin basin. These units are laterally equivalent to submarine fan and turbidite sedimentary rocks deposited into the basin from the west, south, and east.

The lithology of the Brown Shale and Belridge Diatomite is controlled by original composition and subsequent burial diagenesis. The muds underwent diagenetic alteration with the development of silica phases in the sequence: (1) unaltered diatom frustules (biogenic amorphous silica or opal-A); (2) diagenetic amorphous silica (opal-A); and (3) diagenetic crystalline silica (opal-CT). In the oil field, the Belridge Diatomite grades downward from a massive or faintly laminated siliceous mudstone with diatom frustules and opal-A', to a laminated and massive siliceous mudstone with opal-A' and some well-preserved diatoms. The Brown Shale grades from a massive or laminated siliceous mudstone with opal-A' and some diatoms to a well-laminated argillaceous, diatom-bearing mudstone with opal-A' and some opal-CT. There is no distinct break in lithology between the Belridge Diatomite and Brown Shale reservoirs, but recrystallization and detrital clay increase downward across the boundary.

Porosity in the best diatomite is about 62%, and permeability is about 1 md.

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Lower Pleistocene Quiet-Water Lacustrine Ooliths from Koobi Fora Tuff, East Lake Turkana, North Kenya

Complex, asymmetric ooliths occur within a thin (5 to 50 cm) carbonate deposit exposed along the northeastern margin of Lake Turkana, an alkaline lake located south of the Kenya-Ethiopia border. The limestone is part of a lower Pleistocene sequence of tuffaceous lake margin sediments (the Koobi Fora tuff) and outcrops over an area of 45 sq km. It is the only laterally extensive, oolitic unit within the 300-m section of Pliocene-Holocene lacustrine and fluvial sediments in the basin. Structurally, the limestone consists of multiple, well-cemented layers, the tops of which in some places exhibit desiccation cracks. Texturally, it ranges from oosparite to biosparite. The unit is composed predominantly of complex ooliths (2 to 80%), biogenic grains (0 to 10%), micritic, low-Mg calcite cement (0 to 15%), and blocky/sparry low-Mg calcite cements (15 to 90%). The ooliths average 0.8 mm in diameter and consist of nuclei that are unevenly coated by as many as 15 incomplete, overlapping, fan-shaped rims of radial-fibrous, low-Mg calcite. Both texture and mineralogy appear to be primary. Within a single oolith, every "fan" shows an orientation of fibrous crystals which is unique with respect to adjacent "fans." Each fan-like lamina thus represents a different episode of calcite accretion.

The ooliths formed on a coastal plain inundated by proto-Lake Turkana during a relatively high stand of lake level. Calcite precipitated only on the up-sides of stationary nuclei, however grains remained at the sediment surface long enough to be moved repeatedly by high energy waves and acquire composite cortices. The occurrence of asymmetric ooids indicates that agitation may play a minor role in oolitic deposition. In quiet water settings, nuclei availability, presence and concentration of organic matter and/or microorganism activity may be the major factors controlling ooid growth and morphology.

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Biostratigraphy of Discocyclinid-Bearing Beds, Eocene Llajas Formation, Southwestern Santa Susana Mountains, California

Tests of the discocyclinid foraminifer *Pseudophragmina clarki* occur in several 50-cm thick beds that are widely dispersed within alternating laminated and bioturbated sandstone of the Llajas Formation. At the 575-m thick type section, this sandstone makes up the interval from 100 to 370 m above the base of the formation.

Most of the beds consist of laminated to bioturbated, calcareous, very fine to fine quartzarenite; many are channel deposits, within which tests are concentrated in small pods. *Turritella andersoni lawsoni* may or may not occur with the discocyclinids, but if present it is the only megafossil. Associated foraminifers, listed in decreasing abundance, include *Robulus, Nodosaria, Cibicides, Operculina, Asterigerina,* and *Quinqueloculina.* Most of the genera are extant and are found today in tropical to subtropical shallow marine waters.

The fragile tests of *Pseudophragmina clarki* are mostly complete, unabraded, and 1.5 to 7 mm in diameter. Associated fossils also show no obvious signs of abrasion but they must have been transported because they occur in what are interpreted to be channels. Absence of significant abrasion and fragmentation is suggestive of minimal transport. *P. clarki* and associated fossils, therefore, constitute transported assemblages which are in the same environment in which they lived. The paleontologic evidence of a shallow marine environment is in keeping with the presence of the fossil beds within alternating laminated and bioturbated sequences. Modern examples of such sequences are found predominantly in inner shelf environments.

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Mesozoic and Cenozoic Base Maps

Sixteen maps are presented illustrating the relative positions of the continents from the Early Triassic to the Recent. The spreading history of the Atlantic and Indian Oceans is based on the plate tectonic models of Sclater et al; Norton and Sclater; and Phillips and Tapscott. The age of the oceanfloor has been plotted using Sclater's data-base of worldwide linear magnetic anomalies.

Mesozoic and Cenozoic paleomagnetic data were compiled and selected for reliability. Pole positions obtained from samples that were insufficiently demagnetized, that were from unstable tectonic areas, or that did not exhibit a primary remanence, were rejected. A global apparent polar wander path (African coordinates) was constructed using these selected paleomagnetic determinations. The position of the magnetic pole for each plate tectonic reassembly was estimated by interpolating along this polar wander path.

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Trace Fossil Assemblages as Indicators of Shelf-Sandstone Facies, Upper Cretaceous, Northwestern Colorado

Five facies of upper Mancos shelf-sandstones have been identified using sedimentary structures and subsurface data. Microfossil and subsurface studies suggest that all five facies were mid-shelf deposits, yet each of the facies has a distinctive trace fossil assemblage. The Low Energy Shelf Facies is intensely bioturbated by horizontal indistinct forms with some *Helminthoida*, "armored" burrows (*Diopatra*-like), *Terebellina* (plural curving tubes), and "donut" burrows. The intensely bioturbated lower Back Bar Facies contains abundant *Helminthoida* with common donut and some armored burrows, and *Trichichnus*. This grades vertically into the more diverse assemblage of abundant *Teichichnus, Terebellina,* "nest structures," and common *Thalassinoides* with some *Ophiomorpha,* armored burrows, and *Helminthoida* near the highly bioturbated top. The overall bioturbation drops dramatically in the Central Bar Facies in which *Teichichnus* and nest structures are the most common. *Ophiomorpha* and *Thalassinoides* are rare. The upper part of the Central Bar contains only rare *Ophiomorpha* and nest structures. The Ramp Facies, seaward of the Central Bar, contains only rare *Thlassinoides* and nest structures. The High Energy Shelf Facies is more diverse than the Low Energy Shelf and is moderately bioturbated with abundant *Ophiomorpha, Thalassinoides, Teichichnus,* nest structures, *Terebellina,* and armored burrows.

The distinctive trace fossil assemblages found in the five facies that were deposited on the mid-shelf suggest that physical energy and substrata characteristics control trace fossil distribution.

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Models for Deep-Water Sedimentation in Tectonic Basin: Stevens Sandstone, San Joaquin Basin, California

Observed relations between facies associations, sand-body geometries and submarine fan subenvironments commonly appear anomalous when facies interpreted from cores are compared with relations described by some currently popular fan models. Such anomalous relations were observed in cores from several fields producing from the Stevens Sandstone. To explain these inconsistencies an "on-lap" model and a "confinement" model are proposed for some of the observed depositional patterns of the upper Miocene Stevens Sandstones in the San Joaquin basin.

Along the eastern margin of the basin, where deposition occurred on a relatively undeformed homoclinal surface, patterns of turbidite sedimentation and facies associations generally conform to the Mutti and Ricci Lucchi submarine fan model. However, in the central and western parts of the basin the fan model is inappropriate.

The on-lap model describes turbidite deposits which lap onto and stack vertically against rising anticline structures. Internally these sand bodies exhibit distinct sedimentation cycles and facies associations characteristic of fan progradation. Externally these sand bodies pinch out crestward, may or may not be lobe- or fan-shaped, and tend to be abnormally thick. The Paloma field is an example of the on-lap model.

In the confinement model, turbidites are confined to bathymetric lows between adjacent (en echelon) anticlines. These deposits, which accumulated in synclinal lows, tend to have an external channel-like morphology but do not necessarily exhibit facies associations commonly ascribed to channels in fan models. Deep-water sediments from Yowlumne, Tule Elk, and Elk Hills fields are best described by the confinement model.

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Conditions Under Which Fractures Form and Create Conduits for Fluids

The underground occurrence of open extension fractures is important in petroleum exploration because the fractures provide plane conduits for the migration and storage of fluid. Extension fractures are considered to be natural hydraulic fractures that form like the artificial hydraulic fractures produced during well stimulation. Mechanics of natural hydraulic fracturing are discussed, so that the implications of the theory for the migration and accumulation of hydrocarbons are apparent.

Development of open extension fractures in the earth's crust is inhibited by gravitationally induced confining pressures; there should exist a depth above which extension fractures could form and below which faulting would be the dominant mode of failure. Mechanical considerations indicate that for the development of extension fractures on a regional scale this limiting depth is rather shallow—on the order of a few hundred meters to a few kilometers. Alternatively, mechanical considerations indicate that extension fractures could form locally in anomalously stressed regions at much greater depths if the ratio of pore fluid pressure to overburden weight approaches one. Thus, open extension fractures will be most likely to occur at depth in the earth's crust in places where the mean total stress is anomalously low, and where the pore pressure is anomalously high.

Fracture porosity depends critically on fracture aperture, and on degree of infilling with secondary mineral matter. Observed apertures of fractures are usually one to three orders of magnitude larger than that predicted by theory, suggesting that pressure solution is important to the aperture of fractures.

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Application of Biologic Markers in Combination with Stable Carbon Isotopes to Source Rock/Oil Correlations, Prudhoe Bay, Alaska

Novel biologic marker parameters are applied to problems of geochemical correlation of crude oils and source rocks in the area of Prudhoe Bay field, northern Alaska. The molecular structures used for fingerprinting the shale extracts, the kerogen pyrolyzates, and the crude oils are steranes, terpanes, and monoaromatized steranes. The major sources of the principal oil accumulations are shown to be the Shublik (Triassic), Kingak (Jurassic), and the deep post-Neocomian shales. In two of the three (Kingak and Shublik), the indigenous nature of the bitumen was proven by pyrolysis and quantitative biomarker data. Possible source rocks based on geologic reasoning and bulk geochemical data include the deep Kayak (Mississippian) shale, the shallow post-Neocomian, the Neocomian, and the Upper Cretaceous shales. However, all of these are shown by biologic marker techniques not to have generated the petroleum accumulations studied. Of the nine oils investigated, one (Kingak) rises from a single source (Kingak shale). The others have very similar source fingerprints using 10 different molecular and several bulk