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

parameters in combination. These results are achieved by using a new quantitative approach based on concentrations and ratios of specific biomarkers by integration of mass chromatograms. The assessment of all parameters in combination results in a well-documented, internally consistent picture permitting the above conclusions. In addition, these biomarker data permit in hindsight a reasonable interpretation of the wide range of carbon isotope data. All results are consistent with the geologic setting. The approach adds a new dimension in assisting the petroleum explorationist toward paleoreconstruction.

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South-Aniuy Suture (West Chukotka)

The geologic data indicate that Phanerozoic and probable late Proterozoic rocks of Chukotka and Alaska are very similar. The paleomagnetic results indicate that during most of the Phanerozoic, the drift of the North American craton did not conform to the drift of the Siberian craton. This contradiction can be settled only by searching for a suture within the bounds of northeastern Siberia, along which the North American plate once apparently collided with the Siberian plate. To the west of the Okhotsk-Chukotka belt there is only one suture possessing all the features of an ophiolitic suture—the South-Aniuy. Its characteristic features are linearity, large extent, and abundant ophiolites and turbidites. It is probably the site of the collision of the Hyperborean and North Asiatic plates. During the Late Jurassic these plates collided with the accompanying subduction of the oceanic lithosphere southwestward and the formation on the northern margin of the Omolon massif of a zone of island arcs and back-arc basins with characteristic sedimentation and magmatism. On the whole the geologic data on the structure, metallogeny, and history of development of West Chukotka agree with the hypothesis of a marginal-continental location of wide regions of the northern part of the Omolon massif over a former subduction zone. The Late Jurassic (Volgian) volcanism fixes the most active deformation along this zone and the bringing together of the plates. More clear becomes also the position of the Triassic volcanism of the Oloy-Aniuy interfluve which probably reflects another, but more transitory appearance of a subduction zone on the margin of the continent.

After collision (possibly with some transcurrent movements) of the Hyperborean and Asiatic plates, the geodynamic conditions in the northeastern part of Asia changed and the whole territory to the west and the north of the Okhotsk-Chukotka belt was already a united continental monolith with an old "cicatrice"—the South-Aniuy suture zone.

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Changing Patterns of Phosphogenesis in Mesozoic and Cenozoic

During the Mesozoic and Cenozoic Eras, major global phosphogenic episodes occurred during the Upper Cretaceous-Eocene and Miocene Epochs. A minor phosphogenic episode occurred during the Jurassic Period.

The Jurassic and Miocene phosphogenic provinces were primarily located on the eastern sides of oceans on continental shelves where upwelling ocean paleocurrents were associated with paleotrade winds. Major exceptions are the Miocene phosphorites of the southeastern United States which probably were associated with the paleo-Gulf Stream, and the Miocene phosphorites of the Chatham Rise, New Zealand, which possibly were associated with the Antarctic circumpolar paleocurrent. The Miocene phosphorites probably were the result of increased vertical oceanic circulation, mainly trade-wind belt coastal upwelling. Jurassic phosphorites appear to be paleo-oceanographically analogous to the Miocene phosphorites.

The Late Cretaceous-Eocene phosphogenic province was primarily an east-west equatorial circumglobal province of Tethys and Pacific seamounts. The Upper Cretaceous-Eocene phosphorites of the Atlantic paleo-ocean continental shelves in Togo, Gabon, Senegal, and Brazil are an exception to this distribution. The major Upper Cretaceous-Eocene phosphorites probably were the result of vertical circulation due to equatorial divergent upwelling.

Tertiary and Mesozoic phosphogenic episodes appear to be due to a combination of the onset of increased rates of oceanic circulation after periods of oceanic stability, periods of high sea level, and favorable paleogeography.

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Economics of Small-Scale Oil Shale Retorts

A graphic portrayal of conventional oil in the United States and Saudi Arabia since 1880, vis-a-vis a series of predictions since 1918 of the economic feasibility of obtaining oil from shales, has been used to examine the problems and prospects for commercialization of oil shale in the United States. Time series analysis, and analogy to R. M. Catlin's 1920 commercial plant and Union Oil's 1957-58 aborted commercial entry reveal that the economic infeasibility of shale oil is not merely the result of inflation; subjected solely to the influences of inflation, oil from shale would today cost only slightly more than $8.00 per barrel.

Given this rejection of inflation as the prime deterrent to commercialization, the most critical factors which continue to cause cost projections for shale oil to exceed even OPEC's escalation of oil prices since 1973 are identified. The work of Edward W. Merrow and the RAND Corp., have identified some of these constraints. A review of state-of-the-art extraction and environmental technology, and the more common theories as to the continued economic infeasibility of commercial scale plants lead to a focus on seven specific factors—two economic and one each of technologic, financial, logistic, environmental, and socio-economic/political.

A potential resolution or significant mitigating influence has been identified for each of these factors, the proposal's synergism examined and commercial operation under it compared to more conventional alternatives. A conceptual feasibility study and computer sensitivity analysis reveals the potential for oil shale prices well below those of conventional oil. Based on current oil industry statistics, a forecast of the long-run market potential of shale oil and a surprising estimate of eventual market segmentation have been made.

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Highlights in History of Geophysical Exploration

While some preliminary geophysical studies were made in