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PETROLEUM GEOLOGY OF COASTAL PERU AND ECUADOR

Oil fields of coastal Peru and Ecuador lie within the only significant coastal plain along the western margin of South America. This plain is underlain by chiefly marine lower Tertiary and variably marine to continental upper Tertiary sediments, and is capped by a spectacular, but locally heavily dissected, elevated Quaternary marine terrace, or *Tablazo*. Although evidence is meager, the marine lower Tertiary sediments are considered not to have been deposited as in a basin, but more likely as in a half-basin or marine bank on a narrow continental shelf, facing the open ocean on the west.

The principal producing areas in this belt, from north to south are (Ecuador) Ancon, and (Peru) El Alto, Lobitos, Talara-Negritos, and Portachuelo. Estimated ultimate recovery from established reserves are: Ecuador, possibly in excess of 125 million barrels of 37° gravity oil; and Peru, possibly up to 1 billion barrels of 37° gravity oil. Production comes chiefly from Eocene sandstones and conglomerates, with fracturing commonly playing a major part in reservoir permeability.

The Tertiary coastal belt is one of both common stratigraphic complications and a rather unique structural arrangement. Much of the marine Tertiary sedimentary sequence demonstrates rapid facies change and evidence of large-scale submarine landslides, resulting in common turbidity deposits and recurrent faunal zones. The structural situation is dominated by a myriad of normal faults having no regular pattern, but predominantly following a rule of faulting which favors downward movement of the updip block (in a regional sense), which is interpreted as dislocation resulting from a westerly spreading or creep of the sediments of this ancient marine bank during periodic recurrent elevations of the ancestral Amotape mountains on the east, with no massive basement buttress on the west to contain this semi-plastic mass.

Because of both the restricted remaining undeveloped area and vertical sedimentary column in the onshore, particularly in Peru, development of additional major reserves may be expected to come chiefly from the submerged continental margin adjacent to existing production.

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COMPARISON OF PLIO-MIOCENE SEDIMENTATION OF GULF COAST WITH ATOKAN SEDIMENTATION OF ARKOMA BASIN

The Plio-Miocene sediments of the Gulf Coast and the Atoka sediments of the Arkoma basin represent similar stratigraphic sequences deposited in quite different tectonic settings. The Plio-Miocene units are associated with the orogenically placid Gulf Coast geosyncline. The pattern of deposition has been development of load-produced basins (depocenters) during cyclic offlap. The Atokan units are associated with the Ouachita orogeny and represent shelf and trough suites. Certain aspects of these stratigraphic sequences are comparable with the modern sediments of the northwestern Gulf of Mexico.

The depositional patterns of the Plio-Miocene and the Atokan sedimentary prisms reflect structural-sedimentation interrelationships. In each prism, flexure zones demark abrupt thickening of the sedimentary units. The Atokan sediments were deposited on more competent sub-strata than were the Plio-Miocene sediments so that fewer major flexures developed. The depositional axis of the Atoka probably was tectonically controlled (a facies scarp) and the depositional axis of the Plio-Miocene (if properly located) was determined by sedimentary processes.

The Plio-Miocene and the Atoka have other features in common. Each is very predominantly clastic, represents a new area of maximum sediment accumulation in the depositional basin, and displaced a carbonate-shale facies. Prograding deltaic facies dominate the depositional environments but cyclic deposition is a prominent aspect of the sedimentation. Both the Atoka and the Plio-Miocene thicken at comparatively rapid rates and attain greater thicknesses than the associated older and younger sediments.

Kuendig (1959) has suggested that geosynclines should be classified by structural configuration, not sedimentary content. However, the similarities of the Plio-Miocene and the Atoka indicate that sedimentary patterns reflect source areas, transport and depositional processes, and topography. They do not reflect the structure of the catchment basin.

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EARLY DIAGENESIS: COMPOSITION OF INTERSTITIAL WATERS OF RECENT MARINE MUDS

The earliest diagenetic changes that may be observable in a Recent marine sediment are those due to chemical reactions between the solid minerals and trapped sea water. The nature and extent of the reactions may be interpreted from the chemical composition of the interstitial water in combination with the mineralogy of the sediment. The water composition may be a more sensitive clue to some reactions than the mineralogy of the solid.

Interstitial waters have been extracted from four different sets of long cores of fine-grained recent marine sediment of the Atlantic Ocean using a modified filter press. Four cores come from an area off Cape Cod, Massachusetts; two cores are from the western side of the Atlantic off the coast of Brazil; three cores are from the Romanche Deep in the equatorial Atlantic; seven samples came from the preliminary test for the Mohole, off Guadalupe Island in the Pacific. More than 150 samples of waters, similar in composition to sea water, have been analyzed for Na, K, Ca, Mg, Cl, and SiO_2. It appears that in the sediment waters, in comparison with the overlying sea water, there is some tendency for sodium and chloride to increase slightly, calcium to decrease, magnesium to remain constant, and silica to increase greatly. Wide variations in water composition are correlative with sediment lithology. Changes in water composition may be due to post-burial reactions between sea water and clay and carbonate minerals as well as to salt-filtering effects of the compacting clay membranes. Calcium concentration may be reduced by precipitation of secondary $CaCO_3$. Sodium and chloride increase as a result of salt-filtering, although some paleosalinity effects may be possible in some nearshore areas where hydrography was strongly affected by Pleistocene events. Silica increases as a consequence of the dissolution of amorphous siliceous organisms and is probably poised at concentrations in equilibrium with montmorillonite. Shipboard determinations of pH on fresh cores compared with pH of

aerated squeezed waters indicate that CO_2 pressures in the sediment may be an order of magnitude higher than that in equilibrium with the atmosphere, an effect probably related to the bacterial decomposition of organic matter.

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SIGNIFICANT 1961 EXPLORATION DEVELOPMENTS EXCLUSIVE OF NORTH AMERICA

Oil discoveries were recorded in 1961 in Colombia, Libya, the Sahara, Turkey, Iran, Gabon, Australia, India, and the Philippines. A significant gas discovery was reported from New Zealand. Exploration was underway in Peru, Ireland, England, the Spanish Sahara, Greece, Somalia, Australia, Southwest Africa, Bechuanaland, South Africa, Ivory Coast, Mauritania, Sardinia, Sudan, Tunisia, Niger Republic, Yeman, Portuguese Timor, and many of the Middle East countries. Argentina was the scene of both exploration and development drilling on a large scale. A significant development was the first export of oil from Libya, where exploration concessions were first granted in 1955. Various concession areas were surrendered after substantial exploration expenditure in the Gulf of Paria, Nigeria, Jordan, Lebanon, Dhofar, and Portuguese Guinea. Individual operators withdrew from Turkey and Argentina. Exploration operations ceased outside the producing areas in Iraq. Offshore acreage acquisitions or applications were announced in Turkey, Nigeria, France, Israel, Tunisia, Libya, Burma, Honduras, and Trinidad. First marine offshore drilling on the African continental slope was underway off Gabon; offshore drilling occurred also off the southern Netherlands, in the Persian Gulf, and Sicily. Many new American operators were either active in foreign areas or had applied for concessions. Russian, French, Italian, and Rumanian technicians appeared for the first time in several new areas. Up until November 1, when summarized, the really outstanding exploration development of 1961 was that it became more truly world-wide than ever before.

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TERTIARY GEOLOGIC HISTORY OF WESTERN OREGON AND WASHINGTON

The region of western Oregon and Washington at the beginning of the Tertiary was the site of a north-trending eugeosyncline that is inferred to have occupied the site of the present Coast Range-Olympic Mountains uplift and the Puget-Willamette trough. The distribution of marine and continental facies suggests that the eastern margin of the eugeosyncline extended under the Tertiary volcanic rocks of the Cascade Range. Analysis of the distribution, thickness, facies changes, and sedimentary structures of a thick Eocene turbidite sequence indicates that the western margin of the eugeosyncline lay west of the present coast line.

Tholeiitic pillow lavas and breccias, as much as 20,000 feet thick, were erupted in places into the subsiding geosyncline during early to middle Eocene time and interfingered complexly with marine tuffaceous siltstone and sandstone. Uplift south of the geosyncline during middle Eocene time resulted in an influx of great quantities of arkosic sands which were swept generally northward along the axial part of the trough by turbidity currents. Concurrently, northeast of the geosyncline, a plutonic and metamorphic terrane supplied large quantities of arkosic detritus that accumulated on a broad coastal plain and intertongued westward with marine beds.

In post-middle Eocene time broad uplifts and thick volcanic accumulations divided the geosyncline into several separate basins. These basins were the sites of deposition of as much as 15,000 feet of upper Eocene to Pliocene marine sandstone and siltstone and associated pyroclastic and epiclastic volcanic debris. Upper Eocene and middle Miocene basalt flows from local centers interfinger in places with this sequence.

In western Oregon these Tertiary strata have been folded and faulted into structures that trend predominantly northeastward, parallel with the structure of the pre-Tertiary rocks of the Klamath Mountains. North of the Columbia River, the principal structures trend northwestward, approximately parallel with the structural grain of the pre-Tertiary rocks in northern Washington. This trend is interrupted by the more complex Olympic Mountains uplift.

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SAND-GRAIN ORIENTATION AND IMBRICATION IN TURBIDITY-CURRENT SANDSTONES

Orientation studies of thirty-five sandstone samples of turbidity-current origin show statistically significant preferred grain orientation. There is a consistent angular divergence between sand-grain orientation and the linear sole features such as groove casts and flute casts associated with individual sandstone beds. This relationship persists throughout the 80-foot stratigraphic section studied. Sole features show divergences of 40°–60° (47° average) from preferred grain orientation in the overlying sandstone. Differences in lineation of the two types of features are due to differences in direction of erosional and depositional currents, even though the currents may not be separated greatly in time.

Imbrication studies throughout the section show consistent southeast inclination of elongate grains with respect to the bedding. Flute casts, small-scale crossbedding and regional paleogeography indicate a southeastward sediment source; thus the imbrication data are in agreement with the theory of up-current imbrication. Three-dimensional orientation analysis indicates that grains are oriented parallel with the depositing current. This suggests that sand grains were oriented parallel with the current through original deposition from suspension, or if some grains rolled along the bottom, they were re-oriented before reaching a final position of rest.

Grain orientation can provide general information on source direction for turbidity-current deposits; imbrication indicates the sense of current movement along that direction. Limited paleogeographic inferences can be drawn from local studies of the relationship between grain orientation and erosional sole features.

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MIDDLE TERTIARY VERTEBRATE FAUNA FROM AUSTRALIA

A middle Tertiary vertebrate fauna has been discovered in the Great Artesian Basin east of Lake Eyre, South Australia. The fossils occur in the Etadunna Formation and have been called the Ngapakaldi fauna. The Etadunna Formation (? Oligocene), consists of more than 100 feet of green lacustrine claystone, sand-