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DEPOSITIONAL AND TECTONIC HISTORY OF TERTIARY SEQUENCE ON CONTINENTAL MARGIN OF BRITISH COLUMBIA

Sampling and seismic profiling in the Tofino basin west of Vancouver Island have disclosed a thick sequence of Tertiary rocks ranging in age from Eocene to Pliocene. Most of these rocks were deposited in deep-water environments and subsequent uplift has exposed them in many areas. Eocene and Oligocene sediments were deposited in a belt along the present shoreline area off Vancouver Island, whereas Miocene and early Pliocene rocks are present farther seaward. Later Pliocene rocks form a regressive sequence overlapping the older Tertiary in most areas.

Several major periods of deformation resulted in faults, folds, and diapirs on the continental shelf. Deformational patterns show a marked change from north to south. North of Brooks Peninsula, including Queen Charlotte Sound and Hecate Strait, sediments are generally undeformed by folding but are truncated by faults along the steep continental slope. The Kyuquot uplift south of Brooks Peninsula exposed Eocene and Oligocene rocks across the shelf. Farther south, Miocene and Pliocene rocks unconformably overlie the uplift. Folding increases southward, culminating in an area of diapirism off Nootka Sound. Elongate diapirs trend parallel or subparallel with the coastline.

Tectonic features observed on the shelf and slope probably can be explained best by a consideration of the configuration and projected relative movements across spreading centers and along transform faults off the coast of British Columbia. The juxtaposition of differing tectonic styles may be due to the presence of a triple-point junction which has subsequently migrated north.

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RADIOLARIAN DEFINITION AND PALEOECOLOGY OF LATE MIOCENE TO EARLY PLIOCENE IN SOUTHERN CALIFORNIA

The late Miocene to early Pliocene appears to be well represented by radiolarian faunas in formations in southern California. From radiolarian biostratigraphic studies in southern California the writers suggest that the base of the Mohnian (as represented by the section at Newport Bay) is equivalent to the base of the *Ommatartus antepenultimus* Zone of Riedel and Sanfilippo, and the top of Delmontian (as represented by the Malaga Mudstone at Malaga Cove) is within the *Pterocanium prismatium* Zone of these same writers. The uppermost occurrences of *Prunopyle titan, Lychnocanium grande* and *Theocyrtis redondoensis* and the lowermost occurrence of *Lamprocyclas heteroporos* occur relatively close together and represent the Miocene-Pliocene transition in the Malaga Cove section. The most reliable datum plane for the Miocene-Pliocene boundary in southern California might be the lowermost occurrence of *Lamprocyclas heteroporos*, for this appears to be an evolutionary event.

From radiolarian paleoecologic studies in southern California we suggest that the late Miocene to early Pliocene was a period of paleotemperature fluctuation with sea surface temperatures fluctuating as much as 10°C. The radiolarian diversities also fluctuated during this same period with a general trend toward a diversity decrease upsection. There were differential (selective) radiolarian extinctions during this same period in that "shallow water" (epipelagic) forms appear to be more severely affected than deep or tropical submergent forms.

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INTERPRETATION OF MIOCENE SHALLOW MARINE DEPOSITIONAL ENVIRONMENTS USING SEDIMENTARY STRUCTURES

Comparison of sedimentary structures in certain sedimentary rocks with those that form in the modern environment can provide a powerful interpretive tool. An example can be drawn from a well-exposed middle Miocene marine-nonmarine transition in the southeastern Caliente Range, California. Within this transition, shallow-marine sandstone (part of Branch Canyon Sandstone) intertongues on the northwest with marine siltstone (Saltos Shale Member of the Monterey Formation), and intertongues on the southeast with nonmarine redbeds (part of the Caliente Formation). Flow structure in extrusive basalts in the upper part of the transition and paleocurrent features in overlying Miocene alluvial deposits indicate that the shoreline at the time of deposition trended north-northwest.

The marine-nonmarine transition consists of a succession of individual progradational sequences that extend westward (seaward) into marine strata. The sequences exhibit a fairly consistent internal stratigraphic arrangement. A typical complete sequence has a basal unit of unbedded siltstone (Saltos Shale) lying on an erosion surface. A thin zone of conglomerate commonly occurs within the siltstone directly above the lower contact. The siltstone grades up into bedded or unbedded fine-grained sandstone (Branch Canyon Sandstone). This fine sediment is sharply overlain by a coarse, pebbly, crossbedded facies of the Branch Canyon, which grades upward into finer and predominantly planar-bedded sandstone. The planar-bedded sandstone grades up into muddy structureless sandstone that in turn grades up into red or green mudstone (Caliente Formation), which caps the sequence.

The progradational nature of the sequences implies that the fine-grained sandstone near the base was deposited in the marine environment somewhat shoreward from the gradationally underlying siltstone, which locally contains marine invertebrates. Bedding, where present in the fine sandstone, is defined by concentrations of biotite; the bedding is either planar or shows medium- and small-scale cross-stratification. Bioturbational disruption abounds. Crossbedded lenses of well-sorted granular sand are interbedded with the fine sand in its upper part. Foresets in these lenses dip predominantly toward the southeast. Similar structures form in response to the passage of waves in modern high-energy environments. The foreset orientation thus suggests that during the time of deposition the waves approached from the northwest.

The coarse, pebbly sandstone that sharply overlies the fine-grained sandstone is the thickest and best exposed unit of most sequences. Bedding is generally well developed, and bioturbational structures are rare. Pebbles tend either to occur as lag deposits scattered along extensive erosion surfaces within the sandstone or to be concentrated within conglomeratic beds. Crossbedding is abundant and dips predominantly west-southwest (offshore); a small secondary mode dips south-southeast. This secondary mode may reflect the influence of longshore currents resulting from the oblique approach of the waves with respect to the shoreline. A few large-scale crossbedding units dip east and southeast and suggest the presence of offshore bars trending oblique to the coast, parallel with the prevailing wave crests. The dominantly offshore-dipping crossbeds are best explained as the result of rip currents. The erosional contact at the base of the coarse sandstone resembles the contact formed at the base of rip channels in the modern environment.

The planar-bedded sandstone in the upper part of the sequence is well sorted and contains planar concentrations of magnetite that resemble those formed on the upper foreshore of modern beaches. Many planar laminations are inversely graded like those that form at present in the upper swash zone. Where attitudes were measured, most of the planar beds dip gently seaward (west), which also supports a beach origin.

The overlying structureless muddy sandstone may represent deposition in a vegetated back-beach environment. The redbeds of the Caliente Formation probably formed in coastal swamps, lagoons, or alluvial plains.

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GRAVITY AND STRUCTURE OF CONTINENTAL MARGIN: OREGON TO SOUTHEASTERN ALASKA

Reconnaissance surface-ship gravity measurements over the continental margin of western North America extend from northern California to southern Alaska. The gravity measurements, spaced approximately 2.5 km apart along tracklines approximately 40 km apart, have an estimated RMS uncertainty of approximately 5 mgl. A negative free-air anomaly along the base of the continental slope is attributed to the dip of the Mohorovič discontinuity, lateral density variations in the upper mantle, and in some locations a sediment-filled trough. Off the north end of Vancouver Island a free-air anomaly greater than −150 mgl occurs over the Scott Islands fracture zone, suggesting a sediment thickness in the fracture zone of 4–6 km. Hypothetical crustal cross sections of the continental margin constrained by the free-air anomalies and the available seismic refraction data suggest crustal thicknesses are approximately 20 km in western Oregon and Washington, and 25–30 km in the Insular Belt of British Columbia and the Alexander Archipelago. The relatively thin crust in the region between the continental shelf and Coast Mountains of British Columbia and the Cascade Range in Oregon and Washington is characteristic of the transition from oceanic to continental structure in western North America.

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RINCONADA FAULT IN SOUTHERN COAST RANGES, CALIFORNIA AND ITS SIGNIFICANCE

The Rinconada fault near Santa Margarita is a major northwest-trending, high-angle fault that separates a terrane of granitic basement on the northeast from one of Franciscan basement on the southwest. Southeastward from Santa Margarita this fault extends continuously into the "Nacimiento" fault across Cuyama Gorge to intersect the Big Pine fault in the San Rafael Mountains. Northwestward the Rinconada fault does not extend into the Nacimiento fault near the Nacimiento River, as presumed, but veers northward through Paso Robles into a line of faults locally called San Marcos, Jolon, and Espinosa faults, nearly to Reliz Canyon west of King City.

Detailed mapping reveals that all these aligned faults are parts of one major fault, 160 mi long. Therefore, it is proposed to call it the Rinconada fault. It is separated by a 2-mi gap from the Reliz fault, aligned northwest along the base of Sierra de Salinas. The Rinconada fault, as defined herein, is nearly parallel with, and about 22 mi southwest, of the San Andreas fault. Southeastward from Santa Margarita the Rinconada fault is along the southwestern border of the Salinia block; northwestward from that town it extends into this block. Drag folding along and near the Rinconada fault indicates right-lateral movement. Much of this movement occurred before deposition of the Paso Robles Formation. Strata of Miocene and early Pliocene ages are offset about 11 mi near Paso Robles; those of Late Cretaceous-early Tertiary age are offset nearly 40 mi.

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USE OF PHOSPHATES IN SEARCH FOR OIL

Phosphatic facies are useful in oil exploration as tools for stratigraphic analysis, and as identifiable sources of hydrocarbons. Such discrete, near-continuous phosphate-bearing strata of mid-Eocene age have extended over 20,000 sq mi in southern and central California. Foraminiferal studies establish that correlative phosphate deposition began in Relizian time, was particularly widespread in the early Luisian, and continued locally in Mohnian time. Other extensive facies appear in late Eocene and in early late Pliocene beds.

The use of phosphatic facies in stratigraphic studies may be cited in four examples: (1) they may represent condensations of large thicknesses of strata, (2) differentiate between apparently similar formations, (3) establish equivalency of units on either side of major faults, and (4) have shown that formations of the same apparent lithology and foraminiferal age, juxtaposed across major faults, are not continuous.

Because phosphorus-rich waters nourish phytoplankton, underlying strata are commonly rich both in phosphate and organic remains. Five examples of phosphatic facies as source beds for the generation of oil of giant fields may be given: in California, in Colombia and Venezuela, in eastern Kansas, in Alaska, and in Wyoming. Other examples are known around the world. In California, the regional distribution of phosphate correlates with the regional distribution of petroleum.

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SIRENIANS IN WEST COAST MARINE STRATIGRAPHY

Sirenians are fairly common as fossils in many late Tertiary nearshore marine deposits of the West Coast. The general pattern of their evolution in the North Pacific from early Miocene to recent times is now known. With the exception of the early Miocene forms, all the known species are stratigraphically successive and seem to belong to a single, unbranching evolutionary sequence.

Their evolution was particularly rapid during the late Miocene and early Pliocene in response to changing climate, and the resulting morphologic changes were so profound that different evolutionary stages can be recognized, and rough stratigraphic correlations made, on the basis of quite fragmentary skeletal material. In at least two areas of California (Santa Cruz and Orange Counties), sea cows have been collected from several different zones near the Miocene-Pliocene boundary. These sequences of fossils well illustrate these rapid changes, and in the former case considerable evolution can be observed even within a single species. More detailed study of these and other sections may permit the use of sirenians in correlating widely separated marine deposits on the West Coast.

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DISCOVERY AND DEVELOPMENT OF SAWTELLE OIL FIELD

The Sawtelle oil field, discovered by Occidental Petroleum Corporation in 1965, is the westernmost of nine producing fields along a 15-mi trend of anticlinal oil accumulations distributed *en échelon* along the northerly margin of the Los Angeles basin.

Wells at Sawtelle confirm that the normal stratigraphic section has been disordered by approximately 7,000 ft of apparent vertical displacement along the northerly trending Santa Monica thrust fault zone. The mountainous hanging wall block is comprised of a thin veneer of recent sediments; nonproductive lower Pliocene and upper Miocene sandstone and shale; middle Miocene sandstone, shale, and volcanic rocks; and Mesozoic Santa Monica Slate. Beneath the fault zone, within the basinal footwall block, are lower Pliocene sandstones and shales, oil-bearing upper Miocene sandstone and shales, and middle Miocene sandstones and shales.

Production has been established in two pools: on the south in the upper Miocene "Rancho" sands within an asymmetric southeast-trending anticline where net pay exceeds 500 ft, and on the north where these same sands appear even thicker within the south limb remnant of a parallel anticline which has been