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ABSTRACTS

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Two-Stage Laramide Orogeny in Southwestern United States: Tectonics and Sedimentation

The Laramide orogeny (80-40 Ma) in the southwestern United States is usually thought of as a single tectonic event with attention concentrated on its early stage because of its dramatic expression in the sedimentary record. The sharpest pulse of deformation, however, occurred in the latest Paleocene–early Eocene and was separated from the early stage by a tectonic lull and development of widespread lateritic weathering profiles, remnants of which are preserved in some early Tertiary basins. The first stage correlates plate tectonically with opening of the North Atlantic and Labrador Sea, the second stage with opening of the Norwegian Sea and Eurasian basin in the eastern Arctic. Rapid convergence between the North American and Farallon plates decreased the dip of the subducting Farallon plate, until by early Eocene (55 Ma), strong viscous coupling was occurring between the Farallon plate and the overlying lithosphere. Change in direction of convergence from west-southwest–east-northeast during the early stage to southwest-northeast during the late stage brought the first-order shear direction into near parallelism with the north-northeast-trending southern Rocky Mountain deformed belt in New Mexico. This parallelism allowed the Colorado Plateau to decouple from the craton along right-lateral wrench faults. The Colorado Plateau was translated 100-130 km north-northeast with a comparable shortening across the Wyoming province.

Both sedimentation rates and coarseness of synorogenic sediments increased dramatically from Wyoming to the Gulf Coast of Texas beginning in the early Eocene. Simultaneously, an en echelon series of strike-slip basins formed along the zone of decoupling from southern New Mexico to southern Wyoming. Deformation in the Wyoming province also increased sharply, resulting in as much as 21 km of overhang on range-front thrusts and up to 15 km of structural relief between adjacent uplifts and basins. As much as 2,500 m of Eocene orogenic sediments were deposited in rapidly subsiding basins. Deformation was so rapid that surface drainage was disrupted and runoff was impounded in huge lakes in which as much as 1,000 m of lacustrine sediments accumulated to form the oil shale province.

Wrench faulting along the eastern margin of the Colorado Plateau was distributed across a 100-km wide belt that followed zones of weakness inherited from Precambrian and late Paleozoic deformation. Wrenching changed from nearly parallel in New Mexico to strongly convergent in Colorado and southern Wyoming because of a change in structural grain from north-northeast in New Mexico to north-northwest in Colorado. At least 25 km of shortening across the zone of decoupling during convergent wrenching caused conspicuous low-angle thrusting, which has tended to mask the lateral component of movement. Major north-northeast shortening across the Wyoming province and a lack of such shortening on the High Plains demand right-lateral wrench faulting. Offset of transverse aeromagnetic anomalies across the zone of decoupling in Colorado and New Mexico, offset of Precambrian metavolcanic belts and age province boundaries, and offset of northeast-trending lineaments and distinctive rock types provide independent measures of the magnitude of right slip. Northward translation of the Colorado Plateau was a relatively minor part of regional right-lateral shear that extended through much of the North American cordillera in the early Tertiary.

Recognition of the wrench-faulted nature of the eastern margin of the Colorado Plateau and Wyoming province creates new opportunities for petroleum exploration. These can be divided into: (1) subthrust plays beneath low-angle faults caused by convergent wrenching; (2) structural, stratigraphic, and fracture-controlled traps along wrench faults; and (3) fracture reservoirs along northeast-trending lineaments dilated during wrenching. Recognition of wrench faults paralleling the structural grain of the southern Rocky Mountains also means that isopach and facies maps drawn smoothly across the zone of decoupling should be reevaluated with careful attention to control points.

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Depositional and Structural Architecture of the Northwest Gulf Coast Tertiary Continental Platform

The northwestern margin of the Gulf of Mexico is a broad depositional platform constructed in the Cenozoic by terrigenous clastic sediment derived from the continental interior of North America. This platform was built onto transitional crust fringing a deep oceanic basin. Cooling and loading of stretched transitional crust by sediment infill induced flexural subsidence, producing a total Tertiary sequence exceeding 6.5 km in thickness.

The large-scale depositional architecture of the platform is characterized by offlap. Successive continental margins cumulatively prograded basinward approximately 350 km from the Mesozoic margin. The combination of offlap depositional geometry and flexural subsidence produced a primary depositional unit resembling a highly flattened sigmoid, which is thickest at the position of its contemporary paleomargin. Depositional geometry and consolidation history of the continental margin and slope lead to a predictable distribution of tensional and compressional stress regimes. Mobilization of thick Jurassic salt complicates this relatively simple structural pattern along the Quaternary margin.

Source terranes for this tremendous sediment influx included the southern and central cordillera and adjacent high plains, as well as the continental interior and adjacent volcanic and epeirogenic uplands. Depocenters shifted from the Houston to the Rio Grande and finally to the Mississippi embayments, reflecting contemporary tectonic events of the western North American craton. Large-scale offlap pulses recorded Laramide (late Paleocene–early Eocene) deformation of the southern cordillera, late Paleogene uplift and volcanism, and Neogene extension and epeirogenic uplift of the Rockies and adjacent high plains.

Offlap of the continental platform was episodic, and most of the depositional episodes encompassed two or more depocenters. Each major offlap unit consists of several principal depositional elements, including one or more fluvial/deltaic systems and wave-dominated shore-zone systems, along with a shelf system, offlap slope sequence, and localized onlap submarine canyon and fan complexes. The correspondence of episodes with the proposed worldwide eustatic curve is relatively good in the late Neogene, when glacial eustasy became increasingly likely. However, relationships of Oligocene episodes to eustatic events are confused at best. Eustatic correlation in the older Paleogene section appears poor.

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Depositional and Structural Architecture of Prograding Clastic Continental Margins

Progradation of a clastic continental-margin sediment wedge onto attenuated continental or oceanic crust is characterized by load-induced crustal subsidence and a predictable internal structural and depositional architecture. The prograding wedge has one free surface, characterized by a very low but nonetheless unstable slope. Here, sandy, normally consolidated sediment is deposited on top of an underconsolidated mud-rich foundation. The combination of large scale, morphology, and undercompaction make continental-margin sequences prime sites for syndepositional gravitational tectonics, including gravity gliding, gravity spreading, and diapirism.

Strain regimes reflect the focus of tensional stress along the continental margin and of compressive stress at the toe of the slope. A belt of active, listric normal faults defines the contemporary shelf margin, producing a structurally defined shelf edge/upper slope depocenter. In contrast, the lower slope is a compressional tectonic terrane characterized by uplift, folding, and overthrusting.

Major prograding clastic margins, such as the Gulf Coast Cenozoic wedge or the Niger delta, contain one or more principal depocenters where deltaic headlands prograde to the contemporary shelf edge, feeding sediment directly onto portions of the continental slope. Marginal to such headlands, submarine canyon systems may act as pipelines, funneling large amounts of sediment across the outer shelf, down the slope, and onto the abyssal plain in front of the offlap wedge. Eustatic sea level changes may temporally or locally affect depositional and erosional patterns, but are commonly masked or overwhelmed by regional intraplate tectonic events and extrabasinal controls on rate and location of sediment transport into the basin.

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Worldwide Basin Classification and Oil-Play Prediction

A system is proposed that classifies sedimentary basins worldwide into specific as well as general categories. The system is based on the origin and evolution of basins in the context of their geologic history. The main elements used to classify basins are basin-forming tectonics, depositional cycles, and basin-modifying tectonics. Basin-forming tectonics are deduced by knowledge of the type of underlying crust, past plate tectonic history, basin location on the plate, and type of primary structural movement involved in the basin formation (such as sagging or faulting). The result is eight single tectonic-cycle or simple basin types: interior sag, margin sag, interior fracture, wrench, trench, trench associated, oceanic sag, and oceanic wrench.

Basin-modifying tectonics include episode wrenches, basin-adjacent foldbelts, and completely folded basins. These have been identified and placed on a scale of increasing magnitude, from movements of slight to major structural effects. More complex basins, called polyhistory basins, may contain several different tectonic cycles plus basin-modifying tectonic events. The eight simple basin types, their depositional fills, and tectonic modifiers have been given letter and number symbols so the specific geologic history of each basin may be written as a formula. The formulas may then be compared between basins, and similarities or differences noted.

After the basins have been classified, major hydrocarbon plays are located and the specific parameters responsible for these plays are noted. For example, certain types of basins commonly may be the site of rich source rock or clean reservoir sand deposition, or may contain block-fault or wrench-type structures. From producing basins, these oil-play parameters can be projected into frontier areas via the global basin classification system, and oil-play predictions can be made.

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Practical Characterization of Eolian Reservoirs for Development: Nugget Sandstone, Utah-Wyoming Thrust Belt

The Jurassic-Triassic Nugget Sandstone of the Utah-Wyoming thrust belt is a texturally heterogeneous eolian reservoir with anisotropic directional properties that have been inherited primarily from the depositional environment, but also somewhat modified by diagenesis and overprinted by tectonism. Porosity ranges from several percent to the mid-twenties, and maximum horizontal permeability covers five orders of magnitude from a darcy to hundredths of millidarcys. Where productive, the formation ranges from approximately 800 to 1,050 ft (244 to 320 m) thick, at depths of about 7,500 to 15,000 ft (2,286 to 4,572 m) below the surface. Because some reservoirs are fully charged with hydrocarbons, an understanding of their internal complexity is important to monitor production performance and maximize hydrocarbon recovery.

Depositional processes determine the three-dimensional distribution of facies-related bedding types, which can have unique grain size and sorting textures, primary and diagenetic mineral compositions, and tectonic deformational fabrics, resulting in characteristic porosity, permeability, permeability directionality, and pore geometry attributes. Such characteristics can be quantified or calculated from core analysis, capillary pressure, nuclear magnetic resonance, conventional log, dipmeter, and production data to generate a practical geologic model on whatever scale of detail is necessary.

Nugget dune deposits (good reservoir facies) consist of cross-bedded grain-flow and grain-fall strata and generally lower angle, wind-ripple-generated laminae. Interdune, sand-sheet, and other nondune deposits (poor reservoir facies) are characterized by wind ripples and more irregular bedding types, some of which are commonly associated with the presence of damp or wet conditions (e.g., bioturbation, wavy bedding, and soft sediment deformation). Dune grain-flow laminae exhibit the best reservoir quality and the least heterogeneity in bedding texture, followed respectively by grain-fall and wind-ripple strata. Anisotropy in permeability directionality resulting from bedding can range over several orders of magnitude. Irregular bedding types, especially those associated with wetter conditions, commonly contain an abundance of the finest grained material available in the depositional environment and generally have the poorest reservoir properties.

Postdepositional modifications to the reservoir include diagenesis and tectonism. Although compaction, cementation, clay mineralization, and dissolution events have occurred, diagenesis has not ultimately altered the relative hierarchy of bedding-controlled reservoir quality determined by depositional texture. Tectonic deformation has primarily created networks of low-permeability gouge-filled fractures and microfaults, although intermittently open fractures with somewhat more effective permeability also exist locally.

Depositional models incorporating dune morphologies, facies distribution, permeability directionality, and theoretical concepts regarding dune migration through time are useful in defining the correlative intervals that are most likely to have continuity and potential communication of reservoir properties. Well-devised stratigraphic models can be adapted for engineering reservoir simulation studies and can also be used in solving structural resolution problems if a correlatable vertical sequence or a relatively consistent cross-bed orientation are known.

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Point Arguello Field—History and Geology of a Giant Oil Discovery

The Point Arguello field is a giant field with more than 300 million bbl of recoverable oil. The biogenic, fractured Monterey Formation forms the primary source and reservoir in this major offshore California discovery. The trap is a complex, anticlinal structure and is difficult to delineate seismically at depth. As is often the case, the original exploration concept differs from the final discovery. Chevron's structural and stratigraphic concepts have changed from the early days to the present.

The Point Arguello structure extends across a thick Miocene depocenter. A low influx of terrestrial clastics, general reducing conditions, high organic productivity, rapid burial, and a high heat flow created an extraordinarily productive oil-generating depocenter. Today, this small subbasin is ringed by announced and unannounced oil accumulations. Recognition of this "cooking pot" concept was a factor in Chevron's bidding strategy for OCS Federal Lease Sale 53.

In addition, early silica diagenesis of the diatom-rich Monterey within this small subbasin created an attractive Monterey reservoir. By 1970, Chevron and others in the industry were aware of silica phases and their importance in creating a commercial fractured reservoir. By the end of the decade, university research seemed to confirm these earlier observations. However, based on field measurements, some silica-phase–fracture relationships have recently been questioned.

A giant accumulation formed under a rare combination of favorable circumstances. Eight wells have delineated two major oil pools whose gravity ranges from 11° to 34° API. The primary reservoir is the middle and upper Miocene fractured cherts, porcellanites, and dolostones. The open-fracture system forms about 1.0 to 2.0% of the reservoir volume.

Three production platforms may be in place by the end of 1986. Careful planning is necessary to ensure a timely development in an environmentally sensitive area.