rotating faults remain closed. In both cases, formation and rotation of the faults may occur in one tectonic event. Fault displacements may therefore remain small and difficult to detect on seismic records. From the mechanical point of view, one has to differentiate between book shelf operations controlled by an externally imposed simple shearing and those responding to an imposed extension.

The mechanical analysis of book shelf operations induced by simple shearing shows that, under certain conditions, this operation requires less driving shear stress than an accommodation of the imposed shear by shear-parallel faulting. The operation of cross faults between neighboring Riedel faults in a wrench zone is a typical example.

Large-scale rotation of parallel normal faults in domino style (tilted block tectonics) is primarily associated with the extension of ductile substrata. It may be inferred from mechanical arguments and sandbox experiments how the process, and in particular the dip direction of the faults, is controlled by the way the substratal extension progresses, by the direction of a substratal squeeze flow, by the presence of a surface slope, and by the configuration of the rock boundaries that confine the set of faults in the direction of extension.

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Late Mississippian Lime Mud Mounds, Pitkin Formation, Northern Arkansas

Carbonates deposited under shallow, open shelf conditions during the Late Mississippian in northern Arkansas exhibit numerous discrete to coalescing lime mud mounds up to 20 m (65 ft) high and tens of meters in diameter. The mounds are composed of a carbonate mud core, typically with fenestrate texture, entrapped by a loosely organized framework dominated by cystoporate bryozoans and rugose corals in the lower part, and by blue-green algae and cryptostomous bryozoans in the upper part. Disarticulated crinozoan detritus is common throughout the core, suggesting that these organisms also contributed to entrapment of lime mud. During deposition, the mud core was indurated enough to support and preserve vertical burrows. Also, rubble of core mudstone is found on the flanks of some mounds, suggesting some erosion.

Intermound lithology is a shoaling-upward sequence dominated by oolitic and bioclastic grainstones and packstones. Shale is also present in minor amounts. The Pitkin mounds, interbedded with these intermound sequences, developed contemporaneously with them. Depositional relief was probably less than 3 m (10 ft). The mounds expanded laterally during periods of quieter water; their growth was impeded during times of higher energy. Contacts of the mound and intermound lithologic characteristics are sharp, truncating surfaces. Mound deposition ended with the onset of high energy conditions throughout the region.

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Cenozoic Basin Development in Hispaniola

Four distinct generations of Cenozoic basins have developed in Hispaniola (Haiti and Dominican Republic) as a result of collisional or strike-slip interactions between the North America and Caribbean plates. First generation basins formed when the north-facing Hispaniola arc collided with the Bahama platform in the middle Eocene; because of large post-Eocene vertical movements, these basins are preserved locally in widely separated areas but contain several kilometers of arc and ophiolite-derived clastic marine sediments, probably deposited in thrust-loaded, flexure-type basins. Second generation basins, of which only one is exposed at the surface, formed during west-northwesterly strike-slip displacement of southern Cuba and northern Hispaniola relative to central Hispaniola during the middle to late Oligocene; deposition occurred along a 5-km (3-mi) wide fault-angle depression and consisted of about 2 km (1 mi) of submarine fan deposits. Third generation basins developed during post-Oligocene convergent strike-slip displacement across a restraining bend formed in central Hispaniola; the southern 2 basins are fairly symmetrical, thrust-bounded ramp valleys, and the third is an asymmetrical fault-angle basin. Fourth generation basins are pull-aparts formed during post-Miocene divergent strike-slip motion along a fault zone across southern Hispaniola. As in other Caribbean areas, good source rocks are present in all generations of basins, but suitable reservoir rocks are scarce. Proven reservoirs are late Neogene shallow marine and fluvial sandstones in third generation basins.

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Comparison of Basin Types in Active and Ancient Strike-Slip Zones

Hydrocarbon exploration in strike-slip zones requires awareness of several distinct basin types, traditionally defined on the basis of bounding fault geometry: pull-aparts (P), fault-wedge basins (W), fault-angle basins (A), fault-flank basins (F), and ramp valleys (R). We compare the characteristics and frequency of these basin types in an active (40 post-Eocene basins of the northern and southern Caribbean) and ancient (19 Late Devonian-Carboniferous basins of the northern Appalachians) strike-slip setting. Pull-apart basins, which lengthen and deepen at fault discontinuities with increased strike-slip offset, constitute the best studied and most numerous basin type. Other recognizable basin types are less numerous and often shorter lived than pull-aparts, and this may reflect: (1) their role as precursory structures prior to concentration of strike-slip displacement on a single fault; (2) their role as interference structures at random fault junctures; and (3) the unlikelihood of preservation because of thinner sedimentary fill. Several disrupted basins of complex or unknown origin (D) appear to have initiated as pull-aparts and subsequently to have been been offset into halves or modified into compressional ramp valleys. Using observations from active basins, several geologic criteria for distinguishing compressional vs. extensional origin of reactivated ancient basins are discussed.

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Dead Sea Rift: Impact of Tectonics and Climate on Patterns of Sedimentation

The Dead Sea Rift, a classic strike-slip basin, occurs along a transform that connects the Red Sea, where sea-floor spreading is occurring, to the Taurus Mountains, where plate convergence is occurring. The rift formed primarily from left-lateral displacement of about 105 km (65 mi) since the Miocene, producing uplift and normal faulting along its shoulders. Sedimentation within the transform occurs primarily in elongate, asymmetric pull-apart basins such as the Dead Sea, as transform segments pass each other along the zone of strike slip.

Pleistocene and Recent patterns of sedimentation were mapped on a scale of 1:50,000 along the west bank of the Dead Sea for a distance of 50 km (30 mi). Three sedimentologic units are recognized: an older sequence of debris flows and shallow-water fans; a medial unit of fan deltas interfingering with shallow-to-moderately deep-water lacustrine deposits; and an upper unit comprised of beach gravels, deltaic sands, and playa deposits. Their combined thickness is about 3,500 m (11,500 ft) along the western border fault, where they exhibit repetitive small-scale cyclical patterns of deposition within a general fan delta complex that prograded into the Dead Sea; there, geophysical studies show that the prograding subsea fans have been intruded by salt diapirs.

Such patterns of deposition clearly are related to recurrent movement along the border faults, producing rhomb-shaped basins, high-relief topography, and a unique rift climate. As the moist air rises over the shoulders of the rift, it cools adiabatically yielding as much as 800-1,000 mm (31-39 in.) of rain per year to high discharge ephemeral streams that transport huge quantities of coarse clastics into the basin. Conversely, as the air descends into the basin, it warms adiabatically, evaporating more than 2,000 mm (80 in.) of water per year, thus causing a concomitant drop in the Dead Sea level, precipitation of evaporites, change in the base level, and progradation of fans into deeper water.

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Computer Modeling of Minnelusa (Pennsylvanian-Permian) Paleotopography in Eastern Powder River Basin, Wyoming, with a Case History

Most Minnelusa Formation (Pennsylvanian-Permian) oil production in the Powder River basin is from paleotopographic traps. These traps occur where upper Minnelusa dune sands are encased in the overlying supratidal red Opeche Shale (Permian). The morphology of these sands suggests northwest-southeast-trending barchanoid sand ridges.

Thickness variations in the Opeche mirror the relief on the Minnelusa surface. Opeche isopahcous maps are one of the main methods used to explore for Minnelusa paleotopographic traps. Hand-contoured isopachous maps can be subject to ambiguous interpretations in areas of low-density control. This difficulty is partially overcome when the map is mathematically produced.

Observations from oil tests in the area indicate that Minnelusa paleotopography is cyclic with a wavelength of approximately 3 mi (5 km). Double Fourier transforms are appropriate in modeling this kind of cyclic data.

For a test township, the calculated double Fourier surfaces showed good correlation with the actual data values. This technique was then applied to a Minnelusa prospect in Campbell County, Wyoming.

Double Fourier surfaces were calculated for several structural datums and isopach intervals. Additionally, regional dip was determined from a polynomial fit, the section was restored to horizontal, and then was modeled to reveal paleotopography.

The paleotopographic-high axes and Opeche thin axes showed remarkable coincidence. This trend is believed to represent the trace of a paleo sand dune.

A test well sited using conventional geologic methods plus input from the double Fourier maps confirmed the accuracy of the calculated surface.

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United States Assessment Procedures and World Energy Resources Program

Resource assessment is a people-oriented endeavor. At every stage of the exercise, good judgment is essential to satisfactory results. There is no single procedure that can guarantee an approximation of truth, but clearly there are procedures and techniques to be selected from within the context of the problem to be solved that serve to lessen subjectivity in the final outcome.

The U.S. Geological Survey has had the responsibility of determining petroleum potential, especially for basin size areas. This determination assists in the decision process relative to lease sales, wilderness areas, and international relations. Our requirement is basin understanding, not exploration well siting. Considering the dimension of the objectives, the time frame of need, and the resources available (both people and data), volumetric analysis at the level of the play (group of prospects) is rarely practical. Rather, as described in U.S. Geological Survey assessment documents, we have utilized a variety of volumetric/analogy techniques, sometimes comparing with Klemme classifications, with specific United States or foreign basins, or internally within the basin being assessed, which in effect is a degree of maturity analysis. The petroleum geology of the basin and the results of the various number-generating processes are then subjected to the Delphi process, as reported elsewhere, for the group assessment.

The assessment so determined is the hypothesis of the petroleum potential of the area. Because the hypothesis derives from an analysis of petroleum parameters such as source rock, reservoir rock, traps, and seals (which data are published), it is subject to testing as exploration proceeds or as new data are made available. The advantage of the assessment is only partly in the number. In addition, the organization of data permits the recognition of anomalies in the exploration process or in resource reports, thus permitting ongoing adjustments in the assessment or its analysis.

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Geology and Petroleum Potential of Hanna Basin, Carbon County, Wyoming

The Hanna basin is one of the world's deeper intracratonic depressions. It contains exceptionally thick sequences of mature, hydrocarbon-rich Eocene through Paleozoic sediments, and has the requisite structural and depositional history to become a major petroleum province.

Stratigraphic traps exist within the deeper central parts of the basin in low permeability, possibly overpressured Eocene, Paleocene, and Upper Cretaceous rocks. The Eocene-Paleocene Hanna and Ferris Formations consist of up to 20,000 ft (6,100 m) of organically rich lacustrine shales, coals, and fluviatile sandstones. The Upper Cretaceous Medicine Bow, Lewis, and Mesaverde formations consist of up to 10,000 ft (3,050 m) of marine and nonmarine dark, organic-rich shales that enclose many stacked hydrocarbon-bearing sandstones.

Structural prospecting should be most fruitful around the edges of the basin where Laramide flank structures exist. Deformation of the Hanna basin sediment package into its 30-mi (50-km) wide by 8-mi (13-km) deep present configuration should have produced out-of-the-basin thrusts terminating in closed anticlines. Strata along the northern margin of the basin, located on the southward-displaced Emigrant Trail–Bradley Peak-Shirley thrust complex, were crumpled into anticlinal folds such as O'Brien Springs and Horseshoe Ridge. Oil and gas ranging in age from Pennsylvanian to Upper Cretaceous have been found in these structures.

Only 7 wells have been drilled in the deeper part of the Hanna basin. Two of these tested gas at commercial rates from Upper Cretaceous rocks at depths from 10,000–12,000 ft (3,050–3,660 m). Sparse drilling along the basin flanks has revealed structurally trapped oil and gas at depths from 3,000–7,000 ft (915–2,130 m). The encouragement from the few wells drilled indicates that a more concerted exploratory effort in the Hanna basin is justified.

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Petroleum Potential of Serpentine Plugs and Associated Rocks, Central and South Texas

During deposition of the Upper Cretaceous Austin Chalk and Taylor Marl, "serpentine plugs" formed by submarine volcanic activity along major fault zones in the ancient Gulf of Mexico. After eruption, palagonite-tuff mounds, formed by the hydration of basaltic glass, localized deposition of shoal-water carbonates on topographic highs.

The serpentine plugs occur along an arcuate belt extending approximately 250 mi (400 km) from Milam County southwestward to Zavala County, Texas

Hydrocarbon traps in and around serpentine plugs have yielded approximately 47 million bbl of oil and significant quantities of natural gas from altered volcanic tuff and associated shoal-water carbonates. Shallower production is from overlying sedimentary rocks structurally influenced by volcanic plugs.

Entrapment of hydrocarbons occurs as: (1) stratigraphic traps within porous zones of carbonate units; (2) stratigraphic traps within porous volcanic tuff (serpentine); (3) structural traps within overlying sands; and (4) traps within high-porosity fracture zones. Exploration for plugs should be concentrated along existing fault zones by either magnetic or seismic surveys.

Analysis of the plugs suggests that there are at least 3 distinctive groups: (1) a southern group characterized by well-developed and productive marginal sands; (2) a middle group characterized by hydrocarbon-saturated biocalcarenite and reworked volcaniclastic facies; and (3) a northern group in which the dominant hydrocarbon saturation is in the volcanics themselves. Each of these groups appears to reflect a somewhat different geologic history.

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Provenance and Diagenesis of Ivishak Sandstone, Northern Alaska

The Ivishak sandstone of northern Alaska is a regressive sequence of Lower Triassic fluvial and paralic deposits that constitutes an important hydrocarbon reservoir in the Prudhoe Bay area. A petrographic study of the formation, utilizing samples from wells from both reservoir and nonreservoir rocks, was undertaken to determine the provenance and diagenetic histories of the formation.

The Ivishak sandstone can be characterized as a low-rank or lithic graywacke. The major detrital species it contains include: (a) quartz (46%), dominantly reworked sedimentary and volcanic monocrystalline quartz and metamorphic polycrystalline quartz; (b) chert (22%), containing variable amounts of inclusions (clay and carbonate); (c) sedimentary rock fragments (10%), largely mudstones and silty mudstones; and (d) meta-