glass or (2) minor enrichment in uranium resulting from diagenesis. Whole-rock Th/U ratios average about 2 whereas ratios in glass alone are about 3 to 4, implying that a significant fraction of uranium is contained in relatively Th-poor detrital components such as zircon. Th/U ratios in sediments do not show any correlation with either stratigraphic position or mineralogic zone, implying that no measureable uranium depletion has occurred.

Fission-track maps of glassy sediment show that uranium occurs in glass and in high concentrations in zircons and amorphous iron hydroxides. In altered rocks uranium is enriched in amorphous iron hydroxides and is unevenly distributed in moderate concentrations through the groundmass associated with no distinct mineral. Opal, calcite, clinoptilolite, and analcime contain little uranium. This shows that solution of glass, including minor etching during hydration, releases uranium but most is immediately absorbed by hydroxides. Later recrystallization of diagenetic minerals does not mobilize uranium. Diagenesis which affected amorphous iron hydroxide could mobilize uranium.

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Tectonics of Western Permian Basin

The Permian basin of west Texas and southeastern New Mexico probably originated in late Precambrian time as a shallow geosynclinal trough on the southern edge of the North American craton. The extreme southern part of the region formed part of a subduction trough.

By Late Cambrian time the seas in the southern part of the trough had advanced over part of the craton, and Paleozoic sedimentation began. Perhaps in late Precambrian a north-facing salient of the trough developed into an aulacogen with lateral dextral movement along steep faults in what later became the eastern part of the Delaware basin.

During early and middle Paleozoic time the region was tectonically quiet. However by Middle Mississippian the Precambrian zones of weakness were reactivated and the Delaware and Midland subbasins began to form. At the same time the Marathon-Ouachita trough began to deepen.

In early Middle Pennsylvanian time active tectonism with stresses from the northeast formed a small mountain chain between the two subbasins, on the site of the Central Basin platform. In later Pennsylvanian and Early Permian time renewed tectonism resulted in low-angle thrusting of early Paleozoic rocks northward from the Marathon trough. At the same time there was renewed vertical movement on the ancient lateral faults which formed the eastern edge of the Delaware basin.

Middle and Late Permian was a quiet time tectonically with the only movement being slight subsidence, probably due to differential compaction in the basins. This regime continued through the early Mesozoic. By Early Cretaceous, however, a major change in paleogeography resulted in an advance of the sea over the region which was by then securely welded to the craton.

The area was protected from severe deformation during the Laramide orogeny by the beam effect of the Matador and Amarillo uplifts on the north and the east-west folds of the Marathon belt on the south. Tectonic activity since the early Tertiary has been minimal.

Tectonic style in the Delaware basin is characterized by eastward tilt in the Permian and younger rocks. The older rocks are folded and cut by steeply dipping faults. The Central Basin platform style comprises supertenuous draped structures in the younger rocks. These overlie closed folds with steeply dipping faults in the older rocks which trend north-northwest. The Midland basin contains en echelon faults and extension fracturing, reflecting moderate movement. The extreme southern part of the Permian basin consists of deep folded troughs bounded by thrust faults. The trend of these structures forms a large angle with the trends of the Central Basin platform.

The long interval of tectonic stability in the region since the early Permian has undoubtedly contributed to the maturation and accumulation of the oil and gas resources of the basin.

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Geothermal Anomalies in Western Trans-Pecos Texas

Several major geothermal anomalies are present in Trans-Pecos Texas because of warm to hot water springs and wells, silica geochemical indicators, and shallow thermal gradient measurements.

Forty-four thermal water (30°C or above) occurrences have been located in the area. The largest concentration of thermal waters is in southern Hudspeth and western Presidio Counties adjacent to the Rio Grande. The thermal waters range from slightly fresh to salty; total dissolved solids range from 275 to 11,500 ppm. Major ions in the high dissolved solid waters include sodium and chloride.

As indicated by the silica geothermometer temperatures, subsurface waters above 125°C exist at seven locations in northeast El Paso, western and southeastern Jeff Davis, western and northern Presidio, and southern Brewster Counties. The areas having highest silica temperatures are (1) west of the Hueco Mountains in northeastern El Paso County and extending northward into southwestern Otero County, New Mexico; here maximum silica temperatures are 151°C and maximum measured water temperatures reach 71°C; and (2) north of Candelaria in western Presidio County where maximum silica temperatures reach 177°C and maximum measured water temperatures are 72°C.

Geothermal gradients have been measured in over 70 wells and boreholes, most of these in Presidio County. Average gradient is 77°C/km in the Rio Grande Valley, with 30°C/km in the highlands east of the valley; this would seem to reflect the possible boundary of the Basin and Range and Great Plains tectonic provinces. In addition, a drilling program has been underway in northeastern El Paso County to investigate the geochemical anomaly west of the Hueco Mountains. Twelve to 14 holes drilled yielded gradients of over 100°C/km, and two of these penetrated the limestone bedrock, where the elevated gradients continued to increase with depth. Heat-flow values of 9 and 11 HFU were calculated for these latter two holes. On the basis of these gradients a geothermal resource may exist close to El Paso.

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Deposition and Diagenesis of Horquilla Carbonates, Big Hatchet Peak Section, Pedregosa Basin

In the Big Hatchet Peak section the Pennsylvanian-Permian (Morrowan to Wolfcampian) Horquilla Formation is 3,230 ft (985 m) thick and consists of shallow shelf carbonates which accumulated along the outer shelf margin of the Alamo Hueco basin.

The lower Horquilla (Morrowan to Desmoinesian) is 1,363 ft (415 m) thick and consists largely of micrite and fossiliferous limestones with abundant chert in many beds. Depositional cycles, consisting of grainstones, packstones, and wackestones, occur throughout the interval.

The upper Horquilla (Desmoinesian to Wolfcampian) is 1,867 ft (569 m) thick and consists of limestones and dolostones; chert is less abundant than in the lower Horquilla. Phylloid algal biostromes are present in some upper Horquilla limestone intervals. Six laterally extensive dolostone units range in thickness from 48 to 154 ft (15 to 47 m).

In both upper and lower Horquilla limestones many grainstones were subjected to intertidal and subtidal cementation within marine environments. Micritization of ooids and skeletal grains, which also developed in the marine environment, is abundant in most Horquilla limestones.

Nearly all Horquilla limestone intervals bear two or more of the following evidences of having stabilized within fresh-water diagenetic environments: (1) selective dissolution of aragonitic shells and formation of hollow micrite envelopes; (2) precipitation of meteoric vadose and phreatic calcite cements; (3) recrystallization of original lime mud matrix; (4) replacement by silica which first nucleated within ooids, shells, and peloids and then invaded the surrounding matrix to form nodules or discontinuous layers. At one stage most Horquilla limestones contained large volumes of primary and/or secondary porosity, all or virtually all of which has been occluded by subsequent precipitation of marine or meteoric cements.

All upper Horquilla dolostones were formed by neomorphic dolomitization of originally unstable carbonate sediments. At one stage considerable secondary intercrystalline and moldic porosity existed in most dolostone intervals; much of this was subsequently obliterated by epitaxial dolomite cements on original rhombs and by coarse recrystallization. Gravitational calcite cements partly filled many of the larger voids, and outer tips of many of these microstalactites subsequently became paramorphically dolomitized.

In the upper Horquilla, anhydrite porphyroblasts and nodules were emplaced in many limestone and dolostone intervals by hypersaline groundwaters to form tertiary (third order) stairstep molds, many of which are still open in dolostones.

The only preserved porosity is in dolostones and these may represent potential hydrocarbon reservoirs in the subsurface.

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Cyclic Hydrologic and Diagenetic Events in San Andres Formation: Geologic Implications

In the San Andreas Formation in Roosevelt, Curry, Quay, and DeBaca Counties, New Mexico, cyclic hydrologic and diagenetic events reflect rhythmic fluctuations in sea level, climate, and sedimentation.

Depositional cycles in the San Andres record: (1) rapid transgressions which accompanied eustatic rises in sea level; (2) seaward progradations of subtidal, intertidal, and supratidal (sabkha) facies during stillstands of sea; (3) subaerial exposure during lowstands of sea level; and (4) continuous subsidence of the area. Effects of fluctuation in sea level, climate, and sedimentation were transmitted to San Andres carbonates through changes in hydrology which produced distinctive diagenetic overprints.

The following cyclic hydrological events are recorded in many San Andres intervals: (1) dolomitizing fluids dolomitized initially unstable carbonates; (2) hypersaline brines emplaced anhydrite as partial to nearly complete replacement of carbonate (anhydritization) and as cement; and (3) low-salinity ground waters dissolved much anhydrite, brought about replacement of anhydrite by gypsum, hemihydrate, calcite, and silica and also caused dedolomitization. Many San Andres carbonate intervals bear evidence of having been subjected to overprints of two cyclic fluid invasion sequences.

Nearly all primary and secondary porosity in dolostone has been occluded by dolomite, anhydrite, and calcite cements. In limestones (exclusive of dedolostones) nearly all primary and secondary porosity has been occluded by calcite and anhydrite cements. Many San Andres limestones were formed by paramorphic replacement of dolomite by calcite (dedolomitization). Secondary intercrystalline and moldic porosity in the original dolostone have been preserved after dedolomitization.

Diagenesis and porosity relations within the San Andres reflect the relative flux of dolomitizing, anhydritizing, and low-salinity fluids within a given interval. Tertiary porosity is extensively preserved in intervals in which the low-salinity stage of a "hydrologic cycle" has not had its overprint superseded by dolomitizing or anhydritizing fluids of a subsequent "cycle." The most highly porous intervals contain both secondary intercrystalline and anhdrite moldic porosity.

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Application of Basin Analysis to Exploration Strategy Determination

To model the exploration environment of the Permian basin and to consider available strategies for each plan a computer model was developed using network (decision trees) designed to simulate the environment. Monte Carlo simulation was used to evaluate the variability of the data.

Statistical and engineering techniques were used with commercially available data bases to provide forecasts of remaining potential for each play. Additional input such as drilling cost, seismic cost, and lease availability were obtained from company and commercial sources.

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Integrated Geophysical and Geologic Study of Deep Structure and Tectonics of Permian Basin

An integrated geophysical and geological study of the deep basement structure and tectonics of the Permian basin of west Texas and southeastern New Mexico was made using gravity, magnetic, and subsurface data. Over 6,000 gravity and 13,000 magnetic readings from different sources were used to construct gravity and magnetic maps of the area. The Central Basin platform is reflected by prominent positive Bouguer gravity and magnetic anomalies. However, both the gravity and magnetic maps show an east-west trending saddle in the Central Basin platform region which must be due to a deep-seated intrabasement structure. The West Platform fault zone which separates the Central Basin platform from the Delaware basin is reflected by a steep gravity gradient. By combining gravity and abundant well data in two-dimensional computer modeling, earth models were derived for two profiles crossing the area. These earth models show that the gravity relief between the Central Basin platform and the Delaware basin is far too large (± 40 mgal) to be explained simply by the thickness of the sedimentary section of the Delaware basin. These models indicate a deficiency of mass in the basement underly-