the radiogenic gases permit estimates of the rate of evolution of the atmosphere.

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Saline Waters of Sedimentary Rocks

Most saline waters of marine sedimentary rocks were probably similar initially to present-day ocean water. Many early diagenetic changes are closely related to organic content and bacterial activity; ion exchanges and perhaps some other early changes are inorganic.

Recent studies indicate that compaction of sediments and escape of interstitial water begin with deposition and continue for millions of years. Fine-grained sediments behave as semi-permeable membranes, permitting selective escape of water and concentrating dissolved components in remaining pore fluids. With increasing salinity, proportions of some ions also change, especially with calcium increasing relative to sodium. Most explanations favor liquid-solid cation exchange reactions; some evidence also suggests selective escape of Na, carbon dioxide (as HCO_3?), boron (as H_3BO_3?), and possibly ammonium ions. If rates of escape do indeed differ, they are probably related to size and electrical charge of the dissolved hydrated components. Carbonates may dissolve as carbon dioxide escapes, increasing calcium in the retained brine. Original ocean water in contact with normal sediments has thus evolved to connate (redefined) or fossil water vastly different in composition, and these changes must be closely related to the origin of petroleum. Rates of migration and evolution depend on the environment.

Chemical and isotopic criteria also clarify the origin of saline waters other than those of normal marine sediments, including connate waters of evaporites; waters of relatively low salinity that have dissolved evaporites; sulphate and bicarbonate waters of oil fields; waters driven from sedimentary rocks during progressive metamorphism; and magmatic waters that have migrated into sedimentary rocks. Relatively complete analyses of waters from oil fields and elsewhere illustrate some of the principles involved, but extensive additional studies are needed.

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Embar Field, Andrews County, Texas

From its discovery, May 14, 1942, to January 1, 1963, the Embar field produced 26,543,022 barrels of oil from pays in the Grayburg, upper Clear Fork, lower Clear Fork, Devonian, Fusselman, and Ellenburger. San Andres production on the Embar structure is not included in this figure since it is incorporated with the Martin San Andres field. Up to 1,500 feet of sandstone and red shale of Tertiary, Cretaceous, and Triassic age cover the Permian which in turn is about 6,400 feet thick and directly overlies a major unconformity. Beds ranging in age from Pennsylvanian to Precambrian are present beneath this unconformity, but within the limits of the Embar Ellenburger field, beds no younger than Precambrian, Ellenburger, or basal Simpson are found.

The pre-Permian structure of the Embar field is an anticlinal fault block which is part of a much larger anticlinorium. The structure was peneplaned following its uplift in late Mississippian or early Pennsylvanian time and again in late Pennsylvanian or earliest Permian. This structure is faintly reflected through the Permian pay formations because of drape or renewed uplift along the old axes. The Devonian is productive on the south flank of the Embar structure in updip pinchouts complicated by faulting. Although analyses reveal that oils from the different formations in the Embar field are similar, waters are distinctive. This does not damage the concept that the oil from the upper and lower Clear Fork, Devonian, and Ellenburger are probably from the same source. This source may have been dark shales of Pennsylvanian and Mississippian age which were preserved in structurally lower areas. It is theorized that migration may have begun in post-Clear Fork time when all the present reservoirs were covered. From the source beds the oil may have followed the unconformity at the base of the Permian strata, then fault planes, until it reached the Ellenburger and Devonian. From these formations the oil may have gradually migrated vertically to the lower and upper Clear Fork beds.

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Pennwell-to-Means Upper San Andres Reef of West Texas

The Permian Central Basin platform consists in large part of a great carbonate build-up of Wolfcamp to upper Guadalupe age, and within it may be recognized a great many individual but related reefs. One of the best revealed of these reefs is one of upper San Andres age which extends more than 70 miles along the east flank of the Central Basin platform from the Pennwell-Jordan pool of Crane and Ector Counties to the Means pool of northern Andrews County. Isopach and facies studies demonstrate that during upper San Andres time this reef grew in relatively shallow water along the then eastern margin of the platform. On the east lay somewhat deeper water of the Midland basin where rocks of the same age are sandstone, limestone, and dolomite. On the opposite or western side of the reef the water was nearly as shallow as over the reef itself, but slightly more saline, and the rock is dolomite with traces of anhydrite.

Growth of the upper San Andres reef ceased at the close of San Andres time, but the reef was affected by subsequent post-San Andres crustal movements so that now the southern part of the reef is 600 feet higher than the northern end.

During reef growth, porosity developed widely throughout its extent and can now be traced almost continuously from the southern to the northern extremity, but beyond the reef toward the east and the west relatively little porosity was produced. By the beginning of post-San Andres time the voids had been filled with fluids: gas, oil, and water. These fluids, according to their specific gravities, responded to subsequent structural movements, within the limits of available porosity, so that now the oil is concentrated in the several pools which occupy much of the trend.