this type of migration. Fortunately for all concerned, these chemical changes can be distinguished from those chemical transformations which stationary petroleums slowly undergo in response to reservoir temperatures and pressures over geologic time intervals.

In contrast to the relatively minor chemical changes that can be attributed to secondary migration, certain petroleums, produced from distinct but narrowly separated strata within a single field or limited geographic area, are markedly different in chemical composition. Other chemical characteristics of this group of oils, however, suggest that they were derived from a common source. The observed chemical differences can not be explained as transformations of the stationary maturation variety. Detailed studies of the compositional differences encountered in such oil sequences imply that these oils must have experienced physical separations of major petroleum fractions prior to or during the migration process. This variety of petroleum segregation, capable of producing major chemical changes, is herewith designated as a "separation-migration" mechanism to distinguish it from the typical secondary migration phenomenon which results in relatively minor petroleum composition changes.

Although the recognition of a new petroleum migration mechanism may appear to further complicate our already strained concepts of petroleum migration and segregation, the existence of a "separation-migration" mechanism is in accord with and a plausible consequence of some of the best-founded hypotheses of petroleum evolution.

THEIS, CHARLES V., Staff Scientist, U. S. Geological Survey, Albuquerque, New Mexico

Ground Water in Southwestern Region

The outstanding generalization about ground water in the parts of New Mexico and Texas in this region is that reserves will be exhausted in a few to several decades at the present rate of use. In nearly all areas development has increased exponentially since 1945. In New Mexico some legal check on exploitation is available in the doctrine of priority; in Texas no legal check exists.

Generalizations concerning the hydraulics of the important ground-water bodies are: most recharge is close to development; the localities of natural discharge are from a few to 100 miles distant; the exploitation of ground water by wells involves either the depletion of storage or a decrease in stream flow to which it is tributary.

The prolific aquifers are unconsolidated deposits of Quaternary and Tertiary age in bolsons, stream valleys, and the High Plains, and limestones especially of Permian and Cretaceous ages.

Bolson aquifers include the interconnected water bodies between the Basin Ranges of southwest New Mexico, the Estancia Valley, Tularosa Basin, and the Dell City areas. River-connected aquifers include the alluvium of the Rio Grande and the alluvium and limestones of the Pecos River and other Texas streams. The development of the Roswell Artesian Basin resulted in the New Mexico ground-water law, upon which the laws of nine other western states are modeled. Saturated brines enter the Pecos in the Delaware Basin.

The Staked Plains contains probably the largest area of ground-water mining, and one of the largest ground-water reservoirs in the United States. Its size made necessary the first application of a non-steady theory of ground-water movement 30 years ago and the widespread mining resulted in 1963 in the first legal determination that ground water is a depleting mineral resource.

The hydrodynamics, development, reserves, and depletion of individual ground-water bodies are given.

THODE, H. G., President and Vice-Chancellor, and MONSTER, J., Research Chemist, Hamilton College, McMaster University, Hamilton, Ontario, Canada.

Sulphur Isotope Geochemistry of Petroleum, Evaporites, and Ancient Seas

It has now been established that considerable sulphur isotope fractionation occurs in the biological sulphur cycle and that the bacterial reduction of sulphate, which leads to the enrichment of S^{34} in sulphate and its depletion in sulphide, is largely responsible for the wide fluctuations in isotope ratio which occur in marine sediments.

In this regard, present-day ocean water sulphate is remarkably uniform in sulphur isotope content, both in depth and in geographical location at a value of $\delta = S^{34} = +20$ (20 parts per mil enriched in S^{34} with respect to sulphur in meteorites) and provides a base level in isotopic ratio from which fractionation can be reckoned. However, in dealing with ancient sediments and petroleum, we need to know the S^{34} content of the ancient oceans or seas.

Recently (Thode and Monster, 1963) a study of the sulphur isotope distribution in the marine evaporites of some ten sedimentary basins of several continents was carried out. From this study it has been possible to estimate the sulphur isotope ratio for the various ancient oceans and to establish the pattern of change throughout geological time.

The pattern of change for petroleum sulphur appears to be parallel with that for the evaporites and ancient seas. However, the petroleum sulphur is, in general, depleted in S^{34} by about $15°/_{oo}$ with respect to the contemporaneous gypsum anhydrite deposits. This displacement of $\sim 15°/_{oo}$ in the S^{34} content, which is about the isotope fractionation expected in the bacterial reduction of sulphate, is strong evidence that sea water sulphate is the original source of petroleum sulphur and that it is first reduced by bacterial action in the shallow muds before being incorporated into the petroleum. The lack of any sulphur isotope fractionation in the plant metabolism of sulphate would seem to rule out plant sulphur as a major source of petroleum sulphur.

Since the δS^{34} values for petroleum pools in a given horizon, e.g., Devonian (D-2), are fairly uniform over a large sedimentary basin and since these values vary from one horizon to another depending on the S^{34} content of the contemporaneous seas, sulphur isotope studies should be useful in solving migration problems.

WASSERBURG, G. J., Professor of Geology and Geophysics, California Institute of Technology, Pasadena

Origin of Rare Gases in Natural Gases

Studies have been made by several laboratories on the isotopic and chemical abundances of He, Ne, Ar, Kr, and Xe in natural gases from both gas wells and geothermal areas. This work has shown that the rare gases consist of a mixture of two distinct components—atmospheric and radiogenic. These investigations give information on the evolution of natural gas accumulations from considering the dissolved atmospheric components and the production of He^4, A^{40} and Xe from nuclear processes. The importance of solubility phenomena in fractionation of these elements may be approached by using a simple model. Measurements of the radiogenic gases permit estimates of the rate of evolution of the atmosphere.

WHITE, DONALD E., Research Geologist, U.S. Geological Survey, Menlo Park, California

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.

WILLIAMS, JACOB L., Geologist, Phillips Petroleum Company, Midland, Texas

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.

YOUNG, ADDISON, Phillips Petroleum Company, Midland, Texas

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.