

this type of migration. Fortunately for all concerned, these chemical changes can be distinguished from those chemical transformations which stationary petroleum 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 petroleum, 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 deter-

mination 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‰ with respect to the contemporaneous gypsum anhydrite deposits. This displacement of  $\sim 15$ ‰ 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  $\delta S^{34}$  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<sup>4</sup>, A<sup>40</sup> 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