1. Petroleum Geology

A brief review of petroleum geology is helpful to understand world oil resources and production rates since geology sets the upper bound on production potential from the finite petroleum resource.

Geologists generally agree that petroleum deposits were formed from the remains of enormous quantities of aquatic plants and organisms which became mixed with sand and mud at the bottom of bodies of water. If a certain regime of temperatures and pressures existed, this biological material was converted into petroleum during geologic time. The pressure in the earth's crust forced the petroleum into the tiny open spaces between the grains of imbedded sandstone and other coarse textured strata (and not into vast underground pools). For petroleum to be present in commercial quantities some sort of trapping mechanism must have been present to prevent its escape. In addition, these traps must have not been breached by natural means after accumulation occurred.

There are two major kinds of trapping mechanisms. Structural traps are created by a deformation of the earth's crust; the folding or faulting of rocks results in the entrapment of petroleum. Stratigraphic traps result from the relative difference in the porosity and permeability of the oil-bearing rocks compared to less porous and permeable adjacent rocks, which then serve to prevent the further movement of oil. Many traps are combinations having both structural and stratigraphic features.

Since the oil reservoir (a rock formation or trap holding an accumulation of petroleum) was formed from sea sediments, most reservoirs also contain salt water. In addition, natural gas is almost always present either dissolved in the oil or as free gas separate from the oil. The associated water and natural gas are important in maintaining pressure during petroleum production.

The theory of petroleum formation and occurence has led to the search for areas containing thick beds of sedimentary rocks. Geophysical techniques have led to the discovery of approximately six hundred basins (a tract of land in which the rock strata are tilted toward a common center), both onshore and offshore, which may contain oil or natural gas. Sufficient seismic work has been done to give an indication of their prospective petroleum area and their general structural aspects. In approximately four hundred of these basins exploratory drilling in varying amounts and degrees of success have taken place; commercial quantities of oil and gas are being produced from approximately 160 of these basins.

There remain approximately 200 basins which have not been drilled. However, the size, characteristics of the sediments, and the gross structural features of these basins have been determined by geophysical work.* This lack of drilling has been due to many factors including the location of the areas, restriction on access caused by individual governments and territorial disputes, and most importantly, judgments about their potential for yielding petroleum. In particular, some of these basins lie in the offshore Arctic for which the past prices of oil have not been sufficient to justify exploration (although this appears to be changing).

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* M. **Halbouty,** "Acceleration in Global Exploration," American Association of Petroleum Geologists Bulletin, May 1978.

Although oil has been found in commercial quantities in approximately 160 basins, 25 of the 160 basins (containing discoveries of over 10 billion barrels) have accounted for over 80% of total discoveries.* Not only have oil discoveries been concentrated in a few basins, but the majority of oil has been found in a relatively small number of large fields.**

Over 90% of the oil has been found in a small number of large fields containing at least 100 million barrels of liquid petroleum or liquid - equivalent (liquids plus natural gas) resources. Thus, of the more than 20,000 fields discovered, 1700 contain over approximately 900 of the 1000 billion barrels which had been produced or were known to exist at the end of 1975.*** Further, an even smaller number of approximately 280 giant fields (containing at least 500 million barrels in liquids or liquids equivalent) contained approximately 75% of the oil found through 1975.

The U.S. has a smaller share of oil found in large fields than the worldwide average of 90%. However, approximately 70% of the oil found in the U.S. has been found in large fields containing at least 100 million barrels of liquid petroleum or liquids equivalent. The significance of large fields for the U.S. is illustrated by the petroleum discoveries in the Permian Basin, which were responsible for 18% of the crude oil and 10% of the natural gas discovered in the U.S. through 1974. The Permian Basin has been extensively explored, resulting in the discovery of over 4000 oil and gas fields by the end of 1974. At that time over 60% of the oil and gas had

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*D.R Root and E.D. Attanasi "World Petroleum Availability," United States Geological Survey, 1979.

**Field is used to refer to a single accumulation (in which case it is synonymous with reservoir) or a set of closely related accumulations of petroleum.

***R. Nehring, Giant Oil Fields and World Oil Resources. Rand Corp., June 1978, p. Vii.

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been discovered in the 70 largest fields while only 2% had been discovered in the 2700 smallest fields (fields containing less than 1 million barrels of oil or equivalent).*

Many experts expect the importance of large fields for new discoveries to continue, for both upon geologic and economic reasons. In new offshore areas, only large fields are economical to develop at today's oil prices ($30 per barrel), although in places where the associated infrastructure (pipelines, etc.) exists, smaller finds may be sought and developed.

The earliest discoveries of oil and gas made over a century ago were based on surface seepages and analyses of surface geology. After a century of exploration, petroleum exploration has become extremely sophisticated. New techniques and instrumentation, such as geophysical surveys, geochemical analysis and subsurface logging, combined with the use of computers, provide information on structural characteristics of the subsurface.

These techniques provide only raw data which must be evaluated by geologists and geophysicists; the room for judgment and, therefore, differences in interpretation remains great. Drilling remains the only way to determine the actual existence of petroleum resources, with the other exploration techniques providing guidance as to the most promising locations within a basin.

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*D. H. Root, L. J. Drew, "The Pattern of Petroleum Discovery Rates" in American Scientist, vol. 67 (1979), pp. 648-652.

An example illustrating the geologic uncertainties and risks in oil exploration is the Destin Dome located in the Gulf of Mexico. Over six hundred million dollars was paid by oil companies for leases around the Destin Dome in view of its extremely promising petroleum potential. After drilling many dry holes, the companies involved returned the leases to the government with no petroleum produced.

Once oil is found in commercial quantities, there is a substantial delay until production begins, and such delays can last several years in many offshore areas. After the initial discovery further drilling and planning is necessary to determine the optimum way to exploit the find. In addition, the necessary infrastructure (pipelines, other supporting equipment and people) must be located and bought. In many Arctic areas the technology to allow production must still be developed.

Production begins initially with the oil allowed to flow naturally from the high pressure area underground to the surface. This natural recovery, called primary recovery, depends on reservoir pressure and the natural drive mechanism. The drive mechanism refers to the sources of energy within the reservoir that will assist production, and depends upon the physical properties of the oil, gas and water found in a reservoir and upon their relative proportions and locations.

Secondary recovery is another procedure used to boost recovery from a reservoir. This procedure consists of reinfecting either associated gas or water near the well to maintain underground pressure. In the past, secondary recovery techniques followed the use of primary recovery techniques; today these techniques may be used simultaneously to increase total production.

The percentage of the oil in place recovered using primary and secondary recovery varies greatly from field to field. Thirty three percent is sometimes used as an average figure based upon experience in the U.S.; however, recovery in the East Texas oil field which has a natural water drive may exceed 75%.

Production rates are limited by the drive mechanism and other geologic factors. In addition, economic and resource maximization considerations (production at too fast a rate would lead to a reduction in total recovery) also influence production rates. A general planning guide for a country or region is that 1/15 of the recoverable oil remaining can be produced each year; this is referred to as the 15 to 1 reserves to production ratio. This planning guide is only a rough estimate and is, to some extent, a function of well density. Production from U.S., Canadian and Australian fields, which are in a mature state of development, exceed the 1/15 ratio. In the U.S. the figure is about 1/10.

With the increased price of oil since the 1973 embargo, other procedures have become economical for recovering additional oil from existing fields where primary and secondary techniques have already been used. This is especially true for the U.S., since many early U.S. fields were exploited ineffectively causing a large portion of oil to be left in the ground. These additional techniques, called enhanced recovery techniques, consist of injecting heat or chemicals into the reservoir.

Except for heat injection, most of these techniques are currently in a developmental stage.* The success of these techniques varies greatly from

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*See the OTA report Enhanced Oil Recovery Potential in the United States, January 1978, for a more detailed review of these techniques.

field to field. A range of approximately 2-10% has been given as the additional percentage of oil in place that can be recovered in the U.S. using enhanced recovery techniques.* Since enhanced recovery techniques are expensive and require energy for their utilization, the extent of the use of these techniques will depend upon the future price of oil and the price of the chemicals and steam required for their implementation.

The production of heavy oil requiring steam for its primary recovery is not included in enhanced recovery estimates. However, heavy oil fields for which some production is possible without steam injection are included in enhanced recovery estimates. Thus most heavy oil fields in California are included in enhanced recovery estimates.

About 95% of the production of liquid petroleum in the world and 85% in the U.S. is of crude oil from primary, secondary, and enhanced recovery techniques. The remaining 5%, 15% in the U.S., is natural gas liquids resulting form natural gas production. The term liquid petroleum is used to refer to the sum of crude oil and natural gas liquids production.

In some publications production and resource estimates are given for crude oil while in other publications these estimates are given for liquid petroleum. These differences lead to potential confusion in comparing resource and production estimates from various sources. Unless otherwise specified, estimates in this paper will be liquid petroleum estimates.

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* Ibid.