MINERAL RESOURCES OF THE ATLANTIC EXCLUSIVE ECONOMIC ZONE

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Abstract

Potential mineral resources of the Atlantic Exclusive Economic Zone (including the Gulf of Mexico and U.S. Caribbean areas) include petroleum, sand and gravel, phosphorite, placer deposits of heavy mineral sands, ferromanganese nodules, and fresh water. Although major efforts have been made to search for petroleum, the oil and gas resources of the region are well known only in the western Gulf Shelf and more exploration is underway. Heavy-mineral placer deposits, which may be sources of titanium, gold, rare earths, etc., have been sampled, but the extent and, therefore, economic value of the deposits has not been identified. Sand and gravel, phosphorite, and ferromanganese nodules all are represented by fairly well established deposits and only modified market conditions would be necessary to cause detailed exploration and mining.

1. Introduction

The Exclusive Economic Zone (EEZ) (Fig. 1) for most of the United States is a frontier exploration area for almost all economic mineral resources. This is emphatically not the case for one resource of major value in one area, however — petroleum in the western Gulf of Mexico — and petroleum probably will turn out to be the major resource of our entire EEZ. I will catalogue the resources as they are known now, starting with the most proven and most valuable, and proceeding to those that seem to me to be more problematical. Much of this review has been summarized from two reports by panels of a recent U.S. Geological Survey (USGS) symposium on the U.S. Exclusive Economic Zone (EEZ): those of Klitgord and Watkins (1984) and Ballard and Bischoff (1984).

2. Petroleum

We shall begin with a consideration of the western Gulf of Mexico and proceed to the eastern Gulf and the U.S. East Coast, progressively lesser-known areas from a petroleum-resource point of view. The petroleum geology regions and the boundaries of the U.S. Atlantic-Gulf of Mexico EEZ are identified in Figure 1. These regions represent separate basins on the East Coast (Klitgord and Behrendt, 1979) and areas of thick sediment accumulation but different sedimentary facies in the Gulf.

Western Gulf of Mexico -- The western Gulf of Mexico has been a region of active terrigenous clastic (land-derived) sedimentation since the Late Cretaceous. Gas and oil are produced from many thousands of wells on the Texas and Louisiana continental shelf, primarily from Miocene and younger strata. Sedimentation rates during the Cenozoic (last 66 million years) have been exceptionally high, resulting in accumulation of more than 15 km of sediment. This situation contrasts strongly with the eastern Gulf and U.S. Atlantic continental margin, where Cenozoic deposition rates were comparatively very slow. Although subsidence rates have been fast, the western Gulf, along with all other eastern U.S. margin areas, should be considered as tectonically quiet. Structural features providing petroleum traps in the western Gulf have resulted mainly from the flow of salt and shale in response to loading by overlying sediments (Fig. 2). Salt is an extremely mobile material in a geological setting, and the western Gulf salt probably has migrated seaward many hundreds of kilometers to reach its present location (Fig. 2) (Martin and others, 1982).
movement of the mobile salt (and in some places shale), has created domes and pillows as well as a complex network of faults. Growth of the domes and faults result in oil traps. Leasing in the western Gulf now is moving to deeper water; numerous deep-water leases (200 - 2000 m) were sold in recent Lease Sales 72 and 74.

Eastern Gulf of Mexico — The eastern Gulf of Mexico region (Fig. 1), along with the Florida Platform and Blake Plateau to the east (Fig. 3), formed a single carbonate platform for most of its history. Relatively little salt and more anhydrite accumulated in the eastern Gulf area during its early history than in the western Gulf, and salt domes are uncommon in the offshore area, although the largest structure on the shelf, the Destin Dome, probably does represent a salt swell. This feature lies south of the Florida panhandle, in the transition zone between the eastern and western Gulf provinces. Intense exploration by oil companies in the dome has not resulted in any petroleum discoveries, however. Leasing activity on the broad West Florida Shelf also has occurred on the sides of the Tampa Embayment on the shelf west of Tampa and on the shelf west of southern Florida, in the South Florida Basin. Some of the productive units that have been drilled on land may continue offshore in the eastern Gulf, particularly the Jurassic strata around Mobile Bay and the Upper Cretaceous Sunniland Formation that produces oil in southern Florida.

Blake Plateau Basin — The Blake Plateau Basin (Figs. 1 and 3) is filled by a thick sequence of dominantly carbonate platform deposits, just as in the eastern Gulf region. Structures are poorly developed. The reef or shelf-edge structure that probably existed on its eastern boundary has been eroded away, or at least truncated by erosion, and thus any oil that had been trapped there has escaped. Traps in the central part of the basin would be stratigraphic traps (carbonate banks, pinchouts of permeable strata, etc.) and not easily found. Because the main part of the basin lies beneath the Blake Plateau, under about 1000 m of water, no exploratory drilling has been attempted there. Exploratory drilling in the landward extension of the basin beneath the continental shelf, a region known as the Southeast Georgia Embayment, has produced six dry holes. Targets were supposed structural traps in Paleozoic and Triassic (?) units.

Carolina Trough — The Carolina Trough (Figs. 3, 4, and 5) is a long linear basin (500 km long by only 50 km wide), marked by a row of salt domes on its seaward side and a set of growth faults on its landward side. Because the domes are very precisely located on the East Coast Magnetic Anomaly, we presume that their locations are controlled by a basement structural feature. The faults result from salt withdrawal into the domes (Fig. 4) (Dillon and others, 1982). This is the only significant group of salt domes on the North American eastern margin south of eastern Georgias Bank and the Nova Scotian margin. Potential traps probably are associated with the domes and faults, both of which are actively moving. Unfortunately, the domes are situated in about 3000 m of water and the faults in almost 1000 m. Fault-associated traps in the western Gulf often result from "rollovers", anticlinal structures that form in the strata above a fault because strata sag toward a concave-up fault as the seaward block subsides to seaward. In the Carolina Trough, however, subsidence of the block to seaward of the fault system seems to be nearly vertical, with no obvious development of rollovers and even possible compressional effects (which would generate a different type of trapping structure). A broad, basin-edge anticline exists at the seaward side of the Carolina Trough (Fig. 5). The structure probably resulted from depositional dips to seaward on the eastern side and subsidence over the central part of the basin area due to thermal and loading effects and to salt flow. The Carolina Trough
may have a relatively high petroleum potential for the U.S. East Coast because the presence of a significant amount of salt shows that the basin subsided rapidly early in its history. Therefore, it may have been more likely to subsequently accumulate marine deposits that are good petroleum source beds. No exploratory wells have been drilled in the Carolina Trough.

Baltimore Canyon Trough -- The Baltimore Canyon Trough is a classic trailing-edge-type continental-margin basin, which contains evaporitic, carbonate, and terrigenous clastic deposits in a well-defined basin seaward of a basement hinge zone (Fig. 6). A Jurassic-Cretaceous shelf-edge high (Fig. 7) probably was formed by reef building at many locations. This is considered to be part of a structure that was formed as a reef or platform-margin bank and which probably extended discontinuously from Mexico to Canada (Fig. 8). Structures related to this feature are major petroleum producers in Mexico. Two recently completed tests of the reef complex have been drilled off New Jersey in about 2000 m of water and have been declared dry. The locations and depths of the completed tests were projected about 5 km to a USGS seismic profile for Figure 7. A third test well is underway, which will test the seaward side of the reef, where highly organic, deep-basin deposits that lap against it may act as source rocks. In all, 30 petroleum exploration holes have been drilled in the Baltimore Canyon Trough. In general, on the shelf, source beds are not thermally mature for petroleum generation above about 3000 m, whereas at greater depths porosity and permeability decrease (Mattick and others, 1981). A group of wells testing the Great Stone Dome (Fig. 6) Mobil-Shell) turned out dry probably because the dominant continental facies in the area resulted in poor source-bed characteristics. Another group testing a faulted structure above a probable salt swell near the shelf-edge (Fig. 6, Texaco) resulted in four wells with measured flows of gas and one with measured flows of gas and oil. Three other wells in the Baltimore Canyon Trough have produced shows of gas, but no commercial field has been declared in the region.

Georges Bank Basin -- The Georges Bank basin (Fig. 1) is located at an irregularity in the axis of rifting that was developed when Africa and North America broke apart. As a result, it is characterized by a more complex structure than other basins of the eastern U.S. continental margin. Irregular block faulting of basement created several sub-basins, some of which,
accumulated evaporites (Fig. 9). The sedimentary deposits that accumulated on the continental margin after rifting of the continents was completed, are relatively thin here, compared to those of other east coast basins (8 km compared to 12-15 km). Salt swells, buried shelf reefs, and drapes across basement highs have formed possible traps, but drilling has resulted in eight dry holes. Future exploration probably will move to the shelf-edge reef or bank in deeper water, as in the Baltimore Canyon Trough.

Future Directions -- As noted above, the most significant target for current petroleum exploration on the eastern U.S. margin is the shelf-edge reef or carbonate bank that probably represents the remnants of a more extensive feature of Jurassic-Early Cretaceous age (Fig. 8). Perhaps stratigraphic traps associated with the reef will be significant, although these are harder to identify in seismic profiles than structural traps. Other stratigraphic traps that could become important are permeability pinchouts at the flexure and, on the west sides of the main basins, facies changes at old shoreline features (Fig. 3), and facies changes at the base of the continental slope where deep-sea deposits interfinger and fill eroded channels in slope deposits.

Rift basins filled with inferred Triassic deposits (Figs. 3, 4, 6, 9) also may have considerable petroleum potential that is almost unevaluated. Rift lakes that formed in the basins early in the period of continental breakup, commonly contain richly organic sediments, appropriate as source beds. Strata that could form effective seals and reservoirs probably are present, and the basins would have had high heat flow to achieve maturation. Those rift basins closest to the main rift (now beneath the continental shelf) are likely to have had the greatest marine affinities and greatest heat flows, and, therefore, are most likely to have generated oil.

Clathrates, also known as gas hydrates, are ice-like materials that form by the combination of free gas and water at fairly low temperatures and high pressures, conditions found in near-bottom sediments at water depth greater than several hundred meters. Evidence for presence of these materials has been noted down to several hundred meters below the sea floor, at which depths the rising temperature makes them unstable. Thus a uniform-thickness layer of clathrate-cemented sediment is produced, the base of which parallels the sea floor and can be observed in seismic profiles. Clathrate-cemented sediments can act as gas seals, and velocity studies show that gas is trapped by such seals (Dillon and others, 1980). Gas traps can be formed by clathrate seals in several ways (Fig. 10). Where the sea floor forms a hill, the clathrate-cemented layer (which parallels it) forms a dome that can trap gas, as in the Blake Ridge off South Carolina (Fig. 10). A dome in the base of the clathrate can also be found over salt domes, where both the anti-freeze affect of diffusing salt ions and increased heat conductivity of solid salt tend to cause an upbowing of the base of the clathrate. Traps also are seen where permeable strata dip back into the continental margin, bounded by impermeable strata, if the permeable layer is sealed at its updip end by the clathrate layer. The clathrate itself contains large amounts of gas which, ultimately might be extracted directly, although many technical problems will have to be solved before that can be done.

3. Sand and Gravel

The value of offshore sand and gravel probably will be greater than for any other offshore non-fuel mineral product. Presently sand-and-gravel production from land sources is a $3 billion per year industry. Deposits on land are becoming progressively more difficult to utilize because of land-use restrictions, especially near big cities where demand by the construction industry is greatest; this allitates toward offshore sources. Furthermore cost of transportation is a significant factor in sand-and-gravel prices, and because barge transportation is relatively cheap as compared to trucking, the large coastal cities are in particularly good locations for utilization of offshore sources.
Very large volumes of sand are known to be present on the eastern and southern coasts of the U.S. on the basis of nearshore surveys by the U.S. Army Corps of Engineers and regional surveys by the USGS (Fig. 11) (Schlee, 1975). For example, 400 billion tons of sand are estimated to be present in the top 3 m of sediment on the U.S. east coast continental shelf and slope. Some sand deposits in the EEZ are less desirable due to admixture of silt or clay, particularly in Tertiary rocks. It is found most often as irregular nodules, but is also present in beaches. Extraction at such locations will not affect the beaches.

Gravel is most common where it has been derived from glacial sources on the shelf north of Delaware. To the south are found carbonate shell gravels or winnowed gravels formed by the reworking by waves of coastal-plain deposits, especially relict fluvial deposits.

4. Phosphorite

The United States is a major producer and exporter of phosphorite and demand is increasing for use as fertilizer. The resources presently being mined are expected to be adequate only for the next 20 years. About 35 million tons per year are mined in Florida (about 3/4 of the U.S. total production).

Phosphorite has been dredged and cored extensively on the continental shelf from southern Florida to North Carolina, where it appears to be an offshore extension of onshore deposits. Drilling indicates its presence at depth beneath the shelf in middle Tertiary rocks. Phosphorite occurs on the sea floor as lag deposits, presumably derived from the middle Tertiary rocks. It is found most often as irregular nodules, but is also present in sizes from pellets to solid pavements. The amount of lag deposits available on the Blake Plateau has been estimated as 2 to 3 billion tons (F. Manheim, personal communication, 1984) and more than a billion tons have been estimated for the shelf off North Carolina (Krigs and others, 1982).

5. Placer Deposits

Grains of dense, generally dark-colored minerals (called heavy minerals) occur widely disseminated in igneous rocks; commonly they are weathered out and carried to streams and the ocean, where they are concentrated by wave and stream activity. This concentration into "placer deposits" occurs because their hydraulic response is different from low density mineral grains. Such heavy-mineral placer deposits commonly have been mined for minerals that provide such valuable elements as titanium, rare earths, gold, tin, chrome, etc. Many of these commodities now are imported to the U.S., although heavy mineral deposits have been mined onshore in the coastal plains of New Jersey, Florida and Georgia.

Seismic profiling has disclosed many old beach ridges and buried stream channels on the continental shelves of the EEZ. These are likely to be the sites of heavy mineral placer deposits and preliminary sampling has suggested that these may be economic in many locations. Recent work off the southern Delmarva Peninsula, off Georgia-South Carolina and off Cape May, N.J., have revealed concentrations of heavy minerals adequate to sustain economic development if volumes are as large as anticipated (E.C. Escowitz, personal communication, 1984). Concentration of titanium minerals was exceptionally high in the Cape May area. Many of these placer deposits are in submerged former beaches and lend themselves to a dual mining operation in which heavy minerals are extracted and the remaining sand and gravel is used for construction or (for sand) for beach replenishment. Promising areas also have been identified in the Gulf of Mexico off Mobile Bay, Appalachiocola and Galveston and off the north coast of Puerto Rico where gold placers once were mined in streams.

6. Ferromanganese Deposits

Ferromanganese nodules long have been known to occur in large accumulations on the Blake Plateau, east of Florida (Fig. 11). The Blake Plateau is a broad (300 km wide) plateau at water depths of about 1000 m. The plateau is bordered on the west by a continental slope and on the east by the steep Blake Escarpment that descends to oceanic depths (5 km). Nodules are formed by accretion of iron and manganese oxides (with small amounts of other metals) around a nucleus. On the Blake Plateau, the nucleus generally is a fragment of phosphorite, and pavements and slabs of ferromanganese also form on outcrops of phosphorite. Formation and accumulation of significant quantities requires a very slow sedimentation rate (essentially nondeposition); on the Blake Plateau, this slow rate results from the scouring effect of the Gulf Stream (Manheim and others, 1982).

Nodules on the Atlantic margin are not as rich in valuable metals (such as nickel, copper, and cobalt) as are the Pacific nodules southeast of Hawaii, but discovery of platinum levels of 0.1 to 0.5 g per ton has caused increased interest in the Blake Plateau nodules. Mining might eventually begin because of additional uses for unrefined nodules in removal of pollutants from...
Figure 11: Some hard mineral resources of the Atlantic EEZ (compiled by Frank Manheim, USGS).

Stack gases or as catalysts in petroleum refining. The presence of metallic oxides in a highly porous and permeable form makes the nodules a good catalytic filter. Furthermore, the metallic oxides are reduced to sulfides in the process of removing pollutants from stack gases, which makes the metals more easily recoverable by common processing methods. The use of nodules in petroleum refining also could increase their value as an ore by increasing their vanadium and nickel content. Industrial interest in Blake Plateau nodules in the 1960’s and 70’s (Deep Sea Ventures, Reynolds Metals) resulted in the testing of a prototype airlift system for harvesting, but depressed metal markets have discouraged any recent activity.

7. Fresh Water

Fresh water probably is our most important natural resource and does occur beneath the continental shelves of the EEZ. Offshore fresh water occurs as artesian water flowing from an onland recharge area, as off Florida, Georgia, and South Carolina (Stringfield, 1966; Manheim, 1967), or as remanent fresh water that flushed shelf sedimentary rocks during the period of glacially lowered sea level, as noted off the northeastern U.S. (Hathaway and others, 1979).

No doubt, fresh water would be produced in the offshore region only under highly unusual circumstances. However, its conservation may be critical because the presence of such water may have a major impact on protecting nearshore land wells from salt water contamination. For example, mining of minerals, such as phosphate, on the continental shelf, must be done with care to avoid breaching aquicludes in critical locations of artesian systems. The offshore water of the EEZ may, in essence, be produced onshore.

8. Summary

No doubt, petroleum will be the most valuable product of the EEZ. The western Gulf of Mexico already has produced large amounts of petroleum and production is moving toward deeper water from similar traps. The rest of the EEZ is a frontier area for petroleum. Present exploration and research suggest that we will be moving to deeper water sites for the most promising traps related to the reef trend that follows the continental
margin, salt domes, faults, and deep-sea stratigraphic traps.

Present trends toward controlling land use near cities and limits on the extraction of sand and gravel almost certainly will force such mining to the offshore areas. Phosphorite is well known in the offshore area; its exploitation appears to be a matter of the time (perhaps tens of years) when onshore resources become inadequate.

Significant concentrations of heavy minerals of economic value are present in shelf sands. Whether these are present in economic quantities is only just beginning to be known, but data suggest that they are. Combined mining efforts, in which heavy minerals are extracted and sand and gravel used for the construction industry and beach nourishment are promising.

Ferromanganese crusts and nodules are well known to be present in large quantities on the sea floor; they probably could be mined fairly easily. When such mining will begin depends on economic factors and development of additional uses for the nodules.

Fresh water beneath the sea floor probably is valuable in a role of protecting onshore water sources from salt water contamination.

Valuable resources exist in the U.S. Atlantic and Gulf of Mexico EEZ. Some are well known and they only await detailed analyses of their deposits and the proper economic conditions to be exploited (phosphorite, ferromanganese nodules, sand and gravel). Some require considerably more exploration before development (petroleum, placer heavy mineral deposits). In all cases, this is the time to study the resources and logical constraints to their exploitation.

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