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The University of Texas

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Introduction.--The uranium industry, born in boom in the late 1940's and early 1950's, fell upon hard times after about a decade of lusty growth as anticipated private markets failed to develop on schedule and the United States Atomic Energy Commission cut back and stretched out its purchase program. Exploration for uranium in the United States came to a halt. Mills closed down or operated on reduced schedules as contracts expired. But in 1965 there were signs of change as more and more announcements of construction of nuclear reactors for generation of electric power appeared in the newspapers, and by 1966, the discouraged uranium salesman found doors opening rapidly and smiles on the faces of his potential customers. The hoped for private-sector market for uranium had become a reality. By September 1, 1966, a total of 47 reactors were either in operation, under construction, or firmly committed in the United States; of the total, orders for or commitments for 32 were made since February of 1965. The industry considered this sharply rising curve, looked at the nuclear fuel requirements, appraised the known reserves of uranium ore, and literally sprang into action. In the first half of 1966, only about half a million feet of exploratory drilling was completed; twice this was scheduled for the second half of the year and a million and a half feet has been budgeted for 1967. Scheduled developmental drilling shows the same sharp increase (Engineering and Mining Journal, November, 1966, pp. 78, 85). The reason for the new exploration push is made clear by comparison of projected needs and known reserves.

In 1966, the Atomic Energy Commission estimated domestic reserves as 61,600,000 tons of ore containing 145,000 tons of U_3O_8. These reserves are in the <$10/lb. of U_3O_8 category. Each electrical megawatt of installed power capacity requires one pound of uranium fuel; over a 30-year plant life, fuel requirements are estimated at a total of 5 pounds of uranium per electrical megawatt. The latter estimate is based on present reactor design and recycle of fuel. Projected nuclear power fuel needs are 200,000 tons by 1975 and 475,000 tons by 1980. These quantities include the initial fuel charge and the reserve necessary to fuel the plant over a 30-year life. The 1980 rate of use is estimated at 30 to 40 thousand tons per year. The uranium industry, then, must find at least half a million tons of uranium available at <$10/lb. over the next 15 years to provide a comfortable and secure fuel reserve at a cost that will not drastically alter power economics. This analysis ignores foreign requirements which constitute a consideration for U. S. producers because about 25 percent of the non-communist world's reserves of <$10/lb. uranium are in the United States (most of the remainder are in South Africa and Canada).

For nearly ten years the uranium industry asked itself--"Will there develop a large enough commercial market to sustain a domestic uranium industry?" Now, the electric utilities are asking the question--"Is there enough uranium to sustain a nuclear fueled electric power generation industry?" The question is not concerned with uranium supplies in the absolute sense but with the amount of uranium available within a price range so that the price of fuel will not radically alter the cost of power generation. With reactors currently in use, the upper limit of fuel cost appears to be about $10 per pound of U_3O_8. Present prices are well below this. The market is still a buyer's market with quotations ranging from $5.00 to $6.50 per pound. An increase of $1 per pound in fuel costs increases the cost of power about 0.08 mills per kwh. New engineering efficiencies in reactors probably will make it possible to utilize higher cost fuels within the present electric power price structure (Engineering and Mining Journal, November, 1966, pp. 88-89).

However, the electric utilities are not the only ones with a vexing question. The uranium industry, faced with new investments in exploration, development, mines, and mills, is looking at probable technological changes in reactors which could alter the fuel market. There is under development a breeder reactor which promises greater fuel efficiency and produces new fuel (plutonium). Initially, the breeder requires a large fuel expenditure and thus at the outset breeders will result in increased fuel demands, but the long term result will be lower fuel requirements and costs. If breeder reactors become economically feasible in 20 or 30 years, they may alleviate an acute shortage of uranium, and the uranium industry, with amortized mines and mills, may be delighted to see them. If, on the other hand, the breeder reactor is economically feasible much sooner, the industry may be faced again with the problem of the early 1960's--large reserves and milling capacity but a reduced fuel market. Farther down the road, the industry is looking at a new technology based on atomic fusion and not requiring uranium fuel.

History of the uranium industry in Texas.--In the early 1950's, uranium prospectors fanned out from the Colorado Plateau area where the first strikes were made, penetrated southward and eastward into New Mexico, and eventually spilled over into Texas. Exploring the Chinle Formation, a known host for uranium ores in Utah, prospectors working southeastward found themselves in redbeds of the same age called the Dockum Formation in Texas. Radiation anomalies were detected in these strata exposed in the Canadian River valley and along the High Plains escarpment. Anomalies were also found in Trans-Pecos Texas in volcanic rocks (lavas and tuffs) and associated conglomerates and sandstones, in coal and lignitic deposits, and in limestone. No significant deposits were developed in West Texas, although the surface was worked carefully and some small shipments of the highest grade material from deposits in the Dockum were made to the nearest mill at Grants, New Mexico.

Prospectors accustomed to free access to the vast tracts of public domain and national forest in other Western States, encountered a very different land situation in Texas. Unlike other States, Texas, upon entering the Union, retained title to her public lands (and also to her public debt). Most State lands were sold and are now in private ownership, so that the prospector must negotiate with the landowner for prospecting privileges and an operating lease. However, there are about 7 million acres where the State has sold the surface and retained the hard mineral estate, and about a million acres where the State owns both surface and minerals. Mineral exploration and development of these lands is administered by the General Land Office of Texas.

Late in 1954, a light plane carrying scintillation equipment was flying over South Texas in an attempt to relate radiation intensity to oil fields; a strong anomaly was detected in Karnes County near Tordilla Hill. This anomaly led to the discovery of uranium mineralization in Eocene-Miocene strata of the Texas Coastal Plain in an environment not previously considered by geologists as favorable for uranium exploration. It resulted in the discovery of a new uranium district in the area of Falls City, Texas and the establishment of mines and a uranium mill. It opened up to prospecting a large territory extending from South-central Texas to the Rio Grande. Uranium mineralization was discovered in a broad belt following the Jackson, Frio, Catahoula, and Goliad Formations from Fayette County south to Starr County. Deposits of commercial interest were located in Karnes, Live Oak, and Duval counties. A total of about 1 million tons of ore containing 0.10 to 0.25 percent U_3O_8 has been developed in the Karnes--Live Oak County region. About 1 million tons of 0.15 percent ore are known in Duval County, but none has been mined because of anticipated difficult high-cost mining conditions. A mill built by Susquehanna Western, Inc., went on stream in Karnes County in 1960 with a rated capacity of 200 tons per day and a relatively low processing cost. It closed in February of 1965 but almost immediately reopened in August 1965 in the face of the projected increase in demand for uranium and with a contract for sale of uranium to West Germany. This is a clear indication of how fast the situation changed. About half a million tons of ore from the Karnes--Live Oak County area has been mined and milled to date. The mill has been producing considerably in excess of its rated capacity. These figures on production and reserves have been generalized. According to an Atomic Energy Commission Press Release dated May 3, 1966, reserves in Texas and seven other minor States are 2.9 million tons of 0.18 percent ore. More detailed reserve and production data are not in the public realm.

During the Texas uranium boom, a 1955 Bureau of Economic Geology Mineral Resource Circular, "Prospecting for Uranium in Texas" (No. 37), went into four printings in six months. Over 10,000 copies were distributed. The Atomic Energy Commission established an office in Austin in 1955, closed it in 1962, and reopened it in 1965. Between 1954 and 1958, AEC geologists examined 170 prospects in 33 Texas counties. AEC preliminary reports on prospects are on open file in the Bureau of Economic Geology office.

In 1955 the U. S. Geological Survey began a program of mapping, surveys, and research in areas thought to have a uranium-producing potential. The following summary is from D. H. Eargle (personal communication, December 1966). The first unit of the program was a stratigraphic study of the Karnes County area and of the uranium deposits discovered through 1956 (Eargle and Snider, 1957a). An airborne radioactivity and magnetic survey was made in 1956, before the radioactivity pattern of the land had been disturbed by exploration and mining activities. The resulting airborne radioactivity and geologic map, covering about 14,700 square miles of the southeast Texas Coastal Plain (Moxham and Eargle, 1961), showed a close relationship between the bands of outcropping sedimentary rocks and radioactivity. In general, outcrops of those rocks that contain volcanic ash as an important component show the highest radioactivity; glauconitic marine formations containing the radioactive element K^{40}, next highest. Less extensive radiation anomalies were found over deposits of heavy-mineral-bearing sands, and, in some places, faults were found to be abnormally radioactive.

In the Karnes County area a detailed radioactivity and plane-table survey was made of the area that includes surface anomalies and oxidized-ore deposits (MacKallor et al., 1962). In the same area a study was made of the radioactive gas radon in the soil and in the air overlying the deposits (Tanner, 1964). Other studies include:

(1) The petrology and geochemistry of the rocks and their diagenesis by weathering, an explanation of the origin of the deposits (Weeks and Eargle, 1963).

(2) The physical properties of the uranium host rocks, including their permeability, porosity, and saturation; their electrical logging characteristics, and the chemistry of their contained water, derived from about 1,500 feet of cores taken from the vicinity of the deposits before mining (Manger, 1958b).

(3) Aerial observations of terrestrial gamma radiation, gained mainly from the regional aerial survey of the southeast Texas Coastal Plain (Moxham, 1964b).

(4) Continued studies of the unoxidized ores recently found and now being mined down the dip from the surface (Eargle, 1966).

(5) Uranium in the vicinity of Palangana salt dome, Duval County; a study mainly of the radiometric equilibrium of the ores.

(6) Possible relation of surficial radioactivity anomalies to sour-gas oil fields, pointing out a geographic and a possibly genetic relationship between the occurrence of the two.

Eight preliminary maps showing the detailed geology of the mining area (Brown, Eargle, and Moxham, 1961a, b; Eargle et al., 1961a, b, c; Eargle and Moxham, 1961a, b; Trumbull, Eargle, and Moxham, 1961) and another preliminary map of an area in Live Oak and adjoining counties that includes the Mabel New uranium mine (Eargle, Stanford, and Davis, 1966) are available.

The Texas situation as of the end of 1966.--In view of the rapid change in the uranium industry and the outlook for increased exploration, it seems appropriate to review the Texas situation, sum up what is known about the occurrence of uranium in the State, and assess the prospects for additional discoveries.

From the state of knowledge as of 1966, there appear to be two areas of Texas that hold out prospects for discovery of new uranium deposits--the central and southwest Gulf Coastal Plain and the High Plains. The Trans-Pecos cannot be counted out but on the basis of present knowledge, prospects for discovery of significant deposits are not as good as in the Coastal Plain and the High Plains. Mineralization in the Trans-Pecos, mostly in volcanic rocks (lavas and tuffs), is erratic and no prospects contain any appreciable volume of mineralized rock.

What is known about uranium occurrence in the Texas Gulf Coastal Plain may be summed up as follows:

(1) Uranium mineralization occurs in Tertiary strata of Eocene to Pliocene age extending in a belt more than 300 miles long from Fayette County in South-central Texas to Starr County along the Rio Grande in extreme South Texas. Within this area, a uranium content of at least 0.10 percent has been reported from about 30 prospects. Mineralization has a stratigraphic range of 2 to 3 thousand feet, occurring in rocks of the Jackson Group (Eocene), Frio Formation (Oligocene?), Catahoula Formation (Miocene), Oakville Formation (Miocene), and Goliad Formation (Pliocene).

(2) The most important deposits discovered to date occur in: (a) the Whitsett Formation, Jackson Group in Karnes County, (b) a sandstone at the top of the Whitsett or base of the Frio in Live Oak County, and (c) the Goliad sandstone and conglomerate in Duval County.

(3) In general, deposits were formed by leaching of uranium from tuffs by alkaline ground waters and subsequent deposition in permeable and porous host rocks. These include sandstones, siltstones, and conglomerates, tuffaceous or lignitic in some areas. Precipitation was effected through evaporation in a hot, dry climate, or through reduction by carbonaceous matter or hydrogen sulfide gas. Ore control is both sedimentologic and structural. Mineralization in the Jackson Group is mostly in tongues of sandstone in a sandstone, siltstone, clay, tuff, lignite sequence. Mineralization in the Frio, Catahoula, and Oakville Formations is mostly in channel sandstones and conglomerates. In some areas faults appear to have provided passageways for movement of hydrogen sulfide gas or to have restricted and concentrated movement of pregnant uranium solutions. In Duval County primary control of mineralization is structural; deposits occur in sandstone and conglomerate of the Goliad Formation overlying the Palangana dome. The host rock does not appear to have been strongly deformed by the salt intrusion so perhaps the structural attitude of the

Goliad did not have as much to do with localization of the deposits as the manufacture of H_2S in the caprock of the dome and its subsequent emanation. The uranium deposits appear to overlie sulfur deposits in the caprock.

(4) Known deposits of commercial interest range from 35,000 tons of 0.25 to 0.35 percent U_3O_8 to 1,000,000 tons of 0.15 percent U_3O_8.

(5) In the early days of exploration in the Coastal Plain, prospecting was mostly surface radiometric prospecting. Few prospectors had a clear idea of stratigraphic relationships or geologic controls of mineralization. Subsequently, discoveries were made by surface and subsurface geologic mapping followed by drilling to intersect a projected favorable host. In the future, geochemical prospecting together with detailed geologic studies and followed by drilling to test targets appears to be the most promising. Probably less than 5 percent of the total prospectable acreage has been explored as of January 1, 1967.

Less is known about the occurrence of uranium in the High Plains of Texas:

(1) Mineralization occurs in terrestrial Triassic redbeds (sandstone, siltstone, and shale) of the Dockum Formation which underlies the High Plains of Texas and extends westward into New Mexico. The Dockum is exposed on the south and east sides of the High Plains escarpment and in major drainages which cut through the caprock. About 30,000 square miles of Texas is underlain by Dockum, but in only about 10 percent of this area is the Dockum exposed. The maximum thickness of the concealing strata on the High Plains is about 500 feet. The Dockum has a maximum thickness of about 1,200 feet in the central High Plains area south of the Canadian River; the stratigraphic range of uranium mineralization within the formation is not known but most prospects examined are in the lower part.

(2) Control of mineralization is sedimentologic. Deposits appear to have been formed by precipitation of uranium from ground water circulating in conglomeratic sandstones, mostly channel sandstones, within the formation. The common association of uranium with concentration of plant debris suggests that the carbonaceous matter fixed the uranium.

(3) Known deposits are small; discoveries will probably be in the 10,000- to 50,000-ton class.

(4) Prospecting to date has been radiometric surface prospecting. In the future, detailed sedimentological studies, surface and subsurface mapping of channels and other sedimentary facies, geochemical studies, and drill testing of targets may be rewarding.

<u>Conclusion</u>.--The Texas Gulf Coastal Plain is a proven uranium province in an early stage of exploration. Prospects for new discoveries are excellent. The High Plains area warrants prospecting but in the judgment of the writer deposits will be harder to find and the prizes will be smaller than in the Coastal Plain. In the Trans-Pecos, studies to develop data on sources and controls of mineralization are needed to guide prospecting.

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