INTRODUCTION

There are over 300 reported occurrences of heavy oil and bitumen-impregnated rocks in the State of Oklahoma. Surface oil seeps in the southern part of the State led to the discovery of some of the giant oil fields in that area. Historical records describing the mining activity in the Tri-State area of Kansas, Oklahoma, and Missouri indicate that heavy oil had to be removed daily from some mine shafts before the shafts could be worked.

The Oklahoma Geological Survey, in cooperation with the United States Department of Energy, has recently completed a resource appraisal of the heavy-oil potential of two counties in northeastern Oklahoma. The results of our study suggest that heavy-oil potential for the Oklahoma portion of the Tri-State area is not as great as previous estimates indicated.

About 20 percent of the State’s heavy-oil and oil-sand occurrences are in south-central Oklahoma, in Carter and Murray Counties. Bitumen-impregnated rocks in this area consist of Ordovician sandstones and limestones and Pennsylvanian sandstones. Many such outcrops have been quarried for local paving needs. Heavy oil occurs in shallow wells at 70 to 75 m (230 to 245 foot) depths and also in hand-dug water wells. We believe that oil sands and heavy oil in south-central Oklahoma could significantly increase the fossil-fuel resource base of the State.

NORTHEASTERN OKLAHOMA

Figure 9-1 shows the location of Oklahoma as well as the major geologic features in the State. The area in northeastern Oklahoma that has been investigated for heavy-oil potential is shown in figure 9-2.

Geology

The northeastern shelf area indicated in figure 9-1 has yielded Wi billion barrels of oil and contains several giant oil fields (ultimate recovery of more than 100 million barrels). Baker (1962) called this area the Cherokee Petroleum Province, because most of the production has been from rocks of the Cherokee Group (Middle Pennsylvanian).
THE FUTURE OF HEAVY CRUDE AND TAR SANDS

Other investigations (Wells and Anderson, 1968; Ebanks and James, 1974; and Ebanks et al., 1977) also indicate that middle Pennsylvanian rocks hold the greatest heavy-oil potential. In northeastern Oklahoma, these rocks were deposited on a post-Mississippian erosional surface that dips westward at 4.75 m per km (25 feet per mile). Mississippian rocks have been mined for lead and zinc in the eastern part of the study area (McKnight and Fischer, 1970). The Middle Pennsylvanian Krebs Group (figure 9-3) overlies Mississippian rocks and, in this area, consists of alternating sandstones, shales, and thin coal beds. These sequences are cyclic in nature, and thin coal beds commonly mark the termination of each cycle. The upper part of the Krebs Group contains a few thin beds of limestone in the western part of the study area. Individual sandstone units are somewhat discontinuous and vary considerably in thickness where they are laterally continuous.

Some Middle Pennsylvanian sandstones of northeastern Oklahoma were interpreted as deltaic in origin by Visher et al. (1971). These authors used criteria taken from the study of modern deltaic systems and were able to identify interdistributary, distributary, and prodelta sequences in the Bluejacket (Bartlesville) Sandstone, one of the major reservoirs in the area.

Throughout much of the study area, Pennsylvanian rocks change from sand-rich to shale-rich facies within a very short distance. This characteristic makes correlation of sandstones difficult and minimizes the possibility of economically recovering significant quantities of heavy oil that might be trapped. Reservoirs that result from constantly shifting sand depocenters do not hold as much potential for exploration and development as would laterally continuous, blanket sandstone bodies. Reservoir characteristics are variable and are described in detail in another section.

The two major sandstones in the Krebs Group are the Warner and Bluejacket (Bartlesville) Sandstones (figure 9-3). In the study area, both units are characterized by highly-localized, sand-rich lobes. The Bluejacket (Bartles-
ville) attains a maximum thickness of about 18 m (60 feet) and is restricted to the western portion of the study area. The Warner Sandstone consists of three major lobes that vary from 3.6 to 4.9 m (12 to 16 feet) in thickness.

Reservoir Parameters

Table 9-1 shows data obtained from core material taken from typical boreholes; oil and water saturations for boreholes 6 and 11 are also shown. The oil-bearing sandstones recovered from boreholes 6 and 11 are very fine to medium grained and contain minor amounts of feldspar, chert, and clay. Within a predominantly sandy section, there are commonly distinct lamination of clay that vary from 3 to 19 mm (1/8 to 3/4 inch) in thickness. The clay laminations would serve as effective seals within a single sandstone and thus constitute a significant reservoir problem. The influence of such lithology is shown by the 46.79 m sample from borehole 6, which has 3 and 40 percent saturation of oil and water, respectively, but a permeability of only 0.33 millidarcies. Two samples form borehole 11 likewise have some degree of oil and water saturation but are essentially impermeable. Table 9-1 shows that borehole 1, which was barren of oil, had the highest permeability of any sample measured. Lack of oil in sandstones with good reservoir characteristics indicates that heavy-oil potential is low.

Heavy-Oil Potential of Northeastern Craig and Northwestern Ottawa Counties

The Oklahoma Geological Survey conducted an 18-hole drilling and coring program during the summers of 1977 and 1978. Depths ranged from 27 m (89 feet) to 118 m (338 feet). The locations of these boreholes, of which seven showed some evidence of liquid hydrocarbons, are shown in figure 9-1. Three had oil shows in the Warner Sandstone, three at the top of the Mississippian limestone, and a single borehole had a show in the Bluejacket (Bartlesville).

The shows in the Warner Sandstone occurred in boreholes 5, 6, 7, and 11, which were drilled in an east-west transect some 9.7 km (6 miles) in length. Subsequent drilling between the latter two resulted in boreholes 8 and 9, which were positioned to determine (a) lateral continuity of the Warner Sandstone and (b) whether the sand, if present, contained oil. Borehole 8 did not penetrate any sand in the Warner interval. Borehole 9 did encounter Warner Sandstone but was barren of oil.

Boreholes 6, 8, and 9 had oil shows at the top of the Mississippian limestone. These shows were confined to fractures and large voids connected by fractures. Borehole 3 penetrated oil-bearing Bluejacket (Bartlesville) Sandstone; however, boreholes 2.4 km (1.5 miles) east and west of this hole showed no evidence of oil.

The lack of significant oil shows in our 18-well program and the presence of relatively good-quality reservoir rocks indicate that the heavy-oil potential of the study area is quite low. These results also suggest that earlier estimates of heavy-oil resources in the Oklahoma portion of the Tri-State area were overly-optimistic.

SOUTH-CENTRAL OKLAHOMA

We feel the four areas indicated in figure 9-5 have considerable potential for oil-sand development. Carter and Murray Counties have more than 60 occurrences of surface and near-surface oil-sand and heavy-oil deposits (Jordan, 1964). At least 15 sites in these two counties have been exploited to a limited extent as asphalt quarries. Bitumen content ranges from 4 to 18 percent and occurs...
Figure 9.4  Map showing location of boreholes and hydrocarbon shows in northeastern Oklahoma study area.

Geology

The geology of most of Murray County and much of Carter County is complex and is strongly influenced by the processes that produced the Arbuckle Mountains, one of the most structurally complex regions in the State (see Ham, 1969).

All of the occurrences indicated in Carter County (figure 9-5) are in sandstones of Pennsylvanian age. Some of the bitumen-impregnated sandstones can be traced on the surface for many miles (Jordan, 1964).

Area 1 contains several inactive quarries as well as outcrops that have only been prospected or sampled for bitumen content. Faulting in the vicinity of Area 1 has brought rocks of Ordovician and Mississippian age in contact with sandstones and shales of Middle Pennsylvanian age. Middle Pennsylvanian sandstones appear to contain most of the bitumen although a systematic investigation of other rocks has not yet been undertaken. The influence of structure on the distribution of bitumen is not apparent, inasmuch as impregnated intervals occur locally in synclines as well as anticlines. Two major quarries have operated in Area 1 and were located at outcrops of sandstone that had bitumen concentrations of 8 to 17 percent. Other outcrops sampled have up to 12 percent bitumen but have not been properly evaluated as to depth-of-impregnation and continuity. At one site, the major bitumen-bearing sandstone is overlain by a shaly sandstone that is relatively easy to remove; thus the site was convenient for exploitation. Steep dip (23°) however, creates overburden problems, and open working of this deposit was restricted accordingly. Another quarry operated at an outcrop where local folding and faulting produced near-vertical dips. This site has considerable bitumen-in-place, but the vertical attitude of beds has severely limited exploitation (Woodruff, 1934).

Area 2 of figure 9-5 contains three major abandoned quarries and several minor ones. One quarry was equipped with crushing equipment and was situated at an outcrop of Pennsylvanian sandstone with 8.5 to 13.5 percent bitumen. This particular site was reportedly quarried to a depth greater than 15 m (50 feet) (Woodruff, 1934), but steep dip apparently limited the development of this deposit. Another site in Area 2 has bitumen-bearing sandstone in vertical position adjacent to a fault plane. Area 2 has been quarried extensively in the past; however, the geology at specific sites caused development problems.

Area 3 consists of many quarries and outcrop areas of bitumen-impregnated sandstone. Most of the worked quarries are associated with faults that have made the bitumen-bearing intervals easily accessible. This area is poorly understood structurally. Many of the worked deposits are in sandstone beds with vertical dip; thus development of particular quarries has been essentially down bedding planes. These operations were severely limited by the depths from which existing machinery could recover bitumen-impregnated material and by water problems. Although the Lower Pennsylvanian sandstones that crop out in this area have 90° dips, underlying Silurian and Devonian sequences, at depths of 915 to 1,310 m (3,000 to 4,300 feet), define a relatively gentle anticline. The sandstones are Springer and Morrow in age and contain up to 18 percent bitumen. Outcrop areas that have not been exploited are usually partially covered with soil and/or bedrock, thus bitumen determinations are not as abundant as for quarried sites. However, available data indicate a range of 8 to 11 percent bitumen content.
The Sulphur and Dougherty quarries are located in Area 4. These two quarries have been worked extensively and are relatively well known from the literature (Grandstone et al., 1955; Ball and Associates, 1965) and from detailed geologic study (Gorman and Flint, 1944; Gorman et al., 1944). Bitumen occurs in Ordovician limestones and sandstones and averages 7-8 percent at the Sulphur deposit and about 4 percent at Dougherty.

The Dougherty deposit is controlled by faulting and jointing. Bitumen appears to be confined to the Viola Limestone, and field evidence suggests that bitumen ascended from underlying strata along fault planes, joints, and fractures (Gorman and Flint, 1944). Nearly a million tons of bitumen-bearing limestone have been removed from the Dougherty deposit, which occupies an area slightly greater than 1.3 km² (0.5 mi²). The limestone matrix makes the material from the Dougherty deposit excellent for paving uses, and most of the production was for this purpose. Gorman and Flint (1944) indicated the presence of some 20 faults in the Dougherty area with displacements varying from 15 to 244 m (50 to 800 feet).

The Sulphur deposit covers about 2.6 km² (1 mi²) and, like the Dougherty deposit, is characterized by complex geology. Most of the bitumen occurs in a single unit, the Oil Creek Formation of Middle Ordovician age. Production from this deposit has been about 1.5 million tons of bitumen-bearing sandstone; most of the material was mixed with that obtained from the nearby Dougherty deposit and used by the paving industry (Gorman et al., 1944). The sandstone is poorly cemented and breaks down into individual sand grains when the bitumen is extracted. The small to medium quartz grains are well sorted and well rounded.

Coring programs and exploration wells indicate the presence of a significant interval of bitumen-impregnated strata under shallow subsurface conditions. A well drilled directly north of the Sulphur site penetrated more than 73 m (240 feet) of impregnated sandstone with an overburden of 30 m (100 feet). Several coring programs have been conducted in the vicinity of the Sulphur deposit. The results of some of the recent coring operations have not yet been disclosed but results of earlier activity suggest that depth of impregnation is greater west and north of the surface deposit. Lateral continuity of the bitumen-bearing sandstone also appears to be most favorable west and north of the abandoned quarries.

The bitumen-bearing sand in Area 4 has chemical characteristics that warrant further comment. Two glass-sand companies are operating in and near Murray County and are hydraulically mining high-purity sands from the Oil Creek and McLish formations. The Oklahoma Geological Survey has conducted preliminary investigations on the chemistry of the sand from the Sulphur deposit. After extracting the bitumen with a soxhlet apparatus, the sand residue was flash-heated in a furnace at 750°C for a few minutes. Flash-heating destroys the organic material that remains after solvent extraction, and the resultant silica sand has the characteristics shown in table 9-2, which includes specifications for First Quality Optical Glass Sand. The Fe₂O₃ content of the sand from the Sulphur deposit is greater than specifications for First Quality Sand; however, washing could bring such sand to specification. Based on available data, it appears that the high-purity silica sand that would be quarried and handled as part of an oil-sand processing scheme would be a marketable product. Such a by-product could be an attractive economic incentive for development of certain oil-sand deposits in southern Oklahoma.

**Oil-Sand Potential of South-Central Oklahoma**

Available data on depth of impregnation, amount of overburden, and lateral continuity of bitumen-bearing strata are sparse and permit only a rough approximation of the oil-sand resource in south-central Oklahoma. The total potential of all four areas shown in figure 9-5 was evaluated as follows. The average depth of impregnation for
THE FUTURE OF HEAVY CRUDE AND TAR SANDS

Table 9-2. Comparison of Chemical Characteristics of Oil Creek Sand and First Quality Optical Sand

<table>
<thead>
<tr>
<th>Oxide</th>
<th>Oil Creek Sand</th>
<th>First Quality Optical Sand</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO₂</td>
<td>99.51</td>
<td>99.80 + 0.100</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>absent</td>
<td>00.10 + 0.050</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>0.26</td>
<td>0.02 + 0.005</td>
</tr>
<tr>
<td>CaO + MgO</td>
<td>0.07</td>
<td>0.10 + 0.050</td>
</tr>
</tbody>
</table>

many of the larger quarry sites is about 12 m (40 feet). Assuming 10 percent saturation, the areas defined by quarry activity, prospected sites, and sampled outcrops would contain something on the order of 800 million barrels of in-place bitumen. If a 3 m (10 foot) depth of impregnation is assumed, the resource estimate would be 200 million barrels of in-place bitumen. Specific sites have been shown to have over 70 m (230 feet) of impregnated rocks and an overburden of about 30 m (100 feet); however, further investigation (coring and drilling) is required to determine the extent of such conditions.

The oil-sand deposits of south-central Oklahoma appear to be large enough to justify further investigation. Present and proposed price policies for crude oil may make oil-sand resources in many areas competitive with oil produced by conventional means. We feel that certain areas in southern Oklahoma offer opportunities to develop deposits potentially capable of producing bitumen for possible upgrading to a refinery-grade material and silica sand for the glass industry.

GEOCHEMISTRY OF OKLAHOMA HEAVY OIL AND OIL SANDS

The geochemical characteristics of both heavy oil and bitumen extracted from oil sand are important for determining suitability for refining to particular products and because of potential problems in refining operations. Table 9-3 shows the results obtained by extracting the bitumen from several samples in the two study areas and by fractionating the bitumen into several classes. In general, oils with significant quantities of hydrocarbons (paraffins and aromatics) are easier to refine and have greater value. The data show that heavy oil from northeastern Oklahoma contains greater hydrocarbon content and thus would be a better feedstock for most refining processes. Heavy oils and tar sands are thought to result from chemical and microbial degradation. Although the northeastern Oklahoma borehole samples shown in table 9-3 were from relatively shallow horizons (maximum depth, 39 m or 127 feet), the protection afforded by the overburden prevented extensive degradation.

Tissot and Welte (1978) indicated that a good correlation exists between sulfur, metals, and asphaltene content of crude oils. Metals usually exist as organo-metallic complexes in the resin and asphaltene fractions. Severely weathered or degraded oils become enriched in asphaltenes (with respect to other classes or fractions) and correspondingly enriched in such metals as nickel and vanadium. Table 9-3 shows how the high nickel and vanadium values correspond somewhat with high asphaltene content. These data suggest that the oil sands in south-central Oklahoma have experienced considerable degradation as a result of exposure at the surface.

Table 9-3. Concentrations of specific organic fractions and Ni and V content of selected samples

<table>
<thead>
<tr>
<th></th>
<th>Bitumen</th>
<th>Total HC’s</th>
<th>Paraffins</th>
<th>Aromatics</th>
<th>NSO’s</th>
<th>Asphaltenes</th>
<th>Ni (ppm)</th>
<th>V (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>%</td>
<td>%</td>
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<td>ppm</td>
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<tr>
<td>Northeastern</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Borehole 5</td>
<td>0.28</td>
<td>71.4</td>
<td>36.2</td>
<td>35.2</td>
<td>18.2</td>
<td>11.4</td>
<td>nd</td>
<td>nd</td>
</tr>
<tr>
<td>Borehole 6</td>
<td>2.40</td>
<td>72.4</td>
<td>40.3</td>
<td>32.1</td>
<td>22.6</td>
<td>5.0</td>
<td>18</td>
<td>18</td>
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<tr>
<td>Borehole 9</td>
<td>1.21</td>
<td>88.6</td>
<td>56.5</td>
<td>32.1</td>
<td>9.1</td>
<td>2.4</td>
<td>&lt; 1</td>
<td>1</td>
</tr>
<tr>
<td>Borehole 11</td>
<td>2.09</td>
<td>64.9</td>
<td>31.7</td>
<td>33.2</td>
<td>27.7</td>
<td>7.3</td>
<td>14</td>
<td>24</td>
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<tr>
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<td></td>
</tr>
<tr>
<td>Area 1</td>
<td>9.27</td>
<td>40.1</td>
<td>14.2</td>
<td>25.9</td>
<td>29.2</td>
<td>30.7</td>
<td>130</td>
<td>220</td>
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<tr>
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<td>7.54</td>
<td>45.9</td>
<td>22.1</td>
<td>23.8</td>
<td>26.3</td>
<td>27.8</td>
<td>180</td>
<td>310</td>
</tr>
<tr>
<td>Area 3</td>
<td>9.85</td>
<td>7.7</td>
<td>5.2</td>
<td>2.5</td>
<td>8.0</td>
<td>84.3</td>
<td>150</td>
<td>340</td>
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<td>33.9</td>
<td>12.9</td>
<td>21.0</td>
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<td>37.7</td>
<td>88</td>
<td>160</td>
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<tr>
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<td>5.43</td>
<td>14.1</td>
<td>24.0</td>
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<td>36.1</td>
<td>84</td>
<td>180</td>
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<td>27.8</td>
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<td>9.27</td>
<td>40.1</td>
<td>14.2</td>
<td>25.9</td>
<td>29.2</td>
<td>30.7</td>
<td>83</td>
<td>120</td>
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</table>

+ Designates bitumen in limestone matrix
* Designates bitumen in sandstone matrix
nd—Not determined
Acknowledgments

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References Cited


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