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PALEOGEOGRAPHY AND PETROLEUM EXPLORATION

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ABSTRACT

Paleogeography in a broad way controls the deposition and distribution of source beds and reservoirs. The search for new deposits of petroleum is aided by the use of special paleogeographic maps. The term eulithogeography is introduced to cover distribution of favorable lithologic areas. Other types of maps that may be used show salinity, thickness of sands, paleogeology and paleotopography. All of these maps can be combined with structural contour maps to show depositional and post-depositional dips.

The three physical requirements for a commercial accumulation of petroleum are a source, a gathering system and a reservoir. In most petroliferous provinces possible reservoirs far outnumber the oil fields. As nature insures survival of the species by supplying more offspring than can possibly reach maturity, so are the stratigraphic sections supplied with more possible reservoirs than there is oil to fill them. Sheet sands, sand belts, porous limestones, buried hills and limestone reefs are some of the more common types.

Some possible reservoirs are not connected with source beds. Others are not closed or were not closed during the critical stages when oil was available. In other cases it is difficult to explain the "popcorn" porosity on closed structures. Likewise, a few source beds had no connection with gathering systems and reservoirs, or lost these connections before all the oil escaped. In other places the source beds were never rich enough to yield commercial oil. No one knows how numerous these unharvested sources are but presumably they are relatively common.

Gathering systems are freely permeable rock zones through which oil can migrate in spite of water saturation. The one type of gathering system not dependent upon paleogeography is the diastrophic fault-fracture system, which sometimes allows oil to accumulate where it would not otherwise be expected.

In almost every commercial oil field we find that the physical geography, ecology, structure and sedimentation are unitized. Optimum conditions for marine life occur in areas of agitation due to bottom irregularities. Irregularities in epicontinental seas mean shallow water. Currents moving over these shallows bring the cooler, food-bearing, bottom waters up into the zone of photosynthesis. Irregularities usually are either of structural origin, or they produce depositional or compactional structures in the overlying beds. If the topographic highs extend above sea level, they are attacked by erosion and either rendered more porous if made up of soluble rocks, or truncated to form porous wedges if the exposed section is composed in part of sandstones. Currents flowing along the shoreline or over the crests of the submerged hills concentrate the necessary coarse clastics for reservoirs and gathering systems, or if the shallow waters are warm and lime-saturated, they bring food for limestone-depositing organisms. The same currents that supply the coarse clastics and the food for both the lime-secreting and oil-forming organisms sweep the fine clastics and the dead organisms out into the deeps to wait for oil generation. This is the contribution of paleogeography to the formation and accumulation of petroleum.

The science of paleogeography was born when the foundations of stratigraphy were based upon a limited number of not too well known surface sections.

Early contributions to oil-finding were either negligible or even deleterious. Now with the number of borings on which we have accurate, dependable, stratigraphic information reaching into the hundreds of thousands, and with a much better command of the outcrop sections, we have a firm scientific basis for petroleum paleogeography. However, so numerous, extensive and unexpected have been the past geographic changes that we can seldom eliminate the "farmers sand" until a well reaches the basement.

For pools located on anything but the most obvious surface structures, it is difficult to determine the basis for picking the first successful location. Therefore, it seems more my place to suggest a few localities where paleogeography could have contributed to the finding of petroleum, rather than to tell how, where and by whom it was used. Certainly the science has added a number of tools, concepts and working hypotheses to the equipment of the petroleum geologist.

The best known of these tools is the conventional paleogeographic map. These maps can be used throughout the exploration and development program to give a general picture of geological and structural relationships to the non-technical management as well as to the geologists.

The main reasons that conventional paleogeographic maps are not used more extensively are that they take time to prepare and are never complete until development is finished. On most of them the units mapped are too large and they are based on age of the rocks rather than the all-important composition.

Lithology and sedimentary history are determined at the time of deposition and are as much products of geography as is original distribution. Besides they are the factors that control and limit production. So the first step is to work out the stratigraphy, from this to determine the favorable or eulithologic portions of the section, and then to map the eulithogeography. This is not simple because in many areas we do not know the stratigraphic expectancy. The Permian Basin with its upper salts and redbeds is a good example of a province that was condemned until the eulithology of the deeper formations was discovered.

On the Duval trend in South Texas it is not enough to know that Jackson beds are present but it is necessary to know the distribution of the permeable Jackson sands. Likewise, in the South Tampico area, the Cretaceous Tamaulipas formation underlies the whole district but it is only the El Abra facies that brings smiles to the production men.

Sometimes the eulithogeographic data are really mapped; at other times they are used without being formally plotted, and that is why concepts and working hypotheses were included above as exploration equipment. The eulithogeologic map might well be called a fairway map with many wells still being drilled in the rough. This is fortunate because wild wildcats still contribute much important geological data.

A modified lithogeographic map frequently used is the lithologic isopach. Citing Duval County again, the productive possibilities vary directly with the total amount of sand in the Jackson section. In some parts of the mid-continent, isopach maps showing the amount of limestone in a given section are as valuable as structure maps. Limestone loves shallow water and the shallowest water usually occurs over submerged structural highs. Thus a limestone isopach map would point out the Cement pool in south central Oklahoma as a very likely prospect even if the surface structure were not apparent.

Compound maps showing structural trends on an eulithogeographic base are extremely useful. They really tell which structures are in the fairway. As long as the lithology is favorable, the trend can be followed with confidence that tests drilled will give a run for the money. In cases where oil is abundant enough to overflow the local structural traps, lithogeography is more important than structure.

Sedimentary trends, like the shoestring sands of Kansas and the limestone reefs of the Permian Basin, tend to make their own structures. In both cases the relative uncompressibility of the porous rock causes dips in the overlying strata. It makes little difference whether the limestone highs are reefs or limestone islands or whether the sands are bars or rows of sand dunes.

The approximate location of narrow porous trends that are known to exist in parts of the section, can frequently be determined by a careful stratigraphic analysis of the dry holes in the area. Productive porosity is largely limited to shallow water or to subareal deposits. Deep water limestones are usually dense and almost impervious and most of them are dark colored. Dense shallow water limestones are more often white. Porous zones, when present, come between the dense white and the dense dark areas or within the dense white areas. Deep-water clastics are represented by silts, shales and silty or shaley sandstones. On the up-dip edge of the porous sand zone, the productive sands are usually missing due to truncation, overlap or shoreward gradation. In the past it has usually been too much of a job to search the section for all of these possible porous zones and only those accidentally found productive have been worked out. Another excuse for not doing this work is that in many areas stratigraphic information is not sufficiently detailed to carry it through successfully.

Diastrophism cannot be left out completely. Mashing of the earth's crust puts widely separated depositional facies in juxtaposition and sometimes links source beds to reservoirs. Plastic paleogeographic maps that pull the section back into its proper depositional distribution sometimes clear up the problem. Very little work has been done with this type of map but a few areas that would normally be condemned have been opened for exploration by their use.

Fossils and sediments usually reflect the salinity of the water in which they were deposited. From these data salinity maps can be drawn. Some oils may have originated in fresh water deposits but so far little search has been made for non-marine petroleum.

Brackish water is normally less densely populated than marine water and the oil in brackish deposits is seldom as prolific as in true marine sediments. The line between brackish and marine areas may be very sharp but it tends to fluctuate and the deposits frequently overlap. The Wilcox of the Gulf Coast was long regarded as a brackish deposit and not rated highly as a petroliferous prospect, but wells have shown that marine sediments start a short distance from the outcrop.

Excessive salinity inhibits life even before calcium sulphate precipitation concentration is reached. Many primary dolomites are very low in fossil content but the barrier zones in barred saline basins are frequently sought because of their structural position and because of the killing and preserving effect of the brines within the basins.

Lack of circulation and a consequent deficiency in oxygen tends to produce black shales. In some areas, as in the Comanchean section of the Rio Grande Embayment, excessive evaporation accompanies lack of circulation. Anhydrite and even salt may thus be mixed with the black shales. Black shales are not necessarily good source rocks. It is true that most of the organic matter is preserved but the lack of bottom dwellers cuts down on the amount of available organic matter and the lack of currents to distribute the coarse clastics necessary for a gathering system cuts down on the oil harvest except along the margins.

Paleogeologic maps, as the name implies, show the areal geology of some period in the past. They are used most extensively in mapping the sole of an unconformity and in outlining the distribution of porous beds, and are especially useful in locating and developing production around "bald-headed" structures. These maps are geographical inasmuch as paleogeography was largely dependent upon paleogeology.

Paleotopography of an overlapped unconformity is frequently as important as the paleo-areal geology. Limestones and other soluble rocks produce from buried hills. Examples are the Ellenburger production at KMA in North Texas, the Arbuckle production at Oklahoma City, the Mississippian chat production in Kansas and the serpentine plugs of the San Antonio district.

Topography on an unconformable surface also tends to control production in the overlying section. Hills and buttress ridges thin or completely cut out flank sands. East Texas is a good example. Depositional and compaction dips, developed over the topographic highs during and after burial trap oil in many pools. In West Texas, the submarine and subareal topography of the pre-Permian surface was directly responsible for the initiation and location of the Permian reefs. Most paleotopographic maps pass under the name of structural maps but there is a distinct difference.

Although the topography of an overlapped unconformity is important, the topography of a coastal area is secondary. Major streams frequently bring in coarse material across wide coastal flats and currents distribute this material along the flat bottoms. If there are no coarse clastics, porous limestones may develop to take their place. Granite wash of the Panhandle type is possible only where the shore line is backed up by a granite ridge, but granite wash is just another coarse clastic. Almost any other material of similar size grade would serve as well. Besides, oil in the Panhandle is produced from the associated limestones as well as from the wash.

Other paleogeographic features could be mapped but it is believed that the maps listed above cover most of the commonly used and practical paleogeographic contributions.

While the term "map" is used above, it should be understood that many of the features are best shown on cross sections. Some geologists are so familiar with the areas in which they work that they use and interpret paleogeographic data without formally plotting them.

CONCLUSIONS

Paleogeographic methods are most effective in sedimentary basins showing differential subsidence, widespread unconformities and horizontal variations in sedimentation. Where these basins are filled largely with marine sediments, they are natural petroliferous provinces.

Effective use of paleogeography in locating or extending deposits of petroleum requires an extensive knowledge of province stratigraphy. Modern subsurface methods furnish much of the necessary information. Both deep, off-structure wildcats and field wells are important.

Paleogeography can seldom be used to find oil in widespread sheet formations. Neither is it especially useful in locating fracture-type reservoirs. Those are problems for the structural geologist. Oil found by paleogeography will occur as high on the local structure as open porosity will permit. The main thing to be remembered is that paleogeography, although a science in itself, is just one of the supplementary tools used in petroleum geology.

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