PLATE TECTONICS AND THE LOCATION OF OIL FIELDS

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ABSTRACT

From the present-day properties of plates of lithosphere we have developed a computer algorithm that reconstructs the continents in the past. The basic input data includes oceanic magnetic lineations and paleomagnetic observations. The addition of geological information allows one to reconstruct the major plate tectonic features in the past if this is desired. For this study we have plotted the position of major oil and gas fields, oil shales, and oil sands on these maps. Direct visual correlation with the latitude in the past shows that many petroleum deposits were formed within 35° of the paleoequator. The reconstruction is most promising in delineating broad exploration targets in the Paleozoic Era. In particular, Cambrian and Ordovician basins in North America and Asia should be explored because of their position on the equator during the lower Paleozoic. The tectonic activity and the pattern of continental grouping is important in the development of favorable basins.

INTRODUCTION

The relationship between the location of oil-fields and their geographical latitude at the time when the reservoir rocks were deposited has been studied by Irving and Gaskell (1962), Deutsch (1965), Irving, North and Couillard (1974). Advances in the reconstruction of plate tectonic models (Kanasewich, Havskov and Evans, 1978) for the whole of the Phanerozoic Era have made it worthwhile to examine the question again. North (1971) has emphasized the importance of the tectonic history in the formation of oil bearing basins. Therefore sedimentary basins should be studied in the context of their plate tectonic setting. This preliminary report includes major oil and gas fields as plotted on world maps on the basis of the age of the reservoirs. Strictly speaking the correlation should be based on the age of the source rock and the position of the basin with respect to the paleolatitude. Except for a few mature fields this information is not available or is in dispute. For many fields the geological age of the source rocks and the reservoir is similar. This is because barriers to vertical and horizontal migration are often very effective. Known exceptions will be discussed as each period is taken up.

A reconstruction of the major tectonic features of the earth during the past 600 million years is of interest to exploration geophysicists for three major reasons:

(1) Areas with favorable environmental conditions for the mass proliferation of biological life are identified. This is a precondition for the formation of coal, oil and gas. In particular, the generation of oil depends upon the primary production of plankton and this is controlled by water temperature, the action currents and the availability of nutrients.

(2) The metamorphic and tectonic history within a sedimentary basin should be known. There must be sufficient thermal activity so

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that oil and gas are formed and collected in reservoirs. The tectonic activity must not be so intense that the preservation of the hydrocarbons is endangered.

(3) Mineral deposits are associated with both spreading centers and subduction zones so exploration may be centered in the most probable areas.

The hypothesis of plate tectonics has been notable in accounting for present tectonic activity and for allowing reconstruction to be made on the basis of magnetic lineations up to the Cretaceous-Jurassic boundary. Making use of 10 principles which appear to define present-day plate tectonic activity, Kanasewich et al (1978) have used paleomagnetic observations to reconstruct continental fragments for six periods between the Cretaceous and the Cambrian. An interactive computer program was developed to rotate continental segments about any pole of rotation. The paleomagnetic results were used initially to position each continental segment on the appropriate latitude and in the correct orientation so that all averages of measured poles were exactly on the south pole. The interactive routine was used to eliminate overlap of continental margins while monitoring a display screen. An innovation, never used before, was the application of a least squares inversion procedure to determine a limiting absolute longitude. This is based on the principle that an absolute reference frame for plate tectonics is defined, to a good approximation, by minimizing the translational motion of plate boundaries. The velocity of plates, at the present time, is proportional to the amount of continental lithosphere they contain. Purely oceanic plates move about five times as fast as purely continental plates. When the relative longitude could not be obtained from magnetic lineations, the largest contiguous continental group was given priority since present evidence indicates that purely continental plates have the lowest velocity. The velocity was determined along a small circle, centered on the pole of relative motion from one period to the next. This procedure was applied, in order of continental area, to the remaining group of continental segments. The solution is not unique, but it is the most conservative estimate and is valuable in giving a quantitative estimate of the minimum velocity that satisfies paleomagnetic and geologic observations. Determination of the location of continents with a computer program reduces the effect of human bias in the reconstruction. When stratigraphic and structural geological data is added to the maps it becomes possible to deduce plate boundaries for periods when this is not given by oceanic magnetic lineations.

**BASIC DATA**

**TERTIARY PERIOD, ANOMALY 13-38 Ma**

The models for each period have been generated by a digital computer and a Calcomp plotter on a mercator projection. More specifically the projection is a Miller-modified mercator one in which the map ordinate is \( y = c \ln \tan \left( \frac{45 + 0.4\phi}{2} \right) \) where \( \phi \) is the latitude in degrees and \( c \) is a scaling constant. This modification allows one to depict the earth with less distortion at extreme latitudes. The Tertiary period at the time of formation of magnetic anomaly 13 (Pitman et al, 1974) is shown in Figure 1. The petroleum deposits that are plotted are given in the table in the Appendix. The references for the data are extensive but rely heavily on Halbouty et al (1970), Demaison (1977), North (1971), Irving et al (1974), Rigassi (1976) and Gillen (1976) and other reports in World Oil. Many oil fields have production from several systems and, although the principal producing horizon is generally well known, the reserves are not well documented for secondary horizons. For cases where the distribution was not known, secondary horizons were arbitrarily assigned one-third of the known total. The Tertiary fields have been plotted on present day coordinates and also the coordinates that were found for the Tertiary period. The present day map shows the distribution of warm and cold oceanic currents and warm ocean water. It is seen that some warm currents traverse high latitudes and this may explain the occurrence of fields north and south of a latitude of 35°. On the geologic map it is seen that most major fields are within ±35° and that they are also associated with mildly active tectonic areas. The Ekofisk field in the North Sea is an exception but the basin has much Cretaceous and Triassic production when the area was at a latitude of 35° and more directly in contact with warm oceanic currents.
PLATE TECTONICS AND THE LOCATION OF OIL FIELDS

Fig. 1. Top. The position of the continents and some stratigraphic data at the Eocene-Oligocene boundary (magnetic anomaly 13, 38 ma) on a Miller-modified mercator projection. The positions of oil and gas field with production in Tertiary sediments are shown. Bottom: Tertiary oil and gas fields are plotted with the present-day position of continents. Mean annual surface ocean water temperatures and currents are also shown.

Note: Oil in billions of barrels; gas in trillion of Cubic ft.
Fig. 2. Oil and gas fields for six periods in the Phanerozoic Era plotted with the present-day position of the continents.
PLATE TECTONICS AND THE LOCATION OF OIL FIELDS

CRETACEOUS (110 Ma) AND TRIASSIC (190 Ma) PERIODS

Figure 2 shows all the Mesozoic and Palaeozoic fields on a series of 6 maps with the continents in their present day coordinates. A comparison of figures 2, 3 and 4 shows that plotting fields in their Mesozoic coordinate system places more fields in the equatorial zone. However, there were many widespread shallow seas in Asia and North America that extended far north. A notable exceptional case is the Prudhoe Bay Field in northern Alaska. Most of the production is in Mississippian to Jurassic rocks when Alaska was at a latitude of 50°N as compared to its present 70°N. However, the most important source rocks are thought to be Cretaceous

Fig. 3. The position of the continent and some stratigraphic data in the middle Cretaceous (magnetic anomaly M1, 110 ma). The longitude is not absolutely determined but was obtained from a least squares minimization of continental velocities between the Cretaceous and Tertiary periods. The position of oil and gas fields with production in Cretaceous sediments is shown.

Fig. 4. The position of the continents and some stratigraphic data in the Triassic period (190 ma). The longitude was obtained by a least squares minimization of the Laurasian and Gondwanaland continental velocities between the Triassic and the Cretaceous periods. The positions of the oil and gas fields with production in the Triassic and Jurassic sediments is shown.
marine shales because they contain 5.4% of organic carbon as compared to 1.9% for Jurassic marine shale and 1.1% for basal Mississippian shale (Morgridge and Smith, 1972). According to our paleomagnetic reconstruction the latitude of Prudhoe Bay was 81°N in the Cretaceous. It was 50°N in the Carboniferous and 35°N in the Devonian.

North (1971) believed "that the oil on the Arctic slope will prove to be of Devono-Mississippian origin (the age of the Ellesmerian orogeny)." However, little is known of the Devonian sedimentation in the area between Brook's Range and Barrow Arch. The question of source rocks for Prudhoe Bay cannot be answered definitively at present.

Fig. 5. The position of the continents and some stratigraphic data in the Permo-Carboniferous periods (280 ma). The longitude was obtained by a least squares minimization of Laurasian and Gondwanaland velocities between the Carboniferous and the Triassic periods. The position of the oil fields with production in Permian, Pennsylvanian or Mississippian sediments is shown.

Fig. 6. The position of the continents and some stratigraphic data in the Devonian period (370 ma). The longitude was obtained by a least squares minimization of continental velocities between the Devonian and Permian periods. The position of the oil fields with production in Devonian sediments is shown.
PLATE TECTONICS AND THE LOCATION OF OIL FIELDS

In general it is found that oil deposits in the Mesozoic are distributed over a wide range of paleolatitudes. This may reflect the high ocean temperatures that were present in the Cretaceous. From $^{18}O$ isotope studies on calcareous fossils (Urey et al., 1951, Emiliani, 1966) it is found that sea temperatures were as much as 10°C higher than now. Therefore these plate tectonic reconstructions for the Mesozoic are only useful insofar as they give tectonic information. To keep the maps from being too cluttered, information on model spreading centers, subduction zones and eugeosynclinal deposits have been omitted from the figures here but they may be seen in Kanasewich et al. (1978).

THE PERMO-CARBONIFEROUS AND DEVONIAN PERIODS

From figures 5 and 6 and the tables in the appendix it is seen that except for two gas fields in Australia and one oil shale in South America, the petroleum deposits in the Permo Carboniferous are all north of present-day latitude 26°. All major Devonian oil and gas fields lie between present-day latitudes of 28°N and 77°N. When plotted as in figures 5 and 6 on reconstructed paleolatitudes for the Permo-Carboniferous and the Devonian periods, the fields are within 40° of the equator. Note that the reefs in the Alberta basin all lie within 15° of equator in Devonian times. The results are consistent with the migration of reef belts as tabulated by Schwarzbach (1963).

ORDOVICIAN AND CAMBRIAN PERIODS

There are only a small number of oil and gas fields which produce from the lower Paleozoic. On the paleo-reconstruction of figures 7 and 8 the Ordovician and Cambrian fields in Oklahoma and Texas are found within 20° of the equator.

There is a considerable body of paleomagnetic data for the lower Paleozoic which indicates that there was a major reorganization of continental segments between the lower and upper Paleozoic. This probably coincides with the various episodes of the Caledonian Orogeny. The evidence from paleomagnetism also indicates that rather high velocities (5-7 cm/year) of continental plate segments must have occurred. North Africa is placed in the south polar region and this is supported by various glacial indicators (Beuf et al., 1968, Fairbridge, 1969, 1971) in the geological outcrops. The unusual occurrence of several oil and gas fields in Libya and Algeria at paleolatitudes of 77°S to 85°S in the Ordovician and 56°S to 65°S in the

Fig. 7. The position of the continents and some stratigraphic data in the Ordovician period (470 ma). The longitude was obtained by a least squares minimization of continental velocities between the Ordovician and Devonian periods. The position of the oil fields with production in Ordovician and Silurian sediments is shown.
Fig. 8. The position of the continents and some stratigraphic data in the Cambrian period (550 ma). The longitude was obtained by a least squares minimization of continental velocities between the Cambrian and the Ordovician periods. The position of the oil fields with production in Cambrian sediments is shown.

Cambrian indicates that the source rocks are higher stratigraphically than the reservoir rocks. The source rocks for the Hassi Messaoud field (Balducci and Pommier, 1970) are thought to be Triassic or Silurian shales. The source rocks for the Amal and other related fields in Libya (Roberts, 1970) are thought to be the R&b formation of Cretaceous age.

CONCLUSIONS

The influence of continental geometry, climate and tectonic activity on the generation of petroleum can only be evaluated by obtained accurate plate tectonic reconstruction. Future work should incorporate models of ocean currents and data on paleotemperatures. More paleomagnetic data is needed in many critical areas, particularly in China, South America and the Arctic of North America. The results of studies such as these are best applied to Paleozoic basins. The maps of the Ordovician and Cambrian should be of particular value in considering broad exploration targets. In particular it would appear that because of the equatorial position of North America and Asia during the lower Paleozoic, basins with Ordovician and Cambrian sediment should be explored more intensely.

REFERENCES


PLATE TECTONICS AND THE LOCATION OF OIL FIELDS


Appendix - Data on Hydrocarbon Deposits

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