as the result of movements under the influence of gravity, and their distribution is related to growth stages of the delta. Rollover anticlines on the downthrown sides of growth faults form the main targets for oil exploration, the hydrocarbons being found in sandstone reservoirs of the Agbada Formation.

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Mud into Shale: When and How?

Coring of surficial sediments on the sea floor to date has not revealed the presence of indurated, clayey sediments that are worthy of the name mudstone or shale, even though some clay as old as 50 million years has been recovered. In contrast, very young, argillaceous rocks on continental platforms are in many places indurated and cemented. Shale, in the sense of a fissile argillaceous rock, is uncommon in the younger part of the geological record though it is common in older rocks. Therefore, one can conclude that the induration to mudstone and the development of fissility of shale have two different time scales and thus result from two different processes.

The initial process of induration is clearly linked to simple mechanical compaction under load where water can be expelled, as studies of marine sediments have shown. During this stage there is little gross mineralogical or chemical change in the sediment. Later stages include chemical additions that fill pore space and increase bulk density. Chemical additions are restricted to sediments that do not remain buried permanently under deep water; the additions result from ground-water movement through the mud, a movement that is initiated by the bed being raised above sea-level and thus making possible a hydraulic head in the outcrop area. Much of the chemical precipitation in this stage is simply redistribution of carbonate, but small amounts of silica generally are added too.

Fissility, as was noted long ago, is correlated directly with the growth of phyllosilicate minerals in the *ab* plane, parallel with the bedding. It appears that the 10 A.U. micas and the chlorites are the principal causes of fissility. Accompanying this growth is a general increase in cementation that reduces porosity to low levels. However fissility does not always accompany cementation.

Fissility, then, is the result of preferential growth of the 10 A.U. micas and the chlorites under load that is induced by the geochemical environment. That environment may be characterized as one whose K^+/Na^+, Mg^{++}/Na^+, and alkali/H^+ ratios are relatively high compared with sea water, and whose dissolved silica concentration is close to that in equilibrium with quartz. The environment that has these characteristics is that of concentrated subsurface brines typical of most ancient sedimentary basins. The correspondence of the time scales of the production of fissility in shales and the formation of brines is important support for this hypothesis.

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History of Oil Development in Libya

Concessions were first granted in Libya during late 1955. At that time 14 companies obtained concessions totaling 130 million acres. By November 19, 1959, concession areas had increased to 265 million acres, but they decreased to 174 million acres by September 1, 1965. On July 29, 1965, 98 individual blocks totaling 147,589,617 acres were made available for bidding. As of September 1, 1965, no additional acreage had been granted.

Exploration activity has been concentrated in two basins. Of primary interest is the Sirte basin in east-central Libya.

Since drilling activities commenced in 1956, 1,572 wells have been completed in Libya, of which 44 per cent were wildcats. In the Sirte basin 12 per cent of the wildcat wells have been successful, and in the Ghadames basin of western Libya 18 per cent have been successful. No oil has been found in the Murzuck or Cufra basins.

More than 11 million feet of hole has been drilled, 4.84 million feet of which has been wildcat drilling. Eighty-five oil fields, 59 in the Sirte basin and 26 in the Ghadames basin, have been discovered by means of wildcat drilling. It is estimated that more than 9 billion barrels of oil in place have been found. Individual pool reserves range from a few thousand barrels to more than one billion barrels of recoverable oil. The largest reserves are in Eocene and Cretaceous rocks of the Sirte basin.

At the end of 1961, one company was producing at the rate of 40 thousand barrels per day. Today five companies are producing more than 1.25 million barrels per day.

Industry has spent over 1.3 billion dollars in the search for oil, increasing from 33 million dollars in 1957 to more than 270 million dollars in 1964.

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Low-Angle Regional Unconformities

Brief periods of erosion without concurrent structural deformation have produced low-angle regional unconformities. These unconformities may provide the environment for stratigraphic traps where hydrocarbons accumulate within the truncated beds. However, the slight amount of erosional stripping (a few feet per mile) and the absence of significant changes in the lithology make the detection of these low-angle regional unconformities difficult. The chances of recognizing and delineating them seem to depend, at least in part, on the selection of a datum.

Low-angle regional unconformities are common in the Western Canada basin. Only three were selected as examples, because they occur in a sequence generally considered to be one continuous depositional unit: (1) beneath the Mississippian Debolt, (2) beneath the Devonian Calmar, and (3) beneath the Devonian Ireton Formations.

Slight variations in local rates of subsidence effect continuous changes in the direction of the depositional dip. These changes from formation to formation generally are minor. When sedimentation resumes after an hiatus, its new depositional dip represents the cumulative shift in regional tilt gradually introduced during the absence of deposition. The new dip direction in many cases relocated individual members of a sedimentary cycle, more especially the occurrence of sand lenses in a clastic province or of reef build-ups in a carbonate-shale sequence.

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Geology of Arctic Islands

The Arctic Islands present opportunities for study of the most completely undeveloped potential oil basin anywhere in the Western Hemisphere. Strata are well exposed over a very wide area. As a result, there is a sufficient variety of representative structural features and stratigraphic sections exposed at the surface so that it is possible to establish a reasonably accurate evaluation of the oil prospects of this large sedimentary basin.

Normally, in the evaluation of a new sedimentary basin, it is necessary to drill many deep holes to arrive at a fair assessment of the stratigraphic section and the potential oil and gas reservoirs. In the Arctic Islands, however, the exposed stratigraphic sections are so numerous and so conveniently spaced that relatively modest sums of money spent in studying exposed sections can take the place of many millions of dollars spent in acquiring similar stratigraphic detail by drilling. For example, facies studies of the type commonly made between well borings for the purpose of outlining oil- and gas-producing trends can be made in the Islands relatively cheaply by studies of outcrops.

As proof of the above concept, it is shown that hydrocarbon seepages are associated with what has been interpreted to be buried reef trends, and that reefoid and other related buried reservoirs can be identified by surface expression of deep-seated features.

The writer's conclusion is that surface geology, supplemented with seismic and other geophysical methods, will reduce the number of dry holes drilled on the Arctic Islands far below that normally required in a new-basin area.

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GRADED FLOOD DEPOSITS AND TURBIDITES: COMPARISON AND SIGNIFICANCE

Similar assemblages of sedimentary structures may be produced in two different environments if similar depositional processes are active in both environments. A study of some non-marine Carboniferous rocks in southeastern Massachusetts seems to support this conclusion.

Several sections of the Pennsylvanian Wamsutta Formation comprise alternations (cycles) of coarse- and fine-grade beds. Most of the alternating cycles represent vertical accretion, over-bank, flood-plain deposits. Many of the beds are graded graywacke which displays sole markings. The grading may be repetitive. These properties generally are thought to be typical of turbidites and deep-water flysch, and of eugeosynclinal deposits. These sedimentary types have been discussed at length in the recent literature, as have other features, including horizontal, ripple-drift, and convolute laminations, and intraformational conglomerate associated with graded sandstone. However, well-developed mudcracks interbedded in sandstones indicate that the normal depositional environment was a sub-aerial one which became periodically submerged and then exposed. The top stratum probably was subjected to these floods on a seasonal or annual basis. The typical sedimentation unit rests on an erosion surface, cuts into the underlying bed, and grades upward from conglomerate or sandstone at the base to massive siltstone at the top. Each sedimentation unit represents an episode of flooding on the flood plain, on levees adjacent to sinuous channels, and in crevasse splays and low-lying areas.

Flood and turbidity currents have much in common: (a) flows may appear suddenly in a foreign environment; (b) flows are characterized by high discharge, velocity, turbulence, and load; (c) the sediment load comprises a wide range of size grades; (d) currents are able to erode the bottom and remove scoured material; and (e) the sediment load is released progressively as the intensity of the flow decreases away from the source. The resulting beds are graded vertically and laterally. Similar depositional processes active in environments as different from each other as flood plains and marine slopes and basins can produce similar assemblages of sedimentary structures.

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MORROW COUNTY, OHIO—CASE HISTORY OF EXPLORATION AND PRODUCTION

Regional geologic studies of the Cambro-Ordovician in the eastern part of the United States led to the delineation of several areas in north-central Ohio for further investigation. Reconnaissance gravity, magnetic, and seismic surveys were completed in July, 1960. As a result of these surveys, several acreage blocks were acquired in Morrow County, Ohio, for exploratory drilling to evaluate the possibilities for oil production. The discovery in June, 1961, of the Myers field, located in Canaan Township, Morrow County, was the forerunner of a major exploration and drilling program, resulting in the discovery of approximately 150 oil fields in Morrow County by the end of 1964. Reservoir characteristics, completion techniques, development activity, production, and other information related to the potential of the Cambro-Ordovican in Morrow County and other parts of Ohio are discussed.

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CAMBRIAN AND ORDOVICIAN OIL POTENTIAL OF ILLINOIS BASIN

More than half of the sedimentary rocks of the Illinois basin are of Cambrian and Ordovician ages. Within the area of the basin where younger Paleozoic rocks already have produced about 2.9 billion barrels of oil, these older sediments still remain virtually unexplored. Three holes have tested the Cambrian and Lower Ordovician rocks within the productive region. The Galena (Trenton) near the top of the Ordovician is productive on the western and northeastern flanks of the basin, but has been tested by less than one well per thousand square miles in the deep part of the basin and on the southern flank.

Cambrian and Ordovician rocks probably are more than 6,000 feet thick in much of the deep part of the basin. They thicken and become finer-grained and darker basinward, indicating that a basin structure was present during early Paleozoic time. The rocks appear to be entirely marine; they contain brines whose salinity is more than 10 per cent. Dolomite, sandstone, shale, and limestone are present in that order of abundance.

Indications of hydrocarbons in these beds on the basin flanks have been slight. Sparse seismic data in the basin and drilling in neighboring provinces indicate that structures beneath the pre-Middle Ordovician unconformity are complex and correspond only in part to those in the younger rocks. Drilling depths of 6,000–14,000 feet, which would be required to test these older rocks, are not great by modern standards.