tectonic development of the basin is necessary to prospect for this type of trap.

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WORLD PETROLEUM EXPLORATION

Of the 135 countries of the world whose current status of petroleum exploration was reviewed, 65 are producing oil and gas (including 2 about to have production); in 70 countries activity is confined to exploration or preparations to explore. About 90% of the petroleum exports from the noncommunist world flows from Arab or closely affiliated countries.

At least 75% of the world's proved and potential petroleum reserves exist beneath the continental terrace, which includes the coastal plain, the continental shelf and slope, and also many partly enclosed seas, gulfs, bays, deltas, estuaries, straits, *etc.*

Most of the available basins of the world, as well as some nonbasin areas, including the offshore shelves, *etc.*, have been leased for petroleum. There is a wide tendency in area selection to overvalue the less attractive and commercially submarginal areas, and to underestimate the potential of the much smaller percentage of bonanza class areas. The greater part of the leased area of the world is of the former type.

World production has more than doubled in each of the last 2 decades to 48 million bbl/day in 1970. If production merely doubles in each of the next 2 decades a minimum of 22 trillion bbl of new oil must be added to meet the production demands of the period and leave a 20-year supply ratio (15 trillion bbl to leave a 10-year supply ratio). The current year's supply ratio is 31; also 15 to possibly 25 trillion bbl of oil is the range of estimates by informed geologists of recoverable liquid oil (proved plus potential) remaining in the world. By any reasonable projection, the years of the petroleum age are finite.

The demand for petroleum energy has been growing at a rate 3 to 5 times the rate of population increase, and over the present decade will more than equal that of the 112 prior years following Col. Drake's discovery. The rate of finding giant and supergiant fields does (or soon will do) no more than keep pace, and then only briefly, with the years supply ratio. The time required to find and develop the main crop of fields in new producing basins has very rapidly and greatly decreased. Some geologists have looked unduly to the stratigraphic trap, greater depths of drilling, and the deeper ocean bottom areas as the answers in meeting the petroleum demands of the future.

Worldwide oil occurrence studies indicate that the temperature gradient varies greatly over the world's basin areas, and from basin to basin, depending on the geologic background. They also indicate that the gradients have a strong influence both on the incidence of petroleum occurrence and on the initial and optimum depths of such occurrence. This apparently explains in a large and often critical measure many of the unanticipated exploration disappointments as well as successes.

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DELTAIC SEDIMENTATION AND GROWTH FAULTING, UPPER CRETACEOUS, COLORADO

The upper Pierre, Fox Hills, Laramie, and Arapahoe Formations in the western Denver basin record deltaic sedimentation during the final regression of the Cretaceous sea from eastern Colorado. Prodelta shales and siltstones (Pierre Formation) are overlain by delta-front sandstones (Fox Hills), and delta-plain sandstones, claystones and coals (Laramie Formation). The younger conglomerates of the Arapahoe Formation are braided channel deposits of the fluvial system.

Two types of penecontemporaneous (growth) faulting are recognized in 5 mi of outcrop from Golden south to Interstate 70. One type of faulting cuts delta-plain sediments, resulting in a thickness increase of the Laramie Formation from 330 to 530 ft in a horizontal distance of 800 ft. By normal fault movement at the time of sedimentation, an extra 200 ft of lower Laramie sandstone, with minor claystone and thin coal, was deposited on the downthrown side of the fault. The northwest-trending fault plane curved downward toward the south from a dip of about 60° to a low-angle bedding plane fault.

A second type of faulting records slumpage on oversteepened prodelta slopes created by seaward progradation of the shoreline. One slide block of shallow-water distributary-mouth sandstone (Fox Hills) about 100 ft thick moved southward down the prodelta slope into water depths estimated to be from 100 to 175 ft and was subsequently buried by prodelta clays (Pierre).

The geographic position of these growth faults in the delta sequence appears to have been controlled by recurrent movement of deep-seated faults in the Precambrian basement which at the time of Laramie deposition was at depths in excess of 10,000 ft. Growth faulting, heretofore unrecognized in the Cretaceous of the Rocky Mountain area, may be a common occurrence in the areas of deltaic sedimentation. Some abrupt thickness changes may be explained more readily by this process than by the commonly invoked theories of facies change or unconformities.

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PRESIDENTS, PRECEDENTS, PROVOCATION, AND PREROGATIVE—ARE GEOLOGISTS SCIENTISTS?

It is the prerogative, in fact the duty, of a president of a scientific society to break precedents, at the certain risk of provocation of society members. Utilization of the exploration geologist as a decision maker and representative of industry in the development of natural resources has led some geologists who search the earth's crust for enormously valuable fossil fuels and minerals to downgrade themselves as scientists. Because profit is involved, some academic colleagues and administrators assume that our application of geology is an impure utilization of pure scientific principles.

Industrial administrators, clients, and geologists themselves have noted that obsolescence comes quickly to anyone whose scientific work becomes routine rather than an exciting adventure in continuous learning. To break this insidious syndrome of security, the exploration scientist must fight apathy, lethargy, and inertia. At every turn, it is the geologist with pride in his work who must reestablish the fact that he is a true scientist *first, a professional second, and a dedicated member of* his scientific associations third.

The American Association of Petroleum Geologists, classed as a learned professional society, is also a business league made up of scientists. As such, all petroleum geologists and geophysicists can be willfully provocative, must break hampering precedents, and should assume their rightful prerogatives as pure scientists. We are neither professional sinners nor philosophical saints, but if we allow the development of professional unionism within our Association, our value as scientific, economic, and political decision makers in the search for, discovery, and production of our natural resources will be greatly impaired. Personal pride in profession is the outstanding characteristic of excellence among scientists. Are geologists scientists? I say emphatically, Yes!

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FORMATION OF AUTHIGENIC CLAY IN DETRITAL SAND

Coarse Columbia River sand, with neither silt- nor clay-size grains present, altered to sediment composed of 82 wt. % sand, 5% silt, and 13% montmorillonitic clay in a 5-month hydrothermal experiment. Run conditions were 200°C and 200 psi in a brine solution as the fluid phase. The original sand was composed largely of volcanic detritus from andesitic sources. Hypersthene grains were severely etched during the runs, and other mineral grains and lithic fragments probably also participated in the reaction to form clay. The clay, which coated various parts of the hydrothermal apparatus, appeared to form at least partly as a precipitate. The fluid phase showed a slight increase in Na and K, a slight decrease in Ca and Mg, and saturation with Si. The pH remained constant at 3.5. Oxidizing conditions probably prevailed throughout the experiment.

A similar experiment was run with Columbia River silt as starting material. Montmorillonitic clay was also produced, and the fluid phase showed the same changes.

Similar reactions undoubtedly take place in natural systems. Clay matrix in sandstones must, at least in part, be formed by chemical alteration of thermodynamically unstable clasts.

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CUMBERLAND BASIN, NOVA SCOTIA—POSSIBLE RIFT

The Cumberland basin of Nova Scotia has long been considered a structural basin by virtue of the elliptical outcrop and inward dip pattern of the Pennsylvanian outcrops. Recent data indicate that subsidence began in the Late Devonian perhaps resulting from a graben or rift. The Mississippian sediments which filled the growing depression were continental, lacustrine, and marine with evaporites. The cessation of the rift-forming processes are recorded by the alluvial swamp-type sediments of the Pennsylvanian which filled the depression. More than 25,000 ft of Carboniferous rocks are believed to be present in the deepest part of the basin. Starting with the rift hypothesis some speculations about the kinds of sediments and their locations, and about the structural features present beneath the Pennsylvanian surface may be ventured. From surface exposures and a limited amount of subsurface data, it is theorized that the Mississippian evaporites acted as glide zones which effectively divided the basin into 2 horizontal structural layers. The rocks above the evaporites, responding to Appalachian stresses, formed the long diapiric folds with cores of over-thickened evaporites. Below the evaporites the structures are related to movements of the rift floor, compaction closures, and structures formed by differential horizontal movements of the rift walls. In its deeper parts the rift probably contains more and a greater variety of marine rocks than the outcrops indicate. Should the rift hypothesis be correct, the possibility of finding hydrocarbons is enhanced.

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GEOGRAPHY AND FAUNAL PROVINCES IN TREMADOC EPOCH

A major change took place in trilobite faunas during Late Cambrian and Early Ordovician time, that is, during the Tremadoc Epoch. The majority of preexisting families died out shortly before or during this epoch. They were replaced by several short-lived, new groups and the earliest members of other families which dominated succeeding Ordovician trilobite faunas. The dissimilarities between samples of Tremadoc trilobite faunas from 18 areas in the world were analyzed by a nonmetric multidimensional scaling technique. Groupings obtained by such analyses reveal faunal provinces of the Ordovician, and for the early part of the period 4 provinces were recognized. The analyses of Tremadoc faunas should reveal whether or not changes in provinces occurred during this epoch. The assumption that a faunal province originally extended over the shallow seas surrounding a single continental mass is used, with palaeomagnetic data, to propose a model for Tremadoc paleogeography.

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CHARACTERIZATION OF OIL TYPES IN THE WILLISTON BASIN

The characterization of genetic crude oil types within a given petroleum province can be accomplished readily by 4 commonly used techniques—carbon isotope ratio measurement, gas chromatography, optical rotation measurement, and infrared spectrophotometry. Obtaining carbon isotope ratios on both the whole oil and its aliphatic fraction is desirable. Gas chromatography is carried out on the $C_4$-$C_7$ fraction and the $C_{15}+$ fraction of each oil. A semilog plot of carbon isotope ratio versus optical rotation is helpful in characterizing oil types.

Application of these techniques to approximately 200 oils from the Williston basin has revealed the presence of 3 major oil types within the basin. One type occurs primarily in Ordovician reservoirs, but is found in some Silurian, Devonian, and Mississippian reservoirs as well; a second type is found almost entirely in Mississippian Madison reservoirs, and the third type is restricted to Pennsylvanian Tyler reservoirs. A few oils either were derived from minor sources or were modified by contributions from minor sources. Other oils appeared to be mixtures of 2 major types. A classic example of commingled Ordovician and Madison types was found in Weldon field. The effects of thermal maturation are evident on the carbon isotope optical rotation plot.

The source of the Madison-type oils appears from geochemical data to be the Upper Devonian–Lower Mississippian Bakken Shale. The Tyler-type oil seems to have originated in the Tyler shales. Geochemical data have not established clearly the source for the Ordovician-type oil, but its prevalence in Ordovician reservoirs suggests the Ordovician Winnipeg Shale as the probable source.