and magnetic maps on a continental scale. These may be used to assemble such maps as the basement structure and the derived structure of the Mohorovicic surface itself, including a fault-block mosaic of the continent. The relations shown help establish contour control for additional maps showing such measurements as age of basement rocks, hydrodynamics, and heat flow. A knowledge of such "deep" maps assists in the construction of paleogeographic maps. It is the thesis of this paper that the factors establishing these maps play a fundamental part in the accumulation of oil and gas and the survival of trap areas.

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SANDSTONE POROSITY—HOW DEEP?

Sandstone porosity and permeability tend to decrease with depth. Controlling factors are complex and there is no accurate method of computing the depth to which commercially interesting porosities might extend.

The optimistic view is that quartz is an exceedingly strong material and that short-time crushing experiments indicate that porosities persist to depths roughly double those drilled to date. Other experiments involving saline waters, elevated temperatures and pressures, and times measured in days, show that quartz sand is very much weaker than its theoretical strength and that failure and compaction is progressive over the longest times investigated. As in natural sandstones, experimental consolidation of quartz sands involves two distinct processes, compaction and cementation. Both are accelerated by high temperatures, moving water solutions, and large "overburden" pressures.

Highest porosity might be expected for pure, well sorted and rounded sands of the type examined experimentally. Conditions resulting in porosity reduction in these sands to some minimum value,—say 15 per cent,—should produce similar or greater reduction in most oil sands. Assuming sands are water-bearing and depth is constant, then temperature is the most important variable affecting pore reduction. Experiments indicate the effects of time and temperature are interchangeable, the log of time being a linear function of absolute temperature.

Compaction curves for dry quartz sand at room temperature and for saline water-saturated sands at pressures and temperatures simulating burial, are roughly parallel with trends of maximum porosities in natural sands. These trends seem to be temperature-dependent. If published temperature gradients for the Gulf Coast are accepted, then rough extrapolations indicate that pure quartz sands would be reduced to 15 per cent maximum porosity at depths less than 20,000 feet in the Galveston area and somewhat deeper, perhaps 25,000–27,000 feet, on the Mississippi Delta. These figures are for young Cenozoic sediments. Similar porosities should be attained at lesser depths within older formations.

Scarcity of reliable temperature data sharply limits the accuracy of this type of analysis. Good temperature logs of a few deep wells within a region would be of great value in estimating deeper drilling possibilities.

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APPLICATION OF MULTIVARIATE STATISTICAL TECHNIQUES TO THE STUDY OF THE CHEMICAL COMPOSITION OF SANDSTONES

The technique of discriminant function has been applied to data previously presented (Middleton, 1960, G.S.A. Bulletin) in order to confirm that the chemical composition of sandstones varies significantly with the tectonic environment of the basin of deposition. After rejection of all sandstones with less than 5% Al_2O_3, the remainder were distributed between three classes: A, eugeosynclinal sandstones; B, exogeosynclinal sandstones and others; C, taphrogeosynclinal sandstones.

Discriminate function coefficients (which correspond with rules for the assignment of sandstones of unknown tectonic setting to a tectonic classification) have been calculated for the three groups, based on the original data, a logarithmic transformation and an Arc sin square-root transformation. By the logarithmic transformation (for example) the discrimination is highly significant, and the probability of misclassification is as follows: between A & B, 0.17; between A & C, 0.06; between B & C, 0.13.

The reliability of the discriminate function was tested empirically by its application to 19 eugeosynclinal sandstones and 4 exogeosynclinal sandstones whose analyses were not used to calculate the function. Of these, only 2 eugeosynclinal sandstones and one exogeosynclinal sandstone were misclassified. The number misclassified corresponds closely with prediction, and the use of the technique may be considered to be vindicated, in spite of the failure of the data to follow closely the assumptions of the mathematical model.

An attempt has also been made to use factor analysis to indicate significant groupings of chemical variables and to suggest the basis for a chemical classification of sandstones.

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ECONOMICS OF OFFSHORE OIL AND GAS PRODUCTION

The petroleum industry, truly seaborne in many ways, is active in waters ranging from Alaska to the Persian Gulf. It is producing from sizeable oil and gas fields located far from shore, drilling from floating platforms, completing wells beneath the sea, even floating refineries to far-off shores—accomplishments that were visionary a few short years ago. Important, significant reserves of oil and gas have been found in the submerged lands and much of the world's future supplies of petroleum energy will come from beneath the sea.

But the industry's sea legs still are shaky in some respects and rougher sailing is ahead. There is a critical imbalance in the ratio of expenditures to returns. There is continuing Federal-State conflicts on offshore development which conceivably could spread to other points of difference. Discernible future trends of offshore development will require new technological developments with attending higher costs, placing even greater strain on the rate-of-return structure.

The situation today demands a new era of enlightened industry and governmental statesmanship if there is to be a continuation of successful offshore development.

Specific steps and proposals are suggested to attain this vital objective.

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TECTONIC PATTERN OF MIDDLE AMERICA

From a study of the major tectonic features—Precambrian outcrop, post-Precambrian metamorphic outcrops, major intrusives, eruptive centers, folds and fold belts, and fractures and faults—of an area in the western hemisphere bounded by latitudes 40°N and 14°S and longitudes 60°W and 108°W, it is concluded that this part of the earth's crust has been segmented into major blocks bounded by wrench fault zones. The absence of "island arcs" in this area is noted. Four occurrences of triangular crustal "building blocks" bounded on two sides by wrench-fault zones and on the third by autochthonous fold belts are pointed out, as are other recurring crustal components.

An interpretation of basement faulting based on the application of the principles of wrench-fault tectonics to observed tectonic features leads to the conclusion that the observed tectonic pattern of Middle America can have resulted from the interplay of essentially meridional crustal compression and equatorial compression, both of which are thought to have been active throughout geological time.

There is a clear relation between the distribution of oil and gas provinces and the basement tectonic pattern.

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SEDIMENTARY FRAMEWORK OF CONTINENTAL MARGINS

The sedimentary framework of selected continental margins of North and Central America has been investigated by means of non-explosive, continuous-reflection seismic systems. These records have been interpreted in the light of present knowledge of distribution of sedimentary facies and the processes of transgression and regression on modern continental shelves.

As a result of these studies, it is concluded that there is no typical continental margin. Fundamental differences exist in regional tectonism, rates of supply of sediments, and oceanographic agents of transportation, deposition, and erosion. Predominantly tectonic-erosional versus depositional types can be recognized, but are not necessarily related by evolutionary sequence. Submerged Pleistocene deltas are important in shaping present continental shelves and slopes. All types of shelves and slopes recognized today, existed prior to the Quaternary, but without the depth uniformity and abruptness of shelf break.

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MIETTE REEF COMPLEX (DEVONIAN), JASPER NATIONAL PARK, ALBERTA*

A small limestone reef complex occurs in the Front Ranges of eastern Jasper Park. From exposures in three thrust sheets, reconstruction indicates a sub-rectangular outline with an area of about 30 square miles. The main reef sequence is in the order of 1,400 feet thick, circumscribed by a slightly thinner succession of shales and argillaceous carbonates. This reef is comparable to the moderate sized biostromal reef complexes of the Alberta basin.

The depositional history of the reef can be interpreted from the reef geometry and stratigraphy, well exposed reef margins, and carbonate petrology. The basal transgressive sediments are represented by a widespread, thin, argillaceous, fine calcarenitic, stromatoporoidal and *Amphipora* limestone (Flume) deposited over a flat erosion surface on Cambrian strata. Due to increasing rates of subsidence the deposition of organic, biostromal carbonates (upper Cairn) was restricted to the areas underlain by a thicker development in the basal limestone of stromatoporoidal carbonates, presumably shoals. Stromatoporoid reefs with thin interbeds of *Amphipora* limestone and calcarenite form the main constituents of the Cairn biostromes. Fine calcarenites (Maligne) deposited adjacent to the biostromes probably represent detritus eroded from their margins. Further increase in the rate of subsidence induced growth of bioherms around the margins of the stromatoporoid biostromes. These bioherms enclosed a central lagoon. In the central part of the Miette reef this resulted in a gradual change from dark-colored, stromatoporoidal carbonates (upper Cairn) to light-colored, fine, non-skeletal, granular limestone (lower Southesk). Black, pyritic shales (Perdrix) deposited during this period in the adjacent basin indicate stagnant, poorly circulated waters. More rapid subsidence appears to have drowned the reefs, and terrigenous muds reduced basin relief (lower Mount Hawk). Gradual emergence of the reef produced a small platform or bank above which non-skeletal lime sands (main part of Southesk) were deposited in the restricted and agitated waters. Carbonate muds derived from the bank were added to the terrigenous muds (middle and upper Mount Hawk), further reducing basin relief. Lime sands (upper Southesk) gradually spread over adjacent Mount Hawk muds. Scattered small coral reefs developed near the edges of the bank. During this final stage of slow sedimentation interspersed with periods of non-deposition, quartz silts were deposited over the region.

The Miette reef was localized above the positive pre-Devonian arch which parallels the eastern Front Ranges and Foothills. Growth of the Miette reef appears to have been largely controlled by continued differential subsidence above this arch and by shoals and stromatoporoid reefs in the upper part of the Flume.

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GEOLOGIC HISTORY AND FRAMEWORK OF GULF-ATLANTIC GEOSYNCLINE

A coastal geosyncline (paraliageosyncline) extends more than 4,000 miles along the eastern margin of North America from Newfoundland to British Honduras. About half of this element, which ranges from less than 100 to more than 500 miles in width, is covered by waters of the Atlantic Ocean and Gulf of Mexico. In the uncovered part, some Jurassic—but mostly Cretaceous and Cenozoic—strata crop out in belts which are progressively younger seaward. Rocks and features which have been considered to be inherent features of either miogeosynclines or eugeosynclines are found in the province.

The geosynclinal sedimentary mass, lithically variable, roughly lenticular in cross section, and built on a basement of differing Precambrian and Paleozoic rocks, is relatively linear in plan between Newfoundland and Florida. Between the latter and British Honduras, it constitutes a great irregular arc which almost encircles the Gulf of Mexico. Maximum thicknesses of the sedimentary materials are on the order of 25,000 feet in the Atlantic segment and 50,000 feet in both the northern and southern Gulf of Mexico. These occur generally near the margin of continental (sialic) material. Notable landward deviations (embayments) exist in the vicinity of the Mississippi River and Rio Grande, whereas significant seaward extensions form the Florida and Yucatan platforms. The thick sedimentary depocenter of the northern Gulf of Mexico