

Inter-sand-bar deposits consist of carbonaceous dolosiltite which does not contain skeletal grains. A sample transect from sand-bar crests to inter-bar basins shows a continuous, progressive gradation from sparry calcarenite to dolosiltite.

During deposition of upper Salem sediments, a fine-grained calcisphere calcarenite overlapped all three facies described above. This facies was deposited in restricted, shoaling conditions, as indicated by the presence of dolomite, quartz silt, and clay minerals.

The final phase of Salem deposition is represented by a thin but persistent, laminated, argillaceous dolosiltite. Scour-and-fill structures, dolomite rhombs, and a lack of fossil grains indicate that this was an intertidal mud flat deposit comparable with New York Devonian "waterlimes."

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#### EXPLORATION DECISION-MAKING: TEN-YEAR FORECAST AND CASE HISTORY ON ANADARKO SHELF, 1956-1966

An 8,000-square-mile area of the Anadarko basin shelf in Oklahoma and Kansas was studied in 1956 to provide a forecast that hydrocarbons would be found in 50-80 per cent of a series of drilling ventures. Since 1956, more than 1,000 square miles have been proved productive and have been developed with a success ratio in excess of the predicted 50-80 per cent.

Conventional geological and reservoir engineering methods were used, augmented by probability/statistical theory which quantified and codified an exploration strategy to guide in the acquisition of leases. The deterministic *versus* the probabilistic approach to finding productive hydrocarbons is the problem. Because geology/land/engineering/economics are interrelated and inexact sciences in the oil business, more reliance must be placed on probability and statistics. There is no sharp demarcation between the beginning of one discipline and the beginning of another. The ideas on probability theory that commonly fall into disuse or misuse can be powerful mathematical tools in the search for hydrocarbons.

Geological maps, sections, and intervals are based on the original work. Rock and hydrocarbon distributions are then examined as a practical problem in statistical geometry by information theory, Bayesian methods, and the Laplace law of succession, much as a meteorologist can study cloud and weather patterns.

Regarding engineering, the pressure decline *versus* cumulative production of the predominantly gas reservoirs can be correlated statistically with the entropy of the shelf by random well sampling, or from wells selected by rigid, fixed patterns.

The economics and conversion to dollars can be figured through time by the amount of gas produced and the price paid by the pipeline companies. Leasehold and drilling costs are further related to the original forecast.

The mathematics serve well to predict the present status of this gigantic gas province from a small amount of data available in 1956. The continuing and expansive development of the reserves is testimony to the integrity of the approach through operations research methods.

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#### EXPLORING NORTH SEA

Exploration for oil and gas in the North Sea has been carried on at a high level since the first licenses were granted in 1964. Several commercial gas fields have been discovered in British waters.

The North Sea basin has been a depositional site for potentially productive sediments at different times since the early Carboniferous. Interpretation of seismic data is complicated by variable thicknesses of Permian salt overlying the older productive strata.

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#### ABSOLUTE AGE, STRATIGRAPHIC CORRELATION, AND MINERALOGY OF ASH LAYERS IN TERTIARY SEDIMENTS FROM ATLANTIC OFF FLORIDA

Volcanic ash layers were penetrated in three of the sediment cores recovered during 1965 off Florida as part of the JOIDES deep drilling program. The ash in these cores consists of shards of fresh acidic glass with a size distribution centered in the 30-60-micron fraction. In all samples, the ash is in Oligocene strata, as indicated by planktonic Foraminifera such as *Chiloguembelina cubensis*, *Globoanomalina micra*, *Globovalia postcretacea*, and *G. yeguaensis*. Such a fauna is typical of the Vicksburg Group of the United States, and other Oligocene sections in Europe and Africa. Potassium-argon dates of the ashes provide absolute ages for the Oligocene. These JOIDES ash layers appear not to be correlative with ash beds found in the Tertiary Oceanic Formation of Barbados.

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#### NAKED FORAMINIFERA FROM SHALLOW-WATER ENVIRONMENTS

Abundant live and dead Foraminifera having different degrees of calcification were found in samples collected in bays, marshes, and lagoons along the northeastern coast of the United States. Live standing crops of uncalcified, "chitin-like" Foraminifera have not been discussed previously in detail, and specific reasons for the occurrence of abundant multi-chambered "chitinous" inner linings have not been postulated.

The bottom sediment at all locations from which a large live standing crop of uncalcified Foraminifera or abundant inner "chitinous" linings was recovered consists of fine silt and clay with abundant fecal pellets and (or) decomposed vegetation. This supports previous observations that low pH conditions are important in the occurrence of these forms.

However, results of the present study make it possible to suggest that the presence of a particularly acid alga which lives in the areas collected may be a specific cause of local lack of calcification in live standing crops of Foraminifera, and that bottom-dwelling invertebrates play a significant role in the local environment by consuming calcareous Foraminifera and excreting their "chitinous" linings.

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#### RADIOMETRIC DATING OF CENOZOIC EPOCHS

As a result of (1) careful selection of datable samples in close and demonstrable correlation with fossiliferous beds and (2) perfection of radiometric dating techniques, an excellent understanding of the time scale of the Cenozoic epochs has been achieved. This knowledge extends from the base of the Paleocene to

the present with non-dated intervals being virtually non-existent. One of the most interesting sets of facts to emerge has been the relative refinement of correlation attainable with different paleontological disciplines. A complete time scale based on mammalian correlations is presented. Special emphasis is placed on dating of rocks in the time-range 50,000–2 m. y. B.P., and thus on the time scale of human evolution.

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#### COMPARISON OF MARINE-BAR WITH VALLEY-FILL STRATIGRAPHIC TRAPS, WESTERN NEBRASKA

Marine-bar and valley-fill stratigraphic traps in the Cretaceous "J" sandstone in Cheyenne and Banner Counties, Nebraska, illustrate control of reservoir shape, size, and characteristics by depositional environment.

Reservoirs deposited as shallow-marine bars are elliptical lenses 2–5 miles long, 0.5–1 mile wide, and less than 25 feet thick. Sandstone grades laterally into marine mudrock. There are two generations of bars in this area, closely spaced stratigraphically, but with different directions of elongation. These lenses presently are tilted with a regional southwest dip. Entrapment is independent of structural closure. Most bar bodies are entirely oil-filled.

Reservoirs deposited as a valley-fill occur within a prism of sandstone more than 20 miles long, 2,000 feet wide, and 50–80 feet thick. The boundaries of this body are erosional. Oil is trapped only where the valley-fill trend crosses plunging anticlines. The valley-fill interconnects all pools as a single aquifer system.

Exploration and production efforts are guided by the following. Position of marine-bar reservoirs can be predicted by techniques which map gradients in sandstone-shale proportions, such as those based on mechanical logs. Bars in this area are scattered and not in chains; orientation is varied. Structure is unimportant. In contrast, valley-fill reservoirs are separated by erosional boundaries from enclosing rocks; hence, they can not be detected by examination of the enclosing facies. Where located, however, the valley-fill has great continuity and persistence of trend. Structure is vital. Valley-fill reservoirs have water drives and high primary recoveries, whereas marine-bar reservoirs have only solution-gas energy.

Environmental interpretation of these reservoirs is based on fossils, sedimentary structures, textures, facies relations, and geometry. A single core commonly allows correct interpretation. Exploration and production programs are guided profitably using environmental concepts at an early stage.

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#### MARINE GEOLOGY OF SANTA CRUZ SUBMARINE CANYON, CALIFORNIA

The beaches and shallow offshore areas of Santa Cruz and Santa Rosa, the two major northern channel islands off the California coast, are the sole source areas for sediment that ultimately is deposited in the Santa Cruz basin. The intermediate position in this three-stage sediment-transfer system is occupied by the Santa Cruz submarine canyon. Through a network of tributaries at its head the canyon receives material from the islands. The material is moved

down the canyon axis and dispersed across the basin as a submarine fan. A main channel, with natural levees, persists across the fan and a series of distributary channels develop from it.

Cores recovered from the canyon axis and fan contained graded layers of sand and gravel, including one such unit 116 centimeters long. The gradation in this last unit is somewhat unusual, in that it differs greatly from the "fine-at-the-top, coarse-at-the-bottom" conceptual model of graded bedding. Instead, there is a constant compositional population with a modal class at  $+2\phi$ , which decreases in over-all percentage as the bottom of the unit is approached. A second, coarser-grained population appears midway in the unit, with a modal class at  $+0.75\phi$ . This second population increases in over-all percentage and shifts its modal class gradually to  $-4.25\phi$  toward the bottom of the unit.

The coarsest particles in all the graded beds are disseminated in a narrow zone *above* the base of the bed. Thus the bottom of each graded bed is a zone of reverse graded bedding.

All graded sand and gravel layers are extremely clean, usually containing less than 1 per cent silt and clay. Contacts with overlying mud are sharp and distinct. Lower contacts, where visible, commonly are gradational. Detailed pipette analyses show that overlying "pelagic" mud in many places is graded (in the usual sense). Electron micrographs show a decrease of organic remains (diatoms, coccoliths, etc.) toward the base of the graded beds, with a marked, increase at the base. Maximum organic remains are in mud surrounding the sand layers.

The writer postulates the existence of an originally clean sand and gravel body that was able to move down the canyon or across the fan, *maintaining its internal integrity*. Such a body would exhibit properties described above. It may act as a triggering mechanism; itself setting off "true" turbidity currents.

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#### ATEABASCA OIL-SAND EVALUATION USING COMPUTER AND DATA-PROCESSING METHODS

A 4,000-acre oil-sand mining operation in northeastern Alberta is being conducted by Great Canadian Oil Sands, Ltd. The sandstones contain as much as 18 per cent by weight of low-gravity oil or tar, they are lenticular and interbedded with barren shale and siltstone. In order to determine in-place oil content and other ore-body characteristics, an extensive coring and well-logging program was conducted during the winters of 1963–64 and 1964–65. Using a comprehensive well-log-analysis computer program, core-analysis data, and a geological data-processing system, the average grade, in-place oil reserves, and other characteristics of the mining lease were determined. Of all logging devices tested, the formation density-laterolog 3 combination provided the best borehole measurements of porosity and water saturation. Numerous comparisons of core *versus* log analysis results indicate that accurate oil content can be ascertained in the oil-sands using conventional log-analysis methods. Core and log information was combined to produce continuous oil saturation, water saturation, porosity, and bulk-density profiles for each test hole. Stratigraphic correlations and oil-grade cutoff tops and bases also were included for each test hole. From this information numerous maps and cross sections for use in defining the ore body and in mine planning were produced, using the computer-plotting combination.