NATLAND, M.L., Atlantic-Richfield Company, Los Angeles, Calif.

NEW CLASSIFICATION OF WATER-LAID CLASTIC SEDIMENTS

Because of their economic importance as petroleum reservoirs, water-laid clastic sediments may be classified usefully according to their mode of deposition, including transport, which determines to a great extent their lithologic composition. Although an infinite number of variables can affect deposition and composition, there are four principal processes of aqueous sedimentation which produce characteristic deposits herein designated as tractionites, gravitites, turbidites, and hemipelagites.

A *tractionite* is a bed of clean, winnowed sand or coarse clastics deposited by moving water which sorts the particles as it sweeps or drags them along the bottom. Tractionites are prevalent in river beds, beaches, offshore-marine areas where bottom currents are strong enough to move coarse sediments. Ripple marks and other current-produced features are common. These beds contain little if any fine-particle matrix.

A *gravitite* is a bed of poorly sorted clastics, ranging in size from clay to boulders, deposited by a sedimentary flow in which the motivating force is gravity that causes the sediment to move as a unit down a slope with sufficient gradient at speeds ranging from very slow creep to those of considerable momentum. Bedding features are poor because the particles are not in suspension and, therefore, are not able to respond hydrodynamically. Fossils, if present, are randomly oriented and scattered through the heterogeneous mass. If the velocity of movement becomes great enough, the sediments may be stirred sufficiently with water to form a suspension mixture capable of generating a turbidity current.

A *turbidite* is a well-graded sedimentary unit deposited rapidly from the suspended load of a turbidity current and includes all of the intervals, grading upward from coarse sand to silt and clay, resulting from a single flow. Because the prime motivating power of a turbidity current is the density differential between the turbid water with its suspended load and the clear water which it encounters, a turbidity current once generated can move along a flat bottom. Turbidites are well graded because particles in a suspension flow are able to respond hydrodynamically. If the suspended load includes a wide range of particle sizes, a "complete" turbidite is formed with at least three distinct divisions, the graded sand interval at the base overlain by the current-bedded interval and the pelitic interval. A turbidite is characterized by features indicating suspension flow, such as preferentially oriented megafossils, hydrodynamically sorted microfossils, and a high (10–30 per cent) silt-clay matrix in the graded sand interval. Turbidite contains only reworked faunas if faunas are present.

A *hemipelagite* is a layer of marine debris formed by the slow accumulation on the sea floor of organisms and fine terrigenous particles. Though a hemipelagic deposit generally caps a turbidite, the hemipelagite is not part of the turbidite but is indicative of an interval of quiet between turbidity-current flows. Its thickness is related to the time during which this type of sedimentation takes place without interruption. Hemipelagite contains the only indigenous fauna in the turbidite sequence.

Examples of the preceding sedimentary processes and deposits are discussed with the aid of slides and motion pictures.

NEWENDORP, PAUL D., and JOHN M. CAMPBELL, School of Petroleum and Geological Engineering, University of Oklahoma, Norman, Okla.

APPLICATION OF UTILITY THEORY TO PETROLEUM DECISION-MAKING

The application of logic to the exploration for minerals may be divided into two discrete phases—preparation and analysis of the raw data, and the decision-making process based on such analyses. Both involve non-random characteristics that are not entirely encompassed by the procedures of classical probability and statistics methods, which are based largely on the supposition of random systems.

This paper is a report on a study in depth of the decision-making process in several petroleum companies, one of which is a "major." The purpose of the study is to define better what role "utility theory" might play (if any) by establishing whether or not characterization of individuals and groups is feasible. This necessarily involves the establishment of criteria for such characterization so that the degree of the non-random factors may be better understood.

NOBLE, FRANK J., Union Oil Company of California, San Marino, Calif

EXPLOITATION OF CALIFORNIA OFFSHORE FIELD, PARCELS 14 AND 20A, HUNTINGTON BEACH, CALIFORNIA

Union was awarded Parcel 14 by the State of California in 1962 for a bonus of $6,110,000. In 1964 Union bought the southern part of the adjoining Parcel 20A from the Signal Oil Company. Development of both parcels is complete and resulted in a westward extension of the offshore Huntington Beach oil field.

Parcels 14 and 20A are located on the west-plunging nose of a large east-west-trending asymmetrical anticline. Oil is produced from upper Miocene division "C" sandstones, defined as the Upper Main (UM) and Main No. 1 (M-1) zones. Both of these productive sandstone zones thin and grade laterally into shale in an easterly direction, up the plunge of the anticline, forming a stratigraphic trap. Maximum net oil-bearing sandstone penetrated in wells is 512 feet.

Asymmetry of the structure is formed by a steep-dipping south flank, with a known maximum dip of 65°, and a shallow-dipping north flank averaging approximately 10°. The axis hades toward the north at approximately 70°.

Faulting on Parcels 14 and 20A is minor; two 50-foot normal faults have been mapped.

Thirty-eight wells have been drilled directionally and completed from Union's Platform *Eva* on 10-acre spacing. These wells are positioned on a five-spot water-flood pattern for future secondary operations.

An estimated 40 million barrels of 22° oil ultimately will be recovered from Parcels 14 and 20A by both primary and secondary recovery methods of depletion.

NORDIN, CARL F., JR., and JAMES K. CULBERTSON, U. S. Geological Survey, Fort Collins, Colo.

STATISTICAL PROPERTIES OF DUNES GENERATED BY UNIDIRECTIONAL WATER CURRENTS

Field and laboratory studies of ripples and dunes formed in sand by unidirectional water currents show for coarse and very fine sand that the ripple index is related to median particle size and to flow intensity as measured by a dimensionless shear stress parameter. However, for medium-grained sand (0.25–0.50 mm.)

the ripple index is approximately constant and is independent of flow intensity. For medium-grained sand statistical properties of the ripples and dunes other than the ripple index are required to correlate the characteristics of the bed configurations with flow parameters.

Two methods of analysis for medium sand have been developed. In the first, spectral analyses of profiles of the channel bed lead to a linear second-order Markov model which describes the essential statistical properties of the dunes. All the parameters of the model are simple linear functions of the water discharge per unit width of channel. One of the parameters, the standard deviation of the bed elevation about the mean, shows excellent correlation (correlation coefficient of 0.99) with unit water discharge for flows ranging from 0.7 to 10 cfs. per foot of width and for average dune lengths from 2–25 feet.

The second method of analysis consists of defining distributions of dune lengths, amplitudes, ripple indices, and angles of downstream faces, and relating the moments of these distributions to flow characteristics. All the distributions are skewed, and the skewness correlates roughly with flow intensity. This analysis gives useful indications of the variations in the geometric properties of ripples and dunes, but it is time-consuming and requires extensive data. Moreover, the parameters describing the ripples and dunes show only a crude relation to flow characteristics. Of the two methods, the spectral analysis appears to be more useful.

OSBORNE, ROBERT H., Department of Geology, University of Southern California, Los Angeles, Calif.

R-MODE FACTOR ANALYSIS OF CINCINNATIAN (UPPER ORDOVICIAN) LIMESTONES

An *R*-mode factor analysis based on 20 petrographic variables observed in thin sections of 60 Cincinnatian biomicrosparrudites was made to determine genetic relations among several limestone classes. Thin sections were used for point-count estimates of whole and broken brachiopod grains, whole and broken bryozoan grains, disarticulated crinoid columnals, whole gastropods, and broken trilobite carapaces, as well as matrix (micrite and enclosed dolomite) and sparite. The correct volume of each measured variable lies within 5 per cent on each side of the obtained value with a 95 per cent confidence. The weight percentage of insoluble residue contained in each limestone sample also was determined. These measurements were combined into a 20 × 60 data matrix. The product-moment correlation coefficient was computed for each pair of variables, and the results were arranged in a 20 × 20 correlation matrix. Five statistically significant factors were extracted from the correlation matrix, which account for 82 per cent of the total variance. The geologic interpretations of the factor axes in order of extraction (decreasing significance) are: (1) mechanical energy gradient at the depositional site, (2) substrate firmness, (3) degree of lithification, (4) relative contributions of carbonate mud and skeletal grains to the sediment, and (5) Eh at or slightly below the depositional interface.

PAYNE, MAX B., Worldwide Geothermal Exploration Company, Los Angeles, Calif.

STRATIGRAPHY OF PRODUCING GEOTHERMAL FIELDS

Natural steam production is found in reservoir rock overlain by impervious cap rock. These rocks may be volcanic, sedimentary, metamorphic, or plutonic. The age and composition of these rocks are not important but only Pliocene and Recent magmas are known as an underlying heat source. Reservoir rocks usually are highly fractured and rendered porous by solutions, must be of sufficient thickness (minimum 100 meters), and of an areal extent to sustain continuous production. Porosity values should be at least 10 per cent.

Man has utilized natural steam and hot waters throughout historic time. There are many present-day uses for natural heat, such as wood-pulp manufacture, evaporation of salt, space heating, and greenhouse farming. The first electricity made from natural steam was in 1905 at Larderello, Italy. Iceland, New Zealand, and Japan also were early users of geothermal energy. The Geysers in California is the first and only geothermal field generating electricity in the United States. Pacific Gas and Electric installed the first 12,000-kwh. turbine-generator in 1960, a 14,000-kwh. unit in 1963, and in 1966 installed a 27,500-kwh. unit for a total of 53,500-kwh. capacity. A fourth unit is planned in 1968 bringing the total to 81,000 kwh. The rapid industrialization and population growth of the western states, as well as the world, has led to increased demands for energy. The U.S. Bureau of Mines Circular 8230 states that, if the growth in electric energy consumption occurs as projected, construction of considerably more thermal-generating plants will be required. Natural steam probably is the cheapest source of energy.

Potential geothermal resources of steam are evacuated by five fundamental criteria: (1) source of heat; (2) regional and local structural features; (3) source of meteoric waters (to infiltrate and circulate to depth); (4) reservoir rock sufficient to retain geothermal fluids in volume; and (5) impervious cap rock overlying reservoir for trapping steam.

Facca and ten Dam recommend exploration in four stages:

1. Preliminary survey and selection of area (includes geological, geophysical, and geothermal information, stratigraphic studies, and porosity and permeability data).
2. Detailed survey of selected area (includes photogeology, volcanological and petrographic studies, hydrogeochemistry, and hydrogeology and gradient surveys).
3. Test drilling.
4. Probing and evaluating (includes output measurements and production tests).

Stratigraphic data of three producing geothermal fields for comparison are given.

Larderello field, Tuscany, Italy, discussed by Facca (1963). He described the sequence and conditions as follows: (1) basement rock, quartzitic and anagenetic; (2) reservoir rock, evaporitic dolomite with high porosity and permeability, Late Triassic; (3) cap rock, flysch-like, shaly, impervious *argille scagliose*, Late Cretaceous-early Miocene age; (4) no Recent volcanoes; (5) heat flow provided by a deep-lying magma; (6) temperature of producing zone is 200°C. (392°F.); and (7) surface hydrothermal activity occurs as hot springs and steam jets of 100° to 190°C. (212° to 374°F.)

Wairakei field, North Island, New Zealand, was described by W. G. Grindley (1961) as a volcanic region 240 kilometers long, a Recent graben filled exclusively by volcanites. Two volcanoes are active at each end of the graben. The impervious Huka Formation is the controlling factor in heat accumulation. The produc-