tional), and irreducible water saturation.

The state of knowledge regarding reservoirs is such that, in some cases, rock and reservoir properties can be related directly; in other cases, they can be related empirically or only through speculation and surmise.

After a petroleum-bearing reservoir has been discovered, it can be cored, logged, and studied first-hand. Such a study then should guide field development through primary and secondary production. This type of study also can aid materially in shaping an exploration approach in search of similar reservoirs and in influencing a wildcat drilling program.

Each of the following examples of geologic reservoir studies was directed toward a different specific reservoir problem.

1. A large anticline in Wyoming produces from several reservoirs of different age and genesis; each reservoir has a separate set of production characteristics and problems.
2. A pair of structural-stratigraphic traps in Illinois, although similar in some properties, have different origins, internal geometry, heterogeneity, and recoverable reserves.
3. A gas-condensate reservoir in Oklahoma, where a combined petrographic-relative permeability study led to the installation of a dry-gas repressuring plant and a marked increase in recoverable reserves.

Although these examples are all from United States oil fields, the principles and methods of study are applicable in any petroleum province. Best conservation practices require the integration of geologic reservoir studies into drilling, logging, completion, stimulation, and primary or supplementary recovery operations.

20. W. S. FREDERICK, SR., Phillips Petroleum Co., Bartlesville, Oklahoma

ABNORMALLY HIGH FORMATION PRESSURES AT BOREHOLE AND BEYOND

Presented are examples of the effects of abnormally high formation pressures on drilling wells and illustrations of routine techniques of data handling, *i.e.*, identifying, documenting, and predicting abnormal formation pressures. High-pressure anomalies occur in large, mappable volumes and are present in Rocky Mountain basins. They cause serious drilling problems and add considerably to wildcat and development-well drilling costs.

Examples are compiled from data from the Rocky Mountain area and other areas.

21. GEORGE V. KELLER, Colorado School of Mines, Golden, Colorado

ELECTRICAL PROSPECTING METHODS IN OIL EXPLORATION

Electrical-prospecting methods may be used in an exploration program in one of three ways. (1) They may be used to determine the depth to resistant basement rock. (2) They may be used to detect directly the presence of oil. (3) They may be used to map variations in texture associated with lithologic traps.

Electrical-prospecting methods are being used extensively in some parts of the world for mapping major structural features within sedimentary basins, but in the United States seismic methods have proved to be far more effective for such studies. Electrical-prospecting methods have been used in the past to detect increases in resistivity caused by the presence of oil, but such applications have been limited to very shallow occurrences. The direct discovery of oil by electrical methods at greater depths would require great improvement in techniques. Electrical methods have been little used in the study of lithologic changes in a sedimentary column associated with oil traps. The Department of Geophysics at the Colorado School of Mines has been investigating such an application, using both well logs and field surveys from the Denver basin.

22. H. B. EVANS, JOHN C. HARMS, AND PHILIP W. CHOQUETTE, Marathon Oil Company, Littleton, Colorado

GRAPE*—DEVICE FOR CONTINUOUS POROSITY DETERMINATIONS

A rapid, accurate, and continuous method for measuring porosity or bulk density of cores from boreholes has been developed. The method is based on gamma-ray scattering.

The principal technical advantage of this porosity-measuring device is that variations in porosity encountered by a moving, pencil-size, gamma-ray beam are recorded continuously, whereas other methods yield only an average porosity for a particular core piece.

Basically, this device consists of a variable-speed drive system to move geologic material between a shielded gamma-ray source and a shielded detector, an optical caliper to measure the sample thickness, and a computer to calculate density and porosity from the measured parameters. The measured thickness and the computed density and porosity of the sample are recorded on a strip chart. Because the sample and the recorder chart are driven at the same speed, a direct comparison between the recorded parameters and the actual sample is possible.

Excellent agreement exists between porosity values of common sedimentary rocks measured by this method and by other conventional methods.

The system is designed for either field or laboratory use and only one operator is required. The device handles cores 1–4½ in. in diameter, conventional core plugs, and slabbed cores at drive speeds more than 3 in./min. At this speed, 100 ft. of core can be analyzed for density and porosity in about 6 hrs.

The device was designed primarily for density and porosity evaluation of sedimentary rocks obtained in oil exploration and development. Other applications of this system are possible. They include porosity measurements of unconsolidated recent sediment samples, determining oil content of oil-shale samples, measuring the ore content of metalliferous deposits, and estimating acoustic wave velocities or average density for geophysical purposes. Porosity profiles measured by the gamma-ray device for a variety of rock types illustrate uses of these results.

23. JOHN P. HOBSON, JR., Cities Service Oil Company, Tulsa, Oklahoma

CYCLIC SEDIMENTARY SEQUENCES IN FRONTIER FORMATION (UPPER CRETACEOUS), CASPER ARCH AREA, WYOMING, AND SOME STRATIGRAPHIC AND POSSIBLE PALEOENVIRONMENTAL IMPLICATIONS

The Frontier Formation is generally about 1,000 ft. thick in the Casper arch area and consists of a series

* Gamma-Ray Attenuation Porosity Evaluator.

of asymmetric, upward-coarsening, depositional sequences referred to here as "cycles." Four major cycles called sandstone "zones" by others, have been studied in exposures and mapped in the subsurface in a preliminary manner. Thinner, less conspicuous cycles occur within each major cycle.

Where typically developed, a cycle begins with relatively non-sandy gray shale at the base and becomes progressively more sandy upward, terminating where the cycle is thickest with a conspicuous body of fine- to medium-grained, submature to mature, chert-rich orthoquartzite having a relatively sharp upper boundary. Chert-rich pebble conglomerate of uncertain origin occurs in places within the sandier parts of the cycles.

Detailed correlations of bentonitic layers reveal that the major cycles pinch and swell laterally in a complex but generally systematic manner, displaying two- to four-fold thickness variations. The relatively thick parts of each major cycle generally lie on flanks of the underlying cycle. Proceeding upward through the sequence, axes of maximum sandstone development are offset progressively eastward away from the central Casper arch. The uppermost cycle also is relatively thick and sandy on the arch.

Upward coarsening within the cycles and the complex, but orderly, shifting pattern of the depositional axes of the major cycles suggest that the rate of sediment influx exceeded the rate of subsidence in the area during deposition of the Frontier. The thickness variations are *not* most plausibly explained by differential compaction or by differential subsidence, at least in the lower three major cycles. Thickness trends suggest that the major source of sand was north and northwest of the Casper arch area.

Although the cycles appear to be essentially regressive in nature, sand deposition under transgressive conditions is suggested in places by more glauconitic and (or) calcareous upper parts of the sandstone bodies. West of the Casper arch, coaly beds and channel-like conglomerate lenses directly overlie sandstone bodies in cycles that otherwise are similar. Definite evidence of non-marine deposition has not been observed in the Casper arch study area and general observations suggest that the sequence is essentially marine. As reasoned from stratigraphic observations, the general slope at the top of the lowermost major cycle did not exceed $\frac{1}{2}°$ and the maximum depth of water in the area was about 100 ft.

Although understanding of the depositional agents must await additional studies specifically aimed at this objective, some analogies are drawn between gross characteristics of the cycles and typical features of deltaic deposits along modern shorelines.

More realistic concepts of the internal geometry and genesis of sandstone and shale complexes could be of considerable aid to the petroleum geologist in explaining and predicting oil and gas occurrences.

24. EDWIN D. MCKEE, U. S. Geological Survey, Denver, Colorado

STUDY OF SEDIMENTARY STRUCTURES

Primary structures in sedimentary rocks are significant in the interpretation of ancient environments. They furnish data on the processes involved and on the general geologic setting inasmuch as most are formed at the time of deposition. Because numerous sedimentary structures are poorly understood, much information still is needed both from observation of modern sediments and from controlled experiments before general conclusions can be reached concerning the genesis of many rock types.

Principal varieties of stratification and cross-stratification are described with reference to environments in which they are known to have been formed. Some of these structures are typical of more than one environment; most environments are characterized by two or more varieties of structures. Knowledge concerning natural combinations or associations of structures, therefore, is especially useful in interpreting conditions of deposition.

25. DARYL B. SIMONS, Colorado State University, Fort Collins, Colorado

INTERPRETATIONS OF SEDIMENTARY STRUCTURES BY FLUME EXPERIMENTS

The various types of bed roughness that are formed by the interaction between the flowing water and a sand bed form distinctive but complex sedimentary structures. The resultant forms of bed roughness and sedimentary structures are related to many variables such as regime of flow, channel geometry, velocity, and the characteristics of the sediment. By studying the characteristics of the sedimentary structures, it is possible to determine quantitatively the magnitude of many of these variables. The characteristics of the sediment can be determined by analyzing samples from the sedimentary structures. The regimes of flow and forms of bed roughness can be identified from the cross-bedding of the sedimentary structures. The spacing and amplitude of these structures indicate velocity and depth of flow at the time of deposition. From relations describing channel geometry and with preceding information, channel width can be determined approximately. Last, knowing channel geometry, type of bed roughness, and the characteristics of the sediment, various sediment transport relations can be used to estimate the total bed-material discharge.

In summary, utilizing knowledge of the relations between bed forms, bars, sedimentary structures, hydraulic variables, sediment variables, sediment discharge, and channel geometry, it is possible to determine quantitatively many of the hydraulic and hydrologic characteristics of the depositional environment that formed the sedimentary structures.

26. CHARLES D. MASTERS, Pan American Petroleum Corporation, Denver, Colorado

STRATIGRAPHIC ANALYSIS THROUGH DETERMINATION OF DEPOSITIONAL ENVIRONMENTS

The Mesaverde Formation of the Western Interior Cretaceous seaway includes rock units representative of off-beach, beach, lagoon, swamp, and floodplain environments of deposition. Because of migration of the shoreline by transgression and regression, the sedimentary products of various environments are arranged vertically in the geologic record in the same succession as they occurred laterally at the time of deposition. The detailed distribution of the potential reservoir beach sandstone bodies in a regressive sequence follows different patterns, depending on variations in the relative rate of submergence during progradation. These variations are reflected in the character of the back-beach environment. A mainland beach-floodplain progradation, reflecting a low rate of submergence, results in a tabular sheet of beach sandstone which intertongues only slightly with the overlying flood-