northern Oklahoma have proved this to be false. The afore-mentioned discoveries indicate that similar potential for the Mississippian exists along the Las Animas arch.

The authors conclude that a carefully planned exploration program will prove, during the next few years, that the Las Animas arch truly is a "New Oil Province."

17. ROBERT W. SCOTT, Chorney Oil Company, Casper, Wyoming

Petroleum Potential along South Flank, San Juan Basin, New Mexico

During the past 2 years, a detailed analysis of the southern flank of the San Juan basin, northwestern New Mexico, has been made. This area probably has been one of the most neglected and yet one of the most promising basin areas remaining in the Rocky Mountain region for the discovery of Cretaceous and major Pennsylvanian reserves at reasonable depths.

The author believes that the "Gallup" production within the study area is related primarily to an offshore marine facies and a possible unconformity above the lower massive Gallup equivalents. Several of the productive sandstone bodies appear to be channel fills on this unconformity. The lower massive Gallup sandstone beds southwest of the study area are believed to be the source for the sandstone in the younger Hospah-type channel fills.

As shown by discrete mapping of Graneros-Dakota reservoirs, this section is a highly prospective interval for petroleum accumulation. Many of the sandstone developments and pinch-outs mapped have had significant oil or gas shows in downdip wells. The updip evaluation of these shows has not been accomplished to date by the industry. Even within the Dakota-Graneros productive areas at the north, development and extension have not been realized fully.

Production from the Pennsylvanian in the Four Corners area is associated with shelf, shelf-edge, or a high-energy-zone type of deposition. Similar environmental conditions were present along the southern margin of the San Juan basin, and conditions favorable to the development of bioherm reefs, biostromes, and massive beach sand bodies, all potential major petroleum reservoirs, existed. The significant factors indicative of environmental conditions along the southern margin of this basin are: (1) presence of a continental facies barrier in wells on the North Chaco slope; the section consists chiefly of red, maroon, and variegated shale with tight red and gray, thin-bedded limestone; (2) the presence of a shelf-carbonate facies, potentially prospective for biostromal development, sandstone pinch-outs, and truncation traps; these facies have been found in the few basinward wells tion of a high-energy shelf-carbonate zone, indicated in the West Cuba area, where an unusually thick, porous dolomite section may be associated with possible reefing; and (4) the presence of a deep-water marine downdip from the continental facies; (3) the sugges- facies consisting of hard, dense, tight limestone, with dark gray to black shale, and very fine-grained sandstone and siltstone penetrated in the deeper part of the basin.

18. LLOYD C. PRAY and PHILIP W. CHOQUETTE, Marathon Oil Company, Littleton, Colorado

Genesis of Carbonate Reservoir Facies

Carbonate rocks with porosity characteristics adequate to form petroleum reservoirs commonly are highly specific bodies of rock. They are rare in occurrence and diverse in type. Most are complex, both internally and in their relations with associated non-reservoir rocks. Yet the occurrence of porosity in carbonate rocks is in very few cases fortuitous; some discernible order normally prevails in the facies complex containing the specific reservoirs. Examples of highly specific reservoir facies, where a knowledge of the rocks and an understanding of their genesis can be helpful, are Pennsylvanian phylloid algal reservoirs of the Paradox basin, stromatoporoid-rich bank-margin facies of Devonian age in Alberta, and widely distributed algal-mat reservoirs. Detailed study of the rocks and their pore systems can lead to more effective exploration and exploitation.

The existence of limestone and dolomite reservoirs commonly is related directly to the nature of the original sediment and to early diagenetic processes. In reservoirs retaining significant primary porosity, the size and interconnection of the original pores are more important than the amount of original porosity. Many carbonate reservoirs have pore systems of diagenetic origin. In these, the key factors are rock fabrics with components of different solubility, or of different susceptibility to such diagenetic processes as cementation or dolomitization. Factors favorable for reservoirs of primary porosity may be unrelated or opposed to those favoring diagenetic porosity. For example, some primary reservoirs consist of coarse, well-sorted calcarenite. In other facies complexes, these well-sorted rocks have low porosity and permeability, and the specific reservoirs occur in contemporaneous, poorly sorted, and mud-rich carbonates that were selectively dolomitized and leached.

Modern carbonate sediments of many textural types (mud, sand, and mud-sand admixtures) have porosity values of 40–70%. Newly deposited or reworked carbonate mud and some skeletal sand or growth frameworks may exceed 70% porosity. Yet most ancient carbonate rocks have a porosity of but a few per cent. Even the better carbonate reservoirs have only a small part of their original pore volume. This wholesale reduction in porosity is an important but commonly neglected factor in carbonate-rock interpretation. Reduction of porosity is accomplished mainly by introduced carbonate cement, probably involving thousands of pore volumes of interstitial water. In much limestone the volume of cement may approach or exceed that of the initial sediment. Compaction normally is minor, because of early cementation and compaction resistance of carbonate sediment. Locally, pressure-solution processes are important in porosity reduction. The aragonite-to-calcite volume increase can be only a small factor in the reduction of porosity.

19. CHARLES H. HEWITT, Marathon Oil Company, Littleton, Colorado

Role of Geology in Reservoir Engineering

Every petroleum reservoir has a distinctive origin, peculiar only to itself, as determined by provenance, depositional environment, and post-depositional history. The following geologic factors control all properties, generally thought of as reservoir properties: porosity, permeability (specific, relative, and directional), 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 firsthand. 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.