14. R. W. STAPP, Phillips Petroleum Company, Denver, Colorado

RELATION OF LOWER CRETACEOUS DEPOSITIONAL ENVIRONMENT TO OIL ACCUMULATION, NORTHEASTERN POWDER RIVER BASIN, WYOMING

The Lower Cretaceous rocks produce oil from stratigraphic traps in the northeast Powder River basin. Density of subsurface data allows reconstruction of paleodepositional environments. Through detailed subsurface studies it is possible to relate time-equivalent sandstone bodies to depositional patterns. Structure has little or no bearing on petroleum accumulation in this area.

Identification of paleodepositional environments by means of subsurface studies depends on precise electric-log correlations and a geomorphic interpretation.

The depositional trends of the Lower Cretaceous Fall River sandstone bodies and the so-called "Muddy" sandstone beds are determined readily by selective isopachous mapping. Care must be exercised to recognize unconformities, disconformities, or other breaks in an apparently continuous cycle of deposition. Isopachous maps are constructed by using a lithologic time marker as the upper boundary and either a lithologic time marker or an unconformity as the lower boundary. These continuous cycles of deposition indicate a genetically related depositional environment.

The Fall River contains three sandstone bodies that are mappable as separate units in a complex marginal-marine shoreline environment. These sandstone beds thicken locally in a vertical direction and, in places, merge into a single unit. The Fall River does not have channel characteristics in this area.

The "Muddy" contains two sandstone bodies previously named Newcastle and Dynneson. These sandstone units have distinctly different depositional patterns. Channeling is present in both, and the Newcastle shows a pronounced dendritic drainage pattern.

Oil production is from the eastern updip edges of maximum sandstone development in both the Fall River and "Muddy" sandstone units. By detailed subsurface mapping it is possible to relate time-equivalent sandstone bodies to the depositional environments which control oil accumulation.

15. MILTON O. CHILDERS, Consulting geologist, Salt Lake City, Utah

RESERVOIRS OF LACUSTRINE ORIGIN IN ROCKY MOUNTAINS—EXPLORATION CRITERIA

Large reserves of oil and gas have been found in rocks of lacustrine origin in Rocky Mountain basins, and these strata remain largely unexplored.

Except for the productive limestone of the Sheep Pass Formation (eastern Nevada), lacustrine carbonate reservoir rocks found to date have poor porosity and permeability. Sandstone is the best reservoir rock of the lacustrine suite.

Most of the productive sandstone beds originated in deltaic complexes. Sandstone bodies paralleling old lake shores are much poorer objectives than their marine counterparts because of lower transport energy and relatively unstable water level in lakes. Large deltaic complexes are prime objectives, and directional criteria can be observed within the lacustrine facies as well as in the equivalent fluvial facies.

The oil- and gas-producing sandstone units of the western Green River basin (commonly interpreted to have originated as beaches and bars along the west shore of a Paleocene-Eocene lake) are almost certainly of fluvial origin. These sandstone beds have no low-energy lateral facies equivalents which are characteristic of lacustrine deposits.

Typically the main body of lacustrine deposits consists of very finely and uniformly laminated, well-indurated shale and very argillaceous microcrystalline carbonate rocks. Brown bituminous shale and oil shale are common. Proximal to the deltaic facies, shale becomes more variable. Induration decreases, sorting decreases, lamination and fissility decrease, siltstone is common, and slump structures and load casts are present in some places.

The *distal* margins of sandstone bodies are well-cemented, well-sorted, very fine-grained (grading to siltstone), and thinly and horizontally bedded with abundant small ripple marks. They contain abundant shale partings on well-defined bedding planes. The *main body* of a typical lacustrine sandstone contains well-cemented oölitic laminae and thin beds alternating with thick to massive beds of porous, friable sandstone. Sorting is fair to good. *Proximal to the fluvial facies,* sandstone beds are poorly sorted with abundant clay matrix in many beds. "Soft" clasts (*e.g.*, shale fragments) are common.

16. JOSEPH R. CLAIR, Geological consultant, Denver, Colorado, AND RICHARD W. VOLK, Plains Exploration Company, Denver, Colorado

PRE-PERMIAN PALEOZOICS OF LAS ANIMAS ARCH—NEW OIL PROVINCE

The Las Animas arch has been the site of intermittent exploration during nearly 40 years but still is virtually untouched. Despite two recent, significant discoveries, the arch is a "cold area." The writers believe that this is the result of a lack of careful study of the rocks and the total absence of a planned exploration program.

Detailed analysis of the Pennsylvanian and Mississippian sections indicates that parts of the arch are more favorable than others, although sparcity of control in large areas of the arch precludes eliminating any part of it from consideration.

The results of recent drilling have provided new evidence on the structural history of the Las Animas arch and indicate that it is considerably more complex than has been considered previously. The arch actually is a compound structure with an older axis considerably east of the present axis which originated during the Laramide orogeny.

Each of the five series of the Pennsylvanian System (Virgilian, Missourian, Desmoinesian, Atokan, and Morrowan) is productive on or adjacent to the Las Animas arch, but none of the discoveries to date has been of sufficient magnitude to provide impetus for a concerted exploration effort.

Two discoveries, both producing oil from the Osagean (Mississippian), are very significant, though neither is, of itself, sufficiently large to excite much attention. The significance lies in the fact that both are productive beneath a younger Mississippian rock cover (*i.e.*, within the Mississippian). Heretofore, it was believed that a productive Mississippian reservoir had to be in subcrop contact with overlying Pennsylvanian in order to produce. However, discoveries during the past 6 years in southwestern Kansas and 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 suggesfacies 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 direc-