plain rocks; a barrier island-lagoonal progradation, reflecting a high rate of submergence, comprises a series of discrete sandstone lenses arranged *en échelon*, each lens intercalating landward with lagoonal deposits and seaward with off-beach marine shale. During transgression, because of the step-like topography of a barrier island-lagoonal terrain, shoreline sandstone bodies are developed only discontinuously, giving rise to asymmetrical cycles.

Because of the general paucity of organic remains in the Mesaverde, the determination of depositional environments commonly must be accomplished by the evaluation of stratification. Though there are no single stratification features peculiar to particular environments, sequences of stratification may be diagnostic. Stratification in rocks occurs in response to physical-depositional processes; the vertical sequence of stratification in a regressive suite of rocks reflects the lateral distribution of processes operative at the time of deposition. Beach stratification, from bottom to top, includes laminae deposited in the transition zone between off-beach shale and offshore beach sandstone, the submarine bar zone, the fore-shore beach, and the back-shore beach. A vertical sequence of lagoon stratification may reflect deposition in a tidal delta, lagoon pond, tidal channel, wave flat, and salt marsh. The character of the stratification in the different subenvironments may be determined by study of modern environments and processes; the great variety of processes present within these modern environments yields perspective on the variety of stratification to be expected in the geologic record.

27. M. DANE PICARD, University of Nebraska, Lincoln, Nebraska

### Paleocurrents and Shoreline Orientations in Green River Formation (Eocene), Raven Ridge and Red Wash Areas, Northeastern Uinta Basin, Utah

Paleocurrent data from ripple marks and cross-stratification are related to orientations of shorelines and sandstone-body trends in the lacustrine and fluvial setting of the Green River Formation (Eocene) in the Red Wash field and the adjacent outcrops along Raven Ridge in Utah and Colorado. At 11 localities along Raven Ridge, the northeastern margin of the Uinta basin, 125 paleocurrent directions were measured from cross-stratification and asymmetrical ripple marks in the Douglas Creek and Garden Gulch Members and the lower part of the Parachute Creek Member.

Vertical stratigraphic variation of paleocurrent directions at each locality is small, indicating that the overall current system was stable. A plot of measurements of 68 asymmetric and 84 symmetric ripple marks shows that their distribution is very similar, which is interpreted to be the result of their formation by the same current system. Based on few data, there is an average difference of 5° between paleocurrent directions from cross-stratification and from ripple marks, ripple marks showing less variation than cross-stratification. The dominant paleocurrent directions are toward the north, south, and southeast. Of all observations, 25% range from 331° to 30°, and 51% range from 121° to 210°.

The shorelines in the northeastern Uinta basin area are interpreted to have been generally perpendicular to the dominant paleocurrent directions. Therefore, essentially all of the shorelines had bearings of 31°-120°. An arc of 61°-90° would contain about 40% of the bearings of the shorelines, based on the paleocurrent data. Trends of single sandstone bodies, the total footage of sandstone, sandstone plus siltstone, and net sandstone, and the major facies support the generalizations about the orientations of shorelines and sandstone-body trends.

28. PERRY O. ROEHL, Shell Development Company, Houston, Texas

### Analogs of Recent Low-Energy Carbonate Deposits in Stony Mountain (Ordovician) and Interlake (Silurian) Formations, Montana

Reservoir rocks were studied from the Stony Mountain (Ordovician) and Interlake (Silurian) producing formations in several oil fields on the Cedar Creek anticline, southwestern Williston basin. In early Paleozoic time the basin was covered predominantly by epeiric seas in which were deposited shallow-water, intertidal, and supra-tidal carbonates of distinctive facies and fabric. These deposits now are dolomite in which intercrystalline porosity predominates. However, their delineation and extent are controlled strictly by original facies and subsequent diagenetic structures. Such facies and structures compare favorably with those of modern tidal-flat and supra-tidal deposits of Florida and the Bahama Islands, including the alteration forms which occur shoreward of the mean high-tide line.

A generalized working model of facies relations was derived. This model shows the proposed environment of deposition and some of the kinds of depositional structures in which original porosity distribution was preserved. Most of the important porous structures result from a combination of organic and inorganic processes in zones of low hydrokinetic potential. These are: pelleted, laminated, and burrowed mud and silt; algal mats and stromatolites; flat-pebble conglomerate; endogenic and solution breccia; and a few cut-and-fill structures. Leaching of fossils and anhydrite in certain places has accentuated and improved pore structure.

29. DONALD W. LANE, Tenneco Oil Company, Casper, Wyoming

### Primary Structures and Sedimentary Environments in Dakota Sandstone, Northwestern Colorado

Depositional environments in the Dakota Sandstone in northwestern Colorado have been identified by comparisons of primary structures present in both the Dakota and in Recent sediments. Identification also is aided by study of lithologic character, organic content, and geometry of sedimentary units. The Dakota ideally consists of a transgressive sequence which, from base to top, shows the following environments: (1) channel and floodplain, (2) swamp-tidal flat-lagoon, (3) beach, and (4) surf-zone and other shallow sub-littoral deposits. In places the beach and shallow-marine sandstone bodies are absent, and shallow-marine black shale of the overlying Mancos Shale lies directly on tidal-flat sandstone in the Dakota.

The sediments of most depositional environments contain one or more significant primary structures. Channel deposits contain high-angle cross-beds in irregular, discontinuous units usually 1 ft. thick or more. These cross-beds are formed on point bars by megaripple migration during flood stages. Floodplain stratification is regular, parallel, and continuous. Tidal flats are characterized by very thick channel cross-beds, thin irregular beds containing organism burrows and trails, and shale-pebble conglomerate. Beach deposits consist of tabular to wedge-shape bundles of thin, regular, parallel to subparallel to laminae. Surf-zone deposits contain low-angle cross-beds in tabular to irregular, relatively continuous sets 1 ft. thick or less.

30. R. E. SWENSON, Chevron Oil Company, Billings, Montana

TRAP MECHANICS IN NISKU IN NORTHEASTERN MONTANA

The Upper Devonian Nisku Formation became a productive unit for the first time in late 1960, when the Tule Creek field was discovered in northeastern Montana. Since then 6 additional Nisku fields have been discovered within a 10-mi. radius of Tule Creek. Even-textured, saccharoidal dolomite, which has 50 ft. of net pay, is productive of 40°-47° API oil at these 7 fields.

Data from closely spaced wells amply demonstrate that structural closure is the basic trapping mechanism for oil in the Nisku. Various interpretations have been advanced regarding the type and degree of influence of stratigraphic factors in these accumulations. Current information indicates that primary stratigraphic variations do impose a semi-regional control on the entrapment of oil in the Nisku, but are less important in individual traps.

Steep-sided, flat-topped structures, which typically are less than 1 sq. mi. in area, control the limits of Nisku fields. The writer suggests that the structures are not the products of normal tectonics. Instead, it can be demonstrated, both theoretically and by deep-well data, that the structures are "sedimentary structures" resulting from multiple-stage solution of the Lower Devonian Elk Point salt beds.

The present-day solutional zero edge of the Elk Point salt beds is east of and downdip from the Nisku fields. The writer suggests that an original thickness of 50–100 ft. of salt was present in the Tule Creek area, and that the original depositional edge of the salt was farther west.

31. GRAHAM S. CAMPBELL, Consulting geologist, Salt Lake City, Utah

DOUGLAS CREEK TREND, CASE HISTORY, UINTA BASIN, UTAH

The 75-mi.-long productive fairway of the Douglas Creek Member of the Green River Formation yields 7 million bbls. of oil and 1 Bcf. of gas annually, largely from two fields. It was not until 13 yrs. after discovery that geologists recognized the broad extent and stratigraphic nature of the accumulation along this trend. A more determined and subjective examination of the specific pay unit, ignoring shows in other Green River members, would have resulted in a much earlier definition of the trend.

Subsidence during Douglas Creek time, transverse to usual northwest-striking Green River stratigraphic trends, caused a temporary but significant shift in shore alignment. The Douglas Creek lake-margin sandstone bodies, which are more "marine" than deltaic in character, trend southwestward.

Recent definitive studies to understand the Douglas Creek trend should hasten new and substantial discoveries along it.

32. A. V. ROBERTSON COE, District geologist, Husky Oil Company, Cody, Wyoming

PITCHFORK OIL FIELD, PARK COUNTY, WYOMING

The Pitchfork oil field, discovered in 1930, is on a steeply dipping, surface-anticlinal structure along the west flank of the Big Horn basin, Park County, Wyoming. The discovery well was completed at a total depth of 3,903 ft. in the Tensleep Sandstone. Field production today is primarily from the Tensleep, though a small amount of production is from the Permian Phosphoria Formation. One well was drilled in 1962 to test older formations, and reached a total depth of 7,766 ft. in the Precambrian.

The original oil found in the discovery well was 18° API. Because of the lack of demand for such oil, poor transportation, and low prices, the well was shut in until 1944. Development since 1944 has been sporadic.

The Tensleep is 250–275 ft. thick, and consists of porous, very fine- to fine-grained, heavily oil-saturated sandstone bodies separated by tight, slightly oil-saturated sandy dolomite and dolomite lenses. Within this active water-drive field, there is 130–150 ft. of net pay having permeability in excess of 25 md. and porosity in excess of 10%. As many as 5–6 zones in the field are characterized by such values. However, as development progressed, it became apparent that "pods" of oil were not being drained effectively by updip wells because of the irregular permeability and porosity.

High water cuts are found in low-permeability sandstone beds where the highly viscous oil is bypassed, and in high-permeability fractured zones where communication is established early with downdip, higher water saturations.

The upper part of the Phosphoria Formation contributes 15–20 b/d of oil from 3 dually completed wells. The 30 ft. of crystalline, vuggy, fossiliferous, heavy-oil-saturated Phosphoria dolomite has a porosity range of 14 to 23%, but low permeability reduces the effectiveness of the water drive and results in low fluid recovery.

Development drilling continues within the Pitchfork Unit in the oil-water transition zone because the economic productive limits are undefined.

As of January 1, 1966, 37 wells were producing at the rate of 103,000 bbls. of oil per month from 720 acres on a 23-acre-spacing pattern. Cumulative production to January 1, 1966, was 8,600,000 bbls. of oil and 30,000,000 bbls. of water.

33. JERRY L. BRANCH, Consulting geologist, Shelby, Montana

GENERAL DRILLING HISTORY AND NEW DEVELOPMENTS IN NORTHWESTERN MONTANA

Northwestern Montana is geologically complex, and this complexity is fully reflected in the diversity of type and location of oil and gas accumulations. As a result, the oil and gas history of this area has been one of continual development of new and changing geological ideas.

Until 1963, drilling was concentrated primarily in and around old productive areas associated directly with the Sweetgrass arch. Subsequently, new discoveries essentially were extensions to already productive Cretaceous Cutbank sandstone and Madison carbonate reservoirs in the Cutbank, Kevin-Sunburst, and Pondera fields.