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 ½° 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 floodplain 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