high formation-fluid pressures, (2) fracture-type reservoirs, and (3) water-free gas-condensate production. Abnormal pressures are believed to be caused by high generation rates, volume expansion during conversion of kerogen to a gas phase, and rock-framework collapse. Indigenous fracturing is caused by a favorable stress condition accompanied by critically high formation-fluid pressure. Water-free hydrocarbon production is the result of the nearly complete saturation of available reservoir space by relatively large volumes of generated and only partially expelled gas-condensate.

We believe that the simple pyrolysis technique and its interpretations are applicable to many basins. The method requires only a library of sample cuttings, a supply of test tubes, and a propane torch (or similar heat source) for implementation.

KOCURKO, M. JOHN, Tulane Univ., New Orleans, La.

Diagenetic Phenomena of Chipola Formation, Calhoun County, Florida

The Chipola Formation crops out along the Chipola River, Ten Mile Creek, and Farley Creek in Calhoun County, Florida. The formation, dated at 16.1 m.y.B.P., is predominantly an unconsolidated, bioclastic wackestone. These carbonate rocks have undergone very little diagenetic alteration, and as a result fossil preservation is excellent. Original mineralogy is essentially unchanged, and most shell material is aragonite or high-magnesian calcite. X-ray analysis of unlithified sediment indicates a composition of approximately 75% aragonite and 25% high-magnesian calcite. Disregarding the age of the formation, the unit is considered to be in a very early stage of lithification.

Cementation occurs locally in the unit by the formation of low-magnesian calcite as microspar. The lithified parts of the formation take on a nodular appearance as bioclastic debris is cemented. "Nodules" are usually less than 15 cm in diameter. Sparry calcite locally may be a void-filling cement, but this is usually confined to lithified burrows. Cementation within burrows is apparently controlled by the presence of organic mucus in the sediment. Early stages of pseudosparitization can also be observed in shell material. Alteration to pseudospar appears as a migrating or advancing "front" through the shell material.

KRAMERS, JOHN W., Alberta Research Council, Edmonton, Alta.

Depositional Environments and Diagenesis of Grand Rapids Formation, North-Central Alberta, Canada

The Lower Cretaceous Grand Rapids Formation of north-central Alberta consists of three massive sandstone members: upper A, middle B, and lower C. Maximum thickness of the formation is 90 m. In the subsurface, the A and B sands are bitumen impregnated and form the Wabasca oil sand deposit, with reserves estimated at 10.5×10^9 cu m (66×10^9 bbl).

The Grand Rapids Formation was deposited in a broadly regressive setting, interrupted by two transgressive pulses that resulted in shales forming between the three sandstone members. The C sand and the lower part of the B sand were deposited under offshore marine conditions which gradually shallowed to distributary channels, nearshore bars, and coastal swamps at the close of B sand deposition. The shales between the A and B sands were initially formed in brackish environments, which changed to an offshore marine environment as the result of transgression. The A sand consists of nearshore marine deposits overlain by distributary and tidal-channel sands. Coal seams that cap the A and B sands in the outcrop area indicate a coastal-swamp to interdistributary-bay setting.

The clay mineral assemblage in the sandstones consists of kaolinite, illite, montmorillonite, and minor chlorite. In general, the bitumen-saturated sandstones have lower clay content with a larger proportion of kaolinite and less montmorillonite than the nonsaturated, water-bearing sandstones. Examination of the sandstones in thin section and by scanning electron microscopy shows that most clays are either authigenic or have authigenic overgrowths giving the appearance of authigenic minerals.

KRECOW, F. C., and JAY E. LEONARD, Rensselaer Polytechnic Inst., Troy, N.Y.

Megascale Variability of Sediments on United States Atlantic Continental Shelf and Slope—Multivariate Study

The Atlantic continental shelf of the United States provides an excellent laboratory for application of statistical techniques designed to augment the megascale distribution of spatially oriented geologic data.

Multivariate methods have been applied to data from over 2,000 surface-sediment grab samples in a baseline study conceived both to discern regional trends of textural and mineralogic parameters and to evaluate the relative usefulness of these statistical strategies. The data include textural information on mean grain size, sorting, skewness, and various mineralogic constituents, whereas the statistical techniques employed include cluster, ordination, and trend surface analysis.

Distinct sedimentary facies were first determined by Q-mode cluster analysis, based on the similarity among individual samples utilizing Sorenson's coefficient as the similarity index. To interpret the relations among sedimentary facies, the clusters were plotted in n-dimensional space by Q-mode ordination, employing a highest dissimilarity criterion. The method suggests, for example, that the sediments from the shelf south of Cape Hatteras can be classified on the basis of water depth and calcium carbonate. The sedimentary facies include: a low $CaCO_3$ inner-shelf facies, an outer-shelf facies with variable $CaCO_3$ content, a shelf-break facies, an biogenic upper-slope facies, and a lower-slope facies. Plotting the spatial distribution of these clusters shows the trend toward low $CaCO_3$ content in sediments on the shelf off Georgia, thereby emphasizing the inverse relation between clastic influx and $CaCO_3$ content.

As would be expected, trend surface analysis ignores local variations in sedimentary parameters in favor of extracting the regional gradient. The trend from fine sand nearshore to coarser sand on the shelf below wave

base is consistent. Strong regional trends are also present for the calcium carbonate fraction and the aragonite/calcite ratio on the shelf south of Cape Hatteras. The existence of a nearshore zone of present sediment reworking, longshore clastic transport, and skeletal comminution is implied by the low $CaCO_3$ values along the coastline.

Generally, the combination of cluster, ordination, and trend surface analysis proves to be an excellent strategy for the extraction of sedimentary trends, particularly where local variations obscure the regional gradient.

KRUTAK, PAUL R., Univ. Nebraska, Lincoln, Neb., and SUSAN E. RICKLES, Amoco Production Co., Denver, Colo.

Equilibrium in Modern Coral Reefs, Western Gulf of Mexico—Role of Ecology and Ostracod Microfauna

Two groups of modern patch reefs exist off Veracruz, Mexico. Terrigenous sediments of the Rio Jamapa are being deposited between the two complexes. Longshore drift of these sediments is causing declining coral growth on the southern group (Anton Lizardo), whereas corals on the northern group (Veracruz) are thriving. These differences in coral vitality should be reflected in the water chemistry and microfauna. Environmental data (depth, salinity, pH, temperature, Eh, and dissolved oxygen) were collected and treated as random samples from populations whose normality was established by chi-square goodness-of-fit tests. Chi-square testing at the 0.01 level demonstrated that, out of the six sample populations, only depth, pH, and dissolved oxygen were distributed normally. Depth, pH, and dissolved oxygen data were assembled into two populations representing the Veracruz and Anton Lizardo groups. This permitted us to test the null hypothesis that the variances of the respective populations were equal ($F = 0.005$ level). The variances were found to be equal. T tests (0.01 level) on the population-means of depth, pH, and dissolved oxygen of both Veracruz and Anton Lizardo groups disclosed that there is no significant difference between the two groups of reefs in terms of these characteristics. However, the mean-percent relative abundance of the most common ostracod species (*Loxocorniculum tricornatum*) on both reef complexes is significantly different. Ostracod species dominance also differs radically between the two groups. Therefore, ostracod species abundance and dominance are more sensitive indicators of reefal equilibrium than the environmental parameters themselves.

KULANDER, BYRON R., West Virginia Univ., Morgantown, W. Va., STUART L. DEAN, Univ. Toledo, Toledo, Ohio, and CHRISTOPHER C. BARTON, Yale Univ., New Haven, Conn.

Nature and Field Application of Plumose Structures

Development of plumose structures in brittle rocks has been investigated by analogy to fracturing experiments on glass and ceramic bodies. Plume morphology shows that structures commonly lumped as plumose are a composite of discrete features, formed at all scales, during fracture propagation.

Inclusion hackle forms when an advancing planar fracture front becomes locally distorted at an inhomogeneity. The planar fracture, locally split by the inclusion, does not rejoin in a single plane behind the inclusion. This causes the lagging fracture portion to curve into the leading one forming a steplike tail elongate in the propagation direction. Twist hackle forms when a fracture front abruptly encounters changed stress directions along an extended frontal section. The entire fracture front breaks into individually advancing en echelon twist-hackle faces, each face perpendicular to the new resultant principal tension. Faces diverge and are elongate in the propagation direction. The faces form hackle steps by curving into each other to complete separation. Velocity hackle, uncommon in rocks, forms at a limiting propagation velocity.

Plume axes mark areas of greatest tensile stress and lightest propagation velocities. Plume asymmetry indicates intrastratum fracturing stress distributions. Axes consistently at the top or bottom of each stratum in a layered sequence indicate overall downward and upward (perhaps basement induced) propagation directions respectively. Recognizing twist-hackle faces and steps as differently oriented planes produced by a single fracture event eliminates identification and misinterpretation of false fracture sets.

KULANDER, BYRON R., West Virginia Univ., Morgantown, W.Va., CHRISTOPHER C. BARTON, Yale Univ., New Haven, Conn., and STUART L. DEAN, Univ. Toledo, Toledo, Ohio

Fractographic Distinction of Coring-Induced Fractures from Natural Cored Fractures

Fracture surface structures (hackle plumes, arrest lines, origins) on coring-induced petal-centerline and disc fractures from three Appalachian Devonian shale cores indicate fracture sequence and propagation directions, relative propagation velocities, and tensile-stress distributions at failure.

Surface structures on coring-induced fractures are symmetrically and dimensionally related to the core. In contrast, surface structures on natural fractures, originating away from the core, are asymmetric and oversized. Plume asymmetry shows that stress intensity across natural fractures varied vertically during propagation.

Curviplanar petal-centerline fractures are propagated downcore as shown by convex downward arrest lines and hackle plumes that diverge downward about the core axis. Inclined petal sections curve to vertical from core margin toward core center. Some petals continue to spread vertically downcore, forming the centerline section. Petal-centerline fractures can change downcore from one preferred orientation to another, indicating differing orientation of stresses and thus of any fractures induced in a stimulation program. Petal curvature, absence of cored origins, and the 15-cm curvature radius of closely spaced arrest lines show that petal-centerline fractures originated in front of the bit's cutting surface. Chipped right-hand core to fracture margins, produced by plucking action of the bit, and arrest line-hackle morphology show these fractures were drilled through after propagation.