in two thrust sheets for a distance of 26 miles. The reef complex consists of a lower dolomitic stromatoporoidal limestone (Cairn formation) overlain by well bedded aphanitic limestone (Southesk formation) which contain abundant non-skeletal grains locally mixed with fossil fragments. This reef is comparable to adjacent reefs in the mountains and to some of the subsurface reefs.

The depositional history of the reef has been reconstructed from the stratigraphy, reef geometry, and a detailed study of the well exposed south margin. Thin argillaceous and stromatoporoidal carbonates were deposited over the entire area (Flume formation). Thicker and more fossiliferous portions of the Flume occur beneath the margin of the overlying Cairn reef and appear to represent shoals on and around which organic growth flourished. Differential subsidence combined with a rising sea level drowned most of the stromatoporoidal platform. In the relatively shallow waters above the more positive portions of the basin, stromatoporoidal growth continued. Between 400 and 500 feet of thick, massive stromatoporoidal carbonates and detritus accumulated above these more positive areas, forming the Cairn biostromes of the Ancient Wall and adjacent reefs. The surrounding basin was partly filled with black, predominantly euxinic shales (Perdrix formation). A lowering of sea-level throughout the basin caused shallowing above the biostromal area. Thus the environment was changed to one of very shallow-water bank conditions in which fine carbonate sands and muds with a pelletoid texture (Southesk formation) were deposited.

Gradual subsidence permitted the accumulation of between 500 and 600 feet of carbonate sands. The Southesk bank is flanked by brachiopod limestones and shales which contain local, small, coral biostromes. These fossiliferous carbonates grade into thin-bedded calcareous shales and limestones (Mount Hawk formation) of the surrounding basin. Basin relief was gradually decreased by influx of terrigenous muds and fine carbonate muds and detritus derived from the bank. Further shallowing and basin-filling permitted lateral extension of the bank environment and associated carbonate sands. During the Sassenach transgression the bank was emergent and the margins were eroded slightly.

The abrupt variations in thickness and character at the reef margins indicate differential subsidence during and after accumulation of the reef complex. Thus both differential subsidence and changes in sea-level have exerted control on reef development.

MUEHLBERGER, W. R., DENISON, R. E., and LIDIAK, E. G., Crustal Studies Laboratory, The University of Texas, Austin, Texas

Basement in the Continental Interior of the United States

Buried basement rocks of the central United States are mainly plutonic granitic rock, mafic and felsic metamorphic rock, and diabase. Rhyolite, granitic rock, and gabbro-diabase form a discontinuous belt from eastern New Mexico to eastern Missouri. The 0.5 b.y. rocks in the Wichita Mountains, Oklahoma, are the result of the last major igneous event. The Ouachita structural belt is the southern limit of petrographic knowledge of plutonic rocks.

None of these rock groups bears a simple relationship to basement topography and isotopic age. The Black Hills uplift-Cambridge arch-Central Kansas uplift is underlain dominantly by metamorphic rock with ages ranging from 1.7 b.y. in the north to 1.2 b.y. in the south. Siouxia arch contains 1.4 b.y. granitic and metamorphic rock. Nemaha uplift is underlain by 1.2–1.5 b.y. granite. Diverse rock types of 1.2–1.4 b.y. underlie Amarillo uplift and Red River–Matador arch.

Several large gravity anomalies correspond to major basement structures. The Williston basin is bounded on the south and west by a series of major west- and northwest-trending gravity anomalies and on the east by a belt of south-trending gravity anomalies extending from Canada into the central Dakotas that coincides with the boundary between the 2.5 b.y. Superior and the 1.7 b.y. Churchill Provinces of the Canadian Shield. The Sioux formation (minimum age 1.2 b.y.) lies along the west-trending anomaly in southeastern and central South Dakota. Keweenawan basaltic and sedimentary rock coincides with the mid-continent gravity anomaly and extends nearly continuously from Lake Superior to northeastern Kansas. The prominent gravity feature along the Red River–Matador arch coincides with the boundary between 1.2–1.4 b.y. rocks in the central United States and the 1.0 b.y. rocks in Texas.

MURSKY, GREGORY, Geological Survey of Canada, Ottawa, Canada

Mineralogy, Petrology, and Geochemistry of Porphyries and Granitic Rocks at Great Bear Lake, Northwest Territories

The Precambrian region between Great Bear and Great Slave Lakes is characterized by large bodies of granitic rocks and quartz-feldspar porphyries. In Great Bear Lake area granitic rocks, about 1,800 million years in age, range in composition from granite to diorite. Some are high in potash and have the characteristics of rapakivis. Closely related to granitic rocks are large volumes of quartz-feldspar porphyries which exhibit the peculiarities of ignimbrites. These, when in contact with granitic rocks, are recrystallized but still retain evidence of volcanic origin.

Integration of field data, qualitative and quantitative mineralogy, and distribution of 19 trace elements from 250 samples suggests that the parent magma was acidic and that the phenomena of volcanism and plutonism are closely related, the difference between them being mainly the depth of activity.

O'BRIEN, GERALD D., Shell Oil Company, New Orleans, Louisiana

Survey of Diapirs and Diapirism

Diapirs, *sensu stricto*, are bodies of sedimentary ma terial which have pierced (or appear to have pierced) overlying material as a result of their mobility at comparatively low temperatures. They are composed of evaporites, shales, mud, etc. and range in size literally from molehills to mountains and in age from Precambrain to Recent. They occur associated with marine as well as continental sedimentary sequences and in areas which have been subject to intense tectonic deformation, virtually no deformation other than basin subsidence or to all amounts of deformation in between. As a result of the numerous possible combinations of these different attributes, diapirs of many types occur dispersed over much of the earth. Among those structures which are considered to be forms of diapirs, some of the best known are the diapiric folds of Roumania; the piercement salt domes of the Middle East, the Gulf Coast of Mexico, the United States, and Russia; the salt diapirs of Australia, Europe, and South America; the salt stocks and salt walls of Germany; some of the salt anticlines of the Canadian Maritime Provinces and the western United States; the gypsum diapirs of the Canadian Arctic Islands; the clay diapirs of Borneo, Italy, and the Black Sea area; the mud volcanoes of Colombia and Trinidad; and the intrusive shale domes of the Gulf Coast of the United States.

O'BRIEN, NEIL R., State University of New York, Potsdam, N. Y.

FISSILITY IN ARGILLACEOUS ROCKS

A study was undertaken to determine the cause of fissility and non-fissility in argillaceous rocks such as shale and underclay. The orientation of clay flakes in samples of Pennsylvanian shales and underclays was studied by using an X-ray diffractometer. It was found that clay mineral orientation is a factor in determining the degree of fissility of an argillaceous rock.

Sedimentation experiments were run in the laboratory to study the influence of various factors upon the development of fissility. Clay materials of various concentration were sedimented in different cation concentrations. Regardless of clay or cation concentration, the clay material flocculated. Various amounts of silt were sedimented on top of the flocculated clay masses. Preferred clay mineral orientation was produced in clay material on which silt was rapidly sedimented. Random orientation was preserved in clay material which had dewatered before a small amount of silt was applied.

Samples of clay were also compressed to study the influence of overburden pressure and water content upon the development of fissility. It was found that clay with a lower water content showed less reorientation due to compression than clay with a higher content. This fact suggested that the amount of liquid water relative to rigid water in the clay-water system at the time of application of overburden pressure may be an important factor in facilitating the orientation of clay flakes.

It is concluded that preferred orientation of clay flakes commonly found in fissile shales may have resulted from compression of flocculated clay mud under conditions of rapid sedimentation. The random clay mineral orientation present in underclay may have resulted as a flocculated clay accumulated under overburden pressure. Thus the presence of absence of fissility in argillaceous rocks may depend upon the amount of overburden pressure applied to the newly deposited clay material and the amount of liquid and rigid water in the clay at the time of application of pressure.

OWEN, DON E., Bowling Green State University, Bowling Green, Ohio

CORRELATION OF GRAIN-SIZE DISTRIBUTION AND MINERALOGY WITH DEPOSITIONAL ENVIRONMENT IN THE DAKOTA FORMATION (CRETACEOUS) OF THE SAN JUAN BASIN, NEW MEXICO AND COLORADO*

The depositional environment of units within the Dakota formation of the San Juan basin was determined by means of fossils, sedimentary structures, and facies relationships. Grain-size distribution, heavy-mineral content, and clay-mineral content were found to correlate well with the depositional environment in a manner similar to observations reported from modern sediments. Many depositional environments are represented in the Dakota formation, which grades from lenticular, nonmarine sandstone and carbonaceous shale in the northwestern San Juan basin to regularly interstratified shale and very fine-grained sandstone in the southeastern San Juan basin.

Dakota fluvial sandstones are fine-skewed and are generally poorly sorted. Dakota beach sandstones are coarse-skewed and well sorted, while Dakota offshore marine sandstones are fine-skewed and are generally moderately well sorted. The finer particles in Dakota offshore sandstones were winnowed from beaches and were deposited offshore. Dakota fluvial sandstones characteristically are fine-skewed. The finer particles in these fluvial sandstones were not winnowed and the competence of stream flow sets an upper limit to the size of particles transported.

In a vertical series of samples from Dakota sandstones grading from nonmarine deposits below to marine deposits above, the degree of sorting increases upward into the lower part of the lowest marine sandstone (beach deposit) and gradually decreases in offshore sandstones above the beach sandstone. The change in skewness from coarse in the beach sandstone to fine in the fluvial and offshore marine sandstones is abrupt.

Dakota non-marine shales contain much kaolinite with some illite. The amount of carbonaceous matter in the shales is inversely related to the amount of illite. Dakota marine shales contain much montmorillonite in addition to kaolinite and illite.

Dakota sandstones derived from source areas north and west of the San Juan basin have a small, stable suite of heavy minerals in which zircon and tourmaline predominate. Most of these mineralogically simple sandstones are non-marine. Dakota marine sandstones, such as the Tres Hermanos and Twowells members, which were derived from source areas south of the San Juan basin, contain a suite of metamorphic minerals in addition to zircon and tourmaline.

* Publication authorized by the director of the Bureau of Economic Geology, The University of Texas.

PARKS, JAMES M., The Pure Oil Company, Crystal Lake, Illinois

CLUSTER ANALYSIS APPLIED TO MULTIVARIATE GEOLOGIC PROBLEMS

When 20 or more measurements and (or) counts are made on 100 or more samples (thin sections, bottom samples, pollen or foram concentrates, heavy minerals, etc.), the resulting table of data is so large that interpretation by eye becomes difficult. In some geologic studies it is desirable to group together similar samples and to measure the degree of similarity between different groups of samples. Several measures of similarity are avilable: the product-moment correlation coefficient, cosine-theta (Imbrie, 1962), the matching coefficient, and the distance function (Sokal, 1961). The resulting matrix of intercorrelations is still too large for direct interpretation.

Cluster analysis, a technique developed by psychologists, is a method of searching for structure, or relationships, in a matrix of correlation coefficients. Although not so sophisticated as factor analysis, cluster analysis is a useful tool. The results of a cluster analysis can be presented in an hierarchical diagram in two dimensions that will show where the natural breaks occur between groups. A computer program has been written for the IBM 704 that will handle up to 150 measurements on as many as 200 samples. Non-overlapping clusters are used; that is, a sample can appear in only one cluster.

A 12 variable 40-sample problem based on constituent particle composition of Bahamian sediment samples (Imbrie and Purdy, 1962) is used to demonstrate the options of the program. The clear-cut groups in the cluster analysis solution are similar to the facies described by Imbrie and Purdy (1962) based on factor analysis. The clusters can be used as a basis for facies maps.