dian 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.

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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.

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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.

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

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.

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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.