show the trends of coal-quality parameters for individual seams. The maps are supplemented by a computer program that searches the data base and generates a printout of geographical areas within the state where coal has been sampled that meets the desired specifications. These computer techniques go a long way in helping the user to find target areas within the state to match the right coal to the desired end use.

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Depositional Patterns of a Silurian Shelf Sand in Central Appalachians

The Keefer Sandstone in the subsurface of West Virginia and Kentucky, where it produces small volumes of natural gas, was deposited on the western shelf of the Appalachian basin. The formation is a dolomitic quartzarenite and quartzwacke and ranges from 13 to 50 ft (4 to 15 m) thick. As interpreted from four cores and isopach and lithofacies maps, the sand was transported by longshore currents from a southeastern source area and laid down in a variety of environments. In Kentucky, Keefer deposition was on a wave-dominated coast. The rocks are characterized by physical sedimentary structures and textures which developed under high-energy conditions, and the formation is divided into shoreface and foreshore facies. In adjacent West Virginia, however, Keefer deposition occurred offshore in water near the depth of wave base, swept out onto the shelf by storm-generated currents. Sedimentary structures and textures indicate a lower energy environment, bioturbation is more common, and the formation contains a greater amount of shale. The isopach map shows two linear tracts of thick sand in this offshore facies that may represent a coalescence of subtidal bars on the shelf. Between major sand bodies, the Keefer becomes appreciably thinner and is interbedded with fossiliferous dolomite. In the basin center of West Virginia, sandstone is replaced by shale. Thus, the geographical distribution of lithofacies shows a transition of shelf environments within a blanket sandstone. In all cores, regardless of depositional facies, the sandstone displays evidence of aggrading sedimentation; sedimentation exceeded subsidence, and the sand body built upward into shallower water.

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A Potential Method for Predicting Coal-Mine Floor Heave

Floor heave or deformation of the mine floor into the mine opening is a problem which has plagued coal mines in this country and others. This paper describes the problem as it was manifested in two coal mines located in eastern Illinois, and reports the results of a U.S. Bureau of Mines-sponsored study conducted by the University of Missouri-Rolla. The ultimate objective of the study was to develop a procedure that could be used to define a potential floor heave problem during the exploration phase of mine design—before initiation of production mining.

Floor heave within the mines did not occur with uniform intensity throughout each mine or even within mine panels. Floor deformation was often deep-seated and involved two subfloor lithologies. A wide variation in measured strength for each of the subcoal lithologies was recorded during laboratory testing; underclay triaxial compressive strength best correlated with underclay natural water content. The severely heaved areas were not located in the deepest or shallowest portions of the mines. Severe floor heave occurred in areas of thicker (greater than 6 ft, 2 m) underclay. Severe floor heave occurred at those sites where the natural water contents of the underclay and claystone were highest. The presence of swelling montmorillonite clay did not seem to be a major cause of floor heave. Triaxial compressive strengths measured from underclay samples from severely heaved sites were not the lowest values measured. A bearing capacity model developed by Vesic was modified so that a "heave factor" could be calculated using only that information obtainable from exploration core borings; use of the "heave factor" would have predicted floor heave at the study sites where severe heave occurred.

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Porosity Pods in Whirlpool Sandstone (Lower Silurian), Chautauqua County, New York

The Lower Silurian Whirlpool Sandstone is an important natural gas producing formation in western New York State. The Whirlpool outcrops in Niagara County, and is present in the subsurface in portions of Erie and Chautauqua Counties as well as adjacent areas in Pennsylvania.

In gas-productive areas of Chautauqua County, the Whirlpool usually ranges in thickness from 5 to 20 ft (2 to 6 m). Porosity as measured by the compensated formation density logging tool is typically 4 to 8%. Gas saturation is normally in the 20 to 65% range. The permeability of the rock is limited. Occasional localized areas of sharply greater porosity, permeability, and hydrocarbon saturation ("porosity pods") occur within the larger volume of tight, low permeability Whirlpool. The producing characteristics of the porosity pods are such that gas recovery may increase by a factor of 3 to 5 as compared with an average well. The economic benefits of drilling into these features are therefore substantial.

The presence of a porosity pod is sometimes indicated by an unusually large natural flow of gas from a well prior to stimulation. It can also be detected by certain characteristic indications on the density, resistivity, and neutron logs. Whirlpool porosity pods appear to be mappable and may be sufficiently large to provide 4 or 5 well locations. Recognition of their characteristics can be a significant aid to natural gas exploration in Chautauqua County, New York, and possibly elsewhere in western New York and northwestern Pennsylvania.

STRUBLE, RICHARD A., Tetra Tech, Inc., Columbus, OH, and DAVID P. HODGES, Ohio Geol. Survey, Columbus, OH

Fracture Analysis of Eastern Ohio

Selected shale characterization exploration parameters defined from Eastern Gas Shales Project investigations to identify highly potential Devonian shale exploration areas were used by Tetra Tech, Inc., to select drilling sites in the Appalachian, Michigan, and Illinois basins. The characterization parameters used for site selection were: (1) thickness of the shales, (2) type of organic matter, (3) percent of organic carbon, (4) thermal maturation, and (5) the presence of secondary natural-fracture porosity. The fracture analysis investigation over eastern Ohio using remote sensing techniques describes a method which should prove useful for locating secondary natural-fracture porosity reservoirs in regions of horizontal or slightly dipping strata.

Detailed field checks over a pilot area in Hocking County, Ohio, indicated that approximately 50% of mapped photo linears were not fracture related. A hypothetical interpretive technique developed to identify only the fracture-related photo linears was used in interpreting and mapping fractures over the entire area of eastern Ohio.

Statistical analysis of this data was necessary due to the large volume of data. A computer program was developed that analytically distinguished the regional and local components of the data. Computer-generated first and second-degree and corresponding residual maps showed areas of eastern Ohio where fracture density exceeded or was less than the regional norm.

High-density fracture areas, located within high-potential exploration areas (as defined by the other four exploration parameters) should have high potential for Devonian shale or "Clinton" sandstone natural gas production.

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Targeting Zones of Fracture-Enhanced Production

Many wells in the Appalachians produce from reservoir rocks which have fracture-enhanced matrix porosity. In these rocks, natural fractures are essential for significant production because matrix porosities are highly variable and commonly low. However, only certain penetrative, interconnected, and open fractures are capable of significantly increasing production. It therefore becomes necessary to differentiate these production-related fractures from other fractures in order to predict their occurrence.

The most definitive method for differentiating fractures is by combining petrofabric and geochemical techniques. Basic to this approach are geochemical and textural data on paragenesis and homogenization of methane-bearing inclusions in matrix and vein minerals. This approach has been routinely used in the Appalachians to differentiate and characterize fracture systems and identify their involvement in the migration, entrapment, and production of hydrocarbons. The results provide the explorationist with an improved capability to predict locations of highly fractured zones within potential reservoir rocks.

This approach has helped to define the main fracture domains in New York: the foreland fold: foreland fracture, intraformational fracture, basement fault, strike-slip fault; and normal fault domains. Analysis of the fracture fabrics in each domain has revealed those fractures that are open under the contemporary stress field and that enhance bulk-rock permeability.

For efficient targeting of zones of fracture-enhanced permeability, exploration programs need to concentrate on the production-related fractures. Once these fractures have been identified, analysis of structural contours, isopachs, lineaments, seismic profiles, production trends, logs, and surface petrofabric data can prove to be more rewarding.

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Use of Optical Axis of Vitrinite as an Indicator of Paleo- and In-Situ Stresses in Coal and Coal-Bearing Strata

Increasing level of coalification causes realignment of the optical axis of vitrinite in a direction coinciding with the direction of the maximum compressive stress, either vertical load stress or the resultant of vertical load stress and lateral tectonic stress. Measurable tilting of the optical axis occurs in horizontal coal bed in Beckley, West Virginia, region coinciding with the reported occurrence of strong in-situ lateral stress in the area. The average angle of tilting is 14° in the deeper buried Beckley Seam, and 7° in the shallow Sewell Seam. The former has severe ground-control problems. The basic assumption invoked is that coal, being organic in nature, is readily deformed under relatively lower temperature and pressure conditions than the inorganic host rocks.

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Application of Remote Sensing to Underground Coal Mining: Observations and Experience

Remote sensing in the form of linear analysis has been used for a number of years for the prediction of roof stability in underground coal mines. The advantages and limitations of this predictive method determined from the 6-year working experience of the Roof Control Division of the Mine Safety and Health Administration will be presented. The effectiveness of this method can be quite variable on both a regional and local scale. Factors contributing to this variation, such as mining practices and mine geology, will be discussed.

While the precise nature of the influence of a linear is not always known, a number of observations and experiences provide for a better understanding of the effects of these features. In addition to roof falls and poor roof conditions, more subtle characteristics of some linears have been observed: (1) time-dependent behavior with roof stability deteriorating with time; (2) roof stability which was good during development becoming poor upon retreat mining; and (3) water closely associated with some linears causing mining and roof control problems.

The predictive technique of linear analysis will not delineate all areas where poor roof conditions will be encountered, nor will roof instability be experienced along all linears plotted using this method. To be effective this technique must be integrated with existing engineering and geologic knowledge and practices.

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"Cat-Scan" Geological Assessment Required in Planning Today's Coal Mine

Sophistication of tools and depth of investigations required of a geologist in pre-planning analyses of a coal reserve are analogous to the pre-operative "cat-scan" evaluation a patient might experience prior to surgery. Before a cubic yard of earth is moved, all geologic materials to be encountered in the mining process must be properly identified and characterized both physically and chemically. Today's coal geologists use the latest in computer, petrographic, geophysical, and geochemical techniques to accomplish such a "pre-op" assessment. Geologists, hydrologists, soil scientists, and planning engineers must thoroughly understand the behavioral traits of the various geologic materials in order to prepare viable economic and environmental mining and reclamation plans. Every facet of the mining process is geologic dependent. Reconstruction of prime farmlands is dependent on the presence or absence of suitable rooting materials. Success or failure of a permanent stream relocation is controlled by our ability to understand and properly engineer the behavioral characteristics of geologic materials encountered.

Geologic pre-planning must be twofold in its approach. The geologist must always be looking for attributes and limiting factors of various geologic materials. Limiting factors are defined as those properties of the geology that have the potential for creating undesirable results in mining and reclamation. Undesirable results may range from decreased coal production to environmental degradation and consequent regulatory violations and bond forfeiture. Preplanning efforts should also accentuate the positive attributes or favorable properties of the geology. A constant effort should be made to define those geologic materials that have potential for achieving maximum revegetation productivity and hydrologic benefits following reclamation.

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A Model for Faunal Succession and Reef Growth in Edgecliff Bioherms (Middle Devonian Onondaga Formation)

Two small bioherms from the Edgecliff Member of the Onondaga Formation in Greene County, eastern New York, have been studied in order to formulate a model for Edgecliff reef development. Roberts Hill reef is approximately 720 ft (220 m) in length and 50 ft