date, 72 maps on the elemental analysis have been run and a similar number will be performed on the mineral data.

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How Good are Regional Coal Reserve Figures? Case Study of Winifrede Coal, Boone County, West Virginia

With the increased interest in coal in recent years has come a demand for accurate reserve figures on a regional basis. The tonnage of coal in the area in question is usually all that is considered. This presents a grossly simplified picture, because accuracy is usually implied which may not exist, and much information is not available. With a better understanding of the nature of the raw data and the interpretation process, better use can be made of reserve figures.

To illustrate the process of producing regional coal-reserve figures, recent work of the West Virginia Geological Survey on the Winifrede coal in Boone County was chosen. First, the types of data were considered both from the viewpoint of method of collection and from the viewpoint of value and accuracy. Next, the geologic interpretations, structure, outcrop, cross section, and isopach, were considered. Then the engineering and mining interpretations, percent parting, cover thickness, proximate analysis, sulfur values, mining height, mined area, and reserves, were determined. Finally, economic considerations were overlaid on the geologic and engineering considerations.

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Computer-Aided Graphics for Analysis of Cottageville Field, Jackson County, West Virginia

It has been said that the purpose of computing is insight, not numbers. In the Cottageville field, Jackson County, West Virginia, computer-aided graphics relate structure and stratigraphy to observed gas production. The Akima bivariate interpolation scheme for irregularly distributed data points provides structure and isopach contour maps or perspective three-dimensional surface displays. NCAR (National Center for Atmospheric Research) graphics software is helpful.

Further insight into the Cottageville field is obtained by use of open-flow and production data from the lower Huron Member of the Ohio Shale. These data are converted to graphics quickly displayed on a cathode-ray tube terminal followed by output on a 36-in. (91.4 cm) matrix plotter or a color-microfilm recorder. This method makes it possible to reject or recheck spurious data points or modify previous computations. Correlation using three-dimensional isometric histograms, gray intensity shading, and color blending is useful.

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Fabric-Element-Based Classification for Low-Porosity-Shale Gas Reservoirs

Several hundred shale samples have been characterized by us with respect to mineralogic composition, chemical composition, and petrophysical properties. However, no study based on composition reveals the fabric or manner in which the components are put together to form the resultant rock. Classification by fabric elements, based on X-radiography and direct prints from thin sections, is practical and appears useful for interpretation of both depositional environments and reservoir properties of shale.

Six lithotypes based on fabric elements are defined in Devonian shales of West Virginia: (1) sharply banded shale, (2) thinly laminated shale, (3) lenticularly laminated shale, (4) nonbanded shale, (5) siltstones, and (6) concretions. A gradational series exists from thinly laminated through lenticularly laminated to nonbedded. Thinly laminated and organic-rich lenticularly laminated shales appear the most favorable types for gas productivity because the laminated fabric permits the best lateral continuity of the low porosity (about 2%) present. The higher organic content of these lithotypes also probably acts as sites for significant sorption of gas, which is slowly released during production.

No microfracture system appears to exist, and macroscopic fractures do not necessarily coincide with productive zones. Wells without natural fractures prove productive after stimulation, which suggests that outgassing of a favorable rock type is responsible for the bulk of productive gas in Devonian shale wells. Natural fracture porosity, while important in extending effective volume tapped by a given well, represents only a minor portion of reservoir storage volume.

Thinly laminated shales are interpreted as being generally representative of shallow-marine deposits (dominantly shelf deposits) accumulating under anoxic conditions. Nonbanded and lenticularly laminated shales are deeper water accumulations deposited farther from shore. Sharply banded shales and some siltstones generally represent pulses of more rapid sedimentation in the prodelta environment. A single sample in itself is not diagnostic of depositional environment, but relative abundance of specific lithotypes in a given vertical section is useful for general environmental reconstruction. Better definition of the diagnostic worth of shale fabric-element lithotypes awaits results of more detailed fabric-element studies of modern fine-grained clastics and marine muds.

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Patch Reefs and Interreef Deposits of Silurian McKenzie Formation, West Virginia

Coral-stromatoporoid patch reefs are present in the lower part of the McKenzie Formation of the western West Virginia subsurface. Between these organic buildups is a bedded, argillaceous dolomite with very sparse fauna, and underlying the McKenzie is the Keefer Sandstone which served as the firm substrate on which McKenzie benthic communities became established.

During a transgression of the McKenzie sea, areas of thicker Keefer sand stood as submerged topographic highs. The local relief provided optimum sites for the patch reefs to develop and offered better protection to the fauna from being overwhelmed by incoming terrestrial clays. Conversely, the shaly interreef deposits of the McKenzie are present in areas of thinner Keefer Sandstone; they were laid down in turbid, relatively deep water between highs. A minor regression followed as represented by middle McKenzie intertidal sediments, and growth of the patch reefs ceased when the area emerged above the level of low tide.

Two southwest-northeast tracts of thicker McKenzie Formation and Keefer Sandstone mark the trends of Keefer topographic highs and associated McKenzie patch reefs. These trends now offer the best potential gas in the Middle Silurian of western West Virginia.

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Mauch Chunk Alluvial Plain and Mud-Flat Sediments in Northern West Virginia

Regional subsurface analysis of red beds of the Mauch Chunk Group (Upper Mississippian) in northern West Virginia, using oil and gas well logs and cuttings, suggests that deposition was in alluvial-plain environments grading basinward into mud flats.

Thickest net sandstone in the Mauch Chunk Group is in Barbour, Tucker, and Preston Counties in a belt 10 to 15 mi (16 to 20 km) wide striking north-northeast parallel with and just west of major fold axes of the Appalachian Plateau. This belt comprises numerous dip-oriented (west to northwest), vertically stacked, anastomosing subbelts and dendroids. Belt position reflects a gradient change from what were higher elevations on the east onto more level and tectonically stable areas of northwestern West Virginia. Lithofacies interpreted for the area include (1) channel fill–levee deposits as gray-green sandstone, siltstone, or non-red shale, and (2) flood-basin (overbank-levee) sediments as red and green shale. Streams carried a large suspended load and very fine to fine-grained sand. To the northwest, sandstone percentage decreases, and alluvial-plain facies interfinger with mud flats. Distal mud facies include laterally persistent limestone beds, and tidal-channel units with massive sandstone fill.

The overall genetic aspect of Mauch Chunk stratigraphy is a general regressive facies shift to the northwest. The boundary between Mauch Chunk red beds and coarse clastic alluvial sediments of the overlying Pottsville Group reflects changes in gradient, supply, and source area relief.

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Dilation Brecciation—Proposed Mechanism of Fracturing, Petroleum Expulsion, and Dolomitization in Monterey Formation, California

The Monterey Formation has been selectively replaced by dolomite and subsequently fractured, brecciated, and relithified with several generations of dolomite cement. The two dolomite types are distinctive in morphology, color, stoichiometry, δC^{13}, δO^{18}, and insoluble and trace-element content.

Dilation breccias evidently originate in embrittled rocks through a distinctive sequence of steps induced by tectonism: dilatancy, fluid expulsion, natural hydraulic fracturing, brecciation, hydroplastic flow, injection, and dolomite precipitation. Development is most abundant in, but not restricted to, areas of strike-slip faulting.

Initially, breccia clasts are angular, large, and closely fitted. In advanced development, smaller clasts appear unsupported and volumetrically subordinate to fracture-filling dolomites. Complex examples contain a very wide range of unsorted clasts and cement, similar to a slurry. They appear to be injected under pressure into swollen bedding planes and terminal fractures.

Tectonic stresses cause an initial compression and subsequent dilation (elastic) of rock microcracks and imperfections. With continued stress, the cracks are propagated inelastically and develop into major fracture networks. Fracturing associated with excess pore-fluid pressures triggers an instantaneous flow of connate fluids across several hundred feet of newly fractured strata. The resulting sharp drop in fluid pressure and temperature causes rapid precipitation of fracture-healing dolomite. The relithified rock is then subject to renewed dilatancy and rupture.

The dilatancy is pervasive and sufficient in magnitude to cause the expulsion of indigenous petroleum held initially in the organic matrices of the relatively impervious Monterey Shale. Several periods of petroleum migration are recorded in breccia paragenesis.

Dilation breccia is a distinct form of nondepositional breccia. It probably occurs in many tectonic provinces.

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Constraints and Problems in Producing Gas from Eastern Shales

The enormous gas resources locked in the various Mississippian and Devonian shale layers of the major eastern geologic basins naturally attracts the interest of energy policy makers and commercial entrepreneurs who are motivated to see and participate in the exploitation of that fraction which can be easily recovered. To succeed in this endeavor, however, certain constraints have to be faced, and other nagging problems have to be resolved. This paper classifies the constraints and the problems so that they can be dealt with systematically, and so that the expectations will not overtake the prospects and the realities.

The fact that the shale gas resource is widespread, and indeed reasonably evenly spaced, must be weighed against the observation that so far very few ways have been found to achieve high levels of prolonged production even from the historic reservoir locations. The obstacle that most appears to limit recovery is the fact that the shale matrix which holds much of the gas has the character of a molecular sieve. This means that somehow transport paths must be induced (especially when they do not naturally preexist) so that gas can easily move toward the wellbore sinks. Completing shale wells with stimulations that induce fractures and other types