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PETROGRAPHY OF SELECTED DEVONIAN SHALE CORE SAMPLES FROM THE CGTC 20403 AND CGSC 11940 WELLS, LINCOLN AND JACKSON COUNTIES, WEST VIRGINIA

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ABSTRACT

Forty selected core samples of "Devonian shales" from two wells in western and southwestern West Virginia were analyzed petrographically. Lithologically these samples may be grouped into 6 rock types: shale, silty shale, dolomitic shale, shaly siltstone, shaly dolostone. amd dolostone. Mineralogically, illite comprises the major part of the argillaceous fraction, whereas quartz constitutes the principal non-clay mineral. Carbonate is present in most specimens and is generally dolomitic. The most prevalent heavy mineral is pyrite.

Dark gray (N3) to brownish-black (5YR2/1) organic-rich shale constitutes the most distinctive rock type in the principal "Brown shale" pay zone interval. Organic matter occurs in several forms and comprises as much as 4.4 percent of the shale by weight. Vertical mineral-lined fractures are important in facilitating gas accumulation and migration in most pay zones. Dolomite is the main mineral constituent in these linings; however, small amounts of calcite and barite are also present. Mineral linings serve as propping agents to hold fractures open and thus are important in maintaining porosity and permeability along the fractures. Lenses of silt-size quartz and feldspar may serve as conduits for movement of gas into these fractures.

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INTRODUCTION

The "Devonian shale" interval of western and southwestern West Virginia includes all clastic rocks between the base of the Berea Sandstone (Lower Mississippian) and the top of the Onondaga Limestone (lower Middle Devonian). In the 26 named Devonian shale gas fields of southwestern West Virginia, this interval varies from less than 1000 feet to greater than 3000 feet in thickness (Patchen and Larese, 1976). Recently there has been an increasing amount of Devonian shale research by both industrial and governmental sectors in hopes of significantly increasing the gas potential of this marginal producer. This report summarizes the results of a preliminary petrographic analysis of cores of the Devonian shale interval which have been made available for study.

The objectives of the petrographic study were to define the basic mineralogical, textural, and diagenetic properties of selected Devonian shale core specimens from two wells in southwestern and western West Virginia (fig. 1); the Columbia Gas Transmission Corporation (CGTC) #20403 well in Lincoln County, West Virginia (Permit Number, Linc. 1637) and the Consolidated Gas Supply Corporation (CGSC) #11940 well in Jackson County, West Virginia (Permit Number, Jac. 1369). Both wells were cored through a cooperative agreement with these gas companies and the United States Energy Research and Development Administration. Approximately 1315 feet of core were taken in the CGTC #20403 well, a stratigraphic interval containing the entire Devonian shale section in southwestern West Virginia. In the CGSC #11940 well two partial cores

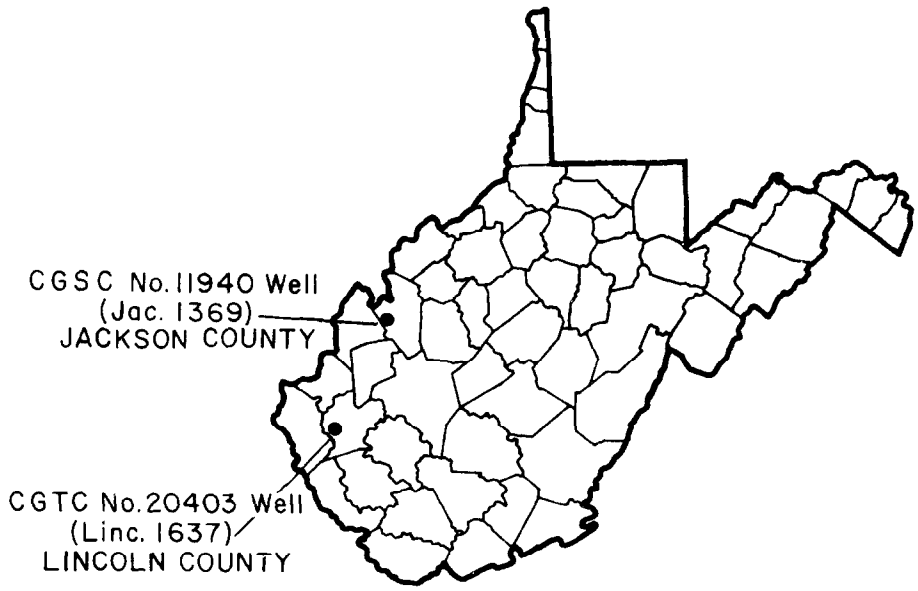

Figure 1. Index map of West Virginia showing locations of cored wells (CGTC #20403 and CGSC #11940) utilized in this study.

totaling 287 feet in length were taken from an organic-rich argillaceous interval within the Devonian shale section commonly referred to as the "Brown shale" zone (Patchen and Larese, 1976). These organic-rich shales are especially significant as they represent the principal gas producers in the 26 shale fields in the State. The relationship of the Brown shale interval to the overall subdivision of the Devonian shale section is depicted in figure 2.

Lithologic descriptions of each of the cores were prepared initially at the well site and later in greater detail at the Morgantown Energy Research Center by Byrer and others (1976). Forty selected samples were then made available for petrographic analysis. After preliminary study under the stereomicroscope, the specimens were subdivided into symmetrical sections for analysis by X-ray diffractometry, light microscopy, low-temperature ashing, and X-ray radiography techniques. The utilization of symmetrical sections insured consistency in comparing results of the various analytical methods employed.

Lithologic Types

Lithologically, the samples analyzed in this study grouped into 6 rock types (fig. 3): shale, silty shale, shaly siltstone, dolomitic shale, dolostone, and very fine-grained argillaceous sandstone, with most specimens being shales and silty shales. Modal analyses indicate that the shales average 89 percent clay-size material, 9 percent silt-size quartz-

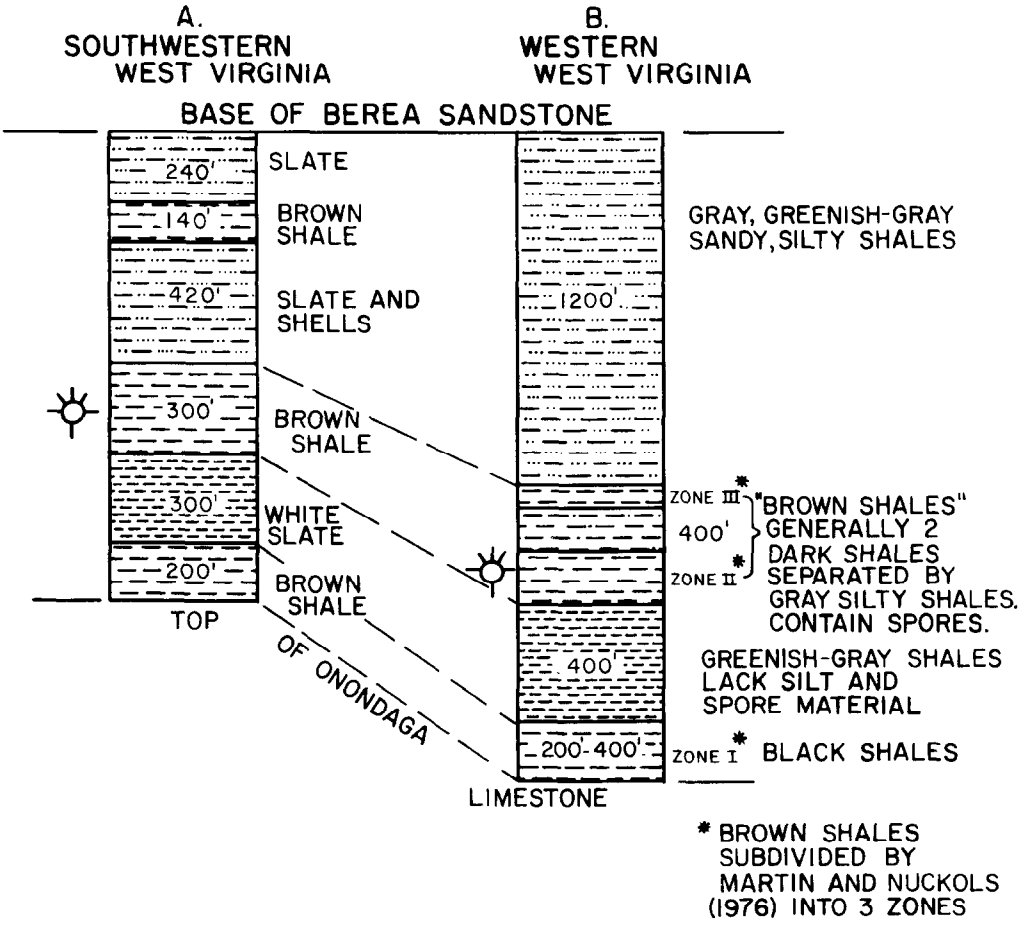

Figure 2. Subdivision of the Devonian shale interval in southwestern and western West Virginia. Section A depicts subdivision in southwestern West Virginia on basis of drillers logs descriptions (Bagnall and Ryan, 1976). Section B represents subdivision in western West Virginia (Jackson, Putnam Counties) on basis of lithologic descriptions (Martin and Nuckols, 1976; Patchen and Larese, 1976). Dashed lines show correlation of these principal subdivisions. Main intervals of gas production depicted by symbol ☼.

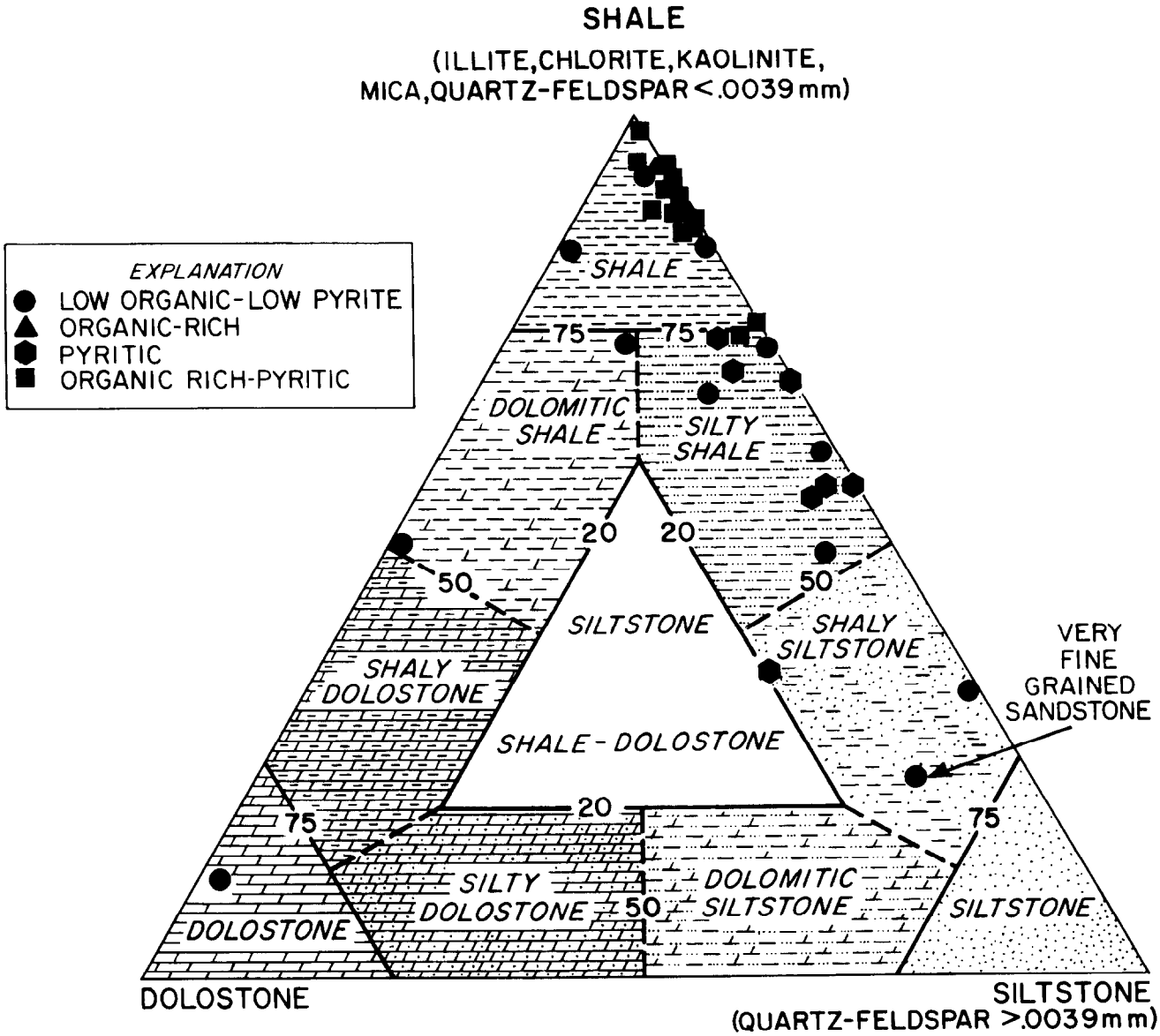

Figure 3. Classification of selected Devonian shale samples from the CGTC #20403 and CGSC #11940 cores.

feldspar, and 2 percent carbonate, whereas the silty shales average 65 percent clay-size material, 32 percent silt-size quartz-feldspar, and 3 percent carbonate.

The color of the shales (fig. 4) in hand specimen ranges from greenish-gray (5GY6/1[1]) to black (N1). In thin section the color of the shale is much lighter, ranging from light tan to dark brown. Some shales contain as much as 92 percent clay-size material composed largely of illite with some small flakes of muscovite, biotite, and chlorite. Clay-size quartz and feldspar may also be present, inasmuch as small amounts of these constituents in this size range could not be recognized in thin section. X-ray analysis indicated that some of the argillaceous material is kaolinite. In the purer shales, the clay particles commonly exhibit excellent preferred orientation, but locally the laminations are crenulated or wavy. A small amount of silt-size quartz with minor feldspar occurs as scattered grains in the shale or in thin laminations and lenses. Some of the small lenses of silt may actually represent clasts of siltstone. Carbonate mainly in the form of dolomite constitutes a small percent of most of the shales, although a few specimens contain as much as 14 percent carbonate.

The brown color of the shales is due to dark organic matter which constitutes as much as 4.4 percent by weight of some samples. In general, higher organic content results in darker color, but the distribution of the organic material also has an important effect. Highly disseminated

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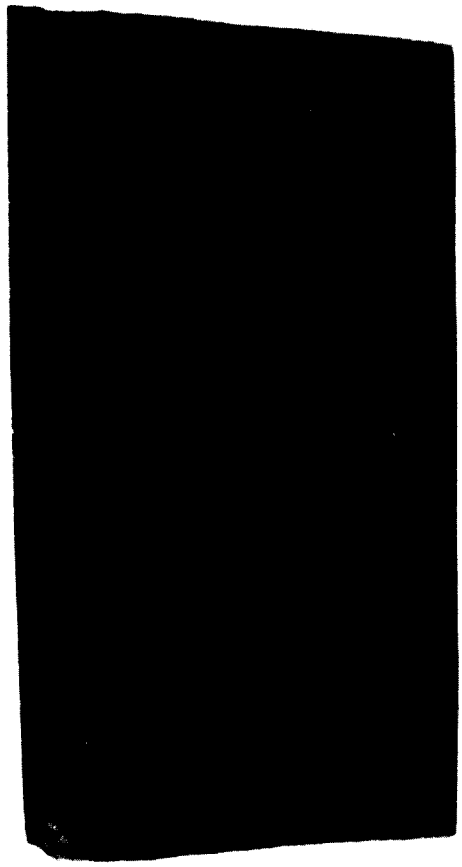
[1] Color terminology based on Geological Society of America Rock Color Chart Classification.



0 10

mm

A.

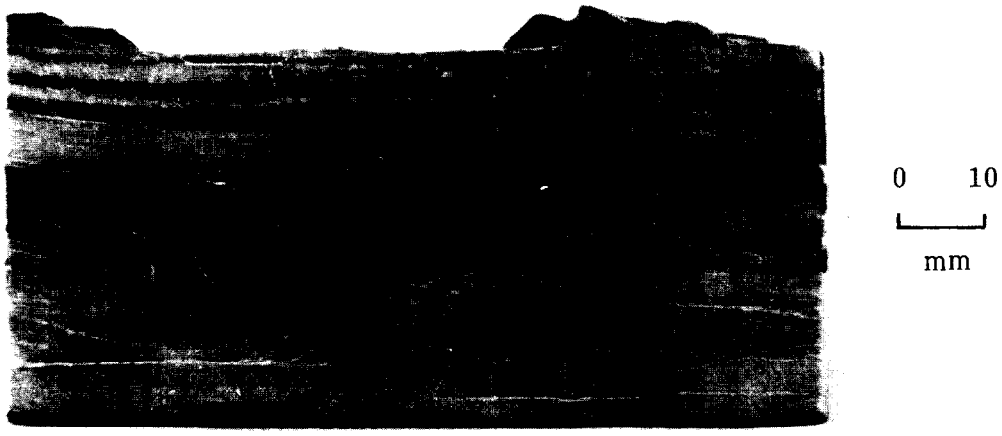
B.

Figure 4. Black (N1) organic-rich shale from the basal portion of the CGTC #20403 core—4028' depth; (A) core sample (B) thin section specimen—note organic material (white arrows), and silt-size quartz (black arrows). Magnification 130 X, plain light.

organic matter imparts a darker color to the shale than an equal quantity of organic material in discrete lenses or laminations. Pyrite is generally more common in the organic-rich shales averaging 3 or 4 percent but ranging up to 18 percent in a few cases. Some shales have laminations of alternating light and dark (generally organic-rich) layers. Locally, a mottled appearance results from small clots of light-colored shale embedded in dark shale or dark clots embedded in light-colored matrix. These clots also commonly possess unique sedimentary structures and presumably constitute reworked material. Subsequent compaction has accounted for the characteristic lenticular shape of these clots. Although a detailed study of fossil content in the shales was not made, the presence of brachiopods was noted in shale samples from both cores. The phosphatic brachiopod Lingula was especially common in several specimens. In addition, conodont fragments were observed in one organic-rich shale specimen from the CGSC #11940 core.

Silty shale specimens are generally lighter colored than the more argillaceous shales because of less organic material. Preferred orientation of the clay particles is less perfect in the silty shales and mica flakes are more common. The distribution of silt is about the same as in the shales, but the silty laminations are thicker and more continuous.

Several beds consist of argillaceous siltstones (fig. 5). Most of the silt-size material is medium to coarse grained and is composed of quartz with a few percent feldspar, largely plagioclase. The argillaceous content averages about 25 percent and is composed mainly of illite with some



A.

B.

Figure 5. Argillaceous siltstone from the upper part of the CGTC #20403 core—2751' depth. (A) Core sample—note dark argillaceous laminations and cross-bedding (arrows); cracks (white) are a result of dessication after the core was removed from the well. (B) Thin section specimen—argillaceous material (arrows) is interspersed with coarse silt-size quartz (Q). Magnification 130 X, crossed nicols.

kaolinite and flakes of muscovite, biotite, and chlorite. The siltstones are characteristically light colored with only minor amounts of organic material. Commonly they contain well defined small-scale cross bedding and load cast features. Carbonate is generally present with some beds containing as much as 20 percent dolomite. The pyrite content of the siltstones is very low. A few sandy beds are coarse enough to be classified as very fine-grained sandstones, but except for texture are similar to the siltstones.

One thin bed in the CGTC #20403 well is classified as a dolostone with 81 percent dolomite. This bed contains approximately 16 percent argillaceous material but only a few percent silt-size quartz. The dolostone is light colored and contains essentially no organic material.

Mineral Constituents

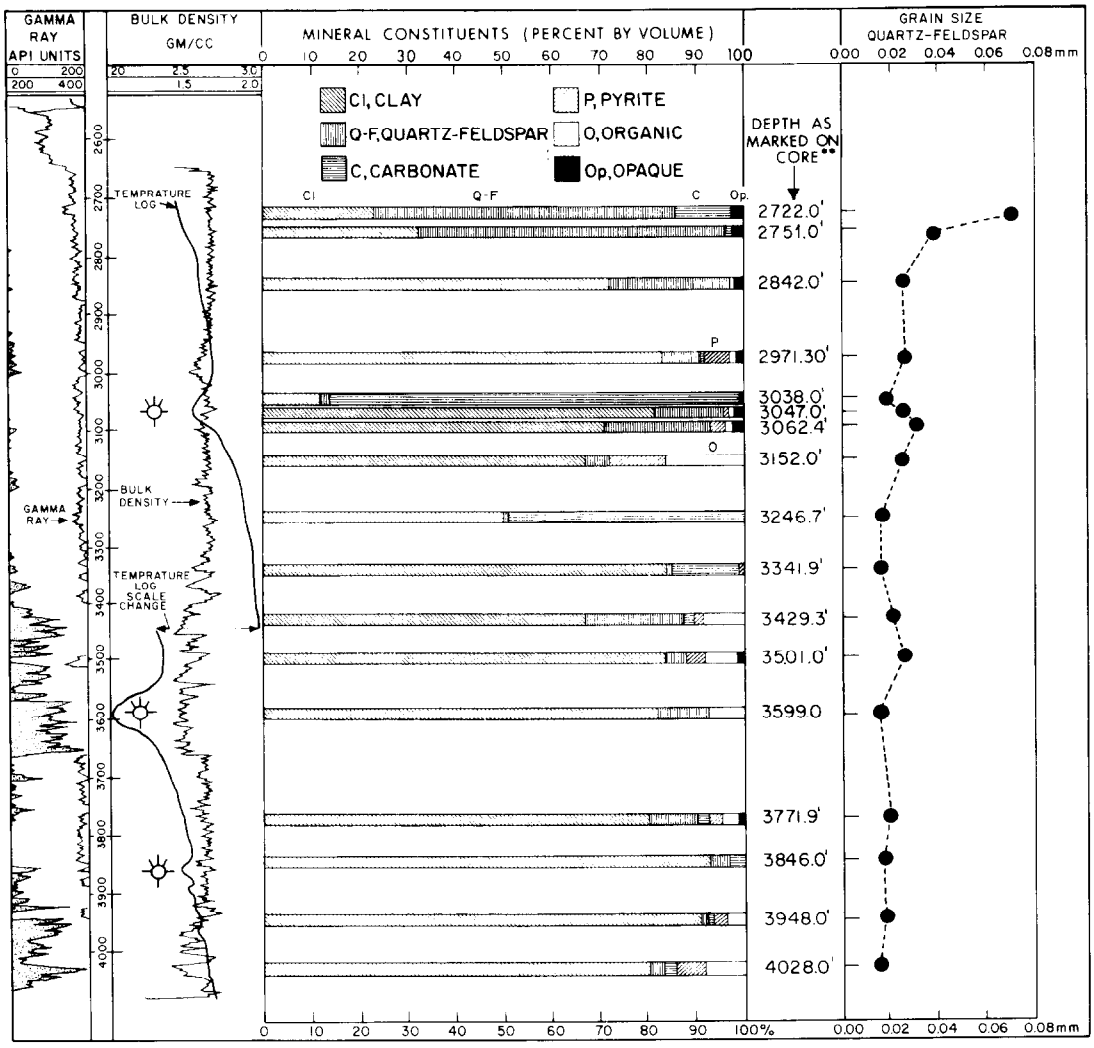
The fine argillaceous material observed in thin section consists principally of illite. This is confirmed by X-ray analysis which indicates that minor amounts of kaolinite are also present. Muscovite occurs primarily as tiny shreds, but may also occur as well defined flakes as much as 0.25 mm in length. Some of the biotite is unaltered showing normal pleochroism, but much of it is bleached or partially altered to chlorite. Distinct flakes of chlorite were also noted which appear to be detrital, although some may have resulted from complete diagenetic alteration of biotite.

Quartz grains present in the samples were originally angular to subrounded and are mainly monocrystalline, although a few are polycrystal-

line. In siltstone beds and silty lenses, secondary quartz is common and results in grain interlocking. Some quartz overgrowths are very uneven because of interference from illite coatings. A moderate amount of pressure solution occurred in the silty zones and produced irregular contacts in some cases. Quartz grains in the highly argillaceous siltstones and shales rarely showed overgrowths, but some small growths could have been masked by the clay. The quartz grains in the shales may have been somewhat modified by pressure solution, but the extent of solution is difficult to ascertain in grains embedded in clay.

Quite often it was difficult to differentiate between quartz and feldspar. Where feldspar exhibited characteristic structure or twinning, it was readily identifiable as orthoclase, perthite, microcline, or very commonly plagioclase. However, where twinning was not apparent, identification was difficult so that the quartz and feldspar were combined in modal analyses.

Measurements on a limited number of quartz and feldspar grains larger than clay size from the CGTC #20403 core indicate that these constituents vary from fine silt size (average 0.015 mm) to very fine sand-size (average 0.071 mm) in individual specimens (fig. 6). Overall, quartz and feldspar possess an average grain size (0.026 mm) in the medium silt-size range. As depicted in figure 6, it appears that aside from two relatively quartz-rich samples in the upper part of the section (2722', 2751'), the average grain size of these constituents remains fairly constant throughout the core.



**Core depths may differ from corresponding geophysical log depths by several feet in some samples.

Figure 6. Geophysical, mineralogical and textural characteristics of the CGTC #20403 well. The principal Brown shale pay zone occurs within interval from 3400 to 3650 feet. Mineralogical and textural data are based on thin section analyses. Core and geophysical log depths are not corrected to ground level.

Chert occurs in a variety of forms. The shape of some chert masses suggests that they have replaced shells and spores. The latter are elliptical in cross section and have pyrite in the center. Lenses somewhat larger than the spores are apparently inorganic and may have formed from early concentrations of silica or later replacement by chert. Some of the small grains of chert are probably of detrital origin. Low birefringent matter incorporated with the argillaceous components might be chert in part but could not be positively distinguished from clay showing low interference colors in thin section.

Dolomite in the shales occurs as single crystals, aggregates of small grains, or as tiny specks disseminated through the argillaceous material. Some crystals form good rhombohedral outlines, but most rhombs are incompletely developed. Dolomite readily replaced argillaceous material and corroded quartz grains leaving very irregular margins. In the siltstones, crystals of dolomite commonly poikilitically enclose several quartz grains. Some concretion-like nodules averaging 1 to 2 millimeters across are rich in dolomite with small amounts of calcite.

Although calcite is much less common than dolomite, it is distinct in some thin sections as fossil shell material. Some of the calcite is in arcuate forms and probably represents valves of brachiopods or pelecypods. Some calcite forms doughnut-shaped rings with brown organic matter in the central "hole." Minor amounts of calcite also occur in dolomite nodules and in some pyrite aggregates.

Pyrite is the most common heavy mineral constituent in the specimens

and is disseminated through many of the shales as small irregular grains, framboids, and euhedral grains. Relatively pure pyrite also occurs in small lenses which are as much as 0.25 mm in diameter. Larger lenses and "knots" have dolomite or anhydrite intergrown with the pyrite. Some of these aggregates of pyrite appear to have grown by replacement and have unreplaced remnants of quartz with a small amount of argillaceous material. Pyrite commonly occurs in distinct patterns which suggest replacement of organic material. Some of this pyrite is in the form of regular rods or tapered rods resembling spicules and in a few cases, intersect to form crosses. Some pyrite occurring in arcuate forms may have replaced valves, and pyrite in small spheres probably represents replacements of pellets or organic remains. Some of these spheres have centers of carbonate. The common occurrence of pyrite in spores is considered later in this report. Other readily identifiable heavy minerals noted in thin section included angular to rounded grains of zircon and tourmaline. In a more detailed analysis no doubt other less common heavy minerals would be detected.

Organic Material

Organic matter, commonly occurring in a finely divided state, imparts a reddish-brown color to argillaceous material as seen in thin section. Some organic matter is black and opaque occurring as tiny specks, shreds, and small lenses. In some of the silty laminations, dark organic matter is

the principal interstitial material. Organic matter in the form of reddish-brown irregular shreds may represent woody material.

Spores are common in some beds and are generally lemon yellow to light reddish brown in thin section. The most abundant type is thick walled (fig. 7), but thin-walled types are also present. Generally the spores are disc shaped as a result of compaction. The centers of many spores are occupied by pyrite much of which apparently formed before spores underwent compaction. The spores which were completely filled with pyrite are spherical as the pyrite core prevented the spore walls from collapsing. Pyrite filling started at the bottom of the voids within the thick-walled spores much as geopedal forms developed in cavities in limestones. Where the spores were partially filled, the top of the pyrite filling was generally horizontal. On compaction, the upper unfilled part of the spores collapsed leaving forms resembling spherical segments with one flat side (fig. 8) which faced "up" in the direction of the original top of the beds. Commonly the upper walls of the spores shifted to one side as they collapsed, leaving a cross section resembling a ladle. It is apparent that pyrite controlled the shape of these forms and must have developed early before the spores underwent compaction.

In many of the highly lenticular spores, there is a small amount of pyrite which is fairly evenly distributed across the middle of the spore. This suggests that the inner walls of the spores were thinly coated with pyrite before collapse. Another possibility is that the pyrite developed after compaction had deformed the spores into the lenticular forms. This

Figure 7. Thick-walled spores in organic-rich shale. The center of the larger spore contains pyrite (P), but the smaller spore is mainly filled with barite (B). A small amount of pyrite is present along the base of the spore (arrow). Magnification 130 X. Plain light. CGSC #11940 core, 3726' depth.

Figure 8. Thin-walled spore in organic-rich shale. The center of the spore is occupied by pyrite (P) which only partially filled the spore. With compaction, the unfilled part of the spore collasped resulting in the relatively flat top surface (arrow). Magnification 130 X. Plain light. CGSC #11940 core, 3726' depth.

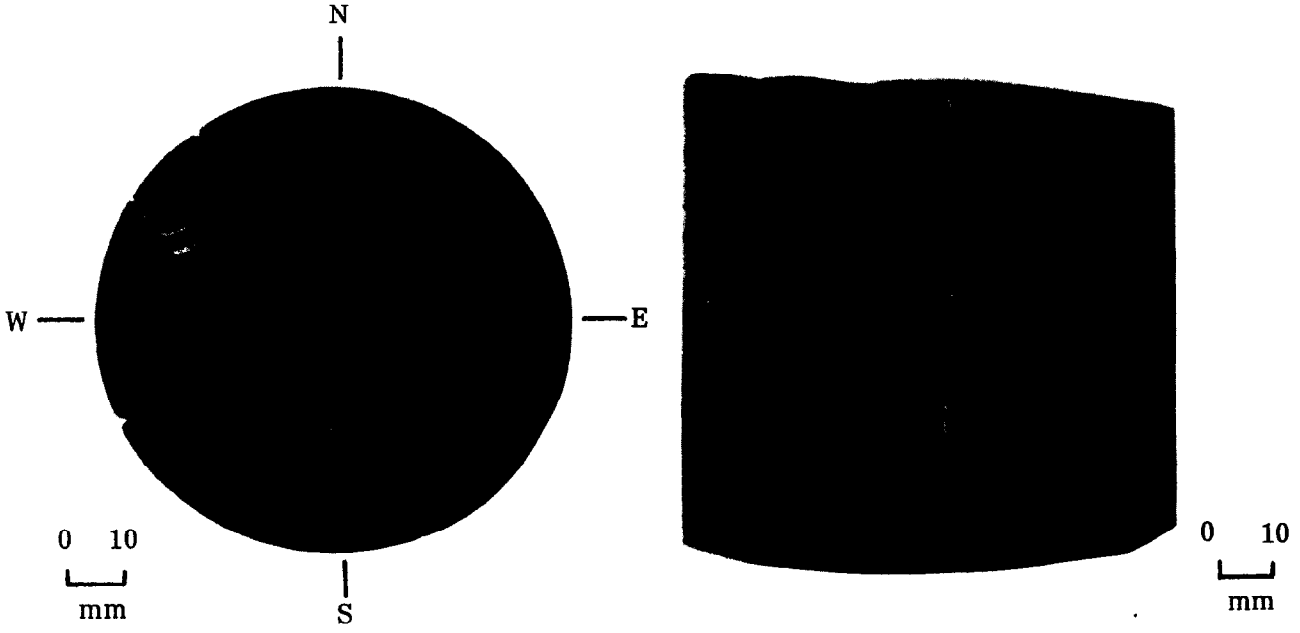
seems less likely as space for pyrite would have been eliminated in most cases in the collapse of the spores. The lenticular spores without pyrite either escaped early pyritization or had completely collapsed before pyrite formed. The walls of many of the lenticular spores ruptured in the process of compaction.

The thin-walled spores contain considerably more pyrite than the thick-walled spores. For this reason many of the thin-walled spores were little affected by compaction and are nearly spherical. In these spores, the pyrite also first formed at the bottom of the spore cavity but with greater deposition on the walls of the spore than in the center. Collapse of the unfilled part of these spores produced a crescent-shaped cross section with the tops of the crescents almost invariably pointing upward. Thus these spores are useful in determining the original top of the beds. In a number of spores, a small amount of dolomite or barite was deposited on top of the pyrite before the spores underwent compaction. A few were almost entirely filled with barite (fig. 7). Some of the smaller spores have rings or centers of colorless material which may be chert.

Quartz-Feldspar Lenses

In very dark organic-rich shale specimens, clastic quartz and feldspar are commonly segregated in lenses parallel to bedding (fig. 9). Although not easily seen in hand specimen, these silt-size lenses are readily apparent in thin section and commonly occur at regular intervals in otherwise

Figure 9. Quartz-feldspar lens (arrows) parallel to bedding in organic-rich shale from the pay zone of the CGSC #11940 well. Magnification 130 X, plain light. 3720' depth.



A. Plan View B. Section View

Figure 10. Core sample from the upper pay zone (3050'-3090', fig. 6) of the CGTC #20403 well containing mineral-lined vertical fracture. The vein averages 1 mm in width, has a N30°W orientation and consists largely of dolomite. Note the vuggy nature of the vein (arrows) in both plan and section views. 3057.8' depth.

homogeneous appearing shales. These lenses probably have higher permeability than shale so may have special significance in serving as conduits for the migration of gas to fracture zones where much of the gas ultimately accumulates.

Fractures

In the pay zone intervals of both wells, mineral-lined vertical fractures were commonly noted (fig. 10; Watts, personal communication 1976). Mineral-lined fractures in the CGTC #20403 core are concentrated in the greenish-gray (5GY6/1) to dark gray (N3) shales (core interval 3036' - 3078') approximately 340 feet above the Brown shale zone, the principal gas producer. Gas shows were noted on the temperature log (fig. 6) for both of these intervals. Measurements on the few core samples made available from this interval showed fracture orientations to vary from N20^{o}W to N30^{o}W.

In the CGSC #11940 core, mineral-lined fractures are restricted to the Brown shale zone (fig. 11) in an interval extending from 3720-3783 feet (Byrer and others, 1976). However, the greatest concentrations occur from 3720 to 3730 feet (Byrer and others, 1976) which correlates with gas shows on the temperature log of the well. There appears to be considerable dispersion in the orientation of mineral-lined fractures in this core (fig. 12), however three directions predominate: N40^{o}-50°E, N10^{o}-20°W, and N80^{o}-90°W.

Four samples with veins resulting from mineralization along fractures

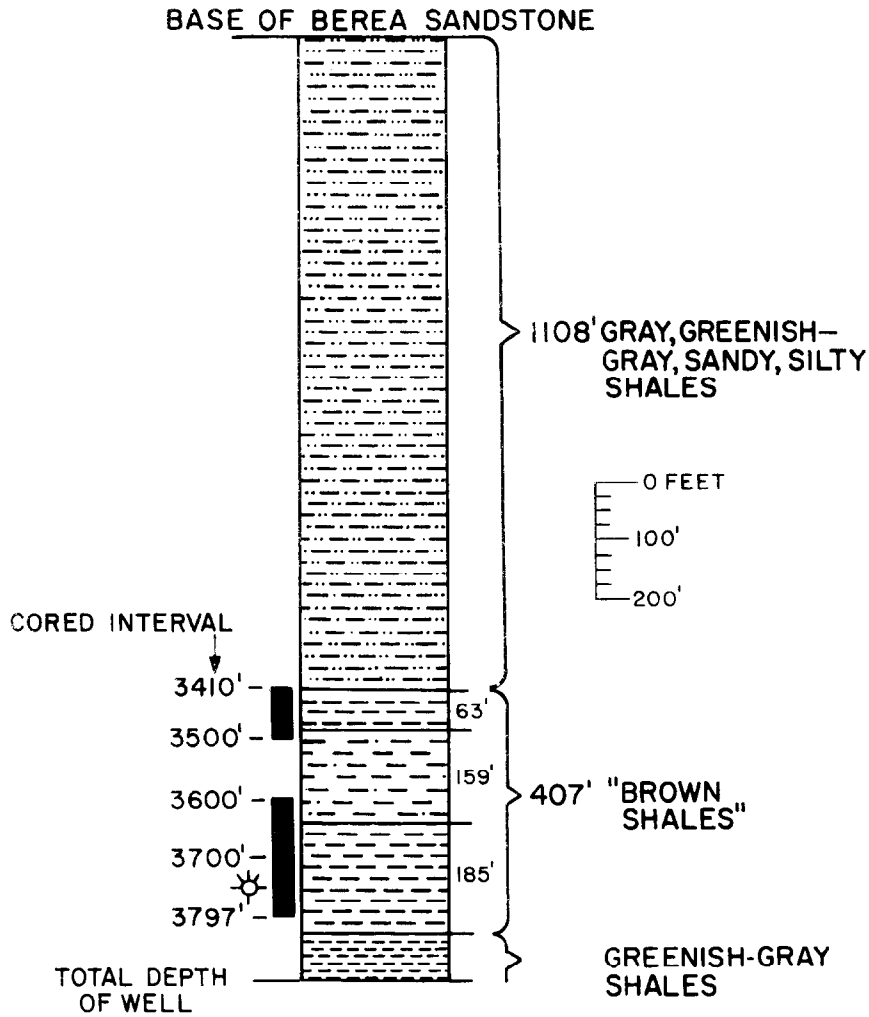


Figure 11. Columnar section of the CGSC #11940 well depicting cored intervals and subdivision of the Devonian shale section as interpreted from geophysical logs. Core depths are not corrected to ground level.

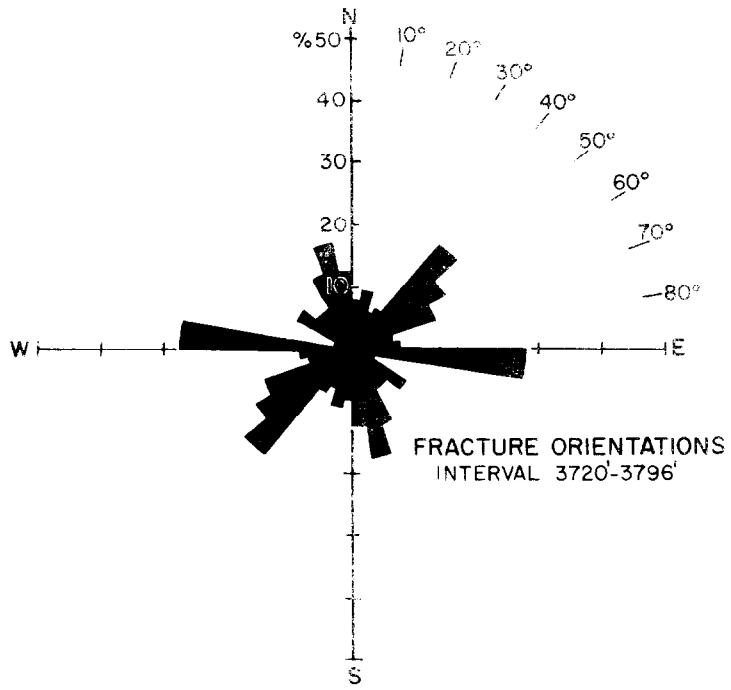


Figure 12. Orientation of fractures in core samples from the pay zone interval (3720'-3796') of the CGSC #11940 well. The majority of fractures measured were mineral-lined. Source of data—Royal J. Watts, USERDA-MERC.

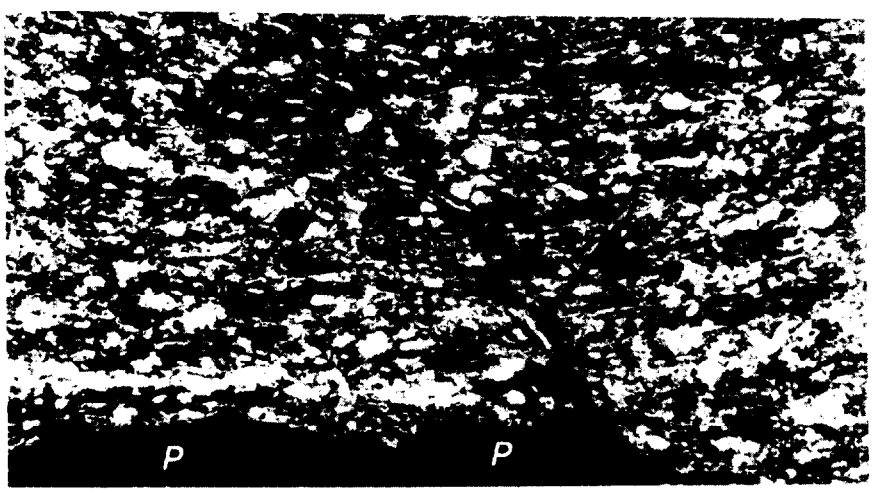


Figure 13. Minute shear fracture in organic-rich shale specimen. Adjustment around the pyrite nodule (P) resulted in fracturing of the enclosing shale. Note small amount of dolomite lining fracture (arrow). Magnification 130 X, plain light, CGSC #11940 core, 3773' depth.

were studied from the CGSC #11940 well in the interval from 3720 feet to 3730 feet. Dolomite was the exclusive vein mineral except for very small amounts of calcite with the dolomite from one sample (3729.5 feet). The maximum width of most veins is 1.5 mm. The vein material in all the samples from the CGSC #11940 well only partially filled the fractures, leaving vuggy openings. The dolomite lining these openings formed saddle-shaped rhombohedrons which built up with overlapping plates resembling a shingled roof. Calcite crystals were more pointed occurring in the form of scalenohedrons with the typical habit of dog-tooth spar. The openings along the veins are generally connected to effect good permeability.

In one specimen from the core, several minute shear fractures were observed within the shale matrix (fig. 13). These shears were commonly associated with pyritic nodules and apparently developed as a result of adjustment around the nodules with fracturing of the enclosing shale. Although very minor amounts of dolomite were noted along the fracture traces (fig. 13), the majority of the shears lacked mineral linings and appeared tight and impervious.

Veins in 4 samples from the CGTC #20403 well were studied in the interval from 3038 to 3062.4 feet (fig. 14) and at 3592 feet. Several veins were 2 mm wide with local swelling to 3 mm. Although barite is a minor constituent of the shales, it is more abundant than dolomite in some of the veins. Barite superficially resembles the carbonates and may easily be overlooked in the cores. However, there are several features which can

be used to identify barite in these veins under the stereomicroscope. Typically the barite is lamellar or somewhat fibrous and terminations are multifaceted, producing a sparkling appearance. Some of the facets are so small that care must be taken not to confuse them with irregularities due to corrosion. Many of the crystals are highly curved with some forming rather unique shapes resembling a shepherd's staff. At 3047 feet in the CGTC #20403 well barite was introduced both before and after dolomite formation. The dolomite and second stage barite are very vuggy so that significant porosity and permeability occur at this zone (fig. 15). At 3592 feet, a thin lens of asphaltic material is laced with veins of several different types of minerals (fig. 16). Some of the veins are limited to the asphaltic material itself and might represent filling of cracks resulting from shrinkage. However, a few of the veins extend into the surrounding shale and are undoubtedly related to tectonic activity. Anhydrite veins with widths up to 0.3 mm first formed in the asphaltic lens. These were followed by white dolomite veins which commonly cut across the anhydrite veins. Very fine veins of tan dolomite formed in a second stage of dolomite development. Some of these veins formed through opening up of earlier veins but others followed new fractures. The tan color of the dolomite is apparently from contaminants of organic matter. Barite was the last and most abundant vein material. Much of the barite is in the middle of the anhydrite veins which opened up as much as 1.6 mm during the final stage of vein formation. Locally pyrite occurs in with the barite.

Except where vein filling was complete, mineralization may have

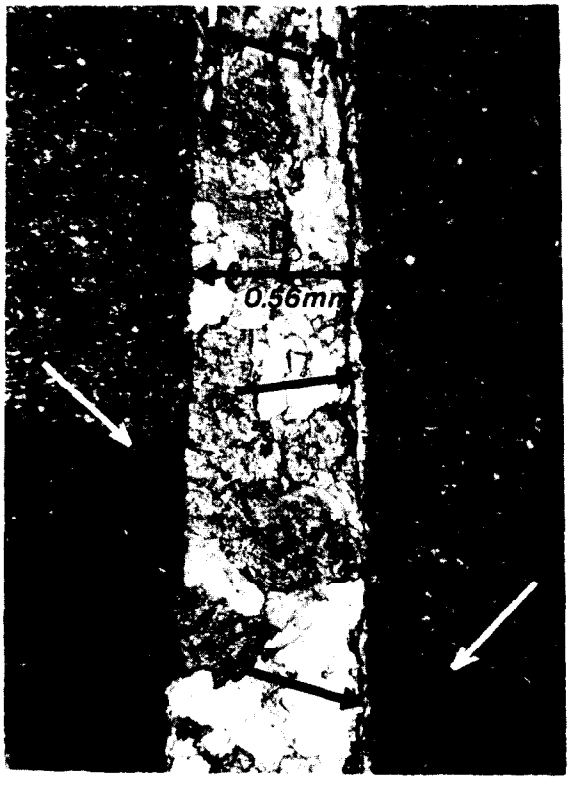


Figure 14. Vein filling in vertical fracture. Barite (arrows) represents the first stage of mineral deposition on the fracture wall while dolomite (D) represents a second stage of mineralization resulting in deposition in the middle of the vein. Note vertical offset (white arrows) of bedding. Magnification 43 X, plain light, CGTC #20403 core, 3047' depth.

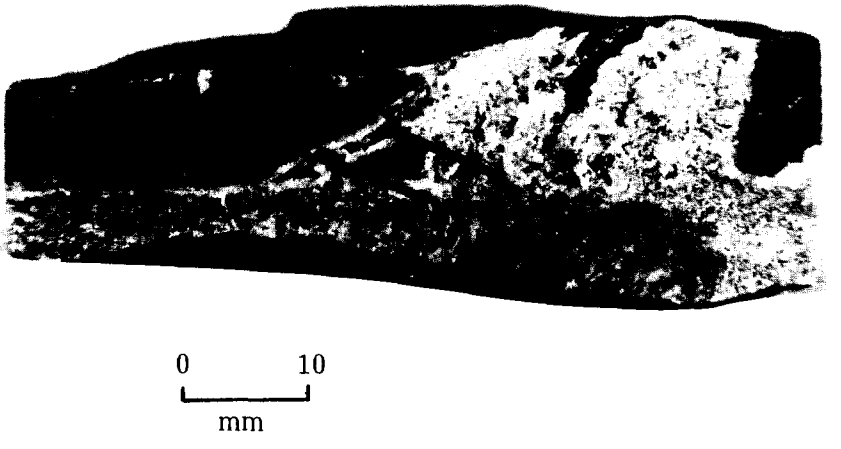


Figure 15. Fracture wall lined with dolomite and barite. The fracture is very vuggy with one of the particularly large openings shown by arrows. CGTC #20403 core, 3047' depth.

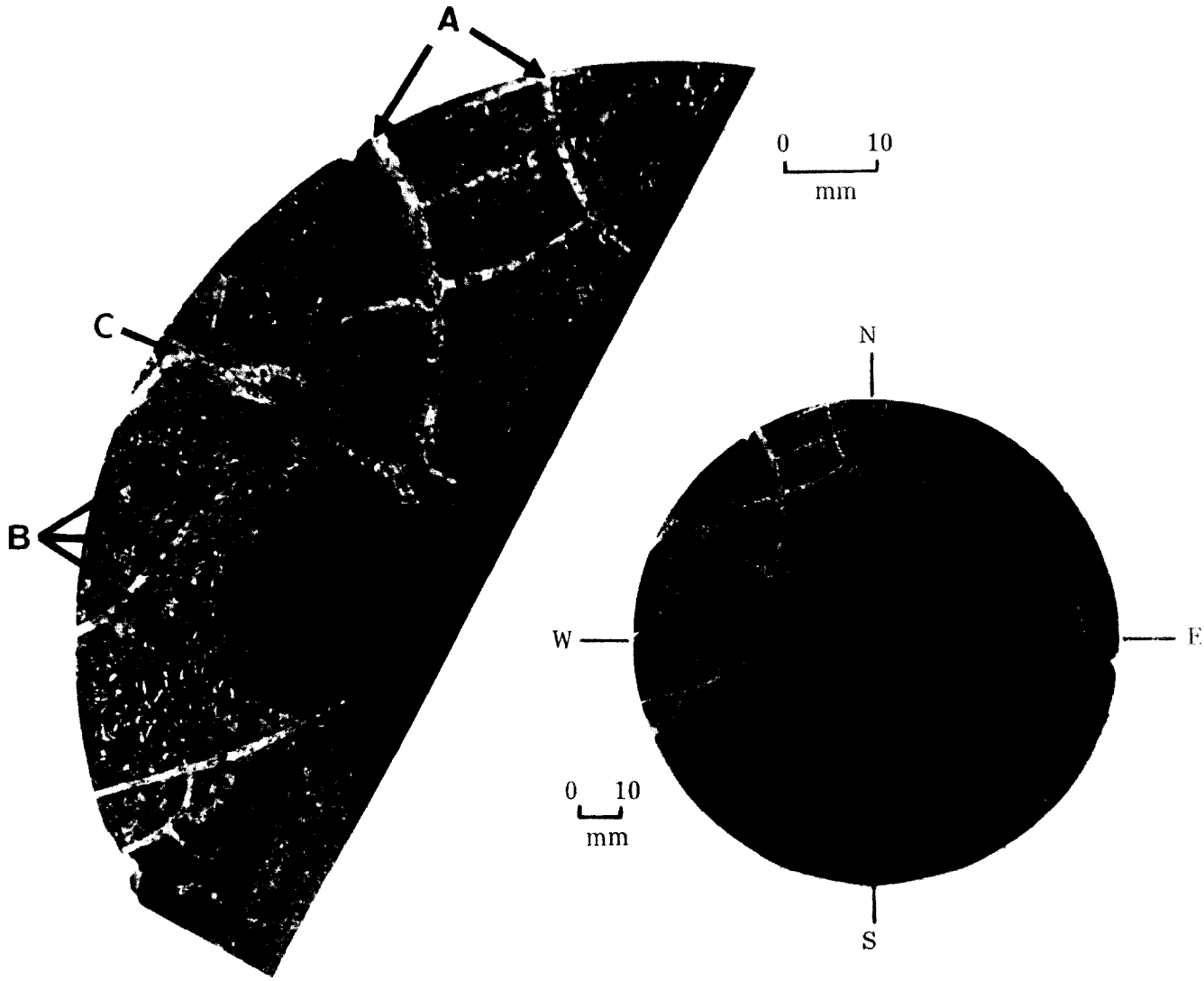


Figure 16. Core split along asphalt lens shown to left of dashed line. The large veins such as at (A) are composed of barite with margins of anhydrite. Most of the fine veins such as at (B) are composed of clear and tan dolomite. Poorly defined vein at (C) is rich in pyrite. CGTC #20403 core, 3592' depth.

been very significant in maintaining openings along fractures through the propping action of the minerals which had grown out from the walls of the fractures. Many of the fractures with vuggy mineralization occur in the pay zone and are probably an important factor in the gas production.

Conclusions

Analysis of temperature logs and selected samples from the CGSC #11940 and CGTC #20403 wells indicates that gas shows are prevalent in dark gray (N3) organic-rich shales which comprise the interval commonly referred to as the Brown shale zone. Organic material occurring as finely divided matter, shreds, and spores may represent the source of gas present within the interval. Natural fractures, commonly mineral-lined, are important factors in gas production both in these organic-rich zones and in pay intervals less organic in nature.

Production decline curves of Devonian shale wells in southwestern West Virginia often show considerable decreases in open flows during the first few years of production followed by a leveling-off of production for many more years (Bagnall and Ryan, 1976). The initial decline may possibly be the result of depletion of readily available gas in natural mineral-lined fractures, whereas the subsequent leveling-off may be attributed to the slow but constant flow of gas into the borehole from the shale matrix (Brown, 1976). If this matrix could be effectively fractured, it might be possible to obtain greater quantities of gas over a shorter period of time.

REFERENCES

Bagnall, W.D., and Ryan, W.M., 1976, The geology, reserves, and production characteristics of the Devonian shale in southwestern West Virginia, in Shumaker, R.C., and Overbey, W.K., editors, Devonian shale production and potential: USERDA-Morgantown Energy Research Center Special Report, MERC/SP-76/2, p. 41-53.

Brown, P.J., 1976, Energy from shale—a little used natural resource, in Natural gas from unconventional geologic sources: Board on Mineral Resources, Commission on Natural Resources, National Acad. Sci., Washington, D.C., p. 86-99.

Byrer, C.W., Vickers, M.K., Rhoades, S.J., and Easterday, B.G., 1976, Lithologic description of cored wells #20402 and #20403 in the Devonian shale in Lincoln County, West Virginia: USERDA-Morgantown Energy Research Center Technical Report, MERC/TRP-76/9, 59 p.

Byrer, C.W., Trumbo, D.B., and Rhoades, S.J., 1976, Lithologic description of cored wells #11940 and #12041 in the Devonian shale in the Cottageville, West Virginia area: USERDA-Morgantown Energy Research Center Technical Report, MERC/TRP-76/7, 22 p.

Martin, P., and Nuckols, E.B., III, 1976, Geology and oil and gas occurrence in the Devonian shales: northern West Virginia, in Shumaker, R.C., and Overbey, W.K., editors, Devonian shale production and potential: USERDA-Morgantown Energy Research Center Special Report, MERC/SP-76/2, p. 20-40.

Patchen, D.G., and Larese, R.E., 1976, Stratigraphy and petrology of the Devonian "Brown" shale in West Virginia, in Shumaker, R.C., and Overbey, W.K., editors, Devonian shale production and potential: USERDA-Morgantown Energy Research Center Special Report, MERC/SP-76/2, p. 4-19.

Rock-Color Chart Committee, 1975, Rock-color chart: distributed by the Geological Society of America, Boulder, Colorado.

Watts, R.J., 1976, personal communication: Morgantown Energy Research Center, Morgantown, West Virginia.