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Mineralogic and Petrologic Overview of Core Samples From the Dept. of Energy's Western Gas Sands Project Multiwell Experiment, Piceance Basin, Colorado

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ABSTRACT

The Petrology Laboratory of Bendix Field Engineering Corporation (BFEC) at Grand Junction, Colorado, is performing mineralogic and petrologic analyses on core samples from the Multi-Well Experiment (MWX) project for Sandia National Laboratories. The samples studied to date include some fluvial sands, transitional sands, and shoreline blanket sands. The sands are generally fine-grained feldspar- and lithic-rich quartz sandstones, with minimal textural and mineralogic variation. Porosity is predominantly microporosity in clays which fill secondary pore space. The primary factor limiting the permeability of these sands appears to be the clogging of the pore space by clay minerals.

INTRODUCTION

Sandia National Laboratories is conducting and directing the Multi-Well Experiment (MWX) core analysis program as part of the Western Gas Sands Project for the Department of Energy's Unconventional Gas Sands Program. The Petrology Laboratory of Bendix Field Engineering Corporation at Grand Junction, Colorado, has been contracted by Sandia to provide mineralogic and petrologic analyses and interpretations on core samples (MWX-1, MWX-2) from the Rulison Field in the Piceance Basin, Garfield County, Colorado. Samples supplied by Sandia for this study were end-chips of core plugs. The remainder of each core plug was used for routine core analysis.

The results of these analyses are preliminary and will be used primarily for delineating variations in mineralogic and textural trends (horizontal as well as vertical) in specified sandstone intervals of the Mesaverde Group at the Multi-Well site. When coupled with data compiled from standard core analyses, log interpretation, and field surveys, these data will help provide the maximum possible information for reservoir characterization. The data will also aid in the determination of factors limiting the permeability of these tight gas sands and in the development of stimulation and recovery technology.

References and illustrations at end of paper.

To date, petrologic study of the MWX cores has been concentrated on the shoreline blanket sands (the Cozzette and Corcoran Intervals) and on the transitional zone (the Coastal and Paludal Intervals) that occurs between the blanket sands and the fluvial sands. Although the fluvial sands have thus far been studied only within a highly fractured section of core, the petrologic study will eventually include all the fluvial sandstone intervals of the Mesaverde Group. This paper is a general summary of the study results obtained to date.

PROCEDURES

Samples provided for mineralogic and petrologic analyses consisted primarily of end-chips from core plugs. Analyses performed for this study include thin section examination, X-ray diffraction (clay mineral and whole rock), and scanning electron microscopy (SEM).

A thin section was made from each sample. Prior to thin sectioning, the samples were impregnated with blue epoxy in accord with the procedure suggested by Gardner[1]. Half of each thin section was stained for calcite, and the opposite half was stained for potassium feldspar using the methods described by Carver[2] and others.

The thin sections were used to characterize mineralogic and textural features. Modal analysis was done by point counting. Grain sizes were determined using an ocular reticule. Other textural features were characterized using methods described by Folk[3] and others. Pore space characteristics were determined by examining areas of the thin section that were impregnated with the blue epoxy. Scanning electron microscopy was also used for examining pore space textures.

Clay size (<2 μm) fractions analyzed by X-ray diffraction were separated using sedimentation techniques. X-ray diffraction analysis of bulk rock samples was used to verify significant variations in mineralogy and to determine the major mineralogic compositions of samples too fine-grained for thin section analysis.

RESULTS

MINERALOGY

Variation in the overall mineralogic composition of the sandstones is minimal throughout all the samples examined to date. The detrital framework consists primarily of quartz, plagioclase feldspar, lithics, and chert. Detrital quartz constitutes between 60 and 80 percent of the framework, plagioclase between 4 and 20 percent, and lithics, including chert, between 10 and 30 percent. Minor detrital minerals include potassium feldspar, muscovite, biotite, detrital opaques, chalcedony, zircon, tourmaline, epidote, and hornblende. Authigenic minerals include carbonates, clays, secondary quartz overgrowths, and pyrite.

Quartz is predominantly monocrystalline and clear, but a few polycrystalline grains were observed in all the sandstones. Some metamorphic and/or cataclastic quartz is also present. Although most of the quartz is clear, inclusions of rutile and apatite are not uncommon. Secondary quartz overgrowths are common on detrital quartz throughout the core.

The principal feldspar mineral is plagioclase, which ranges from nearly fresh to totally altered. Alteration is predominantly to clay and sericite, although a few grains are altered to saussurite.

Only trace amounts (<2%) of potassium feldspar are present in these samples. Microcline is the dominant potassium feldspar, but perthite is not uncommon and orthoclase is rare. Potassium feldspar is generally fresh, with slight alteration to clay.

Lithic fragments are common in all the samples. These fragments include shales, carbonates, and siltstones, as well as plutonic, volcanic, and metamorphic fragments. The sedimentary varieties are the most common. Relatively large mudstone clasts are also common in all the intervals studied.

Calcite, dolomite, siderite, and possibly ankerite are the carbonate minerals present in the MWX cores. Calcite cement is present in nearly all the samples, occurring as poikilotopic and patchy sparite. The calcite cement often replaces detrital grains, including quartz. Dolomitization of the calcite cement ranges from slight to total replacement. Dolomite is also the most common detrital carbonate. Yellowish rims on some of the dolomite may be ankerite. Siderite is present only in the transitional zone, and is especially common in the Paludal Interval. It occurs as micritic patches several times larger than the detrital grains. This micritic siderite often penetrates between the detrital grains and partially replaces them.

Fractures are most commonly filled with calcite. Barite and clay minerals also partially fill some fractures. The barite and clay fillings were usually followed by the calcite filling and were partially replaced by it.

Fragments of carbonaceous material and an oily organic-looking material are present in many samples. The carbonaceous material, which occurs as fragments and as thin stringers squashed along bedding planes, is common throughout the MWX cores. The oily organic material clogs intergranular pore space and is also injected along fractures. C. W. Spencer of the USGS (1982, pers. comm.) has suggested that this oily organic material may be cooked-out oil; it is most common at the top of the blanket sands. Authigenic pyrite is sometimes found associated with these carbonaceous and oily materials.

Clay minerals identified by X-ray diffraction include illite, illite/montmorillonite mixed-layer clay, kaolinite, chlorite, and montmorillonite. Illite and illite/montmorillonite, the predominant clay types, occur throughout the MWX cores; since they always occur together in these cores they will be referred to as illite in this paper. Kaolinite is common in the fluvial and blanket sands and is found as isolated occurrences in the Coastal Interval of the transitional zone. Chlorite occurs in trace amounts throughout the cores. The only occurrence of montmorillonite is in the bottom sample of the Coastal Interval.

POROSITY

The distribution of the clay minerals is significant for understanding the porosity of the sands studied. Although a small amount of the kaolinite was formed as a direct precipitate from pore waters, most of the clay minerals have been formed by chemical weathering of detrital feldspars and rock fragments. Much of the pore space is secondary intragranular moldic porosity, formed by the dissolution of altered detrital feldspars. Some pore space is formed by the dissolution of carbonate cements. Clay minerals fill nearly all of the available pore space in the MWX cores, such that open pore space is rare. As a consequence, porosity in the MWX cores is predominantly microporosity between clay mineral plates. When occurring as parallel oriented plates or as bridging clays in pore throats these clays effectively limit both porosity and permeability (Figs. 1 and 2).

TEXTURE

Textural variations are minimal throughout the core. The sandstones are of very fine (62 to 125 μm) to medium (250 to 500 μm) sand size and are generally well sorted. Detrital grains are angular to subrounded, and grain contacts are concavo-convex and sutured. The sandstones are well lithified, with carbonate, quartz overgrowths, and pressure solution as cementing agents. Large areas in most of the samples are thoroughly fused with secondary quartz and some sandstones are extensively cemented with calcite and dolomite. However, for the most part the framework is fairly open, with clay filling the open pore space. This apparent openness of the framework is caused by the prevalent dissolution of detrital grains and possibly by the dissolution of an early carbonate cement.

MINERALOGIC AND TEXTURAL TRENDS

Although mineralogic and textural variations are minimal throughout the core, some minor variations are evident when the zones are compared. These minor variations are discussed in the section that follows, beginning with the uphole zones and progressing downhole.

FLUVIAL SANDS

The only fluvial sands examined to date have occurred in a highly fractured zone extending from hole depths of approximately 1739 to 1790 m. The fluvial sands display more variation in texture than do the other zones; the most notable variation is the frequent change in grain size. These sediments are characterized by sandstone lenses separated by siltstones and mudstones. The sandstones are generally coarser grained in the fluvial sands than those that occur in the transitional and blanket sands. In general, the upper and lower lenses of the zone are of medium to fine (125 to 250 μm) sand size, and the lenses in the middle of the zone are of fine to very fine sand size.

Calcite is the predominant carbonate cement in the sandstones, and dolomite is the predominant carbonate in the siltstones and mudstones. Dolomitization of calcite is minor in the sandstones near the top of the zone and increases slightly toward the center and bottom of the zone. The central portion of a sandstone lens near the top of the zone (at 1743 to 1745 m) is relatively carbonate-free.

Illite and kaolinite are the predominant clays in the fluvial sands. Illite is the dominant clay near the top of the zone (at 1739 to 1747 m), and kaolinite is generally the dominant clay in the remainder of the zone (at 1748 to 1789 m). Chlorite is present throughout the zone in minor amounts and is more abundant in the fluvial sands than in any of the other sands studied to date.

TRANSITIONAL ZONE

The transitional zone is a fairly broad zone (at approximately 1934 to 2231 m), which forms a transition between the fluvial and shoreline blanket sands. The zone is divided into two intervals, the Coastal Interval (at 1934 to 2006 m) and the Paludal Interval (at 2160 to 2231 m). No core samples were available from depths of 2007 to 2160 m. The sandstones in the transitional zone are generally of very fine sand size, with a few interbedded mudstones and siltstones. Some sandstone lenses in the Coastal Interval are of fine sand size, but these slightly coarser sands are rare in the Paludal Interval.

Calcite and dolomite are the principal cementing carbonate minerals in this zone. The calcite has been extensively dolomitized throughout the zone. Calcite-to-dolomite ratios in the Coastal Interval approach 1:1. Dolomitization in the Paludal Interval is more extensive, and the calcite in some of the finer grained sandstones is nearly totally dolomitized.

Except at the very bottom of the Coastal Interval, illite is the only clay mineral in the transitional zone which is abundant enough for detection by X-ray diffraction analysis. Minor amounts of kaolinite and montmorillonite are present at the bottom of the Coastal Interval. Authigenic chlorite and kaolinite were observed during thin section analysis in many of the samples, but these clays occur only in trace amounts.

BLANKET SANDS

The shoreline blanket sands (at approximately 2387 to 2478 m) include the Cozzette (at approximately 2387 to 2426 m) and the Corcoran (at approximately 2470 to 2478 m) Intervals. Texturally these sandstones are the most uniform in the MWX cores. The transitional sands are of very fine sand size and border on silt size (2 to 62 μm) in the Cozzette Interval.

In all the sandstones containing carbonate cement, the calcite is totally dolomitized except for a calcareous lens near the top of the Cozzette (at 2395 to 2397 m). The sands at the bottom of the Cozzette (at 2423 to 2426 m) are devoid of carbonate cement, as are the mudstones at the bottom of the Corcoran (at 2475 to 2478 m).

Illite and kaolinite are the most common clay minerals in the blanket sands. Illite is the dominant clay mineral throughout. Kaolinite is more abundant in the Cozzette than in the Corcoran and decreases significantly in occurrence at the bottom of the Corcoran.

DIAGENESIS

The diagenetic sequences determined for each sandstone interval are fairly similar throughout the MWX cores, although slight variations are evident for each interval. The following is the general diagenetic sequence for all the sandstones examined to date (early to late):

- Early Calcite Cement(?)
- Feldspar Alteration
- Formation of Chlorite
- Quartz Overgrowths
- Calcite Cement
- Secondary Porosity
- Authigenic Clay
- Dolomitization of Calcite

CONCLUSIONS

The sands in the Mesaverde Group are generally fine-grained feldspar- and lithic-rich quartz sandstones with little variation in detrital mineralogy. The sandstones are well compacted and cemented by carbonate minerals, pressure solution, and quartz overgrowths. Although frequent minor mineralogic and textural variations can be expected in the other fluvial sands, there is no reason to suspect that any major variations in mineralogy will be observed in sandstones further uphole, since Hansley and Johnson[4] have described very similar sands near the top of the Mesaverde Group.

Porosity appears to be limited to microporosity in clay minerals which have filled nearly all the available pore space. Much of the pore space is secondary and is formed by the dissolution of feldspars and rock fragments. Most of the clay filling the pores is randomly oriented, increasing the microporosity between the clay plates; some of the clay occurs in stacked plates, greatly reducing the microporosity (Figure 1). Pore throats are commonly

filled with bridging clay (Figure 2), effectively reducing the permeability of these sandstones. Although some of the intergranular pore space has been reduced by compaction, quartz overgrowths, and carbonate cement, the primary controlling factor that reduces the permeability is the clogging effect of the clay in the pore throats.

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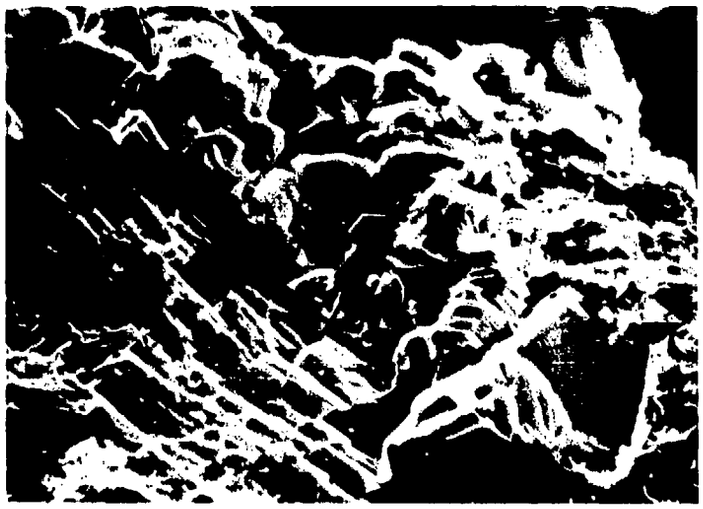

Fig. 1—Pseudohexagonal plates of kaolinite filling a pore. Some of the plates are randomly oriented whereas others occur as stacked books, reducing the microporosity. Field width 80 μm.

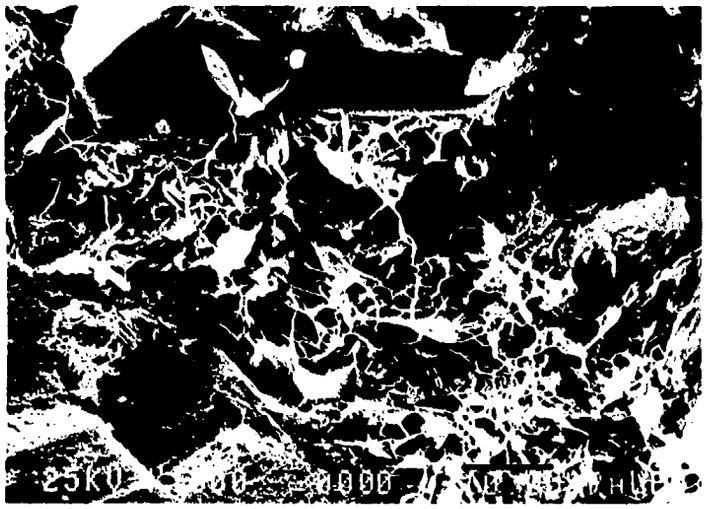

Fig. 2—Scanning electron crograph of a pore throat filled with bridging illite. Field ..dth 8 μm. (Photo courtesy of USGS).