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ALTERED VOLCANIC ASH PARTINGS IN WASATCH FORMATION COAL BEDS OF THE NORTHERN POWDER RIVER BASIN: COMPOSITION AND GEOLOGIC APPLICATIONS

by

Bruce F. Bohor, Richard E. Phillips and Richard M. Pollastro

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Altered Volcanic Ash Partings in Wasatch Formation Coal Beds of the Northern Powder River Basin: Composition and Geologic Applications

Introduction

In contrast to the coal-bearing rocks of the Appalachian and Eastern Interior Basins, those of the northern Powder River Basin exhibit more complex stratigraphic and facies relationships, and regional correlations of coal beds are, therefore, more difficult to establish. Recently, however, several coal beds in the Powder River Basin, as well as coal beds in several other coal basins of the Rocky Mountain region, have been found to contain thin but persistent layers of altered volcanic ash described as kaolinitic bentonites (Bohor, 1976, 1977, 1978, Bohor and others, 1976, 1978, Bohor and Pillmore, 1976). These layers serve as isochronous marker horizons which aid in correlating coal beds over broad areas.

The purpose of this paper is to describe the composition of these layers of altered volcanic ash and to illustrate their use in the correlation and dating of coal beds. These partings were first recognized in coal beds of the Powder River Basin in 1975 during coal resource mapping of the Croton, Truman Draw, and Twentymile Butte Quadrangles. They were shown to be altered volcanic ashes by laboratory analyses and therefore to be potentially useful for correlation and dating purposes. A basinwide study was undertaken in 1976-77 to test their value in correlation of coal beds across the Powder River Basin. Over 100 samples were collected during the course of this study and identified as altered volcanic ash by X-ray diffraction. Of these samples 38 were analyzed chemically for major and minor elements and only 9 were subjected to mineralogical separation and study. Samples from two different coal beds were dated by the fission-track method.

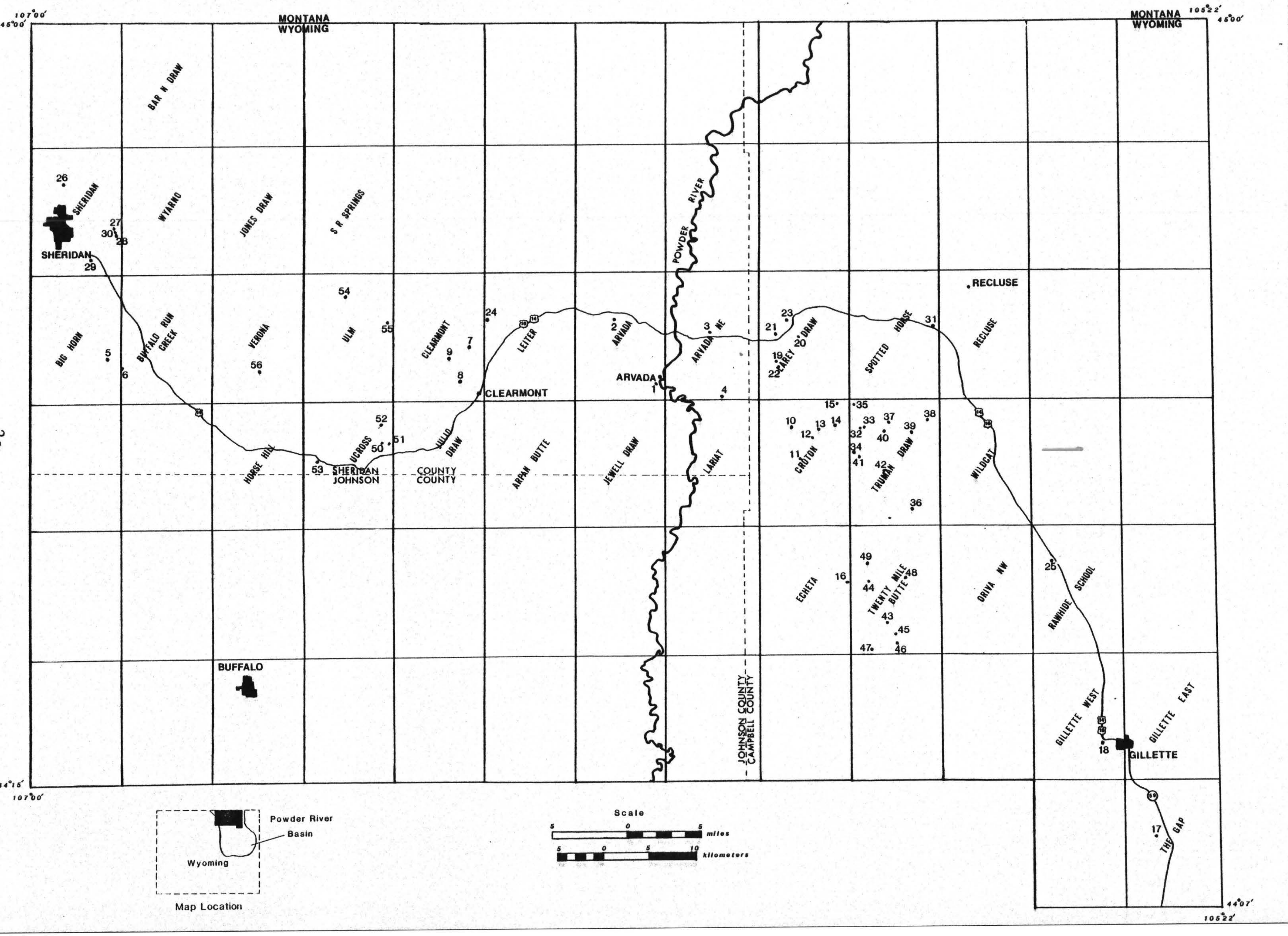
LOCATION AND STRATIGRAPHY

Wasatch coal beds containing altered volcanic ash partings are located in the northeastern Wyoming portion of the Powder River Basin (fig. 1). Two such coal beds have been traced by means of discontinuous outcrops from locations in the Gap Quadrangle, about 15 miles (24 km) south of Gillette, to the Verona Quadrangle, 16 miles (26 km) southeast of Sheridan--a linear distance of over 70 miles (113 km). The Powder River bisects this region, and its valley has cut a wide swath through the Wasatch Formation in which these coal beds are located. This disruption of outcrops by the broad Powder River valley has caused problems with surface correlations of Wasatch coals across the northern Powder River Basin. The Wasatch Formation in the northern Powder River Basin is Eocene in age and conformably overlies the Tongue River Member of the Paleocene Fort Union Formation. The boundary between the Wasatch and Fort Union Formations is transitional and cannot be definitely positioned. However, the two coal beds on which correlation was attempted using these partings, the Felix and the Parnell coal beds of the eastern portion of the basin and their equivalents, are both definitely within the Wasatch Formation.

Felix coal bed

Stone and Lupton (1910, p. 13) named the Felix coal bed for exposures of a thick coal near Felix Station on the Burlington Railroad in the southeast portion of the Twentymile Butte Quadrangle. In most exposures east of the Powder River valley, the Felix coal bed is between 10 and 25 feet (3.0 and 7.6 m) in thickness and contains a pair of thin (1/8-3/8 in.) (0.3-1 cm) altered ash (kaolinitic bentonite) partings near the top of the coal, as well as a 4-

Figure 1.—Index map showing locations and quadrangles for the kaolinitic bentonite samples analyzed from the Wasatch Formation, Powder River Basin, Wyoming



to 6-inch (10- to 15-cm) thick clay-shale parting near the middle of the lower half of the bed. The two partings maintain their position at the top of the bed east of the Powder River and are spaced about 12-15 inches (30-38 cm) apart. Where only one parting was identified, it was assumed to be the lower member of the pair owing to erosion of the upper parting or its inclusion in the over-lying shale. Olive (1957, p. 30) mentioned the presence of persistent partings in the Felix coal bed in his report on the Spotted Horse coal field; these may be the same partings that we have identified as kaolinitic bentonites.

The Felix coal bed has not been recognized as such west of the Powder River. Stone and Lupton (1910, p. 16 and 17) stated that the Felix coal bed becomes much thinner west of the Powder River, decreasing to 5 feet (1.5 m) in thickness where it passes under drainage. In fact, the thinning and splitting of the Felix coal bed occur several miles to the east of the Powder River in the Arvada NE Quadrangle (fig. 7).

Over most of the eastern portion of the northern part of the Powder River Basin, the Felix coal bed is characteristically thick (10-25 ft) (3-8 m) and massive, except for certain exposures in which it thins and splits into natural levees abutting channel sandstones. Thus over this area it is easily recognized by its thickness, being the only thick coal in this part of the section. Even where burned, its position is easily recognized because of a characteristically thick development of clinker of "red dog" (alteration of the overlying beds due to the heat of burning).

Parnell coal bed

The Parnell coal bed was first named by Haddock and others (1976) and further described by Kent and others (1977) from exposures on the Parnell ranch in the Truman Draw Quadrangle. The Parnell bed closely approaches the base of the overlying Truman coal bed (also newly named by these authors) in the Truman Draw Quadrangle and may actually coalesce with it. However, to the west and southwest of Truman Draw, the Parnell can be found as much as 60-80 feet (18-24 m) below the base of the Truman coal bed.

The Parnell coal bed usually contains a single 0.75-inch (1.9 cm) kaolinitic bentonite parting near the top of the bed. In places, however, this bentonite layer actually occurs in the shale immediately above the top of the coal bed. Because none of the other coal beds between the Parnell and Felix beds contain kaolinitic bentonite partings in the eastern portion of the basin, the presence of this parting in the Parnell may help to identify it in stratigraphic sections across the Powder River Basin.

Other Wasatch coal beds

Several other coal beds occurring stratigraphically below the Murray (Felix) coal bed in the western part of the Powder River Basin contain kaolinitic bentonite partings. During field work in the Sheridan Quadrangle, Hinrichs (1978) collected partings from the Bar N, Burgess, and Roland coal beds that have been identified as kaolinitic bentonites. Additional samples or partings from some of these coals in the Sheridan and Big Horn Quadrangles were collected by Hinrichs and the authors during the summer of 1978.

The Arvada coal bed near the town of Arvada on the Powder River (A-1) also contains a kaolinitic bentonite parting. It is not known what the correlation of the Arvada bed is with other named Wasatch coal beds, except that it occurs stratigraphically below the Felix coal bed.

The Ulm 1 coal bed in the Ulm Quadrangle also contains a kaolinitic bentonite parting in at least one location in the Ulm Quadrangle (Mapel's #16, in Mapel and Dean, 1976).

A thin, locally occurring coal bed about 30 feet (9.2 m) below the base of the Felix coal bed in Truman Draw Quadrangle (TD-B-13b) contains a thick parting for which the X-ray diffraction trace resembles a kaolinitic bentonite. One outcrop of this parting was described as a tan shale 2.4 feet (73 cm) thick, with its lower portion pinkish-tan, hard and banded. The unusual thickness and only local extent of this parting may be due to partial water transport after deposition of the ash.

Other coal beds in the Wasatch Formation of the Powder River Basin may contain kaolinitic bentonite partings, but they were not discovered during the course of this study.

LABORATORY STUDIES

Bulk Mineralogy

The bulk-sample mineralogy of these kaolinitic bentonite partings was studied by X-ray diffraction. Representative pieces of the partings, as collected, were passed through a ceramic-faced jaw crusher and the product then pulverized to <100 mesh (150 μm) using a disc grinder (also ceramic faced). This powder was then made up into a soft-paste consistency with distilled water and smeared on a frosted glass slide with a spatula, according to the technique described by Gibbs (1965). The X-ray equipment used was either a Picker Nuclear Corp. diffractometer operating at 35 Kv and 20 ma, or a Rigaku Miniflex diffractometer operating at 30 Kv and 10 ma.[1] Cu-target tubes were used in both machines.

The smear-slide technique has the advantage of recording both the clay and non-clay minerals present, because the whole (bulk) sample is used. Clay-mineral platelets are preferentially oriented with their basal surface parallel to the slide surface by the smearing action, resulting in enhanced diffraction

[1]Use of brand names in this report is for descriptive purposes only, and does not constitute endorsement by the U.S. Geological Survey.

of their diagnostic 00ℓ peaks. However, non-clay-mineral diffraction peaks are also recorded from just below the oriented layer and make qualitative identification of these phases possible.

When the possibility of mixed-layer clay phases was revealed by the X-ray diffraction traces, these slides were treated with glycol vapors in a [illegible] desiccator placed in an oven at 60°C overnight. The treated slides were X-rayed again after this treatment to see if any expandable phases were present. Certain selected slides were also heated in a muffle furnace at 400°C for one hour and re-X-rayed to observe the collapse of these phases.

The results of these X-ray diffraction tests are given in table 1 (appendix). The samples of kaolinitic bentonite partings are listed by the quadrangles in which they were collected, in alphabetical order. The actual sample locations are shown on the map in figure 1.

Clay Mineralogy

Figure 2 shows the X-ray diffraction trace of a typical kaolinitic bentonite parting from the Wasatch coal beds of the northern Powder River Basin. The major mineral peaks of kaolinite and quartz are labelled. Kaolinite is the major mineral phase present, along with a relatively minor amount of quartz. The high degree of crystallinity of the kaolinite is indicated by the sharpness of the basal (001 and 002) peaks and the prominence of the prism reflections between 20 and 21° 2θ. These sharp basal peaks and distinct prism reflections are typical of authigenic kaolinite, formed in place by the alteration of volcanic glass in the swamp environment. Scanning electron micrographs (see fig. 5) confirm the authigenic nature of the kaolinite, showing idiomorphic kaolinite platelets arranged in large vermicular stacks or "worms." These delicate, unabraded crystal platelets

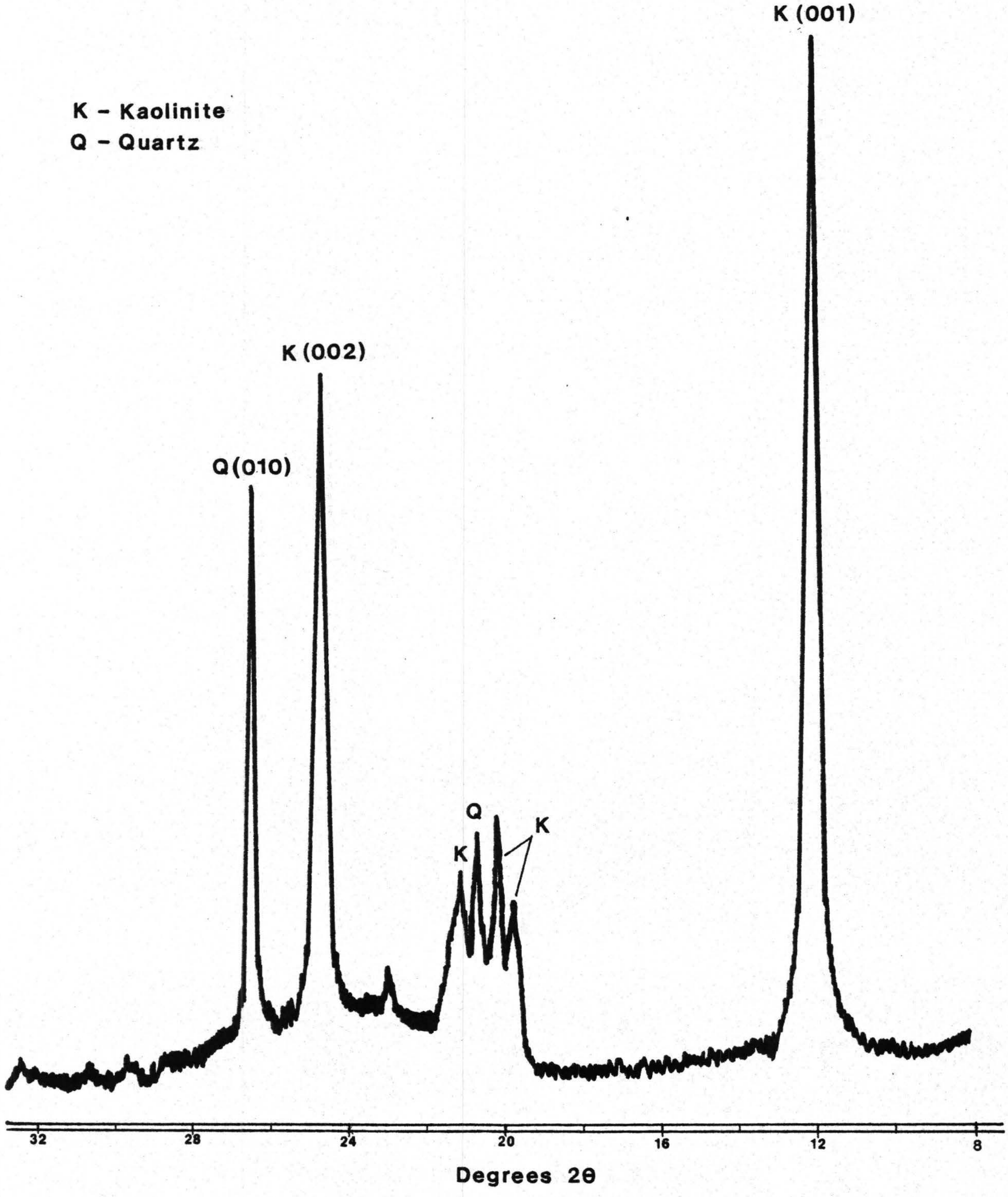


Figure 2.--Typical X-ray diffraction pattern of a kaolinitic bentonite from this study (Felix coal bed).

could not have survived transport in this state, and so must have formed authigenically (in situ).

Sometimes trace amounts (<5 percent) of a mixed-layer clay mineral are observed in these diffraction traces between 6 and 8° 2θ. Often these mixed layers do not expand with glycol or collapse upon heating. In these cases, the mixed layers may be propped apart with hydroxy-alumina interlayers (Vicente and others, 1977). When these interlayers are not present, the expansion and collapse tests indicate that the mixed layers probably are composed of illite and smectite (montmorillonite).

Figure 3 is a typical X-ray diffraction trace of a non-volcanic parting in a Wasatch coal--in this case a 4- to 6-inch (10- 15-cm) thick gray shale parting in the Felix coal bed. The differences between it and a kaolinitic bentonite (fig. 2) are obvious by inspection. The shale parting has the typical detrital clay mineral suite of ragged, low-intensity kaolinite peaks, plus illite and smectite with relatively large amounts of quartz. None of the clay-mineral basal peaks are sharp or well-defined, as is the case with the kaolinitic bentonite, and kaolinite prism peaks are nonexistent. There should be very little overlap between the appearance of a kaolinitic bentonite X-ray diffraction trace and that of a typical detrital clay or shale parting from a coal bed, unless some detrital component is admixed with the volcanic ash fall. This combination rarely happens when the parting is found enclosed within a coal bed because of the extremely low-energy environment, but could occur when the parting is in an impure bony coal or carbonaceous shale.

Non-clay Mineralogy

Heavy Fraction--Heavy-mineral separates from nine samples of kaolinitic bentonites in both the Felix and Parnell coal beds and their possible equivalents, and one sample from the top of the Bar N coal, were analyzed by

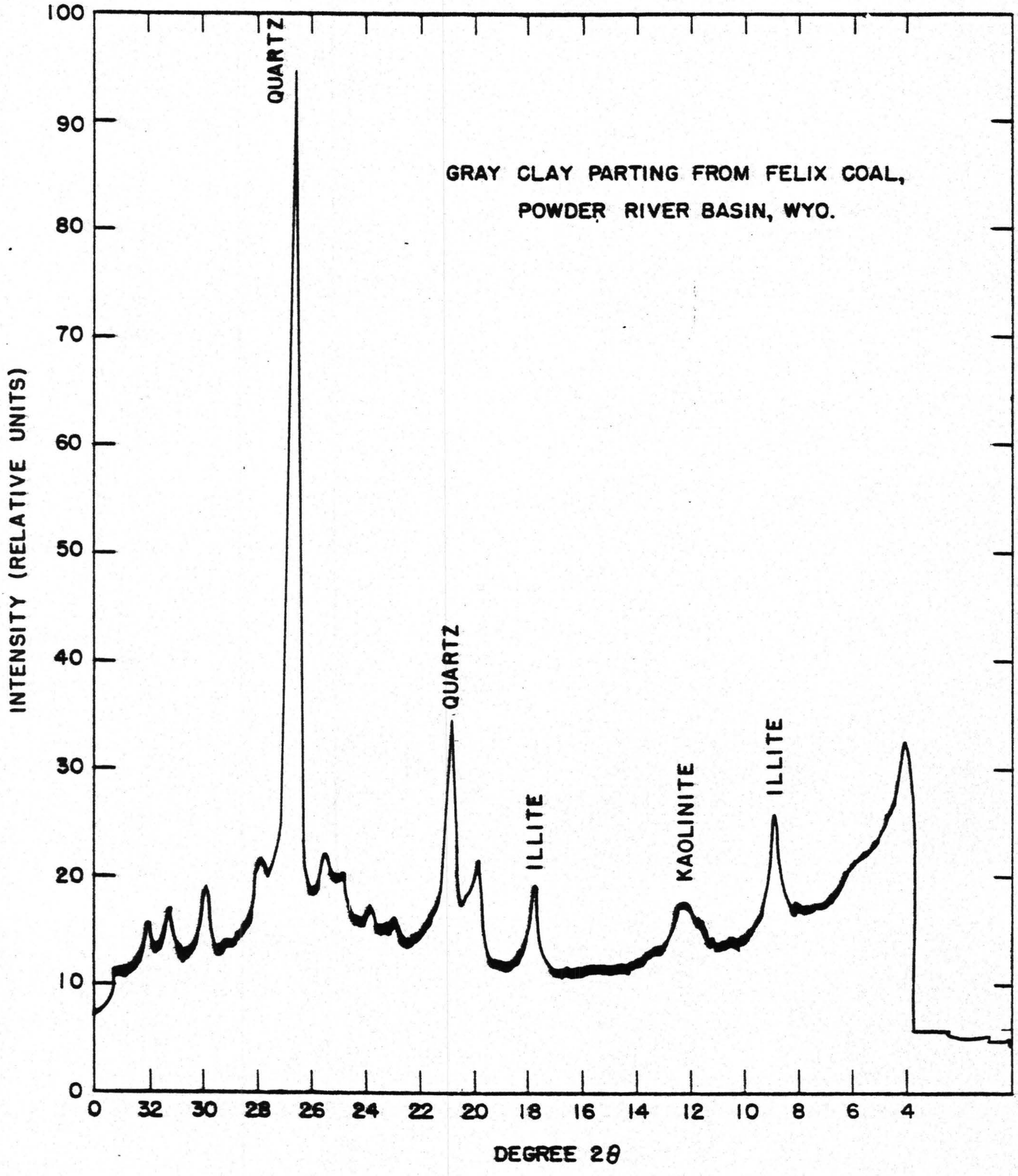


Figure 3.--Typical non-bentonite parting (Felix coal bed)

optical and scanning electron microscopy and X-ray diffraction techniques. Each bentonite was ultrasonically disaggregated, partially cleaned of clay-sized material by settling in water, and, using Bromoform (S.G. = 2.85) as the heavy-liquid medium, fractionated for mineralogical and chemical analysis. Table 2 (appendix) summarized the analyses, listing the samples analyzed and the relative abundance of each phase present. Initial identifications for each of the mineral fractions were performed by optical microscopy using grain mounts in various ranges of refractive-index mediums. Spindle-stage techniques as described by Wilcox (1959) were also employed when needed. Qualitative X-ray diffraction patterns were recorded for each heavy-mineral suite, as well as hand-picked concentrates of specific species of interest from both the heavy- and light-fraction material if further phase characterization of that species was needed. Each phase identification was then complemented by scanning electron microscopy with energy-dispersive X-ray elemental analysis.

Initial petrographic examination of the heavy-mineral fractions from each bentonite sample revealed the common presence of idiomorphic zircon grains, usually occurring as the dominant heavy-mineral species. This was also reflected on X-ray diffraction patterns by strong, characteristic zircon peaks. The crystal size of zircon varied considerably in all samples; however, it always displayed its characteristic prismatic habit with sharp pyramidal terminations. Typically, the grain size of these zircons ranged from 200 μm to 3 μm in length and from 50 μm to 0.5 μm in width. Length-to width ratios (aspect ratios) of these zircons were as large as 40:1. These zircons occurred as elongate rods or extremely fine needles a micrometer or less in width. On the other hand, some has aspect ratios as low as 1:1. They appeared as diamondshaped grains with well-marked crystal faces. The grains were most often colorless, were sometimes zoned, and commonly contained inclusions.

Sphene was identified as a very abundant to rare phase in the heavy-mineral fractions of the samples studied. It most commonly occurred as fairly large (∿60 μm), subhedral, irregular grains of angular aspect exhibiting its characteristic high refractive index, extreme birefringence, and conchoidal fracture. Sphene was also quite readily recognized by its dimpled surface.

All samples examined contained variable amounts of anatase, rutile, and, occasionally, brookite. Anatase occurred as gold- or indigo-blue-colored rectangular grains, commonly having bevelled edges and marked by "geometric patterning." These grains appeared to be isotropic because the orientation of the crystal's optic axis was perpendicular or nearly pendicular to the microscope stage. Simple and compound pyramidal forms of anatase, as well as massive aggregates of crystals, were also common. The presence of anatase is most likely due to <u>in situ</u> decomposition of titaniferous minerals such as ilmenite.

Rutile usually occurs as yellow-brown or red-brown, euhedral, elongate, prismatic grains which commonly contain longitudinal striations.

Orange and brown tabular grains of brookite were identified in a few of the samples analyzed. The grains usually had truncated corners and are thoroughly marked by striations parallel to their tabular outline.

Phenocrysts of allanite, a lanthanum- and cerium-rich rare-earth epidote, were also identified in a few of the bentonites analyzed. Allanite is characterized optically by its strong pleochroism from honey brown to dark reddish brown, strong dispersion, and biaxial negative crystals, which commonly display an optic-axis ("compass needle") interference figure. Spectrum lines of lanthanum and cerium were easily resolved by energy-dispersive X-ray analysis of the allanite grains, confirming its identification. Several allanite phenocrysts also showed some micropitting of their surfaces.

Tourmaline was easily identified in several of the samples analyzed, occurring as irregular grains to euhedral, terminated, prismatic crystals exhibiting characteristically strong pleochroism and commonly containing numerous dark inclusions and gas bubbles. Energy-dispersive X-ray microanalysis of these tourmalines resolved compositions indicating a solid solution of Na, C, F, and Mg in their structure. The tourmalines identified in these bentonites were typically colored slate blue, olive green, or greenish brown. All these colors, as well as habit and refractive index, are characteristic of the variety schorlite.

Colorless to yellow-green grains of epidote were identified in almost all heavy fractions of the samples analyzed. Epidote grains were typically less than 150 μm in size and contributed to 2 percent or less of the heavy-mineral portion; however, sample BM-3 was found to contain 8-10 percent epidote.

Iron-rich garnets containing some manganese were occasionally found, as were relatively large pseudohexagonal plates of biotite. Rarely, topaz, apatite, and tremolite/actinolite also were identified in the heavy-mineral fractions of the analyzed samples.

Secondary jarosite was identified in many of the samples occurring as single deep-yellow rectangular grains or as aggregates of fine crystals. Jarosite is commonly found coating coal beds in the Rocky Mountain region, and concentrations of the mineral are found in cleats, fractures, and partings at outcrops. Jarosite, therefore, is occasionally found to be a major portion of the heavy-mineral assemblage. X-ray diffraction analysis of jarosite from the Powder River Basin samples showed much of it to be either the ammonium-rich variety, ammoniojarosite, or the sodium-rich variety, natrojarosite.

Light-Fraction--After bromoform separations, the light-mineral portion (S.G. <2.85) of each sample was analyzed using techniques similar to those used on the heavy-mineral separates. Analysis of the light fraction is also summarized in table 2 (appendix).

Investigation of the light-mineral fractions revealed the presence of numerous β-quartz forms (hexagonal dipyramids) in all the samples analyzed. Most of the β-quartz forms were found to be perfectly developed, showing sharp crystal edges. Some of the grains of the β-quartz forms did show some rounding, apparently due to in-melt solution, Inclusions were fairly common in these grains. The line drawings of figure 4 show the typical habit of the β-quartz-form crystals from these bentonites. Quartz was always found in two types: the quartz forms as previously described; and anhedral, angular to subangular, clear grains of quartz which were much more abundant than the β-quartz forms.

Sanidine was another non-clay mineral phase identified in the light fraction of the bentonites examined. Sanidine occurred as anhedral to subhedral, subangular grains which were usually clear. Twinning was uncommon. Scanning electron microscopy showed several of these sanidine grains to contain micropitted surfaces. Such micropitting of feldspar has been suggested by others (Keller and others, 1963; Huang and Keller, 1970) to be due to an early stage of kaolinization of the feldspar.

Laths of gypsum were commonly identified in almost all samples analyzed. Gypsum is a common secondary constituent of Western coals and their associated rocks.

Chemical Analyses

Chemical analyses were performed on 36 of the samples collected for this study (see appendix, tables 3-6). Thirty-three of the 36 samples were analyzed using the computerized emission spectrograph in the USGS (U.S. Geological

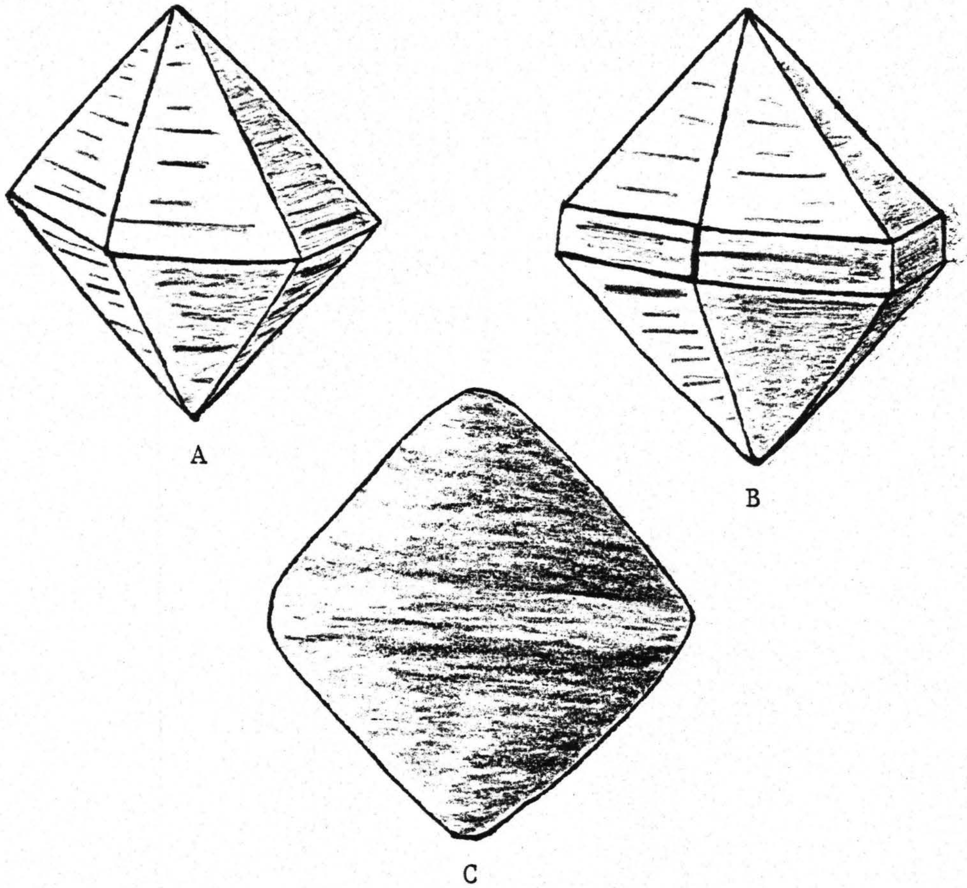


Figure 4.--Typical β-quartz forms found in kaolinitic bentonites:
A - hexagonal dipyramid with no prism face
B - hexagonal dipyramid with short prism face
C - dipyramidal phenocryst showing remelted faces

Survey's) Reston, Virginia, analytical laboratories in order to get a rare-earth analysis; the remaining three were analyzed using the emission spectrograph in the USGS analytical laboratories in Denver. All were analyzed for major elements by X-ray fluorescence and for uranium-thorium by the delayed-neutron method.

The purpose of these analyses was to see if any of the major or minor trace elements would prove useful for correlation of these partings. Because of the high degree of leaching and alteration to which they have been subjected, however, most of the mobile elements from the original volcanic glass have been dispersed and their presence in the samples is highly variable. Only those elements locked in the resistate minerals have remained constant and could possibly be useful for correlation. These elements include U, Th, Ti, and certain rare earths, the latter probably tied up in allanite and apatite.

One interesting bit of information to be derived from chemical analyses of these partings is the ratio between the oxides of titanium and aluminium. Spears and Kanaris-Sotiriou (1975) found that low values of this ratio indicated a silicic (acidic) volcanic source magma, while relatively higher ratios indicated intermediate to mafic (basic) sources. All of the samples analyzed from the Powder River Basin gave relatively low ratios of TiO_2/Al_2O_3, ranging between 0.004 and 0.044, indicating a silicic (acidic) source. The three samples whose ratios exceed 0.020 also had higher than normal Fe_2O_3 values, and a separate iron-titanium mineral or solid-solution phase may be invoked for these samples, possibly from a sedimentary source. Excluding these three anomalously high ratios, the values for the samples then ranged between 0.004 and 0.019. Spears and Kanaris-Sotiriou's acidic (silicic) source samples had TiO_2/Al_2O_3 ratios ranging from 0.004 and 0.021.

Zircon Fission-Track Ages

Heavy-mineral separations were performed on several of the partings, as described in the section "Laboratory Studies--Non-Clay Mineralogy." In each case, zircon was the dominant primary mineral present. This made it fairly easy to hand-pick them, with the aid of a stereomiscoscope, for dating by the fission-track method (Fleischer and others, 1964). Only euhedral, non-abraded zircons greater than 75 μm in length were chosen for analysis. This assured that no detrital grains were dated.

Zircons from two samples were submitted to C. W. Naeser of the U.S. Geological Survey for fission-track analysis. One of them was TMB-10b, which was a bentonite from the Parnell coal bed in the Twentymile Butte Quadrangle. The other sample, designated F.C., is a combination of the two upper bentonites in the Felix coal bed, collected from several localities in the Truman Draw, Croton, and Twentymile Butte Quadrangles.

Naeser reported an age of 43.4 ±1.7 m.y. (million years) for sample F.C., and an age of 43.9 ±2.3 m.y. for TMB-10b (table 7, appendix). According to the time scale proposed by Funnell (1964), these ages would place the samples near the late-middle Eocene boundary. Funnel's time boundaries for the Eocene are as follows: 37-38 m.y. to approximately 45 m.y. for the upper, 45 m.y. to 49 m.y. for the middle, and 49 to 53-54 m.y. for the lower.

Two fossil ages reported by Olive (1957) are slightly discordant with the fission-track ages. Olive stated (p. 19) that Roland W. Brown collected the plant fossil Salvinia preauriculata "from beds above and below a coal bed which is tentatively correlated with the Felix bed....Brown considers this species to be definitely of early Eocene age." Olive also reported (p. 19-20) that freshwater mollusk shells collected by W. J. Mapel "were identified by Teng-chien Yen who considers them to be early Eocene in age." The stratigraphic position of Mapel's collection site within the Wasatch Formation was somewhere between the Ulm_2 and the Felix coal beds (W. J. Mapel, oral communication, 1979).

At present, no simple answer exists for the apparent discrepancy between the fossil and fission-track ages. No other absolute ages are known with which to compare the ages reported here from the Wasatch Formation in the area covered by this report. We hope that further research by the authors, with the aid of C. W. Naeser, will resolve the discrepancy.

EVIDENCE OF VOLCANIC ORIGIN

Clay Mineralogy--The Wasatch Formation in the northern Powder River Basin is continental in origin, as evidenced by the presence of coals and alluvial sandstones and the absence of any marine beds. It apparently formed as a large alluvial plain, filling the basin between the Big Horn Mountains on the west and the Black Hills on the east. Extensive coal-forming swamps developed between the major alluvial channel systems (Sharp and Gibbons, 1964, p. 18-19). The volcanic ash that fell sporadically into these swamps during Wasatchean time was preserved as partings in the low-energy environment of the peat swamp.

The ash was composed mainly of fine glassy dust, as evidenced by the dearth of crystalline material in the bulk samples and the extremely small size of those crystals that are present. This vitric volcanic dust is metastable and would have been very reactive in the low pH, freshwater, organic-rich, high-leaching environment of the peat swamp. It would have altered rapidly to kaolinite under these conditions. Slaughter and Early (1965, p. 74) showed by means of reaction equations that, in a relatively basic system, volcanic glass alters to montmorillonite (smectite), but in a relatively acid system (as occurs in peat swamps), the reaction results in kaolinite being precipitated.

Organic acids play an important role in the preferential development of kaolinite. La Iglesia and Van Oosterwyck-Gastuche stated, in an article on kaolinite synthesis (1978, p. 406), "The genesis of the 'tonstein' beds is also certainly related to a weathering [alteration] through organic matter of the humic or fulvic type".

These authors further stated that kaolinite genesis involves a dynamic equilibrium related to the degree of leaching by extremely dilute solutions; strong leaching conditions result in gibbsite, less strong generate kaolinite, and weak leaching gives sericite or 2:1 layers (smectite). The ionic concentration in the leachates depends more on the degree of leaching than on the nature of the primary minerals, thus confirming the primary importance of the physicochemical conditions of weathering on clay-mineral genesis.

Keller (1970, p. 792) put it more clearly when he stated that the clay mineral formed directly from a parent substance (such as volcanic glass) is a reflection of its genetic environment. Thus it should not be surprising that the same volcanic ash fall alters to kaolinite in a peat swamp (freshwater) and to smectite (montmorillonite) on the seafloor. Waage (1955, p. 28; 1961, p. 18, 25-26, 100) showed by field and X-ray diffraction evidence that ash beds (bentonites) used as key markers in the Dakota Group along the Front Range foothills in Colorado varied in mineralogy from kaolinitic in the deltaic facies to montmorillonite in the marine facies, thus faithfully reflecting the depositional environment in their clay mineralogy. Smectite (montmorillonite) clay minerals are only rarely found in Wasatch altered volcanic ashes of the Powder River Basin because of the absence of normal marine environments which could generate these minerals.

Monomineralic clay-mineral suite, such as these partings (see fig. 2) are almost always the result of the weathering of a homogeneous source material, such as volcanic glass. Detrital clay minerals derived from a varied source terrain result in a mixed clay suite (see fig. 3).

Additional evidence that these partings are volcanic ashes altered in situ is provided by the scanning electron microscope (SEM). Figure 5 is a SEM photo of one of the Felix coal bed partings from the Powder River Basin; it shows curved stacks of unabraded kaolinite platelets (vermicules) that could only be authigenic. Figure 6 is a SEM photo of a Felix coal bed parting showing a kaolinized fragment of what probably was a glass shard in the original volcanic ash. Bentonites occurring in coal beds have been designated as tonsteins in European literature (Williamson, 1970; Spears and Rice, 1973), although not all layers called tonsteins are volcanic in origin. For this reason the term tonstein is not used in this paper, because only bentonites (altered volcanic ashes) fulfill the requirements for an isochronous, datable marker horizon useful for correlation over broad areas.

The term "bentonite" was defined by Ross and Shannon (1926, p. 79) as "a rock composed of a crystalline clay-like material formed by the devitrification and accompanying chemical alteration of a glassy igneous material, usually a tuff or volcanic ash." This alteration takes place in situ following deposition of the ash, and the type of clay material resulting depends on the nature of the depositional environment. Consequently, bentonites do not have to be composed mainly of the clay mineral montmorillonite (smectite), as is generally believed. Weaver (1963) and Schultz (1963) both reported numerous examples of bentonites whose clay-mineral composition is mainly non-montmorillonitic (non-smectite). The coal-forming freshwater swamps of the Eocene Epoch in the Powder River Basin presumably exhibited the low pH, low Eh, highly leaching conditions of their modern analogues, and these conditions favor the formation

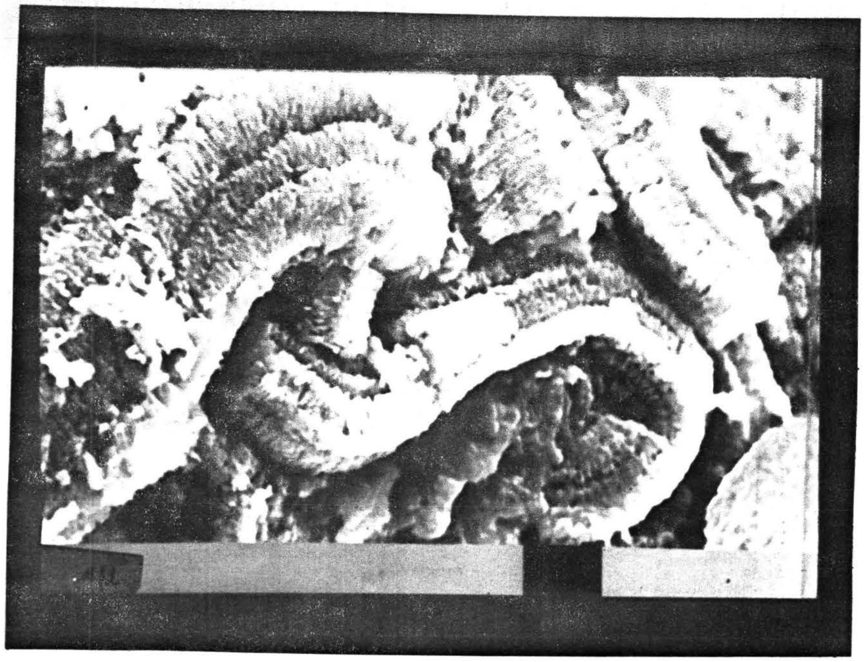


Figure 5.--Vermicular kaolinite from a kaolinitic bentonite (Felix coal bed) photographed with SEM (scanning electron microscope). Black bar at bottom equals 4 micrometers.

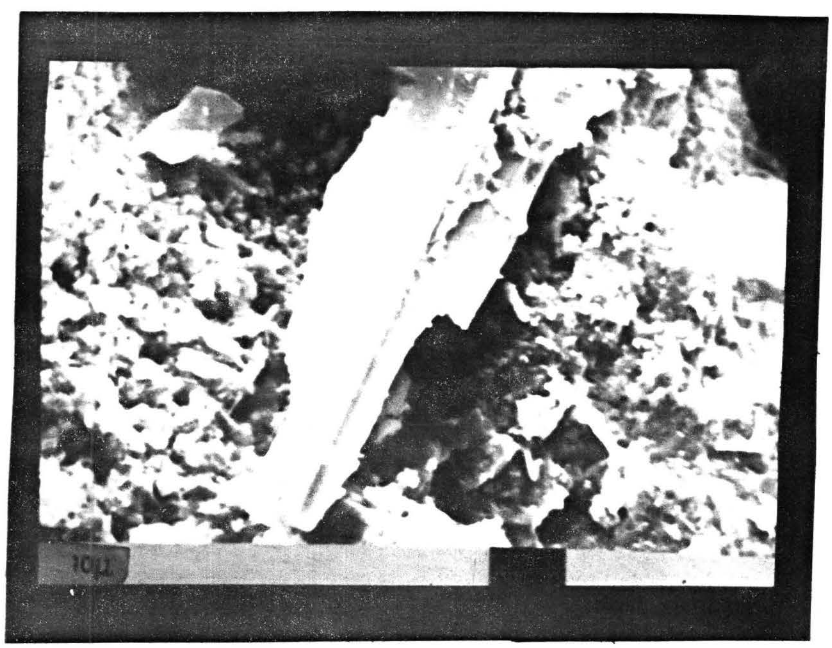


Figure 6.--Kaolinized glass shard in a kaolinitic bentonite (Felix coal bed). Black bar at bottom equals 10 micrometers.

of kaolinite as the stable clay mineral. Thus, kaolinite is the major clay-mineral component of the bentonites in the coal beds of this report.

Non-clay Mineralogy--The paucity of non-clay minerals in these partings argues for their volcanic origin, because most of the ash fall was probably glassy and therefore altered to clay, leaving little in the way of non-clay minerals. Detrital sources would have contributed a much greater percentage of non-clay minerals--especially quartz, which is notably low in these partings, as compared to other argillaceous sediments (Schultz, 1963).

The non-clay mineral suite is very restricted, consisting only of primary resistate minerals, some secondary minerals developed during alteration and weathering, and a few detrital minerals. The light fraction contains two distinct types of quartz--clear anhedral embayed grains, and euhedral hexagonal dipyramidal crystals (β-quartz forms) that are specifically derived from volcanic sources (Rogers and Kerr, 1942, p. 187; Triplehorn and others, 1977; Steen-McIntyre, 1977; Slaughter and Early, 1965). Sanidine, a high-temperature orthoclase feldspar, also occurs in the light fractions of these partings and is specifically volcanic in origin (Rogers and Kerr, 1942, p. 235; Winchell, 1947, p. 353).

The dominant heavy-mineral species in these partings is idiomorphic zircons. The lack of any abrasion of these crystals indicates that they are not detrital and therefore are most likely volcanic in origin. Their concordant age with the enclosing sediments, as determined by the fission-track method, is further proof of their volcanic origin. Allanite, a rare-earth epidote identified in several of the partings, also is considered to be specifically volcanic (Izett and Wilcox, 1968). Apatite is a common constituent of volcaniclastic rocks (Smith, 1967; Weaver, 1963). Sphene, anatase (titanite), and rutile are almost always found in the heavy-mineral fractions of these partings in variable amounts from very abundant to rare. Although not specifically volcanic, they have been found in marine bentonites by other workers (Weaver, 1963; Shall, 1977). The relatively large, euhedral, pseudohexagonal platelets of biotite found in these partings are considered to be specifically volcanic (Huff, 1963).

The other heavy-mineral components of these partings are less specifically volcanic and in some cases may be detrital. Tourmaline is often considered to be detrital, but also has been found in bentonites by Weaver (1963). Common epidote is probably detrital, but its occurrence in these partings also may be due to some form of paragenesis. Topaz, which is rarely found in these partings, has been known to occur in rhyolite, but may also be detrital. The tremolite-actinolite and garnet in these samples are almost certainly due to detrital contamination.

CORRELATION

One of the major purposes of this investigation was to attempt the surface correlation of Wasatch coal beds across the northern Powder River Basin through the use of kaolinitic bentonites. Two coal beds from the eastern portion of the area, the Felix and the Parnell, were selected because both contained these partings and their outcrops were interrupted to the west by the broad valley of the Powder River. It was hoped initially that the individual partings could be specifically identified by distinctive mineralogy or chemistry, but it soon became evident that this would not be the case. Thus, correlation could only be accomplished using these partings when they exhibited some unique physical appearance or pattern of occurrence. Fortunately, these requirements were met by the characteristic doublet of thin kaolinitic bentonites found in the upper portion of the Felix coal bed. Nothing usefully distinctive was discovered about the single kaolinitic bentonite parting in the Parnell coal bed, however, except that none of the other coal beds between it and the Felix contains these partings, at least in the eastern portion of the area studied.

Field work by the senior author in 1977 led to the identification of coal beds correlating with the Felix west of the Powder River valley. One of these Felix-correlative units was called the Murray coal bed by Mapel (1959) in the Lake DeSmet area (Ucross Quadrangle). The Murray coal bed in the Ucross Quadrangle was identified as a Felix equivalent by the presence of the characteristic doublet of kaolinitic bentonites near the top of the bed, even though the Murray coal bed bears little physical resemblance to the Felix coal bed of the eastern Powder River Basin. This same doublet was found in outcrop samples C-#1, 2, and 8, in the Clearmont Quadrangle and sample Le #3 in the Leiter Quadrangle (samples 2, 8, 9, and 24, respectively, in fig. 1). These presently unnamed coal beds are also considered Felix equivalents and correlative with the Murray bed in the Ucross Quadrangle.

Culbertson and Mapel (1976) showed the relative position of Wasatch coal beds in the area east of Sheridan, Wyo. The left-hand portion of figure 7 was modified from their line of sections and shows the Arkanses coal zone of the northern part of their study as being approximately equal stratigraphically with the Murray coal bed of the Ucross Quadrangle in the Lake DeSmet area. We did not find any kaolinitic bentonites in the Arkansas coal zone, however, and thus cannot confirm this equivalency on the basis of these partings.

The Parnell coal bed has been identified and mapped in the Croton, Truman Draw, and Twentymile Butte Quadrangles in the eastern portion of the Powder River Basin. West of these quadrangles, the Parnell is usually missing by erosion, and it is not until some distance west of the Powder River valley

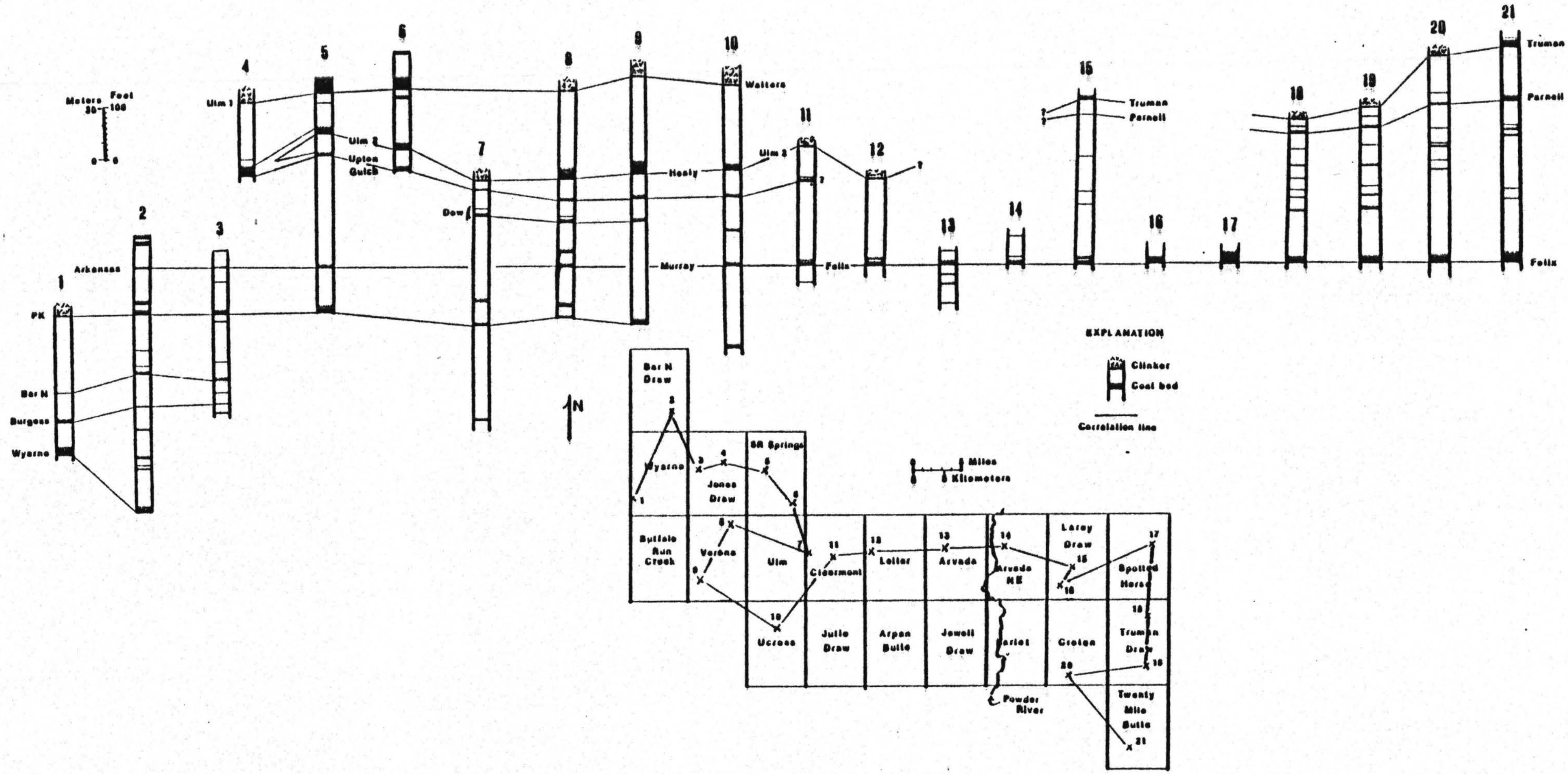


Figure 7.--Columnar sections from outcrop measurements of Wasatch Formation coals across the northern Powder River Basin. Sections 1 through 10 modified from Culbertson and Mapel, 1976.

that enough section is present to contain its equivalent. The interval between the Ulm 2 coal bed and the equivalent of the Felix coal bed in the Clearmont Quadrangle is about right for assuming that the Ulm 2 is the western equivalent of the Parnell coal bed of the eastern Powder River Basin. The Ulm 2 coal bed contains a single kaolinitic bentonite parting, as does the Parnell coal bed. However, the mineralogy of these two partings cannot be definitely correlated at this time, and we can only suggest that the Ulm 2 coal bed may be the western equivalent of the Parnell coal bed. If this suggestion is correct, it would seem to imply that the Ulm 1 coal bed of the western Powder River Basin is equivalent to the Truman coal bed to the east on the basis of interval, thickness, and the characteristic burning on outcrop. Further investigations are needed to clarify these possible correlations.

SUMMARY AND CONCLUSIONS

Field and laboratory studies indicate that several coal beds in the lower part of the Eocene Wasatch Formation, Powder River Basin, Wyoming, contain thin but persistent layers of altered volcanic ash. The clay-mineral composition of these layers is predominantly kaolinite with traces of mixed-layer mineral, and therefore these layers are designated as kaolinitic bentonites. The kaolinite is authigenic, as indicated by delicate vermicular stacks of euhedral crystals. The non-clay-mineral component includes euhedral β-form quartz crystals, sanidine, idiomorphic zircons, biotite, and allanite, all of which are specific indicators of volcanic origin. Titania-alumina ratios taken from whole-rock chemical analyses of these volcanic partings indicate a silicic source magma. The layers of kaolinitic bentonite serve as isochronous marker horizons and aid in correlating coal beds. The Felix coal bed of the Wasatch Formation was traced westward across the Powder River Basin by means of these kaolinitic bentonites. The Felix coal bed of the eastern portion of this area correlates with the Murray coal bed farther west in the Lake DeSmet area, and it may correlate with the Arkansas coal zone of the Sheridan area.

Fission-track measurements on the zircons separated from these partings in two different coal beds gave ages averaging 43.7 m.y.

No specific chemical or mineralogical parameters were found that could be used to identify individual partings. Therefore, at the present time, only unique sequences or unusual thicknesses of these partings can be used for correlation purposes.

REFERENCES

Bohor, B. F., 1976, Mineralogic and textural features of some altered volcanic ash (tonstein) layers in coal-bearing facies of the Rocky Mountain region: The Clay Minerals Society, 25th Annual Clay Minerals Conference, Corvallis, Oregon, Programs and Abstracts, p. 30.

_____1977, Tonsteins as correlation tools and environmental indicators of Rocky Mountain coals: Geological Society of America Abstracts with Programs, v. 9, no. 6, p. 710-711.

_____1978, Kaolinitic bentonite partings (tonstein) in coals of the western United States: Univ. of Oxford, England, Mineralogical Society (Clay Minerals Group), Sixth International Clay Conference, London, England, Book of Summaries, p. 713.

Bohor, B. F., Hatch, J. R., and Hill, D. J., 1976, Tonstein partings in Tertiary coals of the Rocky Mountain region: American Association of Petroleum Geologists Bulletin, v. 60, no. 4, p. 651.

Bohor, B. F., and Pillmore, C. L., 1976, Tonstein occurrences in the Raton coal field, Colfax County, New Mexico: New Mexico Geological Society 27th annual field conference Guidebook, Vermejo Park, p. 177-185.

Bohor, B. F., Pollastro, R. M., and Phillips, R. E., 1978, Mineralogical evidence for the volcanic origin of kaolinitic partings (tonstein) in Upper Cretaceous and Tertiary coals of the Rocky Mountain region: The Clay Minerals Society, 27th Annual Clay Minerals Conference, Bloomington, Indiana, Programs and Abstracts, p. 47.

Culbertson, W. C., and Mapel, W. J., 1976, Coal in the Wasatch Formation, northwest part of the Powder River Basin near Sheridan County, Wyoming: Wyoming Geological Association Guidebook - 28th Annual Field Conference, p. 193-201.

Fleischer, R. L., Price, P. B., and Walker, R. M., 1964, Fission-track ages of zircons: Journal of Geophysical Research, v. 69, no. 22, p. 4885-4888.

Funnell, B. M., 1964, The Tertiary Period, in Harland, W. B., Smith, A. G., and Wilcock, B., eds., The Phanerozoic time scale - a symposium: Geological Society of London Quarterly Journal, v. 120 s. p. 179-191.

Gibbs, R. J., 1965, Error due to segregation in quantitative clay mineral X-ray diffraction mounting techniques: American Mineralogist, v. 50, p. 741-751.

Haddock, D. R., Kent, B. H., and Bohor, B. F., 1976, Geologic map and coal sections of the Croton Quadrangle, Campbell County, Wyoming: U.S. Geological Survey Miscellaneous Field Studies Map MF-826.

Hinrichs, E. N., 1978, Preliminary geologic map of the Sheridan Quadrangle, Sheridan County, Wyoming: U.S. Geological Survey Miscellaneous Field Studies Map MF-1018.

Huang, W. H., and Keller, W. D., 1970, Dissolution of rock-forming silicate minerals in organic acids: Simulated first-state weathering of fresh mineral surfaces: American Mineralogist, v. 55, p. 2076-2094.

Huff, W. D., 1963, Mineralogy of Ordovician K-bentonites in Kentucky, in Clays and Clay Minerals, Proceedings of the 11th National Conference: Pergamon Press, New York, p. 200-209.

Izett, G. A., and Wilcox, R. E., 1968, Perrierite, chevkinite and allanite in upper Cenozoic ash beds in the Western United States: American Mineralogist, v. 53, p. 1558-1567.

Keller, W. D., 1970, Environmental aspects of clay minerals: Journal of Sedimentary Petrology, v. 40, no. 3, p. 788-813.

Keller, W. D., Balgord, W. D., and Reesman, A. L., 1963, Dissolved products of artifically pulverized silicate rocks and minerals — I: Journal of Sedimentary Petrology, v. 33, p. 191-204.

Kent, B. H., Haddock, D. R., and Bohor, B. F., 1977, Geologic map and coal sections of the Truman Draw Quadrangle, Campbell County, Wyoming: U.S. Geological Survey Miscellaneous Field Studies Map MF-917, 2 sheets.

La Iglesia, A., and Van Oosterwyck-Gastuche, M. C., 1978, Kaolinite Synthesis. I. Crystallization conditions at low temperatures and calculation of thermodynamic equilibria. Application to laboratory and field observations: Clays and Clay Minerals, v. 26, no. 6, p. 397-408.

Mapel, W. J., 1959, Geology and coal resources of the Buffalo-Lake De Smet area, Johnson and Sheridan Counties, Wyoming: U.S. Geological Survey Bulletin 1078, 148 p.

Mapel, W. J., and Dean, B. W., 1976, Preliminary geologic map and coal sections, Ulm Quadrangle, Sheridan County, Wyoming: U.S. Geological Survey Miscellaneous Field Studies Map MF-731, 2 sheets.

Naeser, C. W., 1967, The use of apatite and sphene for fission-track age determinations: Geological Society of American Bulletin, v. 78, p. 1523-1526.

Olive, W. W., 1957, The Spotted Horse coalfield, Sheridan and Campbell Counties, Wyoming: U.S. Geological Survey Bulletin 1050, 83 p.

Rogers, A. F., and Kerr, P. F., 1942, Optical Mineralogy: 2nd ed., New York, McGraw-Hill, 390 p.

Ross, C. S., and Shannon, E. V., 1926, Minerals of bentonite and related clays and their physical properties: Journal of the American Ceramic Society, v. 9, no. 2, p. 77-96.

Schultz, L. G., 1963, Nonmontmorillonitic composition of some bentonite beds, in Clay and Clay Minerals, Proceedings of the 11th National Conference: London, Pergamon Press, p. 169-177.

Sharp, W. N., and Gibbons, A. B., 1964, Geology and uranium deposits of the southern part of the Powder River Basin, Wyoming: U.S. Geological Survey Bulletin 1147-D, 60 p.

Slaughter, M., and Earley, J. W., 1965, Mineralogy and geological significance of the Mowry bentonites, Wyoming: Geological Society of America Special Paper 83, 116 p.

Smith, D. G. W., 1967, The petrology and mineralogy of some Lower Devonian bentonites from Gaspe, P.Q.: Canadian Mineralogist, v. 9, p. 141-165.

Snall, S., 1977, Silurian and Ordovician bentonites of Gotland (Sweden): Stockholm Contributions in Geology, Stockholm, Almquist and Wiksell, v. 31, 80 p.

Spears, D. A., and Kanaris-Sotiriou, R., 1975, Titanium in some Carboniferous sediments from Great Britain: Geochemica et Cosmochemica Acta, v. 40, no. 3, p. 345-351.

Spears, D. A., and Rice, C. M., 1973, An upper Carboniferous tonstein of volcanic origin: Sedimentology, v. 20, p. 281-294.

Steen-McIntyre, Virginia, 1977, A manual for tephrochronology: Idaho Springs, Colorado, Steen-McIntyre, 167 p.

Stone, R. W., and Lupton, C. T., 1910, The Powder River coal field, Wyoming, adjacent to the Burlington Railroad, in Investigations of coal fields in Wyoming in 1908: U.S. Geological Survey, p. 5-26.

Triplehorn, D. M., Turner, D. L., and Naeser, C. W., 1977, K-Ar and fission-track dating of ash partings in coal beds from the Kenai Peninsula, Alaska: A revised age for the Homerian Stage - Clamgulchian Stage boundary: Geological Society of America Bulletin, v. 88, p. 1156-1160.

Vicente, M. A., Razzaghe, M., and Robert, M., 1977, Formation of aluminum hydroxy vermiculite (intergrade) and smectite from mica under acidic conditions: Clay Minerals, v. 12, no. 2, p. 101-112.

Waage, K. M., 1955, Dakota Group in northern Front Range foothills, Colorado: U.S. Geological Survey Proffessional Paper 274-B, p. 15-51.

_____1961, Stratigraphy and refractory clayrocks of the Dakota group along the northern Front Range, Colorado: U.S. Geological Survey Bulletin 1102, 154 p.

Weaver, C. E., 1963, Interpretive value of heavy minerals from bentonite: Journal of Sedimentary Petrology, v. 33, no. 2, p. 343-349.

Wilcox, R. E., 1959, Use of the spindle stage for determination of principal indices of refraction of crystal fragments: American Mineralogist, v. 44, p. 1272-1293.

Williamson, I. A., 1970, Tonsteins - their nature, origin, and uses; parts I and II: Mining Magazine, v. 122, no. 2, p. 119-125; no. 3, p. 203-211.

Winchell, A. N., 1947, Elements of Optical Mineralogy - Part II; Descriptions of Minerals: New York, John Wiley and Sons, 459 p.

APPENDIX

Table 1.--X-ray mineralogy of kaolinitic bentonite collected from coal beds of the Wasatch Formation in the northern Powder River Basin, Wyoming

[The mineralogy was determined by X-ray diffraction of smear slides (Gibbs, 1965) made from bulk samples. If unusual peaks occurred on the trace, then a randomly oriented aggregate was prepared and analyzed. The relative amount of quartz was determined by comparing the intensity ratio of the 010(3.34Å) quartz peak to the 002(3.57Å) peak of kaolinite. The following formula was used: I qtz./I kaol. <0.5, trace; 0.5-1, minor; 1-2, moderate; >2, major. "Other clay minerals" refers to clay minerals other than kaolinite, which is the major constituent of all the samples. Abbreviations used in the table: S - smectite; ML- nonexpandable, mixed-layer clay; EML - expandable, mixed-layer clay; I - illite]

Map number	Sample designation	Location	Relative amount of quartz	Other clay minerals	Other identifiable minerals	Name of coal bed and position of bentonites in the bed
			Arvada Quadrangle			
1	A-1	NE 1/4 NW 1/4 sec. 21, T. 54 N., R. 77 W.	major	S	none	2 feet below top of 11-foot-thick Arvada.
2	A-5c)	SW 1/4 SW 1/4 sec. 25, T. 55 N., R. 78 W.	moderate	ML	feldspar(?)	3.2 feet below top of 3.7-foot-thick Felix.
			Arvada N.E. Quadrangle			
3	ANE-5a)	NW 1/4 NW 1/4 SW 1/4 sec. 31, T. 55 N., R. 76 W.	moderate	none	none	2.6 feet below top of 6.3-feet-thick Felix.
4	ANE-7b)	SW 1/4 NE 1/4 sec. 30, T. 54 N., R. 76 W.	major	ML, I	gypsum	0.4 foot below top of 10-foot-thick Felix.
			Big Horn Quadrangle			
5	PRB-stop 2b) 6/15/78	SE 1/4 NE 1/4 SE 1/4 sec. 6, T. 54 N., R. 83 W.	trace	none	none	Bar N coal zone; position in zone not known.
			Buffalo Run Creek Quadrangle			
6	PRB-stop 1b) 6/15/78	SE 1/4 NE 1/4 NE 1/4 sec. 17, T. 54 N., R. 83 W.	major	ML?	rutile(?)	Bar N coal zone; position in zone not known.
6	PRB-stop 1d) 6/15/78	--------------------do---------------------	minor	none	none	Do.
			Clearmont Quadrangle			
7	C-1a)[1]	SE 1/4 SE 1/4 sec. 5, T. 54 N., R. 79 W.	minor	I	gypsum	0.6 foot below top of 2.3-foot-thick Felix upper bench.
7	C-1b)[1]	--------------------do----------------	minor	I, EML	gypsum, jarosite	1.1 foot below top of 2.3-foot-thick Felix upper bench.
8	C-2a)	NW 1/4 SW 1/4 sec. 17, T. 54 N., R. 79 W.	moderate	S, I?	sanidine	0.4 foot below top of Felix; thickness unknown.

Table 1.--X-ray mineralogy of kaolinitic bentonite collected from coal beds of the Wasatch Formation in the northern Powder River Basin, Wyoming--Continued

Map number	Sample designation	Location	Relative amount of quartz	Other clay minerals	Other identifiable minerals	Name of coal bed and position of bentonites in the bed
			Clearmont Quadrangle (cont.)			
8	C-2b)	--------------------do-----------------	moderate	none	none	0.8 foot below top of Felix, thickness unknown.
9	C-8a)	SW 1/4 SW 1/4 NW 1/4 sec. 7, T. 54 N., R. 79 W	minor	none	gypsum, jarosite, feldspar (?)	0.8 foot below top of 3.5-foot-thick Felix upper bench.
9	C-8b)	--------------------do--------------------	moderate	none	gypsum	1.2 feet below top of 3.5-foot-thick Felix upper bench.
			Croton Quadrangle			
10	Cr-B-1	NW 1/4 SW 1/4 sec. 1, T. 53 N., R. 76 W.	moderate	none	none	1.25 feet below top of 13.5-foot-thick Felix.
11	Cr-B-2a)	NW 1/4 NE 1/4 sec. 24, T. 53 N., R. 76 W.	trace	none	none	0.2 foot below top of 14-foot-thick Felix.
11	Cr-B-2b)	--------------------do-----------------	moderate	none	none	1.4 feet below top of 14-foot-thick Felix.
12	Cr-B-5	NW 1/4 NW 1/4 sec. 7, T. 53 N., R. 75 W.	major	none	none	2 feet below top of 13.2-foot-thick Felix.
13	Cr-B-6	NW 1/4 SE 1/4 sec. 6, T. 53 N., R. 75 W.	trace	ML	none	2.3 feet below top of 21.8-foot-thick Felix.
14	Cr-B-8a)	SW 1/4 NW 1/4 sec. 4, T. 53 N., R. 75 W.	minor	ML	none	1.4 feet below top of 14.7-foot-thick Felix.
15	Cr-B-11a)	NW 1/4 NW 1/4 sec. 33, T. 54 N., R. 75 W.	major	none	none	0.3 foot below top of 14.5-foot-thick Felix.
15	Cr-B-11b)	--------------------do-----------------	major	none	gypsum	1.3 feet below top of 14.5-foot-thick Felix.
			Echeta Quadrangle			
16	E-1a)	SW 1/4 SW 1/4 NE 1/4 sec. 28, T. 52 N., R. 75 W.	major	none	none	0.1 foot below top of 18+ foot-thick Felix.
16	E-1b)	--------------------do----------------------	moderate	none	none	1.8 feet below top of 18+ foot-thick Felix.
16	E-1c)	--------------------do----------------------	major	none	none	18.8 feet below top of 18+ foot-thick Felix.
			The Gap Quadrangle			
17	TG-1a)	SE 1/4 NW 1/4 sec. 25, T. 49 N., R. 72 W.	major	none	none	0.9 foot below top of 17-foot-thick Felix.
17	TG-1b)	--------------------do-----------------	major	S	none	1.5 foot below base of 17-foot-thick Felix.
			Gillette West Quadrangle			
18	PRB-stop 1c) 6/14/78	NE 1/4 NE 1/4 sec. 29, T. 50 N., R. 72 W.	moderate	none	none	lowest clay parting in Felix (?), thickness of coal and position in bed unknown.

Table 1.--X-ray mineralogy of kaolinitic bentonite collected from coal beds of the Wasatch Formation in the northern Powder River Basin, Wyoming--Continued

Map number	Sample designation	Location	Relative amount of quartz	Other clay minerals	Other identifiable minerals	Name of coal bed and position of bentonites in the bed
			Larey Draw Quadrangle			
19	LD-1a)	NE 1/4 NW 1/4 sec. 14, T. 54 N., R. 76 W.	trace	none	none	0.2 foot below top of approximately 5-foot-thick Felix.
19	LD-1b)	--------------------do-----------------	minor	none	sphene or anatase (?)	1.3 feet below top of approximately 5-foot-thick Felix.
20	LD-2a)	SE 1/4 SE 1/4 SE 1/4 sec. 36, T. 55 N., R. 76 W.	minor	none	none	0.25 foot below top of 13-foot-thick Felix.
20	LD-2b)	--------------------do----------------------	major	none	none	1.6 feet below top of 13-foot-thick Felix.
21	LD-3a)	SE 1/4 SW 1/4 sec. 35, T. 55 N., R. 76 W.	major	I, EML	none	at very top of 13.5-foot-thick Felix.
22	LD-4a)	SE 1/4 NW 1/4 sec. 14, T. 54 N., R. 76 W.	moderate	none	none	approximately 1.25 feet from the top of 11-foot-thick Felix.
23	LD-7	SE 1/4 SW 1/4 sec. 25, T. 55 N., R. 76 W.	minor	ML, S	none	at very top of 5.5-foot-thick Felix upper bench.
			Leiter Quadrangle			
24	Le-3a)	NE 1/4 NE 1/4 sec. 28, T. 55 N., R. 79 W.	moderate	none	none	2.7 feet below top of 13-foot-thick Felix.
24	Le-3c)	--------------------do-----------------	minor	ML, I	gypsum, feldspar (?)	2.3 feet below top of 13-foot-thick Felix.
			Rawhide School Quadrangle			
25	PRB-stop 2	SE 1/4 SE 1/4 SE 1/4 sec. 23, T. 52 N., R. 73 W.	major	I	none	at very top of approximately 12.5 foot thick Felix.
			Sheridan Quadrangle			
26	NH-4	NE 1/4 SE 1/4 sec. 10, T. 56 N., R. 84 W.	moderate	none	none	Roland (of Taff), thickness of coal and position in bed unknown.
27	NH-6	SW 1/4 SW 1/4 sec. 29, T. 56 N., R. 83 W.	minor	ML	none	Burgess, thickness of coal and position in bed unknown.
28	NH-7	SE 1/4 NW 1/4 sec. 32, T. 56 N., R. 83 W.	minor	S, ML	none	at very top of 4-foot-thick coal bed in Bar N zone.
29	NH-8	NE 1/4 NE 1/4 NE 1/4 sec. 12, T. 55 N., R. 84 W.	minor	S	none	in shale above Burgess, thickness of coal unknown.
30	PRB-stop 3a) 6/15/78	NW 1/4 NW 1/4 sec. 32, T. 56 N., R. 83 W	minor	none	none	2 feet above base of Burgess, thickness of coal unknown.
30	PRB-stop 3c)	--------------------do---------------------	major	none	none	in carbonaceous shale below upper Burgess.

Table 1.--X-ray mineralogy of kaolinitic bentonite collected from coal beds of the Wasatch Formation in the northern Powder River Basin, Wyoming--Continued

Map number	Sample designation	Location	Relative amount of quartz	Other clay minerals	Other identifiable minerals	Name of coal bed and position of bentonites in the bed
			Spotted Horse Quadrangle			
31	SH-1a)	NW 1/4 SW 1/4 sec. 34, T. 55 N., R. 74 W.	major	none	none	at very top of 20-foot-thick Felix.
31	SH-1b)	--------------------do-----------------	major	none	none	approximately 2.5 feet below top of 20-foot-thick Felix.
			Truman Draw Quadrangle			
32	TD-B-4	NW 1/4 NW 1/4 NW 1/4 sec. 11, T. 53 N., R. 75 W.	major	none	none	1 foot below top of 7+ foot-thick Felix.
33	TD-B-6	NE 1/4 NW 1/4 NW 1/4 sec. 11, T. 53 N., R. 75 W.	moderate	none	none	1 foot below top of 15.5-foot-thick Felix.
34	TD-75-B-11	NE 1/4 SW 1/4 NE 1/4 sec. 15 T. 53 N., R. 75 W.	major	none	none	1.1 feet below top of 18.25-foot-thick Felix.
35	TD-B-13a)	NE 1/4 NW 1/4 sec. 34, T. 54 N., R. 75 W.	moderate	none	none	1.3 feet below top of Felix, thickness unknown.
35	TD-B-13b)	--------------------do-----------------	major	S	rutile (?)	in local coal below Felix.
36	TD-B-16	NE 1/4 NE 1/4 NE 1/4 sec. 6, T. 52 N., R. 74 W.	minor	ML	none	3.6 feet below top of 10.7-foot-thick Parnell.
37	TD-B-17a)	SW 1/4 SE 1/4 NE 1/4 sec. 1, T. 53 N., R. 75 W.	major	none	none	0.3 foot below top of 11.5-foot-thick Felix.
37	TD-B-17b)	--------------------do---------------------	minor	none	none	1.2 feet below top of 11.5-foot-thick Felix.
38	TD-B-18	NW 1/4 SW 1/4 sec. 4, T. 53 N., R. 74 W.	trace	none	jarosite, gypsum	at very top of 4.2-foot-thick Parnell.
39	TD-K-2-75	SW 1/4 NE 1/4 NE 1/4 sec. 7, T. 53 N., R. 74 W.	trace	ML	none	approximately in middle of 5.8-foot-thick Parnell lower bench.
40	TD-K-6-75	SE 1/4 SW 1/4 sec. 1, T. 53 N., R. 75 W.	major	none	none	1.5 feet below top of 15.7-foot-thick Felix.
41	TD-K-25a)	SW 1/4 SE 1/4 SE 1/4 sec. 15, T. 53 N., R. 75 W.	major	none	none	at very top of 23-foot-thick Felix.
41	TD-K-25b)	--------------------do---------------------	moderate	ML	none	1.1 feet below top of 23-foot-thick Felix.
42	TD-K-40(K-89)	SW 1/4 NW 1/4 NE 1/4 sec. 25, T. 53 N., R. 75 W.	minor	ML	none	at very top of 4-foot-thick Parnell lower bench.
			Twenty Mile Butte Quadrangle			
43	TMB-HB-2	SW 1/4 NW 1/4 sec. 13, T. 51 N., R. 75 W.	moderate	none	none	1.7 feet below top of 2.3-foot-thick Felix.
44	TMB-B-4a)	NE 1/4 NW 1/4 sec. 35, T. 52 N., R. 75 W.	major	none	none	0.2 foot below top of 18-foot-thick Felix.
44	TMB-B-4b)	--------------------do-----------------	moderate	none	none	1.3 feet below top of 18-foot-thick Felix.
45	TMB-B-6	SW 1/4 SW 1/4 sec. 13, T. 51 N., R. 75 W.	minor	none	none	2 feet below top of 8.3-foot-thick Parnell.
46	TMB-H-7	NW 1/4 NE 1/4 sec. 24, T. 51 N., R. 75 W.	minor	none	none	1.5 feet below top of 8.8-foot-thick Parnell.
47	TMB-H-9	NW 1/4 SW 1/4 sec. 23, T. 51 N., R. 75 W.	minor	EML	none	1.6 feet below top of 4.2-foot-thick Parnell.
48	TMB-10	NW 1/4 SW 1/4 SW 1/4 sec. 29, T. 52 N., R. 74 W.	minor	ML	none	0.16 foot above Parnell.
48	TMB-10a)	--------------------do---------------------	moderate	I	none	approximately 0.8 foot below top of 4.9-foot-thick Parnell.
48	TMB-10b)	NW 1/4 SW 1/4 SW 1/4 sec. 29, T. 52 N., R. 74 W.	trace	ML	jarosite	2.3 feet below top of 4.9-foot-thick Parnell.
49	TMB-K-15a)	NE 1/4 NW 1/4 sec. 26, T. 52 N., R. 75 W.	moderate	none	none	2 feet below top of 22.5-foot-thick Felix.

Table 1.--X-ray mineralogy of kaolinitic bentonite collected from coal beds of the Wasatch Formation in the northern Powder River Basin, Wyoming--Continued

Map number	Sample designation	Location	Relative amount of quartz	Other clay minerals	Other identifiable minerals	Name of coal bed and position of bentonites in the bed
			Ucross quadrangle			
50	Uc-BM-1	NW 1/4 SE 1/4 sec. 5, T. 53 N., R. 80 W.	moderate	none	gypsum, feldspar (?)	1.2 feet below top of 4.8-foot-thick Murray.
50	Uc-BM-2	--------------------do----------------	trace	none	gypsum, jarosite	1.9 feet below top of 4.8-foot-thick Murray.
51	Uc-BM-3	NW 1/4 SW 1/4 sec. 4, T. 53 N., R. 80 W.	trace	EML	none	1.2 feet below top of 4.8-foot-thick Ulm 2 (Healy).
52	Uc-BM-4	SW 1/4 SE 1/4 sec. 32, T. 54 N., R 80 W.	moderate	none	none	1.2 feet below top of 2.3-foot-thick Ulm 2 (Healy) upper bench.
53	Uc-BM-5[2]	NW 1/4 NE 1/4 sec. 15, T. 53 N., R. 81 W.	minor	I, ML	none	2.7 feet below top of 6.2-foot-thick Murray lower bench.
53	Uc-BM-6[2]	--------------------do-----------------	trace	ML	none	1.3 feet below top of 8.7-foot-thick Murray upper bench.
			Ulm Quadrangle			
54	U-M-16	NW 1/4 NW 1/4 SE 1/4 sec. 23, T. 55 N., R. 81 W.	minor	none	none	0.6 foot below top of 14.6-foot-thick Ulm 2.
55	U-M-32	NE 1/4 NW 1/4 SW 1/4 sec. 28, T. 55 N., R. 80 W.	minor	none	none	0.4 foot below top of 24+ foot- thick Ulm 1.
			Verona Quadrangle			
56	V-BM-7	NE 1/4 NE 1/4 sec. 16, T. 54 N., R. 82 W.	minor	ML	none	0.6 foot below top of 5-foot-thick bed in Ulm 2 (Healy) zone.

[1] Both samples C-1a) and C-1b) appear to contain relatively more discrete illite than any of the other samples studied. Samples C-1b) also contain a relatively large amount of mixed-layer clay, which produced a distinct peak at 11.95Å. When treated with ethylene glycol, the basal spacing increased to 13.30Å.

[2] The X-ray traces of oriented aggregate made from samples Uc-BM-5 and Uc-BM-6 both have relatively large peaks at approximately 14Å. Judging from the limited tests performed in our analyses (ethylene glycol saturation and heating to 400° C for 45 minutes), it appears that they represent an interstratified vermiculite-mica clay. Since both of these samples were collected from a stream-bank outcrop, it is possible that this mixed-layer clay formed as a weathering product of the bentonite.

Table 2.--Non-clay mineralogical analysis of kaolinitic bentonites from coals of the northern Powder River Basin, Wyoming

[Relative abundance of each mineral identified: VA - very abundant, A - abundant, VC - very common, C - common, FC - fairly common, S - scarce, R - rare, (--) - absent]

	Sample designation and coal bed								
Minerals	C-2a) Felix	Cr-B-6 Felix	E-1b) Felix	LD-2b) Felix	Uc-BM-2 Murray	TMB-10b Parnell	Uc-BM-3 Ulm 2	V-BM-7 Ulm 2	NH-7 Bar N
Light-mineral fraction									
Gypsum	FC	FC	FC	--	FC	S	S	FC	FC
Quartz (α-form)	C	C	C	C	C	C	C	C	C
Quartz (β-form)	R	S	S	FC	S	FC	S	S	FC
Sanidine	S	FC	--	FC	S	FC	S	FC	S
Heavy-mineral fraction									
Allanite	FC	R	--	--	--	--	--	--	--
Anatase	C	FC	C	C	FC	FC	FC	FC	S
Apatite	R	--	--	--	--	--	R	--	--
Biotite	S	FC	--	R	--	--	R	--	--
Brookite	R	--	R	R	R	--	--	R	--
Epidote	S	FC	VC	C	FC	R	C	C	FC
Garnet	R	--	R	--	--	R	S	FC	--
Hematite	S	S	S	S	FC	FC	R	S	FC
Horneblende	--	--	R	R	--	R	S	--	R
Ilmenite	S	--	S	R	R	S	R	--	R
Jarosite	A	--	--	--	C	--	--	--	--
Magnetite	FC	S	FC	S	S	FC	S	S	S
Pyrite	FC	--	S	--	R	S	--	--	--
Rutile	R	S	C	S	S	FC	S	S	R
Sphene	FC	S	FC	C	FC	S	A	C	VC
Topaz	--	--	--	--	--	--	S	--	--
Tourmaline	FC	S	FC	FC	FC	S	R	S	FC
Zircon	VA	VA	VA	VA	VA	VA	VA	VA	VA
Total wt. percent	.07	.06	.06	.06	.06	.05	.05	.04	--

Table 3.--Major-element analyses by X-ray fluorescence of kaolinitic bentonite partings from the Felix and Parnell coal beds and their equivalents

[Results in weight percent. (<) indicates less than value shown. Refer to table 1 for sample location and position in coal bed]

Sample designation	Al_2O_3	SiO_2	CaO	P_2O_5	TiO_2	Fe_2O_3	K_2O	S	TiO_2/Al_2O_3
Felix coal bed partings									
TD-B11	17	32	0.30	<1.0	0.20	0.05	0.20	0.03	0.018
TD-B-13a)	18	39	.10	<1.0	.20	4.3	1.1	.40	.011
TD-B-17a)	18	63	<.10	<1.0	.80	1.7	.20	.20	.044
TD-K-25a)	25	46	.20	<1.0	.60	1.5	.20	.10	.024
E-1a)	19	28	.50	<1.0	.30	.80	.10	.10	.016
TD-K-6	18	46	.20	<1.0	.30	<.05	.20	<.03	.017
Cr-B-2	31	39	.20	<1.0	.20	.40	.20	.06	.006
TMB-K-15a)	22	34	.20	<1.0	.20	.07	.20	<.03	.009
SH-1a)	14	33	.30	<1.0	.50	3.3	.30	.10	.036
LD-7	32	48	.10	<1.0	.30	.70	.50	.03	.009
LD-4a)	21	42	1.1	<1.0	.20	2.1	.50	.09	.009
C-1a)	19	53	.50	<1.0	.20	.50	1.4	.10	.011
C-2a)	25	45	.10	<1.0	.20	.60	1.2	.04	.008
*C-2b)	28	59	1.9	<1.0	.46	1.9	1.0	2.0	.016
TMB-HB-2	24	36	.50	<1.0	.20	.06	.30	.05	.008
LD-1b)	28	47	.60	<1.0	.30	.40	.40	.10	.011
E-1b)	20	30	.70	<1.0	.10	<.05	.10	<.03	.005
Cr-B-1	20	37	.80	<1.0	.30	.40	.40	<.03	.015
Cr-B-5	22	37	.20	<1.0	.10	.05	.20	<.03	.004
Cr-B-6	32	42	.20	<1.0	.20	.05	.20	.04	.006
Cr-B-8	21	32	1.1	<1.0	.30	.06	.10	.06	.014
Cr-B-11	27	45	1.1	<1.0	.30	.20	.20	.10	.011
Uc-BM-1	19	39	1.3	<1.0	.20	4.3	1.1	.40	.010
Uc-BM-2	19	36	<.10	<1.0	.30	1.3	.40	.10	.016
Uc-BM-6	20	26	1.9	<1.0	.30	.30	.10	<.03	.015
*TG-1b)	32	61	.82	<1.0	.40	1.1	.36	.51	.012
Parnell coal bed partings									
Uc-BM-3	26	46	<0.10	<1.0	0.30	.060	.020	<0.03	0.012
Uc-BM-4	26	50	.30	<1.0	.20	.60	.20	.06	.008
V-BM-7	26	46	.30	<1.0	.30	.70	.30	<.03	.012
TD-B-18	19	41	.40	<1.0	.20	9.2	.40	1.1	.010
TD-K-2	24	56	<.10	<1.0	.40	.40	.40	.08	.017
TD-K-40	27	56	<.10	<1.0	.40	.20	.30	.03	.015
TBM-B-6	25	48	.30	<1.0	.30	.50	.40	.20	.012
TBM-H-7	21	49	<.10	<1.0	.40	.60	.50	.05	.019
*TMB-10b)	29	59	.83	<1.0	.34	1.5	.41	1.2	.012
U-M-16	24	48	.70	<1.0	.30	.80	.30	.04	.012

*Sample analyzed from ash; all others were done on whole rock.

Table 4.--Trace-element analyses by emission spectroscopy of kaolinitic bentonite partings from the Felix and Parnell coal beds and their equivalents

[Results in parts per million. (<) indicates less than value shown. Refer to table 1 for sample location and position in coal bed]

Sample designation	B	Ba	Be	Ce	Co	Cr	Cu	Ga	Ge	La	Li	Mn	Mo	Ni	Pb	Sc	Sr	V	Y	Yb	Zn	Zr
C-1a	29	610	<1.0	53	<1.0	4.1	16	9.3	<1.5	11	<68	43	<2.2	3.8	8.9	1.6	220	10	4.5	.62	<10	220
C-2a	140	550	1.0	<43	1.4	3.3	2.7	13	<1.5	11	<68	26	<2.2	3.4	<6.8	<1.0	180	11	3.2	.36	<10	130
Cr-B-1	14	130	<1.0	<43	<1.0	<1.0	24	16	<1.5	<10	<68	70	3.6	1.7	<6.8	1.1	84	9.2	<1.5	.17	<10	82
Cr-B-2	8.1	210	2.6	69	1.8	3.8	11	26	<1.5	27	78	52	<2.2	14	15	2.0	19	14	8.9	.77	25	32
Cr-B-5	8.5	130	<1.0	<43	<1.0	<1.0	23	16	<1.5	<10	<68	36	<2.2	4.1	<6.8	<1.0	20	6.6	<1.5	.16	<10	60
Cr-B-6	12	80	<1.0	<43	<1.0	<1.0	24	32	<1.5	<10	<68	27	<2.2	6.8	43	1.0	5.8	7.0	<1.5	<.15	21	31
Cr-B-8	20	140	<1.0	<43	1.4	<1.0	25	9.1	<1.5	<10	<68	81	<2.2	3.6	<6.8	1.4	130	7.9	<1.5	<.15	<10	52
Cr-B-11	15	120	<1.0	<43	<1.0	<1.0	16	26	<1.5	<10	<68	23	<2.2	1.7	<6.8	1.4	85	8.8	<1.5	<.15	<10	80
E-1a	17	150	9.0	<43	4.9	2.7	20	8.5	<1.5	<10	<68	120	<2.2	21	<6.8	2.4	98	11	9.3	.19	66	88
E-1b	6.9	130	<1.0	<43	<1.0	<1.0	26	11	<1.5	<10	<68	67	<2.2	<1.5	<6.8	1.1	77	5.5	<1.5	<.15	10	57
LD-16	27	220	<1.0	<43	<1.0	<1.0	12	15	<1.5	<10	<68	31	16	3.3	<6.8	1.1	87	15	<1.5	.16	<10	57
LD-4a	30	140	1.1	<43	<1.0	<1.0	16	13	<1.5	<10	<68	76	<2.2	4.7	<6.8	1.3	79	14	3.4	.45	<10	98
LD-7	21	210	1.3	<43	1.8	4.8	9.1	28	<1.5	<10	<68	47	<2.2	3.2	<6.8	3.6	37	22	2.4	.24	<10	59
SH-1a	25	110	1.8	<43	<1.0	12	27	6.5	5.0	12	<68	13	5.0	4.0	<6.8	4.9	24	29	7.3	1.4	<10	110
TD-B-11	20	250	1.3	<43	1.9	<1.0	30	9.7	<1.5	<10	<68	16	<2.2	9.7	<6.8	<1.0	190	7.4	3.3	.31	18	62
TD-B-13a	29	110	1.2	<43	<1.0	<1.0	23	23	12	<10	<68	19	<2.2	3.8	<6.8	2.2	97	7.5	4.5	.36	<10	83
TD-B-17a)	39	190	1.8	<43	<1.0	8.4	37	22	<1.5	<10	<68	20	11	4.9	66	1.8	33	39	6.6	1.3	<10	100
TD-B-18	19	97	<1.0	58	<1.0	4.9	23	18	<1.5	<10	<68	14	6.6	3.1	46	2.1	150	18	2.4	.17	29	79
TD-K-2	27	190	1.1	46	1.2	14	34	29	<1.5	<10	<68	75	3.2	7.0	<6.8	2.8	33	33	2.9	.30	<10	47
TD-K-6	22	55	<1.0	<43	3.3	<1.0	18	13	<1.5	<10	<68	16	<2.2	45	<6.8	1.2	15	8.4	12	.85	<10	94
TD-K-25a)	16	230	4.7	55	1.3	13	50	24	<1.5	11	<68	17	13	12	10	5.0	64	54	11	1.5	<10	130
TD-K-40	26	68	1.1	<43	<1.0	<1.0	5.1	26	<1.5	<10	<68	26	16	2.5	<6.8	1.5	6.8	25	1.6	<.15	<10	40
TMB-B-6	50	160	<1.0	<43	<1.0	7.1	24	29	<1.5	<10	<68	76	3.4	2.9	8.2	1.8	59	24	<1.5	.24	<10	45
TMB-H-7	110	110	<1.0	<43	<1.0	4.1	23	16	<1.5	<10	<68	59	4.4	2.5	<6.8	1.5	18	27	<1.5	.19	<10	47
TMB-HB-2	7.5	120	<1.0	<43	<1.0	<1.0	27	22	<1.5	<10	<68	57	>2.2	1.6	9.7	<1.0	77	7.9	<1.5	.19	<10	54
TMB-K-15a)	<4.6	73	2.0	<43	2.5	<1.0	37	16	<1.5	11	79	11	<2.2	31	<6.8	<1.0	12	7.2	6.9	.39	17	67
U-M-16	120	110	<1.0	<43	<1.0	2.8	10	20	<1.5	<10	<68	18	<2.2	3.8	<6.8	1.3	17	21	<1.5	.22	<10	40
Uc-BM-1	23	960	<1.0	47	<1.0	2.6	1.7	11	<1.5	20	<68	25	<2.2	2.5	14	1.4	1200	6.7	3.8	.45	15	120
Uc-BM-2	27	190	<1.0	<43	<1.0	5.2	47	8.0	<1.5	<10	<68	25	5.7	3.3	<6.8	1.7	20	13	2.6	.33	<10	45
Uc-BM-3	84	81	<1.0	<43	<1.0	2.8	4.9	27	<1.5	<10	<68	46	<2.2	2.2	<6.8	1.3	23	16	<1.5	.60	<10	36
Uc-BM-4	160	87	<1.0	<43	<1.0	2.5	8.8	17	<1.5	<10	<68	44	<2.2	<1.5	<6.8	1.2	24	11	<1.5	<.15	<10	38
Uc-BM-6	13	800	<1.0	53	<1.0	<1.0	12	2.2	<1.5	28	<68	31	<2.2	2.4	<6.8	1.0	2300	12	1.9	<.15	12	43
V-BM-7	60	130	<1.0	<43	<1.0	6.7	7.0	23	<1.5	<10	89	45	<2.2	2.9	<6.8	1.7	79	17	2.3	.20	<10	37

Table 5.--Elements looked for, but not detected, in 33 kaolinitic bentonite samples from the Felix and Parnell coal beds and their equivalents, Wasatch Formation, Wyoming

[Approximate lower detection limits for these elements from the whole rock by computerized emission spectrographic analysis, U.S. Geological Survey, Reston, Virginia]

Element name	Symbol	Lower limit of detection (ppm) in whole rock
Arsenic	As	150
Gold	Au	10
Bismuth	Bi	15
Cadmium	Cd	32
Dysprosium	Dy	22
Erbium	Er	10
Europium	Eu	1.5
Gadolinium	Gd	6.8
Hafnium	Hf	15
Holmium	Ho	6.8
Indium	In	6.8
Iridium	Ir	15
Lutetium	Lu	22
Neodymium	Nd	46
Osmium	Os	22
Palladium	Pd	1.5
Praseodymium	Pr	68
Platinum	Pt	6.8
Rhenium	Re	10
Rhodium	Rh	2.2
Ruthenium	Ru	3.2
Antimony	Sb	46
Samarium	Sm	22
Tin	Sn	1.5
Tantalum	Ta	460
Terbium	Tb	32
Thallium	Tl	3.2
Thulium	Tm	4.6
Tungsten	W	10

Table 6.--Thorium and uranium analyses by the delayed-neutron method on kaolinitic bentonite partings from the Felix and Parnell coal beds and their equivalents

[Leaders (---) indicate that the concentration was below the detection limit. Refer to table 1 for name of coal bed, sample location, and position in the coal bed]

Sample designation	Lab. number	Thorium (ppm)	Uranium (ppm)	Th/Ur
C-1a)	D196161	3.8	1.0	3.8
C-2a)	D196162	4.8	.9	5.3
Cr-B-1	D196166	3.0	1.2	2.5
Cr-B-2	D196156	32	8.8	3.6
Cr-B-5	D196167	---	.6	---
Cr-B-6	D196168	---	.2	---
Cr-B-8a)	D196169	4.6	.7	6.6
Cr-B-11b)	D196170	3.5	.5	7.0
E-1a)	D196154	8.9	2.3	3.8
E-1b)	D196165	3.6	.2	18
LD-1b)	D196164	---	.7	---
LD-4a)	D196160	4.1	3.4	1.3
LD-7	D196159	---	1.0	---
SH-1a)	D196158	17	11.0	1.6
TD-B-11	D196151	---	.5	---
TD-B-13a)	D196171	4.2	1.0	4.2
TD-B-17a)	D196152	5.4	4.3	1.2
TD-B-18	D196180	4.8	3.7	1.3
TD-K-2	D196181	9.7	7.7	1.3
TD-K-6	D196155	3.1	.5	6.2
TD-K-25a)	D196153	---	27	---
TD-K-40	D196182	---	.6	---
TMB-B-6	D196183	4.6	3.2	1.4
TMB-H-7	D196184	---	2.2	---
TMB-HB-2	D196163	3.8	.5	7.6
TMB-K-15a)	D196157	---	.3	---
U-M-16	D196185	---	.9	---
Uc-BM-1	D196172	4.1	2.5	1.6
Uc-BM-2	D196173	9.9	7.0	1.4
Uc-BM-3	D196175	---	.1	---
Uc-BM-4	D196176	---	.1	---
Uc-BM-6	D196174	4.2	3.2	1.3
V-BM-7	D196177	2.6	.4	6.5

Table 7.--Analytical data for fission-track age determinations on zircons

[The fission-track age was calculated from the equation given by Naeser (1967): Age (years) = 6.49×10^9 ln $[1 + (9.45 \times 10^{-18} \frac{Ps}{Pi} \emptyset)]$ F.C. is a combination of samples of the doublet of bentonites in the Felix coal bed at several different locations in the Croton, Truman Draw, and Twentymile Butte Quadrangles]

Sample	Spontaneous track density (Ps) $\times 10^6$ +/cm^2	Induced track density (Pi) $\times 10^6$ +/cm^2	Thermal neutron dose (Ø) $\times 10^{15}$ n/cm^2	Age $\times 10^6$ yr	Standard deviation ± 2 $\times 10^6$ yr	Number of grains analyzed	Correlation coefficient (r)	Uranium concentration (ppm)
F.C. (Felix coal bed)	5.38 (620)[1]	7.76 (447)[1]	1.05 (3175)[1]	43.4	1.7	6	.991	210
TMB-10b) (Parnell coal bed)	5.38	7.54	1.05	43.9	2.3	6	.932	210

[1]Number of tracks counted