CLAY MINERALOGY AND PETROLOGY OF THE COAL-BEARING GROUP NEAR HEALY, ALASKA

By
Don M. Triplehorn

GEOLOGIC REPORT 52

STATE OF ALASKA

Jay S. Hammond, *Governor*

Guy R. Martin, *Commissioner, Dept. of Natural Resources*

Ross G. Schaff, *State Geologist*

For sale by Alaska Division of Geological and Geophysical Surveys, P.O. Box 80007, College, 99701; 323 E. 4th Ave., Anchorage, 99501; P.O. Box 2438, Ketchikan, 99901; and Pouch M, Juneau, 99811 — Price $1.00.

CONTENTS

ILLUSTRATIONS

CLAY MINERALOGY AND PETROLOGY OF THE COAL-BEARING GROUP NEAR HEALY, ALASKA

By
Don M. Triplehorn[1]

ABSTRACT

Within the coal-bearing group near Healy, Alaska, three different clay mineral associations are recognized: a lower interval with little or no montmorillonite, an upper interval with abundant montmorillonite, and a relatively thin intermediate interval with predominant kaolinite. The montmorillonite and at least some of the kaolinite are interpreted to be of postdepositional origin—the montmorillonite by the weathering of volcanic feldspar.

Greatest potential for stratigraphic correlation is found in certain clay partings that may have originated as volcanic ash falls. Because of their lack of methods for sediment distribution, coal swamps are ideal environments for the preservation of ash falls. The clay partings, if proved to be of volcanic origin, have value as widespread, distinctive isochronous units. Perhaps of more importance is the possibility of obtaining absolute age dates on them, thereby permitting correlation with both marine and nonmarine Tertiary rocks throughout the state.

INTRODUCTION

PURPOSE

The primary objective of this study was to provide reliable geologic criteria for local and regional correlation within the Tertiary coal-bearing group near Healy, Alaska. These criteria would increase knowledge of the distribution and thickness of beds of potentially commercial coals, and result in a more accurate estimate of coal reserves. Also, exact correlation of specific coal beds would aid in predicting the precise location of minable beds.

The coal-bearing group is of geologic as well as economic interest. It includes some unusual aspects of sedimentary petrology, and contains in its beds a record of the Tertiary history of Interior Alaska.

LOCATION

Most of this study has been along Healy and Lignite Creeks, west-flowing streams that join the Nenana River near the town of Healy (fig. 1). Brief examination was also made of exposures just west of Otto Lake. The area is included in the west-central portion of the Healy D-5 quadrangle.

GEOLOGIC SETTING

This area is part of the Nenana coal field on the north flank of the central Alaska Range; it has been extensively studied, particularly by Clyde Wahrhaftig of the U.S. Geological Survey. His recent summary (Wahrhaftig and others, 1969) is recommended for a general overview; his earlier works (Wahrhaftig, 1951; and others, 1951, 1954) provide detail along Lignite and Healy Creeks. Geologic maps of eight quadrangles, including the Healy D-4 and D-5, were issued recently (Wahrhaftig, 1970 a-h).

The coal-bearing group was defined by Wahrhaftig and others in 1969, and divided into five formations as shown in figure 2. In the Healy area, the total thickness is about 2,000 feet and consists primarily of poorly consolidated pebbly sandstones and mudstones, with lesser amounts of conglomerate and coal. Age assignments are based on studies of plant megafossils and palynological material collected throughout the coal field.

Exposures along Healy Creek are on the south flank of a west-plunging syncline (Wahrhaftig, 1970c,d). Dips in most exposures are about 30° north or northwest with relatively minor faulting or other structural complication except near the apex of the syncline about 9 miles east of Healy. Exposures along Lignite Creek are on the south flank of a broad, open syncline that plunges westward. Dips near the mouth of the creek average about 10° north, gradually increasing to the east and becoming more variable where several notable faults occur about 12 miles from the mouth (Wahrhaftig, 1970c).

METHODS OF INVESTIGATION

FIELD STUDIES AND COLLECTION OF SAMPLES

Examination of outcrops and collection of rock samples were made during the summer of 1972. C.N.

[1]Geology department, University of Alaska, College, AK 99701.

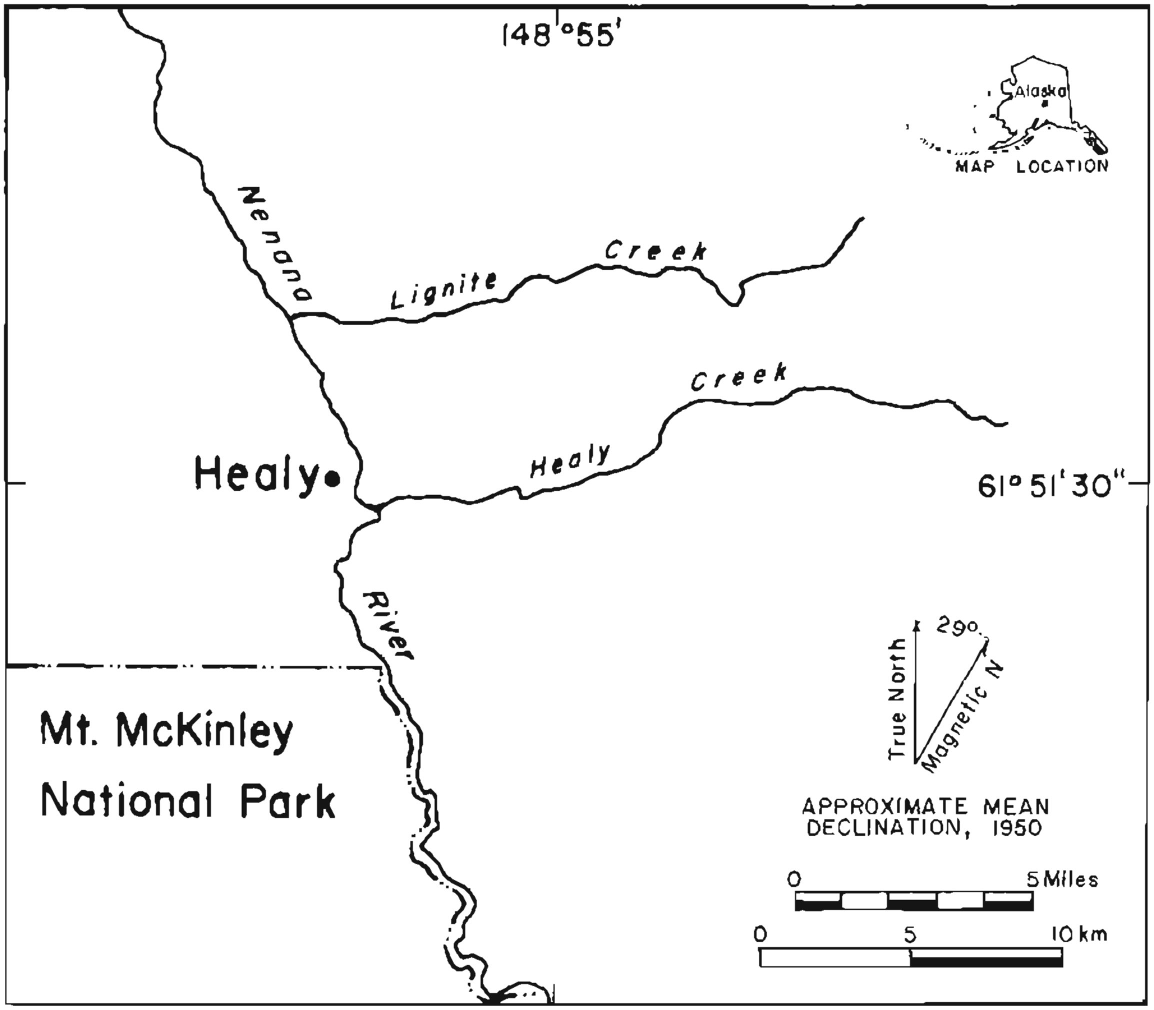


Figure 1. General location of Healy, Healy Creek, and Lignite Creek.

Conwell, Alaska Division of Geological and Geophysical Surveys (DGGS), provided the writer with guidance in locating samples and with other direction in the early phases of the study. Appreciation is also extended to John Wood of Usibelli Coal Mines, Inc., for his identification of coal units; and to R.L. Gebhart and E.M. Burran, who assisted in the field work.

Stratigraphic control and selection of outcrops were largely based on the Healy D-4 and D-5 geologic maps (Wahrhaftig, 1970c,d) and measured sections and maps published in U.S. Geol. Survey Bulletin 963-E (Wahrhaftig, 1951; and others, 1951). Man-made exposures, such as strip-mining pits and road cuts, were used along Healy Creek.

Approximately 30 locations were examined (figure 3). The following samples were collected: 52 of sand, 157 of clay or mudstone, 10 of chert, and a few miscellaneous.

X-RAY DIFFRACTION MINERALOGY

Clay samples were separated, mounted, and analyzed by X-ray diffraction in DGGS laboratories under the direction of T.C. Mowatt.

The clay-sized material was prepared for X-ray diffraction analysis as follows. Clays, mudstones, or sands containing clay were dispersed in distilled water and portions withdrawn at depths and times corponding to 2-micron-diameter particles,[2] using Stokes' equation for the settling of quartz spheres. These suspensions were deposited on ceramic tile plates by suction under vacuum, and then dried at room conditions.

Diffractometer traces were obtained by scanning from at least 2° to 35° using $Cu_{K\alpha}$ Ni-filtered radiation and a 2θ scanning speed of 2° per minute. Samples

[2]Sometimes at less than 1-micron-diameter size.

were analyzed both in the untreated form and after saturation with ethylene glycol vapor to detect the presence of expandable clay minerals.

This preparation procedure is designed to orient the very fine platy clay minerals parallel to the surface of the tile plate, thereby enhancing their response during X-ray diffraction. Eighty-one samples were examined in this manner, and the relative abundance of different clay species was estimated from the relative peak heights of their characteristic X-ray reflections on diffractometer traces. Intensities of selected (usually the most intense) peaks for each of the clay mineral species are summed, and relative intensity (peak-height percent) of each species is expressed as a percentage of this total. These data are listed in the Appendix.

The samples analyzed were only the finer (smaller than 0.002 mm) parts of sandy or muddy sediments; the percentages do not reflect the absolute or even relative abundance of the reported clay species in each whole sample. As used here, clay mineral techniques should be regarded as a reconnaissance tool to distinguish gross differences among sediments.

Fifteen samples of clay, mudrocks, and clay fractions of sandstones were analyzed as whole samples ground to a fine powder. This permits identification of all the major crystalline components where the nonclay minerals may be of interest.

BULK DENSITY

Firm, fresh pieces of clay or mudstone were trimmed to about 1-inch cubes, oven-dried at about 60°C for several hours, and allowed to cool at ambient temperature. The volume of each piece was measured by a special pycnometer using mercury as the displaced liquid. This volume, divided by the weight of each piece, yielded a value for bulk density that was reproducible to about 0.01 or 0.02 density units. These data are listed in the Appendix.

Differences in bulk density can be interpreted in terms of the degree of compaction of muddy sediments and also as a measure of depth of burial. However, because other factors can modify bulk densities, samples must be chosen carefully and the results must be interpreted with caution. Weathering and contained organic material usually result in bulk densities lower than expected; structural deformation and secondary cement (calcite, siderite, and iron oxides) generally produce higher values than expected. Also, effects of varying amounts of sand-sized material and the differences in environments of deposition are uncertain. Regardless of these limitations, an attempt was made to isolate the influence of depth of burial by comparing large numbers of fresh samples of similar lithology. Therefore, only qualitative conclusions should be drawn.

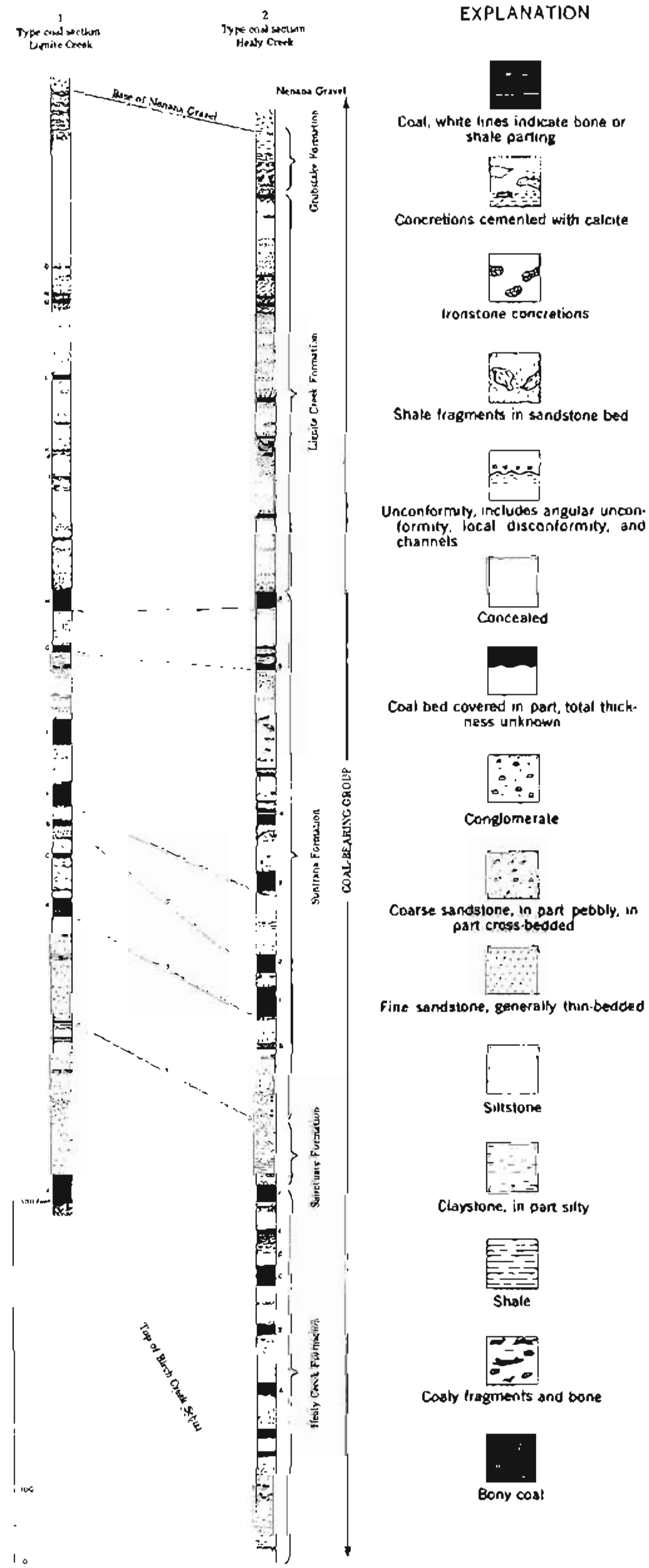


Figure 2. Correlation of type stratigraphic sections on Healy and Lignite Creeks.

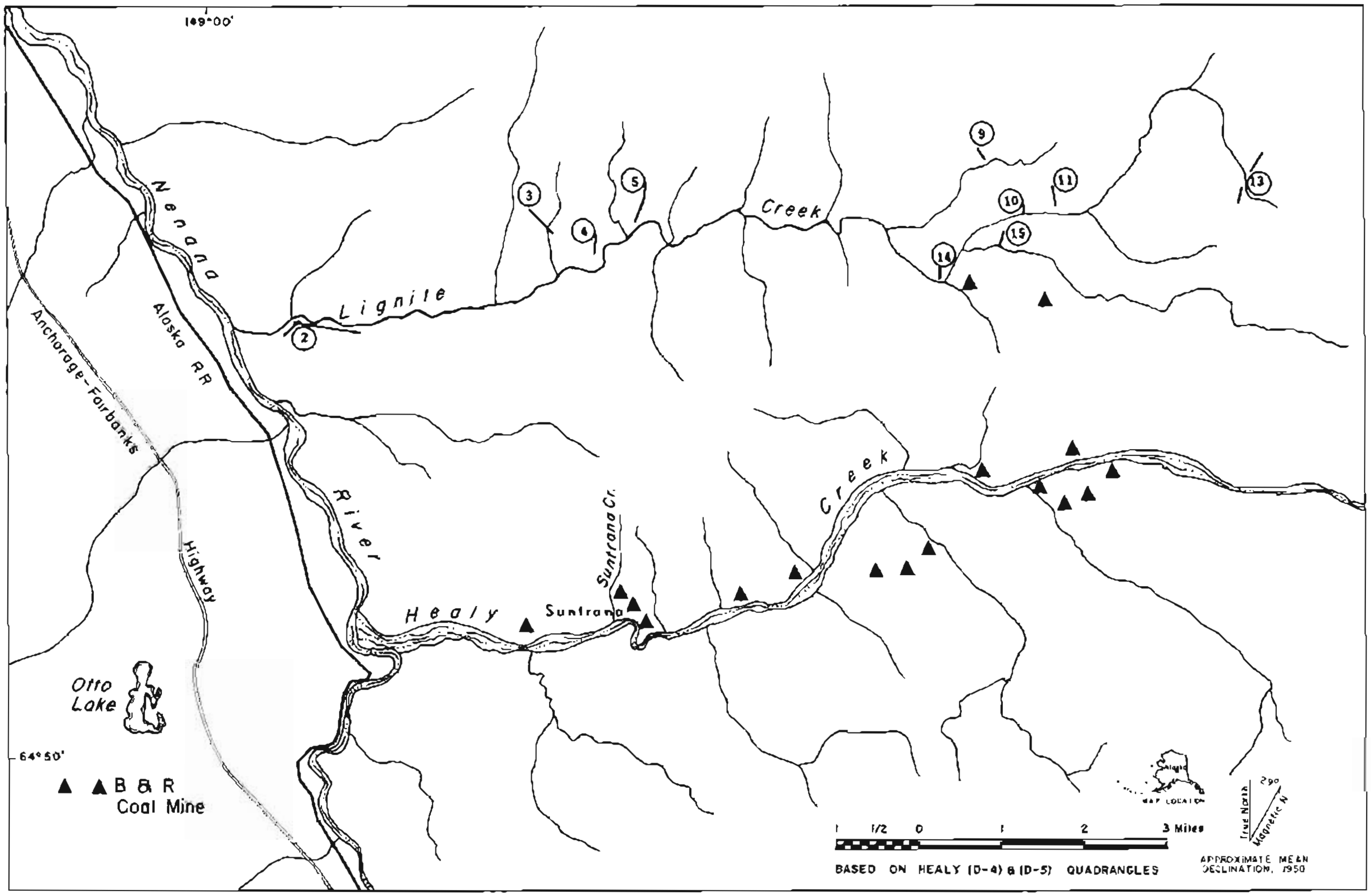


Figure 3. Sample locations, Healy and Lignite Creeks. Numbers in circles refer to sections measured by Barnes and others (1951). Other sample locations shown by ▲.

OTHER METHODS

Twenty-one sandstones and 12 mudrocks were examined in thin section. No quantitative measurements of minerals were made, but major changes in composition could be readily seen. The thin-section study provided information on grain size, sorting, grain shapes and surface textures, small-scale sedimentary structures, grain orientation, and occurrences of authigenic minerals.

As a possible aid to detecting montmorillonite in the field, a water solution of benzidine dye was used. In the laboratory, samples of montmorillonite quickly turn bright blue when wetted with the dye. However, in the field, the tendency to turn blue or not is modified by grain size, induration and permeability, or the presence of organic matter or mineral pigments.

Nevertheless, response to the dye is one more characteristic to record in the field and may be used on an empirical, descriptive basis.

RESULTS OF ANALYSES

CLAY MINERALOGY

VERTICAL VARIATIONS

Figure 4A shows the vertical variation in clay mineralogy in terms of relative peak-height percentages for diffraction maxima at 17Å (montmorillonite), 10Å (illite) and 7Å (kaolinite plus chlorite). Samples are arranged in their estimated stratigraphic order, but the position of the Moose Seam is questionable (as are the exact correlations of some units between Healy Creek and Lignite Creek).

Three major features stand out in figure 4:

1. Montmorillonite is abundant in all samples above the upper part of the No. 1 coal of Healy Creek. The lowermost sample containing abundant montmorillonite is a 3-inch parting in the No. 1 coal about 5 feet from the top.
2. Samples associated with the No. 1 coal are almost entirely kaolinitic (except for the montmorillonitic parting noted above). This includes two clay partings and four samples of the underclay.
3. Samples below the base of the No. 1 coal are all dominated by 7Å clay (mainly kaolinite), with a lesser portion of illite.

The main difference between the upper and lower parts of the section is in the abundance of montmorillonite. Relative proportions of 10Å illite to 7Å kaolinite-chlorite do not change significantly, as shown in figure 4B.

The amount of chlorite relative to kaolinite is uncertain. In other studies, intensities of the nearly coincident 3.52Å and 3.57Å peaks have been used, but resolution of this pair was not adequate in this investigation. Definite chlorite peaks at 4.7Å were frequently present, and these are plotted relative to the adjacent 5Å intensities in figure 4C to give some indication of the abundance of chlorite compared to illite. Absolute intensities were very weak and figure 4C should be interpreted with caution; however, there is some suggestion that a little more chlorite might be present in the upper part of the section than in the lower part.

An additional indication of chlorite is the appearance of a poorly resolved peak adjacent to the intense 3.57Å kaolinite peak (as indicated by a ✓on the right side of figure 4C). Only two of these samples occur below the No. 1 coal, substantiating the earlier suggestion that chlorite is more abundant in the upper part of the section.

In the field, blue staining with benzidine dye generally followed the distribution of montmorillonite later found by X-ray diffraction. Sandstones and mudstones about the No. 1 coal always turned blue with the dye. Between the E and F seams (Healy Creek terminology), results were mixed: a few samples turned either slowly blue or slightly blue, but most exhibited no color change. Below this interval, no samples turned blue when wet with benzidine.

Most of the sediments tested with benzidine in the field were sands, not the mudrocks used for the clay mineral data.

LATERAL VARIATIONS

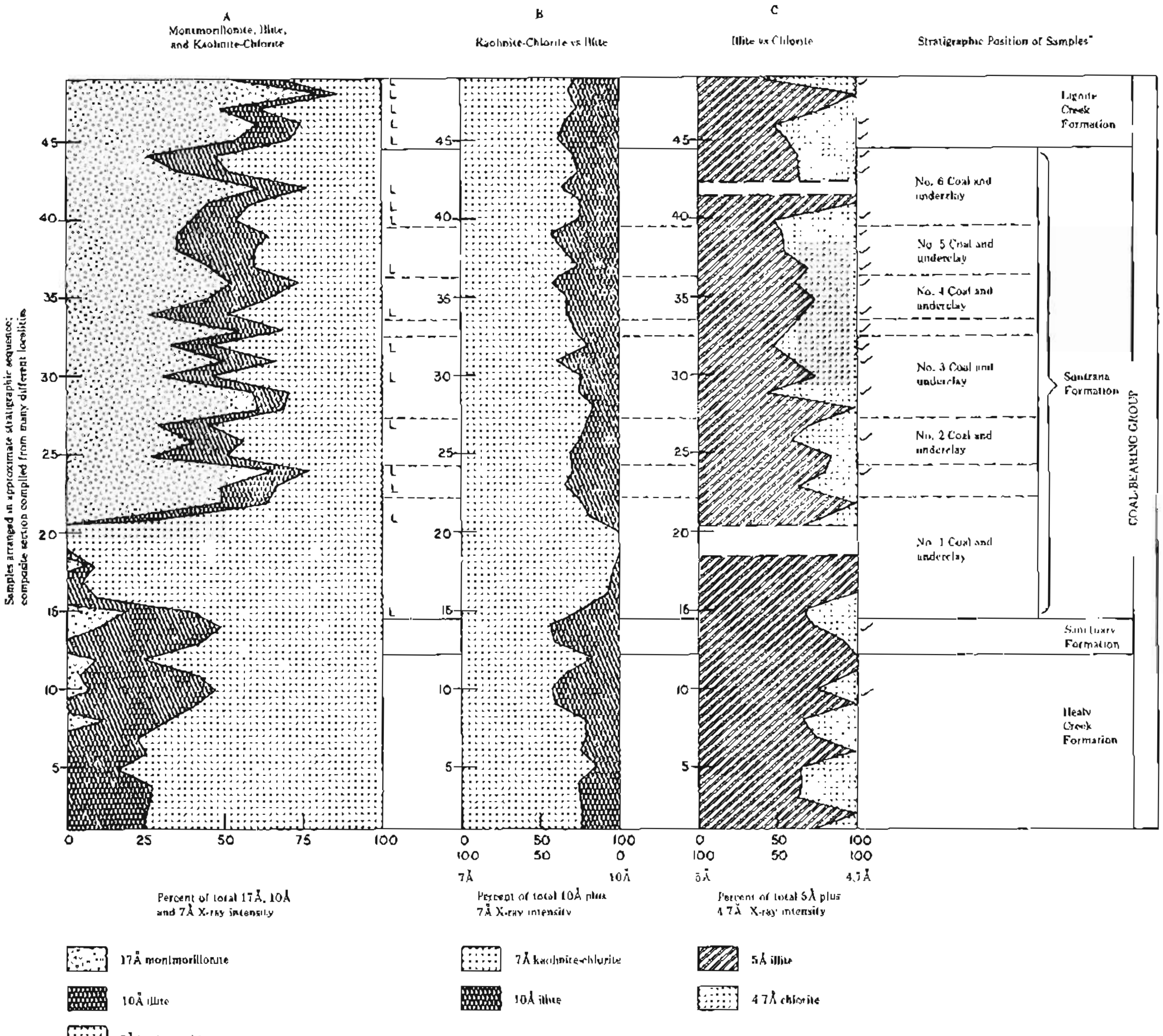
Seventeen samples were taken from Lignite Creek and 32 were taken from Healy Creek, about 6 to 8 miles south. In figure 4A, samples from Lignite Creek are identified by an "L" on the right side. No consistent difference is noted between the two sets of samples. However, sample distribution is unfortunate in that there are no samples from Lignite Creek lower than the base of the Suntrana Formation.

A better comparison is obtained if only the Suntrana Formation is considered; there are 12 samples from Lignite Creek and 18 from Healy Creek. Figure 4 reveals no significant differences between the two locations.

Too few samples were taken to describe detailed clay mineral variations within a more restricted interval; for example, argillaceous beds associated with a given coal. However, the No. 1 coal was particularly rich in kaolinite (figure 4A). This holds true for seven out of eight samples, including both underclays and clay partings; the single exception was the montmorillonitic upper parting mentioned in item 1.

VARIATIONS AMONG LITHOLOGIC TYPES

Thirty-eight of the 49 samples in figure 4 were underclays or clay partings in coal beds. The 11 other samples were less closely associated with coal beds. Neither group is characterized by a particular clay mineral or clay-mineral association. Individual samples



*Best estimates based on Wahrhaftig's measured sections (in Barnes and others, 1951); some uncertainty between Lignite Creek and Healy Creek localities and for the lower part of the section along Healy Creek.

Figure 4. Vertical variation in clay mineralogy—composite section of all samples.

sometimes had clay mineralogy similar to that of adjacent samples. In other cases, marked constraints between adjacent samples occurred, regardless of lithology.

BULK DENSITY

Figure 5 shows the bulk densities of 63 samples arranged in their estimated stratigraphic order. Many of these are not the same samples that were examined for clay mineralogy and shown in figure 4.

Although bulk densities are variable, their maximum values tend to increase from about 2.1 at the top to about 2.4 at the base; this is probably the most important feature of figure 5. Wahrhaftig (1951) reported that coals from Lignite Creek are of a lower grade (lignite rather than subbituminous) than those on Healy Creek; thus lower bulk densities might be expected for Lignite Creek samples. However, no significant difference was apparent. Samples with much organic matter generally tended to have low densities for their stratigraphic positions; this factor is probably responsible for much of the scatter in figure 5.

INTERPRETATIONS OF ANALYSES

ORIGIN OF VARIATIONS IN CLAY MINERALOGY

Clay minerals may have many origins, and a complete discussion here would be prohibitively long. Therefore, the following discussion is limited to interpretations favored by the writer, with an attempt to give supporting data, point out serious contrary evidence, and identify the degree of confidence held.

ORIGIN AND DISTRIBUTION OF MONTMORILLONITE

The marked abundance of montmorillonite above the No. 1 coal and its minor occurrence below that point is the most important vertical change in clay mineralogy. The montmorillonite probably originated from the weathering of volcanic glass—either from flow rocks or shallow intrusives of a bedrock source or from pyroclastics widely distributed in both erosional and depositional areas.

Sample 22, a thin argillaceous parting near the top of the No. 1 coal, reveals the suddenness of the first influx of abundant montmorillonite (figure 4) and raises the possibility that at least some of it originated as volcanic ash. A clay parting about 6 feet below the top of the No. 1 coal has been observed at several locations. If it is a continuous bed, it is likely that it originated as wind-borne volcanic ash; other mechanisms are unlikely to produce such thin, widespread units. These sheetlike units are likely to be produced only by ash that fell into coal swamps. Ash falling elsewhere would tend to be reworked and may be a partial source of the montmorillonite in water-laid sandstones and mudstones of the upper coal-bearing group.

The mineralogy of this unit is also of interest because partings of relatively pure clay in coals elsewhere are almost always kaolinite (Price and Duff, 1969). Such units are sufficiently common and distinctive to receive a special name: tonsteins. Although the origin of tonsteins is still somewhat controversial, they are increasingly accepted as products of volcanic ash falls—primarily on the basis of their thinness, wide distribution, and continuity.

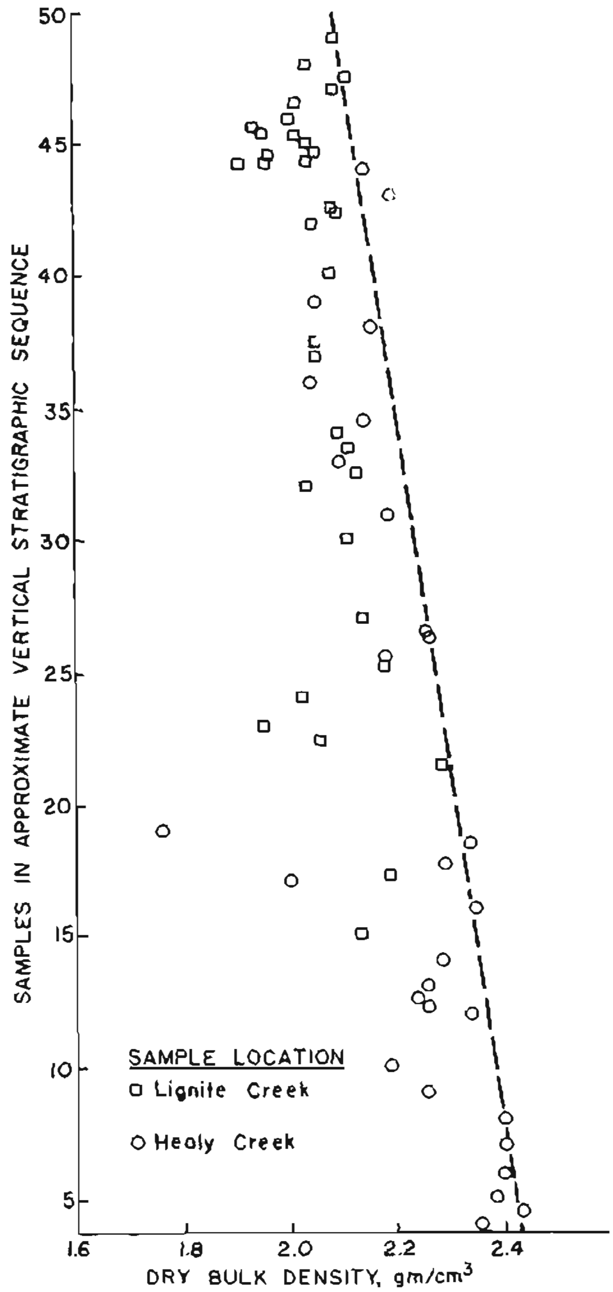


Figure 5. Relationship between bulk density and depth of burial of shales (vertical stratigraphic position). Dashed line follows estimated position of maximum values.

Figure 4B shows that the ratio of 10Å (illite) to 7Å (kaolinite-chlorite) intensities does not change appreciably between the upper lower parts of the section. This suggests that those minerals were supplied continuously from a relatively uniform source and that montmorillonite was added in variable amounts, perhaps originating as periodic influxes of pyroclastic material and at least partly reworked by running water.

ORIGIN AND DISTRIBUTION OF KAOLINITE

Although kaolinite is common in all samples, clay partings and the underclay of the No. 1 coal contain almost pure kaolinite in $<$2-micron fractions (samples 16-20, figure 4A). This underclay is particularly striking in parts of Healy Creek, where it is more than 8 feet thick, appears massive and uniformly fine grained, and weathers to a light-gray color. In thin section, it is a silty, micaceous clay. The elongate mica crystals have a minor degree or preferred orientation parallel to bedding, whereas the finer clay matrix does not. The whole-rock mineralogy, based on X-ray diffraction, consists of abundant quartz, some kaolinite, and a spectrum of poorly organized material, possibly including illite, chlorite, montmorillonite, and their weathering products. Ordinarily, some feldspar would be expected to accompany such a large proportion of quartz and mica. The absence of feldspar suggests its removal by weathering, possibly by alteration to kaolinite.

In this regard, the orientation of the clay matrix of the sandstones is of interest. The abundant clay matrix of the lower sandstones (as noted by Wahrhaftig, 1969) is unexpected, for these are mineralogically mature quartz-chert sands. In one of the coarser sandstones, an angular grain 1/2 inch in diameter was found altered to a soft, white clay. X-ray diffraction revealed that this grain is a mixture of feldspar (microcline?), quartz, and kaolinite. Such postdepositional alteration of feldspars may be a major contributor to the abundant clay matrix of these lower sands. A less likely alternative involves the inclusion of sand-sized pyroclastic material transported and mixed with other sand components. After deposition, alteration of this pyroclastic material to kaolinite would produce the observed abundance of clay matrix and the impression of poor sorting.

These kaolinite-rich lower sands may have served as the source for the distinctive, almost pure kaolinite clays and kaolinitic sandstones associated with the No. 1 coal. Moderate uplift and reworking of such sands would lead to the rapid winnowing of clay from sand and its concentration as almost pure kaolinite in contemporaneous lakes and swamps. For this process it would make no difference whether the kaolinite was a primary detrital component or was produced by the postdepositional alteration of feldspar or pyroclastic material.

BULK DENSITY AND DEPTH OF BURIAL

Baldwin (1971) summarized much of the data relating bulk density and related properties to depth of burial. Assuming that the dashed line in figure 5 represents maximum compaction for any given depth (and ignoring complications noted on p. 3), these bulk density values can be used to estimate the maximum depth of burial.

Baldwin's (1971) composite curve is reproduced here as figure 6. It suggests a maximum depth of burial for the coal-bearing group of between 3,000 and 8,000 feet for the Healy area. However, because the stratigraphic interval consists of about 2,000 feet and because Wahrhaftig and others (1951, p. 153) cite at least 4,000 feet of Nenana Gravel above the coal-bearing group, an intermediate value of 5,000 or 6,000 feet does not seem unreasonable. If so, this means that the coal-bearing group was never buried much deeper than the thickness of the existing sediments in nearby areas.

CORRELATION OF COAL BEDS

These coal beds apparently were deposited in swamps associated with a system of rivers that cut and filled as they shifted across a broad, subsiding alluvial plain (Wahrhaftig, 1969). The existence of a coal-forming environment over a very large area at any one time would not be expected. Furthermore, the laterally shifting channels sometimes eroded earlier-formed coal-like material, as can be seen in several exposures on Healy Creek. Therefore, individual coal beds probably do not exist as continuous units over distances greater than a few miles; a coal-bearing interval, however, might

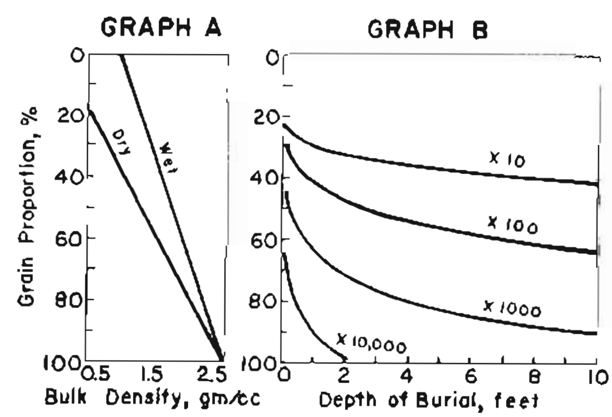


Figure 6. Depth of burial for clay and shale: graph A for converting bulk density to grain proportion (and porosity); graph B shows depth of burial versus grain proportion (and porosity). For each curve, multiply depth-of-burial values by number shown for that curve. (Baldwin, 1971, page 294.)

persist over much greater distances, perhaps tens of miles.

Correlation on a very local level (for example, along Healy Creek) may involve the precise identification of individual beds where they exist as physically continuous units. However, Wahrhaftig and others (1951, plate 227) suggests that between Healy Creek and Lignite Creek, some coals change character or disappear while new coal units appear; thus, identification of individual units becomes questionable over distances greater than a few miles.

As distances increase, the ability to correlate specific stratigraphic units decreases. Hence, the correlation of stratigraphic intervals (rather than units) that were deposited at the same time in different places becomes of prime importance. Such information is essential for reconstructing regional geologic history, but may be of limited value to local mining operations.

GENERAL OR REGIONAL CORRELATION

Most geologic criteria for correlation, such as physical properties or mineral composition, are of a generalized nature and of use only on a regional or general basis. In this study, clay mineralogy, the bulk density of mudrocks, the petrology of sandstones and conglomerates, and fossils may be of value.

CLAY MINERALOGY

The upper part of the section, roughly above the No. 1 coal, is distinguishable from the lower part by the abundant montmorillonite present in it. The No. 1 coal at Healy Creek is underlain by distinctively kaolinite-rich mudrocks, but the lateral continuity of this characteristic has not been established.

With this as a framework, it is interesting to examine a few samples from unknown positions within the coal-bearing group. (See the Appendix for clay mineral data). Two samples were collected from the B & R mine near Otto Lake. Although the samples were collected only a short distance above the Birch Creek Schist, the presence of significant montmorillonite in one of these suggests that it is higher than the lowest beds at the Suntrana tipple, and may be at least as high as the upper part of the Healy Creek Formation. Two other samples are from the new coal pit on the ridge between Healy Creek and Lignite Creek. Here the data are less definitive but the relative lack of montmorillonite suggests that they are from somewhere in the Healy Creek Formation, a position consistent with their obvious location not far above the Birch Creek Schist. Two samples were also taken from a mine in the Jarvis Creek basin, about 100 miles east of Healy. The significance of mineralogical differences at such a long distance is questionable; however, there was significant montmorillonite in one sample, which is characteristic of the upper part of the section at Healy.

BULK DENSITY

Although there is much variability, figure 5 shows that the maximum bulk densities of mudrocks are related to their general stratigraphic position. As illustrated in figure 7, sections from Lignite Creek show only vague lateral or vertical trends in bulk densities.

The four western sections (Wahrhaftig and others, 1951) seem to have higher values at a given stratigraphic position, perhaps indicating greater depth of burial or more deformation (tilting) to the west. The eastern sections shown in figure 7 are less consistent.

Three samples taken at the B & R pit west of Otto Lake have values of 2.06, 2.10, and 2.12. These values are markedly less than those found in the lower part of the section along Healy Creek (figure 5). This suggests that the western coals are equivalent to those somewhat above the lower part of the Healy Creek section. This supports the suggestion made earlier on the basis of clay mineralogy. Densities around 2.10 generally do not occur on Healy Creek below the No. 3 coal, a position that seems far too high for the B & R coals. This further suggests less compaction, by deformation or burial, for the B & R coals.

PETROLOGY OF CONGLOMERATES AND SANDSTONES

Wahrhaftig and others (1969, p. D20) noted a marked change in mineral composition at the No. 6 coal, and this became the primary basis for defining and distinguishing the Suntrana and Lignite Creek Formations.

In brief, the Lignite Creek Formation contains an abundance of mineral types less resistant to weathering than those found in the underlying Suntrana Formation. Although Wahrhaftig (1969) urges caution, this contact could be used to establish the Suntrana-Lignite Creek stratigraphic boundary in areas distant from the type section on Suntrana Creek, and where No. 6 coal cannot be located with certainty.

The minor petrographic and petrologic observations of the present study are consistent with the conclusions of Wahrhaftig and others (1969).

FOSSILS

As stated previously, Wahrhaftig (1960) used plant megafossils and palynological material to assign ages to formations of the coal-bearing group. Additional material or new kinds of fossils might permit further refinement of the rather broad and sometimes controversial age assignments.

A remarkably abundant and well-preserved leaf flora occurs below the D coal at the tipple pit on Healy Creek. This was sampled briefly by J.A. Wolfe (1973, personal communication) as USGS plant megafossil locality 9925 but appears capable of yielding a more

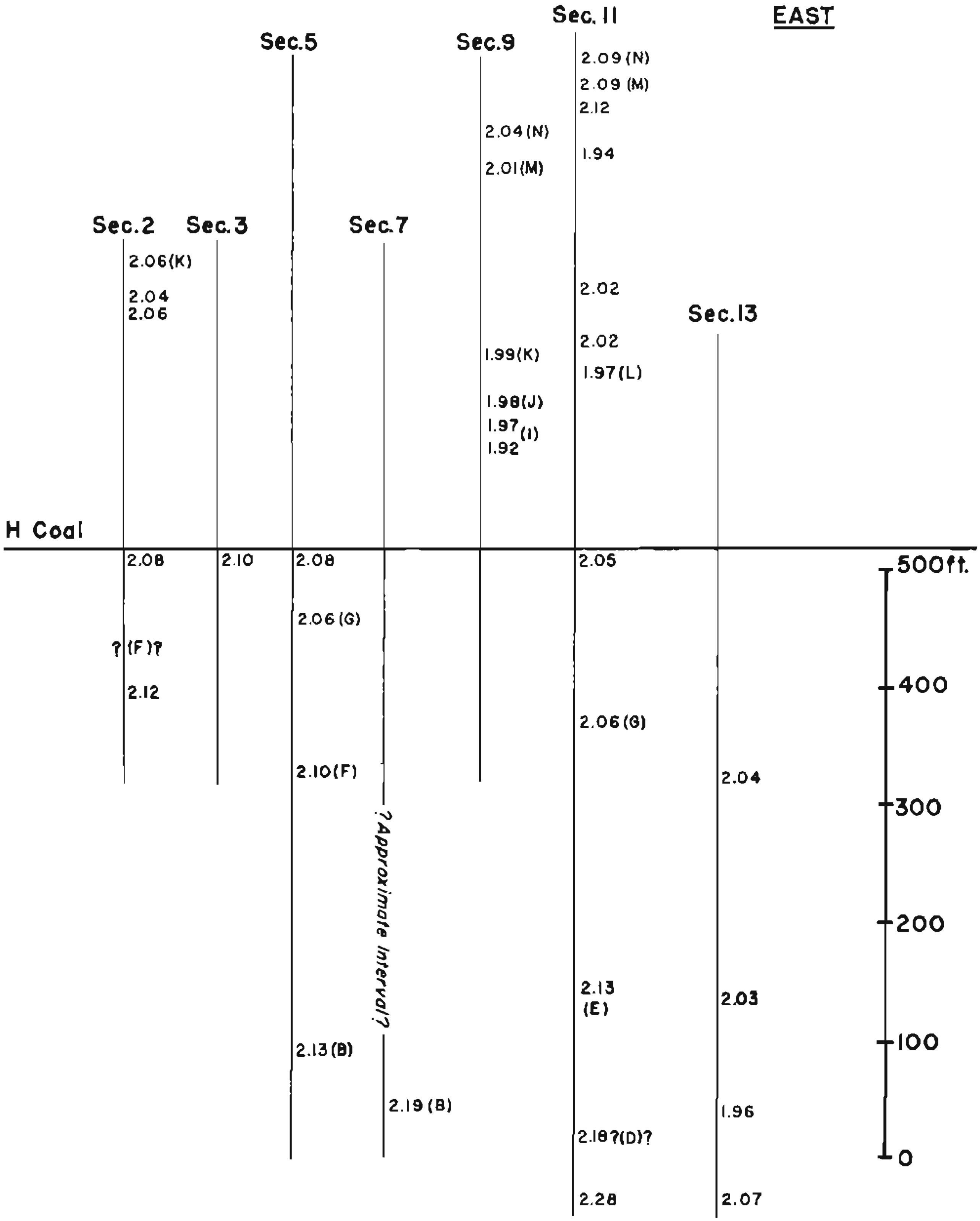


Figure 7. Bulk densities for shale samples from Lignite Creek. Section numbers are from Barnes and others (1951) and increase from west to east. Circled letters are coals as identified by Wahrhaftig (Barnes and others, 1951). See figure 2 for coal nomenclature and lithologic detail of a typical section.

diverse and abundant flora than heretofore. In addition, the writer collected a poorly preserved fish from this locality—the only specimen from this area since the one collected by Schlaikjer (1937), about 3 miles east of Suntrana. Presumably a more extensive search might yield additional specimens of more definitive stratigraphic value.

Diatoms have been found in the Grubstake Formation and in a clay parting in B coal of Lignite Creek. The Grubstake Formation is definitely an ash fall, and the clay parting may be an ash fall, as discussed earlier. Correspondence has been initiated with Wolfe to determine if diatoms would be of significant stratigraphic value.

DETAILED OR LOCAL CORRELATION

If some of the clay partings prove to be of volcanic origin, they may be important stratigraphic markers. Such units are termed tonsteins (p. 7) and are well known in some western European coals (Williamson, 1967, p. 206). As isochronous time units, tonsteins are of considerable value in precision correlation within individual coal beds. A number of tonsteins have been named and traced along coal workings for great distances; under favorable circumstances, they can locate positions in a given coal bed within a few feet.

The ideal condition would be the ability to date, in absolute years, the ages of these volcanogenic tonsteins. This would provide not only an exact position for a given unit within the sequence, but a basis for correlation with Tertiary units of the same age anywhere, regardless of whether they were deposited as physically continuous units. The success of such an approach depends on the occurrence of sufficient kinds and quantities of minerals for radiometric or fission-track dating. Initial attempts to locate such minerals in the Healy area have been unsuccessful.

IMPLICATIONS REGARDING ORIGIN OF THE COAL-BEARING GROUP

The major change in montmorillonite content—abundant above and virtually absent below the No. 1 coal—may reflect an important change in the depositional history of the coal-bearing group. Although there are several possible origins for this montmorillonite, the most likely one is through the alteration of glassy volcanic material. Whether such alteration occurred before or after transport to the site of final deposition is not critical for this broad interpretation, but could be an important detail to pursue later.

Although this evidence is not conclusive, it is sufficient to alert future investigators to the possible role of volcanism beginning about mid-Miocene time.

Coincidentally, distinctive kaolinite-rich beds occur in association with the No. 1 coal, the same position where montmorillonite first becomes abundant. These kaolinitic beds have previously (p. 8) been interpreted as due to interbasin uplift followed by winnowing of authigenic kaolinite from slightly older sands, and concentration of the clay-silt in swampy areas on a fluvial plain. Could such an uplift have been related to the beginning of volcanic activity (resulting in montmorillonite) at the site of the present Alaska Range? Much caution is necessary here, for these thoughts are highly speculative.

SUGGESTIONS FOR FUTURE INVESTIGATIONS

The following suggestions for additional work emphasize the main objective of improving correlations within the Tertiary coal-bearing rocks; however, important petrologic and environmental problems also exist.

1. Investigate possible tonsteins. Criteria should be developed for recognition of volcanogenic clay partings, and attempts should be made to locate and correlate specific examples. If successful, this could produce the key to correlating Tertiary sediments over wide areas—and with great precision.
2. Seek additional fossils at the Suntrana tipple. Plans have already been made to obtain more extensive collections of plant fossils from this prolific locality. These may provide a better stratigraphic determination and improved climatic-environmental interpretations. The single specimen of a poorly preserved fish raises the possibility of finding other aquatic fossils.
3. Investigate the mechanism of cyclic sedimentation. The unusual cyclic sedimentation here is worthy of investigation. The numerical methods of J.R.L. Allen (1970) might be applied to prove the existence of cycles and possibly quantify their details in subsequent study.
   Such information should help interpret the basic control of cyclic sedimentation, which in turn should improve understanding of the lateral distribution and variations of the coal beds themselves.

CONCLUSIONS

1. Some clay partings in coals may be deposits of volcanic ash that fell into swamps and were preserved because no mechanism existed for redistribution of such material. If so, these clay beds are of great potential value for stratigraphic correlation, both as physical markers and as units amenable to absolute dating methods.
2. Clay mineralogy can be used to differentiate three different intervals within the coal-bearing group:
   a. A lower interval with little or no montmorillonite.

b. An upper interval with abundant montmorillonite.
c. A relatively thin intermediate interval with predominant kaolinite (associated with the No. 1 coal).

3. The montmorillonite probably originated by alteration of pyroclastic material; reworking of this material by streams could account for its wide distribution in fluvial sands and muds.
4. At least some of the clay matrix of sandstones is due to postdepositional alteration of feldspars. Reworking of such sands and the concentration of clay could account for the kaolinite-rich interval associated with the No. 1 coal.
5. Bulk densities of mudrocks, interpreted as a function of depth of burial, are of some value in stratigraphic correlation and are consistent with the overall geologic setting.
6. Diatoms—of possible stratigraphic value—may occur only or primarily in units with a pyroclastic component (Blutt and others, 1972, p. 535). This selectivity may be related to the abundance of soluble silica associated with glassy ash.
7. There may be additional plant (and possible animal) fossils of stratigraphic value at the Suntrana tipple. In this investigation, a poorly preserved fish was found as well as diverse and well-preserved plant fossils whose significance is only partly known. (Wolfe, 1973, personal communication, indicates that this outcrop has not been fully exploited.)

REFERENCES

Allen, J.R.L., 1970, Studies in fluviatile sedimentation, a comparison of fining-upward cyclothems, with special reference to coarse-member composition and interpretation: Jour. Sed. Pet., 40, p. 298-323.

Baldwin, B., 1971, Ways of deciphering compacted sediments: Jour. Sed. Petrology, 41/1, p. 293-301.

Blutt, H., Middleton, G., and Murray, R., 1972, Origin of sedimentary rocks: Prentice-Hall, Englewood Cliffs, N.J., Prentice-Hall, Inc., 634 pp.

Price, N.B., and Duff, P.M.D., 1969, Mineralogy and chemistry of tonsteins from carboniferous sequence in Great Britain: Sedimentology, 13, p. 45-69.

Schlaikjer, E.M., 1937, New fishes from the continental Tertiary of Alaska: Am. Mus. Nat. History Bull., 74, p. 1-23.

Wahrhaftig, Clyde, 1951, Geology and coal deposits of the western part of the Nenana coal field, Alaska, *in* Barnes, F.F., and others, Coal investigations in south-central Alaska, 1944-46: U.S. Geol. Survey Bull. 963-E, p. 169-186.

—1958, Quaternary geology of the Nenana River valley and adjacent parts of the Alaska Range: U.S. Geol. Survey Prof. Paper 293-A, p. 1-68.

—1970a, Geologic map of the Healy D-2 quadrangle, Alaska: U.S. Geol. Survey Geol. Quad. Map GQ-804.

—1970b, Geologic map of the Healy D-3 quadrangle, Alaska: U.S. Geol. Survey Geol. Quad. Map GQ-805.

—1970c, Geologic map of the Healy D-4 quadrangle, Alaska: U.S. Geol. Survey Geol. Quad. Map GQ-806.

—1970d, Geologic map of the Healy D-5 quadrangle, Alaska: U.S. Geol. Survey Geol. Quad. Map GQ-807.

—1970e, Geologic map of the Fairbanks A-2 quadrangle, Alaska: U.S. Geol. Survey Quad. Map GQ-808.

—1970f, Geologic map of the Fairbanks A-3 quadrangle, Alaska: U.S. Geol. Survey Quad. Map GQ-809.

—1970g, Geologic map of the Fairbanks A-4 quadrangle, Alaska: U.S. Geol. Survey Quad. Map GQ-810.

—1970h, Geologic map of the Fairbanks A-5 quadrangle, Alaska: U.S. Geol. Survey Quad. Map GQ-811.

Wahrhaftig, Clyde, Hickcox, C.A., and Freedman, Jacob, 1951, Coal deposits on Healy and Lignite Creeks, Nenana coal field, Alaska, *in* Barnes, F.F. and others, Coal investigations in south-central Alaska, 1944-46: U.S. Geol. Survey Bull. 963-E, p. 141-165.

Wahrhaftig, Clyde, and Birman, J.H., 1954, Stripping-coal deposits on lower Lignite Creek, Nenana coal field, Alaska: U.S. Geol. Survey Cir. 310, 11 p.

Wahrhaftig, Clyde, and Hickcox, C.A., 1955, Geology and coal deposits, Jarvis Creek coal field, Alaska: U.S. Geol. Survey Bull. 989-G, p. 353-367.

Wahrhaftig, Clyde, Wolfe, Jack A., Leopold, Estella B., and Lanphere, Marvin A., 1969, The coal-bearing group in the Nenana coal field, Alaska: U.S. Geol. Survey Bull. 1274-D, p. D1-D30.

Williamson, I.A., 1967, Coal mining geology: London, Oxford Univ. Press, 266 pp.

APPENDIX—CLAY MINERALOGY AND BULK DENSITY DATA

	Stratigraphic Position	Sequence in Figure 4	Complete Sample Number	Clay Mineralogy: Peak-Height % 17Å	10Å	7Å	7Å/10Å	5Å/47Å	Bulk Density, gm/cm³
Lignite Creek Formation	N Coal	49	7-27-72-4	50	13	37	75/25	45/55	2.09
		48	7-29-72-7	79	7	14	68/32	100/0	2.04
			8-22-72-8	11	0	89	100/0	- - -	
	M Coal		7-27-72-8						2.12
		47	7-27-72-7	48	13	39	74/26	80/20	2.09
			7-27-72-9						2.02
		46	7-29-72-8	60	14	26	66/34	50/50	2.01
			7-27-72-15						1.97
	K Coal		7-27-72-10						1.94
			7-27-72-13						2.02
		45	7-29-72-4	53	18	29	62/38	58/42	2.04
			7-17-72-4						2.06
			7-17-72-2						2.04
			7-17-72-3						2.06
			6-71-8	74	4	22	86/14		2.39
			6-71-7	47	16	37	70/30		2.12
			6-71-6	60	16	24	61/39		2.08
			6-71-5	63	11	26	71/29		2.15
	J Coal	7-29-72-3	7-29-72-3						1.98
	I Coal	7-29-72-1	7-29-72-1						1.97
			7-29-72-2						1.92
Suntrana Formation		44	7-13-72-1	26	21	53	71/29	65/35	2.15
	H Coal	43	7-13-72-2	36	16	48	74/26	65/35	2.20
	(No. 6)		7-17-72-5						2.08
			7-18-72-3						2.10
		42	7-27-72-3	62	14	24	63/37	- - -	2.05
		41	7-28-72-1	45	13	42	76/24	100/0	
		40	7-19-72-13	39	14	47	77/23	50/50	2.08
		39	7-12-72-11	35	28	37	57/43	54/46	2.06
	G Coal	38	7-12-72-12	35	24	41	63/37	54/46	2.16
	(No. 5)								
			7-19-72-12						2.06
		37	7-27-72-1	45	15	40	73/27	70/30	2.06
		36	7-10-72-12	52	21	27	56/44	62/38	
	F Coal		7-10-72-13	46	19	35		64/36	2.04
	(No. 4)	35	N-17	46	18	36	67/33	73/27	
			6-71-4	63	12	25			2.14
		34	7-19-72-11	27	24	49	67/33	68/32	2.10
			7-18-72-1						2.12
	E Coal	33	7-11-72-6	55	13	32	71/29	59/41	2.10
	(No. 3)		7-27-72-17						2.13
		32	7-28-72-9	33	13	54	80/20	48/52	2.04
		31	7-10-72-16	50	16	34	68/32	60/40	2.18
		30	7-19-72-10	30	16	54	75/25	74/26	2.12
		29	N-16	58	12	30	73/27	44/56	
		28	N-22	61	7	32	83/17	100/0	
	D Coal	27	7-19-72-9	28	16	56	78/22	69/31	2.14
			7-10-72-4						2.26
			7-11-72-3						2.27

Stratigraphic Position	Sequence in Figure 4	Complete Sample Number	Clay Mineralogy: Peak-Height % 17Å	10Å	7Å	7Å/10Å	5Å/47Å	Bulk Density, gm/cm^3
Suntrana Formation (cont.)	26	N-20	41	15	44	74/26	59/41	
		7-12-72-7						2.18
		7-27-72-18						2.18
	25	N-21	27	23	50	68/32	83/17	
	24	7-28-72-6	67	10	23	70/30	80/20	2.03
	23	7-28-72-5	48	18	34	65/35	82/88	1.96
		7-28-72-2						2.08
		8-22-72-2	57	9	37	80/20	. . .	2.28
	22	7-9-72-7	49	14	37	73/27	100/0	
		8-21-72-8	23	8	55		87/13	2.07
	21	7-19-72-5	11	18	71	80/20	72/28	
		7-26-72-4	3	21	76	79/21	- - -	
	20	7-9-72-8A	0	0				
	19	7-9-72-8B	0	0	100	100/0	. . .	1.77
		7-12-72-1						2.34
B Coal	18	N-19	7	2	91	97/3	100/0	
(No. 1?)		7-9-72-10						2.29
		7-19-72-4						2.19
	17	7-9-72-9	0	5	95	95/5	100/0	2.00
	16	7-9-72-6	0	8	92	92/8	100/0	2.35
	15	7-19-72-7	18	20	62	76/24	68/32	2.13
Sanctuary Formation	14	7-12-72-2	8	40	52	56/44	73/27	2.28
	13	7-12-72-3	0	42	58	58/42	92/8	2.26
Healy Creek Formation		7-13-72-5						2.24
		7-11-72-4						2.27
F Coal	12	7-12-72-5	8	16	76	83/17	100/0	2.34
	11	N-18	3	38	59	66/34	100/0	
	10	7-13-72-4	7	40	53	57/43	74/26	2.18
	9	7-11-72-5	0	40	60	58/42	100/0	2.26
	8	7-13-72-6	12	19	69	78/22	66/34	2.40
D Coal	7	7-6-72-13	0	22	78	78/22	72/28	2.40
	6	7-6-72-12	0	25	75	75/25	100/0	2.40
	5	7-6-72-11	0	15	85	85/15	63/37	2.38
	4	7-6-72-10	0	27	73	73/27	65/35	2.36
		4-9-72-5	0	25	75	75/25	- - -	
		4-9-72-6	0	29	71	76/24		2.44
A Coal	3	7-6-72-4	0	26	74	74/26	62/38	
	2	7-6-72-3	0	24	76	76/24	100/0	
	1	7-6-72-2	0	24	76	76/24	70/30	
MISCELLANEOUS SAMPLES								
B & R Coal Mine:		7-25-72-4						2.10
		7-25-72-5	22	24	54			2.12
		7-25-72-2	1	41	58			
New pit between Healy Creek and Lignite Creek :		9-2-72-1	10	13	77			2.16
		9-2-72-3	7	28	63			
Jarvis Creek :		8-24-72-1	31	27	42	60/40		2.19
		8-24-72-3	8	- -	92	100/0		1.87