Use of altered volcanic ash falls in stratigraphic studies of coal-bearing sequences: An example from the Upper Cretaceous Ferron Sandstone Member of the Mancos Shale in central Utah

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ABSTRACT

Coal beds most commonly occur in stratigraphic units characterized by rapid lateral facies changes for which determination of time relationships and correlation of facies are difficult. The Ferron Sandstone Member of the Mancos Shale in central Utah is such a unit. The Ferron records the activity of a delta system that prograded in a northeasterly direction into the Interior Cretaceous seaway during late Turonian time. The Ferron consists of five delta cycles, each of which includes one coal zone. Each of the coal zones contains at least one, and usually several, laterally persistent kaolinitic claystone partings. Laboratory study of the partings demonstrates that they represent altered volcanic ash falls. These partings have proven particularly useful in reconstructing the depositional history of the C coal bed of the Emery coal field. They permit division of the C coal bed into four isochronous units. The coal bed accumulated in a basin that developed concurrently with subsidence of the delta plain during both the constructive and destructive phases of the third delta cycle of the Ferron. The area of peat accumulation expanded in both seaward and landward directions during the interval of time represented by the coal. Peat accumulation was terminated by transgression of the sea across the seaward part of the peat deposit, where prodelta and delta-front strata of the fourth delta cycle now disconformably overlie the coal. In its landward part, the C coal bed is overlain, with no evidence of erosion, by delta-plain strata of the fourth cycle.

INTRODUCTION

Coal beds that are thick enough and of sufficient lateral extent to be of economic value occur, with few exceptions, in strata that accumulated in delta-plain, back-barrier, or alluvial paleoenvironments. These strata are characterized by rapid lateral facies changes, making determination of time relationships and correlation of facies within them difficult. Many of the Cretaceous and Tertiary coal beds of the Western Interior of North America and associated fine-grained strata contain laterally continuous kaolinitic claystone partings. Laboratory study has shown that most of these partings are altered volcanic ash falls (Bohor and others, 1976). Kaolinitic claystone partings called "tonsteins" (German word for claystone) have been used successfully for many years to correlate coal beds in Europe (Williamson, 1970). Despite the fact that they are quite common in the Western Interior of North America, altered volcanic ash falls have not been widely used in correlating coal beds and coal-bearing strata in the Western Interior, probably because most North American coal geologists

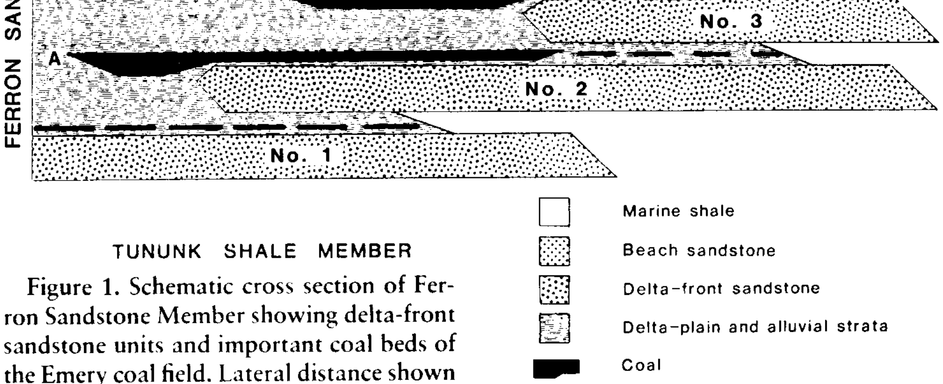

Figure 1. Schematic cross section of Ferron Sandstone Member showing delta-front sandstone units and important coal beds of the Emery coal field. Lateral distance shown in this figure is about 60 km. Maximum thickness of Ferron shown is about 200 m.

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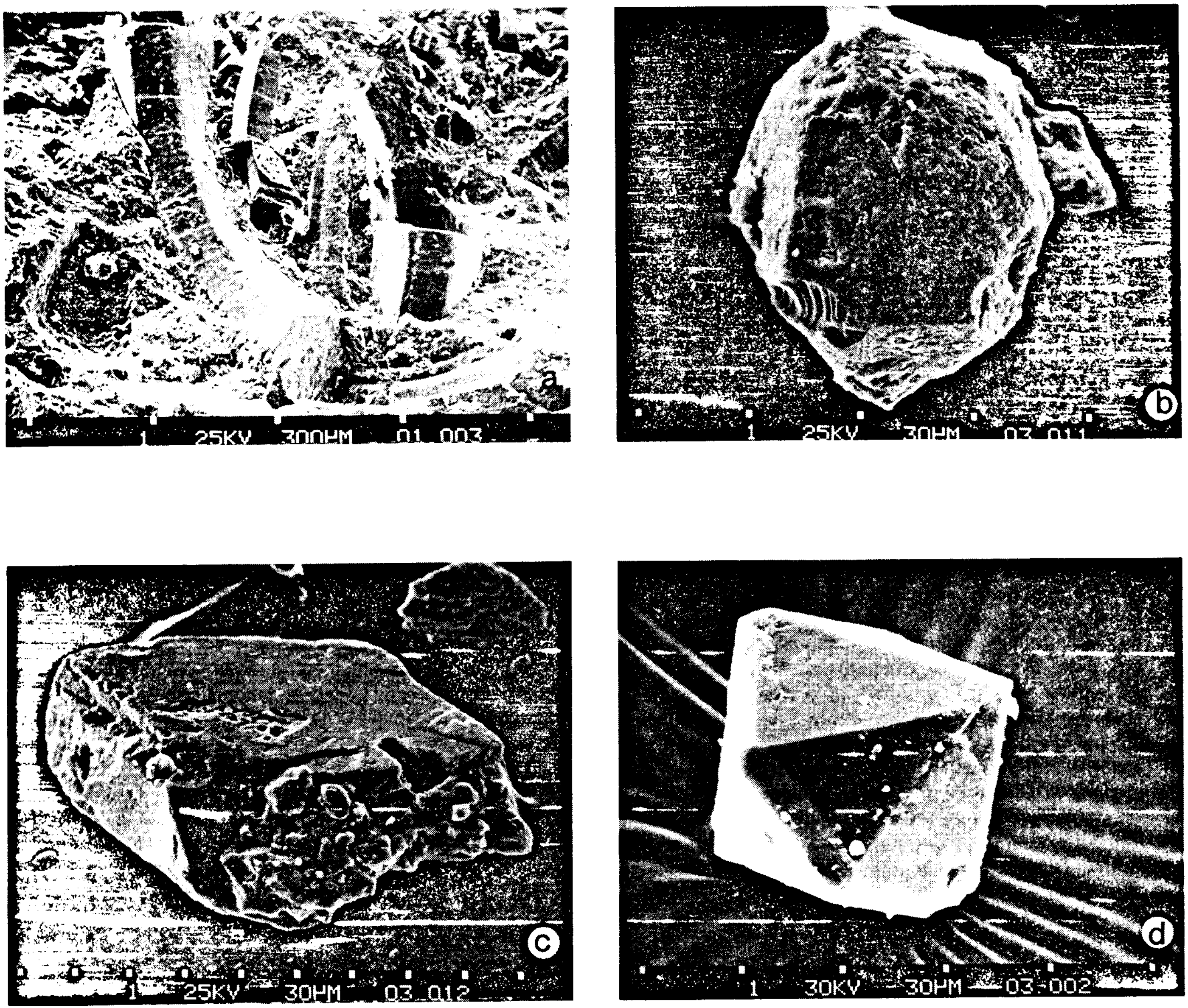

Figure 2. SEM photographs of crystals in claystone partings of the Ferron Sandstone Member. (a) vermicules of authigenic kaolinite; (b) corroded, partially resorbed β -quartz phenocryst (α -quartz after β -quartz); (c) sanidine; and (d) for purposes of comparison with (b), a non-corroded β -quartz crystal (α -quartz after β -quartz) from an altered volcanic ash of Late Cretaceous age in southwestern Wyoming.

do not recognize these partings as volcanic in origin. They are, in fact, the terrestrial equivalents of the smectitic bentonites that are so common in Cretaceous marine shales in the Western Interior.

Stratigraphers have long recognized the value of bentonites in correlating marine strata, particularly when they are used in conjunction with biostratigraphic studies (for example, Hattin, 1971). Viewed as time surfaces, bentonites may, in some cases, be used to determine paleotopography. For instance, detailed correlation of resistivity patterns of electric logs, which reflect the bentonite content of fine-grained rocks, have been utilized by Asquith (1970) to reconstruct the submarine topography of parts of the Interior Cretaceous seaway. We believe that altered volcanic ash partings can be used in similar ways for coal-bearing strata.

Recent studies have demonstrated that the geometry, quality, and geochemistry of coal beds are related to their depositional setting and paleoenvironmental history (Horne and others, 1978). Accordingly, the role of paleoenvironmental reconstruction is becoming increasingly important in coal exploration, mine planning, and mine development. As we will demonstrate with an example from the Ferron Sandstone Member in central Utah, partings of altered volcanic ash can be of considerable value in reconstructing the paleoenvironmental history of a coal bed.

DEPOSITIONAL SETTING OF FERRON SANDSTONE MEMBER

The Ferron Sandstone Member of the Mancos Shale records the activity of a high constructional delta system that repeatedly prograded in a northeasterly direction into the Interior Cretaceous seaway during late Turonian time (Katich, 1953, 1954; Cotter, 1975, 1976; Ryer, 1979). Prodelta, delta-front, delta-plain (including distributary channel), and alluvial facies are recognized. On its outcrop in southern Castle Valley, the Ferron consists of five delta cycles (Fig. 1). During constructional phases, the delta system prograded seaward, the deposits of the more landward facies coming to overlie those of the more seaward facies in progradational sequences. Subsequently, the landward facies were mildly to deeply eroded by the advancing shorefaces that developed during intervening phases of delta abandonment and destruction.

The important coal beds of the Emery coal field occur within the delta plain facies of the Ferron. With the exception of the first cycle, which is not exposed in its entirety, each of the delta cycles contains one thick, laterally continuous bed of coal that, together with its associated rider coal beds, is regarded as constituting a coal zone. The coal zone of the fifth cycle (I coal) is split by alluvial strata into two coal zones (I_1 and I_2) in the landward direction. Each of the coal zones contains at least one and, in most cases, several kaolinitic claystone partings.

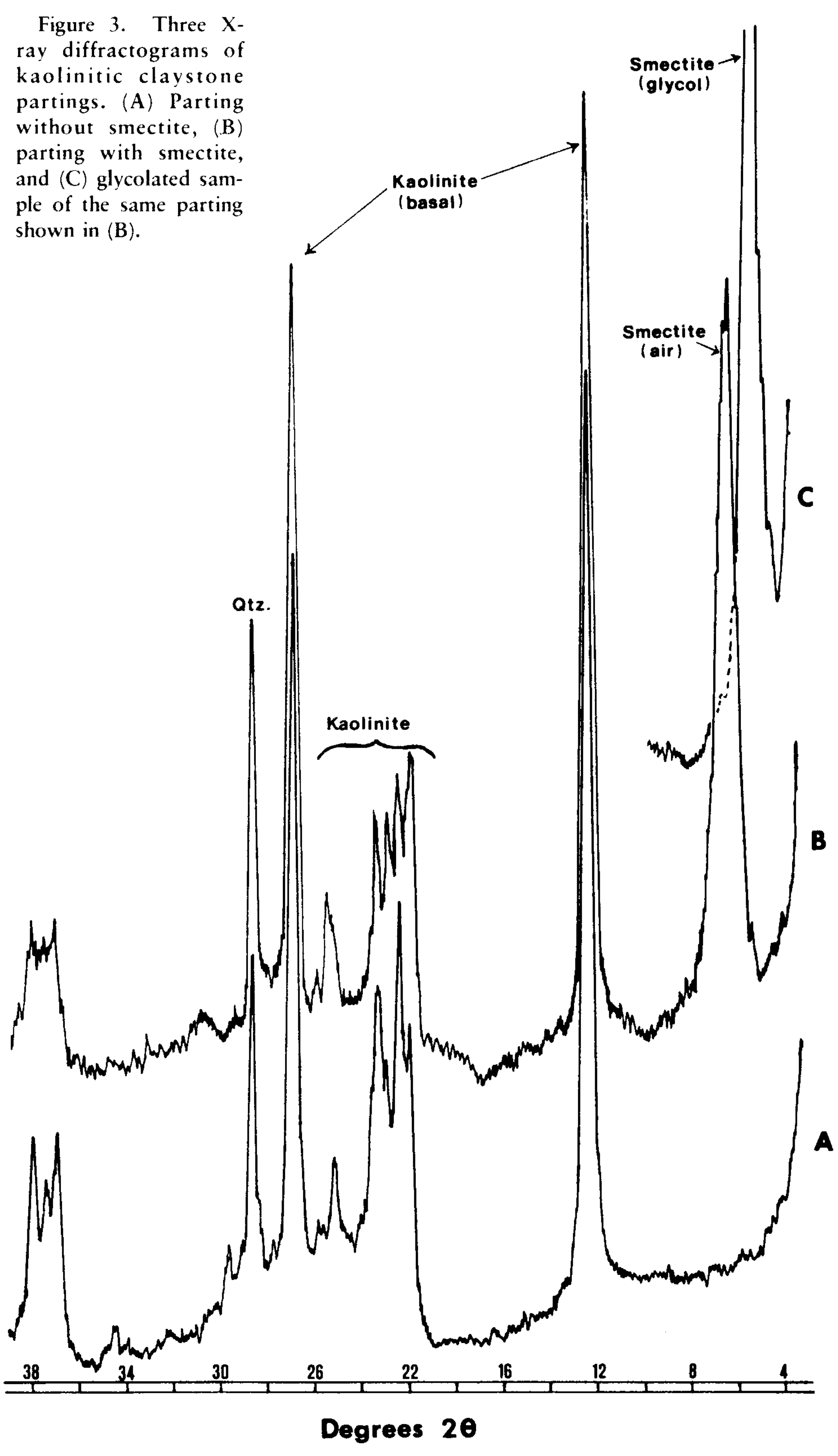

Figure 3. Three X-ray diffractograms of kaolinitic claystone partings. (A) Parting without smectite, (B) parting with smectite, and (C) glycolated sample of the same parting shown in (B).

DESCRIPTION AND ORIGIN OF PARTINGS

The laterally persistent kaolinitic claystone partings of the Ferron are generally easily distinguished from partings of siltstone, mudstone, and carbonaceous shale, all of which are much more variable in thickness and of only local extent. The kaolinitic claystone partings typically weather white or cream-colored, or, less commonly, light gray, bluish-gray, light tan, or greenish-white. The color of a single parting has been observed to change laterally as a function of its position relative to the top or bottom of the coal in which it occurs. The partings lack bedding, are highly cohesive, and display a blocky fracture. Their upper and lower contacts are generally sharp. Many of the partings contain large crystals of authigenic kaolinite, giving them the appearance of micaceous or sandy siltstone. These large kaolinite crystals are sometimes arranged in stacks or vermicules (Fig. 2a) that may be visible to the unaided eye. In the Ferron, the partings range in thickness from less than a centimetre to about 40 cm. An individual parting usually shows little variation in thickness when traced laterally. The lateral persistence of some of the partings is remarkable. This is particularly true for the thicker partings. A 15-cm-thick claystone parting in the A coal bed of the Emery field, for example, has been traced for a distance of 27 km. The thicker partings may even be traced through areas where their enclosing coals have burned on the outcrop. Here they are baked to tan, gray, or white porcellanites. Although most easily recognized in coal, kaolinitic claystone "partings" can also be recognized in carbonaceous shale and mudstone. Partings have been traced from localities where they occur in coal to localities where they occur in shales or mudstones, showing that their origin is not solely a function of the character of the enclosing rock type.

Analysis by X-ray diffraction of the laterally continuous claystone partings in the Ferron demonstrates that the majority are composed mostly of kaolinite with only a trace of mixed-layer clays. Diffractograms display the narrow, intense, kaolinite basal (00ℓ) peaks and sharp, well-resolved, kaolinite prism reflections indicative of authigenic kaolinite (Fig. 3A). Some of the partings contain substantial amounts of smectite. Diffractograms of these partings show sharp, first-order, basal (001) reflections of smectite, particularly after glycolation, indicating that the smectite, too, is authigenic (Figs. 3B, 3C).

The non-clay fractions of the partings, which generally compose only a small percentage of the total by weight, were analyzed using a petrographic microscope, an X-ray diffractometer, and a scanning electron microscope equipped with an energy-dispersive X-ray spectrometer. The light fraction of the non-clay material consists of quartz and sanidine. Quartz was most commonly found as anhedral, angular to subangular grains. However, several corroded β-quartz or "high quartz"–form phenocrysts (α quartz after β quartz) were identified in most of the samples (Figs. 2b, 2d). Sanidine occurs as subhedral to anhedral grains (Fig. 2c). The heavy fraction is minor and contains only a few mineral species. Idiomorphic zircons are dominant. Also present are rare crystals of anatase, rutile, tourmaline, and opaque iron and titanium oxides.

The analyses performed in the laboratory clearly indicate that the clay minerals in the partings are authigenic. The authigenic clay minerals, the presence of β-quartz–form phenocrysts, sanidine, and idiomorphic zircons point to a volcanic origin for the parent material (Bohor and others, 1978). The partings are of uniform thickness and of great lateral extent and can be traced from coal into adjacent rock types. The only explanation that satisfactorily accounts for all of these characteristics is that the laterally persistent claystone partings of the Ferron are the products of in situ alteration of widely distributed layers of volcanic ash.

USE OF ASH FALLS: C COAL BED

The C coal bed of the Emery coal field (Lupton, 1916) occurs in the delta-plain facies of the third cycle of the Ferron Sandstone Member (Fig. 1). The C coal attains maximum thickness in a belt, about 10 km wide, that parallels and is situated landward (southwestward) of the landward pinchout of the associated No. 3 delta-front sandstone unit. This pattern is typical of coals in the Emery coal field (Ryer, 1979). In its seaward (northeastern) part, the C coal bed is disconformably overlain by prodelta and delta-front strata of the fourth cycle. Delta-plain strata of the fourth cycle overlie the landward part of the C coal bed with little or no erosion.

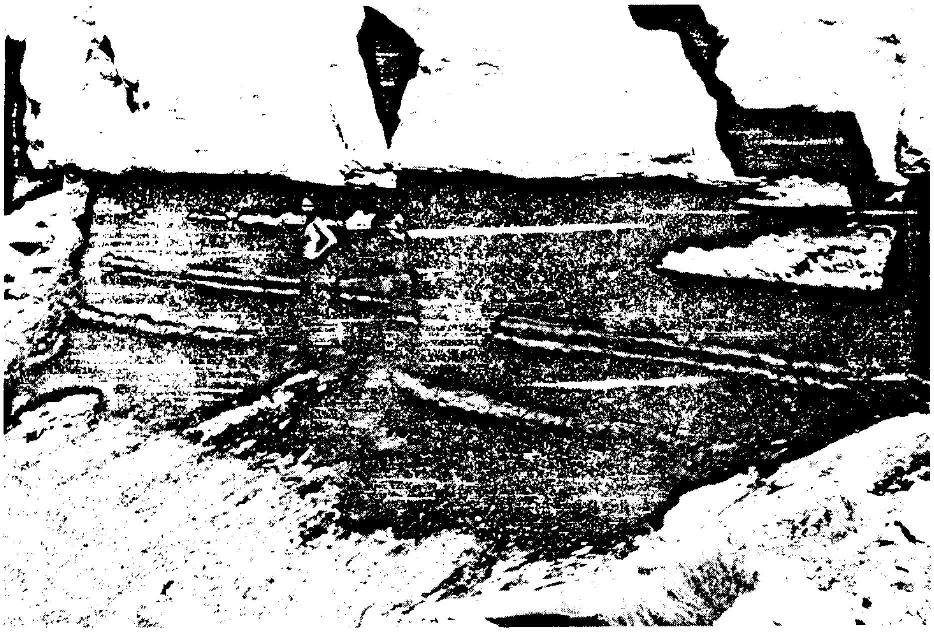

Figure 4. Kaolinitic claystone partings of the C coal bed of the Emery coal field.

The C coal bed contains four partings of altered volcanic ash (Fig. 4): a lower parting, generally about 10 cm thick; a pair of partings or "doublet," each about 3 cm thick; and an upper, very thick parting that is typically 30 to 40 cm in thickness. Exposures of the Ferron Sandstone Member in the Emery area are such that the C bed coal can be traced throughout the coal field with a high degree of confidence. In an area of poorer exposure, however, the distinctive sequence of partings could be used as a correlation tool. Tracked to the southwest (landward) from the area of maximum coal thickness, the partings descend stratigraphically relative to the base of the coal bed and successively disappear as they reach the bottom of the coal. The top parting, because of its great thickness, is traceable beyond the landward limit of the coal. Here it is enclosed in a sequence of carbonaceous shale and mudstone. To the northeast (seaward), the partings also descend relative to the bottom of the coal bed. The lower parting and the lower member of the doublet disappear upon reaching the bottom of the bed. What finally becomes of the upper member of the doublet and the thick upper parting is unknown — exposures of the part of the Ferron that contains the seaward limit of the C coal bed occur in inaccessible cliffs 2 to 3 km northeast of the northeasternmost measured section of the bed.

Assuming that the altered volcanic ash falls of the C coal bed represent volcanic events that were of short duration, the four partings described above may be used to divide the coal body into four isochronous, or nearly isochronous, units (Fig. 5). The section, a southwest-northeast cross section of the C coal bed constructed with the base of the thick, upper parting as the datum, is oriented at a high angle to the depositional strike. The contacts of the coal bed with overlying and underlying strata, of course, cannot be assumed to represent time surfaces. The contact of the coal bed with the overlying No. 4 delta-front sandstone is erosional and irregular — far more irregular, in fact, than could be illustrated on the simple cross section. The relief on the erosional surface is as great as 1.5 m — the upper, thick parting having been removed locally.

The area of peat accumulation on the delta plain of the third delta cycle expanded simultaneously in both seaward and landward directions, as evidenced by the fact that the time lines defined by the altered volcanic ash falls in the C coal bed descend relative to the bottom of the bed when traced in either direction away from the area of thickest coal. This situation can be

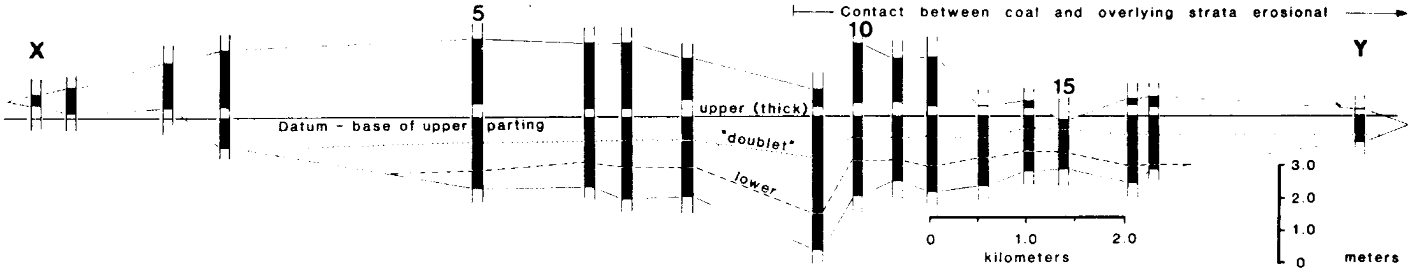

Figure 5. Cross section X–Y, incorporating C coal bed measured sections. The coal bed is divided into isochronous units using partings of altered volcanic ash as time lines.

explained in terms of the depositional setting of the C coal bed. Figure 6, an isopachous map, shows the area in which the C coal bed exceeds 3m in thickness. Also shown are areas where the thickness of the stratigraphic interval between the top of the A coal bed and the base of the C coal bed exceeds 10m. Though not isopached on Figure 6, the A–C interval increases abruptly in thickness to values of 20 to 30 m in the area where the No. 3 delta-front sandstone is present (that is, northeast of its landward pinchout). Two areas where the A–C interval exceeds 30 m in thickness are defined on Figure 6. The eastern of these thick bodies can be examined on the outcrop. It is a fluvial channel system represented primarily by thick units of channel sandstone. The western body, which exists only in the subsurface, is also thought to represent a fluvial channel system. Figure 6 suggests that there is an inverse relationship between the thickness of the A–C interval and the thickness of the C coal bed, the thickest coal occurring in the area where the A–C interval is thinnest. The time lines in cross section X–Y (Fig. 5) indicate that the eastern channel existed contemporaneously with the swamp in which the C coal bed accumulated, the area of peat accumulation encroaching southeastward upon the channel system. Likewise, the coal bed is contemporaneous with part of the No. 3 delta-front sandstone, the time lines descending seaward in much the same way as do bedding planes in the delta-front sandstone itself, though at a much lower angle.

A simple model depicting the history of accumulation of the C coal bed is shown in Figure 7. It is unclear whether encroachment of the area of peat accumulation across the area previously occupied by the channel system is the result of waning and eventual abandonment of the channel system or the result of its migration toward the southeast to a position beyond the present outcrop of the Ferron Sandstone Member. Figure 8 shows the change in configuration of the units resulting from compaction and coalification of the peat. An arbitrary verti-

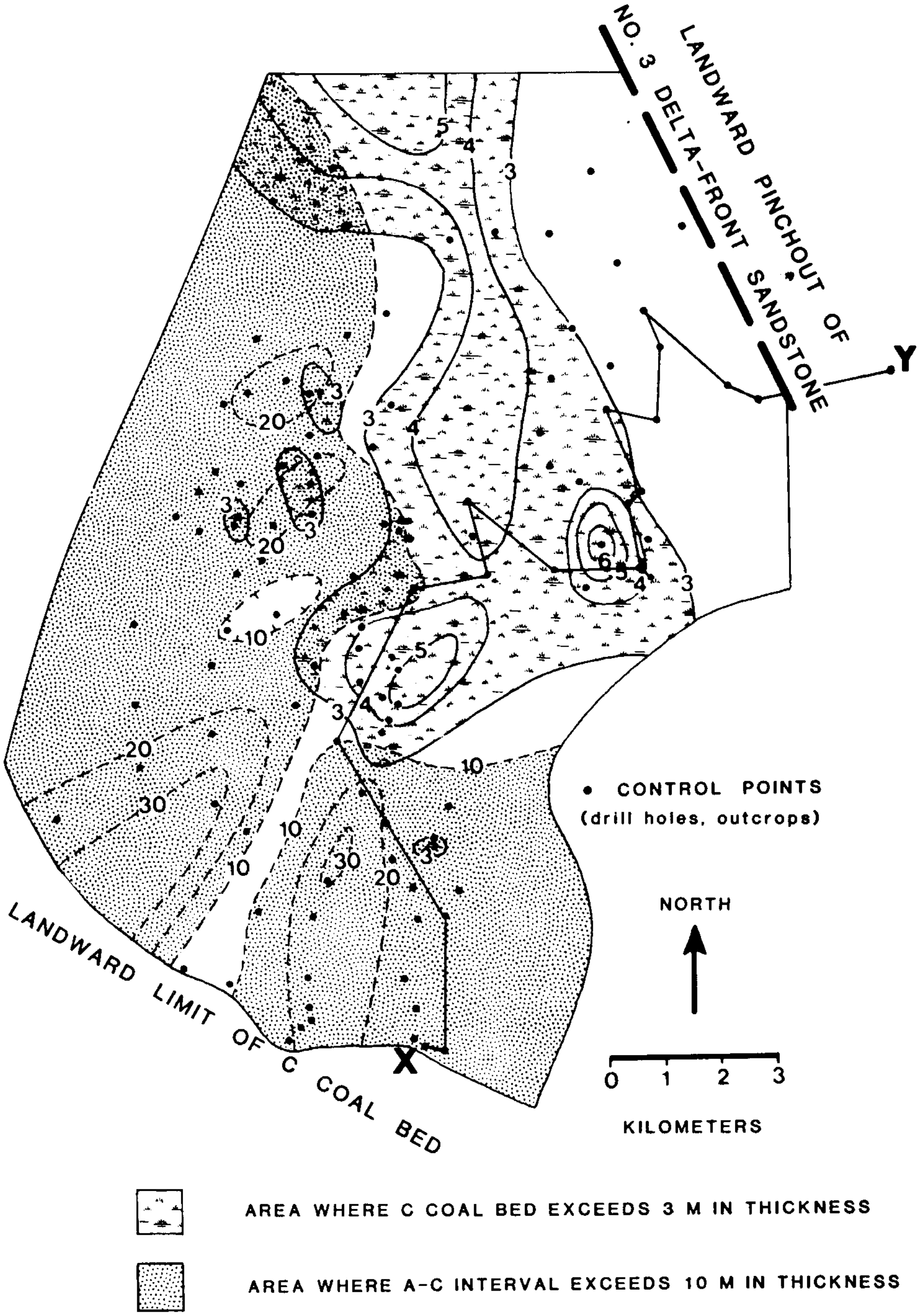

Figure 6. Isopachous map of C coal bed and A–C interval. The line of outcrop is not shown because the map incorporates proprietary data. Location of cross section X-Y is indicated.

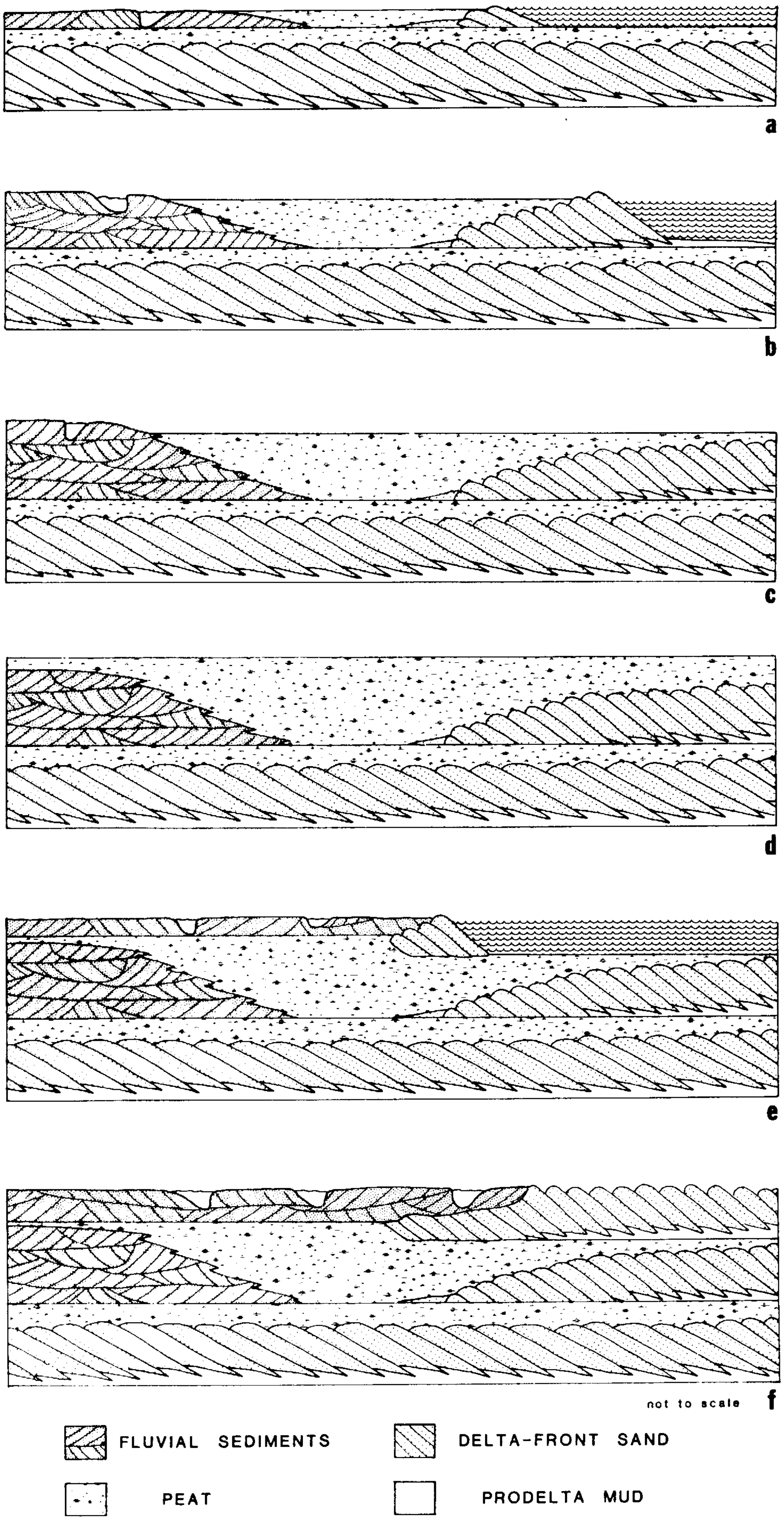

Figure 7. Model depicting history of accumulation of the C coal bed and associated strata along cross section approximately equivalent to X–Y. (a) Early phase of delta progradation. Peat and terrigenous clastic sediments accumulate on top of peat formed in previous delta cycle. (b) Continued progradation. Area of peat accumulation progrades seaward and also encroaches upon fluvial system. (c and d) Area of peat accumulation continues to expand, eventually covering abandoned fluvial channel system. (e) Early phase of progradation of another delta following erosional landward advance of shoreface during delta-destructive phase of previous cycle. (f) Continued progradation, fluvial system eroding landward part of delta-front sandstone unit.

cal scale has been put on Figures 7 and 8 to facilitate the following discussion. In the model proposed in Figures 7 and 8, an inverse, linear relationship exists between the thickness of the stratigraphic interval between the two peat or coal beds and the thickness of the higher of the two beds of peat or coal. For instance, at the center of the basin, the sediment or rock interval is zero, the peat of the upper bed ~50 units in thickness. After compaction and coalification, assuming that 10 units of peat yields 1 unit of coal, the product will be about 5 units of coal. At the margins of the basin, the sediment or rock interval is 50 units thick, and the value for peat or coal approaches zero. At any point between the basin center and the basin margin, the rock interval and coal thickness values will fall on the line shown in Figure 9. This relationship suggests one method by which the model may be tested.

Figure 10 shows data obtained from 44 core and drill holes in the Emery coal field. All of the holes are located southwest of the pinchout of the No. 4 delta-front sandstone unit, where the contact of the C coal bed with overlying strata is believed, in general, to be non-erosional. Although there is a considerable amount of scatter in the data, an inverse relationship between the thickness of the A–C interval and the thickness of the C coal bed is apparent. The slope of the line fitted to the data by least squares linear regression indicates that 10.6 units of peat in the original basin produced 1 unit of coal in the C coal bed, a value that is well within the range of values proposed by Weller (1959). This value assumes zero compaction of original sediments to produce the

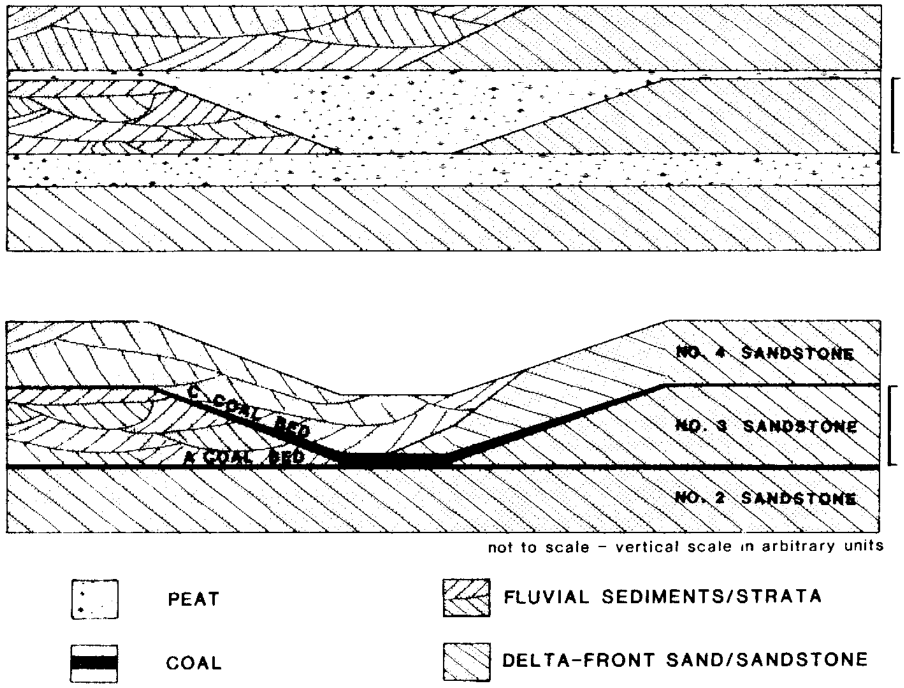

Figure 8. Effects of compaction and coalification. (top diagram) A generalized version of Figure 7f; peat is reduced to 1/10 of its original thickness to produce the coal beds shown in bottom diagram.

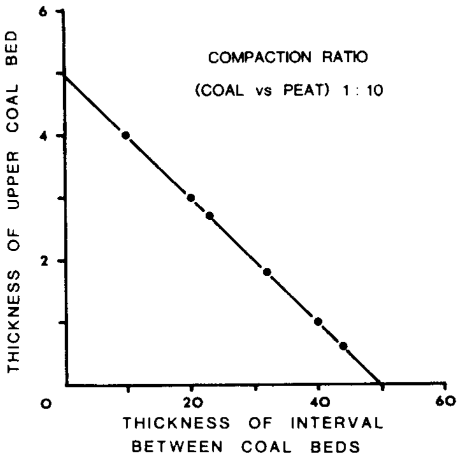

Figure 9. Graph showing the inverse, linear relationship that exists between the thickness of the interval between the two coal beds and the thickness of upper coal bed in bottom diagram of Figure 8.

strata of the A–C interval. Accordingly, the value of 10.6 must be viewed as a minimum value. Although it does not constitute sufficient proof by itself, the fact that the data can be described by an inverse linear relationship supports the model proposed in Figures 7 and 8.

Finally, Figure 11 shows the restored configuration of the peat basin along cross section X–Y. Coal of the C bed has been expanded ten times to represent the original thickness of peat prior to compaction and coalification. Figure 11 indicates that as much as 10 to 15 m of peat was eroded during the delta-destructive phase of the third delta cycle as the sea advanced landward across the peat deposit to a point that coincides with the landward pinchout of the subsequently deposited No. 4 delta-front sandstone unit.

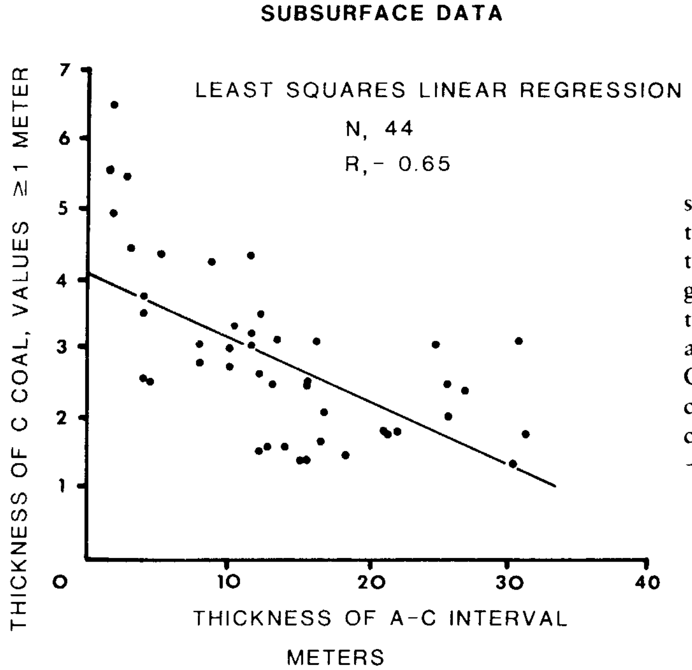

Figure 10. Graph showing an inverse relationship between the thickness of the stratigraphic interval between the A and C coal beds and the thickness of the C coal bed in the Emery coal field. Correlation coefficient (R) for data is − 0.65.

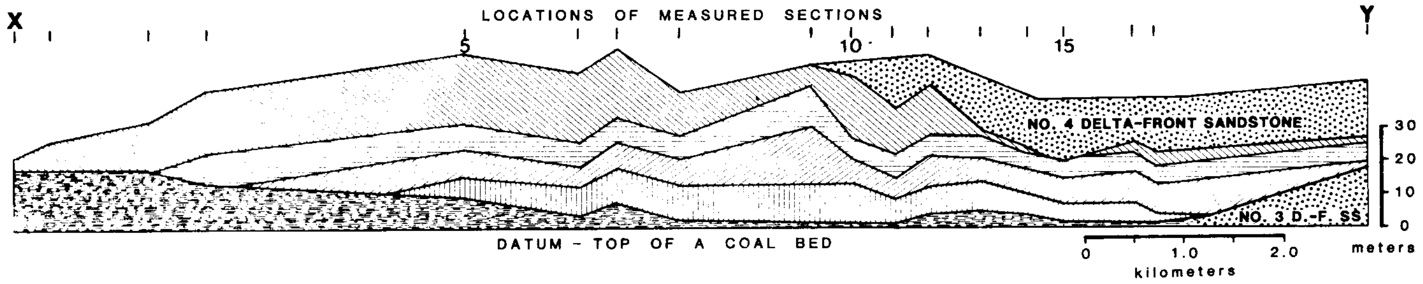

Figure 11. Restored configuration of peat basin along cross section X-Y. Coal has been expanded ×10 to approximate original thickness of peat.

CONCLUSIONS

Laterally continuous partings of kaolinitic claystone are common in coal-bearing strata of Cretaceous and Tertiary age in the Western Interior. They display a variety of characteristics by which they may be recognized in the field and laboratory as altered volcanic ash falls. Because ash falls can be viewed as time lines or time surfaces, they are valuable as correlation tools. As we have demonstrated with an example from the Ferron Sandstone Member, use of altered ash falls can facilitate reconstruction of paleoenvironmental history at a level of refinement that would otherwise be impossible.

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