

VOLCANIC ASH LAYERS IN COAL: ORIGIN, DISTRIBUTION, COMPOSITION AND SIGNIFICANCE

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INTRODUCTION

The main purpose of this paper is to call attention to volcanic eruptions as a source of mineral matter in coal. Volcanic material is apt to have mineral and chemical compositions as well as patterns of distribution different from the more usual types of mineral matter in coal. Recognition of volcanic material requires some understanding of the process of origin, an awareness of the considerable variety of materials involved, and an appreciation of the tendency of volcanic materials to undergo substantial alteration so that their genesis is obscured.

Some comments on terminology are necessary. "Volcanic ash partings" here refers to sedimentary units bounded by organic-rich material (coal, lignite, or organic shale) and which were deposited as air-fall volcanic ash with essentially no subsequent transport or mixing with terrigenous detrital silicates (clay, mud and sand). No specific grain size or composition is implied. The term "tephra" is now commonly used for modern, unaltered, uncompacted material, while the term "tuff" is used for the compacted (rock) equivalent.

A volcanic origin is obvious where there is glass, volcanic phenocrysts, characteristic mineralogy, or absence of terrigenous detritus and lack of sedimentary structures formed by moving water. With increasing age, however, there is progressive alteration and loss of recognizable volcanic features; the product is generally some kind of clay unit. As a general term they might be called altered tuffs. In marine shales they are known as bentonites; these are usually montmorillonitic (smectitic), light-colored, and sticky when wet. In coals, particularly Carboniferous coals, they are usually kaolinitic, light-colored and firm. We prefer the general term "altered volcanic ash" because there is considerable range in physical appearance, original and secondary mineralogy, as well as in the type of enclosing sediment.

ORIGIN

Volcanic ash partings in coals should not be surprising. The recent eruption of Mt. St. Helens spread volcanic ash across several western states and traces of the dust traveled around the world. Consider, however, where a recognizable layer of this ash is likely to be preserved. On land, almost all of it will be eroded by wind and water, mixed with terrigenous sand and clay, and ultimately dispersed into lakes or the ocean. An important exception is to be found in marshes or swamps, the general setting in which plant material accumulates to eventually become coal. Once deposited in a coal swamp, an ash fall has a good chance of

remaining undisturbed because the shallow water, low stream gradients, lack of relief, and sediment baffling effects of vegetation minimize processes that could cause reworking. Portions of such swamps may be so distant from major streams that they receive little or no mud from over-bank floods. Thus it is likely that some ash falls would be buried in organic debris (coal) and remain free of non-volcanic material from fluvial sources.

It follows then that there is a genetic relationship between volcanic ash partings and the coals that contain them: environments of coal deposition provide one of the best places for preservation of air-fall volcanic materials.

Not all kinds of volcanic ash have the same chance of such preservation, however. Many volcanoes, such as those in Hawaii, are characterized by relatively quiet eruptions of mostly fluid lava. Though spectacular on a human scale, these involve only minor injection of fine-grained material into the upper atmosphere where it can be carried long distances by prevailing winds. Only volcanoes characterized by particularly violent eruptive styles are likely to be important in producing the thin, widespread units of ash most commonly preserved in the geologic record. The explosiveness of eruptions is related to several factors, including gas content and geometry of the vent. Of most importance here, however, is silica content: silica increases the viscosity of magma and the tendency toward explosive eruptions rather than quiet flows. Thus volcanic ash partings in coals are primarily the product of such silica-rich eruptions; this has important consequences in terms of the composition of the ash, as will be discussed later.

FIELD APPEARANCE OF VOLCANIC ASH PARTINGS IN COALS

Most volcanic ash partings are thin, ranging from 1 mm to a few cm. A few, however, attain thicknesses of more than 1 m. Some are uniform in thickness and have either sharp or gradational boundaries with the enclosing coal. Many, however, pinch and swell rapidly and may consist of a series of lenses rather than continuous beds, a feature they share with Carboniferous tonsteins (Williamson, 1970). Light shades of gray, brown, or yellow are most common, reflecting a lower organic content than the adjacent coal. Black and dark brown partings also occur, and sometimes these become obvious only after weathering; the oxidation of organic matter then results in a light-colored surface layer of siliceous material. Figure 1 shows the most common field appearance; in this case for a Cretaceous example from southern Alaska.

To a large extent the grain size and degree of induration of these partings depends upon the amount of post-depositional alteration; this in turn is largely a function of age and depth of burial. For example, lignites almost 4-5 m.y. old in southern Alaska contain partings that are loose and sandy; in fact they are clearly recognizable volcanic ash consisting mostly of glass shards. In contrast, 300 m.y. old partings in Kentucky bituminous coal are hard and very fine grained. The latter probably was similar to the Alaskan example at first, but has completely altered to a compact variety of kaolin known as flint clay.

COMPOSITION

Composition of the partings is a function of both the original materials and conditions, and the kind and extent of post-depositional modification. Therefore it is necessary to consider the primary composition (original) separately from the secondary composition (altered).

Primary Composition

The solid products of explosive volcanism include individual glass fragments, individual crystals (phenocrysts), and aggregates of these known as rock fragments. Glass is perhaps the most common component but there is a great variety among modern volcanics. A given volcano may eject different material over its eruptive lifespan. Even a single eruption, lasting perhaps only a few days, may involve changes in ash composition.

Volcanic ashes are characterized by a limited suite of mineral components. By far the most abundant are quartz, sanidine and plagioclase feldspars, certain pyroxenes and amphiboles, magnetite, apatite, biotite, and zircon. The presence of these minerals and the absence of others constitute evidence of a volcanic origin. Certain crystal forms, such as the beta form of quartz and hexagonal prisms of biotite, are particularly useful indicators of origin. Similarly, the presence of sanidine, the high-temperature form of potassium feldspar, suggests a volcanic origin. On the other hand, the presence of non-volcanic minerals such as muscovite and garnet indicates a non-volcanic origin or at least some admixture of non-volcanic (probably fluvial) material.

The specific minerals present reflect the original compositions of the magma. As noted earlier, explosive behavior, the kind most likely to produce ash partings in coals, is characteristic of silica-rich magmas. Thus the minerals cited above, and those to be expected in volcanic ash partings, are those associated with silica-rich magmas. The glass phase will, of course, also reflect this silica-rich tendency.

Original grain size of an ash parting reflects the texture of the material produced by a given volcano plus the progressive loss of coarser and denser components as an ash cloud moves downwind. In other words, texture is in part a function of distance from the source volcano. By far the most common ash partings in coal are thin, uniform and widespread. These probably were derived from distant volcanoes and consisted originally of silt- and clay-sized particles carried by high-altitude winds. Conversely, where ash partings are coarse-grained, thick, and abundant, the volcanic source is assumed to have been relatively close.

Secondary Composition

The primary composition discussed above is important here in that it determines in part the final products of alteration. It should be noted, however, that the factors controlling the degree and direction of alteration have not been thoroughly studied. In our opinion, chemical alteration in the environment of deposition and the length of time involved are probably more important than original composition in determining the final product.

The main secondary products are clay minerals, either smectite or kaolinite. These clay minerals are derived mainly and most readily from glass, but feldspars, amphiboles, pyroxenes, and biotite also alter in part to clay minerals. The alteration to kaolinite involves essentially complete removal of soluble components such as Na, Ca, Mg, K and Fe as well as considerable silica. Pure kaolinite consists of equal parts of silica and alumina and virtually nothing else--this is thus the product of very intensive leaching. Smectite on the other hand requires some Mg and more silica; it is thus the product of less intensive leaching than that which produces kaolinite.

It is uncertain whether the path of alteration can lead directly to kaolinite or must pass through a smectite intermediate stage. Certainly the thickness of the original ash can play a role: thin partings may be altered completely to kaolinite while adjacent thicker partings contain substantial smectite (Triplehorn and Bohor, 1981; Reinink-Smith, 1982). Given more time and further leaching, these smectitic partings presumably would eventually be altered to kaolinite. On the other hand, individual minerals such as feldspars and biotite can be observed altering directly to kaolinite without any smectite involvement.

A variety of other secondary minerals may occur in altered volcanic ash partings. Some of these may be related to modification of the primary constituents but others are more likely introduced by ground water taking advantage of the higher permeabilities of volcanic ash layers relative to the adjacent organic material (now coal). Carbonate minerals in quantities too large to have been derived entirely from the primary volcanic material are not uncommon. Siderite is most abundant although dolomite sometimes is present. Such cementation may obscure the volcanic origin of the original layer because well cemented partings are similar in appearance to the purely sedimentary carbonate layers that are very commonly associated with coals.

Recently occurrences of unusual aluminum phosphate minerals have been found with ash partings in coals (Triplehorn and Bohor, 1983). Since that report we have found a number of occurrences in Alaska and one in the Appalachian area. These minerals were grouped by Palache et al. (1951) as the plumbogummite series, with the general formula $X \text{ Al}_2(\text{PO}_4)_2(\text{OH})_5 \cdot \text{H}_2\text{O}$. End members of interest here include qoyazite (where $X = \text{Sr}$), gorcisiite (Ba), crandallite (Ca), and florencite (Ce, U, and other rare earths). Some layers in Alaska are sufficiently radioactive to give a distinct reading on hand-held radiation detectors in the field.

DISTRIBUTION

Because many geologists are not aware that volcanic ash partings occur in coals it is difficult to interpret the absence of published reports regarding their occurrences. The abundance of such partings is probably much greater than presently recognized. The following generalities regarding their distribution are mainly limited to North America and are based primarily on our own observations, discussions with others, and interpretation of published reports. Specific references to recognized volcanic ash partings in coals are relatively few and restricted mostly to the past few years.

In simple terms ash partings are relatively abundant in Cretaceous and Tertiary coals of the West and rare in Carboniferous coals of the East. We are less certain of the Gulf Coast Tertiary lignites but they appear to have at least a moderate abundance of such partings. To a degree this apparent distribution is related to the fact that the volcanic origin of the younger ash beds is more apparent, while older partings commonly appear as kaolinitic clay beds with little evidence of their volcanic heritage (see Bohor and Triplehorn, 1981). Even so, there is no question that the absolute frequency is higher in the West.

Locally the abundance can be highly variable. Where many coals are present ash partings may be distributed sparsely but uniformly or concentrated in just a few coals. Figure 2 shows an example in Southwestern Washington, in this case including both kaolinitic and smectitic partings (Reinink-Smith, 1982). In the West, where most of our work has been, volcanic ash partings are known from numerous coals in Utah, New Mexico, Colorado, Wyoming, Montana and Washington (Bohor, *et al.* 1978; Triplehorn and Bohor, 1981). Again, the frequency is highly variable. Individual coals in Montana and Colorado contain up to twenty or more ash partings, while the unusually thick coals of the Powder River Basin contain almost none. In Alaska, volcanic ash partings are present in all of the Cretaceous and Tertiary coals we have examined, but appear to be particularly abundant in the Cook Inlet area.

In the Appalachian coal basin and the Eastern Interior Basin, where we have had less experience, ash partings appear to be rare (Bohor and Triplehorn, 1982). The lack of ash partings in Carboniferous coals of eastern North America contrasts with their abundance in European coals of the same age. These have been studied for over a century although their volcanic origin was not generally accepted until the last few decades. Bouroz, *et al.* (1983) provides a good recent summary of some of this work in English.

SIGNIFICANCE

The geologic importance of volcanic ash partings in coals has been summarized previously by Triplehorn (1976). Of greatest importance is their use in correlation, the process of determining the time relationships among rocks exposed at different localities. The simplest use is as marker beds, where individual ash falls can be recognized and distinguished from others on the basis of some textural or compositional aspect. Beds containing the same ash layer (whether in coal or any other rock type) are the same age, although the absolute age (in years) is not indicated. Happily, the absolute age can sometimes be determined by radiometric age dating of certain minerals in the ashes. Potassium-argon dating is used for such minerals as feldspar and hornblende, while fission-track dating may be used for zircon and apatite.

It may be of interest here to note that Williamson (1970) mentioned the high radioactivity of certain ash partings (he called them tonsteins) that made them useful in bore-hole studies because they appeared as sharp maxima on gamma-ray logs of coal beds. Such maxima are conspicuous because coals are generally known for their absence of radioactivity.

He ascribed the high radioactivity of these partings to an unusual abundance of zircons. We have no specific knowledge of these occurrences, but suggest that the high radioactivity might instead be related to uranium-bearing phosphate minerals.

Thus far geologists have paid little attention to the significance of ash partings as indicators of processes and conditions in the coal-forming environment. For example, thin widespread partings without penetrating plant material suggest that these originated as ashes that fell into shallow standing water. Thick ashes should have affected the kind and amount of vegetation, and indirectly the nature of the coal immediately overlying thick ash beds. As yet there is little data in these aspects because geologists have not recognized the potential value of such studies.

For those interested in mineral matter in coal an awareness that some partings may be of volcanic origin may be useful in explaining the distribution of some of these layers and the occurrences of some unusual components, such as strontium, phosphate, or uranium. Volcanic ash partings are likely to be more widespread and uniform in texture, composition and thickness than the more common partings of fluvial origin. They are also more likely to show marked differences from layer to layer, and more likely to contain exotic mineral or chemical components.

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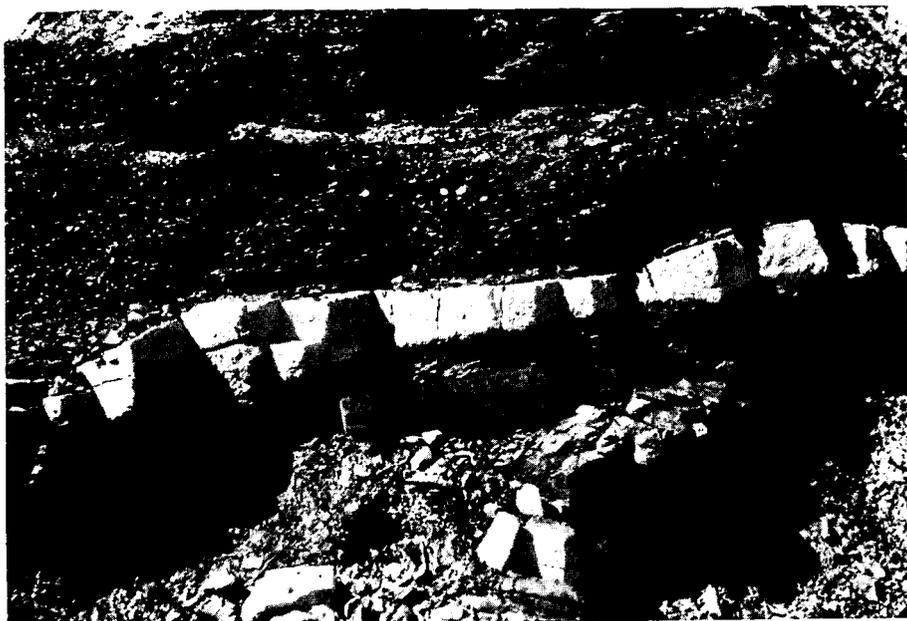


Figure 1. Light weathering kaolinite volcanic ash in coal, southern Alaska.



Figure 2. Multiple smectitic and kaolinitic ash partings in the Big Seam, southeastern Washington.