SOURCE OF THE VOLCANIC ASH DEPOSIT (FLINT CLAY) IN THE FIRE CLAY COAL OF THE APPALACHIAN BASIN

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A flint-clay parting in the Fire Clay coal of the Breathitt Formation (Middle Pennsylvanian, Westphalian B) occurs throughout most of eastern Kentucky and in parts of Tennessee, Virginia, and West Virginia. Two origins for this flint clay have been suggested in the past: detrital and volcanic. The detrital-origin theory holds that the flint clay was formed by the alteration in a peat swamp of a transported heavily weathered soil. The volcanic-origin theory suggests that this flint clay is an alteration in a peat swamp of a volcanic-ash deposit. Arguments for both theories are presented, but volcanic origin is preferred.

Examination of Westphalian continental reconstructions, trade wind patterns, and a present-day, ash-fall distribution indicate that the location of the volcanic source for this flint clay was along a line from Kentucky to North Carolina (approximately due east). The intersection of this line with a palinspastically replaced, known Hercynian magmatic arc occurs in extreme eastern North Carolina. This is the approximate location of the volcanic source for the ash.

This magmatic arc is considered to be a Hercynian subduction zone arc. The occurrence of a volcanic ash from this subduction arc in a Westphalian-B coal indicates active subduction during Westphalian time.

INTRODUCTION

Over 40 major coal beds in the Pennsylvanian rocks of eastern Kentucky have been mapped (Fig. 1). These coals were correlated by the use of key stratigraphic beds such as marine zones, orthoquartzitic sandstones, and the flint clay parting of the Fire Clay (Hazard No. 4) coal (Westphalian B). There are several occurrences of flint clay in eastern Kentucky but none so distinctive and extensive as the parting in the Fire Clay coal (although locally other flint clays resemble the Fire Clay). The occurrence and probable volcanic origin of this flint clay are the subject of this discussion.

The State of Kentucky, which lies in east-central United States, has recently completed a program conducted by the US. Geological Survey and the Kentucky Geological Survey to geologically map the State at a scale of 1:24,000. The eastern part of the State, known as the Eastern Kentucky Coal Field, is part of the Appalachian Basin. Surface rocks are of Pennsylvanian age and were deposited largely in shallow-water and deltaic environments. Most of the coal produced in the State comes from these rocks in the Eastern Kentucky Coal Field. The coal production from this area plus the Western Kentucky Coal Field makes Kentucky the largest producer of coal in the United States, and fifth largest in the world. The Fire Clay coal is one of the major coals in the Eastern Kentucky Coal Field and is

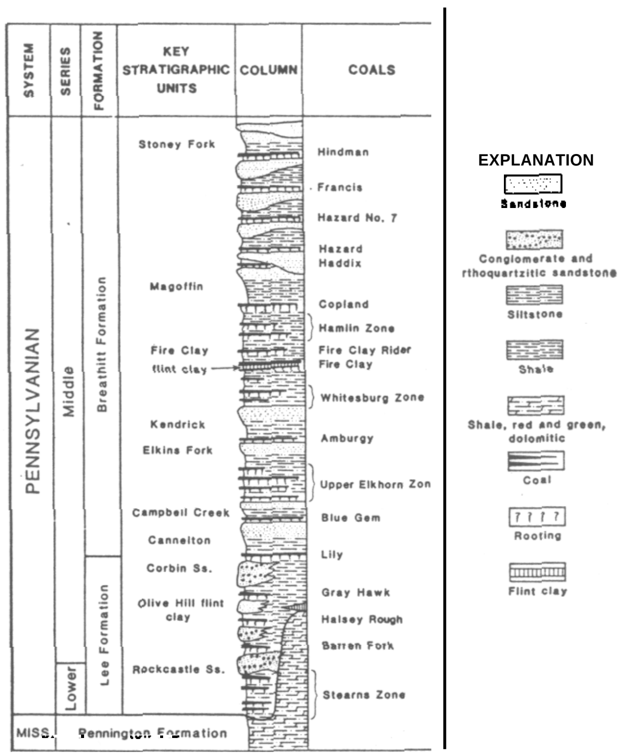

Fig.1 Generalized lithologic column for part of the Pennsylvanian rocks of eastern Kentucky.

important as a key stratigraphic marker in exploration and development. This study is divided into two parts; the first summarizes views on the origin of the flint clay, and the second discusses the most likely source of the flint clay.

FLINT CLAY

Flint clay is a claystone composed of microcrystalline to cryptocrystalline kaolinite or halloysite; it is smooth, hard, flint-like in appearance, and breaks with a conchoidal fracture. The flint-clay parting of the Fire Clay coal is light tan to black, generally unlaminated, averages 13 to 15 cm (5-6 inches) in thickness [but ranges from 0 to 43 cm (0-17 inches)], and usually occurs in the lower one-third of the coal bed. Table 1 lists components of the flint clay found by STEVENS (1979). The top and bottom contacts of the flint clay are sharp. It is known to occur over a distance of approximately 240 km (150 miles) but is locally absent in small areas. Figure 2 shows the occurrence of Pennsylvanian rocks in this region and the distribution of the Fire Clay coal and its correlatives in adjacent states.

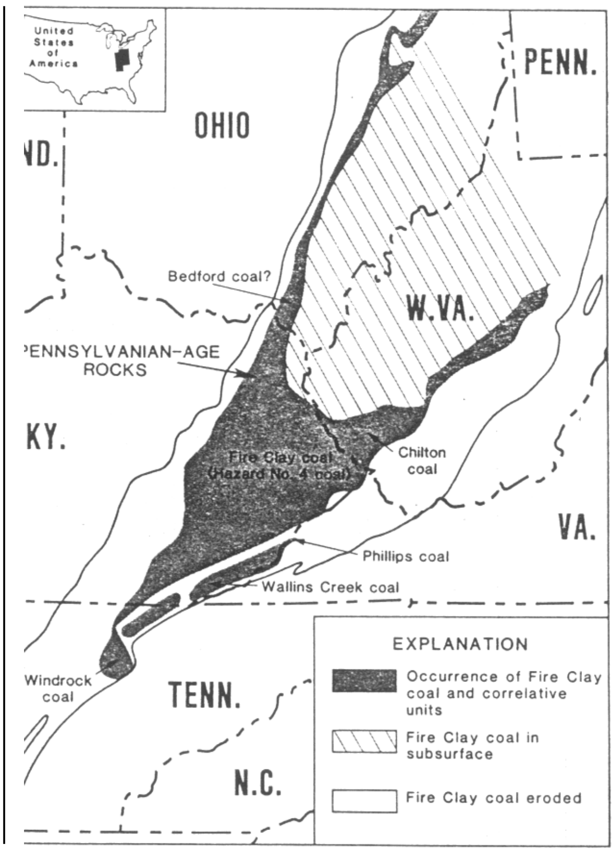

Fig. 2. Outcrop of Pennsylvanian rocks and occurrence of the Fire Clay coal and its correlatives. Shaded area represents surface occurrence of the coal. The coal is subsurface northeast of Kentucky in parts of Ohio and West Virginia. Elsewhere, outside the shaded area, the coal has been eroded.

TABLE 1

Components of the Fire Clay coal flint clay reported by STEVENS (1979)

kaolinite	93-95 %
cryptocrystalline	51 %
micrcocrystalline	42 %
quartz	5 %
zircon	0.2 %
rutile	0.05 %
hematite	0.6 %
crandallite?	0.02 %
leucoxene	0.05 %
siderite	0.04%
chalcopyrite	0.02 %
organics	0.52 %
	100%

ORIGIN OF FLINT CLAY IN THE FIRE CLAY COAL

Two theories have been proposed for the origin of the flint-clay parting: volcanic and detrital. ASHLEY (1928) was the first to suggest a volcanic origin, though SEIDERS (1965) was the first to provide evidence suggesting a volcanic origin. His conclusion was based on the absence of any non-volcanic minerals and debris except carbonaceous matter and kaolinite and the presence of sanidine and embayed quartz.

Arguments for a Non-Volcanic Origin

TANKARD & HORNE (1979), disagreed with the volcanic ash interpretation and suggested that the flint clay was

> "... from weathered soil zones within the basin and transported to the peat swamps that fringed tidal flats. Highly supersaturated solutions and interfering anions resulted in rapid gel formation and conversion of illite to kaolinite by dialysis and dissolution (KELLER, 1968). Both kaolinite and sanidine are probably products of illite alteration in an intense pore-water chemical environment."

Their evidence against a volcanic-ash origin, based on study of the flint clay in parts of Leslie and Perry Counties, Kentucky, are listed below:

1. The thickest development on flint clay did not occur where the lower coal was thickest, but in areas of medium thickness (that is, on the margins of the peat swamp). This distribution suggests sedimentological control because the flint-clay thickness is directly related to swamp sedimentation, not independent of it.

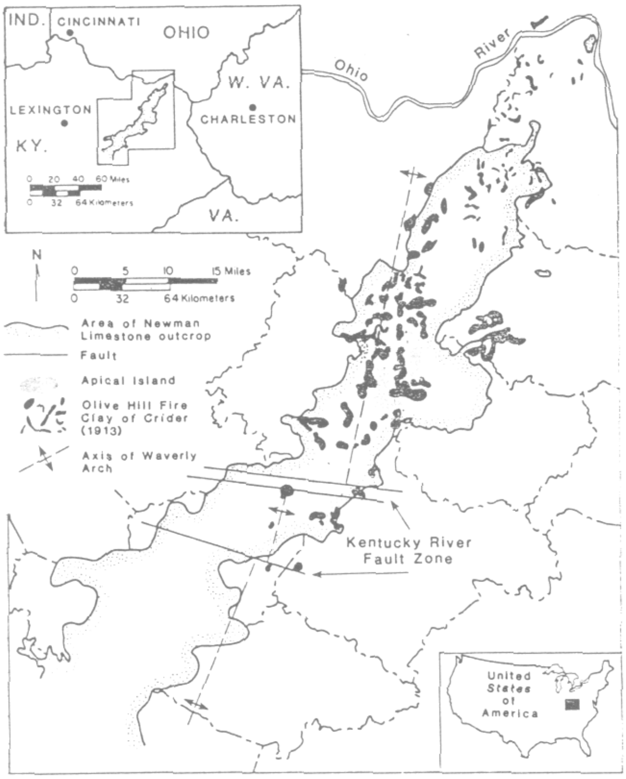

Fig. 3. Distribution of the Olive Hill Clay Bed of CRIDER (1913) (from ETTENSOHN & DEVER, 1979).

2. The lack of bentonite as a lateral facies equivalent to the flint clay argues against a volcanic origin. (Presumably TANKARD & HORNE (1979) assumed that ash deposition in marine conditions should produce a bentonite instead of a flint clay. No lateral bentonite equivalents to the flint-clay parting are known).
3. The lack of glass shards of pseudomorphs of glass shards in the flint clay suggested that the parting is not volcanic in origin since ash deposits commonly contain glass shards.
4. The occurrence of authigenic sanidine and zircon in rocks other than that of volcanic origin could explain the presence of sanidine and zircon in the flint-clay parting.
5. The presence of well rounded quartz grains in the parting indicated a detrital origin.

Arguments for a Volcanic Origin

Subsequent to SEIDERS' study (1965), several other workers (ROBL & BLAND, 1977; STEVENS, 1979; BOHOR & TRIPLEHORN, 1981; RYMER, 1982) proposed a volcanic origin for this flint clay. Their evidence is listed below.

1. SEIDERS (1965), BOHOR & TRIPLEHORN (1981), and STEVENS (1979) argued that the absence of detrital or nonvolcanic minerals other than kaolinite and carbonaceous matter indicates a nondetrital origin for the parting. The rounded quartz cited by TANKARD & HORNE (1979) as a detrital indicator was identified by the proponents of a volcanic origin as magmatically resorbed quartz instead of detrital quartz. Virtually indestructible tourmaline and muscovite mica, common in the Pennsylvanian sedimentary rocks of the Appalachians, are absent in the flint clay.
2. BOHOR & TRIPLEHORN (1981) reported that all phenocrysts are found floating in a kaolinitic clay matrix of the flint clay. They argued that this finding would be contrary to a detrital origin for the flint clay. A detrital flint clay would exhibit graded bedding, not poor sorting.
3. FRANKIE (1982) indicated that there is no relationship between the thickness of the flint clay and the thickness of either the upper or lower coal as described by TANKARD & HORNE (1979).
4. STEVENS (1979) noted the high titanium oxide content and high titanium oxide to alumina ratio were similar to those of tonsteins of known volcanic-ash origin but inconsistent with normal sedimentary rocks and other clay units.
5. RYMER (1982) suggested that the lack of glass shards was due to very rapid alteration of unstable, amorphus glass to kaolinite. Kaolinite does not faithfully pseudomorph any preexisting form (SPEARS, 1977, personal communication *in* STEVENS, 1979).
6. RYMER (1982) suggested that severe weathering could not have occurred because feldspars are present. Feldspars are normally easily weathered minerals.
7. STEVENS (1979) and BOHOR & TRIPLEHORN (1981) argued that the generally sharp contacts of the flint-clay parting with the overlying and underlying coals represent an event short in time, and that a detrital origin would very likely show gradational contacts with overlying and underlying beds.
8. The widespread distribution of the thin parting precludes water-borne transportation through a swamp (SEIDERS, 1965: STEVENS, 1979; BOHOR & TRIPLEHORN, 1981; this study).
9. The Fire Clay coal has an unusually high uranium content compared with other coals of the region (J. C. CURRENS, personal communication, 1982). CURRENS suggested that this high uranium content could be used as a correlation tool in locating the Fire Clay coal. The source of the uranium is possibly related to the volcanic origin of this flint clay parting.
10. The physical, mineralogical, and geological conditions of the Fire Clay flint-clay contrast markedly with a flint clay of generally accepted detrital origin. The

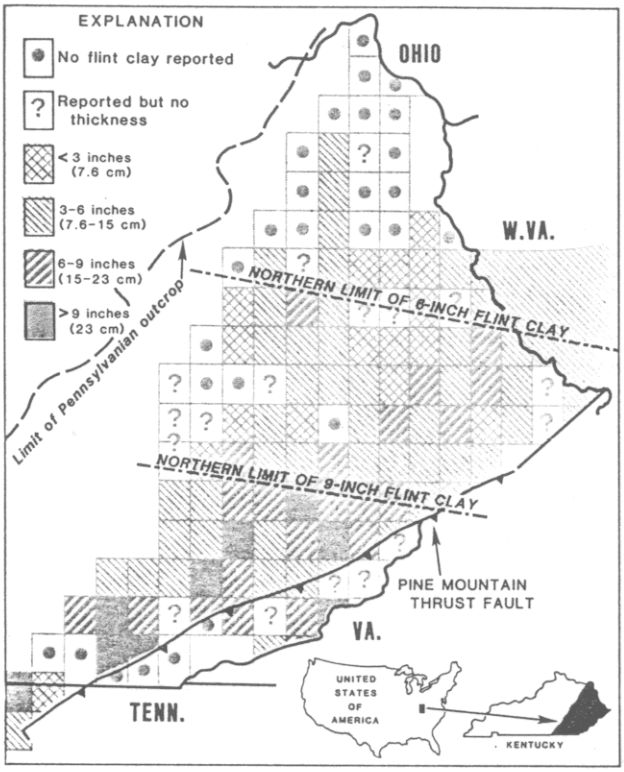

Fig. 4. Distribution of maximum reported thicknesses for the flint-clay parting. Source of information is from geologic quadrangle maps, recent field work, and published literature. The two lines represent the northernmost occurrence of 9-inch- (22.8 cm) and 6-inch- (15.2 cm) thick flint clay. Unnoticed flint clay very likely occurs in quadrangles where it is not reported.

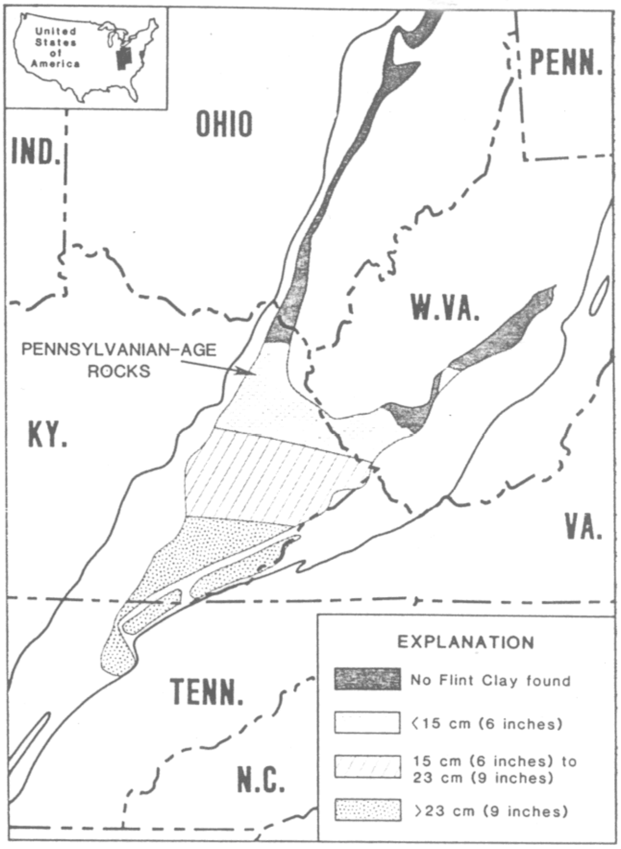

Fig. 5. Occurrence and approximate isopach of the flint-clay parting in the Fire Clay coal bed and its correlatives.

Olive Hill Flint Clay of CRIDER (1913) is a Pennsylvanian flint clay that crops out in northeastern Kentucky: in Ohio it **is** known as the Sciotoville Flint Clay, It **is** almost totally restricted to the northern uplifted fault block of the Kentucky River Fault Zone (Fig. 3), appears to be concentrated in numerous isolated patches on or near an apical island postulated by ETTENSOHN & DEVER (1979). and is commonly restricted to paleokarst or erosional lows in the underlying Mississippian rocks. The clay is generally overlain by a thin coal or carbonaceous shale and has a fine bauxite-like texture as opposed to the smooth, chert-like appearance of the Fire Clay flint clay (E. R. SLUCHER, personal communication, 1983). STOUT *et al,* (1923) reported silt-size grains of tourmaline, zircon, siderite, and sericite in the Olive Hill Flint Clay correlative in Ohio, as well as quartz and needles of rutile. The quartz, rutile, tourmaline, and sericite are detrital. Intensive weathering due to uplift of this area is suggested by repeated karstic and subaerial crusts, recurring unconformities, and occurrence of red oxidized beds. Heavily weathered soils were probably transported to erosional lows and then altered by the action of local overlying peat swamps.

11. Volcanic minerals and debris, some of which are found only in effusive volcanic rocks are reported in the flint clay. Euhedral sanidine was reported by SE1DERS (1965), ROBL & BLAND (1977), STEVENS (1979), BOHOR & TRIPLEHORN (1981), and HUDDLE & ENGLUND (1966). STEVENS (1979) argued that the absence of zoning and vacuoles in the sanidine precludes an authigenic origin. STEVENS (1979) also reported that the sanidine content, as well as flint-clay thickness, increases to the southeast. Beta-quartz was reported by ROBL & BLAND (1977), STEVENS (1979), BOHOR & TRIPLEHORN (1981), and RYMER (1982). Beta-form quartz is only found in effusive rocks such as rhyolite and quartz porphyries formed at temperatures above 575 C. Embayed quartz (SEIDERS, 1965). splintered quartz (STEVENS, 1979), and rounded quartz (STEVENS, 1979; TANKARD & HORNE, 1979: BOHOR & TRIPLEHORN, 1981) are forms thought to be volcanic. The rounded quartz has been identified as a magmatically resorbed quartz by BOHOR & TRIPLEHORN (1981).

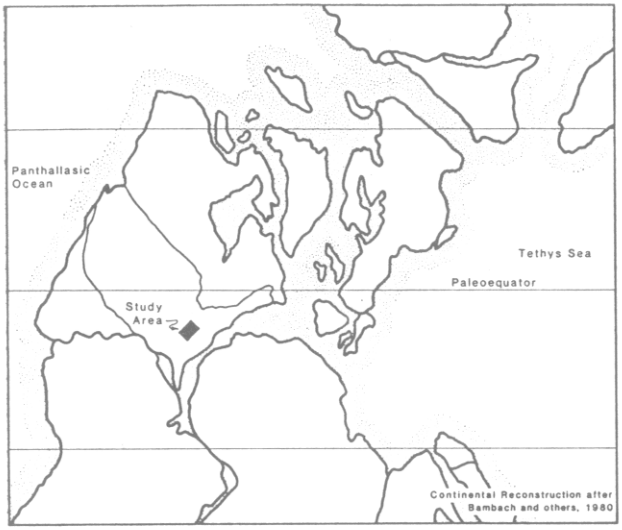

Fig. *6*. Paleogeographic reconstruction of continents during Westphalian time (after BAMRACH *et al.*, 1980). The study area is approximately 7 to 10 degrees south of the equator and rotated about 45 degrees clockwise from its present position.

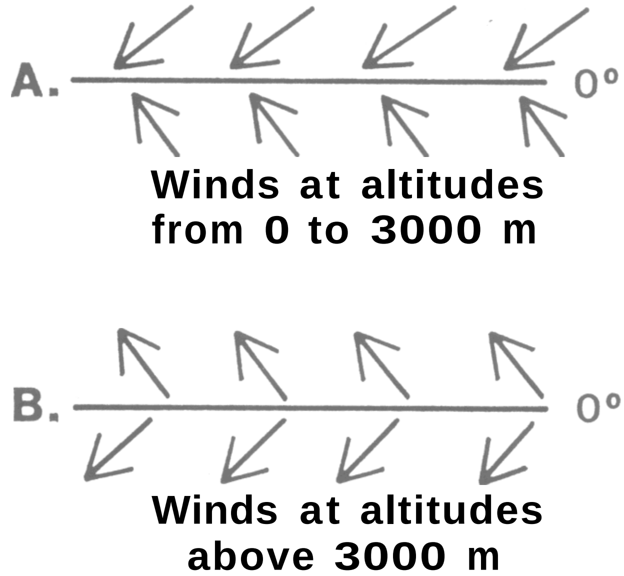

Fig. 7. Low and high-altitude Trade Wind patterns. **(A)** Less than 3,000 meters in altitude. **(B)** More than 3,000 meters in altitude.

Euhedral rutile (STEVENS, 1979; BOHOR & TRIPLEHORN, 1981), euhedral ilmenite (STEVENS, 1979; BOHOR & TRIPLEHORN, 1981), euhedral zircon with a high length to width ratio (STEVENS, 1979; BOHOR & TRIPLEHORN, 1981: RYMER. 1982), euhedral apatite (STEVENS, 1979; BOHOR & TRIPLEHORN, 1981), and anatase with negative crystals (BOHOR & TRIPLEHORN, 1981), are other volcanic minerals found in the Fire Clay flint clay.

VOLCANIC SOURCE

Based upon the foregoing evidence, a stronger case is made for the volcanic origin. This paper will further argue for that theory by documenting the volcanic source.

The distribution and thickness of the Fire Clay flint clay may provide clues to its source. A generalized thickness map (Fig. 4) is based on information provided in geologic quadrangle maps, from recent field work, and from published sources. It shows the maximum reported thicknesses of the flint-clay parting. Two lines were approximated, one at the northernmost occurrence of 22.8 cm (9 inch) or greater flint clay thickness, and another at the northernmost occurrence of 15.2 cm (6 inch) or greater flint clay thickness. This approximate isopach is shown on a larger scale in Figure 5, which also shows the extent of preserved Fire Clay coal. Both maps show a general increase in thickness of the flint-clay parting to the south, a trend also recognized by STEVENS (1979).

The paleogeography at the time of ash deposition may explain this distribution. Almost all the coals in the Pennsylvanian rocks of eastern Kentucky were deposited in Westphalian time: A paleogeographic reconstruction of the continents during Westphalian time (BAMBACH *et al.*, 1980) (Fig. 6) indicates that eastern Kentucky was approximately 7 degrees south of the equator and was rotated about 45 degrees clockwise compared to its present position.

The winds at tropical latitudes are called the Trade Winds or Easterlies, and they blow at angles averaging 45 degrees to the equator. Unlike winds at other latitudes, the Trade Winds are predictable. Below 3,000 meters in altitude the winds blow westward and toward the equator (Fig. 7); however, above 3,000 meters they blow westward and away from the equator (Fig. 7). These winds are also affected by seasonal shifting of the Trade Wind belt. In the summer the belt shifts to the north (Fig. 8), and in the winter it shifts to the south. Figure 9 shows the summer and winter high-altitude winds, which presumably prevailed in the study area.

The recent eruption of Mount St. Helens in Washington state provides clues to the distribution of volcanic ash. The only consistently high-altitude eruption of Mount St. Helens was on May 18, 1980. It produced an ash-fall pattern that was obviously affected by strong, high-altitude winds (FOXWORTHY & HILL, 1982) (Fig. 10). Other lower altitude eruptions have much smaller ash distributions.

Presuming that the widespread distribution of the flint-clay parting resulted from an eruption in which large amounts of volcanic ash reached high altitudes, then one of these two wind patterns (Fig. 9) could have been responsible for ash distribution. Since the flint clay thickens to the south, the winter winds are the only logical choice. It is then possible to reconstruct an original ash-fall dis-

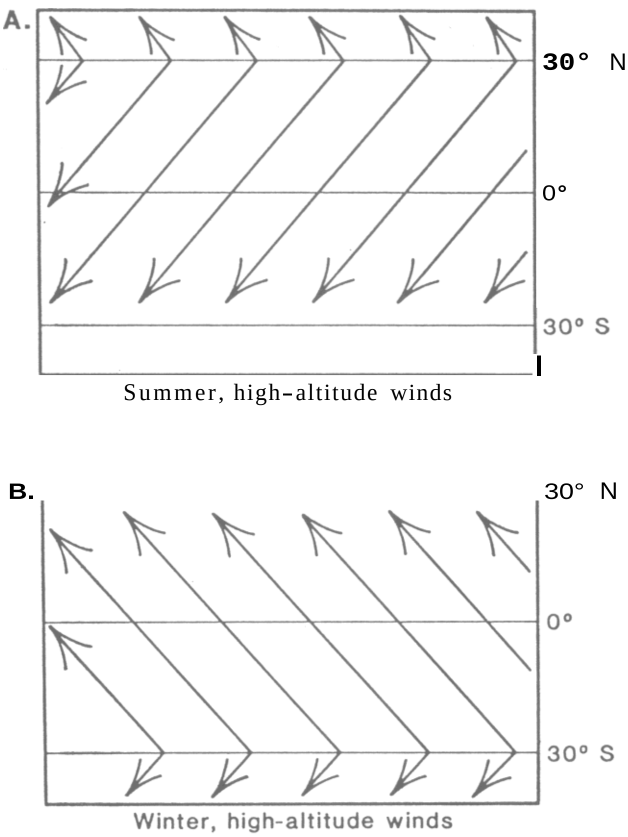

Fig. 8. Seasonal high-altitude Trade Wind patterns, (A) Summer, (B) Winter.

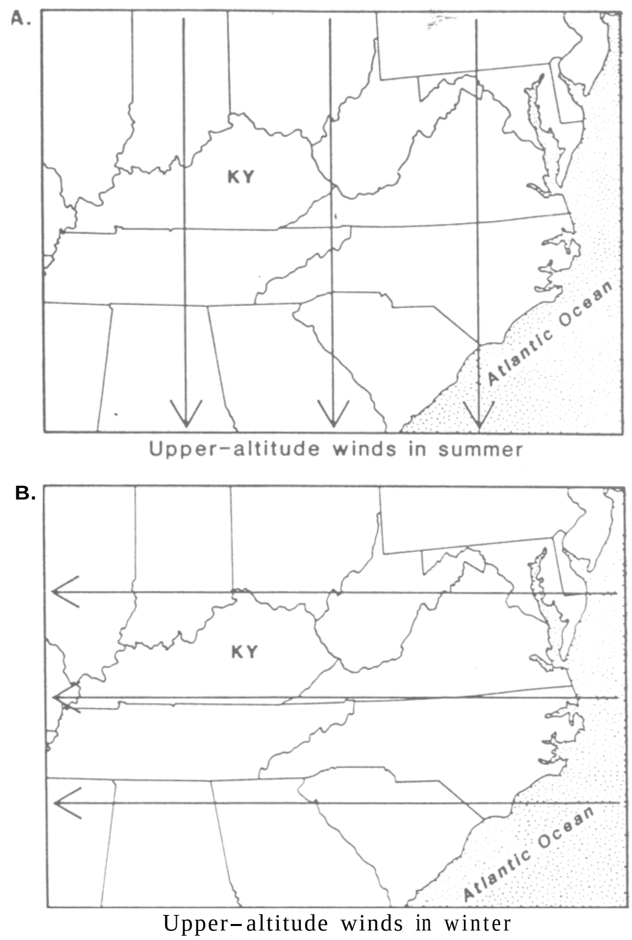

Fig. 9. Summer and winter high-altitude Trade Wind patterns prevailing in the study area. (A) Summer. (B) Winter.

tribution pattern for the flint clay (Fig. 11) based on winter winds, the preserved distribution of the flint clay (Fig. 5), and the lanceolate ash fall pattern as a model. The original geometry of the flint-clay ash was probably lanceolate, as was Mount St. Helen's. This lanceolate ashfall pattern was shifted from present-day north to south with its long axis parallel to the prevailing Westphalian high-altitude wind directions until it matched the preserved distribution of the flint-clay parting. This shape and this position represent a reconstructed pattern of ash deposition. Therefore, from this reconstruction, a likely volcanic source is projected along a line that runs through the states of Virginia and North Carolina.

The intersection of this projected line with the area of Carboniferous volcanoes should pinpoint the volcanic source. Any volcanoes of Westphalian age would have been eroded long ago, but magmatic plutons feeding these volcanoes may have survived. SINHA & ZIETZ (1982) showed the distribution of Hercynian granitic and gabbroic plutons in the central and southern Appalachians and concluded that they were formed in a continental magmatic arc environment generated by a subduction zone (Fig. 11). The intersection of the ash fall reconstruction and this magmatic arc is in North Carolina.

The position of the arc is complicated by the findings of the Consortium for Continental Reflection Profiling (COCORP), which indicate that the Blue Ridge and Inner Piedmont rocks are actually thrust over the basement. COOK (1983) suggested that the subduction zone arc was positioned over the present-day Carolina Slate Belt. The Inner Piedmont and Blue Ridge rocks, which were deformed in previous orogenies, were largely confined between the continental basement and the subduction arc (Fig. 12). When the Gondwanan continent collided with the arc (Alleghenian orogeny), it forced the Blue Ridge and Inner Piedmont rocks onto the North American continental basement and drove the arc and these rocks at least 120 km (75 miles) inland (COOK, 1983). The term "Alleghenian orogeny" is used here to refer to collisional tectonics only. Therefore, the position of the volcanic arc before the Alleghenian displacement was originally at least 120 km further seaward than its present position. Figure 11 shows the reconstructed position of the volcanic arc, the wind direction, and a possible ash-fall distribution, pointing out

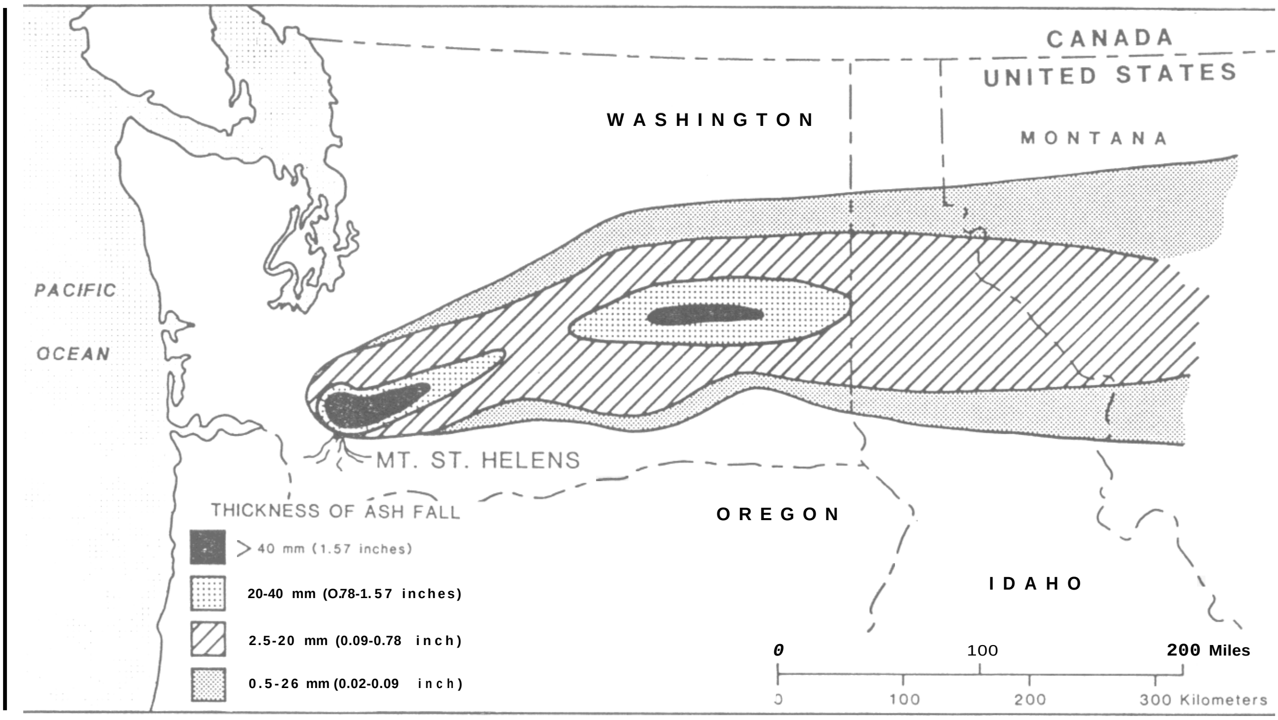

Fig. 10. Ash-fall pattern from the May 18, 1980. eruption of Mount St. Helens. lsopach lines are in millimeters (after SARNA-WOJCICKI *et al.*, 1981).

a volcano originally near the eastern bordcr of North Carolina.

Magmatic arcs associated with granitic plutons, explosive volcanoes, and widespread distribution of volcanic ash (as well as isotopic and geochemical studies in SINHA & ZIETZ, 1982) indicate crustal subduction. The same model has been proposed for Mount St. Helens and othcr related volcanoes in the northwestern United States (FOXWORTHY & HILL, 1982). The tectonic implications are important. WILLIAMS & HATCHER (1982) suggested that the accretion of Alleghenian terranes of the eastern United States was by transcurrent movement. This study suggests that at least some subduction was associated with this accretion (Fig. 13).

IMPLICATIONS OF THE DISTRIBUTION OF THE FLINT CLAY IN THE FIRE CLAY COAL

Several important geological implications are derived from the study of the Fire Clay coal flint clay.

Because of the extensive distribution of the parting, the Fire Clay coal bed is the only coal bed in eastern Kentucky that can be positively identified over a large area. The widespread distribution of this coal bed proves that the swamp in which the peats formed was extensive. We may then assume that other major coal heds could be equally extensive. It has been argued in the past that no coal bed in the Pennsylvanian rocks of eastern Kentucky was extensive or correlatable over a distance of more than a few miles. This study suggests that deposition of the Fire Clay coal bed was in swamps that were quite extensive. A study by Haney and others (this volume) also indicates an extensive Fire Clay swamp.

Distribution and thickness patterns of the flint clay, coupled with reconstructed wind patterns and intersecting magmatic arc, imply a winter-time effusive volcanic eruption somewhere in the southern or central Appalachians. Due to the paucity of Pennsylvanian volcanic rocks preserved in the Appalachians, this ash fall is probably the only evidence for Westphalian volcanism in the Appalachians. Associated with this volcanism is a possible subduction origin for at least part of the pre-Alleghenian orogeny.

Because of the extensive distribution of the flint-clay parting and its unique characteristics, the parting makes an excellent key stratigraphic horizon in the otherwise non-distinctive, recurring lithologies that characterize the Breathitt Formation, of which it is a part. This key stratigraphic marker, in fact, has been used extensively in correlating eastern Kentucky coals. This study suggests that its use as a stratigraphic marker is justified.

The volcanic-ash origin for this flint clay suggests the possibility of using it as a time horizon. An investigation is underway (Gross, Eastern Kentucky University, in

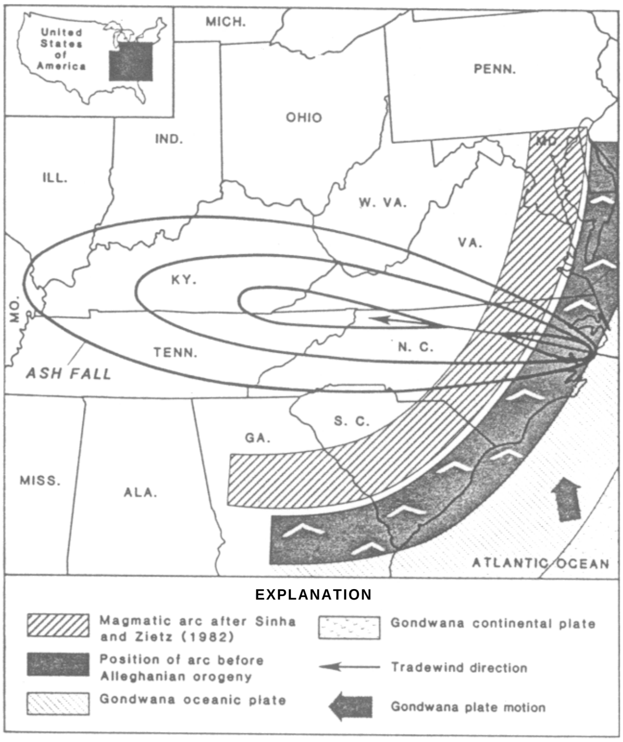

Fig. 11. Probable original ash-fall distribution for the flint-clay parting, based on wind patterns, the present position of a Carboniferous volcanic arc (after SINHA & ZIETZ, 1982). and a reconstructed position of this arc. The collision of the African continent (Gondwanan continent) with the North American continent (Laurussian continent) created the Alleghenian orogeny, which shoved the magmatic arc, the Inner Piedmont, and the Blue Ridge deformed rocks inland by at least 120 km (COOK, 1983).

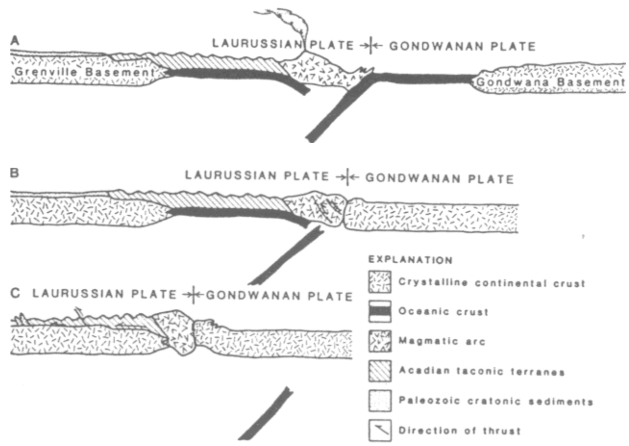

Fig. 12. Post-Acadian tectonic reconstruction of terranes affected by the Alleghenian orogeny. (A) Post-Acadian, pre-Alleghenian orogenies [Mississippian-Middle Pennsylvanian (?)]. The Acadian and Taconic terranes of the Blue Ridge, Inner Piedmont, and the Carolina Slate Belt Provinces were previously deformed and supplied sediments to the craton. A magmatic arc caused by westward subduction of the Gondwanan oceanic crust developed on the eastern edge of the North American continent (SINHA & ZIETZ, 1982). This arc was probably the volcanic source for the Fire Clay coal flint clay. (B) At Late Pennsylvanian (?) time, the Gondwanan continental crust collided with the Laurussian continent (North America). This is the start of the Alleghenian orogeny. (C) At Early Permian time, the Gondwanan continent had pushed the Acadian and Taconic terranes of the Blue Ridge. Inner Piedmont, and the Carolina Slate Belt at least 120 km (75 miles) over the Grenville Basement [information from COOK (1983), SINHA & ZIETZ (1982), and WILLIAMS & HATCHER (1982)].

gress) to study the spores above and below the flint clay to determine paleofloral communities and pioneering assemblages. The time line can also be used to study the paleogeography of the Fire Clay peat swamp.

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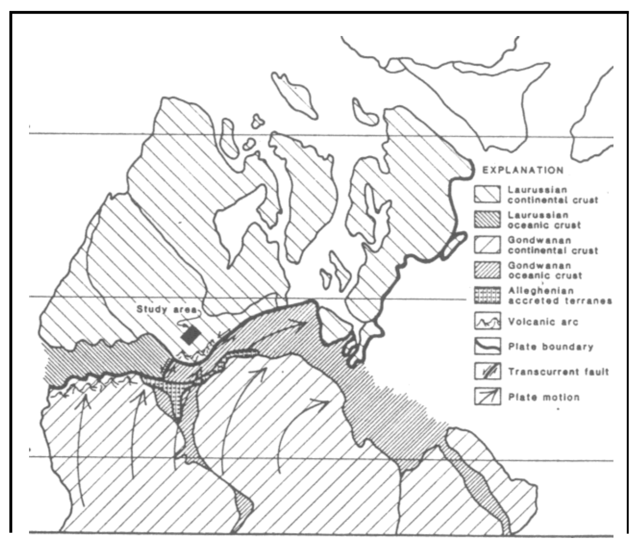

Fig. 13. Reconstruction of pre-Alleghenian plates, plate motions, and subduction zones. WILLIAMS & HATCH (1982) indicated transcurrent accretion of Alleghenian terranes, especially in the northern Appalachians. SINHA & ZIETZ (1982) indicated a westward-dipping subduction zone for the southern and central Appalachians. Plate motions are derived within these constraints.

DISCUSSION

Question

AUGUST H. SIMONSEN (U.S.A.): How was the 3,000 meter boundary for upper air winds selected? Was this selected as the level at which geostrophic flow first occurred?

Answer

DONALD R. CHESNUT: The 3,000 meter boundary was not selected by me, but by Dr. W. PORTIG of Panama City, Panama, who works with Tradewinds. I am not qualified to discuss the physics of these winds but can state only what Dr. PORTIG communicated to me about the altitude of the boundary, the wind directions, and the seasonal shifting of the Tradewind belt. These are discussed in the text. Dr. PORTIG also stated that, unlike wind patterns from other latitudes, the upper and lower winds of the Tradewind belt are stable and predictable.

Question

E. H. FRANCIS (G. B): Were author's reconstructed isopachs based on thickness measurements or on assumptions of wind directions based on palaeolatitude? The danger inherent on palaeowinds is that ash-fall shows great variations over short time intervals. For instance, the author quotes the E-W spread of the 18 May 1980 Mt. St. Helens eruption but other eruptions in the same year from the same volcano were in different directions.

Answer

DONALD R. CHESNUT: First, the isopachs were made before I examined the wind patterns. The main point concerning the isopachs was that the flint clay thickens to the south.

Secondly, it is true that the ash falls of Mt. St. Helen's showed great variations. The smaller and highly variable ash falls were from lower altitude eruptions while the extensive ash fall of the 18 May 1980 eruption was from a very high eruption cloud. This can be explained by two points, first, the only predictable wind patterns are the Tradewinds, and secondly, the lower altitude winds are especially unpredictable, as we who live in the temperate latitudes can attest. The high altitude winds generally travel to the east in this region.

The recent eruption of El Chichón in Central America, however, occurred in the predictable Tradewind belt and its ash fall patterns are known. The high altitude winds carried ash due west around the world. At first this is baffling because the model predicts that the ash should have been carried at an angle to the equator. At the time of the eruption, however, the Tradewind belt was migrating northward such that the midpoint of the belt was directly overlying the volcano. At midpoint of the belt the winds arc parallel and travel to the west. It is assumed that this flint clay was not deposited by a midpoint wind.

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