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Volcanic ash in the northern part of the Bitterroot Valley Ravalli County Montana

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VOLCANIC ASH IN THE NORTHERN PART OF THE BITTERROOT VALLEY, RAVALLI COUNTY, MONTANA

by

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ABSTRACT

Pliocene volcanic ash beds in the Bitterroot Valley, Montana were studied, and an attempt was made to correlate the beds over a limited area. Refractive index and chemical composition of the ash were determined, and the thicknesses of the beds, mineralogy, grain size, and diatom populations were studied. None of the techniques employed could be used for correlation purposes.

A secondary study was made on the effects of the ash on the immediately underlying clay minerals. Apparently montmorillonite is being altered to illite, although this is not necessarily a simple alteration.

Accretionary lapilli indicated a local source for the ash. The source of the ash was most probably associated with some late Tertiary rhyolitic extrusives found in the Bitterroot Valley.

INTRODUCTION

Purpose of Investigation

Volcanic ash beds have been used for correlative purposes for many years as they are excellent marker beds, representing a restricted time interval. Their unique appearance, unlimited environmental distribution, and extensive areal distribution enhance their usefulness. In spite of the fact that volcanic ash is such a valuable tool for correlation, relatively little work has been done on it. In particular, there is a paucity of work concerning the correlation of beds from a single episode of volcanic activity.

In this study several techniques used in an attempt to correlate Tertiary beds of the Bitterroot Valley, Montana are explained and evaluated. A detailed megascopic and microscopic description of the beds is given along with a partial chemical analysis.

Location of Study Area

The study area is located in the Bitterroot Valley in Ravalli County, Montana. The approximate center of the area is latitude 46° 30' N. and longitude 114° 00' W.

The ash deposits are found on the east side of the valley in an area located approximately between the towns of Victor to the south, and Florence to the north, a distance of about 15 miles. (see figure 1).

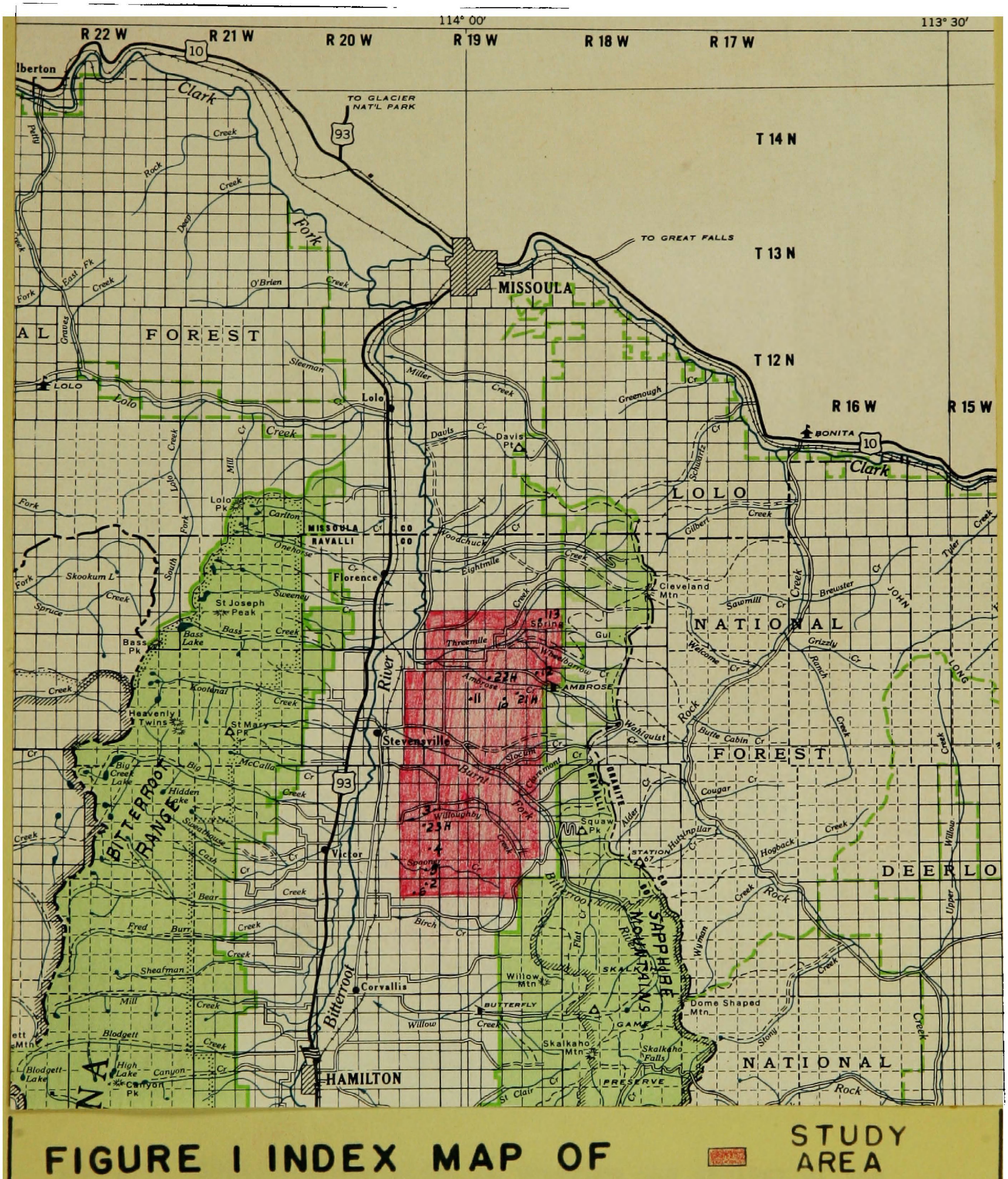

FIGURE I INDEX MAP OF BITTERROOT VALLEY STUDY AREA

STUDY AREA

Field Work

Approximately eighteen days were spent in the field collecting samples. The collecting procedure was to take the samples from a depth of four to six inches within an ash bed outcrop. This eliminated most of the surface alteration and minimized the amount of foreign matter washed in by surface waters. A two inch diameter pipe was used as a sampler and was driven into the cleaned outcrop about three or four inches. When the pipe was removed, the material inside was deposited and stored in labeled plastic bags. In ash beds that were too consolidated to use the pipe as a sampler, an ordinary tablespoon was used, taking care not to contaminate the sample. In either case, the pipe or tablespoon was thoroughly cleaned with a cloth after each sample was deposited in the plastic bag.

Samples were collected at approximately six inch vertical intervals or wherever a change in color or grain size was visible. Samples of the immediately underlying sediments were also collected.

Previous Work

Lindgren (1904) was the first to describe the geology of the Bitterroot Valley. He did not mention the ash beds on the eastern side of the valley, but he mapped some Tertiary extrusives west of the Bitterroot River and also at the south end of the valley. Rowe (1903) in his paper "Some Volcanic Ash Beds of Montana" briefly described the Bitterroot Valley ash, mentioning that these ash beds were "among the best in the state", (p. 25). Douglas (1909) noted the paucity of vertebrate and invertebrate fossils in the Tertiary sediments and the consequent difficulties in dating the sediments. Langton (1935) discussed the structure of sediments in the Valley. In his paper on glacial Lake Missoula, Pardee (1950) discussed portions of the Bitterroot Valley. Ross (1952) described the general geology of the Hamilton quadrangle. Konizeski has written the most recent report on the geology of the Bitterroot Valley (McMurtrey, Konizeski, and Stermitz, 1959).

Elsewhere in North America various workers have considered the subject of ash beds. Anderson and Flett (1902), Milne (1902) and Teal (1902) gave accounts of the 1902 volcanic eruptions in the West Indies and descriptions of the concurrent ash deposits. Landes (1928) in a report on the volcanic ash resources of Kansas described the Kansas ash deposits both megascopically and microscopically, and included a chemical analysis. He discussed some of the probable controlling sedimentary factors, and considered Colorado as a possible source. Landes noted that ash occurs in many regions of the United States. In the Great Plains provine Kansas, Oklahoma, and eastern Colorado and Nebraska have numerous deposits of ash while smaller amounts of ash are found in South Dakota and western Iowa. The Rocky Mountain province has some ash in Colorado, Idaho and Montana. Ash is associated with several recent volcanoes along the Pacific Coast.

Swineford and Frye (1946) made a petrographic study of the Pliocene and Pleistocene ash deposits in Kansas. Using color of the beds, specific gravity of the ash, refractive index, and shape of the shard, they were able to differentiate two ash falls of different ages. A comprehensive bibliography is included in this paper.

On the basis of index of refraction, character of the shards, including shape and vesicules, and composition, Swineford, Frye, and Leonard (1955) differentiated fourteen separate ash falls of Pliocene age in Kansas. A difference in ash falls was recognized in spite of the fact that variations from one fall to another were very slight. The characteristics of the Kansas ash are very similar to those of the Bitterroot Valley ash.

Schlocker and Van Horn (1958) reported on some ash near Denver, Colorado which altered to the clay mineral illite. This is unusual as most ash alters to montmorillonite. The characteristics of this ash are also similar to the ash studied in the Bitterroot Valley.

Acknowledgements

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Physiography and Climate

The area is in the western Montana part of the Rocky Mountain physiographic province and topographically is a north-south trending intermontane valley, which is typical of the province. The Sapphire Mountains border the valley to the east, and the higher Bitterroot Range borders it to the west.

The relief from the valley floor to the highest peaks in the Bitterroot Range is about 6,000 feet while that in the Sapphire Mountains is about 5,000 feet.

The Bitterroot Valley is about forty-five miles long and averages about seven miles in width.

The Bitterroot River is the main stream in the valley, with twenty tributaries entering it from the west and five entering it from the east.

According to McMurtrey, et al, (1959, p. 8):

> "The climate of the Bitterroot Valley is characterized by relatively mild winters, cool summers, light precipitation, and very little wind. The climatic data of Stevensville are as follows: mean minimum temperature 30.2° F., mean maximum temperature 58° F., average annual precipitation 12.16 inches."

GEOLOGY OF THE BITTERROOT VALLEY

The Bitterroot Valley is a structural valley which, according to Ross (1952) and others, was formed at the time of emplacement of the Idaho Batholith late in the Cretaceous period, or early in the Tertiary period.

The valley was then filled with sediments until late in the Tertiary period when the Bitterroot River was rejuvenated and the valley was exhumed, developing high and low terraces on both sides. The present topography of the valley was caused by the rejuvenation and recurrent faulting along the margins of the valley (Pardee, 1950).

The movement was probably greater on the western side of the valley where fault traces can be observed. Possible evidence for faulting on the eastern side of the valley follows: (1) at the one location, (no. 3, middle bed), where a dip and strike of the ash beds can be taken, the beds strike N 30° E, and dip 4° to the northwest, (which could be a primary dip), (2) the ash outcrops are exposed in the valley in a northeast trending direction, indicating a general strike of the beds in this direction, (3) jointing, which is dipping essentially vertical and strikes to the northwest, can be observed in the middle bed at location no. 3.

One would expect the beds to strike parallel to the valley, (north-south), and dip into the valley (west), but the above evidence indicates a slight deviation from the expected attitude of the beds, at least in the vicinity of location no. 3. This can probably be explained as late tilting of the beds, causing them to strike northeast and dip northwest.

During a part of Pleistocene time, the Clark Fork River was ponded by a lobe of ice from the Cordilleran ice sheet, and the resulting lake flooded the Bitterroot Valley. Small beach terraces on either side of the valley which reach an elevation of 4200 feet, indicates the glacial lake must have filled the valley to at least this height.

GEOLOGY OF THE ASH

Nomenclature

The terminology used for the pyroclastic rocks will be that proposed by Wentworth and Williams (1939):

Accretionary lapilli- Pellets, often exhibiting concentric structure, owing to the accretion of fine ash or dust around raindrops falling through an explosion cloud or to similar accretion around a nucleus fragment which rolls along the ground. These are the mud pellets and pisolites of other writers.

Ash - Uncemented pyroclastic debris consisting of fragments mostly under 4 mm in diameter. Coarse ash is from 4 to 1/4 mm in grain size; fine ash is under 1/4 mm.

Dust, volcanic - Pyroclastic detritus consisting of mostly of particles of less than 1/4 mm in diameter, i.e. fine volcanic ash.

Lapilli - Essentially accessory and accidental ejecta ranging mostly from 32 to 4 mm in diameter.

Tuff - Indurated pyroclastic rocks of grain generally finer than 4 mm; i.e., the indurated equivalent of volcanic ash or dust.

Sedimentary tuff - A tuff containing a subordinate amount of sediment introduced either during or after deposition, e.g., the finger deposits of some volcanic mud flows or rocks produced by the erosion and redeposition of pyroclastic ejecta admixed with non-volcanic material.

Sedimentary Features

General description of ash beds

The ash deposits occur as beds or possibly lenses 11 inches to 10 feet thick in Tertiary sediments. The deposits are all quite pure except at the upper contacts where the ash grades into overlying sediments. The ash is compact enough in most instances so as to be a little more resistant than the underlying and overlying sediments, hence in outcrops it is usually a ledge former, (Figure 2). In all cases, the ash can readily be disaggregated by crushing it between the fingers.

On a dry outcrop surface the silts and clays are usually much more compact than the ash, but on a wet surface they become soft while the ash remains fairly well consolidated.

Areal distribution

In western Montana ash deposits are found in several valleys, including the Bitterroot Valley, Missoula Valley, Deerlodge Valley, and the Gallatin Valley.

The Tertiary sediments on the western side of the Bitterroot Valley have either been down-faulted or eroded away, and hence most of the Tertiary sediments in the valley are preserved only on the eastern side. Only one bed, the middle bed, at location no. 3, Willoughby Creek, can be traced for any distance on the surface. (Plate 1).

Pure, relatively fresh ash is found at location no. 13 (Spring Creek drainage) which is 2 miles south and 6 miles east of Florence. A little silty ash has been observed 2 or 3 miles north of this location. To the south ash crops out in some of the east-west trending gullies for about 14 miles to location no. 6, which is the drainage just north of Birch Creek. South of this drainage, the ash is very much reworked and admixed with silts and clays, and hence it is called a sedimentary tuff (Wentworth and Williams, 1939). The sedimentary tuff crops out in several gullies for about five miles south of Birch Creek.

Three ash beds crop out in 70 feet of section at location no. 3, Willoughby Creek, indicating at least three different ash falls in the area.

The elevations of the ash beds in the area range between 3500 feet and about 4100 feet.

Figure 2. Ash bed outcrop at location no. 3

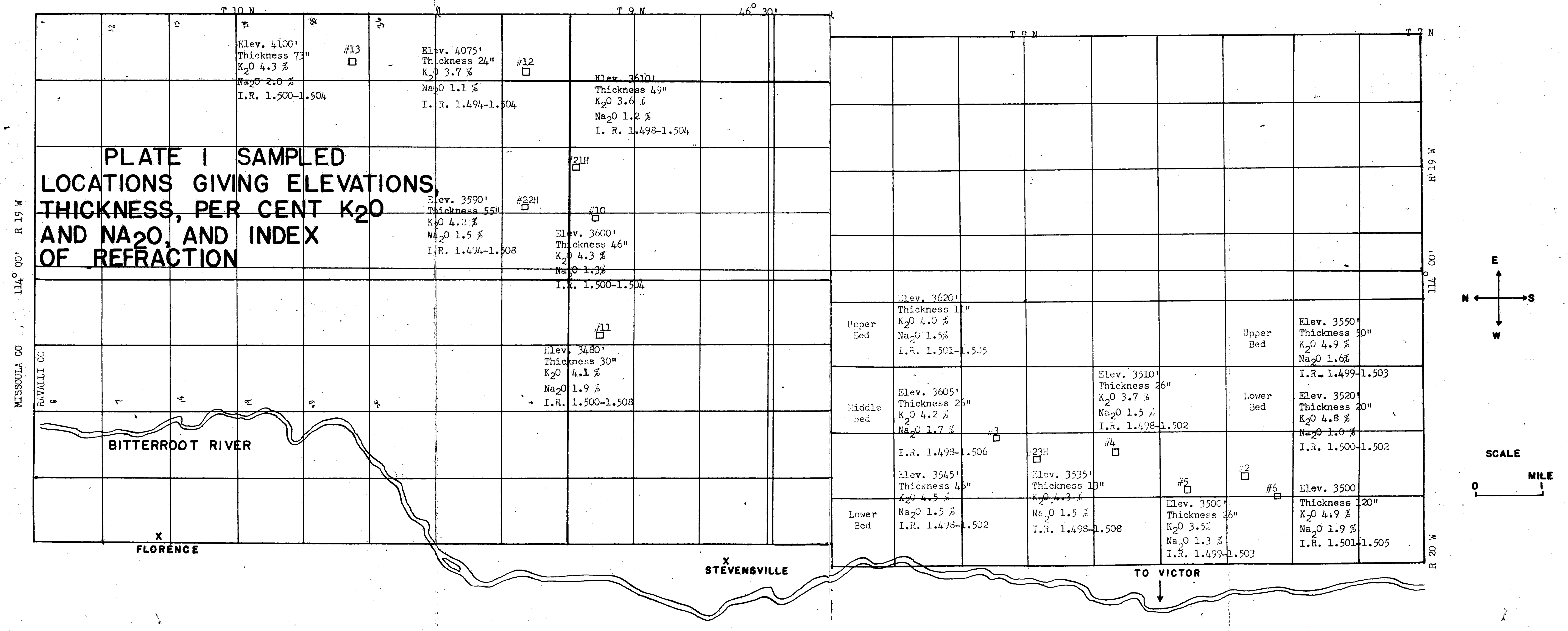


PLATE I SAMPLED LOCATIONS GIVING ELEVATIONS, THICKNESS, PER CENT K_2O AND NA_2O, AND INDEX OF REFRACTION

To summarize, the areal distribution of the pure ash includes a rectangular area 6 miles wide and 14 miles long. However, it is not implied that the distribution is uniform or even that the ash is present over all of this area.

Relation to sediments

The ash beds are deposited on late Tertiary silts and clays, and in some instances (locations 12, 13, 21H, 22H) on a silty arkose which becomes more silty and clayey, and less arkosic basinward. At location no. 3 a 170 foot section of Tertiary sediments is exposed. The lower 30 feet of the section consists of silts, sands and gravels. The next 110 feet consists of silts and clays, and includes three ash beds. Silts, sands, and gravels constitute the top 30 feet of Tertiary sediments.

The bottom contact of the ash is sharp and conformable, but the upper contact is gradational with the overlying sediments.

Thickness

The thicknesses of the ash beds in the area range from 11 to 120 inches. The two thickest beds (location no. 6, 120 inches and location no. 13, 73 inches), occur 15 miles apart and at opposite ends of the area. Hence, no particular thinning or thickening of the beds in a given direction is noticeable. In general, the thicknesses of the beds vary considerably. (Plate 1).

Because of its gradational nature, the exact position of the upper contact of the ash is difficult to determine. Thus the measured thickness of ash beds may be plus or minus one foot from the tabulated thickness.

Description and size range of shards

The color of the ash varies from white to various shades of gray with the lighter color being in the finer-grain size, and the darker color being in the coarse-grain size. The coarse fragments may just appear to be more discolored as they are thicker than the fine grained fragments. In the sunlight the individual fragments reflect light brilliantly. This characteristic along with the negative reaction with hydro-chloric acid differentiates volcanic ash from diatomaceous and chalk deposits.

A hand lens or other source of low magnification reveals the angularity and glassy nature of the individual shards. With a binocular microscope essentially four different types of shards can be observed (Figs. 3, 4, and 5): (1) colorless, platy, angular fragments, (2) more complex fragments having ribs or ridges built up from the platy fragments, (3) fragments in which vesicules or bubbles of glass can be observed, (4) elongate fragments which show a flow structure.

Pirsson (1915) explains the first three shapes of volcanic fragments by relating them to expanding gases in a viscous melt. As gases in the melt expand with a release of pressure, bubbles are formed in the melt. When the ejecta are blown out of the volcano, there is a further release of pressure and the gases trapped in the liquid expand still more until the bubbles burst. The outer

Figure 3. x 51

Fragment of shard having ribs built up from base.

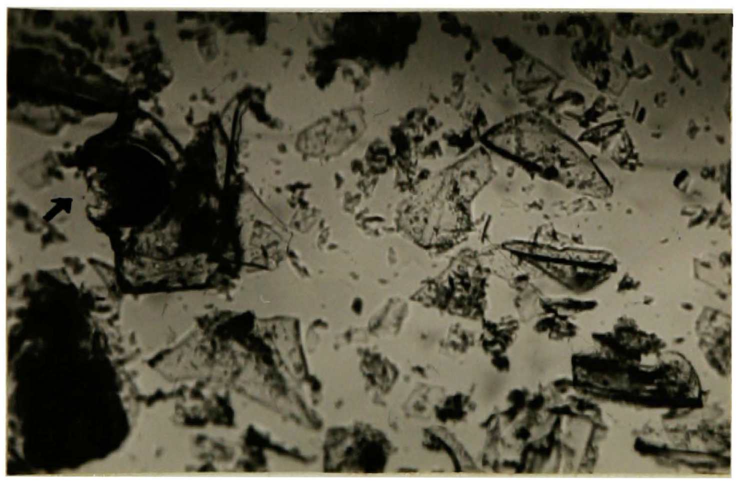


Figure 4. x 51

Fragment of shard showing part of vesicule.

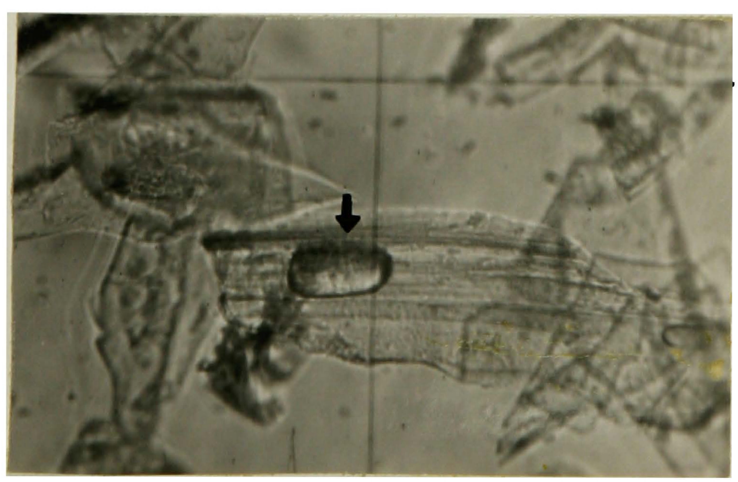


Figure 5. x 240

Fragment of shard showing flow structure and elongate vesicule.

portions of the bubble solidify to form platy shards, and the basal part of the bubble which is attached to a larger shard, solidifies to form the ribbed type of shard, with the ribs acting as divisions between the bubbles. In some of the shards whole vesicules can be observed. The fourth type of shard shows pronounced flow structure, indicating the viscous nature of the lava at the time of eruption.

The size of individual shards ranges from less than .004 to .5 mm, the smaller fragments being termed fine ash and the larger ones coarse ash.

A bed of ash typically consists of alternating layers 3 inches to 2 or 3 feet thick of fine and coarse ash. Each deposit contains several of these alternating layers. The contacts between the layers are parallel to one another, and to the bottom contact. Some beds do not contain any coarse ash, but in those beds that do, it is found near the base of the bed.

A size analysis was made on those beds which have a coarse ash layer near the base, (except at location 23H where the sample was contaminated with clay.) This coarse layer was chosen because it is the most distinct and the most persistent layer present. (However, it was not proven to be correlative.) It is also near the base of the bed and thus would be less susceptible to later erosion. An "X" in a section in Plate 2 indicates the place where a size analysis was made.

Fifteen -gram samples were hand sieved through a series of four sieves of the following sizes: numbers 24 (.701 mm opening), 100 (.149 mm opening), 200 (.074 mm opening), and 325 (.044 mm opening), as standardized by the American Society for Testing Materials. The material which was caught on the no. 24 screen is of little significance as much of it consists of small fragments of altered material and shards cemented together.

The index number was obtained by adding the amount of material present in the 100 - 200 range, plus two times the amount of material present in the 200 - 325 range, plus four times the material present in the less than 325 size, (Landes, 1928).

Twelve size analyses were run, but two of these which were from beds containing no coarse ash could not be compared to the rest, and were therefore discarded. Table I gives the amount of ash present in each grade size.

PLATE 2 LITHOLOGIC DESCRIPTION

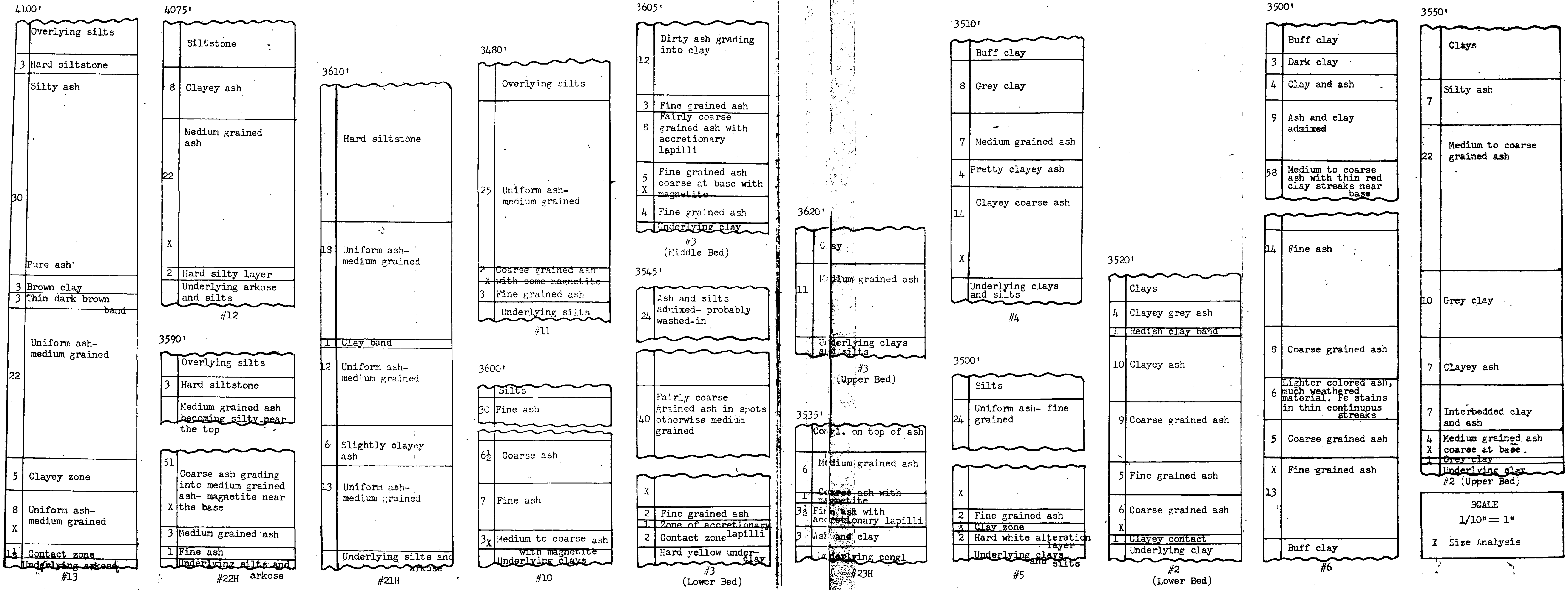


TABLE I
Grain Size Analysis

Loc.	Sample No.	24 .701	24-100 .701-.147mm	100-200 .147-.74mm	200-325 .074-.044mm	325 .044 mm	Index No.
13	198H	.1%	35%	37.5%	16.4%	11%	115
10	261H	1.6	51.5	20.6	14.2	12.1	97
22H	226H	.6	62	15.1	12	10.3	80
3 Middle	46H	.9	62.5	13.9	13.2	9.0	66
11	235H	1.9	68.0	13.3	9.1	7.8	63
2 Lower	140H	1.0	66.5	14.5	11.6	5.7	61
2 Upper	116H	4.0	70.0	8.4	9.9	7.5	58
5	275H	1.7	63.0	20.8	10.1	4.5	49
4	163H	.4	72.5	12.9	10.6	3.7	49
6	92H	1.5	75.3	11.3	9.3	2.6	30

Structures

Three types of structures are found in the various ash deposits. One of these structures is similar to a "fossil bone" structure described by Landes (1928) in Kansas ash, though Ravalli County ash is non-calcareous. (Fig. 6). They are circular to ovate in cross section, and measure .5 to 1.5 cm in diameter. The "fossil bones" form in a branching pattern, having a rough surface and a porous texture. They consist of a hard, white siliceous appearing substance, which shows no crystalline structure

Figure 6. "Fossil bone" structure found in ash at location no. 22H.

Figure 7. Concretions found in ash at location no. 6.

in an X-ray pattern.

The origin of these "fossil bones" can only be hypothesized as being deposited by ground water action. Perhaps worm borings provided a channel through which ground water could flow more easily than through the rest of ash. Dissolved mineral matter might be deposited on the side of the channels as the ground water seeped outward from the channels.

A second hypothesis assumes that roots or some other organic matter were in the ash. Dissolved mineral material in the ground water would then be deposited around the organic matter.

The second type of structures are concretions (Fig. 7). These are hard balls, 2 to 6 inches in diameter, occurring as single balls or groups of balls which are usually flat on the bottom. They are composed of ash which is very well cemented with calcium carbonate. These too, were probably formed by ground water action. These are found at location no. 6 and may indicate that at this locality the ground water is draining off a calcareous rock, such as the Wallace limestone of Precambrian age which crops out in the vicinity.

The concretions fluoresce spottily under an ultra violet light, indicating the presence of either uranal ions or hydrocarbons. A bead test was made, using sodium fluoride as a flux to test for the uranal ion. Under the ultra violet light the bead should have fluorescesed if as little as 3 parts uranium per million were present. The test showed that no uranium was present, so it was concluded that the fluorescence in the concretions was due to hydrocarbons.

The hydrocarbons present in the concretions were probably preserved from oxidation by the carbonate cementation. It is possible that the fluorescence was caused by other minerals present, calcite, in particular. One would have expected the entire concretion to fluoresce, however, if this were the case.

In addition to the above study, all of the underlying sediments were tested under the ultra-violet light to check for the presence of uranium. McKelvey (1955) and Heinrich (1958, p. 323) and others have discussed the association of uranium with volcanic ash. As mentioned earlier, the small amount of fluorescent material which was found, proved to be attributed to organic compounds.

The third structure found in the ash is perhaps the most interesting (Figs. 8 and 9). These are small oblate spheroids about 5 mm in diameter, which are called accretionary lapilli. These accretionary lapilli are composed of a core of ash surrounded by a hard, white, non-calcareous coating, approximately 1 mm thick. The ash shards which form the core, are arranged so as to suggest a concentric structure in the outer edges of the core. The chemical composition of the accretionary lapilli differs from that of the surrounding ash. (Table II).

Within a given ash bed, the spheres are sometimes distributed in a thin zone as in the lower bed at location no. 3. In another instance they are more or less scattered throughout the whole bed, as in the middle bed at location no. 3. The accretionary lapilli are most abundant at location no. 3 in the middle bed.

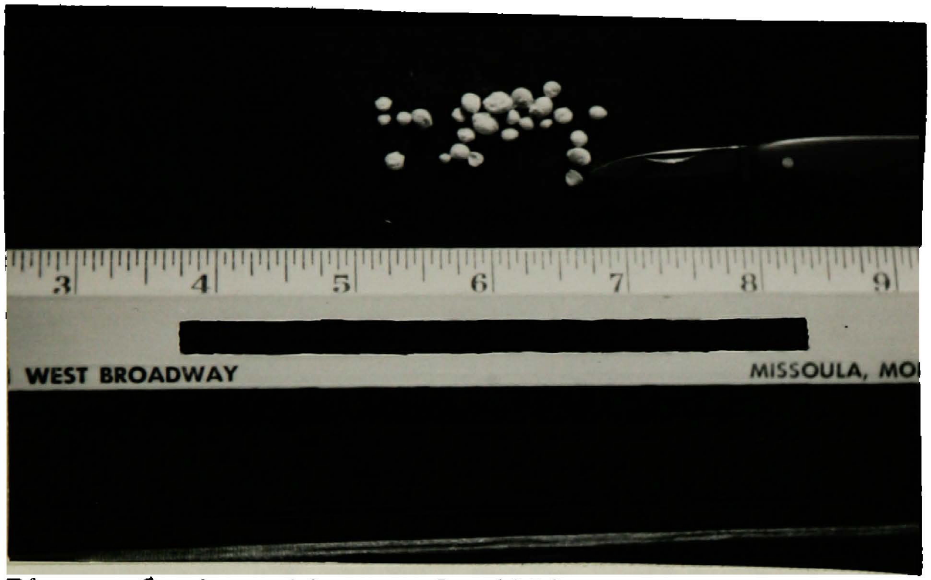


Figure 8. Accretionary lapilli
removed from ash.

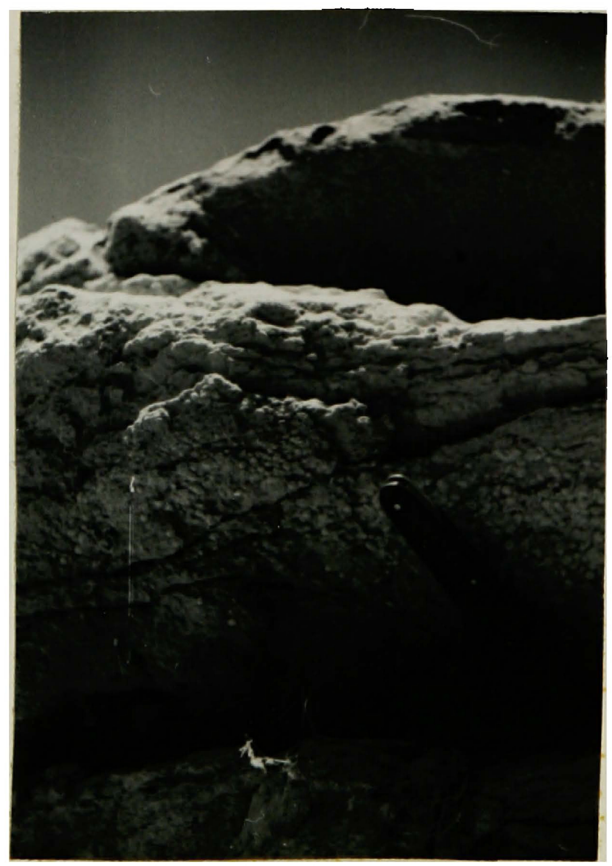


Figure 9. Accretionary lapilli
in place.

Similar structures have been described by Perret (1913) from Kilauea and Vesuvius, and also by Pratt (1916) from Taal Volcano in the Phillippine Islands.

Wentworth and Williams (1932, p. 37) state:

> "They are due to the segregation of tuff particles by condensing steam and fall to the earth as balls of soft mud."

Stearns (1926) suggests that occasionally these can be formed by the rolling of lapilli nuclei over a fresh ash surface. He also suggests that wind and rain action on newly fallen ash may cause the ash to ball up.

Most probably the accretionary lapilli in the Bitterroot Valley ash were formed by the accumulation of the ash on drops of water. Being moist, the accretionary lapilli would tend to form an oblate spheroid after falling to earth, rather than attaining a perfectly formed spheroidal shape. It is believed that the hard, thin, white layer is due to later alteration. The spheres acted as points of accumulation for any material undergoing alteration in the ash. This probably accounts for their difference in composition from the rest of the ash.

TABLE II
Chemical Analysis and Index of Refraction

Location No.	Per Cent $K_2O \pm .2$	Per Cent $Na_2O \pm .2$	Index of Refraction .002	Thickness of Ash in Inches
13	4.3	2.0	1.500-1.504	73
12	3.7	1.1	1.494-1.504	24
21H	3.6	1.2	1.498-1.504	49
22H	4.2	1.5	1.494-1.508	55
10	4.3	1.3	1.500-1.504	46
11	4.1	1.9	1.500-1.508	30
3(Upper)	4.0	1.5	1.501-1.505	11
3(Middle)	4.2	1.7	1.498-1.506	26
3(Lower)	4.5	1.5	1.498-1.502	64
23H	4.3	1.5	1.498-1.508	13
4	3.7	1.5	1.498-1.502	25
5	3.5	1.3	1.499-1.503	26
2(Upper)	4.9	1.6	1.499-1.503	50
2(Lower)	4.8	1.0	1.500-1.502	20
6	4.9	1.9	1.501-1.505	120
Ash containing accretionary lapilli	4.2	1.7	1.498-1.506	
Accretionary lapilli	3.5	.9	1.503-1.506	

Mineralogical Features

A petrographic study of the optical properties of the shards and associated minerals was made. Under crossed nicols, the shards of volcanic ejecta remained extinct on complete rotation of the stage, showing a glass composition. The indices of the glass were measured, using monochromatic light. (Table II)

Small discrete grains of magnetite occur in some of the shards. These tiny, opaque inclusions in the shards cause them to have a smoky or dark appearance and indeed, in some instances, cause them to be completely opaque. The magnetite was identified by X-ray diffraction techniques. The magnetite occurs in the coarse ash zones of some of the deposits. It is perhaps most abundant in a coarse ash zone in the middle bed at location no. 3. In this 2 or 3 inch zone, the magnetic particles constitute approximately 1 per cent (by weight) of the ash.

A few other mineral fragments can be recognized in the ash. Most of these fragments are quartz or apatite, and a few grains of feldspar.

Chemical Features

Using a Perkin-Elmer flame photometer, the amounts of potassium and sodium were determined to plus or minus 3 per cent of the amount present (Table II). The elements are reported as the oxides of potassium and sodium. These samples were prepared by dissolving a one-half gram sample by heating it in hydrofluoric acid and perchloric acid. The sample was diluted to a known volume, and a lithium internal standard was added.

Biological Features

Four species of fresh-water diatoms were identified in the ash beds. The plants are most easily studied by using light from a sodium lamp. They seem to show up much better under this light than under white light.

The species present and their relative numbers are reported. The term "abundant" here means about 20 or 30 individual diatoms present in one oil immersion mount. The other terms are relative to this.

Melosira distans is the most common diatom, and Diatoma vulgare Bory is the next most common. Tetracyclus lacustris Ralfs and Tetrcyclus rupestris (A. Br.) Grun are found in three of the deposits, (Table III and Figs. 10-12). All of these species range from Miocene to Recent.

SEDIMENTATION

The environment of deposition of the ash is not immediately apparent as evidence for both a lacustrine environment and a subaerial environment can be presented. The presence of parallel layering (Fig. 15) in the ash, even though the ash does not necessarily break parallel to this layering, plus the lack of cross bedding, suggest a subaqueous environment. The conformable

TABLE I
Occurrence and Relative Number of Diatoms

Location Number	Diatoma vulgare Bory	Melosira distans	Tetracyclus lacustris Ralfs	Tetracyclus rupestris (A. Br.) Grun
13	Abundant	Abundant	Scarce	None
22H	None	Some	None	None
12	Scarce	None	None	None
21H	Some	Some	None	None
10	Abundant	Some	None	None
11	Scarce	None	None	Scarce
3(upper)	Scarce	Scarce	None	None
3(middle)	Scarce	None	None	None
3(lower)	None	Scarce	None	None
23H	Some	Some	None	None
4	Some	Some	None	None
5	None	Some	None	None
2(upper)	None	Some	None	None
2(lower)	None	Abundant	Scarce	None
6	Abundant	Some	None	None

Figure 10. x 240

Melosira distans from location no. 13.

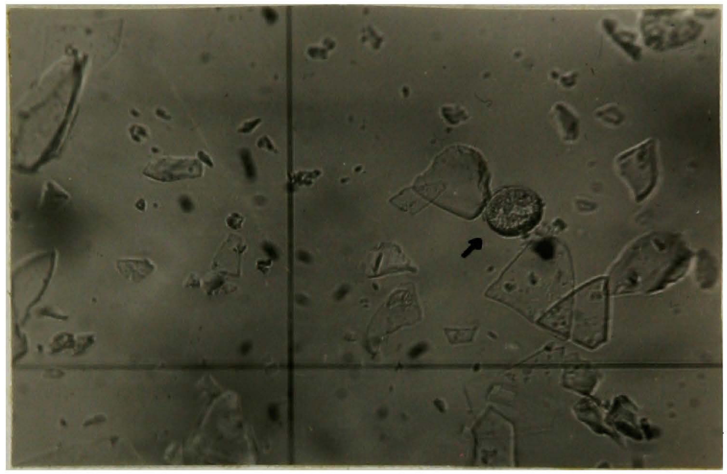


Figure 11. x 240

Diatoma vulgare Bory from location no. 10.

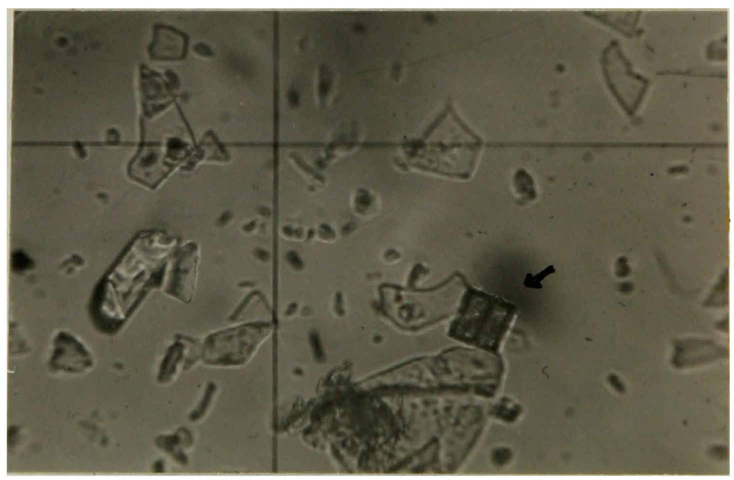


Figure 12 x 240

Tetracyclus lacustris Ralfs from location no. 13. Also fragment of Melosira distans

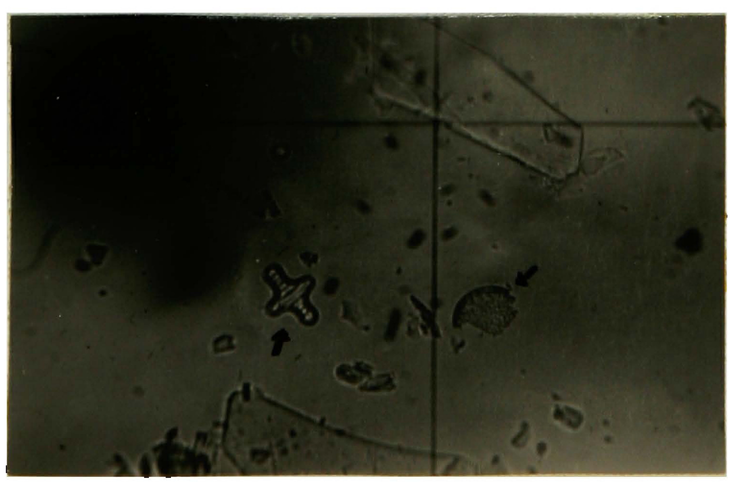


Figure 13. Wavey contact between coarse and fine-grained ash. Note also the jointing. Location no. 3 (middle bed).

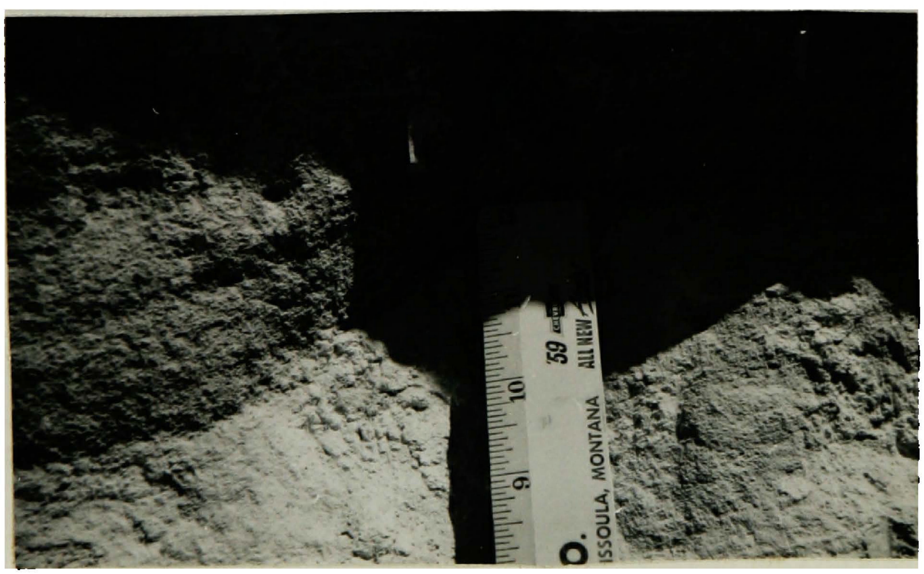


Figure 14. Close-up of wavey contact in middle bed at location no. 3.

Figure 15. Parallel layering in ash, middle bed at location no. 3.

Figure 16. "Dike" of coarse ash in fine ash. Probably caused by burrowing animal; note mound to the left.

nature of the beds would also indicate continuous deposition in a body of water.

The presence of several species of fresh water diatoms strongly suggests a subaqueous deposition, but it is possible that these minute plants were filtered into the ash at a later time. As these diatoms are able to live in seasonal lakes, or even in drainage ditches, their presence would not necessarily indicate a large body of water.

Apparently there was a time lapse after the deposition of a 3 or 4 inch layer of fine ash in the middle bed at location no. 3. Figure 13 shows a wavey contact between the underlying fine ash and the overlying coarse ash. This seems to indicate subaerial erosion. Figure 16 shows this same fine ash layer with a "dike", approximately one inch in diameter, of the overlying coarser ash cutting into it. This is explained as an animal burrow. To the left is a mound of fine ash which has been built by the animal while digging the hole.

Considering the proposed origin for the accretionary lapilli as coalescing in the air, one might expect the environment of deposition to be subaerial. If a lacustrine environment prevailed, the lapilli would probably disaggregate upon hitting the water, although it is possible that they might remain intact.

The variation in thickness of the beds from one location to another is evidence for a subaerial environment.

AGE

Douglas (1909) noted the paucity of vertebrate and invertebrate fossils in the Tertiary sediments of the Bitterroot Valley, but using limited evidence, he dated the beds as Miocene.

Konizeski (personal communication) dated all the Tertiary outcrops in the study area as Pliocene and mentioned that at the time of Douglas's work very little was known about the index fossils of the area.

ORIGIN

A rhyolitic composition for the ash is indicated on the basis of index of refraction, (George, 1924) and sodium and potassium analyses. Any of the nearby Tertiary rhyolitic extrusives could be genetically related to the ash.

Near Florence on the west side of the valley, an extrusive flow rock crops out, which contains breccia composed of angular fragments of probably Pre-Cambrian Belt series sediments. This probably indicates that the vent for the extrusives must be nearby.

Some fragments of the extrusive rock were melted with an oxyacetylene torch to form a glass bead. The bead was crushed and the index of refraction ($1.549 \pm .002$) indicated that the rock is a rhyolite (George, 1924). However, the fact that both the ash and the extrusive rock have a rhyolitic composition indicates little more than the possibility that the source of the ash was the same as that of the extrusives across the valley.

Plotting the index number of the ash from Table I against the distance of the ash from the front of the Bitterroot Range, a slight decrease in grain size away from the mountain front was observed (Fig. 17).

The data are by no means conclusive, but the relationships are in accord with what one would expect if the ash were derived from the west.

Several other larger masses of Tertiary rhyolites crop out south of Hamilton along U. S. highway 93, and around Sleeping Child Hot Springs. Rhyolites have also been found around the village of Sula, which is about 30 miles south of Hamilton. All of these were mapped by Lindgren (1904).

If the accretionary lapilli were formed in the air, then the source of the ash must be close as the lapilli would not be formed far away from the source. A logical source would be that related to one of the extrusive bodies of the Florence area.

ATTEMPTED CORRELATION OF THE ASH BEDS

Since at least three different beds are present in the area, an attempt was made to correlate the ash deposits. Several techniques were employed, but none proved to be satisfactory for a positive correlation.

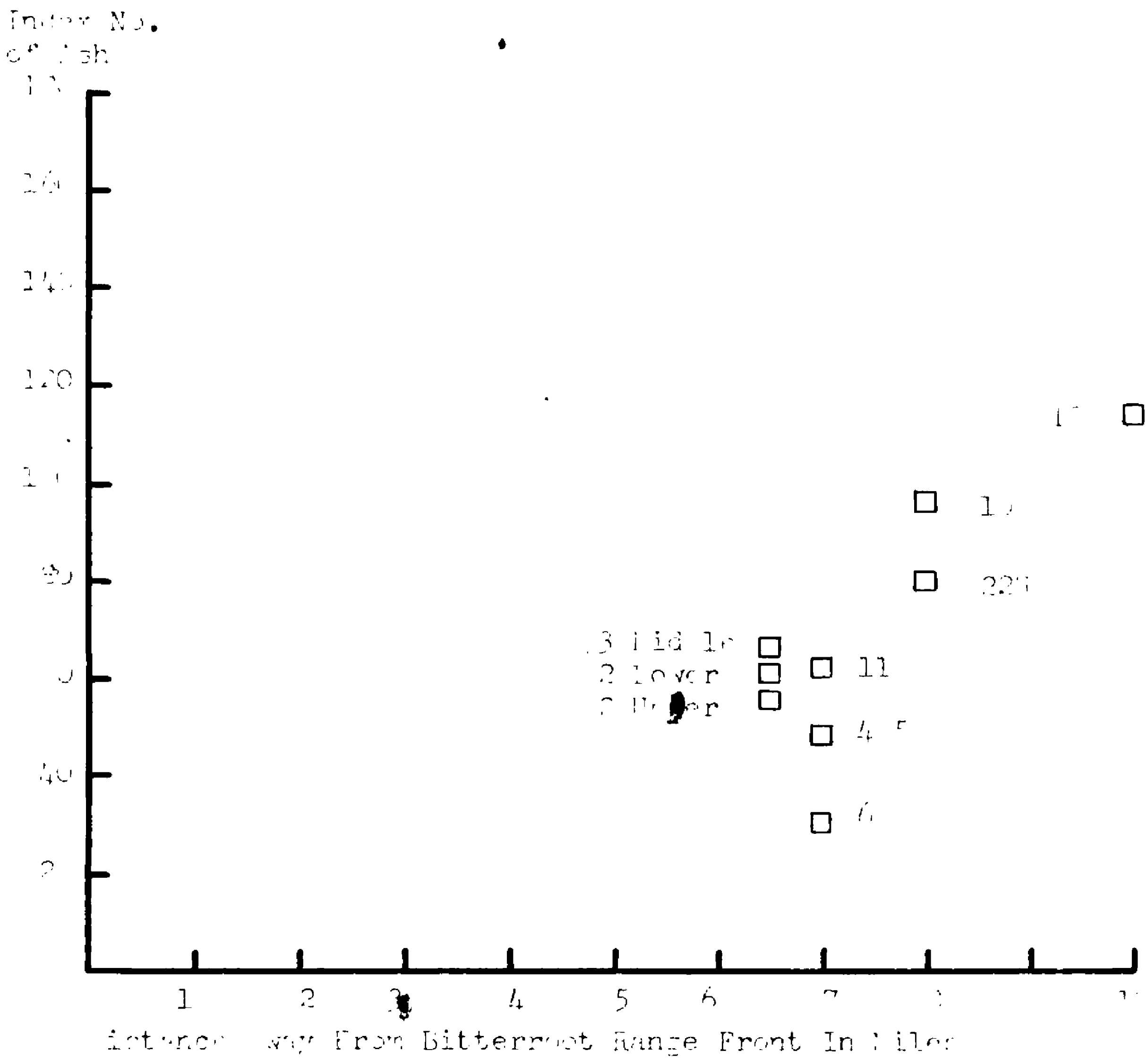


Figure 1?. Distribution of ash by grade sizes

Thickness

The thicknesses of the beds would seem to be a logical criterion upon which to base a correlation. Plate 1 gives the thicknesses of the beds at the outcrop locations. Correlations over short distances are indicated by this map. Three beds which indicate a correlation on the basis of thickness are the ones at locations 22H, 21H, and 10. These locations are within an area of 1 mile by $1\frac{1}{2}$ miles, and a positive correlation can be made with some confidence.

Using thickness as an indication, a second possible correlation could be made between locations no. 4 and no. 5. This would be a correlation over a distance of about $1\frac{1}{4}$ miles.

The beds consist of alternating layers of coarse, medium, and fine grained ash. Thickness of individual layers varies from bed to bed. Plate 2 gives the lithologic description of the beds and illustrates the variation of bed thicknesses.

Two factors may account for the differing thicknesses of the alternating layers. First, if a volcano ejected a greater bulk of medium-grained than coarse-grained material, the beds would be thicker at the locations where the medium-grained material fell to earth. The coarse-grained material would not have formed as thick a bed even though it was closer to the source as the bulk of this grain size would have been less. Since the fine-grained ash would have been carried the farthest and spread over the greatest area, one would expect these layers to be thin.

A second factor influencing the thickness would be the prevailing wind direction. Ash beds along the prevailing wind direction would have received more ash than those in a less favorable position. If the prevailing wind direction changed, then the thickness of the layers would also have changed.

A third reason for uneven thickness of the beds of the same ash fall could be the local winds at the time of deposition. At one place a clump of trees or a hill could have reduced the wind velocity sufficiently enough to cause deposition of all or part of the suspended load while at another place the wind could have maintained enough velocity to keep the ash in suspension.

Index of Refraction

Previous workers with volcanic ash (Swinford, Frye, and Leonard, 1955) have differentiated between ash falls by using the index of refraction as one of the main criteria. The index of refraction indicates that the ash beds fall into three broad groups (Table IV). These groups probably point out a correlation for some of the beds. The narrow range for the indices (1.494 to 1.508±.002) points out the need for accurate optical work. Perhaps if the indices were taken of one particular size and one shape of shard, and if the index of the oils were periodically checked, better results might have been obtained.

TABLE IV
Correlation Based on Range of Index of Refraction

1. 500- 1.504 ±.002	1.498-1.506 ±.002	1.494-1.506 ±.002
location no.	location no.	location no.
13	3(middle)	12
21H	23H	22H
10		
3(upper)		
3(lower)		
4		
5		
2(upper)		
2(lower)		
6		
11		

Mineralogy

There is a limited number of minerals in the ash. Quartz, apatite, magnetite, feldspar, and some mica are present in minor quantities. Magnetite is abundant enough to indicate a possible correlation between beds. The beds at locations no. 10, no. 11, no. 22H, and no. 3(middle bed) all have considerable amounts of magnetite which is found about 6 or 8 inches from the base of the ash. This suggested that these deposits might be correlative. Some magnetite is also scattered throughout the lower and upper beds at location no. 3.

One might interpret the presence of magnetite to mean a close proximity of the source. As magnetite has a high specific gravity, one would expect it to fall a short distance from the eruption. This may be correct, but due to the disseminated nature of the magnetite, the specific gravity of the ash fragments is not as great as it would be if the whole fragment was composed of magnetite.

Diatoms

Location no. 13 has the greatest number of diatoms, and three different species were identified from there. Locations no. 10, no. 2(lower bed), and no. 6 are relatively abundant in at least one diatom genus. The rest of the locations have a moderate number, or very few diatoms present.

Eight of the locations have both Diatoma vulgare Bory and Melosira distans, which are the two most abundant diatoms. Seven locations have either one or the other of these two diatoms species present. Tetracyclus lacustris Ralfs and Tetracyclus rupestris (A. Br.) Grun are scarce.

Using the diatoms present and the relative abundance of each as criterion for correlation, three groupings can be set up. (See Table V).

TABLE V
Correlation Based on Relative Abundance of Diatoms

Abundant number of Diatoma vulgare Bory. Some Melosira distans. location no.	Some Diatoma vulgare Bory and Melosira distans location no.	No Diatoma vulgare Bory. Some Melosira distans. location no.
10	21H	22H
6	23H	5
	4	2(upper)

A slight correlation is indicated by the groupings, but the confidence of a correlation based on these divisions is quite low. One of the reasons why it is low is because the groupings are not persistent over a large area. A second reason for a low confidence level is that the number of diatoms present is quite low.

Chemical Composition

The data obtained from the chemical analysis showed slight difference from bed to bed. Swinford, Frye, and Landes (1955) ran a complete chemical analysis on several beds in Kansas. They found as much variance in composition within a single bed as was found between beds in the Bitterroot Valley.

The data (see Table II) have been arbitrarily grouped into columns which might indicate correlations within each column (See Tables VI and VII). Five deposits, no. 22H, no. 11, no 23H, no. 3(lower bed), and no. 3(upper bed) have similar values for the per cent K_2O, and also similar values for Na_2O present. Since these five beds have values which are consistently similar for a given element, a correlation is indicated, On the basis of 60 feet of stratigraphic separation, however, the lower and upper beds at location no. 3 are proven to be non-correlative. This throws considerable doubt on the validity of this technique as a method of correlation.

Apparently the composition of the volcanic melt rock remained about the same for at least two of the ash falls, and probably remained so for all of them.

TABLE VI
Correlation Based on Per Cent K_2O Present

3.5(±.2)% K_2O	3.8(±.2)% K_2O	4.3(±.2)% K_2O	4.8(±.2)% K_2O
location no.	location no.	location no.	location no.
5	12	13	2(upper)
	21H	22H	6
	3(upper)	10	
	4	11	
		3(middle)	
		3(lower)	
		23H	

TABLE VII
Correlation Based on Per Cent Na_2O Present

1.2(±.2)% Na_2O	1.7(±.2)% Na_2O	2.2(±.2)% Na_2O
location no.	location no.	location no.
12	22H	13
21H	11	
10	3(upper)	
5	3(middle)	
	3(lower)	
	23H	
	4	
	2(upper)	
	6	

Other Techniques

Five techniques of correlation have been discussed above, and two more are worth mentioning, namely correlation by the shape of shards, and correlation by elevation of the beds. The first method mentioned has been used with some success by Swinford, Frye, and Landes (1955) on Kansas ash.

In the Bitterroot Valley ash, the different types of shards are mixed within a single bed, and if any correlation were to be made using the shapes of the shards, it would probably require a quantitative study.

Correlation by the elevation of exposures in the valley is questionable because of the small amount of vertical separation between the beds at location no. 3. Any slight change in the direction or amount of dip could introduce enough elevational difference to throw off a correlation. Any irregularity of the surface onto which the ash fell would also greatly hinder a correlation.

Summary of Correlation

In general, all that can be said for the five techniques used is that they suggest that some of the beds probably are correlative. No positive correlation can be set up, however, as the correlations obtained from one technique do not necessarily correspond to the correlations indicated by another technique. Following is an evaluation of the techniques used.

The thickness of the beds does not appear to be consistent for any one ash fall. Factors other than the total volume of ash ejected must account for the thickness of deposits. Thickness may in some instances only indicate a positive correlation, but as it does not prove a positive correlation it can not be used to prove that beds are not correlative.

The indices of refraction are indeed close, but they probably afford one of the most valuable data for a correlation. Similar indices are caused by similar compositions which may indicate the same ash fall. A problem arises, however, when different ash falls have similar compositions, and hence, similar indices. Correlations by index of refraction have an advantage in that the indices are easily determined.

Correlation based on composition tells one little more than correlation based on index of refraction. It is doubtful, therefore, whether or not this method is necessary. Quite a bit of work must be done to determine the chemical composition.

If the mineral assemblage of an ash fall is extensive, then the mineralogy is a valuable tool upon which to base a correlation. Unfortunately, abundant mineral assemblages are not always attendent with ash falls.

Perhaps a less common method of ash correlation is the use of paleontological criteria, such as diatoms. Some caution must be observed in using these as the same ash fall may have two completely different populations of diatoms due to some factor unrelated to the nature of the ash fall, such as biological barriers.

CLAY MINERALOGY

A very interesting relationship was noticed in an attempt to correlate the ash beds on the basis of an X-ray study of the clay mineralogy of the silts immediately beneath the beds. It was hoped, although not expected, that a change in the clay mineralogy would be observed under ash beds of different ash falls. This change was not noticed. It was observed, however, that the montmorillonite content decreased as illite increased, and that the amount of illite was a function of the thickness of the overlying ash.

Laboratory Techniques

The clay-size material was obtained for X-ray analysis in the following manner. Approximately 25 grams of the sediment was disaggregated with a mortar and pestle by gently tapping small portions of the sample for 3 or 4 minutes. The material was then soaked in water containing 1N solution of sodium metaphosphate for 24 hours. The sodium metaphosphate acted as a peptizing agent and further dispersed the clay-size material.

After soaking, the sample was stirred and allowed to settle for

8 hours and 10 minutes. Using a pipet, the top cm of the solution and suspended clays were decanted. The clays were then centrifuged onto a porcelain plate which was used as a sample holder. (Kinter and Diamond, 1956)

Copper K alpha radiation with a nickel filter was used to obtain the X-ray patterns with were recorded on a Brown recorder. The scanning rate was one degree two-theta per minute, and the chart rate was one-half inch per minute. A Norelco X-ray diffractometer was used.

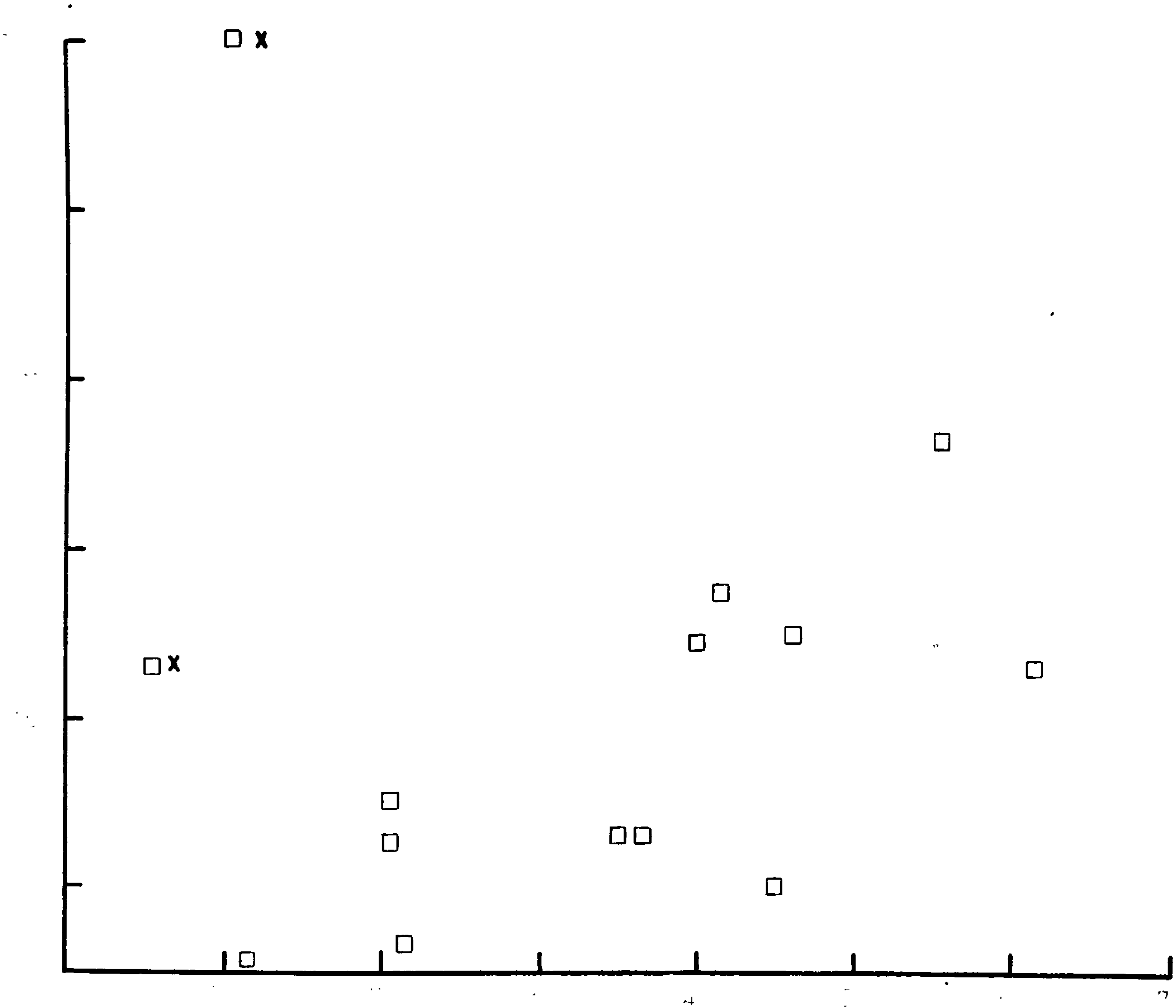
Relative amounts of the clays present, plus or minus 10 per cent, were determined by comparing areas under the peaks in diffraction patterns (Johns, Grim, and Bradley, 1954).

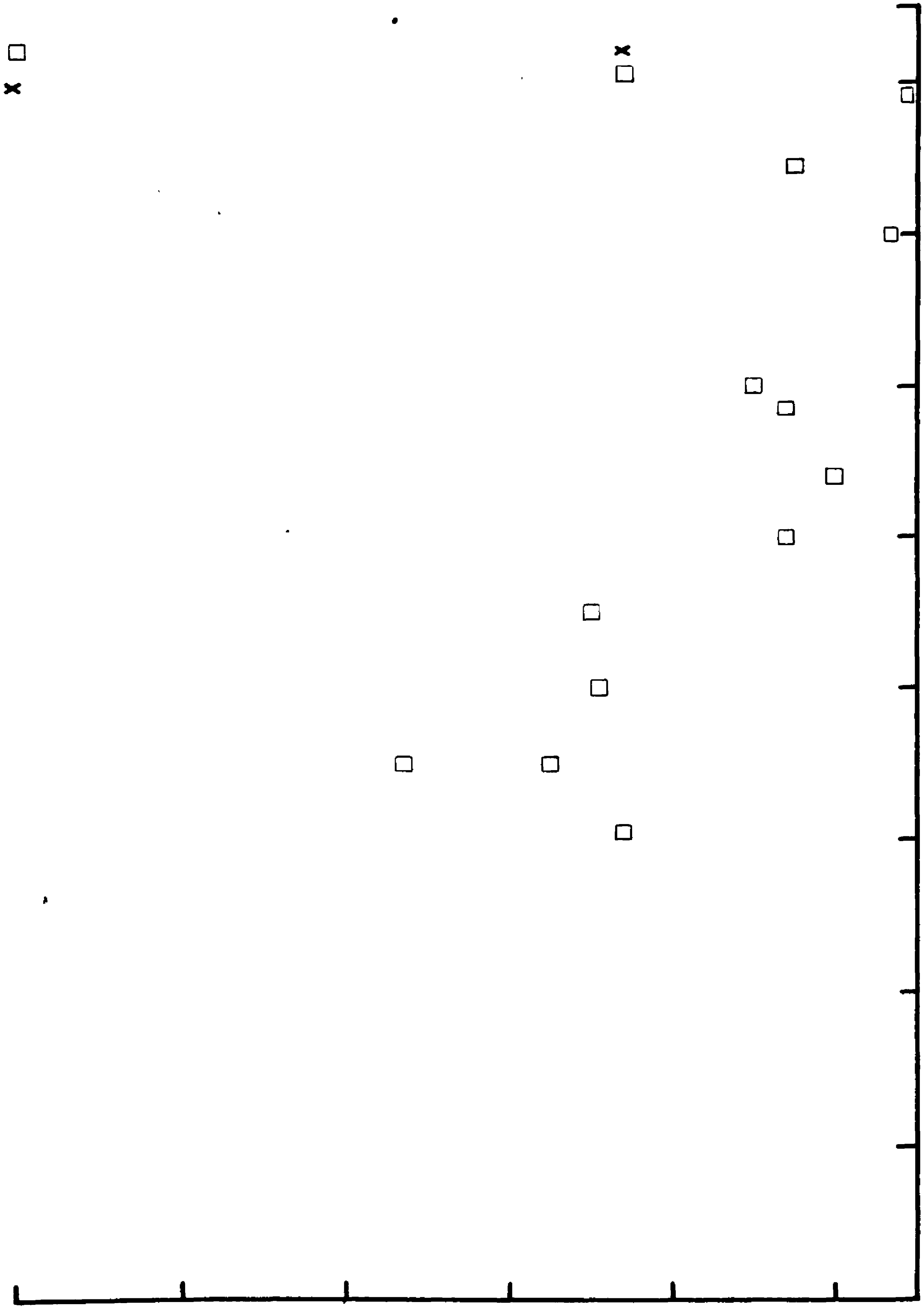
Results of Analysis

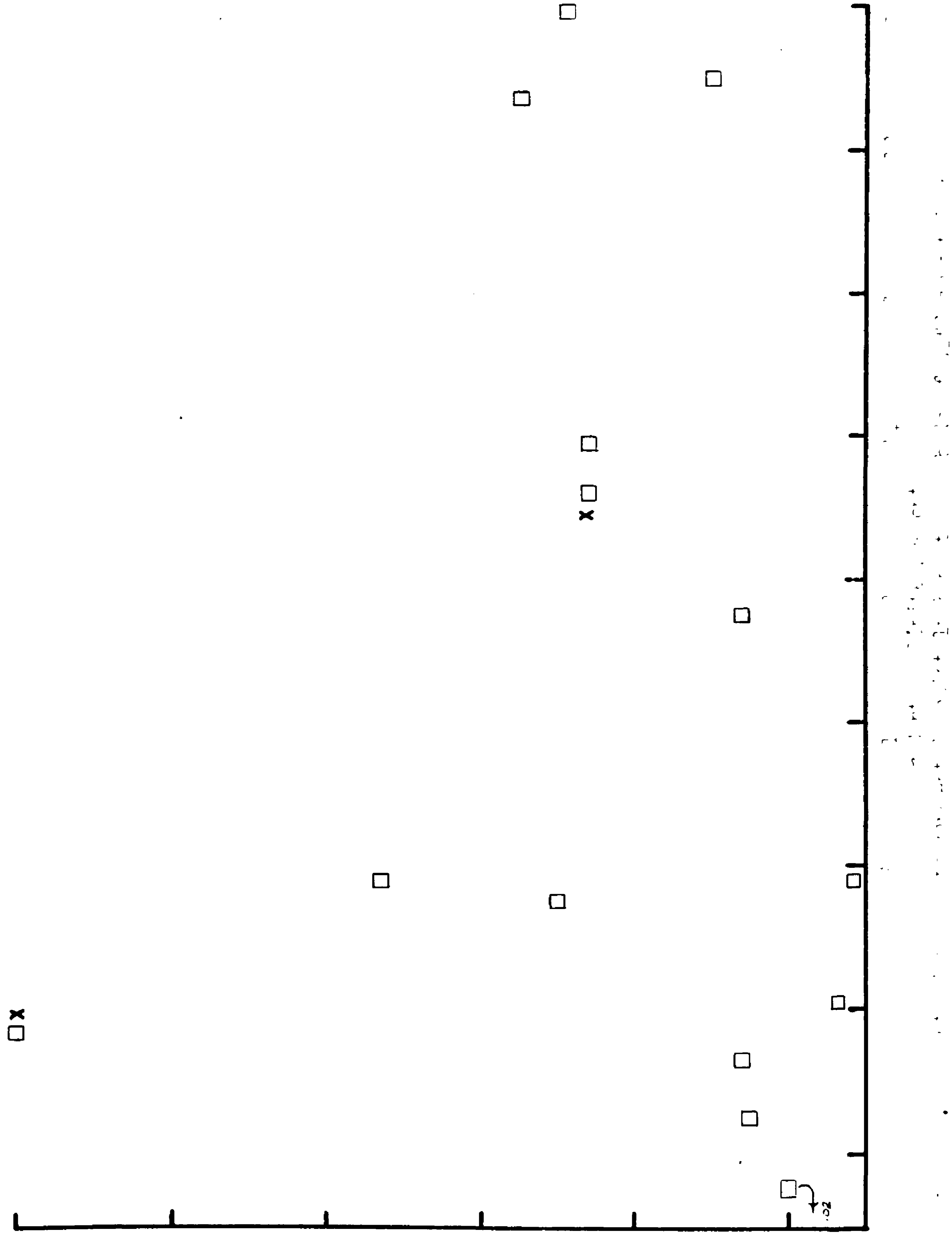
Three different approaches were made in this study to determine the nature of the decrease in illite as a function of the thickness of the overlying ash bed.

First, a study was made of the clay mineralogy immediately beneath (within 4 inches of the bed) 14 ash beds, ranging in thickness from 11 to 120 inches. Three clay minerals (montmorillonite, illite, and kaolinite) were identified in all the sediments. The average abundance of the three clay minerals was: montmorillonite 52 per cent, illite 33 per cent, kaolinite 15 per cent.

An increasing relationship can be seen between the amount of illite present and the thickness of the overlying ash bed (Fig. 18),







and a decreasing relatioship can be observed between the amount of montmorillonite present and the thickness of the overlying ash bed (Fig. 19). No trend is apparent for kaolinite. (Fig. 20).

Excluding two points, which are those marked by an "X" on the figures, the plots have correlation coefficients as follows: increase in illite .73, decrease in montmorillonite -.90, and kaolinite .42. If the other two points are considered in the calculations, the correlation coefficients are less than .1.

Secondly, a study was made of samples taken from 1 to 36 inches from a single ash bed (location no. 3, middle bed). Plots of the amount of illite against the distance from the overlying ash bed indicates an increase in illite within 10 inches of the ash bed. Samples further away than 10 inches, however, show no increase in the amount of illite (Fig. 21). A decreasing amount of montmorillonite is indicated within this same distance from the ash bed. (Fig. 22) No change in the amount of kaolinite is observed. (Fig. 23)

A third study consisted of determining the amounts of clay minerals present in 70 feet of section at location 3. All the samples were taken at least 10 feet away from the ash beds. The abundance of the clay minerals present in the section was obtained by measuring peak heights from 11 samples in the section, and determining the mean. The abundance of the clay minerals away from the ash beds are listed with the mean value for all the samples within 4 inches of the ash beds in Table VIII.

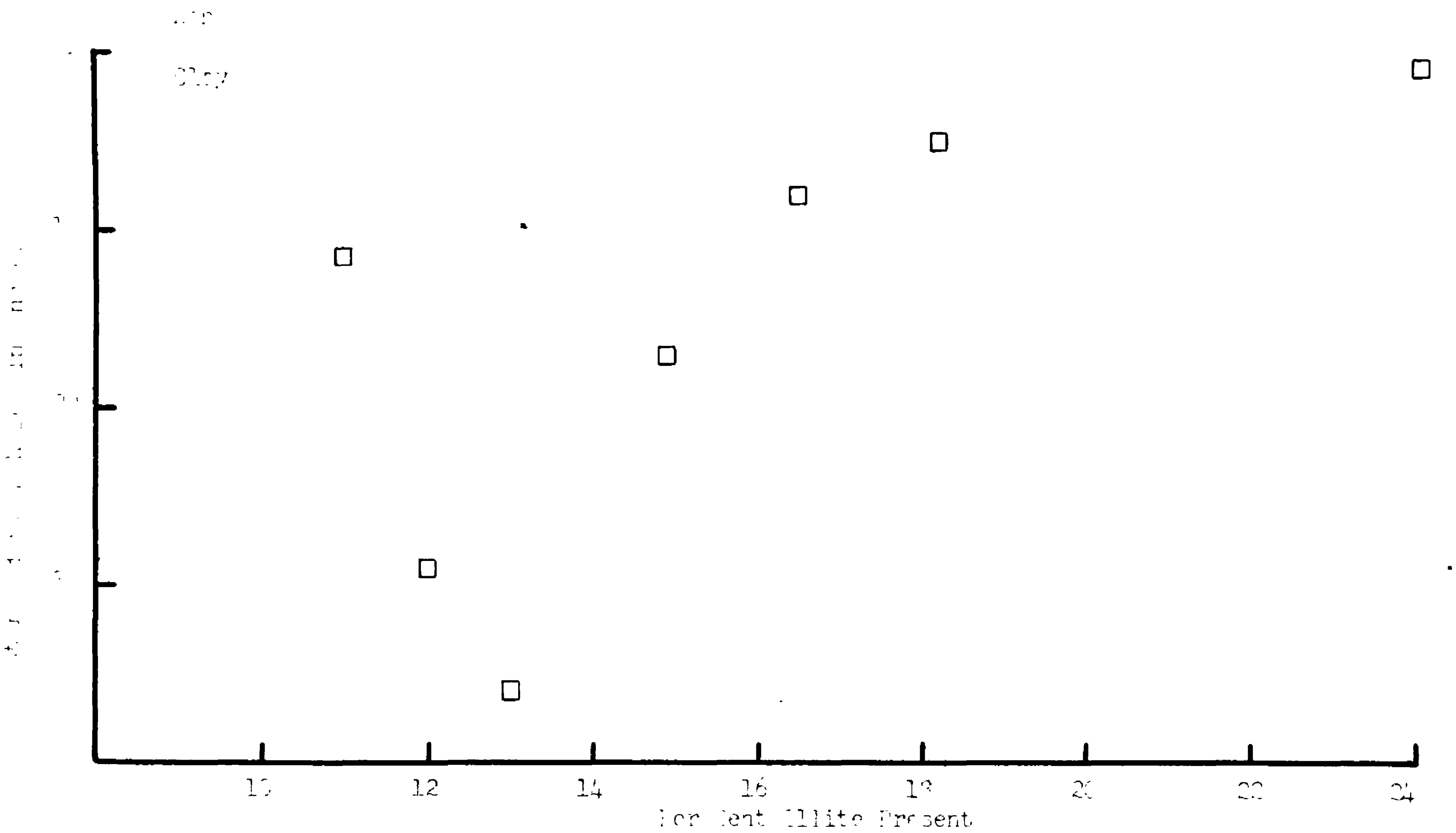


Figure 21. [illegible] of illite [illegible]sent with increasing distance away from one ash bed.

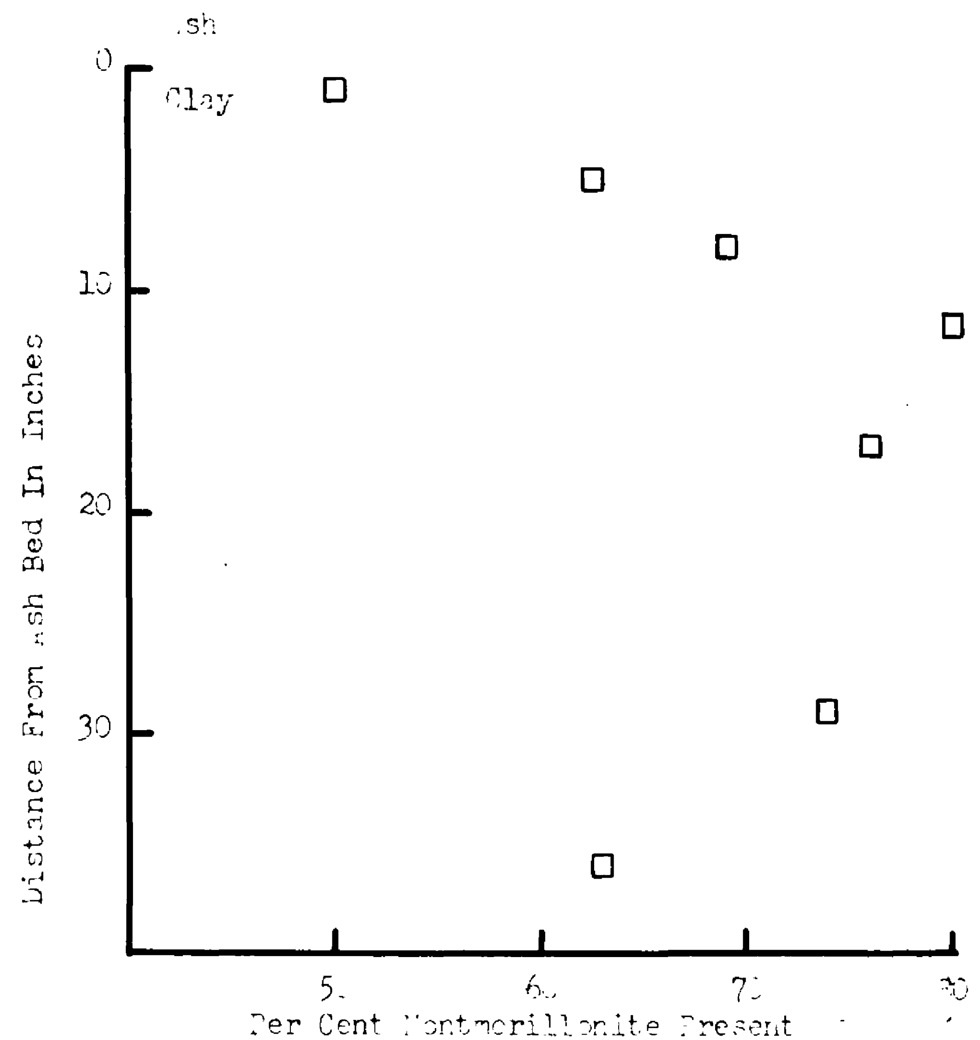


Figure 22. Amount of montmorillonite present with increasing distance away from the ash bed

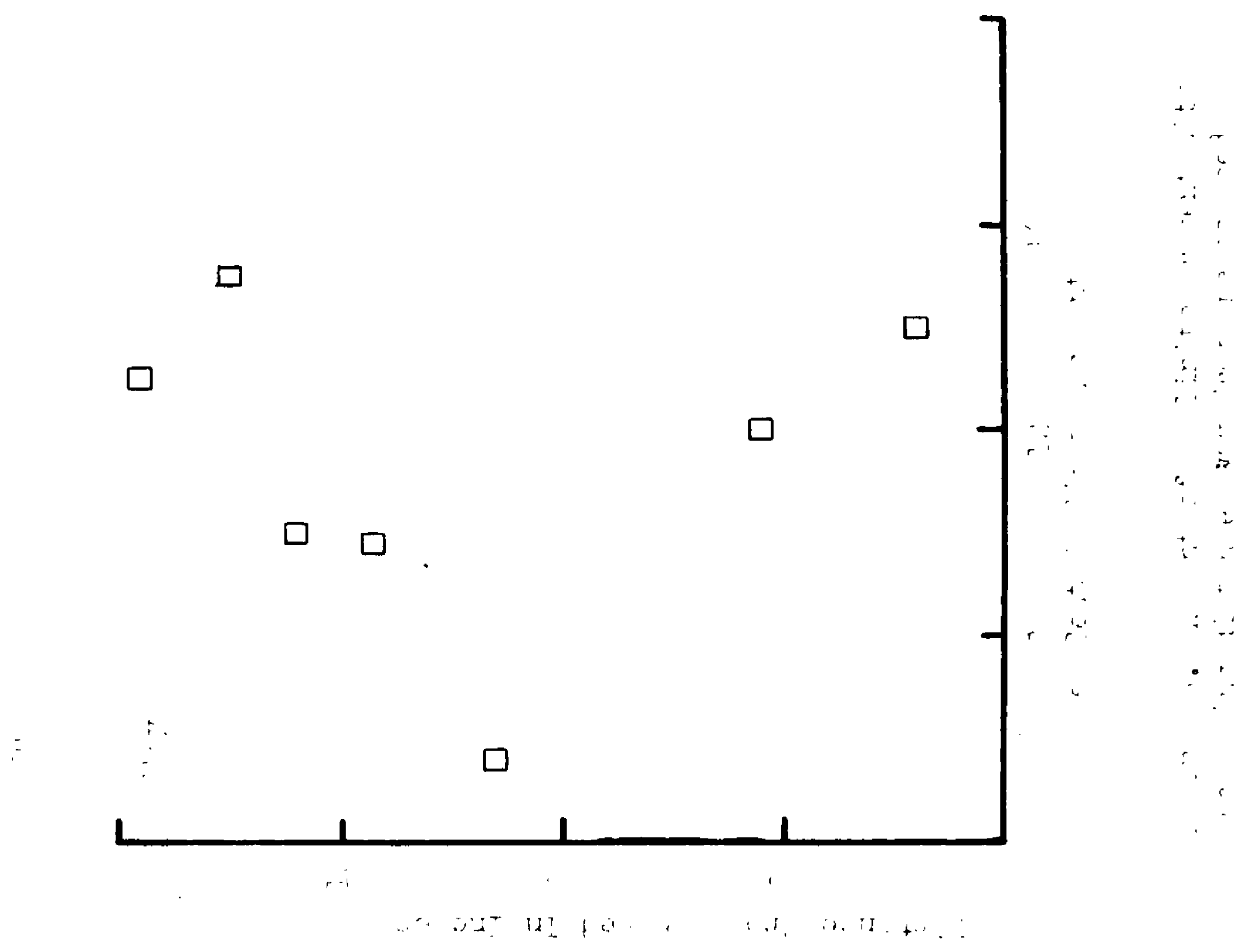


Table VIII
Amounts of Clay Minerals Present

Mean Abundance of Clay Minerals at least 10 feet from Ash Beds		Mean Abundance of Clay Minerals within 4 inches of Overlying Ash Beds	
Illite	19%	Illite	33%
Montmorillonite	63%	Montmorillonite	52%
Kaolinite	18%	Kaolinite	15%

It is interesting to note that the amount of illite present increases about 23 per cent within 10 inches of the ash bed as shown in Figure 21, and that the montmorillonite decreases about 23 per cent within the same distance as shown in Figure 22. Also, Table VIII shows that the mean amount of illite increases 14 per cent, and that the mean amount of montmorillonite decreases 11 per cent immediately beneath the ash beds.

Effects of KOH on Samples

It is important to determine whether the montmorillonite present is a montmorillonite derived from a mica (mica ⟶ montmorillonite) or whether it is one from a volcanic source (volcanic ash ⟶ montmorillonite). A technique employed by Weaver (1958) which involves treating the clays with KOH to determine the nature of the excess negative charge was used. The montmorillonites did not fix potassium even under a vigorous treatment, indicating that there was not a large residual charge present; hence it was concluded that the montmorillonite was derived from volcanic ash.

Review of Literature on Clay Mineralogy

A brief review of the literature will help afford a mechanism for the illite formation. Pauling (1930) illustrated the atoms in a molecule of pyrophyllite (montmorillonite) and showed the substitutions necessary to convert it to mica (illite) (Fig. 24).

Pyrophyllite	Substitute Al for 2Si	Muscovite
$6O^{-}$		$6O^{-}$
$4Si^{++++}$	$+Al^{+++}$	$3Si^{++++}Al^{+++}$
$4O^{-}+2(OH)$		$4O^{-}+2(OH)$
$4Al^{+++}$		$4Al^{+++}$
$4O^{-}+2(OH)^{-}$		$4O^{-}+2(OH)$
$4Si^{++++}$	$+Al^{+++}$	$3Si^{++++}+Al^{+++}$
$6O^{-}$	$+2K^{+}$	$6O^{-}$
		$2K^{+}$

Figure 24. - Substitution necessary to convert pyrophyllite (montmorillonite) to muscovite (illite) (After Pauling 1930).

Page and Bauer (1939) state that a muscovite-like material is formed by the fixation of potassium. They explain that the potassium fixation should be related to the ionic size of potassium and the voids in associated clay minerals. The greatest amount of potassium fixation occurs in soils where montmorillonite is the dominant clay mineral. Montmorillonite can expand parallel to the crystallographic direction, and the amount of expansion depends upon the degree of hydration. The hydration of montmorillonites is a reversible process, but if potassium ions become attached to the basal plane, the structure will not expand.

The size of the potassium ion (2.6A°) and the size of the void in the basal plane of the montmorillonite layers (2.8A°) are very close and the potassium ion fits very well into this void. Once the potassium ion attains this position, it will be held very tightly and the layers will not expand much because (a) the positive charge on the potassium is very close to the negative charge in the montmorillonite structure, and (b) the close packing of the potassium and sheets should act to prevent them from separating.

The charge deficiency in the montmorillonite structure which is caused by the substitution of Al^{+++} for Si^{++++} is the main reason for the fixation of potassium. The potassium ion is fixed in the structure electrostatically balancing the crystal. As the potassium ions fit best on top or in the voids of the tetrahedral layer, substitutions in this layer are most important. The potassium ion is about twice as far from the octrahedral layer, so the charge deficiency introduced by substitution in that layer would have one-fourth the effect on the potassium ion as an equivalent charge deficiency in the tetrahedral layer.

Millot (1942), Caillere and Henin (1949), Wear and White (1951), Grim and Johns (1954), Powers (1954), Griffin and Ingram (1955), Keller (1956), and Grim (1958) have all concluded with some reservation that the transformation of montmorillonite to illite by the introduction of potassium is probably feasible. The same alteration is proposed for some of the illite formation in the Bitterroot Valley.

The mechanism of potassium fixation by montmorillonite to form illite has not been seriously challenged until recently. The most significant paper against this mechanism as a general process was written by Weaver (1958). He states that the formation of illite from a mica ⟶ montmorillonite can happen quite easily, but doubts that the formation of illite from a volcanic ash ⟶ montmorillonite can ever take place.

Discussion of Data

The data presented follow the aforementioned trends in all cases but two, namely location no. 10, and location no. 6. Both of these locations have exceptionally large amounts of montmorillonite and a large amount of organic matter. If the increase in illite and the corresponding decrease in montmorillonite are due to the alteration of montmorillonite to illite, then the organic radicals present might prevent the transformation. The organic radicals can situate themselves in the voids of montmorillonite and prevent the potassium from entering the struture.

Several hypotheses might be suggested for the origin of the illite. It is possible that the increase in illite could be caused by a filtering action, washing the illite down from the ash beds. In addition to the shards, the ash deposits do contain small amorphous particles, most of which are larger than clay size.

This very fine-grained volcanic ejecta undoubtedly has the same composition as the shards, i.e silica, alumina, and potash. Because of its small grain size, the dust would probably decompose readily. Under the proper physical and chemical conditions, it would seem probable that illite would form from this material. Hence, some of the illite present beneath the beds might have originated directly from the volcanic ash beds.

There are problems, however, with this explanation. First of all, there is almost no clay mineral present in the ash beds. If the formation of illite was taking place, one would expect it to be found in the beds. Secondly, the formation of illite in the ash beds does not explain the decrease in montmorillonite. It is true that an influx of illite would dilute the clay material so that the relative amount of montmorillonite would decrease. If this were happening, however, the amount of kaolinite present should show a similar trend. The plots show this trend does not exist.

A second hypothesis used to explain these data suggests that the montmorillonite is being converted to illite. This alteration could take place with the introduction of potassium from the overlying ash beds. Thick ash beds providing more potassium would give rise to a greater percentage of illite than thin ash beds. This relationship can be seen in Figure 18.

Further evidence for the alteration may be supported by the fact that the amount of illite present increases 23 per cent from 10 inches away from the ash bed, and that the amount of montmorillonite present decreases 23 per cent within this distance. The amount of illite present at the 10 inch depth was determined by obtaining the mean of the four underlying samples. This indicates a 1:1 ratio alteration of montmorillonite to illite which would be what one would expect.

More evidence for the alteration of montmorillonite to illite is shown by Table VIII. Comparing the amounts of the clay minerals present immediately beneath the ash beds with the amounts present away from the ash beds, one can observe a difference in the clay mineralogy. This proves that the ash beds have influenced the clay mineralogy.

One mechanism proposed for the illite formation is simply the emplacement of a potassium cation in the void present in the basal plane of the silica tetrahedrons. It is proposed that the alteration took place over a considerable period of time.

A second mechanism for the illite formation proposes that some of the montmorillonite is more or less altered to an amorphous mass of silica and alumina. It is proposed that there is an equilibrium constant between the reaction of montmorillonite, and the amorphous material. An increase of potassium in the system, however, would cause some of the amorphous material to form illite rather than montmorillonite. Hence, when the potassium is added the system would show an increase in illite and a decrease in montmorillonite.

It has been shown that the montmorillonite present is volcanic ash $\rightarrow$ montmorillonite. Weaver (1958) does not believe that the proposed alteration ever takes place unless the montmorillonite is mica $\rightarrow$ montmorillonite. It is believed, however, that given enough time volcanic ash $\rightarrow$ montmorillonite can alter to illite.

Looking at the geologic record, there is further evidence to support the formation of illite from non-micaeous material. In sedimentary rocks, there is a great abundance of illite. The erosion of all the igneous rocks which have been calculated as being present, could not produce enough mica to account for the illite. It must then be concluded that illite is formed from volcanic ash $\rightarrow$ montmorillonite and/or colloidal material.

CONCLUSIONS

1. None of the techniques described allow one to correlate the ash falls in the Bitterroot Valley.
2. There were at least three ash falls in the area.
3. The volcanic eruptions were similar in chemical compositon and explosive nature.
4. The ash is probably from local volcanic activity.
5. The ash has altered part of the underlying montmorillonite to illite.

REFERENCES CITED

Anderson, T. and Flett, J. S., 1902. Royal Society report on the West Indian eruptions: Nature, V. 66, p. 402-406.

Caillere, S and Henin, S., 1949, Transformation of minerals of the montmorillonite family into 10° A micas: Mineral Mag., V. 28, p. 606-611.

Douglas, E. L., 1909, A geologic reconnaissance in North Dakota, Montana, and Idaho: Carnegie Museum Annals, V. 5, p. 211-288.

George, W. O., 1924, The relation of the physical properties of natural glasses to their chemical composition: Jour. Geology, V. 32, p. 353-372.

Griffin, G. M. and Ingram, R. L., 1955, Clay Minerals of the Neuse River estuary, Jour. Sed. Petrology, V. 25, p. 194-200.

Grim, R. E., 1953, Clay Mineralogy, N. Y. , McGraw-Hill Book Co., Inc., p. 384.

_____1958, Concept of diagenesis in argillaceous sediments: Am. Assoc. of Petroleum Geologists Bull. V. 42, p. 246-253.

_____, Dietz, R. S. and Bradley, W. F., 1949, Clay mineral composition of some sediments from the Pacific Ocean off the California coast and the Gulf of California: Geol. Soc. America Bull., V. 60, p. 1785-1808.

_____and Johns, W. D., 1954, Clay mineral investigation of sediments in the northern Gulf of Mexico: Clays and Clay Minerals, Natl. Res. Council pub. 327, p. 81-103.

Heinrich, E. W., 1958, Mineralogy and geology of radioactive raw materials : N. Y., McGraw-Hill, 450 p.

Johns, W. D., Grim, R. E., and Bradley, W. F., 1954, Quantitative estimations of clay minerals by diffraction methods: Jour. Sed. Petrology, V. 24, No. 4, p. 242-251.

Keller, W. D., 1956, Clay Minerals as influenced by environments of their formation: Am. Assoc. Petroleum Geologists Bull., V. 40, p. 2689-2710.

Kinter, E. B., and Diamond, S., 1956, A new method for preparation and treatment of oriented - aggregate specimens of soil clays for X-rays: Soil Sci., V. 81, no. 2, p. 111-120.

Langton, C. M., 1935, Geology of the northeastern part of the Idaho batholith and adjacent region in Montana: Jour. Geology, V. 43, p. 27-60.

Landes, K. K., 1928, Volcanic ash resources of Kansas: Kansas Geol. Survey Bull., V. 14, p. 1-58.

Lindgren, W., 1904, A geological reconnaissance across the Bitter-root Range and Clearwater Mountains in Montana and Idaho: U. S. Geol. Survey Prof. Paper 27, 123 p.

McKelvery, Everhart and Garrels, 1955, Origin of Uranium deposits: Econ. Geology, 50th Ann. Vol., p. 464-526.

McMurtrey, R. G., Konizeski, R. L., and Stermitz, F., 1959, Pre-liminary report on the Geology and Water resources of the Bitterroot Valley, Montana: Montana Bureau of Mines and Geology, Bull. 9, 45 p.

Millot, G., 1942, Relation between the constitution and the genesis of argillaceous sedimentary rocks: Geol. Applic. et Prosp. Min. V. 2, Univ. Nancy, France.

Milne, J., 1902, The recent volcanic eruptions in the West Indies: Nature, V. 66, p. 56-58.

Page, J. B., and Bauer, L. D., 1939, Ionic sige in relation to fixation of cations by colloidal clay: Soil Sci. Soc. Amer. Proc., V. 4, p. 150-155.

Pardee, J. T., 1950, Late Cenozoic block faulting in western Montana: Geol. Soc. America Bull., V. 61, p. 359-406.

Pauling, L., 1930, The structures of micas and related minerals: Nat. Acad. Sci. Proc., V. 16, p. 123-129.

Perret, F. A., 1913, Some Kilauean ejectamenta: Am. Jour. Sci., 4th Ser., V. 36, p. 612-614.

Pirsson, L. V., 1915, The microscopical characteristics of volcanic tuffs: a study for students: Am. Jour. Sci., 4th Ser., V. 40, p. 191-211.

Powers, 1958, Adjustment of clay to chemical change and the concept of the equivalence level: Proc. of sixth National Conference on Clays and Clay Minerals, Pergamon Press.

Pratt, W. E., 1916, An unusual form of volcanic ejecta: Jour. Geology, V. 24, p. 450-455.

Ross, C. P., 1952, The eastern front of the Bitterroot Range, Montana: U. S. Geol. Survey Bull. 974-E, p. 135-175.

Rowe, J. P., 1903, Some volcanic ash beds in Montana: Montana U. Bull. 17, Geol. Survey No. 1, 32 p.

Schlocker, J., and Van Horn, R., 1958 Jour. Sed. Petrology, V. 28, p. 31-35.

Stearns, H. T., 1924, The explosive phase of Kilauea volcano, Hawaii in 1924: Bull. volcanalogique, V. 10, nos. 5 and 6.

Swineford, A., 1949, Source area of Great Plains Pleistocene volcanic ash: Jour. Geology, V. 57, p. 307-311.

______and Frye, J. C., 1946, Petrographic comparison of Pliocene and Pleistocene volcanic ash from western Kansas: Kansas Geol. Survey Bull. V. 64, p. 1-32.

______,______and Leonard, A. B., 1955, Petrography of the late Tertiary volcanic ash falls in the central Great Plains: Jour. Sed. Petrology, V. 25, p. 243-261.

Teal, J. J. H., 1902, Volcanic dust from the West Indies, Nature, V. 66, p. 130.

Wear, J. I. and White, J. L., 1951, Potassium fixation in clay minerals as related to crystal structure, Soil Sci., V. 71, p. 1-14.

Weaver, C. E., 1958, The Clay petrology of sediments: Proc. of sixth National Conference on Clays and Clay Minerals, Pergamon Press.

Wentworth, C. K., and Williams, H., 1932, Bulletin of the National Research Council no. 89- Report of the Commitee on Sedimentation, 1930-1932.