STATE GEOLOGICAL SURVEY OF KANSAS

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Chancellor of the University, and ex officio Director of the Survey

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BULLETIN 96

1952 REPORTS OF STUDIES

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1952 REPORTS OF STUDIES

CONTENTS

STATE GEOLOGICAL SURVEY OF KANSAS, BULLETIN 96
1952 REPORTS OF STUDIES, PART 1, PAGES 1-68, FIGURES 1-4, PLATES 1-7
FEBRUARY 15, 1952

KANSAS VOLCANIC ASH RESOURCES

By
J. SHELDON CAREY, JOHN C. FRYE, NORMAN PLUMMER,
AND ADA SWINEFORD

CONTENTS

ILLUSTRATIONS

TABLES

ABSTRACT

Kansas volcanic ash has been used as an abrasive, ceramic glaze material, an additive to cement, a sweeping compound, and black top highway dressing; potential future uses include the manufacture of lightweight aggregate and cellular blocks, glass, and ceramic bodies, and as an inert filler. This material has been mined commercially in Kansas for nearly 50 years and more than 20 million tons of ash is estimated to occur as minable reserves in 39 counties. Ash deposits consist of relatively pure accumulations of minute platy or curved fragments of volcanic glass and attain thicknesses as great as 30 feet. Most usable deposits are located in the western half of the State but are widely distributed in that region. They are all Pliocene and Pleistocene in age. The stratigraphy, petrography, and uses of Kansas volcanic ash are reviewed briefly and all deposits that have been examined, sampled, or tested are listed and described.

INTRODUCTION

Volcanic ash, a material of many and varied uses, occurs in small deposits widely distributed in central and western Kansas (Fig. 1). It has been mined commercially in Kansas for nearly 50 years and it is estimated that approximately 2,000,000 tons have been produced from more than 35 pits. The total reserves of unmined volcanic ash in Kansas are estimated on inadequate data to exceed 20 million tons. In appearance in outcrops and pits (Pls. 1, 2, 3) volcanic ash is white to light pearly gray, locally with tints of yellow or red; it consists predominantly of small particles of rock glass with a composition similar to that of rhyolite; the particles or shards are generally less than 1 mm across and are commonly more or less compacted—at a few places they are cemented together by calcium carbonate. The deposits are of limited areal extent and range in thickness from a few inches to more than 30 feet.

Volcanic ash has been used as an abrasive, particularly in scouring compounds and soaps; as an important ingredient of ceramic glazes and in ceramic bodies; as an additive to cement to produce certain characteristics in concrete; as a raw material for manufacture of several types of lightweight aggregates; as a sweeping compound; as a dressing for some types of bituminous-matt highways; and it may be usable as a raw ingredient in glass, as a filler, and for many potential future uses. It is the purpose of this report to summarize present information on its occurrence

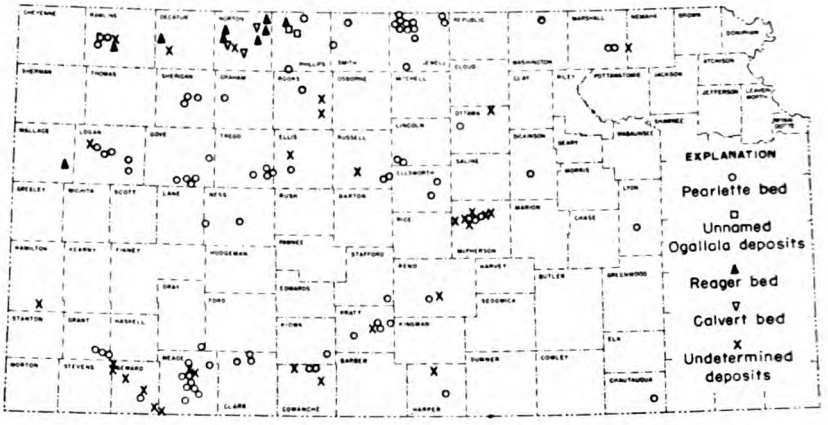

FIG. 1.—Map of Kansas showing volcanic ash deposits listed in this report.

in Kansas and to present data on the character of the material at each of the many localities that have been examined.

This report is the first general inventory of the volcanic ash resources of the State since 1928 when the Geological Survey issued a report as Bulletin 14 (Landes, 1928) that summarized the then existing information on this mineral resource. Since 1928 much important work has been done on the character and utilization of ash. Studies by the Survey's ceramics division have demonstrated its value as a ceramic glaze material (Plummer, 1939; Carey, 1948) and these studies have led to the extensive use of volcanic ash in Kansas potteries. Studies now under way are directed toward its use in ceramic clay bodies as well as additional studies on its use in ceramic glazes. Petrographic characteristics and differences among the many deposits have been investigated (Swineford and Frye, 1946) and the stratigraphy (Frye, Swineford, and Leonard, 1948) and source (Swineford, 1949) of the deposits have been studied. An important new development is the demonstration of the usability of ash as a raw material for the manufacture of lightweight constructional aggregate (Burwell, 1949; Plummer and Hladik, 1951) and of a fine, extremely light and fluffy aggregate for plasters.

Field work for this investigation was carried on during the summers of 1948, 1949, and 1950. Many volcanic ash localities have been reported to the Geological Survey by interested persons

throughout the State. In so far as possible all localities that had not been examined and sampled earlier by a geologist were visited during 1949 or 1950 and samples adequate for analysis and testing were collected. All known localities that have the potential for even small-scale development are listed in the county chapters (160 localities in 39 counties). Some deposits with a maximum thickness less than 1 foot, or where the ash is not of sufficient purity to be usable, are not included. Although data on the extent of most of the deposits listed are given in the county chapters, an estimate of minable tonnage has been attempted for only a few deposits.

In the following sections is given a summary of the general geology of Kansas volcanic ash, a description of the petrographic characters and chemical analyses of the deposits, a review of the more important uses of the material, and location and brief description of all the known usable deposits by counties. Thanks are expressed to the many Kansas residents who have aided in this work, both by sending information to the Geological Survey and by assisting in the field work. Special thanks are extended to the county engineers of the counties listed as in many cases it was they who made possible the location of deposits; to the State Highway Department for data on its operations; and to all the active volcanic ash producers operating in the State for their cooperation.

GEOLOGY

Kansas volcanic ash deposits described in this report are all of Pliocene and Pleistocene age. They occur as lenticular bodies within the mass of alluvial sediments that comprise the Pliocene Ogallala formation and the Pleistocene (late Kansan) Meade formation. All deposits examined show distinct bedding and in some places the individual beds are less than 1 mm thick. Intricate cross bedding in thin zones is common, and ripple marks, rain drop impressions, and imprints of plant leaves have been observed. Nowhere in Kansas has typical eolian cross bedding been observed in the volcanic ash. In some of the Pleistocene deposits, snail shells have been found abundantly at the base of the ash, sparsely scattered throughout the deposit, and in the beds immediately above the ash (Leonard, 1950). Many of these shells

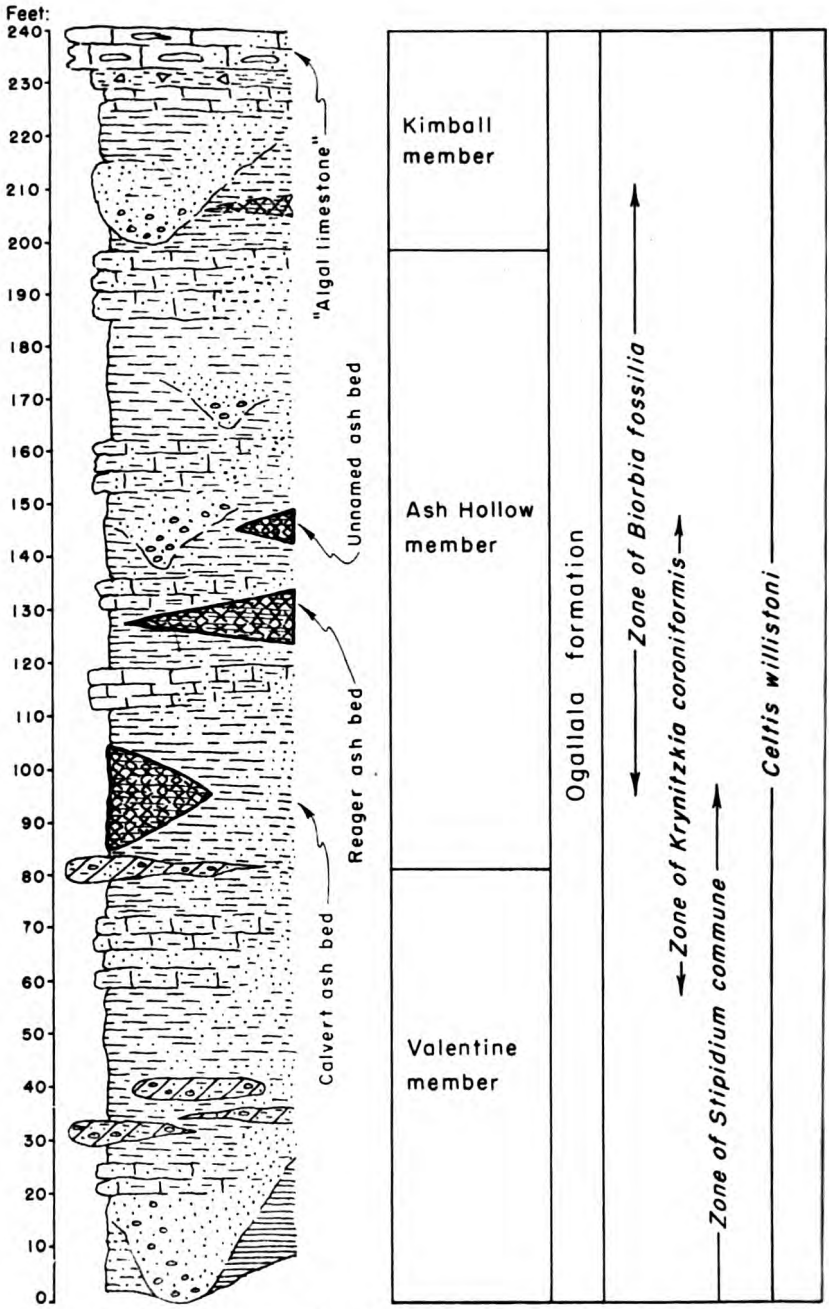

FIG. 2.—Idealized composite stratigraphic column of the Ogallala formation in Kansas showing the tentative stratigraphic placement of Calvert, Reager, and unnamed volcanic ash beds.

are from aquatic animals that lived in ponded water, and at a few localities the percentage of land forms decreases toward the center of the ash lentil. Many of the larger Pleistocene deposits are underlain by a massive gray to light-tan clay and the margins of the lentil suggest that the ash accumulated in a depression. These evidences show conclusively that the ash observed in most localities found its final point of deposition in a permanent or intermittent shallow body of water even though it is clear that the ash shards were carried by winds from a volcanic source somewhere west of Kansas.

Volcanic dust was thrown explosively into the air somewhere in the Rocky Mountain belt, perhaps in north-central New Mexico (Swineford, 1949), and was carried by winds over Kansas and adjacent areas. The ash shards settled to the ground, or were carried down by rains, resulting in a thin layer of fine-textured ash spread extensively over the surface. This thin surface layer of readily available material served to overload rills and minor streamlets leading into ponds or undrained depressions that existed on the extensive plain of alluviation in early Pliocene time, and in Pleistocene time other ponds on aggrading valley flats and even rarely in upland situations. These small tributaries were able to carry material which was predominantly ash into the depressions until they had cleared at least a part of their drainage areas. Such a mode of accumulation accounts for the sharp lenticularity and range in thickness of the deposits, and for the varying degrees of contamination by nonvolcanic grains of silt and sand sizes and also for the apparently random geographic variation in the particle size of the ash itself. It also makes the job of prospecting or exploring for new deposits an extremely difficult one for although the exact stratigraphic positions of the several ash beds in their respective formations may be determined, the presence of a usable deposit at any particular locality is largely fortuitous. On the other hand the determination of the proper stratigraphic position of the beds serves to eliminate much impossible territory and therefore is an invaluable aid in exploration. For that reason the stratigraphy of Kansas volcanic ash will be reviewed briefly.

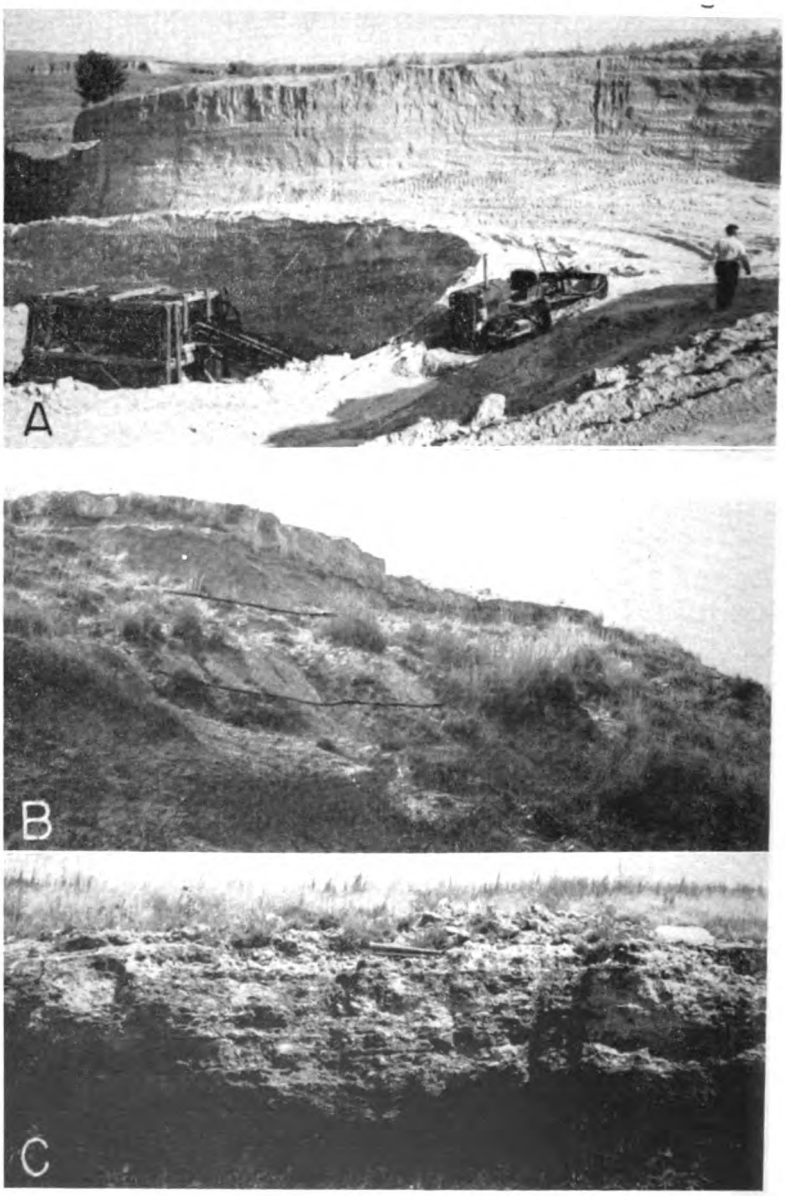

PLATE 1. Pliocene volcanic ash in Norton County. **A**, Mine of Wyandotte Chemicals Corporation at Calvert; Calvert bed, 22 feet thick at this locality. **B**, Exposure of Ogallala formation showing Reager ash bed, type locality, NW¼ NE¼ sec. 36, T. 2 S., R. 25 W. *Biorbia fossilia* (Berry) occurs in beds above volcanic ash. **C**, Cemented upper part of volcanic ash, Reager bed, south of Almena. Fossil seeds both above and below ash bed. (Frye, 1945.)

Pliocene Deposits

In Kansas, beds of Pliocene age are classed as belonging to the Ogallala formation which contains in ascending order the Valentine, Ash Hollow, and Kimball members (Moore and others, 1951). The Ogallala formation consists almost exclusively of alluvial sediments ranging in texture from silty clay to coarse gravels. Uneven loose to firm cementation by calcium carbonate occurs at random throughout the section and has given rise to the local name "mortar beds." In the Valentine and lowermost Ash Hollow members siliceous cement is common (Frye and Swineford, 1946). Nearly all the Ogallala sediments are lenticular in occurrence and for that reason it is extremely difficult to establish any stratigraphic horizon precisely within the formation; in fact at many places it is impossible to establish the member boundaries within tens of feet. Approximate stratigraphic placement within the Ogallala can be made by use of fossil vertebrates and fossil seeds. Diagnostic fossil vertebrates are known from relatively few places and the field geologist is commonly forced to rely on the floral zones described by Elias (1942). The extent and usability of these floral zones in Kansas have recently been discussed (Frye and Leonard, 1949; Moore and others, 1951, p. 18), and they, together with gross stratigraphic position, have been used to determine the placement within the Ogallala of the volcanic ash beds. The generalized stratigraphy of the Ogallala formation in Kansas and tentative placement of the several ash beds is shown in the graphic section in Figure 2.

Four petrographically distinctive volcanic ash beds have been recognized within the Ogallala formation of the Great Plains region (Swineford and Frye, 1946; Frye, Swineford, and Leonard, 1948) and disseminated shards occur at many stratigraphic positions within the clastic sediments. Of these four, one is known from localities in northwestern Texas (Hemphill County) and possibly also from western Oklahoma. In Kansas the Hemphill, Texas, ash has not been identified with certainty although one exposure of weathered ash in Hamilton County, Kansas, possesses some characteristics in common with it. Three petrographically distinctive ash beds occur in the Ogallala of Kansas; the deposits occur primarily in the northwestern part of the State. One of these beds, studied from three exposures in Norton County, is

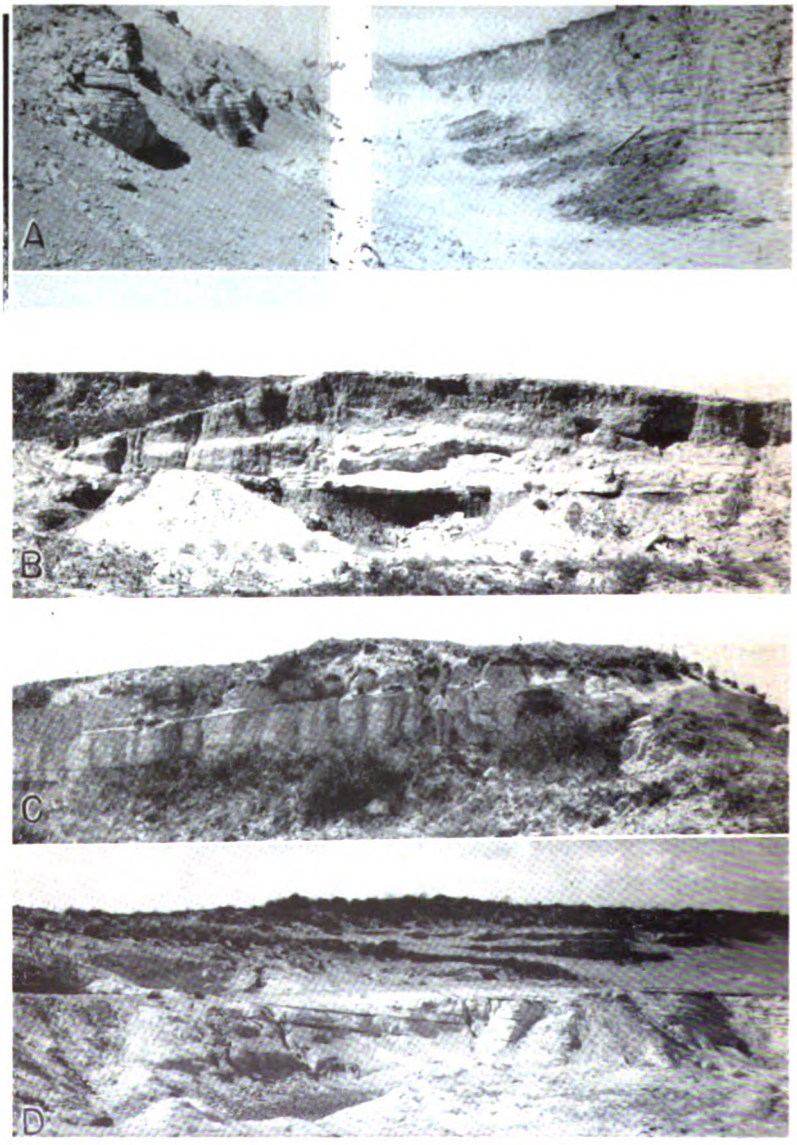

PLATE 2. Pearlette volcanic ash in Meade, Logan, Trego, and Grant Counties. **A**, Pit operated by Mid-Co Products Company, NE¼ sec. 26, T. 32 S., R. 28 W., Meade County; 18 feet of ash exposed. (Frye, 1940.) **B**, Pit in SE¼ NE¼ sec. 11, T. 13 S., R. 35 W., Logan County. Maximum thickness of ash, 9 feet. (Plummer, 1948.) **C**, Exposure along creek bank, NW¼ SE¼ sec. 28, T. 14 S., R. 21 W., Trego County. Maximum thickness, 7.5 feet. (Plummer, 1948.). **D**, Pit in SE¼ NE¼ sec. 1, T. 30 S., R. 36 W., Grant County, 19.5 feet of ash exposed. (Plummer, 1948).

here named the Calvert ash bed, from the pit of the Wyandotte Chemicals Corp. at that northeastern Norton County town. Another bed has been studied from nine localities in Wallace, Decatur, Norton, Rawlins, and Phillips Counties and is named the Reager ash bed from exposures 1 mile north of the stop on the Burlington Railroad in west-central Norton County. The third bed, so far unnamed, is known from two exposures in Phillips County.

Available stratigraphic data place all three of these beds in the lower half of the Ash Hollow member. The Calvert bed occurs low within the member and the Reager bed is significantly higher stratigraphically, perhaps near the midpoint. The unnamed bed is judged on the basis of meager evidence to be at least as high in the section as the Reager bed, and one exposure of weathered and petrographically indeterminate Ogallala ash in central Norton County may be even higher as abundant fossil seeds of *Biorbia fossilia* (Berry) were collected 20 feet below its base.

Although evidence from fossil floras is imprecise it nevertheless furnishes a guide to stratigraphic placement. At the type locality of the Calvert bed (Pl. 1A) fossil seeds have been collected from the upper part of the ash and identified by Dr. M. K. Elias as *Krynitzkia coroniformis* Elias, *Stipidium variegatum* var. *dartoni* Elias, and *Celtis willistoni* (Cockerell). Fossil seeds of *Biorbia fossilia* (Berry) and *Berryochloa amphoralis* have been collected as much as 100 feet higher in the local section but not adjacent to this bed. This floral assemblage suggests a position low within the Ash Hollow or within the underlying Valentine member. It is considered to be above the Valentine, however, as *Stipidium commune* Elias, characteristic of the Valentine member in Norton County, has not been found adjacent to it, and as subsurface data (Frye and Leonard, 1949) show this bed to be locally as much as 100 feet above the base of the formation.

The Reager bed at its type locality (Pl. 1B) is immediately overlain by sediments that have yielded *Biorbia fossilia* (Berry) seeds and is shown by test hole data (Frye and Leonard, 1949) to be approximately 200 feet above the local base of the formation. Two other localities, correlated on the basis of petrographic similarities with the Reager, furnish usable data as to the placement of the bed. South of Almena in Norton County this ash

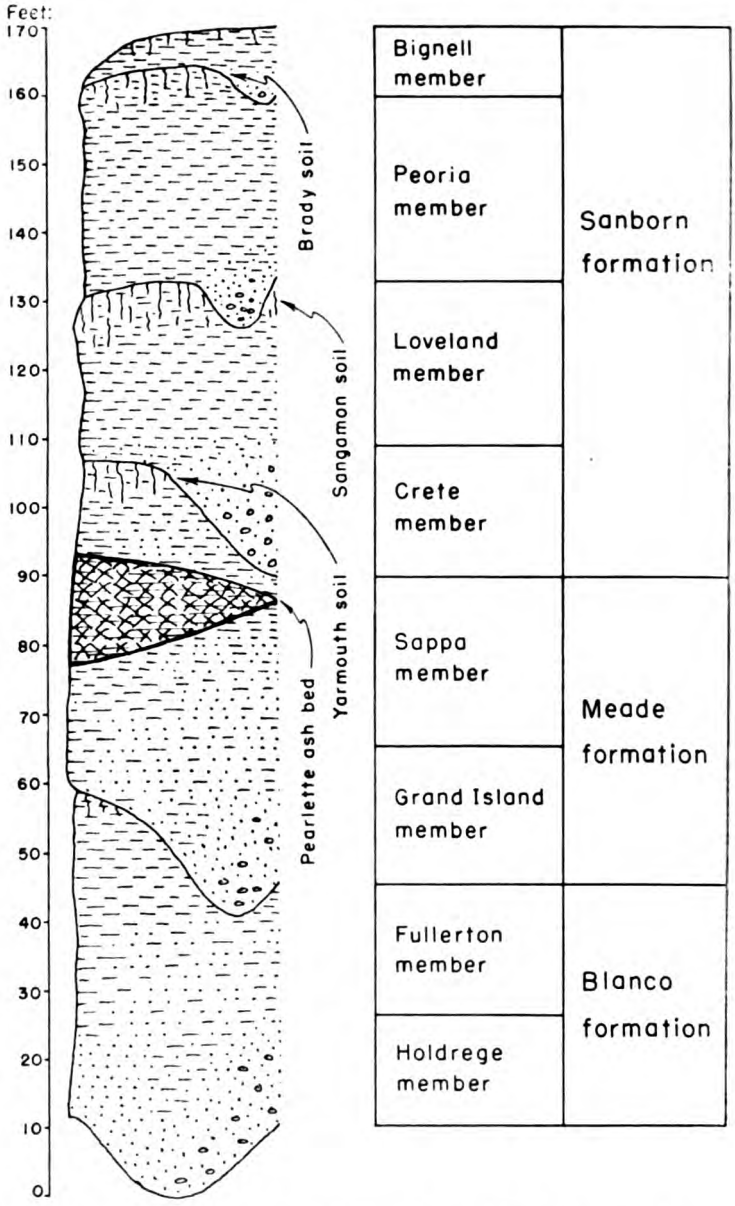

FIG. 3.—Idealized composite stratigraphic column of Pleistocene deposits in western Kansas showing the position of the Pearlette volcanic ash bed.

(Pl. 1C) is exposed in a section where 163 feet of Ogallala has been measured and an adjacent test hole indicates the existence of at least 75 feet of Ogallala below the base of the exposed section. At this locality the Reager ash is 82.4 feet below the top of the local section, below beds yielding abundant *Biorbia fossilia* and immediately above beds yielding *Krynitzkia coroniformis*. This locality is less than 5 miles from the Calvert type pit and relative topographic situations suggest that the Reager bed may be about 50 feet higher in the section than the Calvert bed. In Wallace County the Reager bed occurs 76 feet below the top of the Kimball member of the Ogallala but only 6 feet above the base of the local section (Elias, 1931, p. 157).

The stratigraphy of the unnamed Ogallala bed in Phillips County has not been studied in detail. It occurs in a topographic situation that suggests a placement in the section as high or higher than the Reager bed.

Pleistocene Deposits

The stratigraphy of the Pleistocene volcanic ash is relatively simple. All commercially usable ash of Pleistocene age known to occur in Kansas is assignable to the Pearlette bed (Pls. 2, 3) which occurs within the Sappa member of the Meade formation (Moore and others, 1951, p. 14). This ash bed is distributed throughout much of the State (Fig. 1). Samples of ash from 90 localities in 34 counties have been determined to belong to the Pearlette bed. Its placement within the Pleistocene section of the State is shown in the graphic section in Figure 3. The name Pearlette was proposed for this bed by Cragin in 1896, and recently its petrographic character, stratigraphy, and associated molluscan fauna have been described in detail (Swineford and Frye, 1946; Frye, Swineford, and Leonard, 1948; Leonard, 1950). It is associated at many places with a distinctive molluscan fauna, and at a few localities fossil vertebrates have been collected just below its base. Its presence in sediments deposited during latest Kansan time along the then existing drainage ways makes exploration for new deposits a less difficult job once the Pleistocene geology of the region is understood.

The Pearlette ash occurs in lenticular bodies ranging in size from a few yards to more than a mile in extent and from a few inches to approximately 30 feet in maximum thickness. The silt

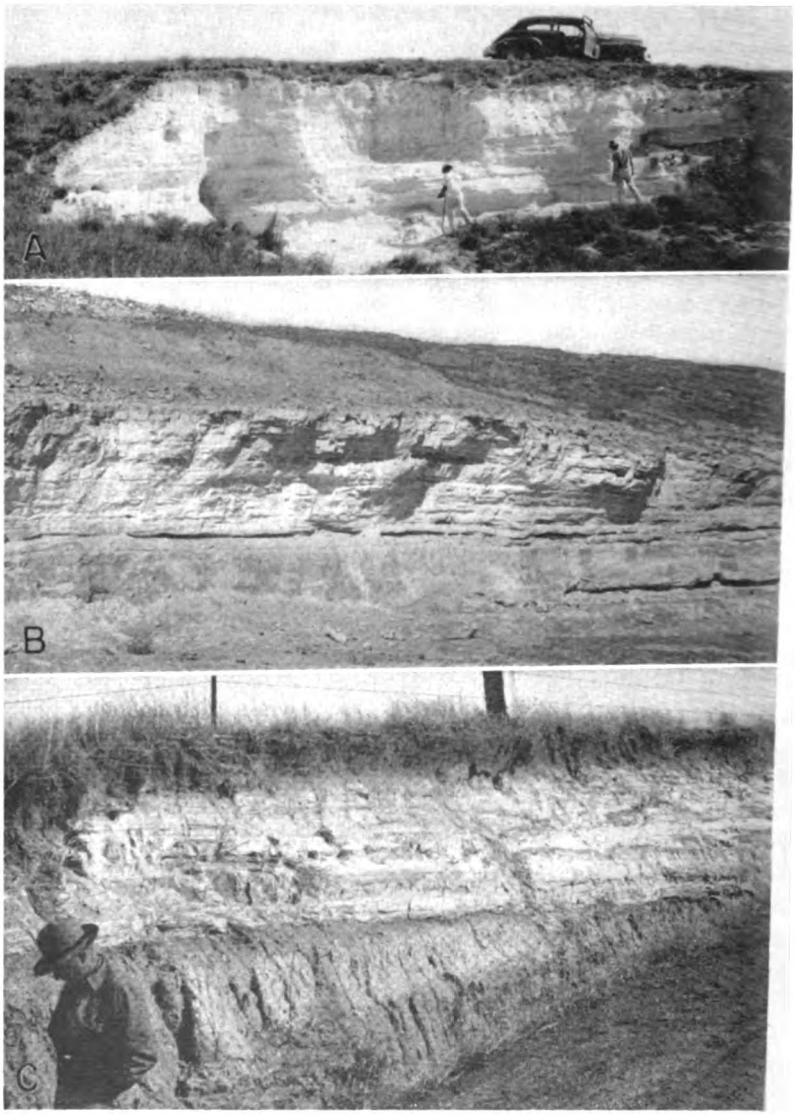

PLATE 3. Pearlette volcanic ash in Gove, Sheridan, and Lincoln Counties. **A,** Pit in the NE¼ SW¼ sec. 21, T. 13 S., R. 26 W., Gove County; 11 feet of clean ash exposed. (Plummer, 1948.) **B,** Pit in the NW¼ sec. 34, T. 8 S., R. 23 W., Sheridan County. Maximum thickness of ash, 16 feet. (Frye, 1951.) **C,** Exposure in road cut, NW¼ SW¼ sec. 27, T. 13 S., R. 10 W., Lincoln County; 7 feet of ash exposed. (Frye, 1951.)

and sand of the Sappa member that contains the Pearlette is commonly relatively thin and constitutes an average overburden of 5 to 20 feet. At some places, however, the Meade formation, which is composed of the Grand Island sand and gravel member below and the Sappa member above, forms the filling of early Pleistocene valleys that have since been abandoned. In such situations the Sappa member may be overlain by various thicknesses of Loveland silt member and Peoria silt member of the

TABLE 1.—*Locations and thicknesses of volcanic ash beds sampled by the State Geological Survey of Kansas*

County	Sample number	Location	Maximum thickness, feet	Remarks
Chautauqua	CQV-1	NW SE 9-34-12E	4.0	
Clark	CLV-1	SE SE 23-30-24W	9.0	
	*CLV-1A	do	4.4	Lower part of CLV-1
	*CLV-1B	do	3.0	Above CLV-1A; 1.6 ft. below top
	CLV-2	NE SW 12-30-23W	6.0	
Comanche	CMV-1	SE NE 12-31-18W	13.0	
	*CMV-1A	do	5.5	Lower part of CMV-1
	*CMV-1B	do	10.0	Upper part; includes 2.5 ft. CLV-1A
	CMV-2	NW SW 24-32-17W	6.0	
	CMV-3	NW SE 29-32-16W	2.5	
	CMV-4	Cen. W½ 7-31-17W	7.0	
Decatur	DRV-1	SE SW 8-4-29W	5.0	
	DRV-2	NE NE 15-3-30W	3.2	
Dickinson	DV-1	SW SW 26-14-2E	1.0	
Ellis	ESV-1	SE SE 17-14-19W	3.5	
	ESV-2	NW SW 5-13-19W	7.0	
	*ESV-3	SW NW 5-13-19W	10.5	
Ellsworth	ELV-2	CNL SW 22-15-7W	9.0	
	*ELV-2A	do	3.0	Lower part of ELV-2 bed
	ELV-24	SE NW 28-16-7W	13.5	
	*ELV-24A	do	7.5	Lower part of ELV-24
Gove	GV-1	NE SW 21-13-26W	17.0	
	*GV-1A	do	6.0	Lower part of GV-1
	*GV-1B	do	11.0	Upper part of GV-1
	GV-2	SW SE 25-15-28W	15.0	
	GV-3	SW NW 17-15-27W	13.5	
	GV-4	E½ NW 33-15-27W	6.0	
	GV-5	Cen. NE 14-15-28W	6.0	
	GV-6	NW NE 26-15-29W	4.0	
Graham	GMV-1	NE SW 11-8-25W	6.0	
Grant	*GTV-1	SE NE 1-30-36W	23.5	
	GVT-2	SE NW 17-30-35W	6.0	
	GVT-3	NW 24-30-35W	15.0	
Gray	GRV-1	NW NW 35-29-27W	4.0	
	GRV-2	SW SW 26-29-27W	11.0	
Hamilton	HNV-1	Cen. 13-26-41W	2.5	
Harper	HPV-1	NE NE 29-33-6W	6.0	
	HPV-2	NW SW 18-31-7W	3.5	

TABLE 1.—*Locations and thicknesses of volcanic ash beds sampled by the State Geological Survey of Kansas (continued)*

County	Sample number	Location	Maximum thickness, feet	Remarks
Jewell	*JV-1	N½ NE 29-5-9W	6.5	
	JV-2	NW NW 4-2-9W	3.0	
	JV-3	NW SE 32-1-9W	9.0	
	*JV-3A	do	5.5	Lower part of JV-3
	*JV-3B	do	3.5	Upper part of JV-3
	JV-4	SE SE 33-1-9W	2.0	
	JV-5	NE NE 20-1-6W	10.0	
	*JV-6	NW NE 16-1-6W	17.0	
	*JV-7	SE NE 6-3-8W	2.5	
	JV-8	NE NE 26-1-10W	4.0	
	JV-10	SE NW 5-2-9W	10.0	
	JV-11	SW NE 7-2-9W	8.0	
	*JV-11A	do	4.0	Lower part of JV-11
	JV-12	SE 3-2-10W	7.0	Reported thickness
Kingman	KMV-1	NW NE 16-25-10W	1.0	
Kiowa	KV-1	NW NE 5-30-16W	10.0	
Lincoln	*LV-1	SE SW 27-13-10W	6.0	
	*LV-2	SW SE 27-13-10W	6.5	
Logan	LOV-1	SW NW 36-12-36W	8.0	
	LOV-2	SE NE 11-13-35W	9.0	
	*LOV-3	SW NW 12-13-35W	14.0	
	LOV-4	Cen. NE 34-14-33W	6.0	
	LOV-5	SE SW 35-13-33W	6.0	
	*LOV-5A	do	6.0	Selected from LOV-5
Lyon	LYV-1	SW SW 10-19-10E	0.5	4 ft. thick in SE SW sec. 10
Marshall	MLV-1	SE 9-4-9E	5.5	
	MLV-2	NE cor. 11-4-9E	2.5	
McPherson	*MPV-1	SE NW 20-18-3W	8.5	
	MPV-2	NW SW 10-18-4W	4.0	
	MPV-3	Cen. E½ 28-18-5W	3.0	
	MPV-4	W½ NW 15-18-4W	3.0	
	MPV-5	NW SW 15-18-4W	4.5	
	MPV-6	SW NW 22-18-4W	6.5	
	*MPV-6A	do	4.2	Lower part of MPV-6
	*MPV-6B	do	2.3	Upper part of MPV-6
	MPV-7	W½ SW 5-18-2W	4.5	
	MPV-8	SE NE 14-18-3W		
Meade	MEV-1	SW 34-31-28W	9.5	
	*MEV-1A	do	5.0	Lower part of MEV-1
	*MEV-1B	do	4.5	Upper part of MEV-1
	*MEV-2	SE SE 33-31-28W	4.0	
	MEV-3	SW NE 26-32-28W	18.0	
	*MEV-4A	NE 9-32-28W	8.0	23 ft. below MEV-4B
	*MEV-4B	do	6.0	Upper bed at MEV-4 locality
	MEV-5	SW 2-31-28W	17.0	(20 ft. with impure ash)
	MEV-5A	do	13.0	Lower part of MEV-5
	*MEV-5B	do	7.0	Upper part of MEV-5
	MEV-6	E½ NE 6-31-26W	20.0	
	MEV-7	NE 21-33-28W		
	MEV-8	SE SE 26-30-28W		
Ness	*NSV-1	SE NW 30-18-23W	6.0	
	NSV-2	SW SW 6-19-26W	9.0	

County	Sample number	Location	Maximum thickness, feet	Remarks
Norton	NNV-1	NW SW 25-2-22W	17.0	
	*NNV-1A	do	7.5	Lower part of NNV-1
	*NNV-1B	do	4.0	Above NNV-1A
	NNV-2	NW NW 2-4-24W	4.0	
	NNV-3	SE SE 25-3-25W	10.0	
	NNV-4	SW SE 2-3-25W	7.0	
	NNV-5	NE NW 36-2-25W	3.0	
	*NNV-6	CSL 1-3-22W	9.5	
	NNV-7	SE SE 27-4-23W	5.0	
	*NNV-8	Cen. SE 16-1-21W	4.0	
Ottawa	OV-1	NE NW 29-10-5W	6.0	
	OV-2	SW SE 3-9-2W	2.0	
Phillips	*PHV-1	NE NE 19-2-18W	9.0	
	PHV-2	SE NE 33-5-19W	5.5	
	PHV-3	NE NE 33-5-19W	15.0	
	*PHV-3A	do	7.3	Lower part of PHV-3
	*PHV-3B	do	6.0	Above PHV-3A; 1.7 ft. below top
	PHV-4	Cen. NE 3-2-19W	6.5	
	PHV-5	NW NE 30-1-19W	1.5	
	PHV-6	SW SW 14-1-18W	0.7	
Pratt	PRV-1	S½ SW 21-27-12W	14.0	
	*PRV-1A	do	7.5	Lower part of PRV-1
	PRV-2	SW SW 23-27-11W	2.5	
	PRV-3	NE SE 22-28-14W	10.0	
	*PRV-4	NW SE 34-27-12W	4.0	
Rawlins	*RWV-1	NE NW 14-3-35W	14.0	
	*RWV-1B	do	6.0	Upper part of RWV-1
	RWV-2	W½ SW 4-4-34W	2.0	
	*RWV-3	NW NW 33-3-34W	6.0	
	*RWV-3A	do	3.0	Lower part of RWV-3
	*RWV-3B	do	3.0	Upper part of RWV-3
	*RWV-4	NW SW 22-3-35W	14.0	
Reno	*ROV-1	NW SE 14-25-8W	10.0	
	*ROV-1B	do	4.5	Upper part of ROV-1
	*ROV-2	SE NE 1-25-7W	3.0	
Rooks	RKV-1	SW SW 18-7-18W	10.0	
	RKV-2	NE NE 7-8-16W	4.5	
	RKV-3	SW SE 31-9-16W	6.0	
Russell	RV-1	SE SW 19-14-13W	3.0	
	*RV-2	NE NW 2-15-11W	7.0	
	RV-3	SW NW 2-15-11W	10.0	
Seward	SDV-1	NW NW 35-33-32W	7.0	
	SDV-2	SE SE 35-34-31W	8.0	
	*SDV-3	SW NE 13-33-32W	8.5	
Sheridan	SNV-1	NW NW 34-8-28W	8.0	
	*SNV-2	NE SW 11-8-28W	6.0	
	SNV-3	SE SW 12-8-27W	3.5	
Smith	SMV-1	NW NW 31-3-15W	15.0	
	SMV-2	NE SE 32-1-14W	3.0	
Stafford	SFV-1	NE SW 28-25-11W	2.0	
Trego	TV-1	NW SE 28-14-21W	7.5	
	TV-2	32-14-22W	2.0	
	TV-3	S. Cen. 26-14-21W	10.0	
Wallace	WCV-1	SE SE 8-14-38W	3.0	
Washington	WV-1	NW NW 30-1-4E	1.0	

* Samples for which chemical analyses are given in Table 2.

Sanborn formation of late Pleistocene age. Overburdens of more than 100 feet are known to occur at places where these younger silts overlie the Sappa. The Peoria loess generally contains disseminated ash shards, but nowhere in Kansas is a deposit of recognizable ash known within this loess.

In the glaciated region of northeastern Kansas a few thin small deposits of Pearlette ash are known to occur in local waterlaid sediments unconformably above Kansas glacial till. The Pearlette volcanic ash bed has been identified also in Texas, Oklahoma, Nebraska, Iowa, South Dakota (Frye, Swineford, and Leonard, 1948), Missouri, and Colorado.

PETROGRAPHY

General

The general aspects of volcanic ash petrography as they are applicable to the Kansas deposits have been described in an earlier Geological Survey report (Swineford and Frye, 1946). All the volcanic ash deposits studied in Kansas (Table 1) consist predominantly of glassy or vitreous shards rather than rock fragments or crystals. The individual deposits display a wide range in their included contamination of detrital grains, but at all the localities where the ash has been mined or is of commercial grade it contains less than 4 or 5 percent nonvolcanic material. The nonvolcanic material is predominantly quartz and feldspar in sand sizes, and traces of heavy minerals similar to those in the containing clastic sediments. Concretions of calcium carbonate which cements ash shards together into variously shaped bodies in the bed are also common at some localities.

The volcanic ash, exclusive of contaminants, is almost entirely glass in the form of curved angular fragments of bubble walls. These bubbles occur both singly and as intersecting clusters, and were produced by gases which were released when the molten rock material was discharged from the volcanic vents. A very small amount of crystalline material is present as a volcanic product. Ham (1949, pp. 78-81) has reported that the Oklahoma deposits contain potassium feldspar and quartz of volcanic origin. Volcanic potassium feldspar has been noted in the Pleistocene ash deposits of Kansas.

In chemical composition the fresh glass commonly contains more than 70 percent silica (SiO_2), approximately 12 percent alumina (Al_2O_3), 2 percent ferric oxide (Fe_2O_3), 7 percent alkalies, and generally less than 3 percent lime (CaO) and magnesia (MgO). Chemical analyses of 54 channel samples of Kansas volcanic ash have been made under supervision of Russell Runnels in the geochemistry laboratories of the Geological Survey and are presented in Table 2.

Mechanical analyses were made by a combination of sieving and pipette methods on 12 channel samples from some of the larger deposits. Thirty grams of sample were shaken for 8 hours in a laboratory shaker and dispersed with NH_4OH. The size distribution of the material finer than 62 microns was determined by the usual pipetting procedure, assuming a specific gravity for the ash of 2.32. After completion of the pipette analysis, the finer particles were removed by repeated decantation, and the remainder was dried and screened for 10 minutes in a Ro-Tap sieve shaker. The combined results are shown in Table 3. Ro-Tap screen analyses of 96 samples are reported in terms of screen mesh in Table 4. The two sets of analyses differ somewhat in the

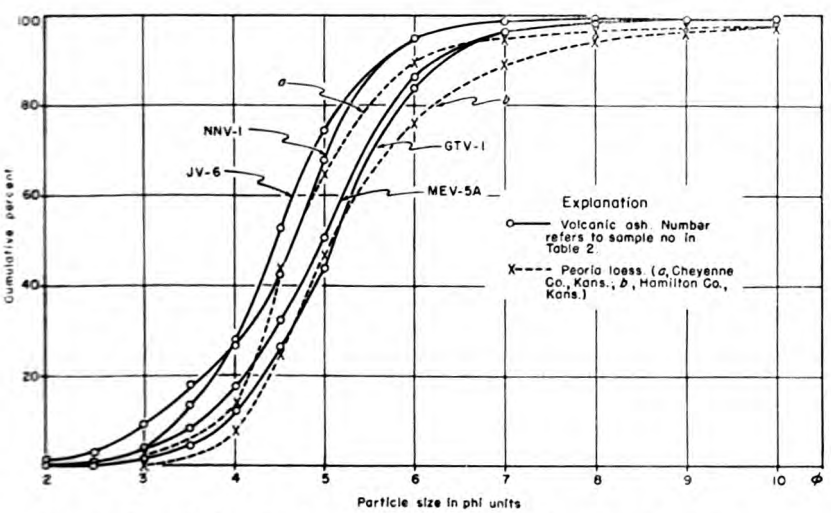

FIG. 4.—Cumulative size frequency curves for volcanic ash and loess. The ash analyses are typical of unaltered deposits and loess analyses used are of samples of Peoria silt in High Plains upland situations. Note the high degree of similarity among the analyses.

TABLE 2.—*Chemical composition of 54 volcanic ash samples* (Analyses in State Geological Survey geochemistry laboratory under supervision of Russell Runnels)

County	Sample no.	Chemical Analysis											
		SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	MgO	P_2O_5	SO_3	K_2O	Na_2O	Loss	Total
Chautauqua	CQV-1	67.75	12.83	2.66	1.78	0.90	0.52	<0.01	0.10		7.82*	5.64	100.00
Clark	CLV-1B	73.73	11.67	1.63	0.49	0.73	0.09	tr	tr	4.95	2.71§	4.00	100.00
	CLV-1A	73.34	10.96	1.86	0.68	0.87	0.14	tr	tr	4.80	3.33§	4.02	100.00
Comanche	CMV-1B	71.68	12.00	1.37	0.49	0.43	0.87	tr	nil	6.76	3.16†	4.02	100.77
	CMV-1A	73.00	12.59‡	1.52		0.59	0.14	tr	nil	5.59	2.82§	3.75	100.00
Ellis	ESV-3	72.96	12.62	1.55	0.21	0.50	0.13	tr	0.31	5.51	2.51†	4.01	100.31
Ellsworth	ELV-24A	72.87	12.68	1.34	0.24	0.64	0.05	tr	tr	5.29	2.64§	4.25	100.00
	ELV-24B	72.53	12.80	1.64	0.30	0.77	0.06	tr	tr	5.03	2.45§	4.42	100.00
	ELV-2A	72.61	11.81	1.74	0.36	0.72	0.15	nil	sl. tr		8.30*	4.31	100.00
Gove	GV-1B	73.13	11.71	1.93	0.29	0.65	0.12	tr	tr	5.68	2.56§	3.93	100.00
	GV-1A	73.43	12.30	1.61	0.22	0.99	0.41	tr	tr	4.77	2.45†	3.90	100.08
Grant	GTV-1	72.78	12.26‡	1.52		0.95	0.07	nil	<0.10	4.96	3.10†	3.84	99.48
Jewell	JV-1	73.36	12.32	1.72	0.54	0.07	0.14	nil	sl. tr		7.93*	3.92	100.00
	JV-3B	72.84	12.12	1.55	0.18	0.62	0.02	tr	tr		8.59*	4.08	100.00
	JV-3A	73.11	12.45	1.41	0.14	0.54	0.06	tr	nil	5.45	2.93§	3.91	100.00
	JV-6	73.32	10.76	1.66	1.36	0.53	0.23	tr	N.D.	5.30	2.27†	3.93	99.36
	JV-7	72.24	11.52	1.68	1.01	0.76	0.21	<0.01	sl. tr		8.25*	4.33	100.00
	JV-11A	73.26	10.94	1.83	1.22	0.66	0.31	tr	N.D.	5.18	266†	3.95	100.01
Lincoln	LV-1	72.51	11.55	1.21	0.54	0.68	0.07	tr	nil	6.86	2.77§	3.81	100.00
	LV-2	72.28	12.60	1.71	0.27	0.69	0.22	0.008	tr	5.45	2.90†	3.83	99.96
Logan	LOV-3	72.31	12.14	1.75	0.26	0.84	0.14	nil	0.10	6.37	2.84†	3.29	100.04
	LOV-5A	72.73	11.55	1.65	0.38	0.92	0.12	nil	sl. tr		8.35*	4.30	100.00
McPherson	MPV-1	72.95	12.30	1.73	0.30	0.69	0.16	tr	nil	5.04	2.90§	3.93	100.00
	MPV-6B	72.66	11.59	1.68	0.51	1.00	0.16	tr	N.D.	4.80	3.05†	4.26	99.71
	MPV-6A	73.06	11.54	1.31	0.97	0.63	0.09	<0.02	sl. tr		8.28*	4.12	100.00
Meade	MEV-1B	71.63	12.22	1.50	0.49	0.83	1.36	tr	nil	5.34	2.11§	4.52	100.00
	MEV-1A	71.47	11.75	1.63	0.50	0.97	1.12	tr	nil	5.18	2.88§	4.50	100.00
	MEV-2	69.82	13.33	1.80	0.16	0.72	0.49	tr	0.31	5.95	2.37†	5.17	100.12
	MEV-4B	72.01	11.40	1.49	0.88	0.77	0.46	nil	tr	5.98	2.68§	4.33	100.00

	MEV-4A	70.26	12.75	1.84	0.70	0.76	0.41	tr	tr	5.54	2.37§	5.37	100.00
	MEV-5B	72.09	11.48	2.07	0.53	1.06	0.65	tr	tr	5.49	2.34§	4.29	100.00
	MEV-5A	72.40	11.45	1.70	0.31	0.76	0.31	nil	tr	5.75	2.42§	4.90	100.00
Ness	NSV-1	71.16	11.70	1.47	0.16	1.46	0.38	N.D.	N.D.		9.84*	3.86	100.00
Norton	NNV-1B	71.98	10.94	1.93	0.33	2.14	0.15	tr	nil	5.94	2.08§	4.51	100.00
	NNV-1A	73.44	11.36	2.01	0.39	0.61	0.08	tr	nil	5.23	2.33†	3.93	99.38
	NNV-6	71.14	11.20	1.89	0.50	1.81	0.41	0.03	tr		7.81*	5.21	100.00
	NNV-8	76.68	9.77	1.44	0.51	1.45	0.27	<0.01	tr		6.86*	3.02	100.00
Phillips	PHV-1	73.03	11.79	1.66	0.31	0.64	0.09	tr	tr	4.77	3.21§	4.50	100.00
	PHV-3A	72.90	12.05	1.61	0.22	0.54	0.09	tr	tr	6.39	2.36§	3.84	100.00
	PHV-3B	72.71	12.28	1.65	0.31	0.58	0.08	tr	tr	5.06	3.39§	3.94	100.00
Pratt	PRV-1A	72.51	11.96	1.70	0.36	0.72	0.18	nil	nil		8.33*	4.24	100.00
	PRV-4	72.89	11.11	2.05	0.31	0.89	0.21	nil	sl. tr		7.65*	4.89	100.00
Rawlins	RWV-1B	73.88	12.08‡	1.64		0.63	0.14	tr	tr	5.98	2.09§	3.56	100.00
	RWV-1	72.77	12.06	1.68	0.24	0.75	0.16	nil	<0.10	6.03	2.71†	3.55	99.95
	RWV-3	67.48	10.73	1.91	0.54	5.10	0.30	<0.10	tr	4.56	1.71§	7.67	100.00
	RWV-3B	60.64	9.32	1.96	0.58	10.37	0.55	nil	sl. tr		5.06*	11.52	100.00
	RWV-3A	72.12	11.49	2.26	0.52	1.10	0.77	0.10	sl. tr		7.03*	4.61	100.00
	RWV-4	73.51	12.10	1.64	0.30	0.63	0.11	tr	nil	5.36	2.67§	3.68	100.00
Reno	ROV-1B	73.14	12.13	2.12	0.67	1.23	0.30	nil	<0.10	4.32	2.37†	3.67	99.95
	ROV-1	74.12	11.20	1.87	0.97	1.08	0.31	nil	tr	4.96	2.77§	2.72	100.00
	ROV-2	72.83	11.06	1.91	1.27	1.37	0.40	tr	N.D.	4.35	3.16†	3.82	100.17
Russell	RV-2	72.77	12.14	1.57	0.23	0.59	0.09	tr	tr	5.76	2.79§	4.06	100.00
Seward	SDV-3	73.16	12.33	1.67	0.36	0.69	0.14	tr	nil	4.97	2.84§	3.84	100.00
Sheridan	SNV-2	72.73	11.82	1.69	0.21	0.76	0.03	tr	tr	6.18	2.51§	4.07	100.00

* Mixed alkalies by difference from 100 percent.
§ Ratio of K_2O and Na_2O by spectographic determination. Percentage figured from undetermined difference.
† K_2O and Na_2O determined chemically.
‡ Includes TiO_2.

TABLE 3.—*Mechanical analyses of 12 volcanic ash samples*

County	Location	Ceramic lab. no.	Bed	ø <2 μ >250	2-2.5 250-177	2.5-3 177-125
Gove	NE SW 21-13-26W	GV-1B	Pearlette	0.4	0.4	2.3
Grant	SE NE 1-30-36W	GTV-1	do	0.2	0.2	1.0
Jewell	NW NE 16-1-6W	JV-6	do	0.1	0.3	2.4
Lincoln	SE SW 27-13-10W	LV-1	do	0.0	0.3	1.3
McPherson	NW SE NW 20-18-3W	MPV-1	do	0.1	0.2	3.3
Meade	SW 2-31-28W	MEV-5A	do	0.4	0.8	2.5
Norton	NW SW 25-2-22W	NNV-1	Calvert	1.3	2.1	6.3
do	SE SE 25-3-25W	NNV-3	do	0.2	0.7	2.4
do	SW SE 2-3-25W	NNV-4	Reager	0.2	0.8	2.6
Pratt	S½ SW 21-27-12W	PRV-1B	Pearlette	0.3	0.6	3.2
do	NW SE 34-27-12W	PRV-4	do	0.6	1.0	3.3
Rawlins	NE NW 14-3-35W	RWV-1	do	0.3	0.7	2.7

coarser fractions because large lumps produced by secondary cementation are not included in the data of Table 3.

The median diameter ranges from 26 to 46 microns in the 12 samples analyzed, and averages 34 microns. The degree of sorting is uniformly high, and the size frequency curves in general are strikingly similar to those reported for wind-blown silt (Fig. 4). This probably is a result of sorting during air transport. Kuenen (1950, p. 345) suggests that volcanic explosions do not produce shards of dimensions smaller than about 5 microns in appreciable quantity. The Kansas size data apparently support his thesis, for all except 4 of the samples show 2 percent or less finer than 5 microns and three of the four exceptions are slightly weathered. However, electron micrographs of the less-than-1-micron fractions show particles having definite shardlike shapes (Pl. 5A) and in a sample from Lincoln County fibrous-type shards were observed in the less than 1 micron fraction. It is possible that sorting is as great a factor as original diameter in determining the size frequency distribution of the ash. Selective weathering may also destroy extremely small particles of glass.

Particle size data on Oklahoma ash reported by Ham (1949) indicate that the Oklahoma material is somewhat coarser than that from Kansas, which is to be expected if Oklahoma is nearer

showing distribution coarser than one micron

Particle size distribution, percent by weight											
3-3.5 125- 88	3.5-4 88- 62	4-4.5 62- 44	4.5-5 44- 31.2	5-6 31.2- 15.6	6-7 15.6- 7.8	7-8 7.8- 3.9	8-9 3.9- 1.95	9-10 1.95- 1	>10 <1	Md ø	Md μ
5.5	9.1	15.1	14.4	33.9	14.1	2.7	1.0	0.3	0.7	5.06	30
3.3	7.5	14.3	16.9	39.6	12.9	2.3	0.9	0.3	0.8	5.15	28
10.8	14.0	24.7	22.0	20.1	4.0	0.6	0.5	0.0	0.5	4.45	46
4.1	10.6	21.1	21.3	28.1	10.9	1.3	0.4	0.1	0.4	4.78	36
7.6	13.2	22.1	17.7	18.7	8.7	3.8	1.8	1.3	1.6	4.57	42
4.7	9.1	14.6	18.3	35.7	10.6	2.0	0.9	0.0	0.5	4.98	31
8.3	8.9	15.6	25.3	27.3	3.4	0.8	0.1	0.0	0.6	4.64	40
4.8	7.0	14.3	28.6	36.1	4.5	0.4	0.4	0.0	0.7	4.87	34
4.4	6.2	12.5	18.7	39.4	10.2	3.3	1.1	0.0	0.6	5.20	27
5.6	13.3	24.5	19.2	21.1	9.0	1.6	0.5	0.3	0.7	4.56	42
4.7	6.6	12.4	15.0	31.6	15.4	5.6	1.9	0.9	1.0	5.17	28
5.0	7.0	13.0	13.5	34.4	16.4	4.0	1.2	0.6	1.0	5.25	26

the assumed source area. However, the Kansas samples analyzed show no uniform geographic trends.

The effects of weathering produce alteration both in the chemical composition and physical appearance of the shards. The percentages of silica and alkalies decrease as weathering proceeds. The individual shards of glass take on a cloudy appearance, crystalline calcite develops, a clay coating is formed on the edges, and if the weathering proceeds far enough the particle size significantly decreases. At a few places thin noncommercial bentonite beds associated with Ogallala ash represent an advanced stage of weathering. This bentonite is generally greenish gray in color and one sample from just above the fresh ash in the Calvert pit was shown by x-ray diffraction analysis to be almost pure montmorillonite (personal communication, W. D. Keller) as shown in the electron micrograph in Plate 5B. The Pearlette ash weathers to a lighter color and some deposits are judged on the basis of electron micrographs to yield kaolinite type clay minerals as an alteration product, although x-ray diffraction studies suggest predominance of a montmorillonite mineral.

The distinctive petrographic characters of the several volcanic ash beds in Kansas are described in the following paragraphs.

Calvert Ash Bed

The Calvert ash is an admixture of two or possibly three closely spaced falls. The glass is characterized by a neutral very light-gray color (approximately N8 of the Munsell classification), although in the field it is usually described as bluish gray. The bluish appearance is thought to be due to reflected light from the sky in the flat platy glass shards, and to the contrast with the more common buff color of adjacent sediments.

The shards of the Calvert ash are characteristically flat and so thin that iridescence is observed in many shards. Bubble

Table 4.—*Screen analyses of 96 volcanic ash samples* (Analyses by S. K. Chakravorty in Geological Survey laboratories)

County	Location no.	Percent retained on 20 mesh	60 mesh	100 mesh	200 mesh	Pan	Comments
Clark	CLV-1B	0.13	0.40	3.27	29.34	66.84	
	CLV-1A	0.00	0.21	0.72	11.20	87.87	
	CLV-2	0.22	1.13	4.46	19.87	74.30	
Comanche	CMV-1B	0.12	0.20	1.27	21.54	76.85	
	CMV-1A	0.00	0.22	1.63	11.70	86.45	
Decatur	DRV-1	5.21	2.72	2.31	10.45	79.30	
	DRV-2	8.35	17.35	11.97	17.19	45.13	All contain sand except I
Ellis	ESV-1	0.24	0.30	2.14	16.34	80.96	
	ESV-2	0.13	0.58	3.17	18.75	77.35	
	ESV-3	0.90	0.56	1.81	13.91	83.62	
Ellsworth	ELV-2B	0.27	0.56	2.40	22.82	73.93	
	ELV-2A	0.52	0.96	14.02	41.29	43.20	Contains silt
	ELV-24B	1.72	1.29	4.94	21.58	70.45	
	ELV-24A	0.32	0.58	3.61	17.61	77.88	
Gove	GV-1B	0.35	0.49	1.92	13.34	83.88	
	GV-1A	0.25	0.85	3.60	24.76	70.52	
	GV-2	0.24	1.00	2.81	18.36	77.38	
	GV-3	0.46	1.93	3.68	17.09	76.82	
	GV-5	0.20	0.94	4.40	26.16	68.28	
Graham	GMV-1	0.10	0.42	1.71	15.78	81.97	
Grant	GTV-1	0.04	0.09	0.70	9.06	90.09	
	GTV-2	0.08	0.67	3.19	19.77	76.26	Contains impurities
	GTV-3	0.27	0.57	1.36	9.18	88.60	
Gray	GRV-1	0.30	1.20	3.30	13.85	81.60	
	GRV-2	0.10	0.30	2.71	11.27	85.60	
Hamilton	HNV-1	5.56	11.34	4.30	9.51	69.27	Contains impurities
Harper	HPV-1	0.55	2.17	6.44	22.51	68.30	Contains silt and sand
	HPV-2	2.46	5.08	3.33	9.13	79.98	
Jewell	JV-1	0.18	0.47	4.10	22.90	72.33	
	JV-5	0.43	0.98	4.19	21.87	72.51	
	JV-6	0.02	0.20	2.51	20.40	76.87	
Kiowa	KV-1	0.23	1.75	4.75	11.43	81.82	
Lincoln	LV-1	1.72	0.71	1.11	10.97	85.48	
	LV-2	0.64	2.22	6.87	29.30	60.97	
Logan	LOV-1	0.33	0.75	1.74	18.04	79.12	
	LOV-2	0.25	0.53	0.85	14.90	83.45	
	LOV-3	0.05	0.65	2.73	18.88	77.67	
	LOV-4	0.18	0.24	2.58	18.59	78.40	

County	Location no.	Percent retained on 20 mesh	60 mesh	100 mesh	200 mesh	Pan	Comments
	LOV-5B	0.06	0.10	1.21	14.88	83.74	
	LOV-5A	0.59	0.85	3.60	19.29	75.67	
McPherson	MPV-1A	1.07	1.48	11.88	28.11	57.45	
	MPV-3	0.38	0.68	3.87	23.37	71.70	
	MPV-12	0.31	0.55	3.17	16.28	79.68	
Meade	MEV-1B	1.39	1.43	2.90	16.03	78.25	
	MEV-1A	0.47	0.73	2.65	17.93	78.20	
	MEV-3B	0.76	0.36	0.76	7.54	90.56	
	MEV-4A	6.51	4.29	2.78	10.63	75.78	
	MEV-4B	0.58	0.76	3.69	16.21	78.75	
	MEV-5B	1.91	7.96	5.26	15.18	69.68	
	MEV-5A	1.89	1.02	1.97	12.73	82.37	
	MEV-6A	0.23	0.50	1.68	14.33	83.25	
Ness	NSV-1	0.04	0.51	2.00	10.97	86.45	
	NSV-2	0.99	0.63	3.44	17.77	77.16	
Norton	NNV-1B	3.03	3.21	6.33	18.82	68.60	
	NNV-1A	5.40	1.31	3.52	17.48	72.27	
	NNV-2	7.40	8.21	4.14	11.38	68.84	Altered by weathering
	NNV-3	3.16	3.34	3.16	13.12	77.21	
	NNV-4	2.38	1.47	3.38	14.40	78.36	
	NNV-5	10.31	6.17	2.26	9.24	72.00	Contains some sand
	NNV-6	2.13	4.28	7.90	21.60	64.08	Altered by weathering
	NNV-7	11.77	6.05	4.68	22.41	55.07	Weathered, contains sand
Phillips	PHV-1	1.12	0.91	1.16	9.50	87.30	
	PHV-2	0.11	0.66	1.83	11.86	86.64	
	PHV-3B	0.41	0.88	1.97	11.41	85.31	
	PHV-3A	0.00	0.49	1.75	11.89	85.86	
	PHV-4	1.36	2.09	6.96	20.71	68.86	
Pratt	PRV-1B	0.10	0.33	2.67	16.16	80.73	
	PRV-1A	0.06	0.35	2.93	15.08	81.56	
	PRV-3B	0.00	0.63	5.38	31.21	62.77	Contains silt and sand
	PRV-3A	0.19	1.82	12.57	50.44	34.97	Contains silt and sand
	PRV-4	0.89	1.05	3.56	12.54	81.93	
Rawlins	RWV-1	0.10	0.38	1.80	8.84	88.88	
	RWV-2C	0.98	1.00	1.74	12.61	83.66	
	RWV-2A	11.90	17.10	9.97	23.07	37.94	
	RWV-3B	2.34	3.50	8.40	23.92	61.83	
	RWV-3A	0.27	0.39	2.52	10.28	86.52	
	RWV-4	0.14	0.30	1.30	12.00	86.25	
Reno	ROV-1	0.29	1.24	9.99	38.45	50.01	
	ROV-1S	0.02	0.33	5.05	16.44	78.14	
Rooks	RKV-1	0.39	1.02	3.11	19.14	76.32	
	RKV-2	1.28	2.18	7.74	31.07	57.71	
Russell	RV-1	0.10	0.74	4.77	28.82	65.55	
	RV-2	0.11	0.56	3.95	37.34	58.02	
	RV-3B	0.84	8.54	6.30	19.50	64.80	
	RV-3A	0.00	0.99	6.53	25.23	67.24	
Seward	SDV-2	4.02	10.95	5.61	10.24	69.15	
	SDV-3	0.09	0.84	1.77	9.74	87.54	
Sheridan	SNV-1B	1.13	0.97	2.12	11.58	84.18	
	SNV-1A	0.10	0.30	2.56	16.01	81.02	
	SNV-2	0.34	0.83	1.79	13.29	83.74	
	SNV-3	2.05	3.06	4.74	2.13	69.98	Contains some sand, silt
Smith	SMV-1C	0.38	0.39	1.29	11.82	86.10	
	SMV-1B	0.44	0.44	0.75	20.80	77.75	
Trego	TV-1	1.05	1.79	4.19	17.41	75.54	
	TV-2	0.60	3.41	5.70	18.19	72.09	
Wallace	WCV-1	23.43	14.53	5.51	14.69	41.82	

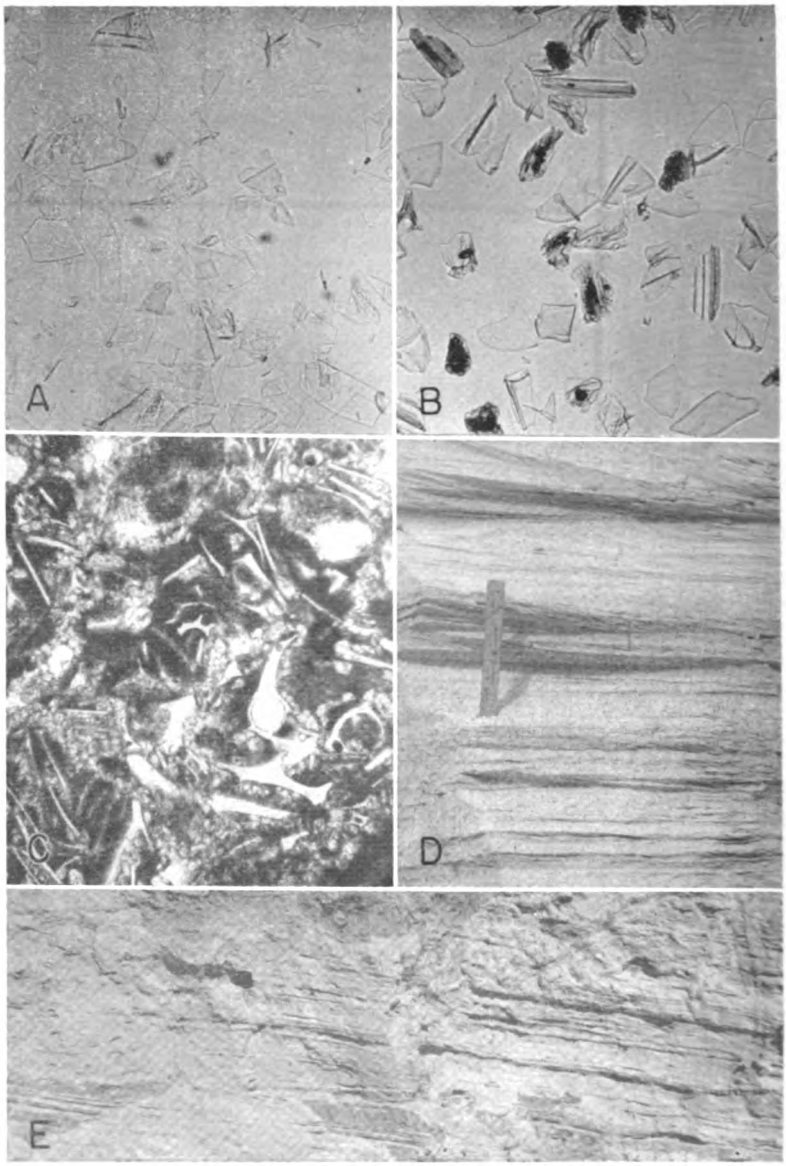

PLATE 4. Petrographic features of Kansas volcanic ash. **A**, Shards from the Calvert mine from the 88-to-125-micron fraction mounted in oil of 1.46 refractive index, magnification 50 X. Note thin flat shards with flat bubble junctures typical of the Calvert bed. (Swineford, 1951.) **B**, Shards of Pearlette ash from the NE¼ NW¼ sec. 14, T. 3 S., R. 35 W., Rawlins County; mounting same as A. Note thicker glass, curved and fibrous shards typical of the Pearlette bed. (Swineford, 1951.) **C**, Thin section of cemented (calcium carbonate) Pearlette ash from the SW¼ SW¼ sec. 14, T. 1 S.,

junctures are straight or almost straight, and more than one is not commonly present in the same shard (Pl. 4A).

The average index of refraction is 1.501 ± 0.001, but there are scattered shards with index slightly greater than 1.503, and the upper part of the bed at the type locality consists predominantly of shards having an index of 1.498 ± 0.001. The Calvert type locality is the only deposit of Kansas volcanic ash in which vertical variation in petrographic character of the fresh glass has been observed. Series samples have been taken from one other deposit provisionally assigned to the Calvert ash bed (location: NE¼ SE¼ sec. 27, T. 4 S., R. 23 W., Norton County) but the degree of weathering precludes differentiation. Many other Ogallala ash deposits have been channel-sampled for this report. Had samples been taken in vertical series they might also have shown nonuniformity of the glass.

The specific gravity of the Calvert glass averages 1.36. Its chemical composition is similar to that of the other Kansas ash deposits, although the percentage of ferric oxide is slightly higher than that of the Pearlette.

Reager Ash Bed

The Reager ash fall consists of glass shards which are more strongly curved than those of the Calvert fall, and a larger proportion of the shards show several bubble junctures. The glass is somewhat thicker, and shards having closely spaced parallel junctures are fairly common. The color is gray with a faint suggestion of an orange cast (slightly grayer than Munsell 5YR8/1). The index of refraction of glass from channel samples of this ash has a greater range than that of any other bed described in this report. The average index is 1.503 ± 0.001, but the range is from 1.500 to 1.507. There is some indication that the high-index shards are less stable than the others, and selective destruction of such shards may make positive identification of the Reager bed difficult in some deposits.

A large proportion of the Reager samples contains coarse sand as a contaminant in the coarser fractions.

R. 18 W., Phillips County, magnification 50 X. (Swineford, 1951.) **D**, Detail of bedding in Pearlette volcanic ash in pit face, in sec. 2, T. 31 S., R. 28 W., Meade County. Ruler is 1 foot long. Note cross bedding. (Swineford, 1951.) **E**, Typical bedding of Pearlette volcanic ash exposed in pit face, NW¼ sec. 34, T. 8 S., R. 28 W., Sheridan County. (Frye, 1951.)

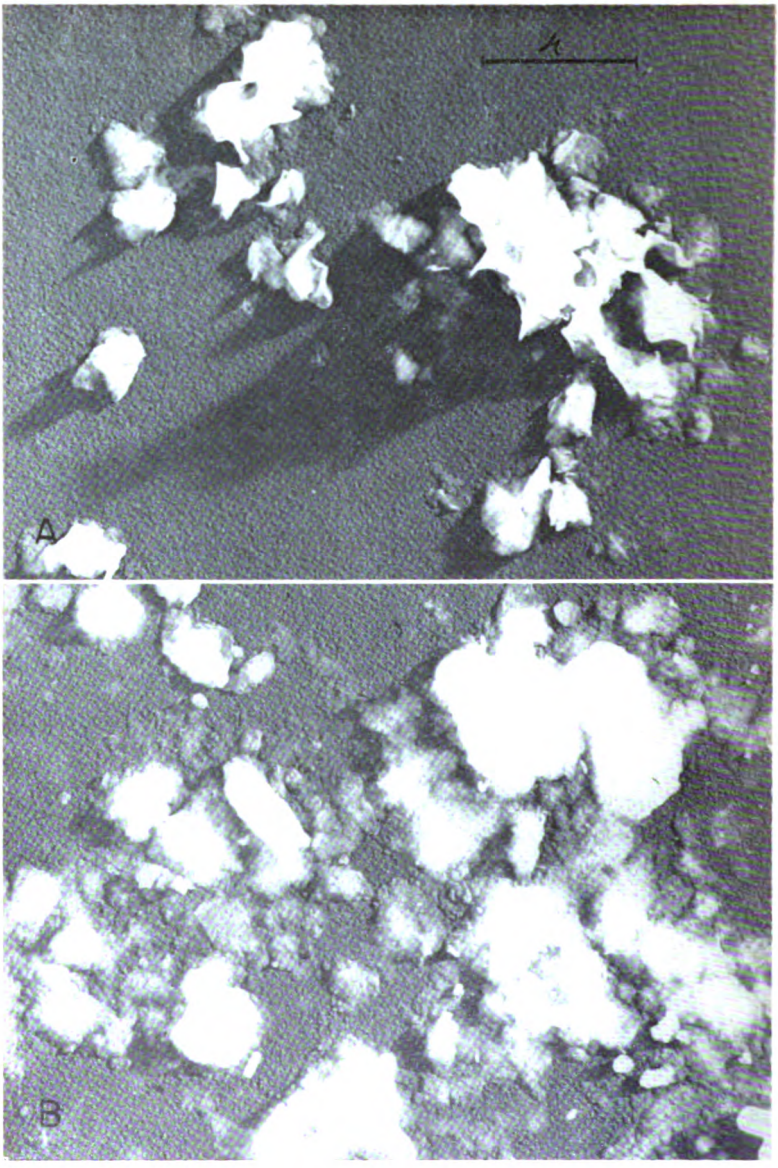

PLATE 5. Electron micrographs of volcanic ash and bentonite. **A**, Shards from minus-1-micron fraction, Pearlette ash, sec. 2, T. 31 S., R. 28 W., Meade County. Note curvature and angularity of glass. Magnification, 20,000 X. **B**, Bentonite from above fresh ash at Calvert pit of Wyandotte Chemicals Corporation (minus-1-micron fraction). Cottony masses are typical of montmorillonite. Magnification, 20,000 X. Electron micrographs by C. C. McMurtry, Department of Oncology, University of Kansas Medical School. Preparations shadowed with 120 A of chromium at 18°. Scale indicates 1 micron.

Unnamed Ogallala Ash Bed

Two deposits of fresh ash—both in Phillips County—apparently represent a single ash fall. These deposits are similar in appearance to the ash of the Reager bed, but all except a very few of the shards have a restricted refractive index of 1.500 to 1.503. Future detailed study of these deposits may either show them to be modified Reager or differentiate them more positively from other Ogallala falls.

Pearlette Ash Bed

The Pearlette ash is lighter in color than any of the Kansas Ogallala ash deposits and on field inspection appears to be white; however, laboratory comparison with Munsell standards shows that it has a faint pinkish hue. The typical color corresponds closely to Munsell 5YR8/1 (pinkish gray).

The individual shards are very strongly curved, and consequently do not reflect as much light as those of the Calvert or even of the other Ogallala beds. Many of the larger shards include parts of several bubbles, and a few complete bubbles are present in all samples which contain coarse shards. Bubble junctures are commonly sharply curved and intersect at high angles. Fibrous shards are the most distinctive feature of the Pearlette ash, particularly in the finer size fractions. Such shards are shown in Plate 4B. The Pearlette is readily distinguished from Ogallala falls by the presence of numerous vesicles in the glass. These are easily observed in transmitted light and are due to the small radius of curvature of the glass and to the entrapment of air in the capillaries of the fibrous shards. The three-dimensional character of the Pearlette adds to its effectiveness as an abrasive. This angularity is also present in the extremely fine particles. An electron micrograph of ash from the pit in sec. 2, T. 31 S., R. 28 W., Meade County (Pl. 5A), shows that particles of 1 micron or less in diameter are strongly curved and angular.

The index of refraction of the fresh glass is uniform from top to bottom of the deposits, nearly all shards having $n = 1.499 \pm 0.002$.

Most deposits of Pearlette ash are soft and unconsolidated. Small concretions cemented with calcium carbonate are present

at some localities, and in Phillips County in the SW¼ SW¼ sec. 14, T. 1 S., R. 18 W., a thin bed solidly cemented with calcite has the appearance of a dense limestone. A photomicrograph from a thin section of this material (Pl. 4C) shows some of the large curved shards in cross section.

USES OF VOLCANIC ASH—PRESENT AND POTENTIAL

In the past and until very recently the chief uses of volcanic ash have been based on its physical properties of fine size and angularity of particles, friability, and light color, as illustrated in its use as an abrasive and as topping for bituminous matt roads. In the past few years increasing attention has been given to the chemical or pyrochemical properties of volcanic ash as an alkaline aluminum silicate flux in ceramics and as a pozzolanic additive to cement in concrete mixtures. In the United States in 1934 the quantity employed for use in abrasives was eight times as great as that used as a cement aggregate and pozzolanic admixture. In 1945 the quantities employed in these two major uses were nearly equal. In 1947 the quantity used with cement was four and one-half times as great as that used for abrasive purposes (Barr, 1949). The most extensive use of pumicite or volcanic ash in concrete has been on the west coast. Only small amounts have been used in Kansas for this purpose, and the tonnage does not appear in the statistics on Kansas production. Inasmuch as commercial production in Kansas is largely for abrasive uses, the quantity used for these purposes is clearly shown in published statistics. The earliest figures available on Kansas production are for the year 1916 when 23,804 tons was produced. Peak production was reached in 1923 with a total of 51,907 tons and from 1923 to 1940 was fairly steady. Reported output ranged from 35,385 tons in 1925 to 49,760 tons in 1929, and the average production for the 17-year period was 41,953 tons. Following a near-average year of 39,215 tons in 1940, the 1941 production declined to 23,659 tons, but by 1945 had recovered to 47,484 tons—exceeding the previous 17-year average. Since 1945 production has declined sharply. As previously stated, these production statistics are available only on commercial production and it is probable that the tonnage used by the State Highway Department substantially exceeds that mined

by commercial producers. In one deposit alone we estimate that at least 25,000 tons have been removed by the Highway Department for use on black-top roads.

Abrasives

Volcanic ash has been used as an abrasive in the United States for about 50 years. In 1903 the entire production of 885 tons in this country was from Nebraska. By 1911 volcanic ash was reported by the U.S. Geological Survey as being mined in Kansas, but production figures were concealed under the heading of miscellaneous items. In 1916 a figure of 23,804 tons was given for Kansas. Doubtless most of this tonnage was used in abrasives.

As an abrasive volcanic ash is adapted for use as a polishing, scouring, and cleansing agent because of its fineness, angularity, and moderate hardness (5.5 to 6.0 on Mohs scale). A large proportion of volcanic ash used as an abrasive has gone into scouring compounds such as Old Dutch Cleanser. Formerly these compounds were composed largely of volcanic ash mixed with small quantities of soap powder or other detergents. Volcanic ash is also used as an abrasive in mechanics paste soap, abrasive hand soaps, and rubber erasers. Very fine ash is used in some toothpaste and powder, and minus-200-mesh ash has been used for polishing plate glass. Volcanic ash could be used instead of powdered pumice whenever the latter material is suitable. These uses include polishing metals, wood, and varnished wood finishes. Other abrasive uses include polishing powders for bone, celluloid, and hard rubber, and in dentists tape.

Processing of volcanic ash for abrasive uses commonly includes only drying and the screening out of coarse particles, aggregates of particles, and incidental contaminants. This practice is possible because of the natural fineness of the material. Screen analyses on 96 samples (Table 4) show that an average of 93.6 percent passes a 100-mesh screen and that an average of 76.3 percent passes a 200-mesh screen. Minus-200-mesh material constitutes more than 80 percent in 34 of the 96 samples. Subsieve analyses on 12 samples (Table 3) indicate that the median diameter of the particles averages 34 microns, which is equivalent to smaller than 400-mesh. Air classification is used in some cases, particularly where grades of 200 mesh or finer are re-

quired. Although volcanic ash is seldom subjected to grinding in order to reduce the particle size, it is readily susceptible to dry grinding in a ball or pebble mill.

Ceramics

Volcanic ash, or pumicite, is composed of minute shards of volcanic glass corresponding roughly to a frit composed of feldspar and quartz. It is surprising that a material with this composition has received so little attention from workers in the field of ceramics. The ceramics laboratory of the State Geological Survey ran a number of tests during 1937 and 1938 using volcanic ash in ceramic glazes and bodies, and the work was summarized briefly by Plummer (1939). Prior to this time the only work done on ceramic uses of volcanic ash in the United States was reported by Preston (1935) on the use of volcanic ash in glass batches. After publication of the 1939 report by Plummer our attention was called to the fact that similar work had been published in the Journal of the Canadian Ceramic Society by Worcester (1934). Worcester used Canadian volcanic ash in ceramic bodies and glazes with results somewhat similar to those obtained with Kansas ash in the Survey laboratory. Additional experiments with Kansas volcanic ash glazes were reported briefly by Carey (1948). During the past three years a number of tests have been run on volcanic ash glazes and ceramic bodies. The results will be published in a Geological Survey bulletin at a later date.

Kansas volcanic ash fuses at a lower temperature than feldspar. The pyrometric cone equivalent of feldspars ranges from cone 4 to cone 10, with a general average of cone 8 to 9 (2240° to 2280° F.). Kansas volcanic ash samples tested have a pyrometric cone equivalent ranging from cone 06 to cone 4, with a general average in the neighborhood of cone 03 to 01 (1975° to 2030° F.). This difference in fusion temperature gives volcanic ash a distinct economic advantage, and in the field of ceramic art permits the use of the lower temperatures considered desirable.

CERAMIC GLAZES

The chemical composition of Kansas volcanic ash from the various deposits is remarkably uniform, as can be observed from the analyses of 54 samples given in Table 2. It is probable that the variations found are due largely to contaminants such as quartz, calcite, and clay.

Volcanic ash from a deposit in Lincoln County (LV-1) has been used extensively in glaze and ceramic body tests because it is easily available and has a chemical composition that is approximately an average of the Kansas ash deposits. The composition of this ash is given below.

Chemical composition of LV-1 volcanic ash

Silica (SiO_2)	72.51 percent
Alumina (Al_2O_3)	11.55
Iron oxide (Fe_2O_3)	1.21
Titanium oxide (TiO_2)	0.54
Calcium oxide (CaO)	0.68
Magnesium oxide (MgO)	0.07
Potassium oxide (K_2O)	7.84
Sodium oxide (Na_2O)	1.79
Loss on ignition	3.81

The molecular formula, or ratio of the molecular weights of the various groups of oxides in this volcanic ash, is as follows.

K_2O	0.6608				
Na_2O	0.2296	Al_2O_3	0.8999	SiO_2	9.5894
CaO	0.0961	Fe_2O_3	0.0604	TiO_2	0.0540
MgO	0.0135				

The formula weight of the above is 794.30. Feldspar from Keystone, South Dakota, has the following molecular formula.

K_2O	0.751				
Na_2O	0.231	Al_2O_3	1.1300	SiO_2	6.230
CaO	0.018	Fe_2O_3	0.0015		

The formula weight of this feldspar is 577.72. Owing to the fact that the volcanic ash has a higher ratio of silica to alumina and the RO group, a substitution of an equal weight of volcanic ash for feldspar is not possible. Roughly 100 parts by weight of volcanic ash may be substituted for 70 parts feldspar and 30 parts potters flint. A more exact method of substitution is given in Table 5. This table is based on molecular ratios of oxides in both materials, and necessitates taking out feldspar, flint, and whiting, and adding volcanic ash and ball clay.

TABLE 5.—*Volcanic ash and clay required for an exact replacement of feldspar, flint, and whiting in glazes or ceramic bodies**

Take out			Add	
Feldspar	Flint	Whiting	Volcanic ash	O-38-4 clay
5.0	2.57	0.09	7.41	0.51
10.0	5.14	0.18	14.83	1.01
15.0	7.71	0.28	22.24	1.52
20.0	10.28	0.37	29.66	2.02
25.0	12.85	0.46	37.07	2.53
30.0	15.42	0.55	44.49	3.03
35.0	17.99	0.64	51.90	3.54
40.0	20.56	0.74	59.32	4.05
45.0	23.13	0.83	66.73	4.55
50.0	25.70	0.92	74.15	5.06
55.0	28.27	1.01	81.56	5.56
60.0	30.84	1.10	88.98	6.07
65.26	33.54	1.20	96.78	6.60

* Parts per hundred in total glaze batch, by weight.

The calculations were made for Keystone feldspar, Lincoln County volcanic ash (LV-1), and a Kansas ball clay (0-38-4) containing 64.67 percent silica, 22.38 percent alumina, 1.58 percent iron oxide, 1.32 percent titanium oxide, 0.27 percent calcium oxide, 0.66 percent magnesium oxide, 1.11 percent potassium oxide, and 0.55 percent sodium oxide. Any similar ball clay could be used. It will be noted that if a total of 100 percent feldspar, flint, and whiting were taken out of a glaze or body a total of 103.38 percent volcanic ash and clay would be added as a replacement. This is due to the fact that the ash and clay contain a higher percentage of inactive ingredients. Although such high percentages of feldspar or volcanic ash are not used in glazes and ceramic bodies, we have prepared a usable glaze containing 95 percent volcanic ash. Ordinarily, however, the percentage of ash included in a glaze batch will not exceed 75 percent, and in most cases ceramic bodies are not improved by additions of more than 25 percent volcanic ash.

A few volcanic ash glazes of proven worth are given below as an illustration of the range of compositions possible. The following glaze matures within the range of cone 02-1.

Eagle-Picher lead silicate	31.4 percent
LV-1 volcanic ash	25.0
Keystone (S.D.) feldspar	2.8
Colemanite	5.5
Whiting	2.1
Zinc oxide	3.2
Barium carbonate	4.2

O-38-4 clay	8.5
Flint	5.2
Zircopax (zirconium silicate)	12.1

The glaze above was used with 5 percent commercial yellow stain to produce a good shade of yellow. Without the stain an opaque glaze is produced.

A very simple glaze within the range of cone 04 to cone 10 has the following composition.

Volcanic ash	70 parts by weight
Colemanite	30 parts by weight
Bentonite	5 parts by weight

This glaze has a rather muddy color due to the iron oxide content of the volcanic ash. The addition of 5 percent whiting will improve the transparency of the glaze. If the glaze is to be used as a base for colored glazes the addition of 5 percent of an opacifier such as zirconium silicate will produce a warm white suitable for this purpose.

A raw lead glaze that has been used very successfully on a number of types of body within the temperature range of cone 07 to cone 04 is given below. It is probable that the glaze could be used over a much longer range.

Red lead	35.2 percent
Volcanic ash	51.4
Whiting	8.4
Zinc oxide	1.0
Florida kaolin	4.0

A high-temperature glaze that has produced excellent results on a siliceous body is given below. This glaze was used at cone 7 and cone 9, but should be usable from cone 6 to 10. Colored glazes can be made by adding the correct oxides or stains.

Volcanic ash	39.9 percent
Whiting	8.4
Magnesium carbonate	7.3
Barium carbonate	4.9
Ball clay (O-38-4)	28.5
Flint	10.0

Volcanic ash glazes are used in at least three potteries in the State and by a number of schools. The chief advantage in the use of volcanic ash is the low cost, although there are the added advantages of an unusually long firing range and the fact that the colors in volcanic ash glazes are somewhat softer than those obtained with the conventional materials. Kansas potteries also

find that advertising the use of volcanic ash glazes attracts customers.

CERAMIC BODIES

The substitution of volcanic ash in ceramic glazes for equivalent amounts of other materials produces very little difference in the final glaze, although the firing temperature may be slightly lower due to the surprisingly low fusion temperature of the ash. In ceramic bodies, however, the results are not so predictable. Generally the results are more beneficial than would be expected. A number of test bodies with different types of clays and shale and with varying amounts of volcanic ash indicate that from 7 to 15 percent volcanic ash additions to a shale or red-firing clay body lowers the vitrification temperature, increasing the firing range for a matured body, and producing a greater rigidity in the ware at the maximum temperature. These qualities produced by the volcanic ash additions permit economy in use of fuel, and reduce losses in the kiln due to the less critical temperature range requirements and the ability of the ware to stand up under its own weight at the maximum temperatures attained in the kiln. Not all clays and shales react with equally favorable results. Some materials are benefited only in that the firing temperature is reduced. The benefits of volcanic ash additions to sewer pipe bodies have received considerable attention. A group of clay plant operators sponsored a project at the Engineering Experiment Station at Ohio State University to test the value of additions of volcanic ash to sewer pipe bodies. J. O. Everhart, research professor in charge of this project, reported to us that definite benefits were obtained by the use of volcanic ash. In a letter accompanying the report Everhart summarizes the effects of volcanic ash as follows: "It seems to have a somewhat stabilizing influence on the mix to which we added it, and might be of considerable value for use in local clay and shale mixes having a short firing range. We attribute this influence to the fact that it forms a very viscous glass which remains so over a long range of temperatures." F. K. Pence (personal communication) of the University of Texas reports that very beneficial results are realized from the use of volcanic ash in a sewer pipe body in a Texas plant.

Somewhat similar results are obtained with additions of volcanic ash to pottery or whiteware bodies, although in this case the fired color of the body is darkened slightly by the iron content of the ash. The use of volcanic ash in amounts ranging from 10 to 25 percent lowers the firing temperature required, or to look at the matter from another angle, it makes it possible for the art potter whose maximum temperature is limited to produce hard-fired ware that does not leak or craze. In general the casting properties of pottery bodies are improved with the addition of volcanic ash. This is due largely to the size and shape of the particles. At least one pottery in Kansas is using volcanic ash with Kansas clay in the casting body and produces a vitrified ware at cone 4.

GLASS AND VITREOUS ENAMELS

Volcanic ash performs the same function in glass and in vitreous enamels as it does in ceramic glazes. Due to the iron oxide of about 1.5 percent the use of volcanic ash in these products is limited. Volcanic ash has been seriously considered as an ingredient in fiber glass batches and in foam glass where the slight darkening of color is of minor importance. If used in the production of fiber glass the problem of preventing the disintegration of the platinum dies by the iron present in the ash would have to be solved.

Laboratory trials with volcanic ash as an ingredient in vitreous enamel were made by one of the major manufacturers of sanitary ware. The laboratory reported that the cream-colored and ivory-colored enamels produced with additions of volcanic ash were slightly superior to those produced with feldspars, but that due to the distance the ash would have to be shipped to their plants no saving in cost would be realized.

LIGHTWEIGHT AGGREGATES AND CELLULAR BLOCKS

The Oklahoma Geological Survey has investigated the possibility of producing cellular products similar to Foamglas and an extremely lightweight aggregate consisting of bloated individual particles of volcanic ash (Burwell, 1949). The cellular product was produced by heating volcanic ash to a high temperature in refractory molds. The resulting product, which was

named "pumicell" by the Oklahoma Survey, is a glass containing small disconnected cells of air. It has high insulating value, and can be sawed or nailed. The bulk density of the product ranges from 45 to 90 pounds per cubic foot as compared to a true specific gravity of 2.34 to 2.48, corresponding to a density of 146 to 155 pounds per cubic foot. The volume of closed cells in the product was as much as 56.8 percent of the total.

Experimental bloating of Kansas volcanic ash in the laboratory of the State Geological Survey of Kansas indicates that the Kansas ash has the same bloating characteristics as the Oklahoma material.

The lightweight aggregate produced in the laboratory of the Oklahoma Geological Survey is similar to expanded perlite, although the method used to "pop" the volcanic ash was not the same as that used to expand perlite. The volcanic ash was expanded by introducing a stream of volcanic ash into the air intake of an inspirator-type gas burner. The product consists of glassy beads containing one or more bubbles. The bulk specific gravity of the "popped" volcanic ash ranges from 0.22 to 0.088, corresponding to a bulk density ranging from 5.5 to 13.7 pounds per cubic foot. Products made from this material insulate against the transmission of heat, sound, and electricity. It can be used in acoustical and insulating plasters, wall board, lightweight blocks, and slabs.

The State Geological Survey of Kansas has been able to produce a similar expanded or "popped" product from Kansas volcanic ash of Pleistocene age. Attempts to produce a similar product from Pliocene ash were not successful. Additional testing is planned, and the results will be published in a Survey bulletin in 1952.

An expanded volcanic ash product similar to perlite is being produced at Hutchinson, Kansas, under the trade name Mira-Colite. The method used for production of this material is not known in detail.

Concrete

About 1,800 years ago the Romans made a cement composed of two parts by volume volcanic ash and one part slaked lime. Seaworks constructed with this pozzolanic cement are in use today. The Roman or pozzolanic cement is extremely slow-set-

ting if made with slaked lime. To avoid this objectionable feature modern pozzolanic cements are made with Portland cement. Cements of this type are of special interest because they resist disintegration by sea water and in some cases minimize the reaction of some types of siliceous aggregates with the alkalies present in Portland cement. Volcanic ash, in addition to its natural cementing properties, serves the purpose of a fine aggregate that fills the voids between the fine sand aggregate and the cement. In concrete made with volcanic ash as much as 50 percent of the cement may be replaced by the ash, although a smaller proportion commonly is used.

According to Barr (1949, p. 752) the principal use of volcanic ash (pumicite) is for concrete aggregate and its use as an admixture in cement for concrete is attaining increasing importance. In 1945 nearly equal amounts of volcanic ash and pumice were produced for use in abrasives and in concrete. In 1947, 4½ times as much of these same materials was used in concrete as was employed for abrasive purposes.

Miscellaneous Uses

Volcanic ash is used as the chief ingredient in some sweeping compounds, as an insulation in packing water and steam pipes, lagging boilers, and as a loose fill insulation in walls and ceilings. It is also used as a filler or diluent in paint and as a carrier for insecticides. Volcanic ash has been used for the purification and clarification of oils by filtration. It is probable that partially altered volcanic ash is used for the latter purpose.

Within the past few years the State Highway Department has produced large quantities of volcanic ash from at least eight pits in Kansas. This is used largely for top dressing on "black top" or bituminous matt roads. It is probable that in Kansas more ash is used for this purpose than in any other state.

VOLCANIC ASH RESOURCES BY COUNTIES

All Kansas volcanic ash deposits of potential commercial value of which we have knowledge are described or listed under the following county headings. Most of these deposits were visited in the field and sampled by us during the course of this investigation, but a few localities are included on the basis of

data reported to us by land owners and staff members of the Geological Survey. One hundred sixty deposits of volcanic ash in 39 counties are listed. The available data indicate that the tonnage of usable ash in Kansas exceeds 20 million tons although detailed estimates of ash reserves are not given for most individual localities described in the county sections. The economically usable tonnage of any individual deposit is affected by many factors such as transportation facilities, nearness to market, overburden, texture, thickness, color variations, etc.; therefore any locality should be considered in the light of the particular development under consideration. The numbers enclosed in parentheses after many of the locations described refer to laboratory numbers of the Geological Survey's ceramics division and are used in the several tables included in this report.

Chautauqua County

Although a volcanic ash deposit was reported in Chautauqua County by Landes in 1937, efforts to relocate it were unsuccessful until 1950 when, with the aid of local residents, the deposit was found to occur in the NW¼ NW¼ SE¼ and the NE¼ NE¼ SW¼ sec. 9, T. 34 S., R. 12 E. (CQV-1) instead of in the NE¼ SW¼ sec. 9, T. 34 S., R. 13 E. as reported earlier. Ash is exposed on both sides of the north-south road and an auger hole in the field to the east of the road penetrated 4 feet of fresh ash overlying a bed of clay. Petrographic examination shows the ash to be the Pearlette bed of Pleistocene age. Field inspection indicates that the ash deposit underlies at least 10 acres.

Clark County

Six sections in the north-central part of Clark County contain deposits of Pearlette volcanic ash. Smith (1940, p. 200) summarized the occurrence of volcanic ash in the county and subsequently three deposits have been visited and sampled by us. A small ash pit has been opened in the SE cor. sec. 23, T. 30 S., R. 24 W. (CLV-1); and auger holes bored in the pit and to the south of it show the deposit to exceed 11 feet in thickness. Of this thickness 9.0 feet is fresh relatively uncontaminated ash. The deposit is known to be at least 400 feet long but the limits were not determined.

Smith (1940) lists outcrops of volcanic ash along the sides of three small valleys tributary to Bluff Creek in secs. 11, 12, and 13, T. 30 S., R. 23 W. A series of auger holes bored by Harley Holliday in the NE¼ SW¼ sec. 12, T. 30 S., R. 23 W. (CLV-2) penetrated fresh, relatively pure ash that ranged in thickness from 2 to 6 feet. Smith (1940, p. 200) described a small exposure on the side of a small draw in the NW cor. sec. 19, T. 30 S., R. 23 W. and another small exposure on both sides of the small draw in the north-central part of sec. 24, T. 30 S., R. 24 W.

Comanche County

Four volcanic ash deposits were visited and sampled in the field in Comanche County, and one additional deposit was reported to us by the State Highway Department. Pearlette volcanic ash has been mined in the SE¼ NE¼ sec. 12, T. 31 S., R. 18 W. (CMV-1). A maximum of 13 feet of ash was determined to occur at this locality by measuring surface exposures and augering in the floor of the pit. Small surface exposures indicate that the bed extends a linear distance of at least 500 feet. The Kansas Highway Department has estimated that this deposit contains 3,000 cubic yards of recoverable ash. Throughout the entire 13-foot thickness the ash is fresh and relatively free of impurities.

Slightly weathered volcanic ash is exposed in a small pit in the Cen. W½ sec. 7, T. 31 S., R. 17 W. (CMV-4). A thickness of 8 feet was measured on the face of the abandoned pit, but the total thickness was not determined. An early estimate by the Highway Department places the reserves at 4,000 cubic yards of recoverable ash in this immediate area.

About 1.5 feet of Pearlette volcanic ash is exposed in the NW¼ SW¼ sec. 24, T. 32 S., R. 17 W. (CMV-2) and augering at the base of the exposure revealed a total thickness of 6 feet of ash. The upper 5 feet is relatively clean ash, but the lower 1 foot is discolored and possibly impure. The overburden ranges from 3 to 4 feet in thickness.

A bed of Pearlette volcanic ash 2.5 feet thick was found in the NW¼ SE¼ sec. 29, T. 32 S., R. 16 W. (CMV-3). The over-

burden at the point sampled is 2 feet thick, and the ash is underlain with clay.

Decatur County

Three deposits of volcanic ash, two of which are listed by Landes (1928, p. 20), have been reported in Decatur County. The first of the two deposits, in the SE¼ SW¼ sec. 28, T. 4 S., R. 29 W. (DRV-1), was visited and sampled during the course of this investigation; it consists of 5 feet of slightly altered clean ash overlain by a maximum of 15 feet of cemented sand, silt, and gravel. The hard nature of the overburden, however, would make exploitation of the deposit difficult. The second deposit listed by Landes occurs in sec. 12, T. 4 S., R. 30 W. A deposit consisting of 3.2 feet of fresh volcanic ash containing some coarse sand and overlain by a maximum of 5 feet of Ogallala mortar beds was sampled in the NE¼ NE¼ sec. 15, T. 3 S., R. 30 W. (DRV-2). The ash at this locality has been assigned tentatively to the Reager ash bed on the basis of its petrographic characteristics.

Dickinson County

One foot of Pearlette volcanic ash is exposed in a cut along the north side of a road and occurs between cemented conglomerate beds and interbedded in silty clays along the S. line SW¼ SW¼ sec. 26, T. 14 S., R. 2 E. The ash is relatively free of impurities but is slightly weathered. The total extent of the deposit seemingly is limited.

Ellis County

Ellis County contains volcanic ash in two known deposits. One of these is a thin but relatively widespread lentil of Pearlette volcanic ash in the SE¼ SE¼ sec. 17, T. 14 S., R. 19 W. (ESV-1). In this area the ash is about 3.5 feet thick, is fresh, and relatively free of impurities. The State Highway Department has mined some of the ash in the southeast corner of the section and the Department estimates the reserves of ash in the area to be approximately 30,000 cubic yards. At the pit the overburden is 10

feet or more in thickness and consists of clay, silt, and fine sand with some volcanic ash.

Another deposit of volcanic ash occurs in the SW¼ NW¼ (ESV-2) and in the NW¼ SW¼ (ESV-3) sec. 5, T. 13 S., R. 19 W. In this area a maximum of 10.5 feet of volcanic ash with an overburden of approximately 8 feet was found by augering, and as the ash crops out in the adjacent sec. 6, this is probably a large deposit. The ash penetrated by augering is rather fresh and free of excessive contaminants. Both of the Ellis County deposits are underlain by clay.

Ellsworth County

Three deposits of Pearlette volcanic ash, two of which were visited and sampled by us, are known to occur in Ellsworth County. A maximum thickness of 13.5 feet is exposed in the SE¼ NW¼ sec. 28, T. 16 S., R. 7 W. (ELV-24) where the ash crops out along a relatively steep bank on the east side of a creek. The lower 9.5 feet of this bed is light-colored clean ash but the upper part contains some streaks of silt and clay. At least 2,500 tons of ash was determined, on the basis of three auger holes put down to the east of the exposure, to occur in this area but the extent of the deposit may be much larger.

Another deposit was sampled in the N½ SW¼ sec. 22, T. 15 S., R. 7 W. (ELV-2) along a cut of the Union Pacific Railroad. At this locality 9 feet of relatively fresh clean ash was penetrated by augering on the south side of the tracks and indications of ash were also observed for some distance to the north of the tracks.

Relatively impure ash is exposed at a third locality in the Cen. S½ sec. 29, T. 15 S., R. 9 W.

Gove County

The minable reserves of Pearlette volcanic ash in Gove County substantially exceed 100,000 tons. Landes (1928, p. 21) described a deposit in the NE¼ SW¼ sec. 21, T. 13 S., R. 26 W. (GV-1) (Pl. 3A) and reported an estimate of available ash of at least 60,000 tons. Several carloads of ash had been shipped from a pit at this location prior to the writing of his report in

1928. Auger holes in the area have served to increase the known maximum thickness from 16 feet reported by Landes to 17 feet and have confirmed or expanded his earlier estimate of available tonnage. Throughout most of the thickness of the bed, the ash is fresh and free of impurities, although scattered concretions occur at a few places in the bed and the lower 4 to 6 feet contains yellowish streaks. The deposit is underlain by chalk.

In the area adjacent to Smoky Hill River in the south-central part of Gove County, four other deposits of Pearlette volcanic ash were examined. Fourteen feet of ash with a silt, sand, and gravel overburden ranging from nil to 15 feet in thickness is exposed along a tributary valley entering the Smoky Hill from the south in the SW¼ SE¼ sec. 25, T. 15 S., R. 28 W. (GV-2). The ash is nearly white in color and relatively clean. In some places a thin layer of clayey silt and sand with snails occurs between the ash and the underlying chalk but at other places the ash rests directly on Niobrara chalk.

Pearlette ash 13.5 feet thick was found to occur in the SW¼ NW¼ sec. 17, T. 15 S., R. 27 W. (GV-3) where the upper 5 feet is exposed and the remaining 8.5 feet was penetrated by augering. The exposure occurs in the northeast bank of a southeastward-trending draw which is tributary to Smoky Hill River. The deposit contains scattered flaky pieces of Niobrara chalk and some silt and sand and rests on the chalk.

In the Cen. NE¼ sec. 14, T. 15 S., R. 28 W. (GV-5) 6 feet of ash is exposed along both sides of a deep draw just below a farm pond dam. The overburden here ranges from 1 to 10 feet in thickness.

A small deposit of ash occurs in the E½ NW¼ sec. 33, T. 15 S., R. 27 W. (GV-4) where 6 feet of ash is exposed on a narrow spur, but the width of the deposit is only about 50 feet.

Another small discontinuous deposit of ash is present in the NW¼ NE¼ sec. 26, T. 15 S., R. 29 W., where thin Pearlette ash occurs directly in contact with the Niobrara chalk and interbedded in deposits of the Meade formation. The maximum thickness is 4 feet, but along most of the exposure the thickness of the ash ranges from a featheredge to 2.5 feet.

Graham County

Only one deposit of Pearlette volcanic ash is known to occur in Graham County. This deposit has been mined in a small pit exposing 6 feet of clean fresh ash on the north side of a draw in the NE¼ SW¼ sec. 11, T. 8 S., R. 25 W. (GMV-1). The upper 3 feet contains nodules and minute grains of calcium carbonate; 3 feet of impure ash containing appreciable quantities of silt and sand overlies the 6 feet of fresh ash. The overburden, including the impure ash, has a maximum thickness of 12 feet.

Grant County

Substantial reserves of Pearlette volcanic ash are known to occur in the southeastern part of Grant County. These deposits were reported in some detail by Landes (1928, pp. 22-23), and were examined and sampled in the course of the present investigation. One deposit in the NW¼ sec. 24, T. 30 S., R. 35 W. (GTV-3) was opened commercially more than 30 years ago and ash is now exposed from the northeast corner to the southwest corner of the quarter section. Landes reports that prior to 1928 this mine was connected with the Santa Fe Railroad by a narrow-gauge spur but the track had been removed at the time Landes prepared his report. In this area 15 feet of ash is exposed and the maximum thickness is judged to exceed this figure slightly. The overburden has a maximum thickness of 8 feet and consists of silt and sand. In general appearance the ash is clean and light colored.

A deposit in the SE¼ NE¼ sec. 1, T. 30 S., R. 36 W. (GTV-1) was being actively worked by the State Highway Department in 1948. The maximum thickness of ash determined both by exposures and augering is 23.5 feet and the face that was being worked in the pit is 19.5 feet thick. The ash is fresh and its only contaminant is a very small percentage of fine sand. More than 99 percent of this ash passes a 100-mesh sieve and 90 percent passes a 200-mesh sieve. The overburden where present consists of silt and sand attaining a maximum thickness of more than 15 feet; the ash rests on sand (Pl. 2D). This deposit is known to extend into adjacent sections to the east and the reserve of ash at this locality is large.

A third deposit occurs in the SE¼ NW¼ sec. 17, T. 30 S., R. 35 W. (GTV-2). A small pit formerly operated at this locality exposes 6 feet of volcanic ash containing some impurities, overlain by 2 to 3 feet of silty to sandy ash, which in turn is overlain by 1 to 5 feet of silt and sand. Sand underlies the ash bed.

Gray County

In 1944 Latta (p. 173) reported an exposure of volcanic ash on the side of a small draw in the NW¼ sec. 35, T. 29 S., R. 27 W. (GRV-1). During the course of the field investigation for this report this locality was visited and two auger holes were bored to determine the thickness and character of the deposit. At the locality reported by Latta 4 feet of clean, apparently fresh ash overlain by 1.5 feet of partly cemented soil was penetrated with the auger. Underneath the ash is yellowish clay with fine sand and silt.

In sec. 26 (GRV-2) adjacent to the north, 11 feet of ash is exposed along the south side of a creek bank where the partly cemented upper part of the ash forms the crest of the bank. The upper 3 feet of the bed contains irregular masses of calcium carbonate and mixtures of sand and some silt. The underlying 6 feet is white to light gray, clean, and relatively fresh. The basal 2 feet of the bed is tan or clean-gray in color but is apparently relatively free of contaminants. Sand underlies the ash.

Hamilton County

Several small deposits of volcanic ash were reported by Landes in 1928 (p. 23) as occurring in southern Hamilton County. These deposits were described by him as ranging in thickness from 1½ to 2½ feet and as occurring at the following localities: near the Cen. E. line sec. 20, T. 26 S., R. 41 W.; SW¼ SW¼ sec. 22, near the Cen. sec. 13, SW¼ sec. 28, and SE¼ sec. 14, T. 26 S., R. 41 W. Other exposures were reported in the SW¼ SE¼ sec. 1, T. 26 S., R. 42 W. and the SE¼ sec. 29, T. 26 S., R. 40 W. Of these localities only the deposit near the Cen. sec. 13, T. 26 S., R. 41 W. (HNV-1) was visited in the field and sampled for this study. At this locality the ash bed is 2.5 feet thick, which represents the maximum of the several deposits described by Landes and crops out for about a quarter of a mile

along a creek bank, but the total extent of the deposit is not known. The volcanic ash is altered throughout by weathering and contains impurities of calcium carbonate, sand, and clay.

Harper County

Commercial mining of Pearlette volcanic ash was initiated in Harper County in 1926 and production from a pit and plant located east of Anthony was carried on for a number of years. This operation is described in some detail by Landes (1928, pp. 25-26) and the pit was visited and sampled by us for the present study. Ash now exposed around the margins of the abandoned pit ranges in thickness from 2 to 6 feet, although along most of the periphery the thickness of ash remaining in the area does not greatly exceed the 2-foot minimum. The ash has been altered by weathering with the resultant production of disseminated clay aggregates, and contaminants of sand and red silt occur generally throughout the deposit. An eastward extension of this deposit occurs on both sides of the highway and to the east of the abandoned pit which is in the NE¼ NE¼ sec. 29, T. 33 S., R. 6 W. (HPV-1).

A second deposit sampled in Harper County occurs in the NW¼ SW¼ sec. 18, T. 31 S., R. 7 W. (HPV-2). The ash bed is not exposed at this locality but by augering through 2 feet of overburden 3.5 feet of ash was found. The ash at this locality is quite similar to the material formerly mined east of Anthony, but as only one auger hole was bored the extent of the deposit is unknown.

Jewell County

The northern part of Jewell County contains large reserves of Pearlette volcanic ash. Landes (1928, p. 28) reports that the Pumicite Company has record of about 30 deposits in that area. He estimates that the reserves of available volcanic ash in the county are probably between 3 and 4 million tons. Samples from 11 localities in Jewell County have been collected in the field and examined petrographically. The ash is relatively unaltered by weathering and free of contamination, it is light in color, and it ranges in texture from coarse to fine. At a few places the ash contains scattered fossil snail shells in the basal part and snail

shells occur in the clay immediately below its base; in general the deposits are relatively free from calcium carbonate nodules.

The thickest of the deposits sampled in Jewell County has a maximum of 17 feet exposed in an open pit in the NW¼ NE¼ sec. 16, T. 1 S., R. 6 W. (JV-6) and the basal 5 feet of the bed was sampled by augering in the bottom of the pit. The pit is located on the east bank of a northward-flowing creek where the overburden ranges from 1 to 14 feet in thickness. Twenty thousand cubic yards of ash have been estimated as occurring in this deposit (Byrne, Houston, and Mudge, 1950).

Two auger holes, 250 feet apart in the NE¼ NE¼ sec. 20, T. 1 S., R. 6 W. (JV-5) penetrated 9 and 10 feet of volcanic ash below an overburden with a maximum thickness of 10 feet. The deposit is quite extensive as it is exposed on both sides of the draw and extends northward into sec. 17, with a total linear distance of outcrop of nearly half a mile.

Nine feet of ash underlain by clay was sampled from an exposure in the north bank of a creek in the NW¼ SE¼ sec. 32, T. 1. S., R. 9 W. (JV-3). For this locality Byrne, Houston, and Mudge (1950) report a maximum thickness of 13 feet of volcanic ash and estimate the size of the deposit at 5,000 cubic yards. The overburden consists of silty clay approximately 4 feet thick. Two small deposits were sampled within a mile to the southeast of the JV-3 locality. Three feet of ash is exposed along a road in the NW¼ NW¼ sec. 4, T. 2 S., R. 9 W. (JV-2) and 2 feet of ash was penetrated in an auger hole in the SW¼ SE¼ sec. 33, T. 1 S., R. 9 W.

Ten feet of volcanic ash was sampled in the bottom of a small eastward-trending valley in the SE¼ NW¼ sec. 5, T. 2 S., R. 9 W. (JV-10). The overburden at this locality is 20 feet thick. Byrne, Houston, and Mudge (1950) estimate that 6,000 cubic yards of ash occurs in the deposit.

At the west side of a small dam along a tributary valley side in the SW¼ NE¼ sec. 7, T. 2 S., R. 9 W. (JV-11), 8 feet of ash is exposed, and other outcrops of this deposit occur to the north and east.

Four feet of ash is exposed along the north bank of a small draw in the NE¼ NE¼ sec. 36, T. 1 S., R. 10 W. (JV-8) and is reported to have been penetrated in a well to the south. The deposit is also exposed across the section line road to the east.

Ash 2.5 feet thick was penetrated by augering in the SE¼ NE¼ sec. 6, T. 3 S., R. 8 W. (JV-7) and clay was found underneath.

One deposit of volcanic ash was sampled in the southern part of Jewell County in the N½ NE¼ sec. 29, T. 5 S., R. 9 W. (JV-1). One auger hole penetrated 3 feet of overburden and 6.5 feet of ash resting on clay. Several exposures occur near the location of the auger hole, but the total extent of the deposit is not known.

A sample of ash obtained from a bored well in the SE¼ sec. 3, T. 2 S., R. 10 W. was submitted to us for examination. The sample consists of fresh and relatively uncontaminated material. It is reported by Mr. F. C. Hockett that 7 feet of ash occurs at a depth of from 93 to 100 feet.

Kingman County

Only one small deposit of volcanic ash is known to occur in Kingman County. In the NW¼ NE¼ sec. 16, T. 25 S., R. 10 W. (KMV-1), 0.5 to 1 foot of ash was sampled from 3 to 4 feet below the surface along a road cut (south side of road). Despite the thinness of the bed this ash may be of interest as a local ceramic raw material because of its unusual fineness (more than 50 percent passes a 325-mesh screen), purity, and nearly white color.

Kiowa County

One deposit of Pearlette volcanic ash was located and sampled in Kiowa County. Ten feet of volcanic ash occurs as the capping bed of a spur of thick Cretaceous Kiowa shale northeast of Belvidere in the NW¼ NE¼ sec. 5, T. 30 S., R. 16 W. (KV-1). The overburden consists of only 1 to 2 feet of relatively loose silt, the ash is gray to light gray in color, and a screen analysis (Table 4) shows the particle size to be finer than average. The deposit is restricted to the crest of one spur and it therefore is not extensive, although it is readily available.

Lincoln County

Pearlette volcanic ash has been mined in Lincoln County during the past several years for use in ceramic industries and as sweeping compound. The ash crops out at a number of locali-

ties in the southwestern corner of the county and has been mined at two pits in the SE¼ SW¼ and the SW¼ SE¼ sec. 27, T. 13 S., R. 10 W. (LV-1 and LV-2). The ash as exposed in the pit faces is 6 to 6.5 feet thick, fairly fresh, and free of contaminants. The overburden consists of silt and sandy silt and is relatively thin. This ash bed crops out along road cuts bordering sec. 27 to the south and west (Pl. 3C) and extends into the adjacent secs. 28 and 34.

Logan County

Of the six known deposits of volcanic ash in Logan County, the thickest bed examined has a maximum thickness of 14 feet and is located in the SW¼ NW¼ sec. 12, T. 13 S., R. 35 W. (LOV-3). Seven feet of ash is exposed in a pit and an auger hole bored in the floor of the pit penetrated an additional 7 feet of ash. The working face in the pit is approximately 200 yards wide and the overburden is 10 feet thick. The material at this locality is fresh and free of contaminants and petrographically similar to that of other Pearlette localities. The State Highway Department has mined ash at this pit and across the road to the west in sec. 11 (LOV-2) where 9 feet of ash rests directly on Cretaceous Pierre shale and is exposed for about 180 yards along the southwest bank of a southeastward-flowing tributary to Smoky Hill River. The lower 1 foot of ash is somewhat cemented with calcium carbonate and the overburden is 5 to 10 feet thick (Pl. 2B). Another exposure of this deposit occurs a quarter of a mile north in the same section.

The State Highway Department has also mined volcanic ash in the SW¼ NW¼ sec. 36, T. 12 S., R. 36 W. (LOV-1) where 8 feet of ash is exposed in a pit face and crops out along the north side of a small valley. Small exposures of this deposit occur to the south and southwest of the pit. The ash has an overburden of 1.5 to 6 feet of loose material and rests on clayey sand; it is light gray in color with a few hard streaks disseminated through the deposit.

Six feet of ash exposed on the east side of a valley tributary to Smoky Hill River was sampled in the Cen. NE¼ sec. 34, T. 14 S., R. 33 W. (LOV-4). The deposit is poorly exposed 200 yards to the west-southwest on the opposite side of the small

valley. The overburden of silt and sand is more than 2 feet thick and dark-tan clayey silt containing snails underlies the ash.

Six feet of light-gray volcanic ash with a few brown streaks was examined in the SW¼ SE¼ SW¼ sec. 35, T. 13 S., R. 33 W. (LOV-5) and in the NE¼ NW¼ NW¼ sec. 2, T. 14 S., R. 33 W. The beds have an apparent dip of 8 percent toward the south.

A relatively small deposit of volcanic ash was reported to us by the county engineer of Logan County as occurring in the E½ NE¼ sec. 17, T. 12 S., R. 36 W.

Lyon County

An early volcanic ash mining operation was carried on within the city limits of Emporia. According to H. G. O'Connor, gravel pits were opened in the area between Sixth and Seventh Streets and just east of Garfield Street (SE¼ SE¼ SW¼ sec. 9, T. 19 S., R. 11 E.) in the late 1880's. In about 1910 volcanic ash was mined by underground methods in this same area and mining operations continued for several years. Local residents report that the maximum thickness of the bed as it was mined ranged from 3 to 4 feet. A sample of volcanic ash obtained from 40 feet below the surface in a well at the corner of Sixth and West Streets (SW¼ SW¼ SW¼ sec. 10, T. 19 S., R. 11 E.), Emporia, was furnished to us by Mr. A. C. Carpenter. This sample, when examined petrographically, proved to be relatively fresh clean Pearlette volcanic ash. The thickness of ash penetrated in this well was 5 inches, but as the well is located five to six blocks from the old mine, the extent of this deposit may be relatively large.

Marshall County

Two exposures of volcanic ash have been sampled in Marshall County. These deposits are both correlated petrographically with the Pearlette bed and occur within an area of glacial deposits. These exposures are located in the SE¼ sec. 9, T. 4 S., R. 9 E. (MLV-1) and in the NE cor. sec. 11, T. 4 S., R. 9 E. (MLV-2). The first of these is 5.5 feet thick and is exposed in a shallow road cut, while the second is 2.5 feet thick and is exposed 50 feet south of Kansas Highway 9 along a creek bank. The ash at this locality is weathered but relatively free of contaminants.

McPherson County

Known deposits of volcanic ash in McPherson County are restricted to a linear belt of nine exposures in the north-central part of the county a few miles north of the City of McPherson; the trend of the group of deposits is east-west.

Samples from three of these localities have been examined petrographically and are characteristic of the Pearlette bed. The samples are all free of significant contaminants and range from fresh to slightly weathered, the weathered specimens showing some calcite inclusions in the glass shards.

The westernmost deposit known from McPherson County is in the Cen. E½ sec. 28, T. 18 S., R. 5 W. (MPV-3), where 3 feet of Pearlette volcanic ash overlain by 12 feet of overburden is exposed in an abandoned pit. Several years ago, volcanic ash mined from the SE¼ sec. 28 was packaged and sold under the name of "Hurricane Cleaner," but this product is no longer on the market.

Five deposits of volcanic ash in T. 18 S., R. 4 W. were visited and sampled. In the NW¼ SW¼ sec. 10 (MPV-2), 4 feet of ash which is relatively free of contaminants is exposed in a road cut and grader ditch along the north-south section line road. In the Cen. W½ NW¼ sec. 15 (MPV-4), 3 feet of ash is exposed in an inactive pit, and in the same section in the NW¼ SW¼ (MPV-5), 4.5 feet of Pearlette ash is exposed along a creek bank. The ash at this locality, relatively unweathered and free of impurities, overlies clay. A maximum thickness of 3 feet of ash is exposed in an inactive pit in a creek bank and road ditch near the southeast corner of sec. 16. In the NW¼ SW¼ sec. 16, ash is exposed along the bank of a small creek. In the NW¼ sec. 20, 1.5 feet of ash is exposed. Six and one-half feet of relatively clean ash is exposed in the face of a small pit in the SW¼ NW¼ sec. 22 (MPV-6). At the time the deposits were visited this ash was being produced to add color and strength to cements.

Relatively compacted and weathered ash is poorly exposed along the west side of a northward-trending valley in the SE¼ NE¼ sec. 14, T. 18 S., R. 3 W. (MPV-8). In the NW¼ SE¼ NW¼ sec. 20 (MPV-1), 8.5 feet of light-colored, relatively clean, fairly fresh Pearlette volcanic ash is exposed in an intermittently worked pit. A sieve analysis (Table 4) shows this to be a rela-

tively coarse ash. The overburden at the pit face ranges from 1 to 10 feet in thickness and clay underlies the ash. According to Landes (1928, p. 30), 45 to 50 thousand tons of ash occurs in this area. In the NE¼ NE¼ sec. 29 volcanic ash is exposed in the face of two pits. The southwesterly and larger of these two pits has been inactive for several years, but the smaller northeastern pit has been worked intermittently in recent years.

Volcanic ash 4.5 feet thick with 4 to 5 feet of overburden is exposed in a pit on the west bank of a draw in the Cen. W½ SW¼ sec. 5, T. 18 S., R. 2 W. (MPV-7). The Highway Department has used ash from this pit but the extent of the deposit is not known. Volcanic ash is exposed in a road ditch in the NW¼ sec. 13, T. 18 S., R. 4 W.

Meade County

Meade County contains perhaps the most continuously active volcanic ash producing area in Kansas. One to several commercial pits have been active in the county each year since fairly early in the century; the cumulative tonnage of ash produced probably exceeds that for any other county. Cragin's type locality of the Pearlette bed (Cragin, 1896) occurs in the NE¼ sec. 21, T. 33 S., R. 28 W. (MEV-7) and all the deposits studied petrographically within the county are assignable to this bed. Its stratigraphic significance in this area is great because of its widespread occurrence and the abundance of fossil mollusks and vertebrates at the base of the ash and in some places disseminated through it. All the deposits sampled are underlain by clay.

The largest volcanic ash operation in Meade County is the mine and plant operated by the Cudahy Packing Company in the SW¼ sec. 2, T. 31 S., R. 28 W. (MEV-5). The plant is served by a spur railroad which connects with the main line of the Chicago, Rock Island, and Pacific Railroad at Fowler. Seventeen feet of clean Pearlette ash is exposed in the face of the pit and is overlain by 7 feet of ash, sand, and silt intermixed and a variable thickness of silt. The ash is relatively fresh throughout its thickness except for the bottom 1 foot which contains a small percentage of clay as an alteration product. Views of the pit and processing plant are shown on Plate 6. The ash, which is mined by open pit methods, is screened and dried in the plant. The

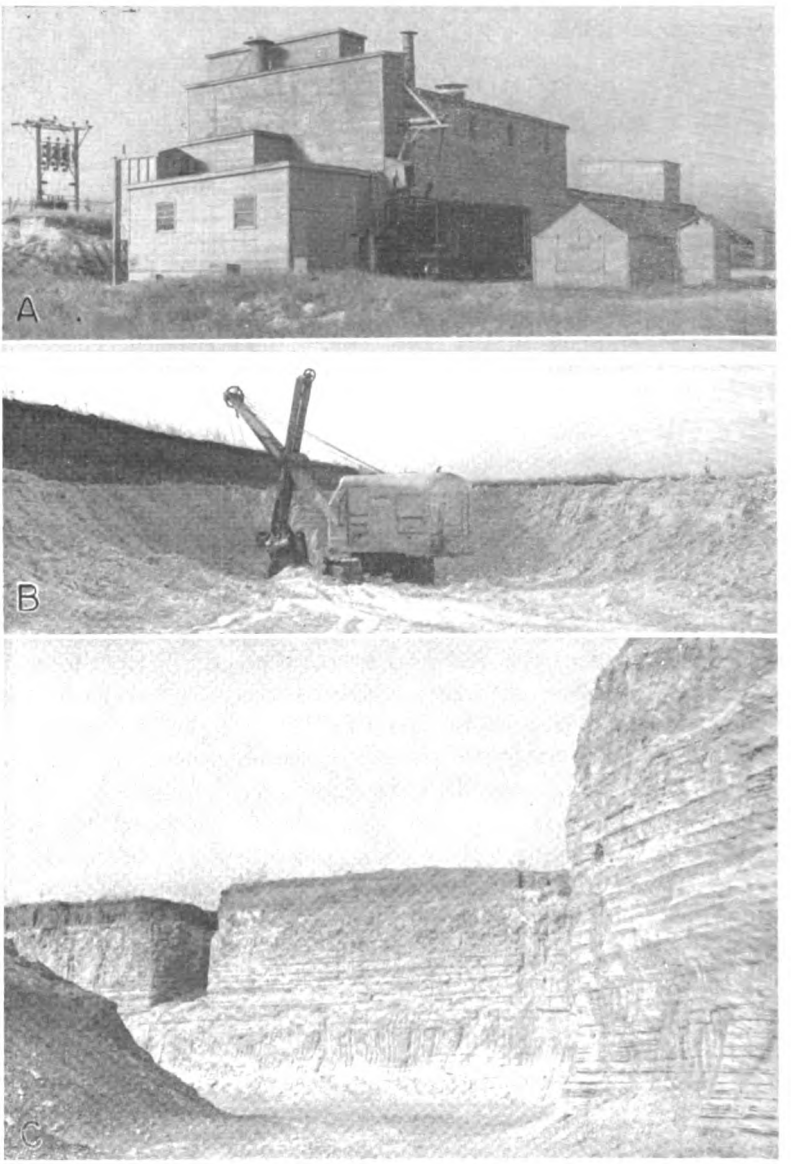

PLATE 6. Plant and pit of Cudahy Packing Company, Meade County. **A**, General view of volcanic ash processing plant. **B**, Loading shovel in operation. **C**, General view of pit in Pearlette ash bed. (Swineford, 1951.)

product is shipped both in bags and in bulk carload lots, loaded on the siding adjacent to the plant.

Volcanic ash has been mined extensively in the area immediately east of Fowler where there are now large abandoned pits in the adjacent corners of SW¼ SW¼ sec. 33, T. 30 S., R. 26 W., in the NW¼ NW¼ sec. 5, T. 31 S., R. 26 W., and E½ NE¼ sec. 6, T. 31 S., R. 26 W. (MEV-6). The ash is reported to have a maximum thickness of 20 feet in this area, although at the time the face was sampled only 10 feet of ash was exposed in the Cen. E½ NE¼ sec. 6, T. 31 S., R. 26 W. (MEV-6). The ash is clean and relatively unaltered by weathering. Although considerable quantities of ash have been removed from this locality by mining operations, a sizeable reserve is judged to remain in the area.

A relatively large pit was operated for a number of years by the Mid-Co Products Company in the NW¼ SE¼ and the SW¼ NE¼ sec. 26, T. 32 S., R. 28 W. (MEV-3) (Pl. 2A). In 1940 when this pit was being mined actively, the maximum thickness of ash exposed in the face was 18 feet, but when it was sampled in 1948 only 8 feet of clean ash was accessible for surface sampling. About 5 acres of the deposit is estimated to have been worked out, but the remaining reserves are probably quite extensive as the ash bed crops out along the east valley wall of Crooked Creek both to the north and south of this locality.

Volcanic ash has also been mined extensively in the SW¼ sec. 34, T. 31 S., R. 28 W. (MEV-1). Ash 9½ feet thick is exposed in the face of a large inactive pit and the reserves are judged to be relatively extensive. The lower 5 feet of the bed as exposed is clean and free of contaminants, whereas the upper part of the bed contains a few silty streaks and scattered calcareous concretions. A continuation of this deposit occurs in the SE¼ SE¼ sec. 33, T. 31 S., R. 28 W. (MEV-2).

Another area of extensive ash mining in former years in Meade County is in the NE¼ sec. 9, T. 32 S., R. 28 W. (MEV-4), where there are several abandoned and slumped-in pits. The ash occurs in two distinct beds separated by sandy silt. Where sampled the upper bed is 6 feet thick and is relatively fresh, clean ash. The lower bed is 8 feet thick and contains dark specks and some yellow streaks.

Volcanic ash has been mined at a number of other localities in Meade County. Pits which are known to have been operated

in the past or which are now in intermittent operation are located in secs. 11 and 12, T. 31 S., R. 28 W.; the NW¼ sec. 18, T. 32 S., R. 28 W.; sec. 9, T. 33 S., R. 28 W.; and the SW¼ sec. 8, T. 35 S., R. 30 W. Volcanic ash of sufficient thickness to be of potential value, but as yet undeveloped, is exposed in the SE¼ sec. 26, T. 30 S., R. 28 W. (MEV-8); the SW¼ sec. 13, T. 32 S., R. 28 W.; the NW¼ sec. 24, T. 32 S., R. 28 W.; the NE¼ sec. 21, T. 33 S., R. 28 W. (MEV-7); and in sec. 3, T. 33 S., R. 28 W.

Nemaha County

Landes (1928, p. 35) reports a deposit of yellowish-white, clayey, impure volcanic ash in T. 4 S., R. 11 E., Nemaha County, on the farm of J. W. Shell, 1.5 miles east of Vermillion and a short distance east of the Marshall County line and south of State Highway 9. A small quantity has been produced in the NW¼ SW¼ sec. 7, T. 4 S., R. 11 E. This apparently is the locality described by Landes, for the present location of State Highway 9 is half a mile north of its former position. When the locality was visited in 1948, the former pit was washed over and ash was not exposed.

Ness County

A deposit of Pearlette volcanic ash occurs in the NE¼ SE¼ NW¼ sec. 30, T. 18 S., R. 23 W. (NSV-1) in the northwestern part of Ness City. The ash is exposed along a creek bank and was sampled by augering a short distance back from the crest of the bank where 6 feet of unaltered ash was found to overlie dark-tan plastic clay. The lateral extent of the deposit is not known because of the small exposure and the fact that it occurs largely below the local drainage level.

Another deposit of Pearlette volcanic ash is exposed in a pit excavated by the Highway Department on the top of a knoll in the S½ SW¼ sec. 6, T. 19 S., R. 26 W. (NSV-2). Nine feet was penetrated by digging and sand was found at the base of the deposit; however, the owner reports a maximum thickness of 12 feet of ash in the area. The ash is irregularly bedded and slightly weathered but relatively clean, although the top part contains sand and many concretions.

Norton County

Active mining of volcanic ash was started in the vicinity of Calvert in 1908 and since that time one or more ash mines have been in almost continuous operation in this area. At the present time one large mine is operated at Calvert in the NW¼ SW¼ sec. 25, T. 2 S., R. 22 W. (NNV-1) by the Wyandotte Chemicals Corporation of Wyandotte, Michigan (Pls. 1A and 7). The ash is mined by the open-cut method, rough screened in the pit, and hauled by truck about one-eighth of a mile to a screening and storage plant along a rail siding at Calvert. In the section adjacent to the southwest, a large abandoned ash pit occurs in the NE¼ NE¼ sec. 35, T. 2 S., R. 22 W. Ash 17 feet thick has been exposed in the active pit faces in the Calvert area; it is reported that the maximum thickness of the bed determined by test borings is 22 feet. The pit of the Wyandotte Chemicals Corporation has been established as the type locality for the Calvert ash bed in the lower part of the Ash Hollow member of the Ogallala formation. The Calvert ash is a darker shade of gray than the Pearlette ash, and the ash exposed in the Calvert area is unaltered by weathering and is free of contaminants of silt and sand, although a few concretions of calcium carbonate occur disseminated throughout the deposit. About 2 feet of bentonite (Pl. 5B) and silty and clayey ash overlie the clean ash exposed in the pit. The deposit apparently extends into sections adjacent to the area of active mining and the quantity of ash available in the Calvert area is judged to be large.

In addition to the Calvert area, volcanic ash has been mined at four localities in Norton County. In the SE¼ SE¼ sec. 25, T. 3 S., R. 25 W. (NNV-3), 10 feet of ash is exposed along the banks of a draw and in an abandoned pit. The owner reports that the maximum thickness of ash at the locality is 15 feet, and at the point where this deposit was sampled the overburden is only 4 feet thick. This deposit is petrographically similar to the Calvert ash; it is unaltered by weathering, and free of contaminants.

Ash 7 feet thick and underlain by silt is exposed in an abandoned pit in the SW¼ SE¼ sec. 2, T. 3 S., R. 25 W. (NNV-4) and also along both sides of a southeast-trending valley 280 yards northward from the section line road. This deposit, which is slightly altered by weathering and contains traces of sand and

silt as contaminants, has been assigned petrographically to the Reager ash bed. Another small pit in the Reager ash bed occurs in the SW¼ NW¼ sec. 16, T. 2 S., R. 21 W. on the east side of a northward-trending valley southeast of the City of Almena. Volcanic ash 6.5 feet thick is exposed in the pit face, and the bed thins southward, with cementation of the upper part of the ash. On the east side of this same valley 2 to 3 feet of ash is exposed along the road cuts of the north-south section line road. A sample of the ash from this locality shows that it has been strongly altered by weathering and contains some calcite, but otherwise is relatively free of contaminants.

Four feet of volcanic ash is exposed in the face of a sand and gravel pit in the Cen. SE¼ sec. 16, T. 1 S., R. 21 W. (NNV-8). The ash at this locality is assigned to the Reager bed. The deposit is relatively unaltered by weathering but contains a significant admixture of coarse sand and is underlain with sand. The extent of the ash is apparently small.

Volcanic ash is exposed at four additional localities in Norton County which have not been exploited. The thickest of these deposits was sampled at the Cen. S. line sec. 1, T. 3 S., R. 22 W. (NNV-6), where 9.5 feet of ash is exposed along the south side of a small valley of a northwestward-flowing stream. The exposure extends about 50 yards in an east-west direction. The overburden is about 15 feet thick and sand underlies the ash. This deposit is assigned only tentatively to the Reager bed for the ash has been somewhat altered by weathering.

A maximum of 5 feet of volcanic ash occurs along the west bank of a small creek in the SE¼ SE¼ sec. 27, T. 4 S., R. 23 W. (NNV-7) where it is exposed for about 100 feet and the overburden ranges in thickness from 5 to 20 feet; sand underlies the ash. This deposit, which can be seen on the west side of U.S. Highway 283, is tentatively assigned to the Calvert bed. The ash is significantly altered by weathering and the uppermost 2 feet contains a strong admixture of sand.

In the NW¼ NW¼ sec. 2, T. 4 S., R. 24 W. (NNV-2) a maximum of 4 feet of volcanic ash is exposed along the east side of a section-line road and in the near-by creek bank to the north. It has a small amount of silt and sand overburden and is underlain by calcareous silt and sand. This deposit is known to occur within the Ogallala formation but owing to alteration of the

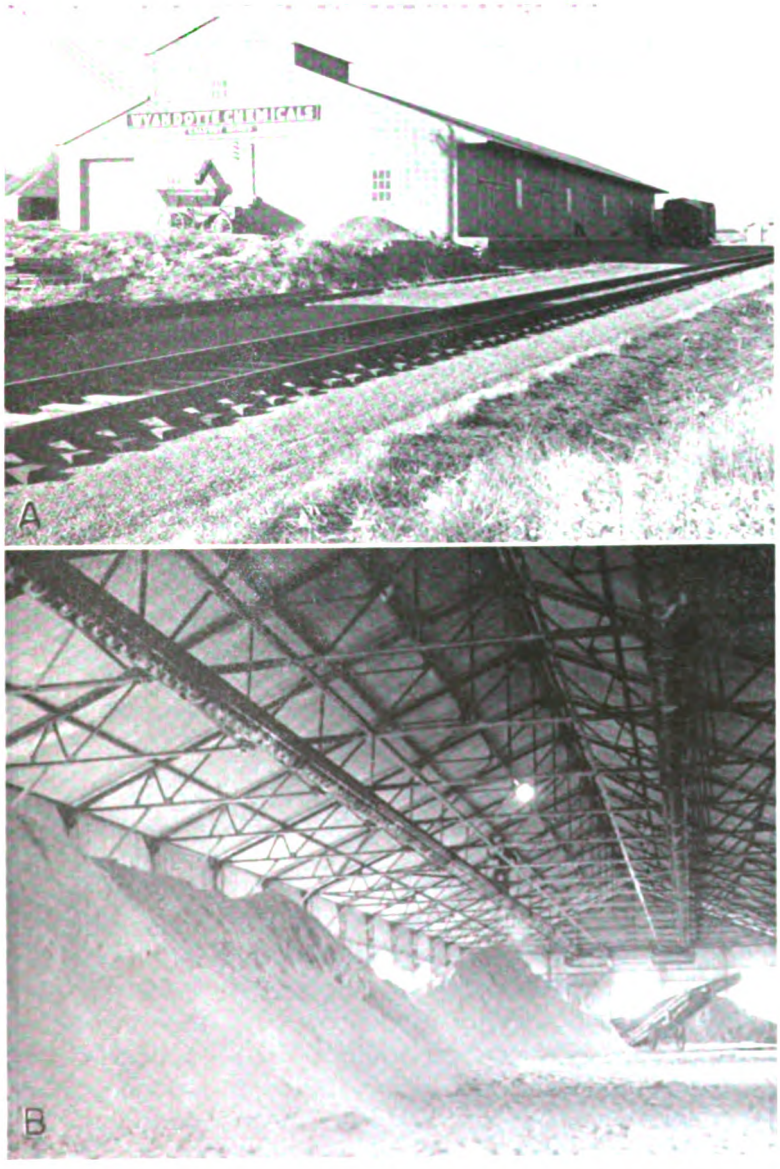

Plate 7. Plant of Wyandotte Chemicals Corporation, Norton County. **A**, Storage and screening plant. **B**, Storage area. (Swineford, 1951.)

shards by weathering it has not been assigned definitely to any of the named beds.

Ash 2.5 to 3 feet thick is exposed along creek banks in the NE¼ NW¼ sec. 36, T. 2 S., R. 25 W. (NNV-5) and in the adjacent section to the north. Mortar beds 8 feet or more in thickness occur above the outcrop sampled and silt underlies the ash. This exposure has been established as the type locality of the Reager ash bed (Pl. 1B). The ash is slightly altered by weathering and contains a small quantity of sand.

Ottawa County

Two deposits of volcanic ash are known to occur in Ottawa County. At the largest of these a maximum of 6 feet of Pearlette volcanic ash is exposed along the east bank of a creek for about 100 feet in the NE¼ NW¼ sec. 29, T. 10 S., R. 5 W. (OV-1). The overburden at the locality sampled is about 14 feet thick. The ash is slightly weathered, nearly white in color, and relatively free of contaminants. Fossil snail shells occur abundantly in the clay at the base of the ash. A small deposit of volcanic ash in a bed about 2 feet thick occurs in the SE¼ SW¼ SE¼ sec. 3, T. 9 S., R. 2 W. (OV-2) along a meander scar in a creek bank.

Phillips County

The largest of five deposits of volcanic ash known to occur in Phillips County and the only one that has been mined commercially to any extent is located in the SE¼ NE¼ (PHV-2) and the NE¼ NE¼ (PHV-3) sec. 33, T. 5 S., R. 19 W. In this area Pearlette volcanic ash is exposed in two pits. A maximum thickness of 15 feet of ash was found by augering in the bottom of the pits. On the pit face where ash was sampled the overburden is only 2 feet thick. The ash is relatively unaltered by weathering and contains a trace of sand. In the SW¼ SW¼ sec. 14, T. 1 S., R. 18 W. a few inches of Pearlette ash crops out along the hillside a short distance north of the section-line road. This deposit is interesting petrographically because of the high degree of cementation by calcium carbonate (Pl. 4C).

Nine feet of Ogallala volcanic ash assigned to an unnamed bed occurs in the NE¼ NE¼ sec. 19, T. 2 S., R. 18 W. (PHV-1)

and is also exposed in adjacent secs. 17 and 20. The lateral extent of the deposit is more than a quarter of a mile. A sample obtained by augering through the bed 10 feet south of the pit showed the ash to be fresh and to contain a small amount of sand admixture. Six and a half feet of volcanic ash, petrographically similar to PHV-1, was sampled in the Cen. NE¼ sec. 3, T. 2 S., R. 19 W. (PHV-4) on the east bank of a northward-flowing stream. The overburden above most of the deposit is excessive and includes 7 feet of mortar beds.

Reager volcanic ash is exposed along a road cut in the northern part of the NW¼ NE¼ sec. 30, T. 1 S., R. 19 W. (PHV-5). At the locality sampled the bed is about 1.5 feet thick but the upper half a foot contains calcium carbonate.

Pratt County

Four deposits of Pearlette volcanic ash were located and sampled in Pratt County. The thickest of these deposits was sampled from a pit in the S½ SW¼ sec. 21, T. 27 S., R. 12 W. (PRV-1), where 14 feet of volcanic ash, the lower 10 feet fresh and free of contaminants, is exposed. The deposit is reported to extend into the adjacent quarter section to the east and southward across the section line into sec. 28; it is estimated to contain a reserve of 48,000 tons of ash. Throughout much of the area of this deposit the overburden is relatively thin.

Ten feet of volcanic ash overlain by 2.5 feet of mixed ash and sand was sampled in a pit in the NE¼ SE¼ sec. 22, T. 28 S., R. 14 W. (PRV-3). The ash is somewhat weathered and has about 2 percent sand and silt admixture. In the NW¼ SE¼ sec. 34, T. 27 S., R. 12 W. (PRV-4), 4 feet of Pearlette volcanic ash was sampled in a pit where the ash is overlain by 6 feet of mixed ash, sand, and silt. The ash is altered somewhat by weathering which gives it a slightly higher clay content than is typical of Pearlette deposits. In the SW¼ SW¼ sec. 23, T. 27 S., R. 11 W. (PRV-2), 2.5 feet of Pearlette ash was sampled. This sample is slightly altered by weathering but is relatively free of contaminants. Volcanic ash is reported to underlie a 40-acre tract at the Cen. sec. 31, T. 27 S., R. 12 W. The owner reports that the ash deposit, which is not exposed, is 15 to 20 feet in thick-

ness. The reserve of ash in the area is reported to be approximately 54,000 tons.

Rawlins County

In Rawlins County two deposits of volcanic ash, each having a maximum thickness of 14 feet, have been assigned to the Pearlette bed of Pleistocene age, one deposit has been assigned to the Reager bed of the Ogallala formation, and a fourth is not given definite stratigraphic placement. Of the Pearlette ash deposits, one occurs in the NE¼ NW¼ sec. 14, T. 3 S., R. 35 W. (RWV-1) and is underlain by clayey silt and sand where it has been mined. The upper 6 feet of the ash is exposed and the lower 8 feet was sampled by augering. The second Pearlette deposit occurs in the NW¼ SW¼ sec. 22, T. 3 S., R. 35 W. (RWV-4), where a sample was taken from an intermittently active pit. The ash in both of these localities is exceptionally fresh and free of contaminants. Both of the deposits are probably extensive; however, the overburden ranges from 10 to more than 16 feet in thickness. The deposit in sec. 14 extends into the SW¼ of the section where 10 feet of ash is exposed in a small gully.

The Reager volcanic ash bed is exposed in a steep bluff adjoining a section-line road and a valley in the W½ SW¼ sec. 4, T. 4 S., R. 34 W. (RWV-2). The Reager ash bed, 2 feet thick and overlain by about 50 feet of overburden at this locality, is slightly altered by weathering and contains small calcite inclusions in the glass. Another exposure of Ogallala volcanic ash, not assigned to a stratigraphic position within the formation, occurs in the NW¼ NW¼ sec. 33, T. 3 S., R. 34 W. (RWV-3). Small outcrops along the edge of a valley indicate that this deposit extends 0.3 mile to the east and north and two auger holes penetrated 6 feet of ash. Sand and silt occurs below the ash. The material in RWV-3 contains 2 to 18 percent of calcium carbonate (Table 2).

Reno County

Several pits have been opened in a Pearlette volcanic ash deposit in the NE¼ SW¼, NW¼ SE¼ (ROV-1), and SW¼ NE¼ sec. 14, T. 25 S., R. 8 W. Where this deposit was sampled

10 feet of ash is exposed in the face of a pit. The ash is relatively fresh and free of contaminants but one of the samples taken is somewhat coarse-textured. Although an estimate of tonnage has not been made, a large quantity of ash seems to be present in this area.

Three feet of volcanic ash is exposed in a small pit in the SE¼ NE¼ sec. 1, T. 25 S., R. 7 W. (ROV-2). The ash at this locality is calcareous, somewhat altered by weathering, but relatively free of sand contamination.

Rooks County

Landes (1928, p. 22) reports 15 feet of volcanic ash underlying an area of about 20 acres in the NE¼ NE¼ sec. 7, T. 8 S., R. 16 W. (RKV-2). At the time the area was visited for this investigation one auger hole bored through the deposit penetrated only 4.5 feet of ash. As this deposit is not exposed at the surface in this vicinity, it must be sampled by augering or by a test pit. The one auger hole reported does not furnish basis for adequate evaluation of the deposit.

A maximum thickness of 10 feet of Pearlette volcanic ash is exposed in an inactive pit in the SW¼ SW¼ sec. 18, T. 7 S., R. 18 W. (RKV-1). The material is fresh and contains a trace of sand.

Six feet of volcanic ash is exposed for several hundred yards along the south and west bank of a meandering stream in the SW¼ SE¼ sec. 31, T. 9 S., R. 16 W. (RKV-3). An additional exposure of volcanic ash in the NW¼ SE¼ sec. 6, T. 10 S., R. 16 W. was reported by a local rancher.

Russell County

A large deposit of Pearlette volcanic ash occurs in the NW¼ sec. 2, T. 15 S., R. 11 W. In this section 7 feet of ash is exposed in the NE¼ NW¼ (RV-2) and 10 feet is exposed in the SW¼ NW¼ (RV-3). These two exposures are nearly half a mile apart and it is quite probable that the deposit is continuous between them. The overburden in the vicinity of these two exposures consists of silt and silty ash ranging from 4 to 11 feet in thickness. The ash is fresh and relatively free of contaminants.

Landes (1928, p. 43) reports 5 feet of ash exposed for more than 350 feet in the upper part of gravel beds along the west side of a small valley near the southwest corner of sec. 19, T. 14 S., R. 13 W. This deposit was sampled for the present study in the SE cor. SW¼ sec. 19 (RV-1) where 3 feet of ash is exposed for a lateral distance of 250 feet. The overburden consists of 4 feet or more of silt. Both of the Russell County deposits sampled are underlain by clay.

Seward County

During 1926 and for an unknown period thereafter a commercial volcanic ash pit was operated in the SW¼ NE¼ sec. 13, T. 33 S., R. 32 W. (SDV-3). Ash 8.5 feet thick is exposed in the face of the old pit where it is overlain by 5 feet of silt and brown sandy volcanic ash.

Pearlette volcanic ash which is fresh and free of impurities, although containing a few fossil shells in the lower part, is exposed in the NW¼ NW¼ sec. 35, T. 33 S., R. 32 W. (SDV-1). This deposit has a maximum observed thickness of 7 feet, but the thickness varies sharply throughout the exposure. The deposit occurs above sand and gravel beds with some silt and is overlain by silt and sand.

More than 8 feet of volcanic ash occurs below a very thin overburden in the SE¼ SE¼ sec. 35. T. 34 S.. R. 31 W. (SDV-2). The upper 4 feet of this deposit is exposed in a shallow pit and 4 more feet of ash was penetrated by digging but the base of the deposit was not reached. This deposit occurs in a field along the south bluff of the Cimarron Valley.

Smith (1940, p. 201) lists two additional pits that have been operated in Seward County. These are a small pit along a road in the SE¼ sec. 7, T. 31 S.. R. 34 W. and a moderate-size pit, in operation at the time of Smith's report, in the NE¼ sec. 19, T. 31 S., R. 34 W. Byrne and McLaughlin (1948, p. 25) report a large inactive volcanic ash pit in the SW¼ sec. 19, T. 32 S.. R. 33 W. They state that the volcanic ash exposed in this pit is 5 feet thick and relatively pure.

Sheridan County

Three deposits of Pearlette volcanic ash were sampled in Sheridan County. The largest of these deposits is exposed along a road cut where 8 feet of minable ash is exposed in the face of a moderate-size inactive pit (Pl. 3B) in the NW¼ NW¼ sec. 34, T. 8 S., R. 28 W. (SNV-1). The ash, which is fresh and free of contaminants, is overlain by 2 feet of silty sandy ash and silt and sand.

Six feet of Pearlette volcanic ash is exposed in the east side of an old pit on the north side of a tributary valley in the NE¼ SW¼ sec. 11, T. 8 S., R. 28 W. (SNV-2). This deposit is also exposed about 200 yards to the southeast of the pit and across the main creek about 400 yards to the east. At the point where the deposit was sampled the overburden ranges from 5 to 10 feet and consists of silt and sandy silt. The ash is fresh and contains about 2 percent sand and silt.

Another small pit is located along an eroded terrace remnant on the north side of South Fork Solomon River Valley in the SE¼ SW¼ sec. 12, T. 8 S., R. 27 W. (SNV-3). Where the deposit was sampled it is 3.5 feet thick, is somewhat altered by weathering, and contains some calcite inclusions.

Smith County

In Smith County one large deposit of Pearlette volcanic ash occurs in the NW¼ NW¼ sec. 31, T. 3 S., R. 15 W. (SMV-1), where the ash crops out along the bank of an abandoned meander loop of a creek. The upper 8 feet of the deposit was sampled from the exposure and the bottom of the deposit was penetrated 7.5 feet below the base of the exposure by augering. Landes (1928, p. 46) reports that the maximum thickness of this deposit is 22 feet. The ash is fresh and free of contaminants.

Three feet of volcanic ash is exposed along a hillside near the Cen. W. line sec. 32, T. 1 S., R. 14 W. and also across the north-south road in sec. 31 adjacent to the west. The ash is relatively fresh and contains a trace of sand. Local residents report that 4 feet of volcanic ash was penetrated by drilling in sec. 1, T. 3 S., R. 11 W. and that ash occurs in adjacent sec. 2. It is also reported that volcanic ash is exposed in sec. 36, T. 2 S., R. 11 W.

Stafford County

One deposit of volcanic ash is known to occur in Stafford County. Two feet of Pearlette volcanic ash was sampled by augering in a sand dune depression in the NE¼ SW¼ sec. 28, T. 25 S., R. 11 W. The material is fresh and contains a trace of sand.

Trego County

Three deposits of Pearlette volcanic ash have been sampled in Trego County. Ten feet of volcanic ash is exposed in the face of a small pit located south of the Cen. sec. 36, T. 14 S., R. 21 W. (TV-3). The lower 6 feet of this deposit is free of impurities although slightly altered by weathering; however, the upper 4 feet is slightly contaminated. Volcanic ash 7.5 feet thick is exposed (Pl. 2C) along a steep creek bank immediately adjacent to the north bank of Smoky Hill River in the NW¼ SE¼ sec. 28, T. 14 S., R. 21 W. (TV-1). The deposit thins to the south and is overlain by about 5 feet of overburden. The ash is slightly weathered and free of impurities. Two feet of Pearlette volcanic ash which is fresh and contains a trace of sand is exposed in sec. 32, T. 14 S., R. 22 W. (TV-2).

Wallace County

Only one deposit of volcanic ash is known in Wallace County. This deposit is reported by Elias (1931, p. 211) and occurs in the SE¼ SE¼ sec. 8, T. 14 S., R. 38 W. (WCV-1). Here a maximum of 3 feet of ash resting on silt is exposed in the steep bluff under an overburden of 54 feet. The deposit was examined and sampled for this report and is assigned petrographically to the Reager bed within the Ogallala formation. The ash is relatively fresh and free of contaminants.

Washington County

One small deposit of Pearlette volcanic ash is known to occur in north-central Washington County. One foot of Pearlette ash is exposed along a road cut and creek bank in the NW cor. sec. 30, T. 1 S., R. 4 E. and on the west side of the section-line road in the NE cor. of the adjacent sec. 25, T. 1 S., R. 3 E. The ash in

this deposit is somewhat altered by weathering but is free of contaminants. The extent of the deposit is probably small.

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