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Morphological Classification of Grass Phytoliths[1]

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ABSTRACT

Opal phytoliths derived from epidermal cells of grass leaves have been identified in atmospheric dust, soils, paleosols, Pleistocene loess, and deep-sea sediments. By comparing oriented shapes of phytoliths in spodograms of 17 common grass species, four classes and 26 types are proposed which distinguish three groups of subfamilies of Gramineae. The Festucoid class contains eight types that are circular, rectangular, elliptical, or oblong forms. The Chloridoid class contains two types of saddle-shaped bodies. The Panicoid class contains 11 types that are variations of crosses and dumbbells. The Elongate class contains five types that have no subfamily implications and occur in all 17 species. Because phytoliths of native tall grasses (Panicoid), short grasses (Chloridoid), and common domestic grasses of the humid regions (Festucoid) can be distinguished, it is possible to determine whether phytoliths in dust, soils, and sediments were derived from local or remote sources.

Additional Key Words for Indexing: **opal phytoliths, silica bodies.**

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[3] R. K. Krauss, 1967. The influence of atmospheric dust upon the Florence soils of eastern Kansas. M. S. Thesis. Kansas State University, Manhattan.

[4] D. S. Pease, 1967. Opal phytoliths as indicators of paleosols. M. S. Thesis. New Mexico State University, University Park.

[5] E. Suess, 1966. Opal phytoliths. M. S. Thesis. Kansas State University, Manhattan.

After establishing a network of dust traps at 15 stations east of the Rocky Mountains in which continuous dust deposition was analyzed each month (25), it was observed that opal phytoliths from grasses were a minor but ubiquitous constituent of the greater than 2-micron fraction. The opaline silica bodies that accumulate in epidermal cells of leaves of the grass family have many shapes and have been identified in atmospheric dust (4, 8, 9),[3] in soils (1, 2, 5, 6, 16, 17, 24, 26, 27, 28), in paleosols (6),[4,5] in Pleistocene loess and other ancient sediments (3, 15)[5] and in deep-sea cores (18).

Suess[5] in a pilot study, recognized that phytoliths from short grasses in western Kansas were different from those in tall grasses of eastern Kansas and that phytoliths in atmospheric dust could be traced to these two groups. The number of grass species has been expanded and a classification of grass phytoliths, based on grass taxonomy, is proposed that can be used as an indicator of provenance for land-derived sediment.

Micromorphology of Grasses

Prat (20, 21, 22, 23) used several microscopic characteristics of the epidermis in describing many grass species. He distinguished three categories of elements in the grass epidermis: (i) differentiated elements, (ii) fundamental elements, and (iii) bulliform elements. Differentiated elements consist of silica cells, exodermic elements (hairs and spicules), cork cells (subereous cells), and stomata. Fundamental elements are epidermal cells that are greatly elongated, parallel to the long axis of the leaf. They are nearly uniform and have few specific characters. By showing the distribution of these three elements in the grass leaf with a dermogram, Prat recognized three subfamilies: Bambusoideae, Panicoideae, and Festucoideae. In Panicoideae he included the eu-panicoid type and the chloridoid type.

Metcalfe (19) also used micromorphology in describing 345 genera of grasses. Though stating that the leaf contains the most important diagnostic characters, he warned (p. XXXIV) that (i) minor anatomical variations occur in a single leaf blade, (ii) structural variations occur among leaves from different layers in an individual plant, and (iii) leaves from plants of a single species can also vary among habitats. The diagnostic epidermal characters that he used were shapes of (i) short cells and silica bodies, (ii) macrohairs, (iii) microhairs, (iv) prickle hairs, (v) papillae, (vi) stomata, and (vii) long cells.

Metcalfe, like Prat, recognized three major taxonomic groups: (i) Bambusoid, (ii) Festucoid, and (iii) Panicoid. The bamboos and related genera are clearly distinct from all other grasses. Using leaf structure, he subdivided the Festucoid and Panicoid groups into several tribes.

Distribution of epidermal cells in the grass leaf is illustrated by a generalized section of the leaf of corn (*Zea mays* L.) in Fig. 1. Siliceous epidermal cells in most grasses are of two distinct sizes, elongate and short. Elongate cells with the long axes parallel to the length of leaf include the "long cells" and interstomatal cells of Metcalfe. Length, wall thickness, and surface ornamentation of long cells are diverse. Ends of interstomatal cells are concave where they fit around stomata, whereas ends of long cells are nearly straight.

Short cells are nearly equidimensional and are classed as either "silica cells," where each is nearly filled with a single silica body or as cork cells, where they act as cork; however, some cork cells may contain silica. The shape of silica bodies in cells may not correspond to the shape of the enclosing cell. In grass taxonomy the shape, frequency, and distribution of silica bodies in short cells of the mature leaf are combined with other properties of the epidermis in identifying species and genera.

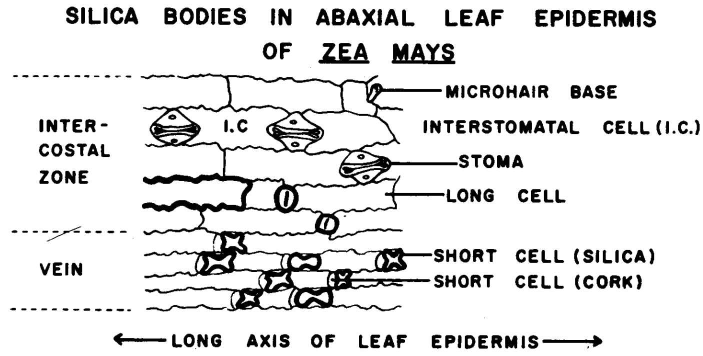

Fig. 1—Spodogram of *Zea mays* L. (after Metcalfe, 1960).

Previous Classifications

In addition to morphological classifications of grass plants, several classifications based on shape of silica bodies derived from epidermal cells have been proposed. Ehrenberg (8) examined several samples of dust from the eastern hemisphere that fell on land and in the sea and proposed 10 genera and 90 species of *Phytolitharia.* He did not attempt to relate them to particular grasses. Folger et al. (9), in their study of a North Atlantic dust fall, stated that the phytoliths were derived from grasses. They revived Ehrenberg's classification by listing two genera and eight species.

Smithson (28) compared opal phytoliths in some British soils with the siliceous epidermal cells of grasses growing at the same locations. He recognized six shapes and could distinguish between Festucoid and Panicoid forms.

Baker (1) proposed a nomenclature for opal phytoliths based on the anatomy of grasses and allied plants; however, he did not trace phytoliths to the particular taxonomic unit from which they were derived.

PROCEDURE

To trace discrete phytolith grains that occur in sediment to a particular taxonomic group in the Gramineae, 17 species rep-

Table 1—Taxonomic groups and occurrences of grasses studied

Species of grass	Common name	Tribe (13)	Taxonomic groups Prat (20) and Metcalfe (19)	Occurrence
Bromus inermis Leyss.	Smooth brome	Festuceae	Festucoid	Domestic
Festuca elatior L.	Meadow fescue	Festuceae	Festucoid	Domestic
Poa pratensis L.	Kentucky bluegrass	Festuceae	Festucoid	Domestic
Triticum aestivum L.	Wheat	Hordeae	Festucoid	Domestic
Aristida sp. L.	Three-awn	Agrostideae	Festucoid	Mountains, Trans-Pecos, Texas
Bouteloua curtipendula (Michx.) Torr.	Side-oats grama	Chlorideae	Panicoid	"Short grass" region or prairie vegetation, Western Kansas.
Bouteloua gracilis (H. B.K.) Lag. and Steud.	Blue- grama	Chlorideae	Panicoid	
Bouteloua hirsuta Lag.	Hairy grama	Chlorideae	Panicoid	
Buchloe dactyloides (Nutt.) Engelm.	Buffalograss	Chlorideae	Panicoid	
Bambusa sp.	Bamboo	Bambusadeae	Bambusoid	Domestic, Austin, Texas
Sorghum vulgare Pers.	Grain sorghum	Andropogoneae	Panicoid	Domestic
Panicum virgatum L.	Switchgrass	Paniceae	Panicoid	"Tall grass" region or true prairie vegetation of eastern Kansas.
Andropogon gerardi Vitman	Big bluestem	Andropogoneae	Panicoid	
Andropogon scoparius Michx.	Little bluestem	Andropogoneae	Panicoid	
Sorghastrum nutans(L.) Nash	Indiangrass	Andropogoneae	Panicoid	
Zea mays L.	Indiancorn	Maydeae	Panicoid	Domestic
Hilaria mutica(Buckl.) Benth.	Tobosagrass	Zoysieae	Panicoid	Water Valley, Texas

resenting three of the groups of Prat and Metcalfe were studied (Table 1).

Two or three leaves from mature plants of each species were individually hand-washed several times in distilled water and dilute HCl to remove any mineral particles on the surface and to soften the mineralized tissue. The leaves were then placed in a ceramic crucible and ashed for at least 6 hours at 500C, then washed again. The residue was permanently mounted in Cadex (refractive index about 1.55) or Canada balsam (n of 1.54) on microscope slides. Two types of slides were prepared: (i) spodograms showing fragments of leaf epidermis with all silicified cells observable and in the growth position, and (ii) slides containing discrete epidermal cells and unidentified siliceous fragments.

Each of the 95 slides was examined with a polarizing microscope using magnifications of 125, 500, and 788. Each new diagnostic shape of silica body encountered while traversing the slide was photographed and enlarged. Silica bodies were grouped into four morphologic classes and 26 types. The slides were reexamined and the relative abundance of each silica body shape was tabulated.

To study phytoliths in soils, paleosols, and Pleistocene sediment, the fraction of each sample ranging from 10 to 25 microns was retained by gravity sedimentation according to Jackson (14, p. 115). Clay aggregates were dispersed by adding 50 ml of a solution of Calgon (102 g/liter) per 1,000 ml suspension. (Use of this product does not imply endorsement by the USDA or that it is superior to other competing products.) The settling process was repeated 10 to 19 times depending on concentrations of clay and organic matter in the 150- to 200-g samples.

After drying, opal phytoliths were separated from silt by centrifuging in a suspension of bromoform and tetrachloromethane with a density between 2.232 and 2.319 as checked by glass cubes of specific density. To increase dispersion, a suspension of about 2 ml of acetone/1.5 g of silt was added to 6 ml of heavy liquid. After evaporation of acetone for 24 hours, the suspension was centrifuged in a clinical centrifuge for 5 min at about 3,000 r.p.m. (5-inch radius). Opal phytoliths and other light minerals were decanted, filtered, washed several times in acetone, dried, and mounted in Cadex on glass microscope slides. Relative abundances of each type of phytolith were recorded.

RESULTS

Morphological Classification of Grass Phytoliths

In most sediments only discrete silica bodies occur so only shape is available for determining from which group of grass the phytoliths came. The classification is on Fig. 2. All phytoliths are oriented as they occur in the epidermal cells with the long axis of the leaf horizontal.

The Festucoid class (Class 1) contains eight types that are circular, rectangular, elliptical, or oblong. These forms are all geometrically simple and correspond to Prat's subfamily, Festucoideae, that includes four tribes: Festuceae, Hordeae, Aveneae, and Agrostideae, which include the common domestic grasses of the humid regions.

The Chloridoid class (Class 2) consists of only two types of saddle-shaped bodies. Prat (21) described them as "battle axes with double edges" and designated them as a type in the subfamily Panicoideae. Harlan (12, p. 59), based on phylogenetic relationships, proposed subfamily Erogrostoidea that included these three tribes: Chlorideae, Eragrosteae, and Sporoboleae. Because saddle-shaped bodies are distinctive and common in atmospheric dust originating in the "short grass" region of the western prairie, we have given it equal rank with the other morphological classes.

Classification of Grass Phytoliths

I) Festucoid Class
- 1a. Circular
- 1b. Rectangular
- 1c. Elliptical
- 1d. Acicular, variable focus
- 1e. Crescent, variable focus
- 1f. Circular crenate
- 1g. Oblong
- 1h. Oblong, sinuous

II) Chloridoid Class
- 2a. Chloridoid
- 2b. Thin Chloridoid

III) Panicoid Class
- 3a. Cross, thick shank
- 3b. Cross, thin shank
- 3c. Dumbbell, long shank
- 3d. Dumbbell, short shank
- 3e. Dumbbell, long shank, straight or concave ends
- 3f. Dumbbell, short shank, straight or concave ends
- 3g. Dumbbell, nodular shank
- 3h. Dumbbell, spiny shank
- 3i. Regular, complex dumbbell
- 3j. Irregular, complex dumbbell
- 3k. Crenate

IV) Elongate Class (no subfamily characteristics)
- 4a. Elongate, smooth
- 4b. Elongate, sinuous
- 4c. Elongate, spiny
- 4d. Elongate, spiny with pavement
- 4e. Elongate, concave ends

The Panicoid class (Class 3) contains 11 types that are variations of crosses and dumbbells. Prat (21) described

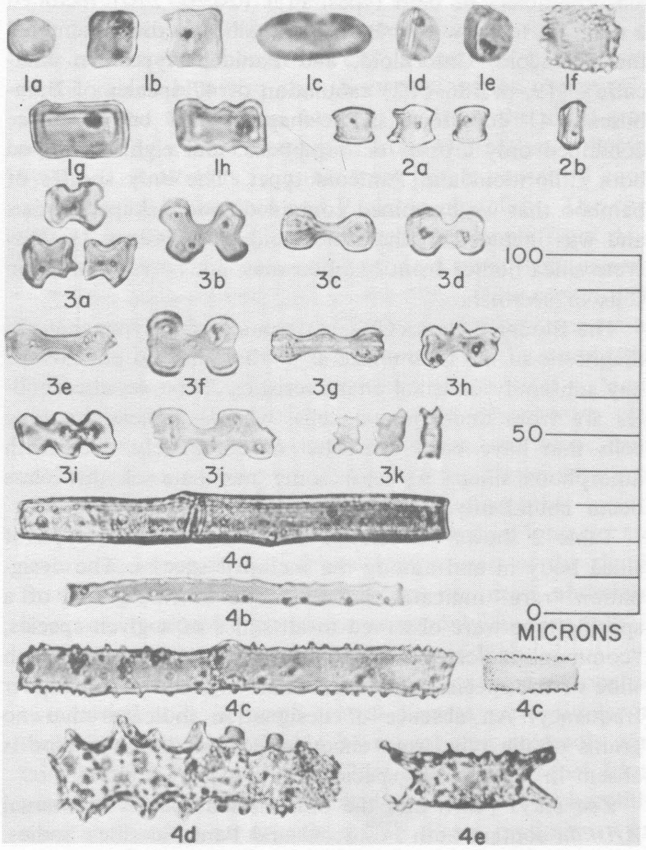

Fig. 2—Classification of grass phytoliths.

Table 2—Distribution of four classes of phytoliths*

	Festucoid Class 1								Chloridoid Class 2		Panicoid Class 3											Elongate Class 4				
Species of grass	a	b	c	d	e	f	g	h	a	b	a	b	c	d	e	f	g	h	i	j	k	a	b	c	d	e
Bromus inermis Leyss.	C	C	C			C	C	C														A		A		
Festuca elatior L.	R	R	C	C	C																		A	A		
Poa pratensis L.	C	C	C	C	C	C	C															A		A	R	
Triticum aestivum L.	C	C		C	C	C		C														C		A	C	
Aristida sp. L.	C	C	C										C		C							C		A		
Bouteloua curtipendula (Michx.)Torr.									C	C												A	C	A		
Bouteloua gracilis (H.B.K.) Lag. and Steud.									C	C												A		A		
Bouteloua hirsuta Lag.									C	C												A		A		
Buchloe dactyloides (Nutt.) Engelm.									C	C												A	C	A		C
Bambusa sp.									C	C													A	A		
Sorghum vulgare Pers.											C	R	C	C		C	R	R	R			A	C	A	C	
Panicum virgatum L.											C		C	C	C		R		R			A	C	C		
Andropogon gerardi Vitman											C		C	C	C	C	R	R	R	R	R	A	A	A		
Andropogon scoparius Michx.											C	C	C	C	C	C						A	A	A		R
Sorghastrum nutans (L.) Nash											C		C	C	C	C	R	R	R		R	R	C	A		
Zea mays L.				C	C						C			C				R	R			C	C	A		
Hilaria mutica (Buckl.) Benth.											R		C	C	C									A	A	

*A = abundant, C = common, R = rare, and no designation = none observed.

them as halter-shaped and designated them as the eupanicoid type in the subfamily Panicoideae. He included three tribes (Andropogoneae, Paniceae, and Maydeae) in the division. Metcalfe (19) also included Isachneae and Oryzeae in the Panicoid group; their silica bodies are modified dumbbells that cannot be distinguished from other Panicoid forms where they occur as discrete particles. In this class are many of the native "tall grasses" of true prairie vegetation.

Both Prat (21) and Metcalfe (19) recognized that leaves of Bambuseae are distinct from Festucoid and Panicoid leaf types; some genera have silica bodies and other leaf characters of both types. Prat (20, p. 220) included a diagram to show that Bambusoid silica bodies resembled the Festucoid, Chloridoid, and Panicoid types. In Metcalfe's (19, p. 586–587) tabulation of 47 species of Bambuseae, 41 contained saddle-shaped silica bodies, three contained only crosses or dumbbells, and eight contained both Chloridoid and Panicoid types. The only species of bamboo that we examined contained saddle-shaped bodies and was included in the Chloridoid class (Class 2). Discrete silica bodies from bamboo may not be recognized in soils or sediment.

The Elongate class (Class 4) contains five types that are diagnostic of the Gramineae as a whole but do not possess any subfamily or tribal characteristics. Type 4e silica bodies are from interstomatal cells, whereas others are long cells that have been encrusted or completely filled with amorphous silica. At least some members of this class occur abundantly in all the species studied.

Table 2 shows the relative abundance of each type of silica body in and among the included species. The designation "rare" indicates that only one or two grains of a specific type were observed in all slides of a given species, "common" indicates several grains (5 to 10) occur in each slide of the species, and "abundant" signifies a still higher frequency. An absence of designation indicates that no grains of the type were encountered, not that the type is absent in a particular species.

Zea mays (corn and the unidentified species of annual *Aristida* contain both Festucoid and Panicoid silica bodies. Prat (21) emphasized that *Zea* has anatomical and morphological characters similar to Andropogoneae and Paniceae and placed it in subfamily Panicoideae. Silica bodies in the intercostal zone (Fig. 1) can be either Festucoid or Panicoid, whereas those over the veins are Panicoid. Hitchcock (13, p. 21), based on megascopic characters, included *Aristida* in tribe Agrostideae of subfamily Festucoideae. In describing five species of *Aristida,* Metcalfe (19, pp. 34–41) reported silica bodies as Festucoid and Panicoid in both over and between the veins. Although *Hilaria mutica* was placed in tribe Zoysieae by Hitchcock (13) and Harlan (12), the silica bodies are Panicoid; no Festucoid forms were observed. These three examples simply emphasize that a morphological classification of silica bodies can be applied to grass taxonomy only with caution.

The classification (Fig. 2) shows the maximum projection area of each silica body but in microscopic mounts of discrete bodies, individual grains may be oriented or rotated around different axes and at different rotational angles. Figure 3 shows some of the several possible shapes that may be observed as a result of orientation of silica bodies. In side views of individual grains, Chloridoid phytoliths cannot be distinguished from Panicoid forms. If only Chloridoid phytoliths are observed in a sediment, then a worker may allocate grains showing side views to this class; otherwise, the grains are placed in a group of unclassified forms.

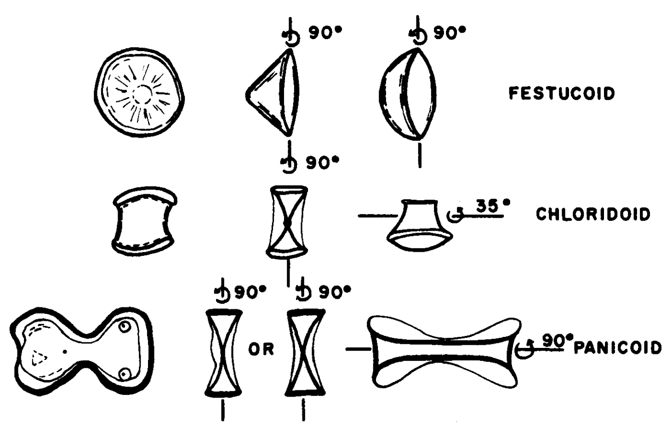

Fig. 3—Shapes induced by orientation of phytoliths.

Table 3—Distribution of phytoliths in sediment*

Type of sediment	Festucoid Class 1 a	b	c	d	e	f	g	h	Chloridoid Class 2 a	b	Panicoid Class 3 a	b	c	d	e	f	g	h	i	j	k	Elongate Class 4 a	b	c	d	e
Atmospheric dust																										
Normal influx, 1965																										
Tribune, Kansas	C	C							A				R	R								A	A	C		
Hays, Kansas									C													C	R	R		
Manhattan, Kansas	R	R							R				R									C	R	R		
Duststorms																										
Wichita, Kansas;April 26, 1935a	R	R							A					R								C	C	C		
Wichita, Kansas;March 28, 1940a	C	C					R		A					R		R						C	C	C		
Manhattan, Kansas; March 18, 1954b									C					C								C	C	A		
Austin, Texas, May 1955c									R				C	C										C		
Recent soils																										
Florence cherty clay loam																						C	C	C		
Monona silt loam									R				C	C	C	C			C			A	A	A		
Hastings silty clay loam									R													C	C	C		
Crete silty clay loam											C		C	C	C				C				A	A		
Kansas River alluvium																						C	C	C		
Paleosols																										
Unnamed paleosol A, under Monona silt loam									R				C	C									A	A		
Unnamed paleosol B, under Derby loamy sand		R					R	R	R				C	C	C								A	A		
Pleistocene sediment																										
Peoria loess																							C	C		
Sangamon soil																							C	C		
Kansas till																							C	C		
Afton soil																							C	C		

*A = abundant, C = common, R = rare ; a = collected by Dr. W A Ver Wiebe, Wichita State University, Wichita, Kansas; b = collected by Dr. C P. Walters, Kansas State University, Manhattan; c = collected by Dan Woodyard, University of Texas, Austin.

Ash of grasses and opaline concentrate from soils and sediments consist of a large percentage of unidentifiable fragments of opaline silica of different sizes that cannot be traced to any part of the grass anatomy. Some are broken cells, some are the small projections from the 4c, 4d, or 4e types, and some are from other parts of the plants. Although such fragments cannot be used in recognizing types of grass, they are part of the sediment and affect its chemical and mineralogical properties.

Application of Classification to Sediment

To test the utility of the classification samples of atmospheric dust deposits (normal influx for 1965 and individual duststorms), soils, paleosols, and Pleistocene sediments were studied. All samples contained phytoliths.

Atmospheric dust deposition—Monthly samples for 1965 from three locations in Kansas (Fig. 4), a part of a larger network of stations (5), were examined for phytoliths; the results are in Table 3. From west to east, short grasses

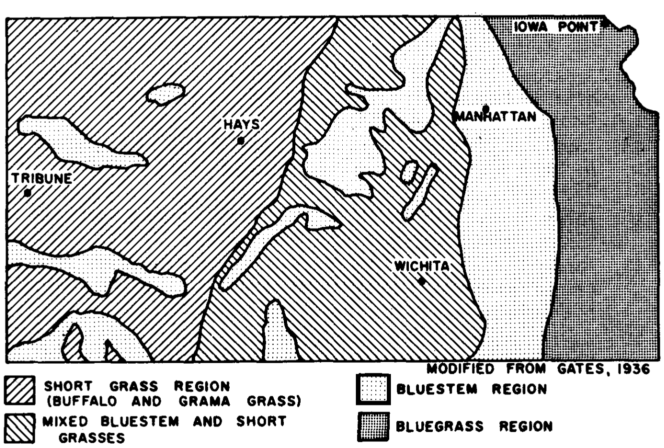

Figure 4.--Native grasses in Kansas.

Fig. 4—Native grasses in Kansas (11).

(Chloridoid) are the dominant vegetation at Tribune, a mixture of short and tall grasses (Panicoid) occurs at Hays, and tall grasses are dominant around Manhattan. Probably the Festucoid phytoliths were derived from the wheatlands and native grasslands. The frequency of phytoliths in the dust deposits increased during May, June, July, and August and decreased during the fall and winter months.

Individual duststorm samples also showed phytoliths. The two samples from Wichita contained forms from all four classes even though the city is near the eastern edge of the mixed bluestem and short-grass region. Seemingly, some of the forms were brought in from the short-grass region of the west. The samples from Manhattan, collected by Dr. C. P. Walters from his front porch, contained equal quantities of Chloridoid and Panicoid phytoliths. The content of phytoliths was lower in the dust sample from Austin, Texas, but Panicoid and Chloridoid types were present.

Recent Soils—Some soils in the Flint Hills region near Manhattan, Kansas, were examined. Surface vegetation of all sites is dominated by tall grasses of the Panicoid type. Descriptions and locations of samples are in Table 4. Many silica bodies in the Florence soil were coated with clay skins, Elongate phytoliths were dominant, and some Panicoid types were observed. Samples from Crete, Hastings, and Monona soils contained uncoated phytoliths, quantities of Panicoid types were greater than in Florence, and several had been broken at the thinnest part of the shank. In all samples, Elongate forms are the most abundant; however, Panicoid types occur commonly in silty soils in which the concentration of phytoliths is high.

Unnamed Paleosols—The amount and type of opal in two buried soils in north-central Kansas were similar to those in recent soils (Table 3) except that paleosols contained more Festucoid and Chloridoid types. Most Elongate forms were pitted and etched and only a few phytoliths were enclosed in an organic sheath. From preliminary examination, either vegetation in the ancient soils contained

Table 4—Name, description, and location of samples of soil, paleosol, and Pleistocene sediment

Name	Description (After Bidwell (7) or Frye and Leonard (10)	Location
Florence cherty clay loam	A dark brown clay-loam surface with chert fragments, part of which was derived from the Florence Limestone (Permian);1-to 2-percent slope; 5- to 15-cm. deep; native vegetation of tall and mid grasses.	East of U.S. 77 in center of NE 1/4, NE 1/4, sec. 21, T8S, R7E, Riley County, Kansas.
Monona silt loam	A poorly developed dark grayish-brown soil partly derived from silty loess;7- to 10-percent slope;12- to 40-cm. deep; native vegetation of tall grasses.	Center of NW 1/4, NW 1/4 of sec. 18, T10S, R5E, Geary County, Kansas.
Hastings silty clay loam	A dark grayish-brown soil developed on loess;4- to 8-percent slope; 5-to 15-cm. deep;native vegetation of tall grasses.	SE corner of NE 1/4, sec. 18, T10S, R5E, Geary County, Kansas
Crete silty clay loam	A dark grayish-brown soil developed on loess on uplands; 0- to 1- percent slope; within 5 to 15 cm. of depth; native vegetation of tall grasses.	NE 1/4, NE 1/4, sec. 3, T10S, R5E, Geary County, Kansas.
Kansas River alluvium	A fine quartz and feldspar rich sand near the channel of the Kansas River.	SE corner of SE 1/4, SE 1/4, sec 36, T10S, R7E, Riley County, Kansas
Unnamed paleosol A	A dark brown silt loam of the A_1 horizon derived from silty loess; about 120 cm. below surface of Monona silt loam.	Center of NW 1/4, NW 1/4, sec. 18, T10S, R5E, Geary County, Kansas.
Unnamed paleosol B	A dark brown loamy sand derived from dune sand; about 100 cm. beneath the Derby loamy sand.	SW corner of SE 1/4, SW 1/4, sec. 9, T12S, R5E, Geary County, Kansas.
Peoria silt	A tan massive structureless silt taken from the lower part of the vertical face of a quarry.	Iowa Point Section NE 1/4, SE 1/4, sec. 6, T2S, R20E, Doniphan County, Kansas.
Sangamon soil	Reddish massive silt with limonite concretions along joint planes.	Iowa Point Section.
Kansas till	Poorly sorted pebbles and cobbles of limestone, metaquartzite, and igneous rocks, and local lenses of brown sand in a matrix of clay and silt.	Iowa Point Section.
Afton soil	Medium gray silty clay loam with a few pink metaquartzite pebbles.	Iowa Point Section.

more Festucoid and Chloridoid grasses or these forms were deposited from the atmosphere.

Pleistocene Sediment—All four samples of Pleistocene sediment from the Iowa Point section in northeastern Kansas contained only Elongate phytoliths generally larger than 20 microns. The phytoliths were severely etched and embayed. Remnants of ancient soils, Sangamon and Afton, and Peoria loess contained more phytoliths than the Kansas till. Perhaps smaller and more characteristic phytoliths of the first three classes had been completely dissolved, so corroded fragments of Elongate forms were all that remained.

SUMMARY

By studying silica bodies in epidermal cells of 17 species of grass that occur in different climatic regions, a morphological classification was developed that is related to three groups of subfamilies of grasses: Festucoid, Chloridoid, and Panicoid. A fourth group, the Elongate class, does not possess any subfamily characteristics but is uniformly distributed in all species. The classification can be used to relate phytoliths in soils and sediments to broad categories of grasses from which they were derived.

The classification is useful to determine the major type of vegetation developed on a particular soil or paleosol and to establish whether phytoliths in atmospheric dusts, soils, and sediments were derived from local or remote sources. Furthermore, because phytoliths are amorphous silica, they are relatively soluble and can influence the chemical and physical properties of soils and sediments.

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