DISTRIBUTION AND IMPLICATIONS OF SPONGE SPICULES IN SURFICIAL DEPOSITS IN OHIO[1, 2]

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ABSTRACT

Microscopic examination of biogenic opal isolated from the 0.05–0.02-mm total mineral fraction of 12 upland soil profiles indicates that fragments of sponge spicules are minor but ubiquitous constituents of Ohio soils, with major concentrations in the upper 10 to 15 inches of the profile. Quantities range from about 30 to 2000 parts per million biogenic opal or 1 to 65 parts per 10 million parts soil. Spicules are absent or extremely rare in calcareous Wisconsin-age till deposits. Their correlation with horizons high in silt content (50–75%), and their size and depth distribution in landscape positions which preclude an authigenic origin, indicate their aeolian transport from aquatic source areas with other loessial materials. Identification of spicules thus provides direct evidence that these horizons have been derived from loess or loess-till admixtures. This microscopic technique may serve useful for the identification of loess when field or laboratory particle-size analysis yields inconclusive evidence.

INTRODUCTION

Many kinds of opaline (hydrated, amorphous SiO_2) constituents of biogenic origin occur in soils. Recently, Siever and Scott (1963), Smithson (1956), and Jones and Handreck (1967) have comprehensively reviewed the various forms of silica found in soils and geologic materials, considering their origins and their identification. Both plants and animals secrete various quantities of silica that may become subsequently a part of the silica fraction of a soil. Aquatic animals which secrete significant quantities of silica include radiolarians, silicoflagellates, and sponges (Vinogradov, 1953). Within the plant kingdom, monocotyledons and diatoms have been considered most important. Opal which is found in characteristic shapes, sizes, and forms localized in the aerial portion of vascular and epidermal tissues of plants is termed *opal phytoliths*. Opal phytoliths and siliceous sponge spicules are minor, but ubiquitous constituents of many soils. The former are by far the more abundant of the two components, but with detailed fractionation and careful microscopic observation, sponge spicules may also be readily identified.

Numerous investigators have reported the occurrence of fresh-water and marine sponge spicules in soils, but different theories have been advanced to explain their presence. In sites subject to wetness or ponding, Brewer (1955, 1956) and Smithson (1959) have interpreted the rich abundance of mostly unfragmented spicules as evidence of their authigenic origin from sponges which once inhabited the area. On the other hand, in positions where topography precludes an authigenic origin, Carroll (1932), Jones and Beavers (1963), and Leeper (1955) have invoked an aeolin transport mechanism from aquatic source areas to explain their presence. The possibility that some spicules may be transported from a close source area by the feet of birds and mammals also has been suggested by Smithson (1959). For most fragmented and widely disseminated spicules, it is not possible from morphological features alone to positively identify whether they have been derived from marine or fresh-water sponges. This uncertainty, combined with the misidentification of opal phytoliths for sponge spicules in certain cases, has resulted in some confusion in the literature concerning the significance of these microfossils in soils.

Previous investigations have been primarily incidental or cursory in scope,

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the emphasis being placed on the documentation of presence or absence of spicules in a particular deposit. This paper presents quantitative data for the depth distribution of sponge spicules in well and moderately well drained soil profiles in Ohio. The following possible origins have been considered in evaluating the presence and distribution of spicules in surficial deposits of these soils: (1) an indigenous origin of spicules from calcareous till deposits underlying these soils; (2) an authigenic origin of spicules from sponges which may have inhabited such sites at some former time; (3) an allogenic origin of spicules that were transported with other loessial materials from adjacent local or regional aquatic source areas favorable for sponge inhabitation.

ANALYTICAL METHODS

The 0.05–0.02-mm opal fraction was isolated from selected horizon samples of 12 upland soil profiles located in the glaciated region of Ohio (figure 1) and the opal isolate examined microscopically for sponge-spicule content. A total of 38 profiles and more than 140 samples, ranging widely in soil classification, particle-size distribution, and drainage, were examined. Representative examples of well and moderately well drained Gray Brown and Red-Yellow Podzolic soils, developed under deciduous forest vegetation, are presented herein.

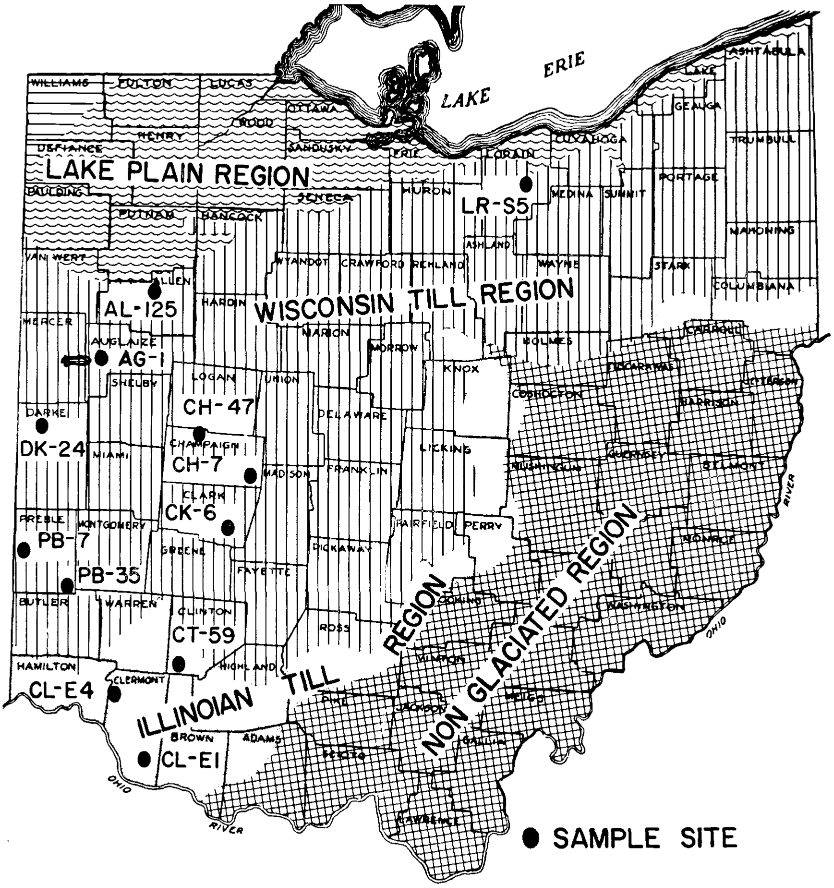

FIGURE 1. Geographical distribution of sampling sites.

Particle-size distribution reported for these soils was determined using the pipette method of Steele and Bradfield (1934). Techniques utilized for concentration of the opal by particle-size and specific-gravity fractionation were essentially the same as those described by Jones and Beavers (1964). Unless these concentration methods are utilized, spicules would rarely be observed because of their scarcity in the total mineral fraction.

Sponge spicules were identified by the following properties: specific gravity <2.3; optically isotropic; refractive index 1.41 to 1.48; acicular in shape with an axial canal extending the length of the tapering form; and a smooth or slightly spinose, relatively non-pitted surface texture (fig. 1, Jones and Beavers, 1963). Phytoliths (plant opal) are usually more strongly pitted and lack the axial canal. Gross differences in morphology between these siliceous bodies are generally sufficient for ready identification, but relatively unpitted, long, rod-shaped phytoliths can be positively differentiated from spicules by the absence of the axial canal. Spicules of different morphology than those described above, such as birotulates, sphaerasters, and other spinose spherules (Old, 1931; Smithson, 1959) are also of sponge origin, but were not identified in these samples, either because of their smaller particle size (most gemmule spicules <0.02 mm) or because they were absent.

The quantity of opal isolated from the 0.05–0.02 mm total mineral fraction was determined gravimetrically and later corrected for impurities by microscopic counts of approximately 600 particles. Spicule concentration in this fraction was estimated by microscopically scanning approximately 10,000 opaline particles and recording the number and length of spicules present. The number of spicules observed in such a scan ranged from 0 to 28, but were frequently less than ten. The actual number of particles counted was determined from the average of several representative field counts multiplied by the number of fields per slide. Counting errors inherent in such an extrapolation procedure are recognized, but this system provides the only practical method for estimation of frequency of spicules. Duplicate scans of the same or different slides were usually in close agreement. Spicule concentration (expressed in ppm) was converted from the opal fraction basis determined above to a value based on their number in the total soil by the following method: the percentage of spicules in the opal fraction was multiplied by the percentage of opal in the 0.05–0.02 mineral fraction, and then times the percentage of this specified size fraction in the total soil. The product of the latter two percentages is presented as "biogenic opal in 0.05–0.02-mm fraction, total soil basis" (table 1).

RESULTS AND DISCUSSION

Particle-size distribution, amounts of biogenic opal, and numbers of sponge-spicules for profiles examined are presented in table 1. From these data it can be seen that spicules, fragmented or occasionally whole, are minor but ubiquitous constituents in Ohio soils, with major concentrations in the upper 10 to 15 inches of the profiles. Length of spicules observed ranged from 0.02 to 0.15 mm for fragments and 0.15 to 0.28 mm for complete spicules.

The mean spicule length was usually considerably greater than the 0.05–0.02 mm limits of the mineral separate from which the opal isolate was derived, though their mean radial diameter was only about 0.01 mm. Greater mean lengths of spicules in this fraction may be explained by their acicular shape, for spicules manyfold longer than their mean diameter are able to pass lengthwise through the 0.05-mm sieve used to make the sand-silt separation and may thus be collected in the coarse silt fraction.

These microfossils are most abundant in horizons which are relatively high (50 to 75 percent) in total silt content and decrease abruptly whenever silt content decreases below 50 percent and/or sand content increases sharply (table 1, fig. 2).

TABLE 1

Particle-size distribution, biogenic opal, and sponge spicules in the soils investigated

Soil and Profile Number	Horizon[1]	Depth (in.)	Total Sand (2–.05 mm) (%)	Total Silt (.05–.002 mm) (%)	Biogenic opal in .05–.02 mm fraction (total soil basis) (ppm)	Sponge Spicules		
						In .05–.02 mm opal fraction (ppm)	In .05–.02 mm total soil fraction (ppm)	Mean length (mm)
Wisconsin Till Region (Central and Southwestern Ohio)								
Miami silt loan	Ap	0–7	22.5	59.3	1500	210	0.32	0.099
(CH–47)	B1	7–12	20.4	49.8	900	164	.15	.130
	II B21	12–19	24.9	33.8	100	104	.01	.082
	II B22	19–25	28.6	31.7	100	0	.00	—
	II C2	42+	41.5	41.2	190	62	.01	.063
Miami silt loam	Ap	0–7	20.8	53.5	2600	102	.26	.055
(CH–7)	B1	7–10	21.2	52.0	1400	176	.24	.115
	B21	10–17	17.8	37.0	300	522	.15	.086
	II B22	17–22	17.6	34.8	200	0	.00	—
	II C2	40–60	33.6	44.8	180	93	.02	.054
Celina silt loam	Ap	0–7	15.4	64.1	2300	37	.08	.120
(CK–6)	B1	7–9	13.2	53.3	1800	64	.12	.087
	II B2	9–13	10.9	45.1	500	0	.00	—
	II C2	31–42	36.0	45.7	400	0	.00	—
Russell variant silt loam	A1	0–3	12.7	70.9	1900	162	.30	.115
	A2	3–8	13.1	68.3	1300	228	.30	.125
(PB–7)	A3	8–11	13.9	63.8	1300	343	.45	.096
	B1	11–15	19.0	50.2	600	588	.35	.058
	II B21	15–20	28.6	27.3	106	49	<.01	.051
	II B22	20–25	38.0	29.2	80	900	.07	.056
	II C2	60–72	44.1	40.7	10	40	.01	.058
Russell silt loam	Ap	0–7½	11.2	69.1	1400	350	.49	.070
	B11	7½–10½	4.3	65.9	400	1652	.66	.073
(PB–35)	B12	10½–18	4.0	61.7	90	1680	.15	.066
	B21	18–21	7.2	58.7	100	798	.08	.067
	B22	21–28	15.2	51.6	41	1855	.07	.077
	II B23	28–35	36.9	31.6	69	630	.04	.053
	II B3	35–42	37.3	28.6	35	406	<.01	.063
	II C2	52–61	46.2	38.1	60	0	.00	—
Wisconsin Till Region (North and Northwestern Ohio)								
Morley silt loam	Ap	0–6	7.4	64.9	500	912	0.46	0.055
	A2	6–9	8.9	67.6	700	920	.64	.063
(DK–24)	B&A	9–12	3.0	52.7	100	2185	.22	.055
	II B21	12–16	2.6	47.3	150	1070	.10	.058
Morley silt loam	Ap	0–7	21.3	61.3	600	881	.53	.087
(AG–1)	A2	7–9	21.0	62.7	1300	418	.54	.092
	B&A	9–12	14.3	50.2	400	701	.28	.087
	II B21	12–16	13.8	41.1	100	156	.01	.055
Morley silt loam	Ap	0–7	31.8	48.3	600	585	.35	.060
(AL–125)	B&A	7–9	28.0	40.5	500	401	.20	.056
	II B21	9–13	27.6	32.6	100	484	.04	.075
	II B22	13–17	26.0	34.2	300	80	.02	.090
Ellsworth silt loam	A1	0–3	18.1	61.9	2100	142	.30	.120
(LR–S5)	A2	3–7	20.9	58.9	300	686	.21	.100
	II B1	9–12	19.7	54.1	100	658	.07	.060
	II B22	16–21	17.2	38.2	100	0	.00	—

TABLE 1—*Continued*

Particle-size distribution, biogenic opal, and sponge spicules in the soils investigated

Soil and Profile Number	Horizon[1]	Depth (in.)	Total Sand (2–.05 mm) (%)	Total Silt (.05–.002 mm) (%)	Biogenic opal in .05–.02 mm fraction (total soil basis) (ppm)	Sponge Spicules		
						In .05–.02 mm opal fraction (ppm)	In .05–.02 mm total soil fraction (ppm)	Mean length (mm)
			Illinoian Till Region (Southwestern Ohio)					
Cincinnati silt loam	A1	0–3	8.7	77.4	700	100	0.07	.054
	A2	3–14	5.5	73.2	700	108	.08	.079
(CL–E1)	B21	14–20	6.4	65.4	300	328	.10	.096
	II B22	20+	27.1	53.5	100	272	.03	.098
Rossmoyne	Ap	0–7	10.9	71.8	2100	66	.14	.090
	A2	7–12	9.5	72.3	1900	112	.21	.050
(CL–E4)	B21	12–18	6.6	66.1	700	138	.10	.096
	B22	18+	4.8	57.7	200	147	.03	.092
Rossmoyne silt loam	Ap	0–9	11.2	73.3	2600	70	.18	.050
	A2	9–20	8.0	65.8	200	560	.11	.096
(CT–59)	II B1	20–28	27.4	43.0	100	196	.02	.060

[1] C—calcareous till horizons.
The roman numeral II designates a change in parent materials.

Frequently there are fewer spicules in the 7- to 8-inch surface horizon of cultivated soils than there are immediately below this depth. This phenomenon may be related to the counting statistics, because surficial horizons contain the largest quantities of the biogenic opal which acts as a dilutent. Mechanical attrition or chemical weathering of larger spicules into smaller fragments that would subsequently appear in the <0.02 mm fraction does not seem plausible, because these data suggest that relative spicule concentrations in the fine and coarse silt fractions parallel each other.

Spicules are absent or extremely rare in the 17 Wisconsin-age calcareous till samples examined. No spicules were observed in 11 of these samples and only one or two fragments per slide in the others. If spicules in surficial horizons had originated from the parent till, they should be more concentrated in the opal isolated from the calcareous till than in the concentrates of the surficial sediments, because the former yields a smaller magnitude of biogenic opal to act as a diluent.

Evidence that weathering losses *in situ* do not account for the sparse number of spicules observed in calcareous till deposits lies in the following arguments. (1) Opal phytoliths and spicules found in calcareous tills do not appear to differ in degree of etching or pitting from similar constituents in acid surface or subsurface horizons. (2) The dense, compact nature of calcareous tills restricts leaching and solution of constituents much more soluble than opal (such as carbonates). (3) Spicules have been well preserved in limestones of Jurassic age (Smithson, 1956). (4) Lewin (1961) has found, from laboratory studies, that siliceous diatoms are essentially insoluble in equilibrium solutions buffered at pH 9.0–9.3. It was concluded that certain adsorbed inorganic cations, especially Fe and Al, markedly decrease the rate of solution of diatomaceous silica under natural environments. In summary, the dearth of spicules observed in calcareous till deposits negates the hypothesis that spicules concentrated in surficial horizons were originally derived from the till parent material. Occasional spicules found in till deposits can be readily explained by their incorporation into the till as glaciers traversed the Lake Erie Basin and pre-Wisconsin outwash areas which represented potential sources of sponges and thus of authigenic spicules.

Evidence that the spicules concentrated in these soils are not of authigenic or sedentary origin lies in the habitat of sponges. Although earlier work by Potts (1918) and Morgan (1930) suggested that freshwater sponges favored clear, moving water environments, more recent ecological studies by Old (1932) and Jewell (1935) have disputed this claim. The latter authors have noted that sponges can tolerate turbid streams, shallow muddy ponds, and even waters polluted by industrial wastes and sewage. Because soil profiles utilized in this study were sampled in upland interfluvial positions, where well or moderately well drained conditions prevail now, and presumably in the past, such environments would not be conducive to sponge inhabitation.

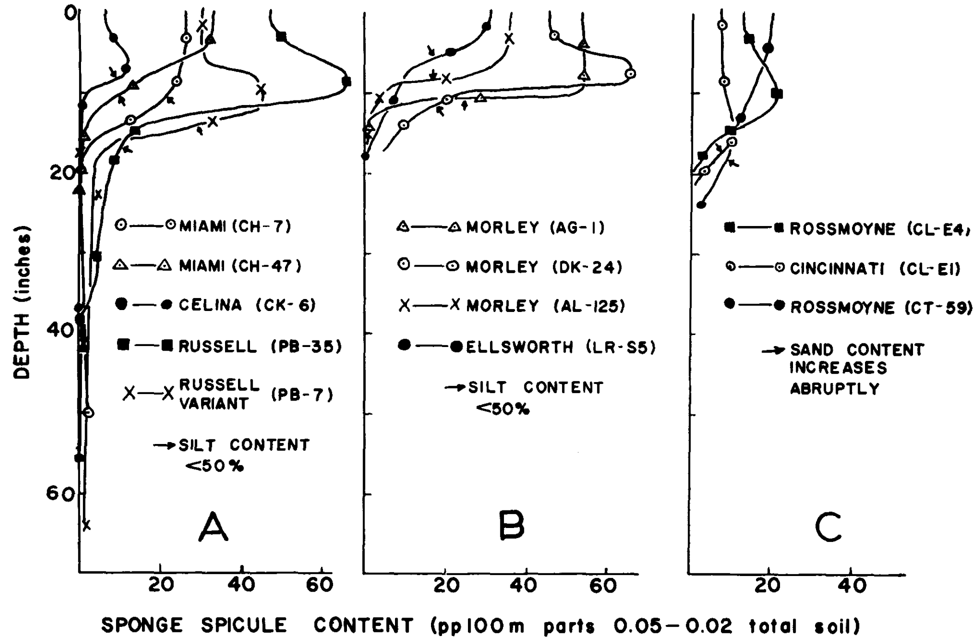

FIGURE 2. Depth distribution of sponge spicules in soils occurring in the southwestern sector (A) and in the north-northwestern sector (B) of Wisconsin glaciated region, and in the Illinoian glaciated region (C) in Ohio.

The most plausible explanation that can be advanced for the size, depth distribution, and correlation of spicules with horizons high in silt content in these soils (table 1, fig. 2) is their aeolian transport with other loessial materials from aquatic source areas. Examples of such areas would be floodplains, lake bottoms, upland depressions, or other sites conducive to sponge growth at some former time.

Sponge-spicule depth distributions for three soils (Miami, Celina, and Russell) which occur extensively in the Wisconsin glaciated sector of southwestern Ohio are presented in figure 2-A. From particle-size data, the thin silt mantle overlying medium-textured glacial till deposits has traditionally been considered loess (Goldthwait, *et al.*, 1965). Identification of sponge spicules and their distribution with depth provide direct evidence to substantiate the interpretation that these surficial deposits are indeed loess or loess-till admixtures. Because of the relatively high sand content in Miami, Celina, and Morley profiles, surficial loess or loess-till admixtures may seem improbable, but the presence of spicules and their distributions, suggests that loess has influenced these profiles to a depth of about 10 to 15 inches. Although such curves provide direct evidence of the depth of loessial contamination, they do not permit accurate estimates of the total amount of loess deposited.

Similar curves are presented for soils of the Wisconsin glaciated region in north and northwestern Ohio (fig. 2–B). The relatively high concentration of spicules in the upper 7 to 12 inches of Morley profiles apparently reflects a local loess source, because neither major valley train nor outwash sediments, nor regional loess deposits are recognized in this sector of Ohio (Goldthwait, *et al.* 1961, 1965). Spicules in the upper solum of the Ellsworth profile in north-central Ohio may have originated from beach or lacustrine deposits of late-glacial lakes or Lake Erie, located to the north or northwest of this site.

Data from soils in the Illinoian region of southwestern Ohio are given in figure 2–C. The relatively low concentration of spicules in the upper solum of Cincinnati and Rossmoyne profiles suggests either a paucity of spicules in the original sediments (classically recognized as loess on the basis of field and laboratory particle-size data) or chemical solution of some spicules concomitant with soil weathering. It is known, on the basis of physical, chemical, and mineralogical evidence, that most soils of the Illinoian region are more intensely weathered than analogues in the Wisconsin region of Ohio (Farnham, 1954). However, solution of spicules would be in conflict with evidence that opal phytoliths (similar in chemical composition to spicules) are relatively stable in soils at least up to 13,000 years before present (Wilding, 1967). It is also quite possible that the stability of the sampling site is important in interpreting spicule depth distributions. For example, on less stable, erosional geomorphic surfaces, where sediments containing spicules could move subsequent to deposition, one would expect the concentration of spicules to decrease markedly at a shallower depth than on more stable or constructional surfaces within the same proximity. On this basis, curves may not be strictly comparable among all the sites investigated.

Spicule concentration and fragmentation may also reflect the distance (Jones and Beavers, 1963) and mode of spicule transport from their aquatic source areas. The greater the transport distance and the larger the number of sedimentary cycles involved, the greater the probability of their fragmentation. Data for mean spicule length (table 1) indicate a trend for greater fragmentation with increasing soil depth. This trend is particularly well expressed in Miami (CH-47), Russell (PB-7), and Ellsworth (LR-S5) profiles. Longer spicules in the upper portion of the profiles may imply a closer proximity of these sites to their loess source. More highly fragmented spicules in subsurface horizons, and even in the surface horizons of some profiles, may be attributed to the magnitude of soil mixing, either by man or by other elements of nature, such as rodents, earthworms, ants, uprooting of trees, and soil cracking. In calcareous till horizons, spicules, when present, are characteristically fragmented, presumably a consequence of spicule attrition during one or possibly multiple cycles of glacial transport and deposition.

Jones and Beavers (1963) report more spicules (1000–7000 ppm opal) isolated from loess deposits in Illinois than are generally found in the upper portion of soil profiles included here. However, without percentages for the coarse silt fraction (0.05–0.02 mm) and its respective opaline content, it is not possible to convert their values to data on a total soil basis for direct comparisons.

In summary, the shape of the sponge-spicule depth distribution curves probably reflects integral functions of: loess thickness, spicule concentration in original loess deposit, proximity of loess source, vector of soil mixing, degree of soil weathering, and geomorphic stability of the sampling site. On the basis of spicule distribution evidence for Ohio soils, it is suggested that a thin mantle of loess has been deposited over most of the glaciated regions of this state. Such parent material discontinuities, here documented, must be considered in future soil-genesis or intensity-of-weathering investigations conducted in this region.

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