levels associated with the brick walls were exposed in the small excavation. Lying alongside a wall, in association with the bones of wild animals, was an impressive array of kitchen utensils, including large stone meat cleavers, slicing slabs, grinding stones, mortars, pestles, and knives. In-the-field analysis showed that the goat may have been domesticated but that the greater part of the meat diet came from anatomically wild animals. There was a large brick-lined hearth sunk into one of the floors; this was not a bread oven, but it may have been used for roasting animals. Still lower we hit the edge of what was probably a pit house. In the area exposed it looks as if a pit had been dug about 1½ feet into earlier refuse and then faced with mud plaster. From this level we extracted a large fragment of an asphalt-coated mat of a type also found in the levels above. Typologically the pit-house artifacts are similar to artifacts from Karim Shahir, excavated in northeastern Iraq and there probably dating back to about 7000 to 9000 B.C. (*7*).

Radiocarbon determinations on charcoal from the two lower levels have recently been completed by Shell Development Company, Houston. Charcoal (sample DL-21, No. 4) from the brick-wall levels was dated 6888 ± 210 B.C., and charcoal (sample DL-21, No. 9) from the underlying pit house was dated 6448 ± 200 B.C. Other samples have not yet been dated. This inversion of dates with respect to levels is curious. Though there was no evidence of it in the field, there is a chance that the samples had been contaminated in some way. The closeness of the two dates may also indicate that the people living in the pit house were abruptly replaced by newcomers at a date later than we would have guessed. We have excavated only to the very top of the early occupation level; we do not yet know when the early occupation began.

Work was brought to a halt before the pit-house level had been completely cleared, but we do know that the flint tools are very different from those found in the levels above and that none of the bones recovered was from a clearly domesticated animal. The list of fauna from this level and from the brick-wall levels is impressive because the Deh Luran area today is marginal agricultural land, lacking fresh surface water except during the few months of winter rain and supporting only a very scrubby vegetation. Gazelle, in remarkable abundance, is the only game animal now present, yet when Ali Kosh was first occupied the area teemed with a varied fauna. Animals whose butchered remains were recovered include onager, gazelle, Mesopotamian deer, wild cattle, wild pig, and goat. In addition, fragments of a fresh-water clam are abundant.

Impressions of plants in brick and clay building material were recovered, along with reeds and possibly grasses which were used for matting. No impressions of grain were noted, though grinding stones attest to the use, for food, of wild plants at least. Not until floral analyses have been made, and perhaps not until the site has been opened further, will we know whether then, as today, Deh Luran lay outside the natural habitat of the grains.

The recency of the radiocarbon dates bears on this question. If correct, they indicate a persistence of the wild fauna well beyond the time when climatic change would have been a factor in their extinction. We are thus led to believe that such ecological changes as are indicated must have been caused by man's destructive hand. It may be that before he had a substantial agricultural base to support a more dense population, and hence more hunters, man was unable to exterminate the wild fauna. The variety of animals whose remains occur in the lower two horizons at Ali Kosh could not occur in the Deh Luran area today. Whether the implied ecological change can eventually be construed as climate-induced or whether it was produced by other natural factors or by man's activity remains to be seen, when plant analyses have been completed and a geological study of the area has been made.

Further work, especially excavation of early sites in Khuzistan, should now be undertaken, because Ali Kosh or a similar site may hold the key to our understanding of some of the factors lying behind the spectacular rise to civilization which occurred in the area a few thousand years later. We do not claim to have at Ali Kosh an unbroken sequence from a hunter's camp to an agricultural village. We can say, however, that the four successive occupations exposed in our small sounding represent, in one site, a development unprecedented outside of Tell-es-Sultan, the Jordanian site said to be the Biblical Jericho.

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1. This project is a part of continuing research into the origins of agriculture and settled life in southwestern Asia [see R. J. Braidwood, B. Howe, C. A. Reed, *Science* **133**, 2008 (1961)]. Working with me in the field was Kent Flannery, a graduate student in the department of anthropology, University of Chicago. Flannery, an archeologist-zoologist, made the faunal identifications. In Iran we benefited from the interest and aid of the Iranian Government's Antiquities Service, the National Iranian Oil Company, the Khuzistan Development Service, and interested Iranian and American officials, missionaries, and private citizens.
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26 February 1962

Stranded Arrangement of Sporopollenin in the Exine of Microspores of Poa annua

Abstract. In the early microspore wall of the grass *Poa annua* L., sporopollenin is arranged in bundles of anastomosing strands. Each bundle contains at least two strands, each about 50 A in diameter, which anastomose or intertwine and look like a meshwork with pores of the mesh up to 50 A in diameter. After the early microspore stage the exine becomes homogeneous; it is similar in this respect to the exines or ornamented parts of the exines of pollen of other angiosperms examined by electron microscopy.

The chemical and physical properties of sporopollenin have been reviewed by Zetzsche (*1*), Erdtman (*2*), Frey-Wyssling (*3*), and Roelofsen (*4*). Like other highly organized biological materials, sporopollenin is characterized by a refractive index between 1.5 and 1.6 (*5*), a weak form birefringence but no intrinsic birefringence (*6, 7*). In the exines of *Alnus glutinosa* and *Lycopodium clavatum* sporopollenin did not produce x-ray interferences (*8, 9*). The empirical formula for sporopollenin worked out by Zetzsche and Vicuri (*10*) was $(C_{10}H_{16}O_3)_n$, and they suggested $C_{90}H_{129}O_{12}(OH)_{15}$ as a reasonable approximation of the molecular formula for sporopollenin from *L. clavatum*. Zetzsche considered that sporopollenin might be a polyterpene. Sporopollenin is far more resistant to reduction than soft rubber but is similar in many respects to hard rubber. It breaks down at 300°C, burns with a sooty flame, and in exines which have not been oxidized the sporopollenins are resistant to most chemical reagents. Recently, however, Bailey (*11*) discovered that fresh pollen exines readily dissolve in 2-amino-ethanol at 97°C.

Two structural orientations have been reported for the sporopollenin in pollen grain and spore exines; one granular-homogeneous, the other granular-lamellar (*7, 8, 12, 13*). In pollen of angiosperms the homogeneous form is typical of the exine proper, with lamellar sporopollenin being reported only in the region of the exine and intine juncture (*7, 14*). The lamellar form of sporopollenin has also been observed in the exine of *L. clavatum* spores (*12*) and in exines of gymnosperm pollen (*8, 15*).

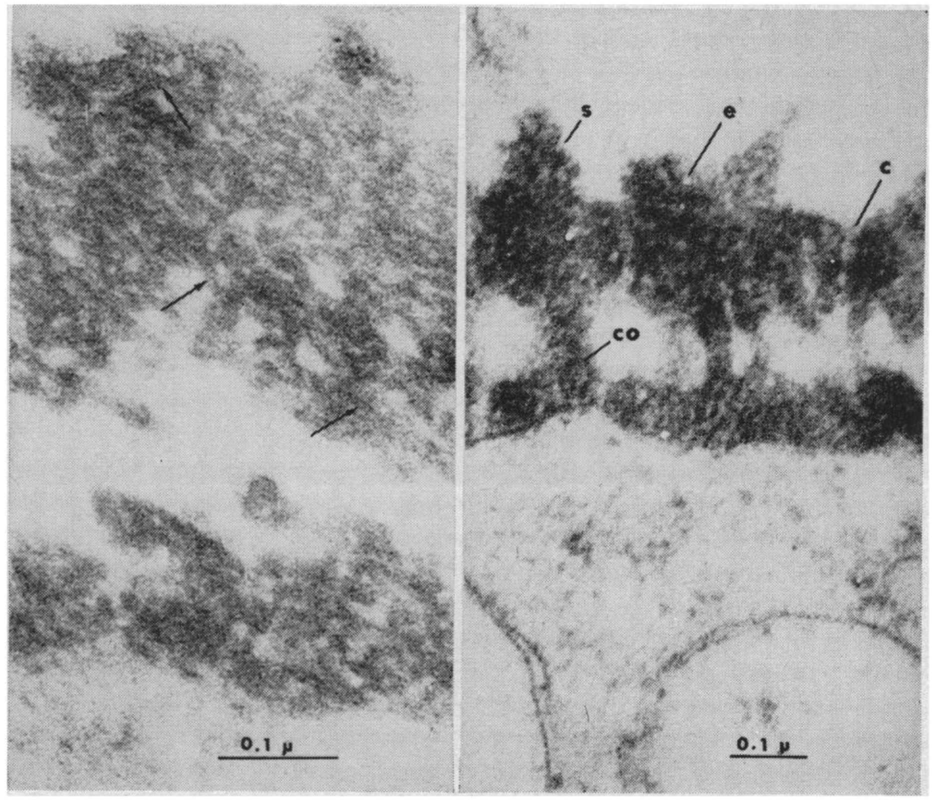

Fig. 1. (Left) Micrograph of exine of *Poa annua* L. Stage the same as in that shown at the right. Anthers were fixed in 4-percent phosphate-buffered formaldehyde and stained with osmium tetroxide. Columellae (right) are discontinuous because of the oblique section. Arrows point to bundles of sporopollenin made up of two or more strands, which appear plaited or mesh-like, often giving way to a series of dots (× about 150,000). (Right) Micrograph of thin section of the microspore exine in *Poa annua* L. at a stage about midway between meiosis and microspore mitosis, from an anther fixed in osmium tetroxide, stained with uranyl acetate, and embedded in methacrylate. The exine (*e*) is composed of two shells separated by an arcaded space; both shells and the columellae (*co*) between them are made of strands of sporopollenin in bundles. The bands of low density crossing the exine between spinules (*s*) and columellae are circular channels (*c*) (about × 100,000).

In a study of pollen grain wall formation in *Poa annua* L. (annual bluegrass) the sporopollenin of mature walls was seen to conform to the typical angiosperm morphology, but during early microspore stages the exine was composed of superposed bundles of sporopollenin throughout (Fig. 1, left). The sporopollenin of early microspore walls had a characteristic appearance after fixation with 1-percent osmium tetroxide solution, veronal acetate–buffered at *p*H 7.6, or fixation with a 7-percent formaldehyde solution, phosphate–buffered at *p*H 7.6, and stained with osmium tetroxide or uranyl acetate. It was seen to be organized into well-oriented bundles of variable diameter in the range of 80 to 150 A. These bundles were composed of pairs of dense strands each about 50 A in thickness, separated periodically by windows of low density having an axial separation of 50 to 80 A and a diameter up to 50 A. The periodic anastomosing structure appeared fenestrated or meshlike and often gave way to aligned dots or granules. Sections normal to the surface appeared similar to sections transversing the wall, except for greater axial alignment of bundles. In early exine formation, sporopollenin in *P. annua* microspores occurred in bundles of strands rather than in lamellae, but cross connections between bundles could produce a system of lamellae similar to that known for *Lycopodium* spores (*12*). Well before microspore mitosis the exine became homogeneous except for the thin film covering the exine. The nonhomogeneous film had a greater density than the homogeneous exine, but both were resistant to acetolysis. Resistance to acetolation, as it concerns pollen grains, is presently regarded as a positive test for sporopollenin. The film of sporopollenin was thickest at the exine-intine juncture, especially under the germinal aperture, but is considered to cover all exine surfaces including channels transversing the exine (*16*). Interpreted in this way, sporopollenin is applied to the covering of the male gametophyte in a stranded form, then becomes more completely polymerized to appear homogeneous with increased orientation of the sporopollenin, owing, perhaps, to availability of a comonomer.

My work on wall development in grass pollen grains provides suggestive evidence for the transfer of sporopollenin-forming monomers or pre-monomers from the tapetum to the exine. Early in exine formation, the spinules on the outer of the two exine shells (Fig. 1, right) appear to be terminuses for strands of material running between the tapetum and the microspore exine. If this material contributes to exine formation and to its increase in volume, then ornamentation of the exine may be influenced by lines of substrate transfer to the exine, or to the protoplast of the male gametophyte, or both. This hypothesis only proposes a relationship between deposition of components of the exine and the routing for interchange of substrate; the myriad of specific exine forms demands control engendered by the genotype (*17*).

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Radiocarbon Ages of Postglacial Lake Clays near Michigan City, Indiana

Abstract. Two radiocarbon dates were obtained for postglacial clays. One sample, 6350 years old, was taken from a bed of compacted and carbonized wood just above a bed of pebbly clay. Overlying the woody bed is 5½ feet of organic bluish clays and beach sands near the present lake level. The upper clay layer contained a younger wood sample, 5475 years old. The blue clays are of shallow swamp origin and were deposited during the late low-water stage of Lake Chippewa; the pebbly clay is assumed to be of Glenwood age (about 11,000 years) or older.

Erosion caused by the present low level of Lake Michigan recently exposed postglacial lake clays 2 miles west of Michigan City, Indiana (Sec. 30, T. 28 N., R. 4 W.). The clays are exposed for about a mile along the shore. The beds are up to 5½ feet thick. Semicircular fractures in the clays are now visible along the entire exposure (*1*). A plastic yellowish-gray clay with pebbles of various sizes underlies the blue clay. Its top surface shows polygons up to 1 foot in diameter; occasional contortions of the beds sometimes resemble folds. A discontinuous bed of strongly carbonized compressed wood was temporarily exposed immediately above the yellowish-gray clay. The carbon-14 age of this wood is 6350 ± 200 years (*2*). About 3¾ feet of dark blue, carbonaceous, fossiliferous clay, in beds 6 to 15 inches thick, overlies both the wood and the lower pebbly clay. Stratified sand up to 2 feet thick is wedged between the lower blue clay beds and a layer of compacted organic clay 10 inches thick which forms the top of the lacustrine series in most places. The top bed, however, edges out laterally into overlying cross-bedded sand. A few pieces of lightly carbonized wood gave the second carbon-14 age for the upper clay bed, 5475 ± 250 years (*2*). Formerly I believed that the clays were deposits of an earlier Lake Chicago high-water stage (*3*). (Figure 1 shows a cross section through the clays exposed west of Michigan City, Indiana.)

In the following discussion the radiocarbon dated clay beds near Michigan City are compared with dated peat deposits near South Haven, Michigan, 60 miles north of Michigan City, described by Zumberge and Potzger (*4*). The South Haven sequence starts with a blue silt at about Lake Michigan level (580 feet above sea level). Contorted laminae are tentatively interpreted as glacial involutions. Wood located just above the silt showed a radiocarbon age of 11,000 years. On the basis of this age, Zumberge and Potzger assign the silt to the Glenwood low-water stage of Lake Chicago. The water-laid silt subsequently became exposed to extensive frost action during the following Bowmanville low-water stage (less than 580 feet above sea level) which caused the involutions. At Michigan City the top of the pebble-containing yellowish clay is found near the present lake level and is older than 6300 years.

Vertical cracks in this clay form small irregular polygons which strongly resemble frost polygons of arctic soils. The local foldlike contortions as well as the polygons are believed to have occurred during the first

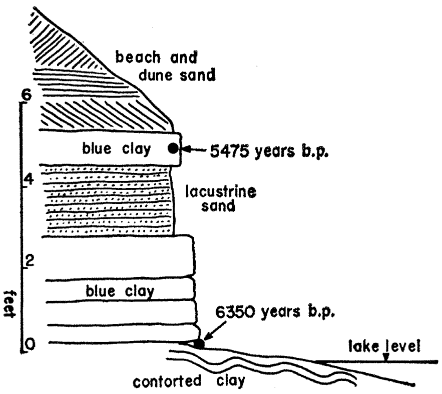

Fig. 1. Cross section through the clays near Michigan City, Indiana.

low-water stage of Lake Chicago; this stage offered the only contact with arctic climate. The clay was covered with at least 10 feet of water or ice following the Glenwood time, which prevented the exposure to heavy frost action then. Again the clays became exposed during the beginning of the Lake Chippewa low-water stage at a time near the hypsothermic postglacial warm weather peak described by Flint and Brandtner (*5*). The occurrence of frost features, therefore, does not appear to be possible during Lake Chippewa time. The yellowish-gray clay of Michigan City is, therefore, believed to be of Glenwood or pre-Glenwood age.

At South Haven, a few feet of bedded sands occur between the blue silt and a 30-inch-thick peat bed. Several carbon-14 ages of the entire peat deposit range from 8305 ± years at the

years before present	Lake Stage (elev. above sea level)		South Haven	Michigan City
0	Lake Michigan	580		
2500	Algoma	595		
3500	Nipissing	605		
4000				
				blue clay
6000	Chippewa	230	peat	
8000				
8500	Algonquin	605	beach sand	
	Nipissing	605		
	Calumet	620		
11000	Bowmanville bel.	580	contorted silt	contorted clay
	Glenwood	640		
13000				

Fig. 2. Comparison of the Michigan City and South Haven sites based on the Correlation Chart of Geologic Events by Zumberge and Potzger (*4*).