

Siliceous microfossils, especially phytoliths, as recorded in five prehistoric sites in Eastern Middle Sweden

Jan Risberg, Lisbet Bengtsson, Britta Kihlstedt, Cecilia Lidström Holmberg,
Michael Olausson, Eva Olsson & Carin Tingvall

At Myskdalen, a Mesolithic site, hearths and hearth pits contained morphologically more varied phytoliths than stone tools. Brackish water diatoms suggest that a presumed grinding tool was used for processing of marine material. A stone implement had abundant phytoliths attached to it indicating plant processing. Östra Vrå is an Early Neolithic site. Two grinding slabs found in a ritual context were verified as having been used for the grinding of plant remains. At Kyrktorp, an Early/Middle Neolithic site, siliceous microfossils on one grinding slab and a replica of it were compared. The lack of siliceous microfossils on the original slab indicated a different use from that of the grinding tools from Östra Vrå. Albertsro is a chieftain's farmstead from the Late Pre-Roman and Early Roman Iron Age. Phytoliths were abundant in the surrounding field system but the stratigraphic variations in the soil were restricted. Gribbylund is a farmstead, used from the Pre-Roman Iron Age to the Migration Period, where two cultivation phases were verified. The phytolith analysis showed that *Linum usitatissimum* was probably cultivated, and the concentrated stratigraphic occurrence of Chrysophyceae stomatocysts indicates that manure was used. It is concluded that siliceous microfossils can be used to deduce anthropogenic activities.

Introduction

Attempts to use siliceous microfossils, especially phytoliths and diatoms, for complementary analyses in connection with archaeological excavations have been made by many researchers (e.g. Rovner, 1971; Piperno, 1985a, b; Vuorela, 1991; Dinan & Rowlett, 1993; Borgmark 1998, Kurberg 2000). Although phytoliths are sometimes to be found in abundance, their stratigraphical distribution has often proved difficult to interpret, largely because of our poor knowledge of how the morphotypes are related to plants and parts of plants. Also, the description and differentiation of morphotypes has proved to be complicated (e.g. Lewis, 1981; Piperno, 1988; Twiss, 1992; Tingvall, 1995; Bergström, 1996). Differentiation between the phytolith shapes typical of cultivated and "wild" grasses is especially problematic (cf. Geis, 1978; Piperno, 1984), in contrast to the situation in tropical areas, where the chances of being able to identify phytolith morphotypes and relate them to plant species seem to be enhanced (e.g. Rosen, 1992; Piperno & Becker, 1996; Runge, 1996).

The question of whether analyses of siliceous microfossils, especially phytoliths, can be used to trace land use and human activities was raised during archaeological excavations

carried out by the Swedish Central Board of National Antiquities in Eastern Middle Sweden. Soil samples from cultural layers and residues on stone artefacts from five sites were analysed (fig. 1), representing different social and economic contexts and different archaeological periods. In this paper the term grinding slab is used for the lower part of the grinding tool set.

The archaeological sites represent two principal fields of study related to the analysis presented here. The questions raised with regard to the three Stone Age sites were related to (a) subsistence activities, (b) the relationship between artefact function and diet, and (c) use of the natural surroundings, while the study of the two Iron Age farmsteads was related to differences in land use and cultivation techniques and a desire to establish stratigraphical phases in connection with the deduced archaeological stratigraphical sequences.

Site description and sampling

Myskdalen, situated at 35–37 m a.s.l. (fig. 2), is a Mesolithic settlement located in a woodland area in the vicinity of Bråviken, a bay of the Baltic Sea. Hearth pits, hearths and grinding tools formed part of the inventory of finds (fig. 3). The site was dated to Mesolithic times by the ^{14}C method (c.

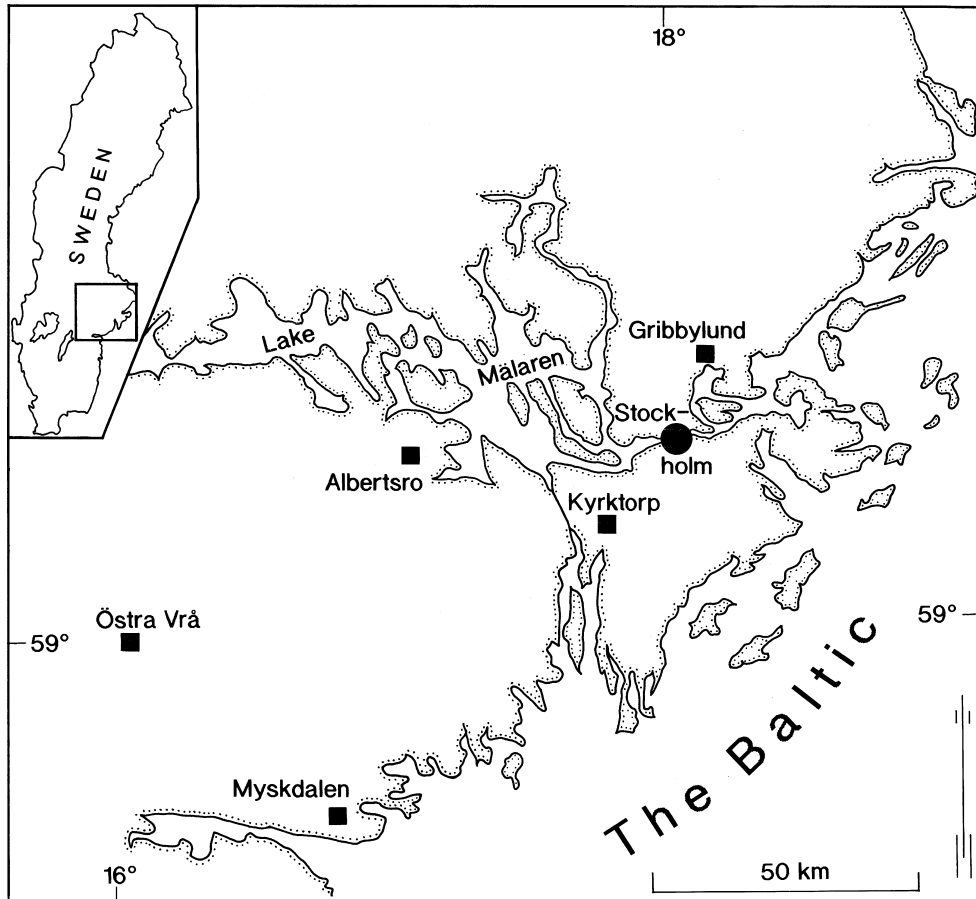


Figure 1. Orientation map showing the location of the five sites investigated (shown as filled squares).

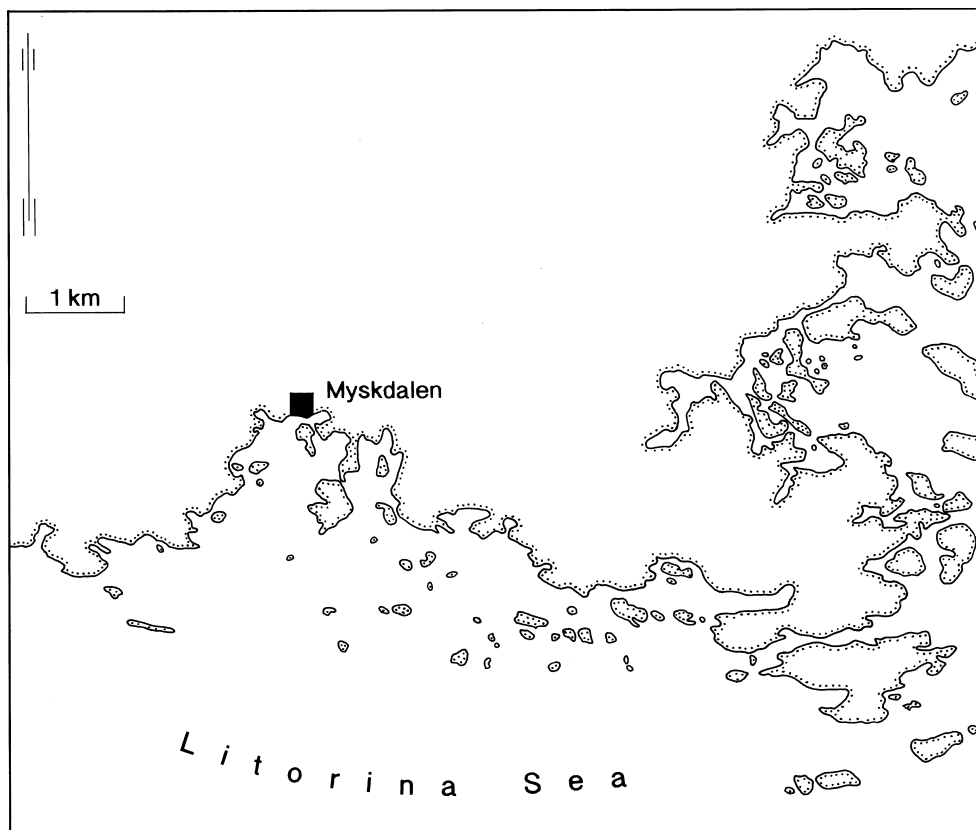


Figure 2. Geographical position of the Myskdalen site when the shore line was 35 m above the present day sea level, i.e. during the Litorina Sea stage of the Baltic, about 5000 ¹⁴C years BP (Persson, 1979, Miller in Brunberg et al., 1985, Risberg et al., 1991).

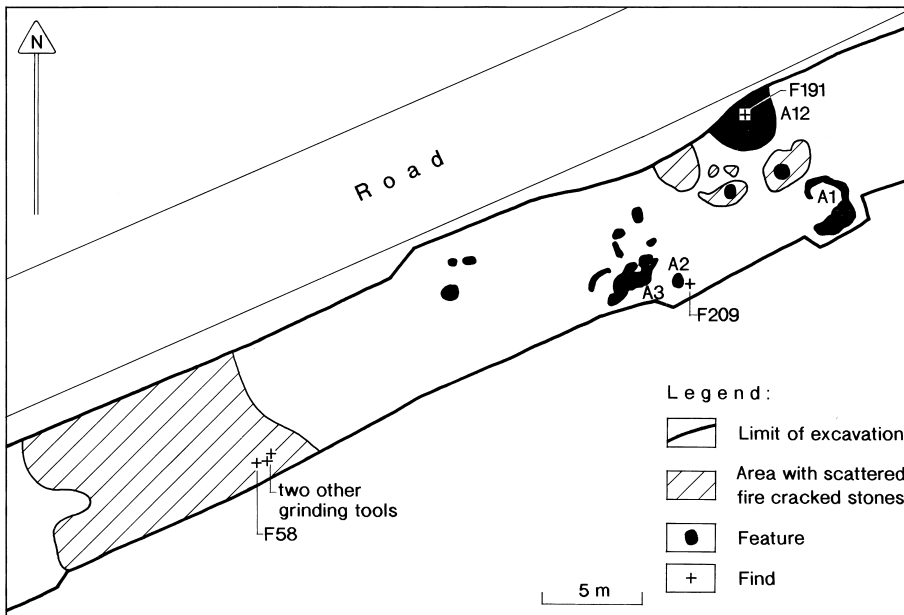


Figure 3. Plan of the excavated section of the Myskdalen site. F58 and F209 refer to the grinding tools, F191 to the stone implement, A3 and A1 to hearth pits and A14 and A2 to hearths.

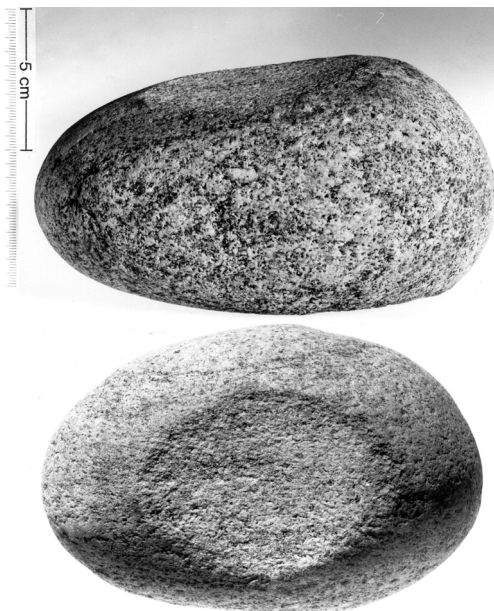


Figure 4 (left). Grinding tool F58 from the Mesolithic site at Myskdalen, analysed for remains of siliceous microfossils. Photograph by Eva Olsson.

Figure 5 (above). The grinding tool at Kyrktorp was found with the hand stone still in position. Photograph by Micaela Fristedt.

4800–4300 cal. BC, c. 5700–5500 ¹⁴C years BP). The excavated sector of the site was located on alluvial deposits, mainly silty sand, and at the time of occupation it probably lay close to the Litorina Sea beach (cf. Thomasson, 1938, Persson, 1979). Since no house remains were found, the dwelling sites may have been placed on shelves of somewhat higher terrain. The beach itself was exposed to the waves and to winds from the south and southwest. We know from the species of charcoal found in the hearths and hearth pits that the nearby vegetation included hazel, alder, oak, birch, elm, willow and pine. Isolated stones and boulders were spread over the excavated sector, most probably placed there by the in-

habitants. Among the most interesting finds were five grinding tools, three of which were located together with other stones and boulders in a circle-like feature about one meter in diameter. A patch of soil within the circle was probably affected by intense heat. The grinding tools are about 10×15 cm in size and are worn on one side or on two opposite sides (fig. 4), making it possible to reconstruct the way the arm and hand moved during the grinding process. Other finds at the site include pieces of knapped quartz, quartzite, flint and greenstone. Three fragments of greenstone axes or adzes with traces of polishing, one stone implement, an unidentified tool (F191 from A12, a pit), some burned clay and a few



Figure 6. An intact and fully functional saddle-shaped grinding slab with leaf-shaped hand stone from Kyrkorp (left) and its replica (right). Both are made of arcose sandstone. The original Neolithic grinding slab is 56 cm in length and the hand stone 35 cm.

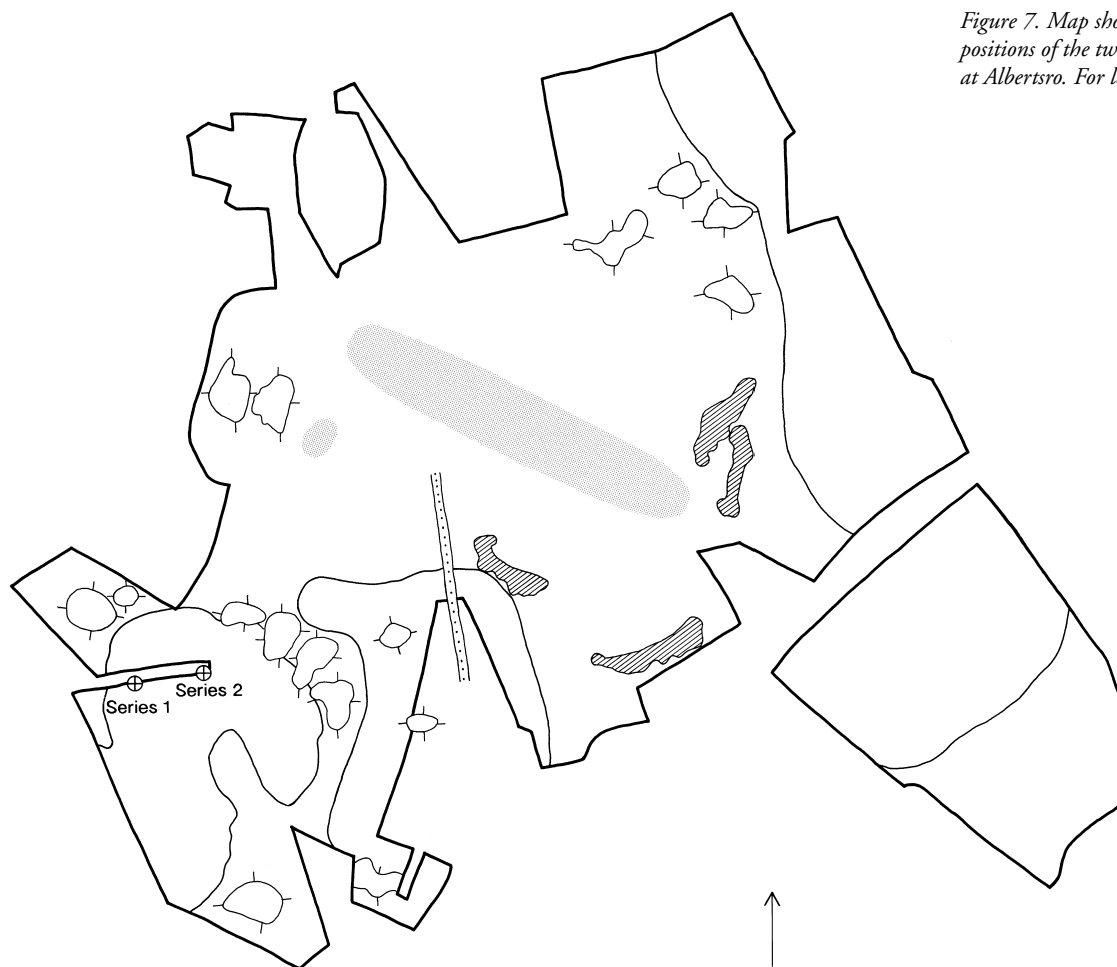


Figure 7. Map showing the positions of the two sites analysed at Albertsro. For legend, see fig. 9.

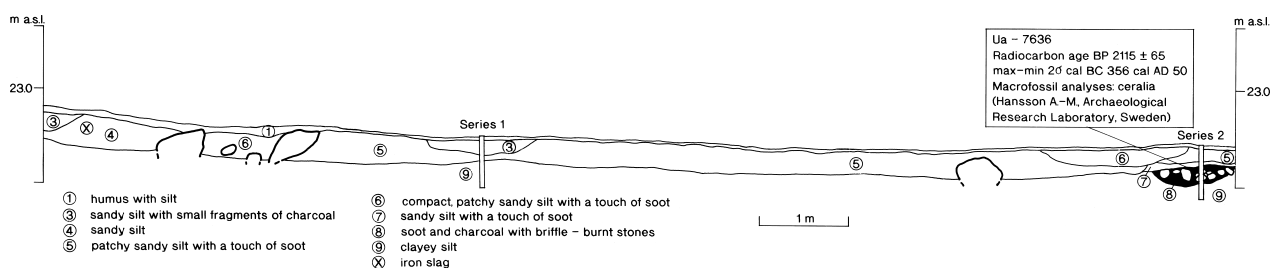


Figure 8. Section showing the stratigraphy at Albertsro.

bone fragments were also found. The fixed features included hearths (e.g. A2), hearth pits, pits (e.g. A12), dark patches and a soot patch. Two of the hearth pits (A1, A3) were very large, about 3×1 m and 0.4–0.6 m deep, and had been dug, filled, cleaned and then filled again.

To obtain information on foodstuffs, food production and the environment as far as the vegetation was concerned, samples were collected from the hearths and hearth pits for the analysis of siliceous microfossils. One purpose of the analysis was to distinguish between the uses made of different features. In addition, samples were taken from one grinding tool, from the soil under two of the grinding tools and from the stone implement. Further material was collected from sediment filling in the hearths and hearth pits and from the sediment underneath two of the grinding tools.

Östra Vrå is an Early Neolithic (Funnel Beaker) settlement site in the central part of the province of Södermanland (fig. 1) that was discovered and partly excavated in the 1930's. Large amounts of pottery and of flint and greenstone artefacts were recovered, and some features interpreted as hut floors were excavated (S. Florin, 1957, M-B. Florin 1957).

The site covers a large area on the sandy slopes of an esker at about 50 m a.s.l. At the time of occupation (c. 3700–3100 cal. BC, c. 4800–4600 ¹⁴C years BP), it was situated on an island in the inner archipelago of the Litorina Sea. The site was not directly shore-bound. The settlement pattern during the Early Neolithic reflects a varied utilisation of resources, with both hunting/fishing and agrarian sites occurring. The location of Östra Vrå and its artefact assemblage suggest that it represents the latter type.

The site also contains features of a ritual character. The stones in the stone packing were grinding slabs, as shown in figs. 5 and 6. It was one of these that was chosen for siliceous microfossil analysis. Two large, partly stone-filled pits, interpreted as earthen burials or sacrificial deposits, were excavated in 1993 (Kihlstedt, 1996) and were found to contain charred bones and teeth of children. One of the pits also contained some carbonised seeds of cereals, one of which (*Triticum*) was dated to c. 3500–3100 cal. BC (4600±60 ¹⁴C years BP). Impressions on pottery from the site have been studied earlier, and cereal grains and other plant remains have been identified. Pollen analyses were performed by M.-B. Florin (1957). Some 80 intact and fragmented saddle-shaped grinding tools (and polishing stones) made up part of the stone packing covering the pits, providing a unique set of artefacts. Carefully produced grinding tools of this type appear in the archaeological record at the Mesolithic-Neolithic transition, and the fact that many of the grinding tools were evidently fully functional when deposited there may support the notion of a ritual character and ceremonial for them. Although grinding tools are generally thought of as everyday equipment for milling cereals, they cannot alone be taken as evidence for agriculture.

Two broken grinding slabs, one from each pit, were chosen for phytolith analysis. One was made of sandstone and the other of granite. Both slabs had been washed during excavation and stored indoors for nearly two years prior to the

analysis, which could imply contamination as a source-critical factor. The purpose of the analysis was to see whether the method could provide detailed information on the use of tools related to foodstuffs and contribute to interpretations of the symbolic meaning of the artefacts. The material from Östra Vrå, and Kyrkorp (see below) and the replicated copy were collected directly from the surface of each grinding slab.

Kyrkorp is situated in the parish of Tumba in the eastern part of Södermanland, SW of Stockholm. The site is situated on the undulating slopes of an esker, at altitudes between about 25 and 50 m a.s.l. It was partially excavated in the 1930's, and has yielded finds representing the Mesolithic, the Early/Middle Neolithic and Pre-Roman Iron Ages (Olsson, 1992).

The Early/Middle Neolithic finds cover a large area, of which the excavation touched only on a small section. The excavated part of the site, a steep slope at 23–35 m a.s.l., was situated close to the Litorina Sea at the time of occupation (Miller & Robertsson, 1982, Risberg et al., 1991), and the finds were classified as belonging to the Pitted Ware Culture (PWC), with dates covering a time span of around 3650–2700 cal. BC (c. 4850–4200 ¹⁴C years BP). Large amounts of pitted ware pottery, clay figurines, quartz and greenstone artefacts and a small amount of flint were found in dark-coloured zones parallel to the ancient seashore. These zones, interpreted as the remains of waste heaps, also contained bones, mainly of seals and fish (Aaris-Sørensen 1978), while hazelnut shells predominated among the carbonised seeds.

Fragments of polishing stones and grinding tools were found over the excavated area, and a saddle-shaped grinding slab was found *in situ* among the debris on the steepest part of the slope, the upper, loaf-shaped hand stone still lying in position (fig. 6). This complete grinding tool differs from other artefacts at the site, as it was found *in situ* and is still functional, which suggests that it had been intentionally deposited rather than discarded. Although the steep slope on which it was found could not have been a suitable place for grinding, one seed of cerealia (*Triticum*), dated to the Early/Middle Neolithic period, approx. 3560–3090 cal. BC (4575±100 ¹⁴C years BP), was recovered a few metres away. Two local pollen diagrams, for the Kyrkorp site and the nearby Korsnäs site, nevertheless show only weak indications of cultivation during this time (Miller & Robertsson, 1982; Karlsson, manuscript).

The special appearance and placement of the complete grinding tool raised questions concerning tool use, material, what it was intended to grind and the reasons for its deposition. To determine what it had actually been used for, an experimental study and analysis of wear traces were carried out on a replica (Lidström Holmberg, 1993). Another purpose was to compare siliceous microfossils attached to the original grinding tool with those on the replica (fig. 6), and to find out to what extent siliceous microfossils could be recovered from grinding tools.

The replica was used for grinding wheat (*Triticum vulgare*), emmer wheat (*Triticum dicoccum*), dried hazel nuts (*Corylus*)

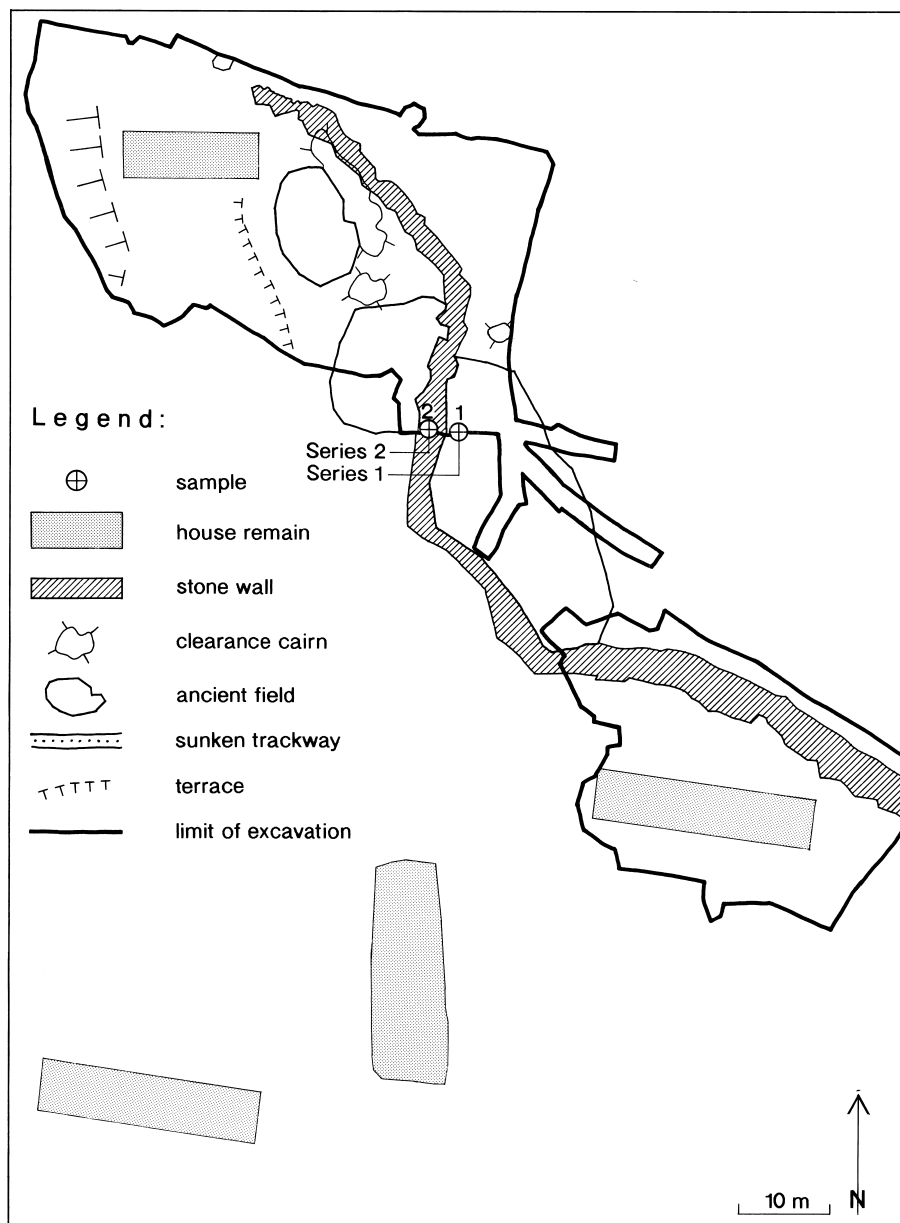


Figure 9. Map showing the position of the two sites at Gribblylund. The legend also applies to fig. 7.

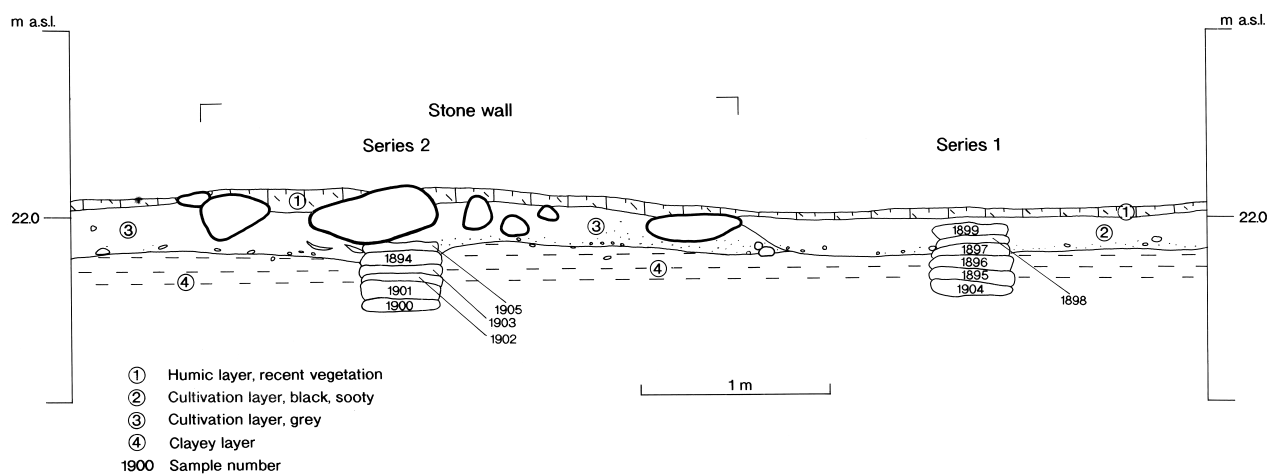


Figure 10. Section showing the stratigraphy at Gribblylund.

and fresh roots of cow parsley (*Anthriscus silvestris*). The experiment showed that this specific type of saddle-shaped grinding slab with an elongated, loaf-shaped hand stone is an effective means of grinding soaked or roasted cereals.

Material from the original grinding slab and the replica was then studied. Both stones were of arcose sandstone. The original grinding slab had been washed during the excavation and stored indoors for six years prior to the analysis, while the replica was washed with water and a brush for 30 minutes in connection with the experiment.

Albertsro is a chieftain's farmstead from the Late Pre-Roman Iron Age and Early Roman Iron Age (c. 200 cal. BC–200 cal. AD; c. 2500–1700 ¹⁴C years BP) that is situated in the northern part of the province of Södermanland, SW of the town of Mariefred (Shützler 2000). The settlement site lies on a hill plateau and is surrounded mainly by moraine ridges, and to a minor degree by stone walls and terraces, at altitudes 21–22 m a.s.l. The site occupied a commanding position and had visual control over the surrounding contemporary settlement sites, including the village of Lida one kilometre to the east. The site contained the remains of a large three-aisled house, 50×10 m, at least one smaller house, probably for storage, and a smithy (Olausson 1998). The houses and the courtyard were surrounded by five more or less well-defined ancient fields bounded by moraine ridges, clearance cairns and stone walls (fig. 7). A few stone settings surrounded the farmyard and infields, and played a role not only as places for interring the remains of the deceased, but also as monuments and places for ancestral worship. These also represented a mental and physical demarcation line in relation to the outfields and forest area and the surrounding settlements. One of the smaller cultivated areas contained several hearth pits and some finds interpreted as remains of iron production. The stratigraphic observations suggested that the area had been used in various ways over a certain period of time, and the purpose of the sampling and analysis was to see whether any differentiation could be detected between iron production and the cultivation activities. Another aim was to answer questions about the crops cultivated and manuring methods employed by comparing the results with the microfossil remains found in the large main building. Two series of samples were collected. The first, from an open section, represents a sandy sequence with single finds of charcoal, charred clay and iron slag (fig. 8), while the second, similarly collected from a sandy sequence, also contained a hearth (dated to around 100 cal. BC–100 cal. AD; 2115±65 ¹⁴C years BP). The material representing Albertsro (and Gribbylund, see below) was taken from open sections. Each sample consisted of sequences of thickness 2–3 cm cut out directly from the section wall using a trowel.

Gribbylund comprises parts of a farmstead, remains of a stone wall system (sw Stensträngar) and cultivation remains covering the time span from the Pre-Roman Iron Age to the Migration Period, approx. 400 cal. BC–500 cal. AD; c. 2500–1500 ¹⁴C years BP, respectively (fig. 9). The area is situated in the parish of Tåby, about 15 km north of Stockholm. The site lies at 20–21 m a.s.l. on a gentle slope south-facing on the

western side of Lake Rönningesjön, which was still connected to the Litorina Sea stage of the Baltic Sea during the early Iron Age (Risberg et al., 1991).

The settlement area was used during two phases, as the remains of one of the two houses excavated were dated to the Pre-Roman Iron Age and those of the other to the Migration period. The older house belonged to a farmstead with arable fields, while the younger one was one of three houses belonging to a farmstead with arable fields that was contemporary with the stone wall system. Thus the farmstead formed one unit in a larger local social and economic system.

An area that had been cleared of stones lay below a stone wall between the two sites investigated, which suggests that the stone wall system was the result of a radical re-organisation of the cultivated land. Samples were collected from open sections east of the stone wall and underneath it (fig. 10), and ancient fields were identified at two depths, 21 cm and 44 cm, based on archaeological finds and differences in soil character and colour. The purpose was to study the cultivation areas beside and underneath the stone wall, respectively, to see whether the analysis could provide any more precise information about changes in cultivation techniques, the selection of crops cultivated and the manuring methods employed.

Methods and Techniques

No uniform classification of phytolith morphotypes has so far been accepted, and similar morphotypes can be named in different ways by different authors (Twiss, 1992). Regarding grasses, the classifications have followed two general approaches; one botanical for intact fragments (Metcalf, 1960; Piperno, 1988; Mulholland & Rapp, 1992), and one morphological for discrete particles (Twiss et al., 1969; Powers, 1992; Mulholland & Rapp, 1992). So far, one of the most widely used classification schemes is that elaborated by Twiss (1992) from the original proposal of Twiss et al. (1969).

The samples collected from Myskdalen, Albertsro and Gribbylund were prepared using the traditional technique for the enrichment of diatoms (Battarbee, 1986). Carbonates were dissolved with 10% HCl and organic material was oxidised with 30% H₂O₂. Clay particles were removed after repeated stirring and sedimentation and decanting in 100 ml beakers at two-hour intervals. Coarser particles were allowed to settle for 5 seconds, after which the microfossil fraction was transferred to another 100 ml beaker. The residue was mounted in Naphrax and studied under ×1000 magnification using oil immersion and phase contrast.

The grinding tools from Myskdalen, Östra Vrå and Kyrkorp (including the replica), together with the stone implement from Myskdalen, were washed with 10% HCl and gently brushed with a toothbrush. The fine-grained residue was mounted and studied.

Diatoms were identified using the floras of Krammer & Lange-Bertalot (1986, 1988, 1991a, b), Mölder & Tynni (1967–1973) and Tynni (1975–1980), and phytoliths, which are three-dimensional structures (fig. 11) which have different shapes depending on the angle of observation

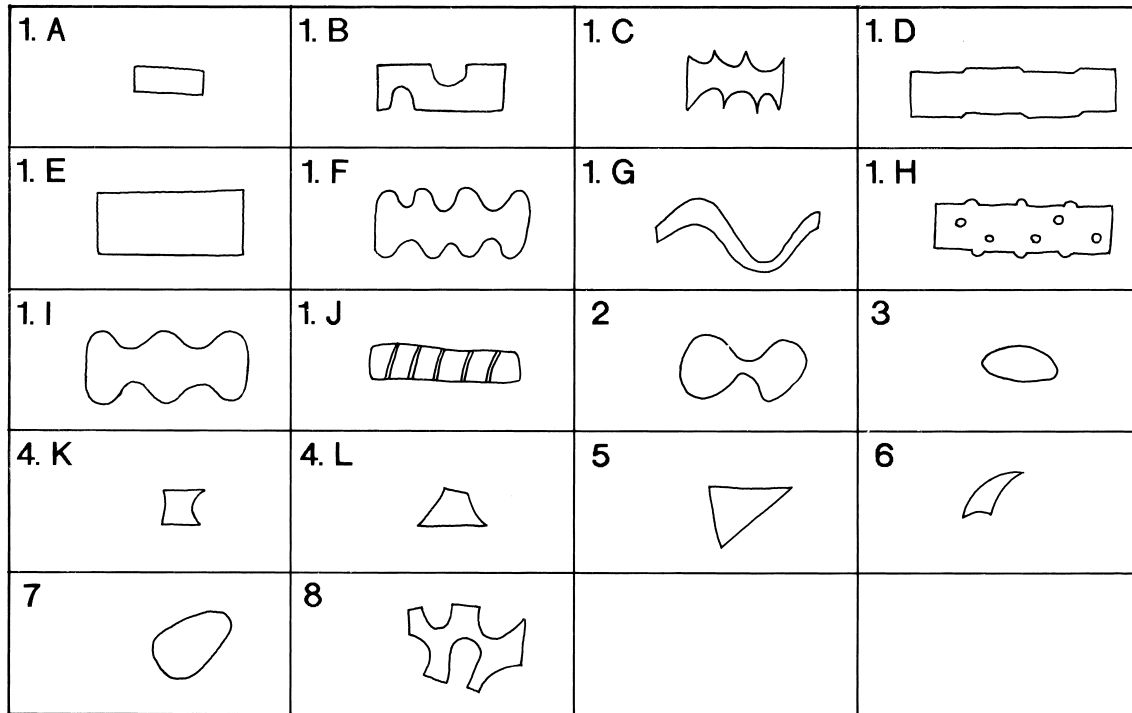


Figure 11. Subdivision of the phytoliths observed in the material. The specifications of the morphotypes are summarised in table 1.

(Rovner & Russ, 1992), were grouped using modified versions of Twiss et al. (1969), Piperno (1988), Vuorela (1991), Mulholland & Rapp (1992) and Tingvall (1995). Fixed residues were studied here in order to facilitate diatom identification, and therefore only two-dimensional features were noted. This is a potential source of error when classifying phytolith morphotypes (cf. Dinan & Rowlett, 1993).

Semi-absolute frequencies were calculated in terms of the number of siliceous microfossils per traverse, where each traverse represents 32 mm on the cover glass. This procedure gives a rough estimate of the absolute numbers of siliceous microfossils.

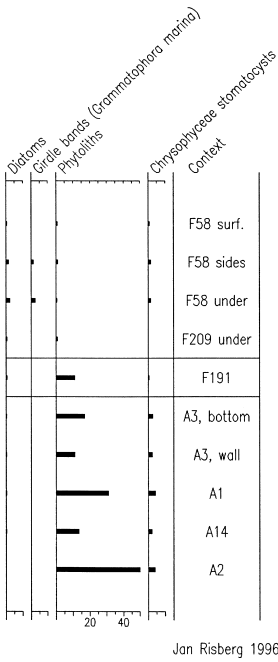
Results and Interpretation

Phytoliths were classified according to their morphology, recognizing a total of 18 types. As the differences between the morphotypes are not always clear, similar forms were combined to yield eight main groups (fig. 11, table 1). Rectangular morphotypes were divided into ten sub-groups (A–J), and square morphotypes into two sub-groups (K–L). Most of the phytoliths observed here are attributable to the panicoid and pooid (festucoid) classes (Twiss, 1992), which include the cereals and other grasses. The conical morphotypes and some of the triangular ones could originate from Cyperaceae (Ollendorf, 1992).

The other siliceous microfossils observed were diatoms, Chrysophyceae stomatocysts and sponge spiculae, in addition, starch grains were identified, belonging to morphotypes that were semi-circular to oval in shape.

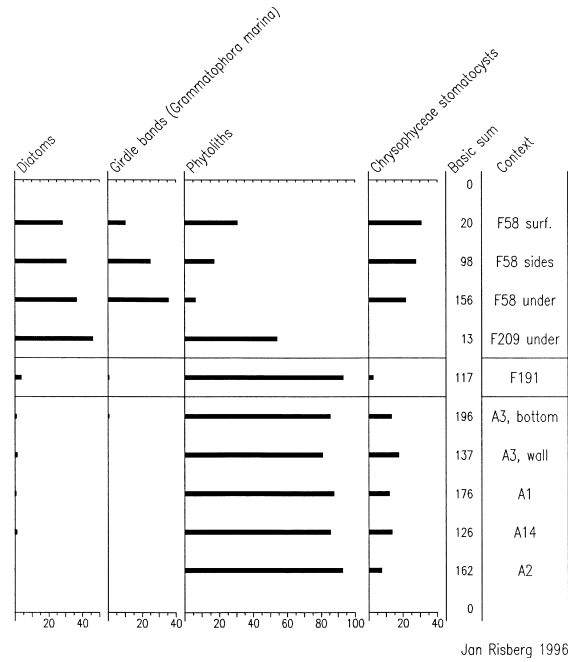
Table 1. Subdivision of phytoliths observed in the material from Myskdalen, Östra Vrå, Kyrktorp, Gribbylund and Albertsro. Note that the distinctions between the morphotypes are not always clear.

- | |
|--|
| 1. Rectangular morphotypes |
| A. Small (c. 15–20×5–7mm), mainly with smooth margins |
| B. Larger than A and with inward bends and/or bulges |
| C. Spiny bulges (cf. Vuorela 1991, p.10) |
| D. Undulating margins |
| E. Larger than A, mainly with smooth margins |
| F. Margins with more than 3 large, smooth bulges (cf. Vuorela 1991, p.10) |
| G. With undulations of varying amplitude |
| H. Margins with small, regular bulges |
| I. Margins with 3 large, smooth bulges |
| J. With several parallel bars |
| 2. Dumbbells (of varying morphology) |
| 3. Centric morphotypes |
| 4. Square morphotypes (with smooth and undulating margins) |
| K. With smooth edges |
| L. With two extended corners |
| 5. Triangular to conical morphotypes (with sharp edges) |
| 6. Morphotypes with a spherical to ovoid base and a conical top (hairs and papillae) |
| 7. Bulliform morphotypes |
| 8. Undefined morphotypes (irregular, asymmetric appearance) |



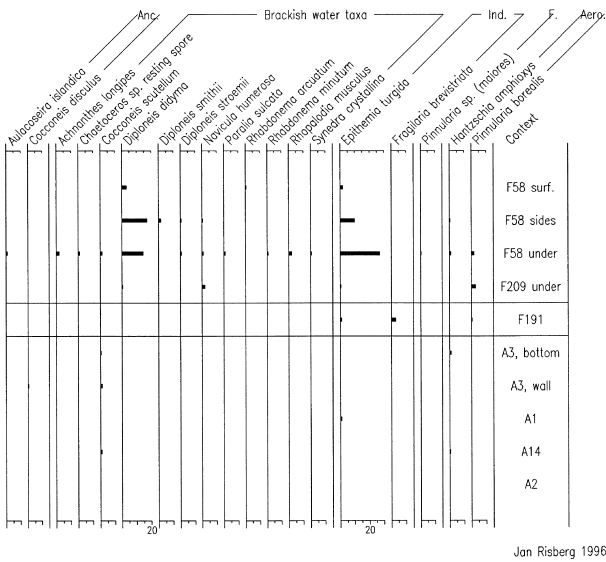
Jan Risberg 1996

Figure 12. Semi-absolute frequencies (numbers per traverse) of siliceous microfossils at Myskdalen. F58 and F209 refer to grinding tools, F191 to a stone implement, A3 and A1 to hearth pits and A14 and A2 to hearths. "surf." = surface of grinding tool, "sides" = sides of grinding tool.



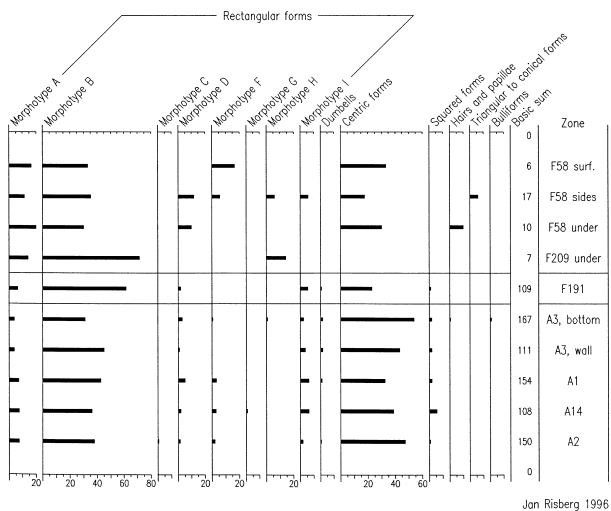
Jan Risberg 1996

Figure 13. Main types of siliceous microfossils found in samples from Myskdalen (%). F58 and F209 refer to grinding tools, F191 to a stone implement, A3 and A1 to hearth pits and A14 and A2 to hearths. "surf." = surface of grinding tool, "sides" = sides of grinding tool. Note that some samples have very low basic sums.



Jan Risberg 1996

Figure 14. Numbers of diatoms identified in samples from Myskdalen. "Anc." indicates diatom taxa typical of the Ancylus Lake stage of the Baltic. "Brackish water taxa" are species that lived mainly in the Litorina Sea stage of the Baltic. "Ind." refers to taxa indifferent to salinity. "F." indicates taxa living in freshwater conditions. "Aero." indicates taxa living under terrestrial conditions. F58 and F209 refer to grinding tools, F191 to a stone implement, A3 and A1 to hearth pits and A14 and A2 to hearths. "surf." = surface of grinding tool, "sides" = sides of grinding tool.



Jan Risberg 1996

Figure 15. Subdivision of phytoliths identified in samples from Myskdalen. F58 and F209 refer to grinding tools, F191 to a stone implement, A3 and A1 to hearth pits and A14 and A2 to hearths. "surf." = surface of grinding tool, "sides" = sides of grinding tool. Note that some samples have very low basic sums.

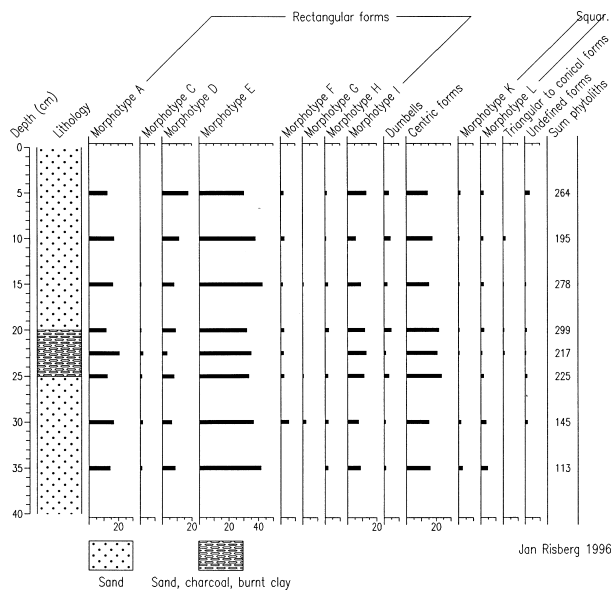


Figure 16. Phytolith stratigraphy at Series 1, Albertsro. Note the small change in phytolith distribution in the sandy layer with charcoal and burnt clay, between depths of 20 and 25 cm. "Squar." refer to square morphotypes.

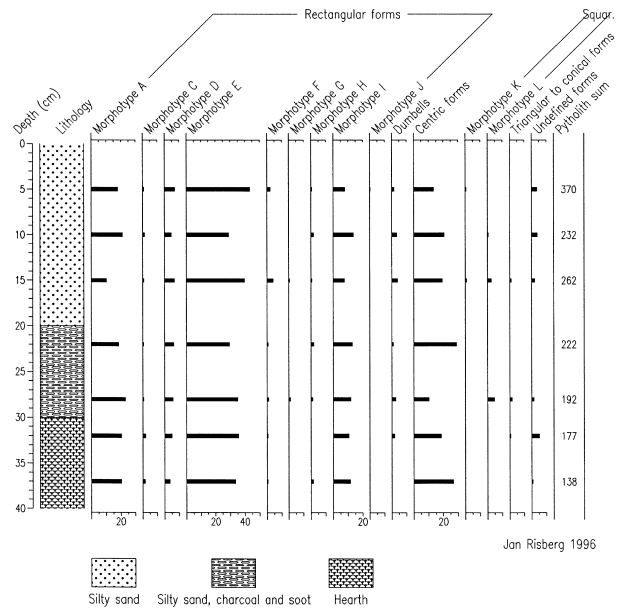


Figure 17. Phytolith stratigraphy at Series 2, Albertsro. Note that the phytolith distribution is very similar at different depths even though a hearth forms part of the stratigraphy. "Squar." refer to square morphotypes.

Myskdalen

The semi-absolute frequencies of siliceous microfossils vary between 1 and 54 per traverse (fig. 12). Diatoms predominate in the samples from the grinding tools, and phytoliths in those from the stone implement, hearths and hearth pits (fig. 13). The most common among the diatoms are the epiphytic brackish water taxon *Diploneis didyma* and the indifferent taxon *Epithemia turgida* (fig. 14), while the rectangular morphotype B and the centric forms predominate among the phytoliths (fig. 15).

The samples collected from the surface, side and underneath of the grinding tool F58 contained a high abundance of diatoms, especially girdle bands of the epiphytic brackish water taxon *Grammatophora marina*, while the phytolith content of the underside of the grinding tool F209 was still higher, although not markedly so. The variation in siliceous microfossils on the first of these artefacts, F58, leads us to question its presumed function as a grinding tool.

The sediments under the grinding tool F209 possessed a few phytolith morphotypes, but as the number was limited, too much emphasis should not be placed on its use as grinding tool for grain. It could possibly have been used for other purposes, such as grinding minerals or shells from shellfish. Use for polishing axe heads is not supported by the widths of the sets of striation marks left on them. Altogether it is possible that the grinding tools found at Myskdalen were used for grinding different types of material.

The stone implement F191 yielded a markedly greater quantity of phytoliths than the grinding tools. A preliminary conclusion is that it was used for cutting or crushing material representing a number of plant species.

The hearths and hearth pits contained larger numbers of phytoliths than the samples from the grinding tools or the stone implement, and the variety of morphotypes was usually higher. This is most probably due to the use of woody plants as fuel.

Östra Vrå

The samples from the two grinding slabs analysed, which were made of sandstone and granite, contained relatively large amounts of siliceous microfossils. Phytoliths predominated on both slabs, the rectangular ones of morphotype A being the most common (table 2). Starch grains were also observed. It can be concluded from this distribution that both slabs had been used for grinding plant remains prior to deposition, but the analysis could not provide any specific information about which plants were used.

The sandstone slab displayed six frustules of the freshwater planktonic diatom taxon *Cyclotella radiosa*, but the granite one displayed a more varied diatom flora, a mixture of *Cyclotella radiosa*, the typical Ancylus Lake taxon *Aulacoseira islandica*, the brackish water taxon *Melosira westii* and the aerophilic *Hantzschia amphioxys*. The difference in diatom composition may indicate that either the material to be ground or the grinding slabs emanated from different sources.

Kyrkorp

The grinding slab from Kyrkorp contained only one siliceous microfossil, a stomatocyst of Chrysophyceae (table 2), in contrast to the replica, which contained phytoliths, starch grains and fragments of diatom frustules. Both dumbbells

Table 2. Numbers of siliceous microfossils and starch grains on grinding tools from Östra Vrå (Early Neolithic; c.4800–4600 ¹⁴C years BP) and Kyrktorp (Early/Middle Neolithic; c.4500–4400 ¹⁴C years BP). “f” indicates fragments. Magnifications of ×400 and ×1000 were used. The number of traverses varies between 7 and around 15.

	Site: Material:	Östra Vrå Sandstone	Östra Vrå Granite	Kyrktorp Sandstone	Kyrktorp Sandstone (replica)
Phytoliths					
Rectangular forms					
A		14	11	–	1
C		–	1	–	–
D		1	–	–	–
E		2	2	–	–
F		6	–	–	–
H		1	1	–	–
I		–	4	–	–
J		1	–	–	–
Dumbbells		–	–	–	1
Square forms		–	–	–	4
Triangular to conical forms		–	–	–	4
Undefined forms		2	1	–	–
Starch grains		47	31	–	8
Diatoms					
<i>Aulacoseira islandica</i> (O. Müller) Simonsen		–	0.5	–	–
<i>Melosira westii</i> W. Smith		–	2	–	–
<i>Cyclotella radiosa</i> (Grunow) Lemmermann		6	1	–	–
<i>Pinnularia</i> sp. Ehrenberg		f	f	–	f
<i>Tabellaria fenestrata</i> (girdle band)		–	0.5	–	–
<i>Hantzschia amphioxys</i> (Ehrenberg) Grunow		–	f	–	–
Varia		2	–	–	1
Chrysophyceae stomatocysts		3	2	1	–
Sponge spiculae		f	–	–	–

and rectangular, triangular to conical and square morphotypes were represented among the phytoliths on the replica (table 2). Since this latter had been used for grinding cereals as well as wild plants, the results suggests that the original tool from Kyrktorp was not used for any of these purposes.

The wear pattern on the surface of the grinding slab reflects the wear on the surface of a hand stone, clearly showing that the upper and lower parts had been specifically designed and used together as a single tool set (Lidström Holmberg 1998:131). Material that had been ground on the slab in its time had evidently acted as lubricant at the centre, causing less friction there than along the sides of the slab.

The results of the phytolith analysis thus could not confirm that the original tool from Kyrktorp had been used for processing cereals or other plants. The question remains, however, how to interpret the lack of phytoliths. The wear marks caused by interaction between the grinding surfaces show characteristic signs of food grinding, as illustrated in experiments performed on the replica (Lidström Holmberg 1993), and the morphology of the tool does not suggest that it had been used for processing non-food items. In addition, the wear marks on the grinding tool set do not give an indication of any specific alternative use.

The lack of phytoliths and siliceous microfossils may be interpreted as a result of prehistoric cleaning procedures and/or efficient washing by waves on the nearby shore. Addi-

tional explanations may be related to the procedures for handling the stone tool after or during the excavation.

Albertsro

Phytoliths are very common in the material studied from Albertsro, the highest semi-absolute frequency, 280 per traverse, being noted in sample series 1 at a depth of 15 cm. The stratigraphic distribution of phytoliths is similar in sample series 1 and 2 (figs. 16 and 17). The most common morphotypes are rectangular (morphotypes A, E and I), together with centric forms. The sandy layer with charcoal and burnt clay in sample series 1 displays a somewhat different phytolith composition, however (fig. 16), as the rectangular morphotypes A and C, together with centric forms, show increased relative frequencies, while morphotypes D and H decrease. Triangular forms display a continuous curve from this layer upwards.

The high semi-absolute abundance of phytoliths, around 200 particles/traverse, is interpreted as representing traces of cultivation. The stratigraphic difference observed in sample series 1 relative to sample series 2 may indicate somewhat different land use at the time of deposition of the sandy layer containing charcoal and burnt clay, possibly an interruption in cultivation activities in favour of iron forging, although this is difficult to prove. It is assumed that even if the oldest cultivation activities were interrupted by a period of iron

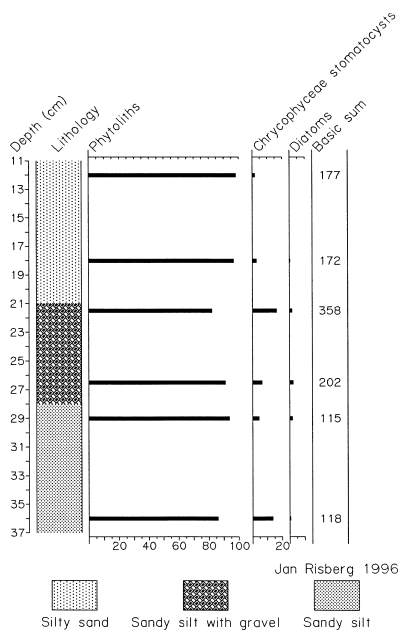


Figure 18. Distribution of siliceous microfossils at Series 1, Gribbylund (%). Note the enhanced amount of Chrysophyceae stomatocysts at depth 21 cm, corresponding to the surface of the ancient field.

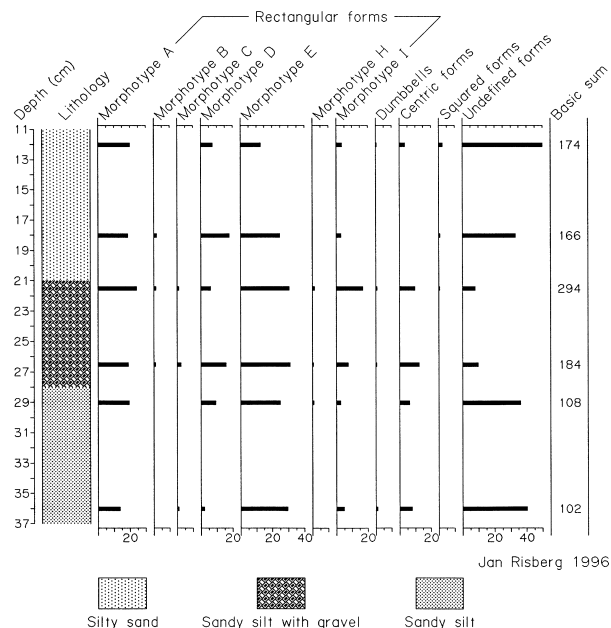


Figure 19. Distribution of phytolith morphotypes at Series 1, Gribbylund (%). Note that the morphotypes in the depth interval 21-28 cm differ somewhat from those in the rest of the section. The depth of 21 cm corresponds to the surface of the ancient field.

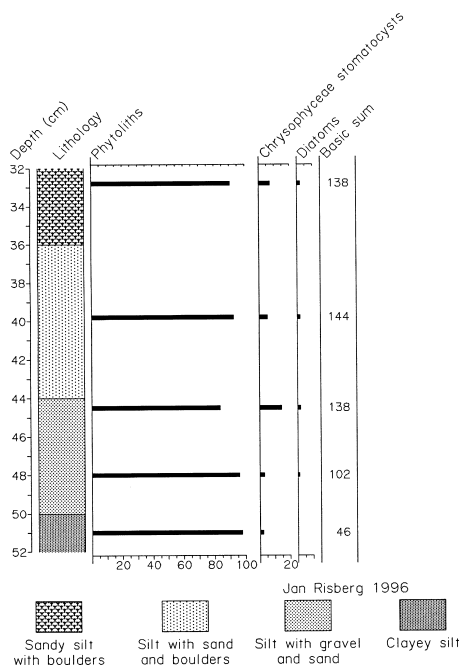


Figure 20. Distribution of siliceous microfossils at Series 2, Gribbylund (%). Note the enhanced amount of Chrysophyceae stomatocysts at depth 44 cm, corresponding to the surface of the ancient field.

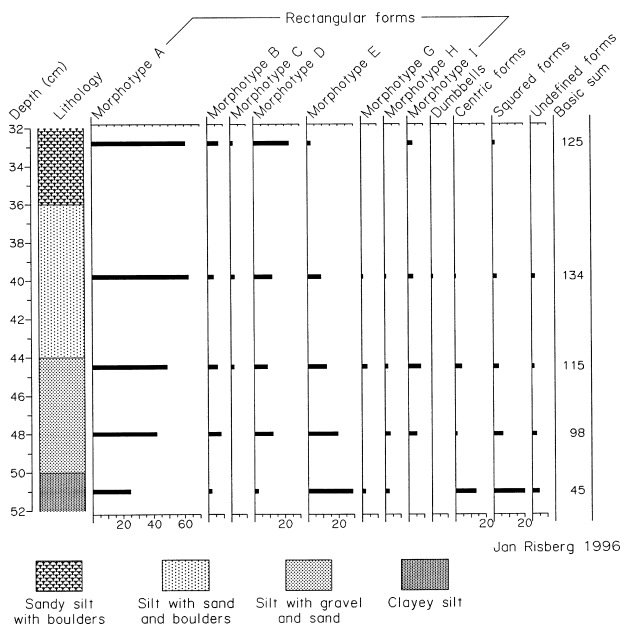


Figure 21. Distribution of phytolith morphotypes at Series 2, Gribbylund (%). Note the change in morphotype distribution at deeper levels. The depth of 44 cm corresponds to the surface of the ancient field.

forging, a later return to cultivation would produce a mixing of the layers, especially since the soil is sandy.

The combination of archaeological observations and analyses of plant macrofossils from the houses provided information indicating the cultivation of barley (*Hordeum*), wheat (*Triticum*), flax (*Linum*) and oats (*Avena*) on manured fields. The phytolith analysis could not provide any further information and could therefore be said to have been of restricted use at this site.

Gribblylund

Sample series 1, taken from east of the stone wall, showed high semi-absolute frequencies of siliceous microfossils, varying between 10 and 120 particles/traverse. The highest concentration was noted on the surface of the ancient field, which lies at a depth of 21 cm, and frustules of the aerophilous diatom *Hantzschia amphioxys* were common from this level downwards. On a percentage basis, phytoliths were dominant throughout the sequence (fig. 18), most notably rectangular forms, especially morphotypes A, D and E, together with undefined morphotypes (fig. 19). The rectangular morphotype I, centric morphotypes and stomatocysts of Chrysophyceae were common on the surface of the ancient field, i.e. at 21 cm. Stratigraphically, it is obvious that the layer containing sandy silt with gravel had a deviating siliceous microfossil content relative to the material above and below it.

In sample series 2, from underneath the stone wall, the semi-absolute frequencies of siliceous microfossils were much lower, varying between 1 and 17 particles/traverse, the highest concentrations being observed in the upper 44 cm. Phytoliths were the most common of the various siliceous microfossils (fig. 20). Chrysophyceae stomatocysts displayed a peak at a depth of 44 cm. Overall, the same phytolith morphotypes occurred as in sample series 1, with the exception of the lower abundance of centric morphotypes (fig. 21).

The results confirm that cultivation took place during both the Pre-Roman Iron Age and the Migration period. Sample series 1 gave a more complex picture of the composition of phytolith morphotypes and pointed to higher semi-absolute frequencies. This is interpreted as implying a longer and more intense period of cultivation during the Migration Period. The diffuse peaks in the relative abundance of Chrysophyceae stomatocysts may be a result of the extensive use of manure (cf. Miller et al., 1979).

Since the plant macrofossil analysis indicated that flax (*Linum usitatissimum*) was cultivated, phytoliths of recent flax were recovered (fig. 22) and compared with the fossil record (fig. 23). The observation of a phytolith similar to that from recent material at a depth of 21 cm in sample series 1, corresponding to the surface of the ancient field, supported the plant macrofossil finds.

Discussion

By tradition, a combination of archaeological observations and plant macrofossil analyses performed on associated organic residues has given significant results concerning the

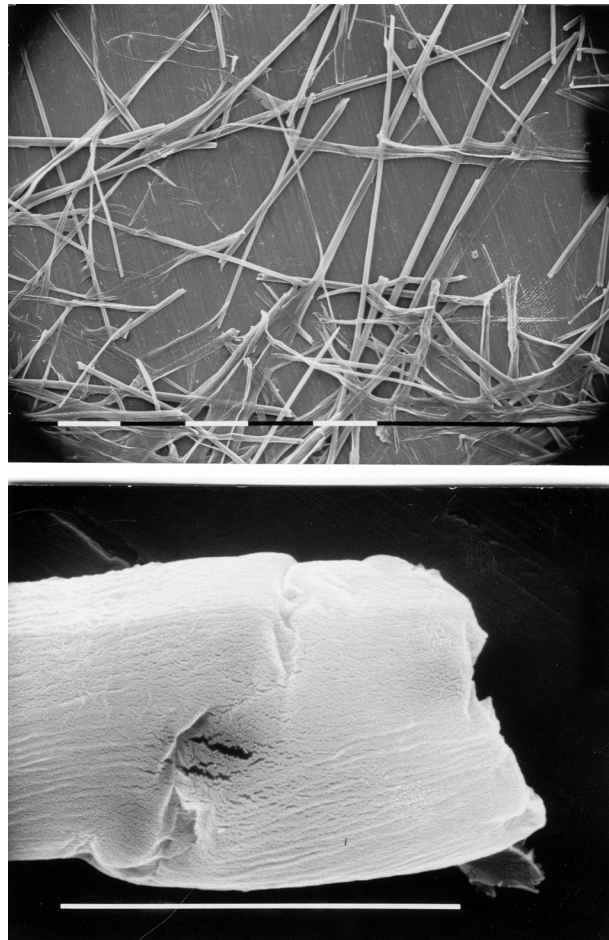


Figure 22. Phytoliths extracted from recent flax (*Linum usitatissimum*) using 65 % HNO_3 . Scale bar: 100 μm (upper) and 10 μm (lower).

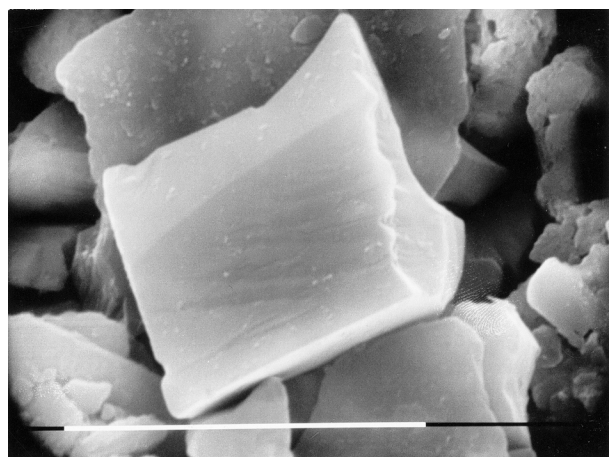


Figure 23. Fossil phytolith found at a depth of 21.5 cm at Series 1, Gribblylund. It is similar in appearance to the ends of phytoliths extracted from recent samples of flax (*Linum usitatissimum*). Scale bar: 10 μm .

crops cultivated and the cultivation techniques used, and analyses of siliceous microfossils are shown here to be a useful ancillary method to some extent. Even though it is not yet possible to determine from which plant, or part of a plant, the different phytolith morphotypes originate, their stratigraphic variations can be assumed to reflect differences and/or changes in land use.

Siliceous microfossils attached to stone artefacts may indicate differences in use, function and source area, and the diatoms present could denote whether the artefact had initially been used on the seashore or on a lake shore.

Experiences with the present investigation suggest that semi-absolute frequencies can be used as an indication of land use. Thus the observation of around 200 particles/traverse at Albertsro can be compared with a maximum count of around 100 particles/traverse at Gribbylund. The numbers observed naturally depend on grain size, but intense cultivation should result in a high abundance of phytoliths in the soil.

The occurrence of *Chrysophyceae stomatocysts* is problematic. These cysts can be found in different depositional environments, e.g. in lakes with neutral pH (Duff & Smol, 1988), in small eutrophic/polluted lakes (Cronberg, 1986), in Baltic Sea sediments (Westman & Sohlenius, 1995) and in peat accumulations (Risberg, 1990, 1991), and they can be indicative of climatic changes (Zeeb & Smol, 1993), although according to Miller et al. (1979), they also occur in nitrogen-rich environments, e.g. anthropogenic waste deposits. If the stomatocysts observed here represent the latter situation, the high abundances at the surface of the ancient fields might indicate anthropogenic manipulation such as the use of manure (cf. Gribbylund).

The benefits of integrating phytolith studies with questions of tool morphology and wear marks on grinding tools lie in the fact that this may provide new and more direct insights into variations, differences and changes in grinding tool use, which may reflect variations in food processing strategies.

The downward movement of phytoliths in undisturbed soil seems to be a minor problem in most cases (cf. Rovner, 1986; Pearsall, 1989; Bobrova & Bobrov, 1997; Madella, 1997), suggesting that phytoliths recovered from the surfaces of stone tools are in fact stable and can be interpreted as representing the original surface where the plants decayed. This more or less direct relationship between artefacts and subsistence is of great importance in principle.

One significant result to emerge from this investigation is that phytoliths can also be recovered and identified at Mesolithic sites. This knowledge brings us to a point where phytolith analysis should be taken seriously as a tool for unravelling our past. Up to now, our knowledge of the Mesolithic in Eastern Middle Sweden has mainly been based on the location of sites and on artefacts of flint and quartz. It is also important to note that it is possible to recover and identify phytoliths from washed stone artefacts several years after excavation.

One aim of our future research will be to build up a reference collection of phytoliths from plants growing in northern Europe, so that more plants represented by the phyto-

liths extracted from excavated material can be identified to a greater level of detail. This could help to establish phytolith analysis as an important additional method for the interpretation of archaeological remains. Research into the connection between phytolith morphotypes and food plants (Cummings, 1992), including cereals (Rosen, 1992), is already being carried out in different parts of the world (Cummings, 1992), but has hardly started in northern Europe, although a knowledge of such connections would be necessary in order to obtain a detailed insight into past human relationships with, and utilisation of, the plant world.

This investigation should be considered a test of the use of siliceous microfossil analyses on cultural layers and stone artefacts. More basic data are needed regarding subsampling processes in the field and preparation techniques, and it is also important to stress that the archaeological contexts in which the samples are found are of the utmost importance.

Acknowledgements

Sven Karlsson, assisted in the field at Gribbylund, and the samples and slides were prepared by Anna Hedenström and Ivan Romero at the Department of Physical Geography and Quaternary Geology, Stockholm University.

Of the authors of this paper, Jan Risberg was responsible for the subsampling at Gribbylund and Albertsro and for the analyses of the siliceous microfossils, Lisbet Bengtsson was the archaeologist responsible for the Myskdalen site, Britta Kihlstedt for Östra Vrå, Michael Olausson for Albertsro and Gribbylund, and Eva Olsson for the Kyrkorp site. Cecilia Lidström Holmberg contributed the experimental studies on grinding tools within the framework of a Ph.D. research project, and Carin Tingvall contributed to the grouping of the phytoliths and the related terminology.

The archaeological investigations were carried out by the Central Board of National Antiquities, Stockholm, Sweden. Parts of the siliceous microfossil project were financed by the Berit Wallenberg Foundation.

English language revision by Malcolm Hicks.

References

- Aaris-Sørensen, K. 1978. *Knoglemateriale fra den mellemeolitiske boplads ved Korsnäs*. Riksantikvarieämbetet och Statens Historiska Museer. Rapport 1978:8.
- Battarbee, R.W. 1986. Diatom analysis. In (B.E. Berglund, Ed) *Handbook of Holocene Palaeoecology and Palaeohydrology*. Chichester: John Wiley & Sons, pp. 527–534.
- Bergström, L. 1996. *Arkeobotaniska växtstenar. En metodstudie och morfologisk analys av kiselphytoliter ur jordprover från Vendel*. CD-uppsatser i Laborativ Arkeologi 95/96. Part 1.
- Bobrova, E. & Bobrov, A. 1997. Phytoliths in soils: species composition along a soil profile, and value as environmental indicators. In (A. Pinilla, J. Juan-Tresserras & M.J. Machado, Eds) *Proceedings from First European Meeting on Phytolith Research, Madrid September 1996. The State-Of-The-Art of phytoliths in soils and plants*. Madrid: Monografías 4, pp. 5–13.
- Borgmark, A. 1998. *Phytoliths and other siliceous microfossils in soils at Piparberg, Arlanda Airport, south-eastern Sweden*. Department of Quaternary Research. Stockholm University. Quaternaria Ser. B, Nr. 14.

- Brunnberg, L., Miller, U. & Risberg, J. 1985. Project Eastern Svealand: Development of the Holocene landscape. *ISKOS* 5, 85–91.
- Cronberg, G. 1986. Chrysophycean cysts and scales in lake sediments: a review. In (J. Kristiansen & R.A. Andersen, Eds) *Chrysophytes: aspects and problems*. Cambridge: University Press, pp. 281–315.
- Cummings, L.S. 1992. Illustrated phytoliths from assorted food plants. In (G. Rapp & S.C. Mulholland, Eds) *Phytolith systematics. Advances in Archaeological and Museum Science 1*. New York: Plenum Press, pp. 175–192.
- Dinan, E.H. & Rowlett, R.M. 1993. Vegetational changes at the Shriver paleo-indian site, N.W. Missouri: Phytolith analysis as an aid in environmental reconstruction. In (D.M. Pearsall & D.R. Piperno, Eds) *Current research in phytolith analysis: Applications in Archaeology and Paleoecology. Museum Applied Science Center for Archaeology*. The University Museum of Archaeology and Anthropology. University of Pennsylvania. Philadelphia. Vol 10, pp. 73–82.
- Duff, K.E. & Smol, J.P. 1988. Chrysophycean stomatocysts from the postglacial sediment of a high Arctic lake. *Canadian Journal of Botany* 66, 1117–1128.
- Florin, S. 1957. *Vråkulturen. Stenåldersboplatserna vid Mogetorp, Östra Vrå och Brokvärn*. Kungliga Vitterhets Historie och Antikvitets Akademien. Stockholm.
- Florin, M.-B. 1957. Pollen-analytical evidence of prehistoric agriculture at Mogetorp Neolithic settlement, Sweden. In (S. Florin, Ed) *Vråkulturen*. Kungliga Vitterhets Historie och Antikvitets Akademien.
- Geis, J.W. 1978. Biogenic opal in three species of Graminae. *Annals of Botany* 42, 1119–1129.
- Karlsson, S. (in manuscript). Vegetational history in the provinces of Södermanland and Uppland, eastern Sweden. In (A. Åkerlund, E. Olsson, P. Gustafsson & U. Miller, Eds) *Södertörn. Interdisciplinary Investigations of Stone Age Sites in Eastern Middle Sweden*. Central Board of National Antiquities. UV Stockholm.
- Kihlstedt, B. 1996. Neolitiseringsen i östra Mellansverige – några reflektioner med utgångspunkt från nya ¹⁴C-dateringar. In (P. Bratt, Ed) *Stenålder i Stockholms län*. Två seminarier vid Stockholms Läns museum, pp. 72–79. Stockholm.
- Krammer, K. & Lange-Bertalot, H. 1986. Bacillariophyceae. 1. Teil: Naviculaceae. In (H. Ettl, J. Gerloff, H. Heynig, & D. Mollenhauser, Eds) *Süßwasserflora von Mitteleuropa 2/1*. Stuttgart.
- Krammer, K. & Lange-Bertalot, H. 1988. Bacillariophyceae. 2. Teil: Bacillariaceae, Epithemiaceae, Surirellaceae. In (H. Ettl, J. Gerloff, H. Heynig & D. Mollenhauser, Eds) *Süßwasserflora von Mitteleuropa 2/2*. Stuttgart.
- Krammer, K. & Lange-Bertalot, H. 1991a. Bacillariophyceae. 3. Teil: Centrales, Fragilariaceae, Eunotiaceae. In (H. Ettl, J. Gerloff, H. Heynig, & D. Mollenhauser, Eds) *Süßwasserflora von Mitteleuropa 2/3*. Stuttgart.
- Krammer, K. & Lange-Bertalot, H. 1991b. Bacillariophyceae. 4. Teil: Achnanthaceae. Kritische Ergänzungen zu Navicula (Lineolate) und Gomphonema. In (H. Ettl, J. Gerloff, H. Heynig & D. Mollenhauser, Eds) *Süßwasserflora von Mitteleuropa 2/4*. Stuttgart.
- Kurberg, E. 2000. *Siliceous microfossils in the cultural layers at the Impiltis hill-fort, north-western Lithuania*. Department of Quaternary Research. Stockholm University. Quaternaria Ser. B, Nr. 21.
- Lewis, R.O. 1981. Use of opal phytoliths in palaeoenvironmental reconstruction. *Journal of Ethnobiology* 1(1), 175–181.
- Lidström Holmberg, C. 1993. *Sadelformade malstenar från yngre stenålder. "Grind my dear one, let her grind"*. The Flaten project. Report 2. Museum of National Antiquities/Uppsala University, Department of Archaeology. Stockholm/Uppsala.
- Lidström Holmberg, C. 1998. Prehistoric grinding tools as metaphorical traces of the past. *Current Swedish Archaeology* 6, 123–142. Stockholm.
- Madella, M. 1997. Phytoliths from a central Asia loess-paleosol sequence and modern soils: their taphonomical and palaeoecological implications. In (A. Piñilla, J. Juan-Tresserras & M.J. Machado, Eds) *Proceedings from First European Meeting on Phytolith Research, Madrid September 1996. The State-Of-The-Art of phytoliths in soils and plants*. Madrid: Monografias 4, pp. 49–57.
- Metcalf, C. 1960. *Anatomy of Monocotyledons. 1 Gramineae*. Oxford.
- Miller, U., Modig, S. & Robertsson, A.-M. 1979. The Yttersele dwelling site: Method investigations. *Early Norrland* 12, 77–92.
- Miller, U. & Robertsson, A.-M. 1982. Biostratigraphical studies in connection with the excavations of the Neolithic site at Korsnäs, southwest of Stockholm. Manuscript 1977, revised 1982. *Sveriges Geologiska Undersökning*. Unpublished report.
- Mulholland, S. C. & Rapp, G. Jr. 1992. A morphological classification of grass silica bodies. In (G. Rapp, Jr & S.C. Mulholland, Eds) *Phytolith systematics. Advances in Archaeological and Museum Science 1*. New York, pp. 65–89.
- Mölders, K. & Tynni, R. 1967–1973. Über Finnlands rezente und Subfossile Diatomeen I–VI. *Comptes Rendus de la Société géologique de Finlande* N:o XXXIX, 199–217 (1967), *Bulletin of the Geological Society of Finland* 40, 151–170 (1968), *Bulletin* 41, 235–251 (1969), *Bulletin* 42, 129–144 (1970), *Bulletin* 43, 203–220 (1971), *Bulletin* 44, 141–149 (1972), *Bulletin* 45, 159–179 (1973).
- Olausson, M. 1998. "Säg mig hur många djur du har..." Om arkeologi och stallning. In (K. Viklund, R. Engelmark & J. Linderholm, Eds) *Fäbus från bronsålder till idag*, Skrifter om skogs- och lantbrukshistoria, Nordiska museet 12, Stockholm, pp. 28–56.
- Ollendorf, A. 1992. Toward a classification scheme of sedge (Cyperaceae) phytoliths. In (G. Rapp, Jr & S.C. Mulholland, Eds) *Phytolith systematics. Advances in Archaeological and Museum Science 1*. New York: Plenum Press, pp. 91–111.
- Olsson, E. 1992. The Grödinge excavations – an example of interdisciplinary study and collaboration. *Laborativ Arkeologi* 6, 31–36.
- Pearsall, D.M. 1989. *Paleoethnobotany. A handbook of procedures*. San Diego: Academic Press, pp. 311–428.
- Persson, Ch. 1979. Shore displacement during Ancylus time in the Rejmyra area, south central Sweden. *Sveriges Geologiska Undersökning C* 755.
- Piperno, D.R. 1984. A comparison and differentiation of phytoliths from maize and wild grasses: use of morphological criteria. *American Antiquity* 49(2), 361–383.
- Piperno, D.R. 1985a. Phytolith analysis of geological sediments from Panama. *Antiquity* LIX, 13–19.
- Piperno, D.R. 1985b. Phytolith taphonomy and distribution in archaeological sediments from Panama. *Journal of Archaeological Sciences* 12, 247–267.
- Piperno, D.R. 1988. *Phytolith analysis. An archaeological and geological perspective*. London.
- Piperno, D.R. & Becker, P. 1996. Vegetational history of a site in the central Amazon basin derived from phytolith and charcoal records from natural soils. *Quaternary Research* 45, 202–209.
- Powers, A. 1992. Great expectations: A short historical review of European phytolith systematics. In (G. Rapp, Jr & S.C. Mulholland, Eds) *Phytolith systematics. Advances in Archaeological and Museum Science 1*. New York: Plenum Press, pp. 15–35.
- Risberg, J. 1990. Siliceous microfossils of a sediment profile near an archaeological site at Kyrkorp, central Sweden. In (H. Simola, Ed) *Proceedings of the 10th International Diatom Symposium, Joensuu 1988*. Koenigstein: Koeltz Scientific Books, pp. 425–431.
- Risberg, J. 1991. *Palaeoenvironment and sea level changes during the early Holocene on the Södertörn peninsula, Södermanland, eastern Sweden*. Stockholm University. Department of Quaternary Research. Report 20.
- Risberg, J., Miller, U. & Brunnberg, L. 1991. Deglaciation, Holocene shore displacement and coastal settlements in eastern Svealand, Sweden. *Quaternary International* 9, 33–37.
- Rosen, A.M. 1992. Phytoliths as indicators of ancient irrigation

- farming. In (P.C. Anderson, Ed) *Préhistoire de L'agriculture*. Monographie du CRA no 6, 281–287.
- Rovner, I. 1971. Potential of opal phytoliths for use in palaeoecological reconstruction. *Quaternary Research* 1, 343–359.
- Rovner, I. 1986. Downward percolation of phytoliths in stable soils: A non issue. In (I. Rovner, Ed) *Plant opal phytolith analysis an archaeology and paleoecology*. Raleigh. North Carolina State University: Occasional Paper of the Phytolitharian 1, pp. 23–30.
- Rovner, I. & Russ, J. 1992. Darwin and design in phytolith systematics: morphometric methods for mitigating redundancy. In (G. Rapp, Jr & S.C. Mulholland, Eds) *Phytolith systematics. Advances in Archaeological and Museum Science 1*. New York, pp. 253–276.
- Runge, F. 1996. Opal Phytolithe in Pflanzen aus dem humiden und semi-ariden Osten Afrikas und ihre Bedeutung für die Klima- und Vegetationsgeschichte. *Botanische Jahrbücher für Systematik, Pflanzengeschichte und Pflanzengeographie* 118, 303–363.
- Schützler, L. 2000. *Fornlämningar vid Albertsro*, Rapport, RAÄ, UV-Mitt 2000:37, Stockholm.
- Thomasson, H. 1938. Kolmårdens Litorinagränser jämte en översikt av nivåförändringarna inom Kolmården. *Geologiska Föreningens i Stockholm Förhandlingar* 60 (1), 19–54.
- Tingvall, C. 1995. *Studier av fytoliter i några recenta sädeslag och andra gräs*. Stockholm University. Department of Quaternary Research. Unpublished report. With English abstract.
- Tynni, R. 1975–1980. Über Finnlands rezente und subfossile Diatomeen. *Bulletin of the Geological Society of Finland* 274, (1975), *Bulletin* 284, (1976), *Bulletin* 296, (1978), *Bulletin* 312, (1980).
- Twiss, P. 1992. Predicted world distribution of C₃ and C₄ grass phytoliths. In (G. Rapp, Jr & S.C. Mulholland, Eds) *Phytolith systematics. Advances in Archaeological and Museum Science 1*. New York: Plenum Press, pp. 113–128.
- Twiss, P., Suess, E. & Smith, R. 1969. Morphological classification of grass phytoliths. *Proceedings Soil Science Society of America* 33, 109–115.
- Vuorela, I. 1991. Phytolith analysis as part of the study in the Helsinki Old town. *Geological Survey of Finland. Special Paper* 12, 143–146.
- Westman, P. & Sohlenius, G. 1995. Chrysophyte cyst and diatom flora of a Litorina Sea sediment sequence from the north-western Baltic proper. In (A.-M. Robertsson, T. Hackens, S. Hicks, J. Risberg & A. Åkerlund, Eds) *Landscapes and Life. Studies in honour of Urve Miller*. PACT 50, 175–184.
- Zeeb, B.A. & Smol, J.P. 1993. Postglacial chrysophycean cyst record from Elk Lake, Minnesota. In (J.P. Bradbury & W.E. Dean, Eds) *Elk Lake, Minnesota: Evidence for Rapid Climate Change in the North-Central United States. Geological Society of America. Special Paper* 276, 239–249.