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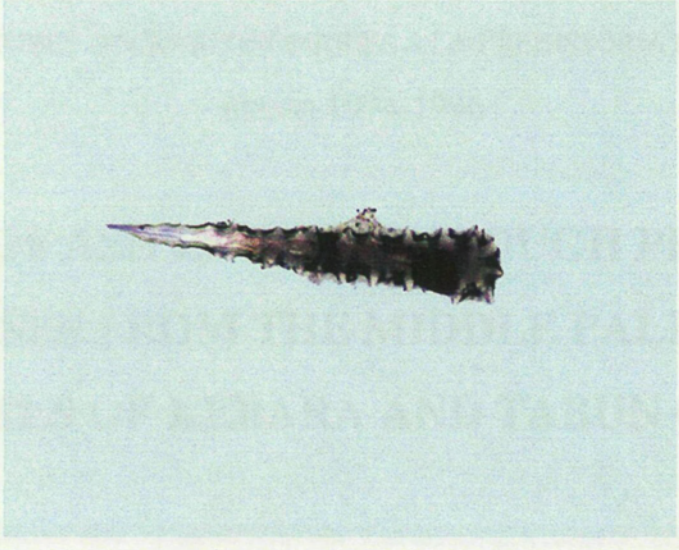

STUDY OF ASH LAYERS THROUGH PHYTOLITH ANALYSES FROM THE MIDDLE PALAEOLITHIC LEVELS OF KEBARA AND TABUN CAVES

TESI PER OPTAR AL TITOL DE DOCTOR EN GEOGRAFIA I HISTORIA

Supervisors: Prof. Josep M. Fullola i Pericot
Prof. Steve Weiner
Dr. Linda S. Cummings

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Presentada per: **Rosa Maria Albert Cristóbal**

Dirigida per: **Josep Maria Fullola Pericot**

Steve Weiner

Linda Scott Cummings

Barcelona, 1999

Para Hector

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SUMMARY

The Levant, and Israel in particular, possesses a rich archaeological record of prehistoric caves from the Middle and Upper Paleolithic periods. Some of these caves have been subjected to intensive multidisciplinary studies, providing information not only on the archaeological record, but also on the diagenetic processes that have affected this archaeological record through time.

One of the most interesting remains preserved in these caves is the ashy features or hearths. They are usually abundant and often visually well preserved. Ash accumulations are sometimes meters thick. Their presence has made it possible to use and develop new techniques in order to obtain more information about the fire related activities carried out in the cave, the functionality of these hearths and their significance in the social life of past cultures.

One of the techniques used for the study of hearths involves the analysis of phytoliths. Phytolith analyses in prehistoric hearths can be used for a variety of

purposes. These include the identification of ash remains, even in locations where they are not visible to the naked eye due to diagenetic alteration; the identification, in a specific hearth, of the use of wood/bark as opposed to other types of vegetation such as grasses, and the identification of different species of trees and/or other plants used as fuel in a specific hearth. It is also conceivable that the latter two sources of information could provide indications of possible uses of fire (cooking, warmth, technical purposes, etc.) based on the different fuels used.

An interpretation of the phytolith data from an ashy feature or hearth needs to be based both, on the morphological characteristics and the quantitative analyses of the phytoliths. This provides information on the absolute number of phytoliths produced by the trees and other plant taxa present in the area, and on the number of phytoliths per unit weight of sediment. This in turn may indicate, for example, the extent of mixing of ash with other soils, the relative proportions of say wood ash and grasses in a hearth, or the use of fruits from trees or other parts of the trees.

This study focuses on the ash layers from two prehistoric caves in Israel, Tabun and Kebara, both located on Mount Carmel, Israel (Figure 1). Tabun was occupied

during the Lower and Middle Paleolithic periods and Kebara was occupied during the Middle and Upper Paleolithic periods. Both caves have visible hearths, with those in Kebara being particularly impressive.

Alternative modes of occupation of Tabun Cave during the deposition of the Mousterian Levels B and C, have been proposed. Garrod & Bate (1937) interpreted the archaeological record of both levels as being indicative of domestic occupational activities. Jelinek et al. (1973) proposed that the presence of articulated limb bones of *Dama mesopotamica* in the Level B sediments below the cave chimney, indicated that the cave was used as a natural game trap. They also noted that the white ash layers in Level C extended across the whole cave, and proposed that this was due to the burning of natural vegetation in the cave. The study carried out in Tabun cave aims at clarifying the modes of occupation during these periods.

Level B sediments closely resembles the terra rossa soil, that is common in this region. Burning activity is inferred from charcoal fragments observed in thin sections. A minor wood ash component is present based on the preponderance of phytoliths with a variable, irregular morphology, produced mostly in wood and bark as compared to those

with a consistent or characteristic morphology, as well as phytoliths with shapes characteristics of those formed in wood and bark of local trees. Thus fires were produced in the cave during this period. The cave may also have been used as a game trap.

Level C is composed of multiple layers of brown, black and white sediments. Micromorphology, mineralogy and phytolith analyses all show that these layers are mixtures of terra rossa soil and ash, with the latter being abundant in the white layers. The phytoliths in these layers are derived almost entirely from wood and bark, and not from grasses. These observations are consistent with a domestic occupational mode.

Kebara cave is a well studied archaeological site. It contains abundant visible hearths and ash derived minerals that are the major component of the Mousterian sediments. The latter are in varying states of preservation. Furthermore, archeobotanic information is available from charred remains. Kebara cave is thus an ideal location to study the potential of phytoliths to provide information on the mode of fire used in the cave, to assess the input of other plant materials, as well as to determine the effects of diagenesis on phytolith preservation.

Sixteen samples were analyzed in terms of their mineralogy, phytolith contents per unit weight of acid insoluble fraction, and phytolith morphologies. In general the preservation of the phytoliths is good, except for the two samples in which the mineral component at present is largely ash-derived calcite. The cave sediments contain about ten times more phytoliths than those present in the four samples analyzed from outside the cave. The major source of plant material input into the cave is clearly from the wood and bark used for the fuel for fires. The grass phytoliths present in the samples are also thought to have been brought into the cave mainly associated with the wood/bark fuel. Sediments from the hearths, as well as those between the hearths, contain abundant wood/bark phytoliths. The two samples of the latter contain also appreciable amounts of phytoliths not known to be present in wood and bark, as do other hearth derived samples. Plant materials other than those used as fuel, were thus also brought into the cave.

The study about Kebara cave shows that phytoliths analysis, in conjunction with detailed mineralogical, stratigraphic, archaeobotanic and field information, can provide a more complete understanding of the use of plant materials in prehistoric caves for both fuel and other purposes.

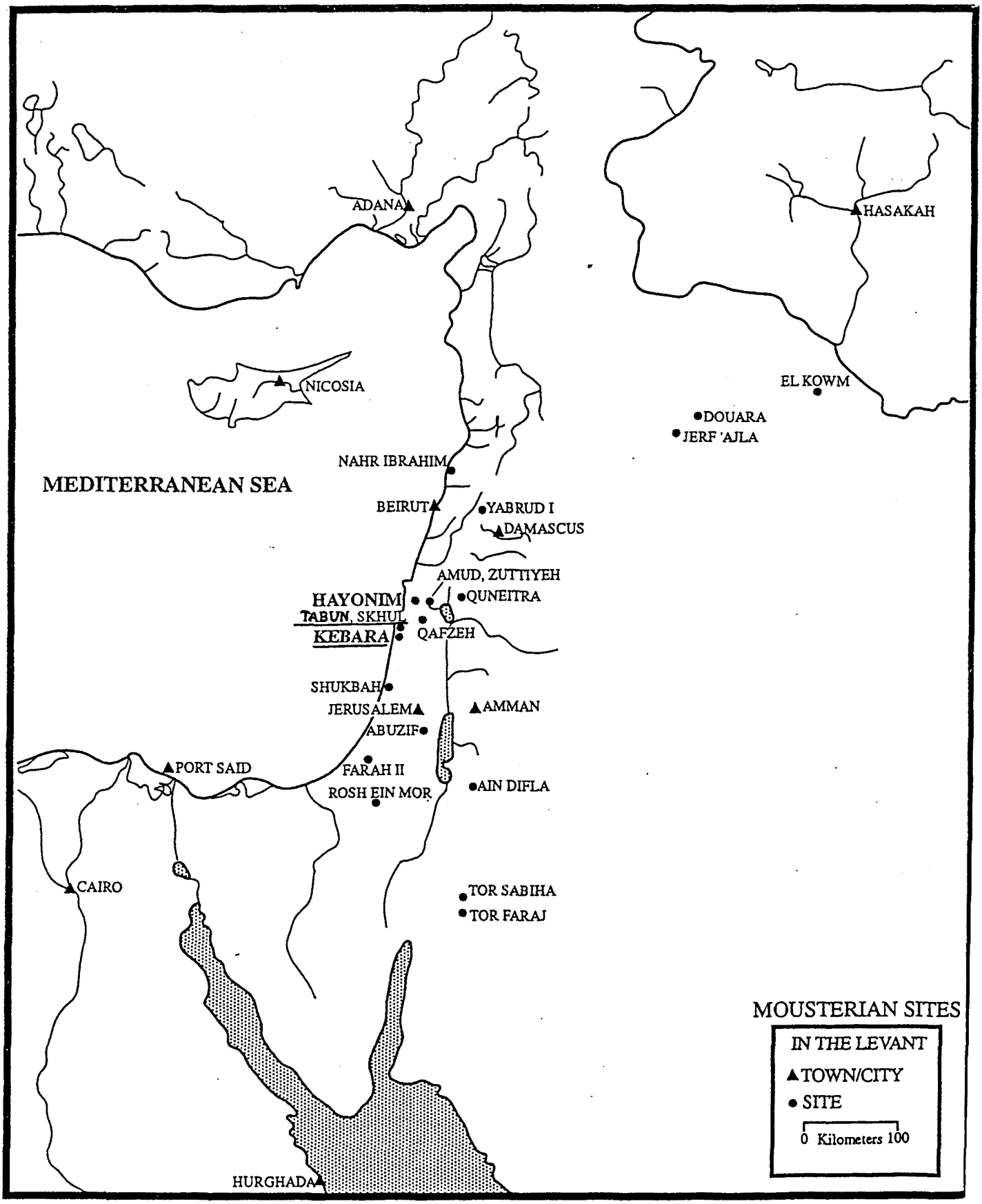

Figure 1 - Map of Israel showing the locations of Tabun and Kebara caves (Mount Carmel). Map is from Schiegl et al. (1996).

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1 - INTRODUCTION

The production and use of fire is one of the most important achievements of the genus Homo. The use of fire provided humans with a number of advantages. These include a source of warmth, and therefore the possibility of living in colder areas; the possibility of occupying new living areas, like caves, by using fire as protection against wild animals; the benefit of light and therefore extending the time for working or other social activities (Oakley, 1961). The possibility of expanding the diet considerably, as many types of plants are toxic when consumed raw (Leopold & Ardrey, 1972). Cooked meat also improved the quality of food and allowed easier digestion. As cooked food replaced a diet consisting entirely of raw meat and fresh vegetable matter, the whole pattern of mastication, digestion and nutrition was altered. Cooking softens the food and makes it in some ways more nutritious, reducing the time and energy consumed in eating (Oakley, 1970).

Remains of fire were observed in several Lower Paleolithic sites in Africa and China (James, 1989). The evidence supporting the use of fire at these sites is weak, and it is even more difficult to distinguish between accidental fires, made for instance by

lightning, or fires produced by humans (James, 1989; Weiner et al., 1998). Fires produced by humans are easily recognizable only in and after the Middle Paleolithic period, where "hearths" are preserved. These are usually oval, lenticular or rounded in plain view, with thickness ranging from a few millimeters to tens of centimeters.

Direct evidence of the use of fire by humans is the presence of charcoal, ash and phytoliths from burned plants that do not naturally grow at the site. Indirect evidence of fires produced by humans is the presence of burned materials, such as bones, flint tools, charred seeds and heated sediments. Note that the presence and identification of wood remains in caves indicates that the fire is of anthropological origin, since trees do not normally grow in caves.

When hearths are absent or not preserved in a site, there are several techniques that can be applied in order to determine the presence of fire. The key to the recognition of baked areas is the presence of discolored reddish/orange patches of sediment. There are several techniques that identify the presence of heated sediments, rocks and other archaeological material present in a site. Some of these techniques are, Thermoluminescence (Melcher & Zimmerman, 1977) based on the study of prehistoric

chert artifacts, ^{40}Ar-^{39}Ar analyses of fire-baked stones (Gillespie, Budinger & Abbott, 1989), ESR spectroscopy of flints artifacts (Robins et al., 1978) and paleomagnetism (Gowlett et al., 1981; Barbetti, 1986; Bellomo, 1993). Paleomagnetic techniques are suitable for determining whether the sediments were heated in antiquity (Barbetti et al., 1980). Campfires generate sufficient heat to produce localized changes in magnetic field intensities whereas tree stump fires and grass fires do not generate sufficient heat to produce localized changes in magnetic intensities (Bellomo, 1993). However to determine the temperature of a heated sediment by paleomagnetic techniques offers some difficulties such as the alteration effects due to weathering and the preservation of good-quality baked material in the hearths (Barbetti et al. 1980).

One of the main questions when analyzing hearths is to find out about the functions for which they were used (cooking, warmth, technical purposes, etc.). To determine the functionality several criteria can be taken into consideration, such as the location of the hearth in the habitat and the identification of the activities carried out in relation to it. This can be achieved by studying the archaeological material and its spatial distribution. The characteristics of the hearth are also informative. For example, the

relative duration of the flames in comparison to the relative duration of the incandescent phase. The type of fuel used can be determined from the direct remains of the fire in the form of charcoal, ash or phytoliths.

Charcoal is the most common macro-remain used for identifying the trees used as fuel in hearths. Charcoal is an inorganic carbon compound, which results from the incomplete combustion of plant tissues. Charcoal production depends on a number of factors, like the type of material burned, and the intensity, duration and temperature of the fire (Patterson III, Edwards & Maguire, 1987). However charcoal is not always preserved.

Ash is another form of direct evidence of fire. The ash is the inorganic residue remaining after the combustion of the plant (Campbell, 1990). Wood combustion produces a highly alkaline ash (pH 9-13.5) (Etiegni & Campbell, 1991). In the Levant, wood ash is composed on average of 98% of fine-grained calcite and 2% of siliceous aggregates and phytoliths (Schiegl et al., 1994, 1996). Normally the ash-derived calcite dissolves and is removed from the site, or interacts with phosphates present in the ground water, to produce a variety of different more insoluble minerals. The result is that when

studying archaeological samples, ash may have different mineralogical compositions, or may be composed only of its relatively insoluble components, namely siliceous aggregates and phytoliths. The ash may also be mixed with other sediments derived from outside the cave.

Siliceous aggregates and silica phytoliths are relatively stable under a variety of soil conditions. Siliceous aggregates are a mixture of several soil minerals, cemented together by an amorphous silica matrix composed mainly of Si, K, Al and Fe. The soil minerals are taken up by the trees together with water, and are conducted through the vascular system to special cells where they are cemented with the silica matrix (Schiegl et al., 1996). Under the microscope they appear as brownish aggregates with soil minerals inside. Scurfield, Anderson & Segnit (1974) and Sangster & Parry (1981) described them as silica aggregates formed in wood. Although siliceous aggregates cannot provide taxonomic information about the type of fuel used in a hearth, they are useful for identifying the presence of burned trees in archaeological sites.

The term "phytolith" is derived from the Greek phito (plant) and lithos (stone). According to this definition phytoliths are "all forms of mineralized substances secreted

by higher plants, including siliceous or calcareous in composition (Piperno, 1988)". Phytolith analyses are mainly based on the study of microscopic remains composed of pure silica (as opposed to the siliceous aggregates) that originate in plants (Piperno, 1988; Pearsall, 1989; Mulholland & Rapp, 1992a). In our study, we refer only to the silica phytoliths, as these are most likely to be preserved in the archaeological record.

The process of formation of phytoliths starts when the plant absorbs silica in the form of monosilicic acid, $Si(OH)_4$, dissolved in the ground water. It passes through the roots and is transported to the aerial parts of the plant through the water conducting vessels (xylem). The monosilicic acid is then polymerized and forms solid deposits of amorphous hydrated silicon dioxide ($SiO_2.nH_2O$). This mineral phase is known as "silica" or "opal". The amount of water contained ranges from 4 to 9% (Piperno, 1988). The silica, once polymerized, is deposited in certain cells of the plants in 3 modes: cell wall deposits (membrane silicification), infillings of the cell lumen, and infilling of intercellular spaces of the cortex (Piperno, 1988). The mechanism of polymerization in plants has been mostly studied in the grass family (Piperno, 1988), but is still not well understood.

The formation of phytoliths is influenced by the mineral composition of the soil, the amount of water and hence indirectly the climate, and the age of the plant (Piperno, 1988). Silicon is one of the most abundant elements on earth. Soluble silica in the soil is mainly derived from the weathering of silicate minerals, like clay and feldspar (Piperno, 1988). It seems that there is a larger concentration of dissolved silicon in soils with more water, than in drier soils. It has been noted that the dissolution of phytoliths also seems to be a source of silica for the plants (Piperno, 1988).

Silica and hence phytoliths are stable in acid and neutral pH environments, but the solubility increases significantly above pH 9 (Wilding, Smeck & Drees, 1977). Phytoliths are optically isotropic, and their refractive indices range from 1.41 to 1.47. Their specific gravity ranges from 1.5 to 2.3. The color of phytoliths, in light microscopy, can vary from colorless or light brown to opaque. The presence of darker forms are related to higher quantities or organic carbon pigmentation occluded within or on the surface of the phytolith, as they have a lower specific gravity than lighter colored forms (Jones & Beavers, 1963).

Phytoliths occur in a large number of plant species. Furthermore the production of phytoliths in plants varies according to different taxa. It has been proposed that there is a mechanism to extract or exclude the soluble silica from the soil, and that this takes place on the external surface of the roots (Parry & Winslow, 1977). They noted that root hairs of some plants with inherently low amounts of solid silica, such as *Vicia faba* and *Ricinus communis*, are enveloped by a thin layer of fatty material that is similar in behavior to cutin and subrin. These substances are permeable to water, and therefore constitute a barrier to the monosilicic acid. Both substances have not been found on the root surfaces of maize and in small amounts in high producers of phytoliths. Studies of metabolic processes also indicated active exclusion of monosilicic acid by the roots of some plants (Van der Worm, 1980); a further indication that cellular silicification is well controlled.

Phytoliths are very abundant in the grass family. They posses distinctive morphologies that make them recognizable. It has been stated that grasses produce 10 to 20 times more phytoliths than dicotyledons (Wilding & Drees, 1971; Kondo, 1977). On the other hand, relatively few studies of phytoliths from dicotyledons have been performed, and have been concentrated mainly on the leaves. It has been observed that

leaves from dicotyledons produce phytoliths with distinctive morphologies that make them distinguishable from the grass phytoliths (Lanning, 1966; Wilding & Drees, 1971; Rovner, 1971; Geis, 1973; Bozarth, 1992).

According to Geis (1973) the extent of silicification in leaves of angiosperms varies considerably between plant taxa, and the mean silica percentage in these species varies from 0.01 to 3.79% dry weight. Lanning (1966) obtained similar results with a percentage range of silica between 0.05 to 3.05% dry weight. He also noted that the content of silica in leaves is much higher than in the stems from the same plant where it ranges from 0.01 to 0.16% (Lanning, 1966). Families such as the Ulmaceae, Moraceae and Aceraceae have the highest silica contents, while the families with lowest amounts of silica are the Leguminoseae and the Laureaceae (Geis, 1973). Piperno (1988) also noted a low proportion of phytoliths in the Laureaceae family, whereas the Rosaceae family presented a higher content of silica. Geis (1973) observed that all the cellular components of the leaf tissue are usually silicified especially the epidermal cells.

Several studies on the presence of phytoliths in leaves from the gymnosperm group have been performed, mainly in the Pinaceae family. Rovner (1971) and Piperno

(1988) state that phytoliths from gymnosperms are not very common and cannot be used for diagnostic purposes. On the other hand studies carried out by Klein & Geis (1978) showed that silicification in gymnosperms is lower than in grasses, but higher than in some angiosperms. They carried out a study on 15 species of the Pinaceae family from the New York area. The values of silica varied from 0.08 to 1.37% dry weight. Geis (1983) observed that the silica content in the needles of the Pinaceae family is only 16% of all the total silica content of the plant. Klein & Geis (1978) and Bozarth (1993) observed that the silicification occurs in all the cellular components of the Pinaceae needles, but mainly in the epidermal tissue. Wall fragments and small spherical masses (3-7 μm in diameter) of solid silica are the most common forms identified. These spherical forms appear to develop as inward projections of the cell wall. They were also observed in the angiosperm group. Klein and Geis (1978) suggest that the wide occurrence of these spheres is a common pattern of lumen infilling in taxonomically diverse plant material.

Studies carried out to date on silica in wood focused on two subjects. An evaluation of the taxonomic significance of the presence of silica, and analyses of the possible correlation between the occurrence of silica and the resistance of the timber to

marine borers or the difficulties in sawing timbers (Ter-Welle, 1976a). However, most of the studies were based on the analyses of American, African and Asian species due to economical reasons (Ter-Welle, 1976a). Espinoza (1987) found a correlation between the presence of silica and their resistance to sawing and external agents. The distribution of the silica in the various tissues is of special importance for taxonomic determination. Ter-Welle (1976b) reported the presence of silica in about 85% of the ray cells, in 20% of the axial parenchyma, and of 4% in fibers and vessels. The importance of the occurrence of silica in ray cells was already noted by Amos (1952) and subsequently by Carlsquit (1988) and Scurfield, Anderson & Segnit (1974).

The amount of silica present in the wood of the 440 species analyzed by Amos (1952) ranged between 0.1 to 3.0% dry weight. Morphologically Amos (1952) divided the silica present in two groups:

a) Silica inclusions, with spherical or irregular forms. These were formed inside the cells although the size is usually smaller than the lumen. They have wrinkled or uneven surfaces.

b) Vitreous silica. The silica is deposited as a lining in the cell walls or can also completely fill the lumen of the cells.

Most authors agree with Amos' observations, that spherical bodies are the most common forms of silica formed in wood. These forms are usually smooth or with rough surfaces (Ter-Welle, 1976a, b; Carlsquit, 1988). Also oval and oblong forms were usually identified (Ter-Welle, 1976a; Espinoza, 1987). The size of the spherical forms varies from 7 to 42 μm (Scurfield, Anderson & Segnit, 1974). Koeppen (1980) carried out a study about the presence of silica in the wood of the Leguminoseae family. His results were in general similar to those obtained for other families. Silica was only present in the parenchyma cells (both ray and axial tissues). The most common forms were spherical forms varying in size about 10-25 μm.

Very few studies have thus been performed to date on the phytoliths present in wood and bark, even though wood and bark are the main materials used for fuels in fire. Furthermore, the few studies that were performed were not archaeologically motivated. The reason for this is most probably that it was only recently recognized that the silica-rich components of wood ash are present in some caves in the Levant, in very large amounts. This may well be true of other caves, but has not, as yet, been investigated.

There is therefore a potentially very interesting record of the use of fire preserved in these caves. The main motivation of this study was therefore to explore the potential of this record.

2 - OBJECTIVES

2.1 - Overall objective:

To determine whether phytoliths can become a useful tool to characterize ash remains and hearths from prehistoric caves.

For this purpose the results of the phytolith analyses have been applied to two Middle Paleolithic prehistoric sites in the Levant, Tabun and Kebara caves (Mount Carmel, Israel).

2.2 – Specifics objectives:

A) Reference collection

To organize a reference collection catalogue of phytoliths from modern plants present in the area of interest during the archaeological period under study, and to

computerize this data for easy access and future expansion of the catalogue. The organization of a reference collection is necessary to provide information on the varying contents of phytoliths in different plant taxa, and on phytolith morphological variations between plants and within a plant species. The computerized catalogue contains photographs of the phytoliths identified, together with information about their contents and morphological characteristics in the plants. The catalogue, available on a CD, will allow other phytolith researchers, as well as non-specialists in phytoliths, to use this information.

B) Archaeological samples

To analyze phytoliths identified in archaeological samples from Tabun and Kebara caves. The analysis is based on the study of both the number per unit weight of sediment, and on the morphological diversity of the phytoliths present in the samples. No phytolith studies to date have measured the number of phytoliths per unit weight of sediment.

C) Interpretation of the use of fire

To use the results obtained through the analyses of the phytoliths to address more general questions related to the use of fire. These include the possible characteristics of the fires used (long/short combustion, flames, smoke, etc.), and therefore infer different functions of the hearths. For these purposes, the comparison of the results with other types of analyses carried out in the area (lithics, fauna, charcoal, mineralogy etc.) is essential. All this information together will contribute to a better understanding of the use of fire by the Neanderthal occupants of Tabun and Kebara caves.

3 - MATERIALS AND METHODS

3.1 - Quantitative approach: the strategy

Previous mineralogical analyses carried out by Schiegl et al. (1994, 1996) and Weiner et al. (1995) showed that in the case of Kebara and Tabun caves, diagenesis affects primarily the more soluble mineral fraction (mainly carbonates, phosphates and organic matter) of the sediments. These diagenetic processes do not affect all the areas of the cave in the same way. Therefore when analyzing the number of phytoliths per unit weight of the sediment, which belong to the more insoluble fraction, the values obtained will vary according to the state of preservation. By removing the soluble fraction the effects of weight changes due to diagenesis are minimized. It is therefore possible to quantitatively compare the results from the reference collection with the archaeological samples, and to compare the results from localities within the archaeological site that are in varying diagenetic states of preservation. The fraction remaining after the more soluble minerals have disappeared is composed mainly of siliceous aggregates and silica phytoliths.

This fraction is defined as the inorganic Acid Insoluble Fraction (AIF). In order to compare the amount of phytoliths from the different samples and the reference collection, we determined the absolute number of phytoliths produced in a plant species or in an archaeological sediment, in relation to a unit weight of AIF. As we are dealing with ashed plant remains, this could be a unit weight of ash (Albert & Weiner, 1999).

For determining the absolute number of phytoliths, the following calculation was made.

$$(\#\ \text{phytoliths counted}) \times \left(\frac{\text{total area of slide}}{\text{area counted}}\right) = \#\ \text{phytoliths on slide}$$

$$(\#\ \text{phytoliths on slide}) \times \left(\frac{\text{weight of pellet (g.)}}{\text{weight on slide (g.)}}\right) = \#\ \text{phytoliths in pellet}$$

$$\frac{\text{total \# phytoliths in pellets}}{\text{weight of AIF (g.)}} = \#\ \text{PHYTOLITHS PER GRAM AIF}$$

3.2 – Archaeological samples

A) Materials

Tabun cave.

Sediment samples from Tabun cave (about 50 g each) were obtained from all the visually discernible layers in Levels B and C exposed in the extant section as excavated by Jelinek et al. (1973). They were collected and stored in glass vials. In total 12 of these samples were analyzed for phytoliths. The locations of the samples relative to the excavation grid are shown in figure 2. Four samples were also collected from outside the cave.

Kebara cave

A total of 79 samples, both from inside and outside the cave were collected from Kebara in June 1996. They were collected from different visually discernible layers of different levels and different locations. Of these 79 samples, 16 samples were processed for the phytolith analyses. Figure 3 shows the locations of the samples in the excavation grid square plan. Four samples were also selected for phytolith analyses from different locations outside the cave.

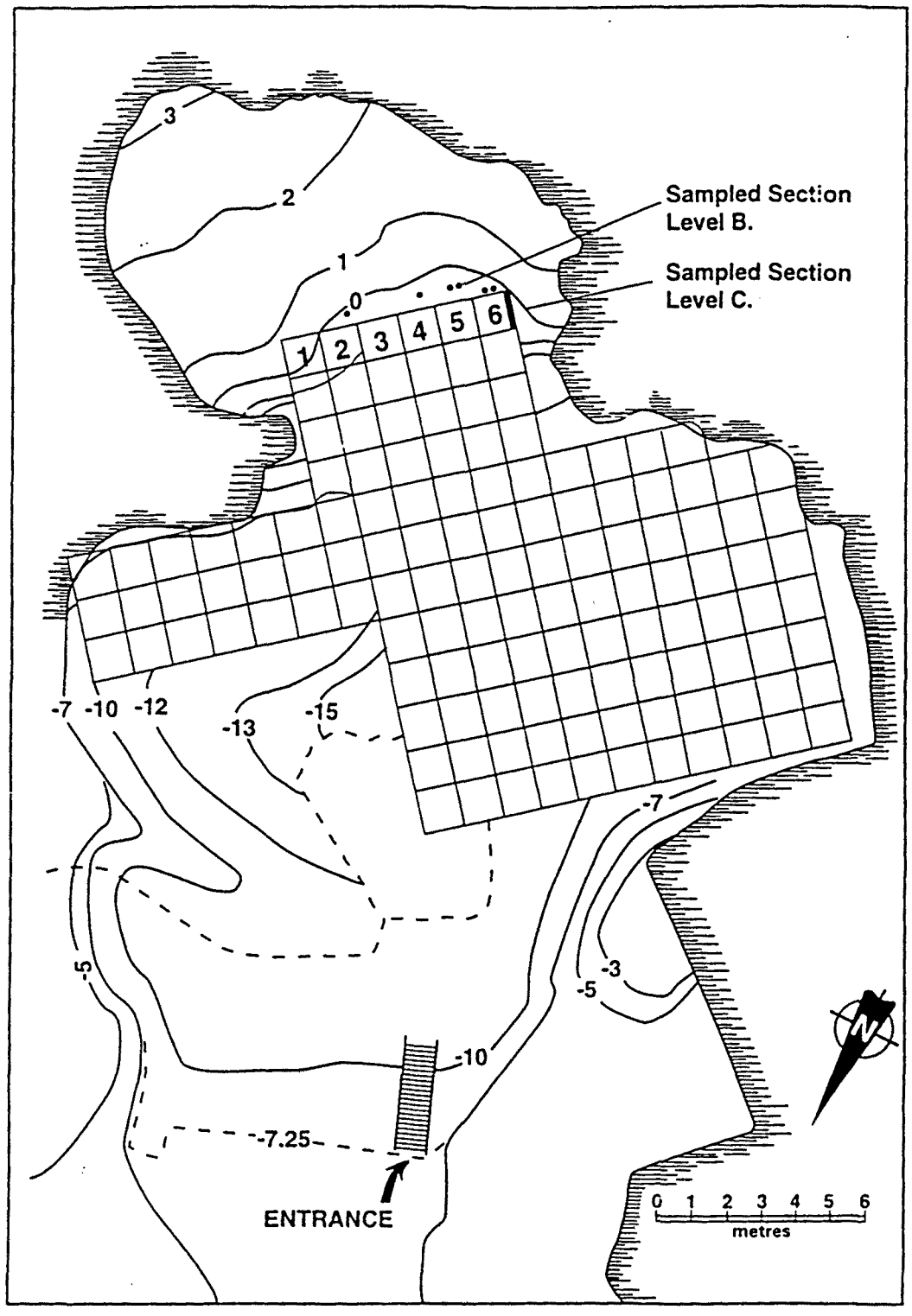

Figure 2 - Map of Tabun cave showing the topographic contours as measured with reference to the datum line of Garrod and Bate (1937), the excavation grid used by Jelinek et al. (1973) and the locations of the 6 samples examined from Level B. The section sampled in Level C is identified in excavation square 6.

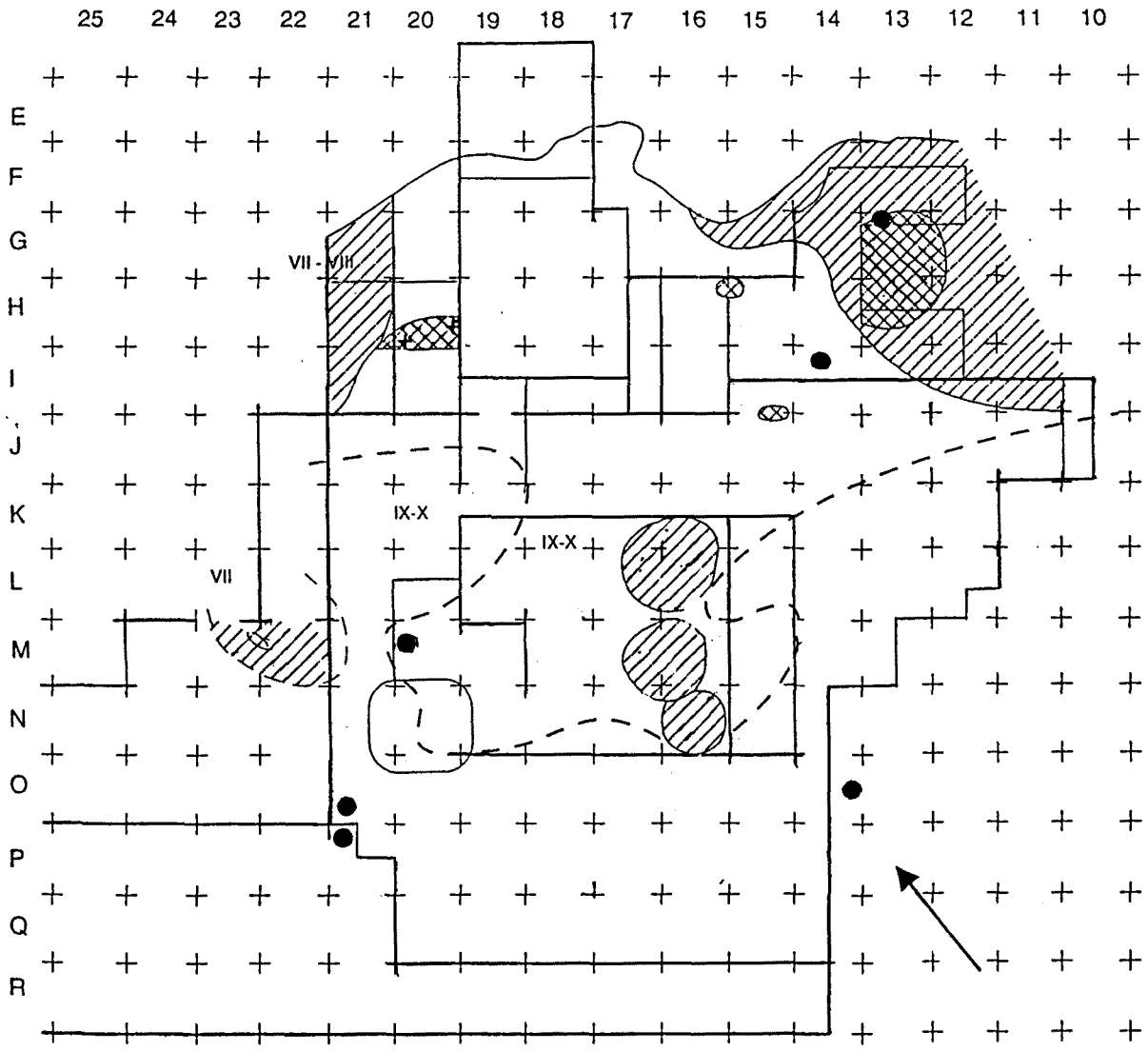

Figure 3 - Map of Kebara cave with the excavation grid squares, showing the locations of the samples studied. All of the samples, except those from square O14, belong to the Mousterian period.

B) Methods

A weighed aliquot of about 0.5 g of air-dried sediment was placed in a 25 ml glass vial to which 10 ml of equivolume solution of 3N HCl and 3N NHO_3 were added. The suspension was heated in a beaker containing boiling water for 30 minutes and then centrifuged at 3000 r.p.m. in a centrifuge IEC (International Equipment Company) Centra MP4, for 2 minutes in a 15 ml polypropylene tube. The supernatant was removed and the pellet was washed three times with deionized water. The pellet was transferred to a glass Petri dish and about 10 ml of 30% hydrogen peroxide was added. The sample was evaporated on a hot plate at 70°C. More hydrogen peroxide was added, if necessary, until all bubbling ceased. The sample was dried under a heat lamp and the remaining sediment was weighed. This is referred to as the inorganic acid insoluble fraction (AIF). Note that the above treatment removes all the phosphate and carbonated minerals, as well as the organic material.

The mineral components of the AIF were then separated according to their densities. The insoluble fraction was transferred to a 15 ml polypropylene centrifuge tube and 5 ml of sodium polytungstate solution ($Na_6(H_2W_{12}O_{40}).H_2O$) of 2.4 g/ml density was added (3 parts polytungstate to one part water by weight). The suspension was vortexed and sonicated (Branson ultrasonic cleaning bath 2200) until it was well dispersed. It was then centrifuged at 3000 r.p.m. for 5 minutes, in the same centrifuge. The supernatant was transferred to another centrifuge tube, 1.0 ml of deionized water was added and the tube was vortexed and again centrifuged as above. This cycle was repeated until no visible mineral particles remained in the supernatant. At this stage the heavy liquid was diluted by filling the centrifuge tube with deionized water, so as to ensure that even the lightest minerals are recovered. After each centrifuge step the sediment deposited at the bottom of the tube (pellet), was transferred to an Eppendorf 1.5 ml microcentrifuge tube. The tube was filled with deionized water and centrifuged in an Eppendorf centrifuge (5417C) at 6000 r.p.m. for 2 minutes to remove the heavy liquid. This process was repeated three times, then the sample was dried under a heat lamp and weighed. In our experience 4 or 5 cycles are usually required, yielding pellets of minerals greater than 2.4, 2.0, 1.7, 1.5 and 1.4 g/ml density respectively. This method has the advantage of using very little heavy liquid and effectively separates the relatively

light opaline phytoliths and siliceous aggregates, which have a density between 1.5-2.3 g/ml (Jones & Beavers, 1963), from the other minerals.

For examination under the optical microscope (Nikon Labophot 2-POL), slides of the pellets were prepared by weighing part of the pellet, with an accuracy of 0.1 mg approximately (Sartorius BP211D), 1 mg of sediment onto a microscope slide. Three or 4 drops of Entellan New (Merck) were added. The samples were mixed with the Entellan as well as possible, and then a cover slide was placed over the suspension. The areal coverage of the sample on the slide was estimated by counting the total number of fields containing sediment grains. Phytoliths were usually counted at 400x in random fields.

Photographs were taken during the study under the microscope with a Lumina Scanning CCD camera at 400x and stored in Extensis Program for Macintosh. The Extensis program allowed us to compare the results with those from the reference collection.

Infrared spectra of representative aliquots were obtained using KBr pellets (about 0.1 mg or less of sample in about 50 mg of KBr) and a Fourier Transform Infrared spectrometer (FTIR) (Midac Corp. Costa Mesa, California). The spectra were collected at $4cm^{-1}$ resolution. The FTIR provides information on the nature of the minerals that constitute the bulk of the sample (Weiner & Goldberg, 1990). This goes together with the identification of the minerals throughout the petrographic optical microscope that provides information on mineral grain morphology, color, and refractive index.

Two samples from Kebara cave (RKE28 & RKE37) were selected for EDS analyses (Energy Dispersive Spectrometry). The preparation of the samples was as follows: samples were embedded in a mixture of Buehler ultra-mount powder and liquid. The embedded sample was polished, using Buehler MINIMET polisher, to obtain a flat sample surface and mounted on an aluminum stub with double-sided carbon tape. The conductivity was further increased using a carbon conductive paste between the embedded sample and the aluminum stub, and the sample was carbon coated for SEM observation (JSM-6400) and EDS measurements (Oxford-ISIS).

3.3 – Reference collection

A) Materials

In order to identify the phytoliths obtained from the archaeological samples we took into account which plants were present in the area during the time the sediments were deposited, and which plants were likely to be used by the inhabitants of the cave. The next step was to organize a reference collection of modern plant taxa from the Mount Carmel area, to understand better the taxonomic significance of different phytolith morphologies and their absolute amounts. Table 1 shows the list of the plants analyzed for the reference collection. At first, the reference collection was mainly based on the study of woody dicotyledons. However, when we analyzed the archaeological samples, it was observed, that other plant taxa were also present. We therefore extended the reference collection to other plant families that might have been brought to the archaeological sites at those times. The selection of the plants analyzed was made in close consultation with Dr. S. Lev-Yadun (a botanist). The selection took into account our understanding of the landscape at the time together with the results of the anthracological analyses of Kebara cave, carried out by Baruch, Werker & Bar-Yosef

(1992), and the macrofloral studies carried out by Lev & Kislev (1993), also from Kebara cave. Palynological results from Tabun cave carried out by Horowitz (in Jelinek et al., 1973) were taken into account as well. A few grasses were also analyzed for comparison.

In total 29 different species were collected from the area. Of these 11 were woody dicotyledons, 2 were gymnosperms, 12 were herbaceous dicotyledons and 4 were grasses. Woody dicotyledons and gymnosperms were separated into different parts (wood, bark, leaves and fruits when possible), to analyze the relative amounts of phytoliths in each part and their morphological differences (Table 1). Although we separated wood and bark, we also report a single value for both, as obviously wood and bark were burned together in fires. We did this by combining the values obtained using the weighted proportions of wood:bark of 0.8:0.2. This is based on the fact that for 5 of the species checked, the proportions of wood:bark from branches between 5 and 10 cm in diameter were around 0.8:0.2. We refer to this calculated "mixed" value as "wood/bark". We assume that this proportion is more or less representative of all the trees analyzed.

Key number	Type	Family	Species	Common name	part/s analzyed
4)	Woody dicotiledons	Anacardiaceae	*Pistacia palaestina* Boiss.	Palestine terebinth	4a:wood 4b:bark 4c:leaves
3)		Caesalpiniaceae	*Ceratonia siliqua* L.	Carob tree	3a: wood 3b: bark 3c: leaves 3d: fruits
10)		Cupressaceae	*Cupressus sempervirens* L.	Italian cypress	10a: wood 10b: bark 10c: leaves 10d: cones
1)		Fagaceae	*Quercus calliprinos* Webb.	Kermes oak	1a: wood 1b: bark 1c: leaves
6)		Fagaceae	*Quercus ithaburensis* Decne.	Tabor oak	6a: wood 6b: bark 6c: leaves 6e: husk 6f: cupules
19)		Lauraceae	*Laurus nobilis* L.	Laurel	19a: wood 19b: bark 19c: leaves
8)		Oleaceae	*Olea europaea* L.	Olive	8a: wood 8b: bark 8c: leaves 8d: fruit
7)		Pinaceae	*Pinus halepensis* Miller.	Aleppo pine	7a: wood 7b: bark 7c: leaves 7d: cone
2)		Rhamnaceae	*Ziziphus spina-christi* L.	Christ thorn	2a: wood 2b: bark
9)		Rosaceae	*Amygdalus communis* L.	Almond	9a: wood 9b: bark 9c: leaves 9e: inner husk 9f: outer husk
11)		Rosaceae	*Crataegus aronia* (L.) DC.	Common hawthorn	11a: wood 11b: bark 11c: leaves
15)		Salicaceae	*Salix acmophylla* Boiss.	Willow	15a: wood 15b: bark 15c: leaves
12)		Styraceae	*Styrax officinalis* L.	Storax tree	12a: wood 12b: bark 12c: leaves
24)	Herbaceous dicotyledons	Anacardiaceae	*Pistacia lentiscus* L.	Lentisk	whole plant
23)		Cruciferae	*Sinapis alba* L.	Mustard	whole plant
14)		Ephedraceae	*Ephedra*	Horsetail	branches
30)		Leguminoseae	*Lens culinaris subsp. orientalis* (Boiss) Schmalh.	Lentil	whole plant
29)		Leguminoseae	*Lupinus varius* L.	Lupin	whole plant
26)		Leguminoseae	*Pisum syriacum (Berg) Lehm. = Pisum humile* Boiss. et Noe.	Pea	whole plant
20)		Liliaceae	*Asparagus aphyllus* L.	Asparagus	whole plant
22)		Linaceae	*Linum pubescens* Banks et Sol.	Wild flax	whole plant
25)		Malvaceae	*Malva sylvestris*	Mallow	whole plant
28)		Myrtaceae	*Mirtus communis*	Common myrtle	whole plant
27)		Thymelaeaceae	*Thymelea hirsuta*	Shaggy sparrow-wort	whole plant
21)		Umbellifereae	*Foeniculum vulgare* Mill.	Fennel	whole plant
13)	Monocotyledons	Gramineae	*Arundo donax L.*	Reed	13a: stem 13b: leaves sheath 13c: leaves
16)		Gramineae	*Hordeum vulgare* L.	Domesticated barley	whole plant
18)		Gramineae	*Hordeum vulgare* L. subsp.*spontaneum* (C.Koch) Thell.	Wild barley	whole plant
17)		Gramineae	*Triticum aestivum* L.	Bread wheat	whole plant

Table 1 - List of the plants from the Mount Carmel area, collected for phytolith analyses, and the specific parts of the plants from which phytoliths were extracted.

In order to check for possible contamination of bark phytoliths by other species, the following test was carried out. A trip to Mt. Carmel was made in April (1997) because at this time of the year, when the cambium is active, bark can be easily separated from wood. Samples of wood, bark and leaves were also collected for thick sections to observe the general plant tissue. The species collected were: *Ceratonia siliqua* (Carob), *Olea europaea* (Olive), *Amygdalus communis* (Almond), *Cupressus sempervirens* (Cypress), *Quercus ithaburensis* (Tabor oak).

The morphological analyses of the phytoliths in the reference collection takes into account the abundance of irregular forms present in the samples analyzed which are mainly in the wood and bark of woody dicotyledons. Based on this difference, phytoliths were divided in two major categories: those with **consistent morphologies**, that repeat themselves, in one or more samples, and those with **variable morphologies,** with highly irregular morphologies.

Phytoliths with consistent morphology were classified and their relative proportions noted. The terms used to describe these phytoliths followed wherever

possible the anatomical terminology of the cell in which they were formed. When this was not possible, terms describing the geometrical characteristics of the phytoliths were used. Additional characteristics, such as surface texture, followed palynological terminology.

While analyzing the reference collection photographs were taken at a magnification of 400x. These photographs were taken with Lumina scanning CCD camera and Adobe Photoshop and stored and catalogued in Extensis program for Macintosh, together with the photographs from the archaeological samples. The photographs were then organized and classified in a Phytolith Image and Data Catalogue written onto a CD (see appendix 1 for instructions and additional information on how to use the Image Catalogue Program in the attached CD).

B) Methods

The extraction process of the phytoliths from the reference collection was as follows. The bark was mechanically separated from the wood. Each sample was washed extensively in water using sonication (Branson ultrasonic cleaning bath 2200). Air-dried

aliquots were weighed. The samples were then burned in an oven (Lindberg/Blue, 848), at 500°C for 4 h. The ash was treated with 10 ml of an equivolume solution of 3N HCl and 3N HNO_3 for 30 minutes at 100°C. The acid insoluble fraction was centrifuged in a centrifuge IEC (Centra MP4) at 3000 r.p.m. for 2 minutes, resuspended in deionized water and centrifuged again. The supernatant was discarded and the washing was repeated three times. The inorganic AIF was re-ashed at 500°C for 90 minutes and then weighed to an accuracy of 0.1 mg on a balance (Sartorius BP 211D). The number of phytoliths in the sample was counted following the same methods and criteria used for the sediments.

To prepare the samples for thick sections we first cleaned and separated the inner bark from the outer bark to avoid contamination, and then we separated the bark from the wood. The inner bark was kept in plastic bags and sealed. The methods to extract the phytoliths from the inner bark were the same as for the rest of the reference collection. Small pieces of inner bark of about 3 mm x 2 mm were collected also, after cleaning the outer bark and they were fixed in a solution of 3/4 of a mix of ethanol and acetic acid (glacial) 3:1 and 1/4 of glutaraldehyde. The same process was carried out with some leaves.

Thick sections of some of the reference specimens were prepared as follows. After pouring out the fixative solution, the samples were transferred into a 15 ml polypropylene tube, filled with ethanol 25%, and shaken for 1 hour. After an hour the old ethanol was poured out and a fresh one was added, and the sample was shaken for another hour. This process was repeated three times. The whole process was repeated 4 more times adding every third time ethanol 50%, 70%, 95% and then absolute ethanol. The ethanol is used to dehydrate the samples. After the third hour in the shaker with absolute ethanol, it was replaced with xylene. The xylene was changed every hour three times and put again in the shaker. Caution should be taken with xylene as it is toxic, and it should be used only in a fume hood. After the xylene treatment, the samples were left in paraffin (Paraplast Plus), a tissue embedding medium. The paraffin was renewed three times every two hours. Note that paraffin should be liquid. Samples were therefore kept in an oven at 65°C. The paraffin is renewed 3 times a day for 5 days in order to achieve good penetration. The blocks were prepared and cut with a rotary microtome (Luca). The final samples were 8 μm thick and were mounted to a slide with albumin. The section was stained with Safranin o and Fast Green as follows:

1) Remove excess paraffin from sections.

2) Stain 30-50 minutes using 1% aqueous Safranin o (that gives red color).

3) Rinse in distilled water.

4) Stain with 0.2% Fast Green FCF (C.C.) in alcohol until the chromatin and nucleoli remain red.

5) Rinse in absolute alcohol.

6) Clear and mount in balsam.

The stained thick sections show the chromosomes, nucleoli and lignified walls in bright red and the spindles, the cellulose walls and cytoplasm in green. Some of the samples were not stained for better observation of the silica under the microscope. One slide from the bark of *Quercus calliprinos* was put it the oven at 500°C for two hours. After that 4 ml of 1N HCL was added and put on the hot plate for 30 minutes to eliminate the calcite. A slide with the remains was mounted with Entellan New (Merck).

C) Description of the morphotypes

Anatomical definitions of the phytoliths follow different references. Morphological definitions of the phytoliths were extracted from the New Shorter Oxford English dictionary. Palynological terms follow Kapp (1969).

The following are the definitions of some of the terms used below for describing surface and profile:

Psilate: surface smooth

Scabrate: small sculptural elements, less than 1 μm in any dimension.

Verrucate: elements as broad as, or broader than, high > 1μm wide.

Echinate: elements in form of pointed spines

Wavy: forming and undulating line or a series of wavelike curves.

Lobate: having or characterized by lobes, lobed.

C.1) - Classification of Phytoliths with CONSISTENT Morphologies

Phytoliths with consistent, characteristic morphologies identified in the samples of both the reference collection of plants and the archaeological sediments were classified according to the following criteria.

A) PHYTOLITHS CLASSIFIED ACCORDING TO THEIR ANATOMICAL ORIGIN

BULLIFORM CELLS (B) (Figure 4a)

Bulliform cells are characteristic of the Gramineae family and other monocotyledons. These cells are found in the epidermis of leaves and they are larger than the typical epidermal cells. They can be found either in the entire adaxial epidermis of the leaves or in parallel strips between the veins. Bulliform cells usually appear in a fan-like arrangement, in which they are the central and the tallest cell. There are different opinions about the function of these cells. Some investigators hypothesize that bulliforms have an important role in the opening of the leaves from the bud, whereas

others suggest that they are involved in the rolling and unrolling of mature leaves (Fahn, 1990). Esau (1953) proposed that bulliforms act as water storage cells.

EPIDERMAL APPENDAGES (EA)

Epidermal appendages result from the outgrowth of the plant epidermis. They can be unicellular or multicellular, with very variable shapes. They are usually termed trichomes (Fahn, 1990). Phytoliths from epidermal appendages have been divided as follows:

- Hair (EA H): A hair is defined as an elongated outgrowth, with a wider base and a narrow end. They can be uni or multicellular, with appendices or smooth surfaces (Figure 4b).
  - Hair armed (EA H a): with appendices.
  - Hair with base (EA H b): when the hair is still attached to the base and this can be still observed.

-*Foeniculum* type (EA H f): this is a specific type of hair that has been found so far only in *Foeniculum vulgare* (fennel). Foeniculum type hairs seem to be formed by a coalescence of several fiber-like structures.

- Hair bases (EA Hb): epidermal cells where the hair is attached to the epidermis.

- Papillae (EA PA): they have a wide, spheroid or angular base and a small short tip. The tip can have a rounded or pointed top (Ollendorf, 1992).

- Prickles (EA PR): short, slender sharp-pointed outgrowth (Figure 4c).

FIBERS (F)

Fibers, like sclereids, are elongated cells formed in the sclerenchyma tissue. Both types of cells are difficult to differentiate. Fibers are usually very long and narrow cells with tapered and sometimes branched ends (Fahn, 1990). Fibers were divided in two groups:

-Fiber (F) *sensu lato.*

-Linum type (F l): this is a specific type of fiber found in *Linum pubescens* (Flax) - Banks et Sol. They have always been observed in a net-like arrangement (Figure 4d).

LONG CELLS (LC)

Long cells, like short cells, are considered to be characteristic of grasses. They are elongated epidermal cells (Fahn, 1990). They can have either a quadrangular or rounded section. They have been subdivided according to their margin profile (quadrangular section) or surface textures (rounded section).

-Long cell psilate (LC p).

-Long cell sinuous (LC si).

-Long cell verrucate (LC v).

-Long cell echinate (LC e) (Figure 4e).

-Long cell dendritic (LC d).

-Long cell wavy (LC w) (Figure 4f).

-Long cell polylobate (with lobes) (LC PO).

SCLEREID CELLS (SC) (Figure 4g)

Sclereids are, like fibers, sclerenchyma cells. They occur in many different places in the plant body. They are usually shorter than the fibers although they also have thickened secondary cell walls (Fahn, 1990).

SILICA SKELETONS (SS)

According to Rosen (1992) silica skeletons are "*fossilized sections of epidermal tissue*". She however referred to silica skeletons as those fossilized epidermal tissues coming from certain monocotyledons (grasses, sedges, rushes, palms) having complete sections of silicified epidermal tissue in the form of contiguous cells. Bozarth (1992) studied articulated epidermal phytoliths from dicotyledons, but he did not call them silica skeletons. However, both Rosen (1992) and Bozarth (1992) defined them according to the form of their cells.

Other types of multicellular structures were identified by Bozarth (1992) and named honeycombed assemblages. These structures are defined by him as: "*silicification of clusters of palisade mesophyll cells form elongate honeycomb assemblages in leaves of many deciduous trees ... Shallow honeycomb assemblages are formed on the bottom of epidermal cells when only the end walls of palisade cells are silicified. Shallow honeycomb assemblages of small (8 to 13 μm), circular to polyhedral cell walls are formed in all of the arboreal and herbaceous dicotyledons that produced elongate honeycomb assemblages*".

We decided to group into the category of *silica skeletons* all articulated cells, both from dicotyledons and monocotyledons, irrespective of their original tissue (e.g. epidermal cells, mesophyll cells, etc.). They have been subdivided into the following main groups.

1 - Silica skeletons formed in the epidermis of monocotyledons. (Cells from the epidermis can vary in shape, size and arrangement, but they always form a compact layer devoid of intercellular spaces) (Fahn, 1990):

- Silica skeletons with long cells quadrangular in section (SS LC) from monocotyledons: (length at least 2 times the width): These silica skeletons are further subdivided according to the profile of their long cells:

- Silica skeleton long cells psilate (SS LC p).
- Silica skeleton long cells sinuous (SS LC si).
- Silica skeleton long cells verrucate (SS LC v).
- Silica skeleton long cells wavy (SS LC w) (Figure 4h).
- Silica skeleton long cells echinate (SS LC e).

Each one of the former groups can also contain in addition to the long cells, short cells, bulliforms, papillae, stomata or prickles.

- Silica skeletons with long cells rounded in section (SS C) from monocotyledons: (length at least 2 times the width). These silica skeletons are further subdivided according to the surface texture of their long cells:

-Silica skeleton cylindroid cells sinuous (SS C si).

-Silica skeleton cylindroid cells verrucate (SS C v).

2 - Silica skeletons from the epidermis of dicotyledons. Two types were mainly recognized in the reference collection, those with polyhedral forms and those with spheroid/ellipsoid forms. Geis (1973) defined Polyhedral phytoliths as having 4 to 8 sides and a square to rectangular overall shape. Bozarth (1992) identified polyhedrons in leaves of wood and herbaceous dicotyledons. He defines them as flat with 5-8 sides. Silica skeletons with spheroids/ellipsoids were also noted by some of the authors. Polyhedrals is one of the most characteristic forms recognized in the epidermal tissue of leaves of dicotyledons and has been recognized by most of the authors that analyzed these group (Wilding & Drees, 1971; Rovner, 1971; Wilding, Smeck & Drees, 1977; Piperno, 1988). Silica skeletons Jigsaw puzzle (Bozarth, 1992) although were not identified in the reference collection they were observed in the archaeological samples.

- Silica skeleton with polyhedral cells (SS Ph) (Figure 4i).

- Silica skeleton with spheroid/ellipsoid cells (SS Sp/E) (Figure 4j). Some of the spheroids ellipsoids from the archaeological samples had also rings (SS SP/R).

- Silica skeleton jigsaw puzzle (SS JS).

3 - Silica skeletons from the mesophyll. (The mesophyll comprises the parenchymatous tissue internal to the epidermis. There may or may not be intercellular spaces and in many plants palisade and spongy parenchyma can be recognized). For clarity these articulated phytoliths were grouped under Bozarth's (1992) definition of "honeycomb assemblages", which is a terminology already known and in common use. Bozarth (1992) divided them into two groups, spherical and elongates. He noted that the elongate type is most commonly found in the leaves of woody dicotyledons.

- Honeycomb assemblages (HA)

  - Honeycomb elongate (HA El).

  - Honeycomb spheroid (HA Sp) (Figure 4k).

4 - Silica skeleton *sensu lato* (SS sl)

For some *silica skeletons*, in spite of their good preservation, it was not possible to make a morphological classification of the single cells, even though they clearly represent pieces of vegetal tissue.

5 - Silica skeleton not identifiable (SS ni)

Poorly preserved vegetal tissue. The morphological identification of the single cell was not possible.

SHORT CELLS (ShC)

Short cells are characteristic of grasses. They are epidermal cells located between the elongated epidermal cells (long cells) (Fahn, 1990). Short cells can have different forms: rondel/elliptical, bilobate, polylobate, with ridges and horns, etc (Twiss et al., 1969; Mulholland & Rapp, 1992b).

Short cells have been subdivided into two categories:

- Short cells *sensu lato* (ShC) (Figure 4l).

- Short cells bilobates (ShC Bi) (Figure 5a).

STOMATA (S) (Figure 5b)

The stomata complex is composed of the stoma, an intercellular space limited by two specialized cells called "guard cells", together with the subsidiary cells (two or more cells bordering the guard cells and functionally connected). Stomata are usually found on the aerial portions of the plant and especially on leaves and ordinary stems. In leaves with reticulate venation the stomata are distributed in no particular order, while in leaves in which the majority of veins are parallel, as in the Gramineae, the stomata are arranged in parallel rows (Fahn, 1990).

TRACHEARY ELEMENTS (T) (Figure 5c)

Silicified cells with spiral lignified thickenings. These cells build up the vessels. They can be either branched or simple.

B) PHYTOLITHS CLASSIFIED ACCORDING TO THEIR MORPHOLOGICAL CHARACTERISTICS

The following categories were used to define the morphology of the phytoliths.

(a) Overall shape.

(b) Surface texture: psilate, scabrate, verrucate, echinate.

(c) Marginal profile: psilate, scabrate, verrucate, wavy, echinate, lobate.

In the following section the letter in the parentheses before each section defines one of the above categories.

(a) **CYLINDROIDS (C) (length at least 2 times the width).**

Definition: A body resembling a cylinder.

The Cylindroid group includes all those morphotypes, with a round or elliptical section, that are not anatomically identifiable as pertaining to grass epidermal long cells. They are classified according to their surface textures.

(b) Cylindroid psilate (C p) (Figure 5d).

Cylindroid psilate bulbous (C p Bu) (Figure 5e).

Cylindroid psilate with diagonal lines (C p DL).

Cylindroid scabrate (C s).

Cylindroid verrucate (C v).

Cylindroid clavate (C cl).

(a) **DISCOID (D)**

Definition: a disc-shaped body.

b) c) With psilate or scabrate thick rim:

Discoid psilate (D p) (Figure 5f).

Discoid scabrate (D s).

(a) **ELLIPSOIDS (E)**

Definition: A body with at least one set of parallel cross-sections resembling ellipses and the rest resembling circles.

- Ellipsoid: when the length is less than 2 times the width. The are separated according to their surface texture:

(b) Ellipsoid psilate (E p) (Figure 5g).

Ellipsoid scabrate (E s) (Figure 5h).

Ellipsoid verrucate (E v).

Ellipsoid polylobate: when the ellipsoid has lobes (E PO).

Note: In the literature some morphotypes are defined as globular (Bozarth, 1992). These forms are included here in the ellipsoids.

(a) **PARALLELEPIPEDS (P)**

Definition: A body bounded by six parallelograms, of which opposite pairs are parallel.

The Parallelepiped group includes all those morphotypes, with quadrilateral sections, that are not anatomically identifiable as pertaining to grass epidermal long cells.

The parallelepipeds are subdivided, taking into account the relationship between the length (L), the width (W) and the thickness (T).

If L>W and T>1/2W the morphotype is called parallelepiped blocky.

If L<2W and T<1/2 T the morphotype is called parallelepiped thin/slender.

If L>2W and W>T the morphotype is called parallelepiped elongate.

(a) **Parallelepiped blocky (P Bk)**

(b) Parallelepiped blocky psilate rounded ends (P Bk p re)

Parallelepiped blocky psilate square ends (P Bk p se).

Parallelepiped blocky scabrate rounded ends (P BK s re).

Parallelepiped blocky scabrate square ends (P Bk s se) (Figure 5i).

(a) **Parallelepiped thin (P t)**

(b) Parallelepiped thin psilate rounded ends (P t p re).

Parallelepiped thin psilate with square ends (P t p se).

Parallelepiped thin scabrate with square ends (P t s se) (Figure 5j).

(a) **Parallelepiped elongate (length at least 2 times the width).**

Definition of elongate*:* Having a slender form; long in relation to its width.

b) c) Parallelepiped elongate psilate (P El p).

Parallelepiped elongate scabrate (P El s) (Figure 5k).

Parallelepiped elongate verrucate (P El v).

Parallelepiped elongate indeterminate (P El in).

(a) **PLATELET (PL) (Figure 5l)**

Platelets are usually irregular forms, thin, with variable surface (psilate or scabrate).

(a) **SPHEROIDS (Sp)**

Definition: A body resembling or approximating to a sphere in shape.

(b) Spheroid psilate (Sp p).

Spheroid scabrate (Sp s) (Figure 6a).

Spheroid verrucate (Sp v).

Spheroid echinate (Sp e).

C.2) - <u>Classification of Phytoliths with VARIABLE Morphologies</u>

IRREGULAR (I)

(b) Irregular psilate (I p): Irregular forms with psilate surface (Figure 6b).

Irregular psilate with protuberances (I p Pr).

Irregular scabrate (I s): Irregular forms with scabrate surface.

Irregular echinate (I e): Irregular forms with echinate surface.

Irregular verrucate (I v).

- Irregular with green elongates (I ge): The same as above but with green forms, usually on their surface.

WEATHERED MORPHOTYPES (WM) (Figure 6c)

Forms that show strong chemical (pits) or mechanical (broken pieces) weathering, which makes classification impossible.

INDETERMINATE (IN)

Shapes that cannot be identified as geometrical or cannot be described in any other way.

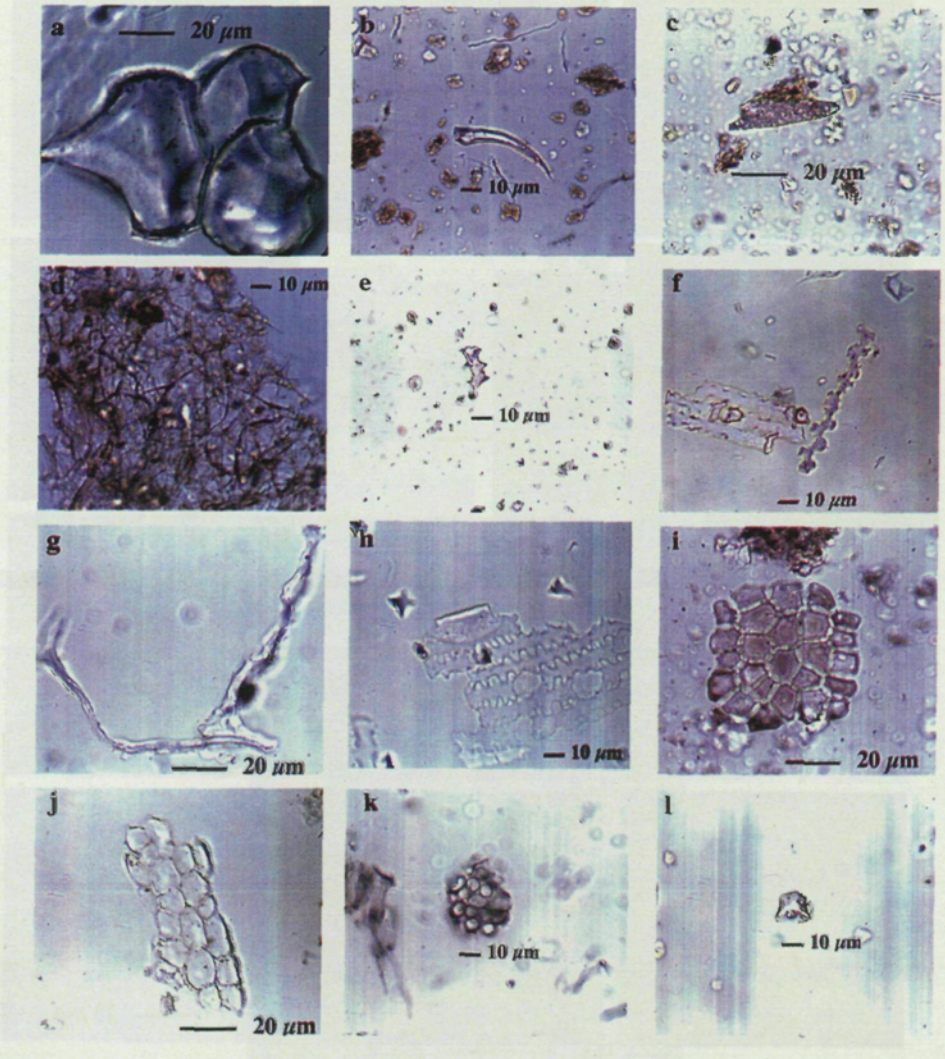

Figure 4 - Photomicrographs of phytoliths. Pictures taken at 400x. a) Bulliform cells from the leaves of *Arundo donax* (Reed). b) Epidermal appendage, hair from *Linum pubescens* (Flax). c) Epidermal appendage, prickle from the bark of *Quercus calliprinos* (Kermes oak) probably contamination. d) Fibers net from *Linum pubescens* (Flax). e) Long cell echinate identified in sample RKE11 from Kebara cave, in the deep sounding. f) Long cell with wavy margin from the leaves of *Arundo donax* (Reed). g) Sclereid from the leaves of *Quercus calliprinos* (Kermes oak). h) Silica skeleton long cells with wavy margin from the leave sheath of *Arundo donax* (Reed). i) Silica skeleton polyhedral from the leaves of *Ceratonia siliqua* (Carob). j) Silica skeleton spheroid/ellipsoid from the leaves of *Amygdalus communis* (Almond). k) Honeycomb assemblage spheroid from the leaves of *Quercus calliprinos* (Kermes oak). l) Short cell characteristic of grasses noted in the bark of Ceratonia siliqua (Carob) probably contamination.

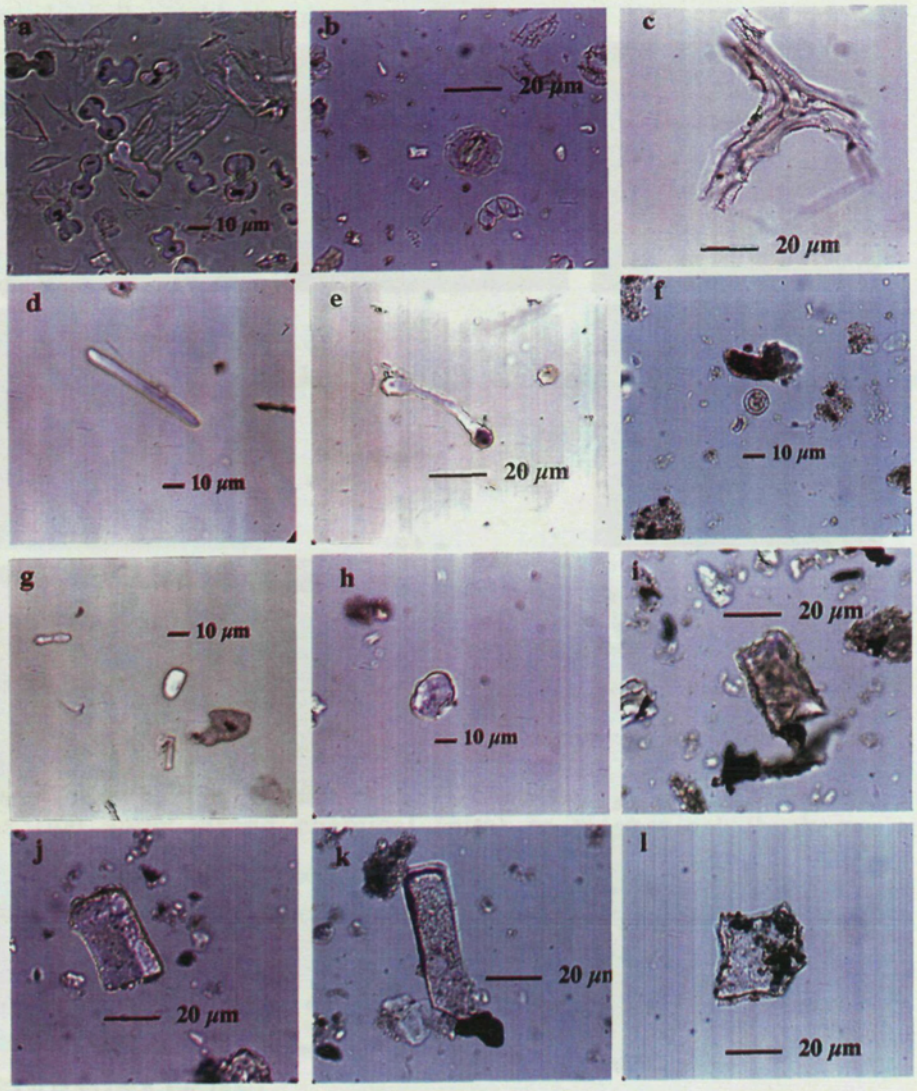

Figure 5 - Photomicrographs of phytoliths. Pictures taken at 400x. a) Short cells bilobate from the leaves of *Arundo donax* (Reed). b) Stomata cell from *Pistacia lentiscus* (Mastic). c) Tracheary element from the leaves of *Quercus calliprinos* (Kermes oak). d) Cylindroid psilate from the leaves of *Pinus halepensis* (Aleppo pine). e) Cylindroid psilate bulbous from the leaves of *Quercus calliprinos* (Kermes oak). f). Discoidal psilate from the bark of *Quercus calliprinos* (Kermes oak). g) Ellipsoid psilate from the leaves of *Pinus halepensis* (Aleppo pine). h) Ellipsoid scabrate from the outer husk of the fruit of *Amygdalus communis* (Almond). i) Parallelepiped blocky with scabrate surface and square ends from the leaves of *Crataegus aronia* (Hawthorn). j) Parallelepiped thin with scabrate surface and square ends from the bark of *Quercus ithaburensis* (Tabor oak). k) Parallelepiped elongate with scabrate surface from the bark of *Quercus ithaburensis* (Tabor oak). l) Platelet identified in sample RKE6 from Kebara cave.

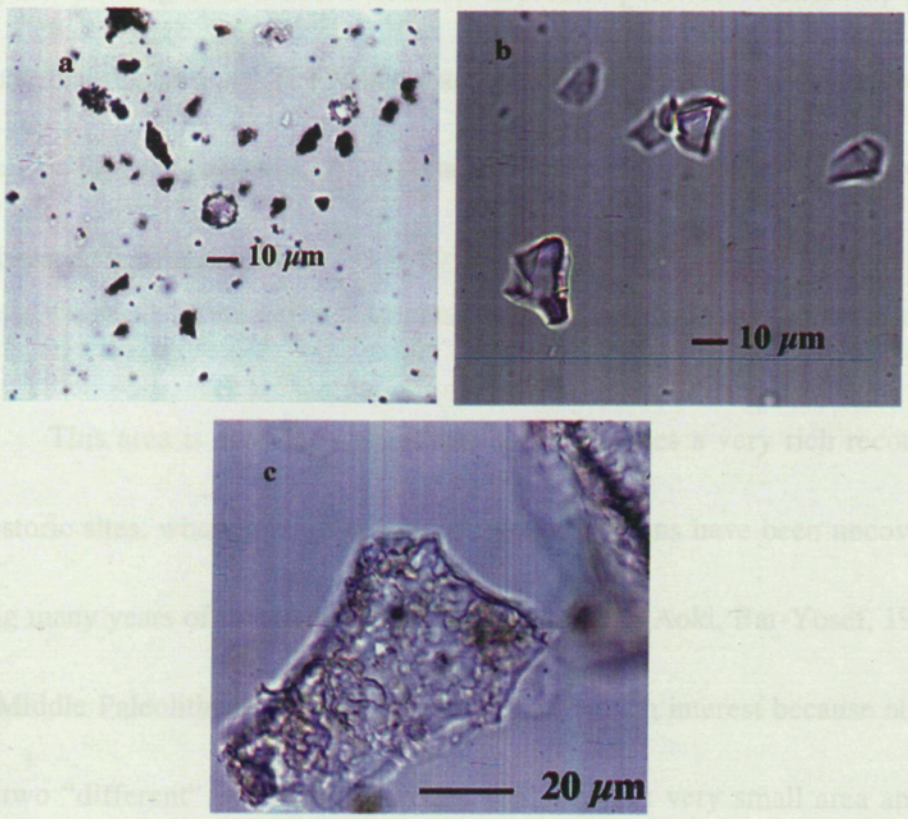

Figure 6 - Photomicrographs of phytoliths. Pictures taken at 400x. a) Spheroid scabrate from the wood of *Laurus nobilis* (Laurel). b) Irregular psilate from the wood of *Quercus calliprinos* (Kermes oak). c) Weathered morphotype identified in sample RKE8 from Kebara cave.

4 – THE MIDDLE PALAEOLITHIC IN THE MEDITERRANEAN LEVANT

The Mediterranean Levant, in southwest Asia, is an important area for the study of the origin of modern humans and their possible relationship with Neanderthal populations. The Mediterranean Levant and southwest Asia occupy a strategic location between Africa, Asia and Europe forming a corridor between Northeast Africa and Eurasia.

This area is especially important as it possesses a very rich record of prehistoric sites, where a large number of human remains have been uncovered during many years of systematic excavation (Akazawa, Aoki, Bar-Yosef, 1998). The Middle Paleolithic period in the Levant is of much interest because at this time two "different" populations are encountered. In a very small area and in caves located in close proximity, modern humans or anatomically *modern Homo sapiens* (AMHS), also known as proto-Cro-Magnon, have been recovered together with Neanderthal remains. For example, in Tabun cave, in Mount Carmel, remains of Neanderthal were identified (McCown & Keith, 1939),

whereas in Skhul, which is located a few hundred meters away, skeletal remains of AMHS or proto-Cro-Magnon were recovered (Vandermeersh, 1982). These unusual findings have made this area one of the "key" points for studying the evolution of modern humans and Neanderthals.

The Levant has been the focus of different archaeological studies since the last century. The systematic excavation of prehistoric sites, mainly from the Lower, Middle and Upper Paleolithic periods started during the 1920's. Some of the most representative were those of D. Garrod who excavated in the Mount Carmel area (Skhul, Tabun & El-Wad), Turville-Petre in Kebara, and R. Neuville in Qafzeh and the Judean Desert. During the 1950's other important sites such as Shanidar cave (Irak) and Kebara cave were also excavated (Bar-Yosef & Vandermeersh, 1993).

The finding of two different human groups in the same area and in a similar cultural context, raised several questions mostly related to chronology, origin, emergence and relationships between the two. Advances in archaeological research during the last years, together with the improvements in

the use of radiometric dating techniques established that the proto-Cro-Magnons inhabited the area about 90,000 years ago, while Neanderthals remains appear around 70,000 years ago. Whether these two groups coexisted after the arrival of the Neanderthals or whether one of them retreated and how they evolved, subsequently is still unclear. At present, it seems that Neanderthal populations occupied Tabun (McCown & Keith, 1939), Amud (Rak, Kimbel & Hovers, 1994), Shanidar (Trinkaus, 1991) and Kebara (Rak, 1990) caves, whereas AMHS or Proto-Cro-Magnons were present in Skhul and Qafzeh (Vandermeersh, 1982; Rak, 1990).

During the last 15 years, archaeological research carried out in the area developed enormously. The combination of field archaeology, together with laboratory archaeology, has opened new areas of investigation. These new areas include in depth studies of the lithic industries, together with site formation processes and past subsistence strategies, in addition to increasing use of radiometric techniques to obtain more accurate dates. Kebara and Tabun caves were part of these new multidisciplinary projects (Akazawa, Aoki, Bar-Yosef, 1998). The analyses of subsistence strategies included the investigation of

biological indications of seasonal occupation of the sites and site formation processes, the latter involved not only micromorphological analyses but also the study of ashes and hearths, bone preservation, etc. (Akazawa, Aoki, Bar Yosef, 1998). The study of climate and environment is also necessary to analyze these questions and try to understand the movements of human populations.

The results obtained on climate and environment, based on pollen cores analyses, study of plant remains, faunal and climatic models, indicate that during the Middle Paleolithic period in the Mediterranean Levant, there were enough resources for survival. The climate was similar to the present day, with winters cold and rainy and summers warm and dry (Bar-Yosef, 1992). Food was available during most part of the year. Seeds were available in spring-summer (from April till June) and fruits in summer-fall (August-October). Animal resources were good through November-December. Some of the most common and stationary game available were gazelle, wild goats, ibex, wild boar, fallow deer and roe deer. The most difficult time for food acquisition would be in December-February (Bar-Yosef, 1992). These results have been supported by the

evidence of lacustrine deposits and travertine accumulations in enclosed basins in Jordan Valley (e.g. Jordan Valley).

The establishment of a reliable chronology to understand what occurred with these two groups has also been one of the main objectives of the research, especially during the last years.

One of the firsts attempts to establish a chronological sequence for the Middle Paleolithic period was based on the study of the Mousterian industry from Tabun cave (Garrod & Bate, 1937). Tabun showed a 25 m section in depth that included the longest sequence of Lower and Middle Paleolithic industry to date. The cultural tradition for these Middle Paleolithic populations was named Levantine Mousterian. According to the studies carried out on the stratigraphic section of Tabun cave the chronological sequence was divided in three phases: Tabun D, Tabun C and Tabun B. In Kebara cave, units IX-X would fall into Tabun B (Bar-Yosef et al., 1992). This chronology has been the basis for relative dating of most of the cultures from the area for a long period of time. During the last two decades other techniques have been used for absolute dating of the

Middle Paleolithic period such as Electron Spin Resonance (ESR) and Thermoluminiscence (TL). TL dating of burnt flint has been applied to several sites in the Levant, including Kebara, Qafzeh, Skhul, Tabun and Amud (reviewed in Valladas et al., 1998). The results showed that, for Skhul and Qafzeh (with proto-Cro-Magnons remains) are about 100,000 years old for, and Kebara and Amud are about 60,000 years old. For more information about the Kebara and Tabun dating see chapters 5.2 and 5.3. The ESR results obtained for Amud cave gave a date of 45,000 years (Schwarcz & Rink, 1998) and for Qafzeh gave about 100,000 years (Schwarcz et al., 1988). The preliminary gamma spectrometric analyses of the mandibule from Tabun cave, Level C produced a date of about 60,000 years old (Schwarcz, Simpson & Stringer, 1998).

There are several hypotheses for explaining the presence of Neanderthals in the Mediterranean Levant. Bar-Yosef suggests that the movement of Neanderthals to the Near East was a result of a late expansion from the European area due to the environmental pressure resulting from glacial stage 4 (Bar-Yosef, 1988; Bar-Yosef, 1998). According to Hublin (1998) the Neanderthals of the Near East resulted from the spread into the middle latitudes

of Eastern Europe during stage 5, which was unusually warm. During this period there was an eastern extension of Neanderthals toward the Ural Mountains, Caspian depression and Central Asia (Hublin, 1998). In contrast, Arensburg & Belfer Cohen (1998) noted that there are large morphological variabilites within both proto-Cro-Magnon and Neanderthal populations (Arensburg, 1989) and they suggest a regional evolution with a very strong influence from African populations (Arensburg & Belfer-Cohen, 1998).

Another important area of debate is the possible differences or similarities either in cultural, economical or social aspects that can help to differentiate these two groups of humans. To date studies carried out in the Near East failed to show differences in the lithic technology, burial practices or subsistence capabilities. The lithic assemblages are very similar in both groups (Bar-Yosef, 1992).

Additional attempts to establish differences or similarities between AMHS or proto-Cro-Magnon and Neanderthal populations include the study of faunal assemblages from the Levant sites. Speth & Tchernov (1998) analyzed

the fauna from Kebara cave. They concluded that the inhabitants of Kebara cave were mostly hunters and not scavengers as traditionally was thought. They were hunting large and potentially dangerous prime adult prey. Therefore no differences in this aspect of behavior seem to be observed (Speth & Tchernov, 1998). Lieberman (1993) analyzed the possible models of mobility in the area by both groups, based on the analyses of climate and environmental context and on the study of seasonal bands in cementum of the animal teeth found in the site. He observed several different mobility patterns, although attributing these differences to each one of the groups was not sustained (Lieberman, 1993). Studies of plant remains are very good indicators of seasonal mobility, however there have been very few analyses in the area, mainly due to the poor preservation of these remains.

The Study of Hearths

Studies of the sediments from prehistoric sites and their formation processes have showed that most of the sediment volume accumulated due to anthropological and biological activities. Kebara cave is a good example

(Laville & Golderg, 1989; Goldberg & Laville, 1991, Schiegl, et al., 1996, Goldberg & Bar-Yosef, 1998). For more information see chapter 5.3.

Hearths and ash layers are an important component of the sediments in Tabun Layer C and Kebara caves, as well as other sites, such as Hayonim, Amud, Qafzeh (in Israel) and Douara (Syria), Tor-Faraj (Jordan), Shanidar (Irak), etc. The study of ash layers and hearths and the study of other archaeological remains directly associated with them, can provide information about the spatial distribution of the activities carried out in the site, the type of fuel used for fires, the type of vegetation present in the area and therefore, the availability of food products as well as technical activities carried out next to these structures. However despite all these possibilities, very few studies have been carried out to date on this subject.

In Tor -Faraj (Southern Jordan) the analyses carried out on the Levantine Mousterian hearths were based on the study of the shape, artifacts distribution and phosphorous concentrations (Henry, 1998). The results showed that these hearths were very similar in construction and phosphorous content to

those observed for modern foragers. According to Henry (1998) Tor-Faraj was an organized base camp during the Middle Paleolithic. He distinguished at least 3 major areas where intensive activities were carried out and that differed from one another. The greater number of hearths and high concentrations of organic residues are consistent with the hearth related activities of working, eating and sleeping (Henry, 1998). Phytolith analyses of the hearths and sediments from this site are being carried out by Dr. Rosen and pendent of publication.

In Shanidar cave the study of the hearths was based on their shape, location in the cave and relationship with artifacts, such as tools, bones, etc. identified close to them. Based on the presence or absence of associated animal bones, they distinguished between warming hearths and cooking hearths. They also suggest the possibility that some of the "hearths" were indeed sleeping nests (Solecki, 1995). However no results from phytoliths or other plant remains analyses are shown in these results to check the type of fuel used for the fire to confirm this hypothesis. For the results of the study on the hearths from Tabun and Kebara cave see chapters 5.2 and 5.3.

As noted the study of plant remains has been limited due to preservation problems. Phytoliths are very stable under neutral and acid conditions but not alkaline conditions above pH 8.5. More studies of phytolith preservation under different soil conditions are however necessary. Studies of phytoliths from ash layers and hearths have hardly been carried out. The wide distribution of phytoliths together with their morphological characteristics can make phytolith analysis a powerful tool for obtaining information concerning some questions such as the use of plants for eating, fuel or other purposes.

5 - RESULTS

5.1 - Reference collection

A) Results

Twenty-nine plant species were collected from the Mount Carmel area (Northern Israel), in order to analyze the relative amounts of phytoliths and their morphological characteristics (Table 1).

In Kebara and Tabun caves, diagenesis primarily affects the more acid soluble minerals of the sediments while phytoliths remain relatively insoluble. It is therefore not possible to compare the amounts of phytoliths in a unit weight from different samples that have been subjected to varying degrees of diagenesis or to compare with the plant reference collection. To minimize this problem we relate the amount of phytoliths to only the inorganic acid insoluble fraction (AIF). Table 2, shows the weight percentage values of the AIF's of the different plant taxa analyzed and their different

parts, as well as the number of phytoliths per 1 g of AIF. We also present the values for wood and bark combined in an 80:20 proportion by weight, as in archaeological ash samples wood and bark will not be separated when used for fuel. We refer to this "mixed" values as wood/bark.

Figure 7 shows the results of the weight percentages of the Acid Insoluble Fraction obtained from the different samples analyzed. Samples were grouped according to different categories (wood, bark, wood 80/bark 20, leaves, fruits, herbaceous dicotyledons and grasses). Wood, bark, leaves and fruits correspond to the woody dicotyledons and gymnosperms group. It can be observed that the weight percent of AIF in grasses is much higher, with an average of 45.2%, than in wood/bark or herbaceous dicotyledons. The low weight percent in wood and bark (with an average wood/bark of 0.7%), is due to the relatively large amount of calcite present in the ash of wood and bark, as Schiegl et al. (1996) observed.

WOODY DICOTS						
Amygdalus communis (9)	*Starting weight*	*Final weight AIF*	*Weight % AIF*	*#phyt.1g.AIF*	*Weight % AIF wood/bark*	*N.phyt.1g AIF wood 80:bark 20*
wood	212.6	0.002	0.15	759,000		
bark	44.9	0.055	0.82	1,283,000	0.49	864,000
leaves	26.0	0.013	0.37	8,921,000		
inner husk	43.53	0.033	9.94	3,616,000		
outer husk	6.19	0.122	14.93	748,000		
Ceratonia siliqua (3)						
wood	286.9	0.003	0.10	3,252,000		
bark	50.4	0.109	2.14	1,024,000	1.12	2,806,000
leaves	35.4	0.016	0.78	5,208,000		
fruits	58.7	0.004	0.16	2,474,000		
Crataegus aronia (11)						
wood	161.7	0.001	0.02	1,198,000		
bark	-	0.295	3.41	831,000	1.71	1,125,000
leaves	30.3	0.037	1.25	1,365,000		
Cupresus sempervirens (10)						
wood	197.4	0.001	0.07	1,587,000		
bark	31.1	0.085	1.97	1,047,000	1.02	1,479,000
leaves	37.8	0.055	1.44	945,000		
cones	88.05	0.081	2.74	662,000		
Laurus nobilis (19)						
wood	152.2	0.002	0.11	2,113,000		
bark	26.1	0.020	1.48	167,000	0.80	1,724,000
leaves	23.4	0.069	5.19	16,625,000		
Olea europaea (8)						
wood	348.5	0.002	0.08	3,475,000		
bark	68.9	0.001	0.03	2,967,000	0.05	3,373,000
leaves	24.5	0.015	1.11	2,557,000		
fruit	69.76	0.001	0.02	547,000		
Pinus halepensis (7)						
wood	187.9	0.001	0.10	2,500,000		
bark	28.2	0.002	0.07	5,476,000	0.09	3,095,000
needles	28.4	0.417	26.65	65,011,000		
cones	116.46	0.276	17.85	19,651,000		
Pistacia palaestina (4)						
wood	255.4	0.001	0.02	942,000		
bark	25.3	0.001	0.04	1,795,000	0.03	1,113,000
leaves	36.2	0.019	0.47	2,010,000		
Quercus calliprinos (1)						
wood	109.7	0.001	0.04	3,850,000		
bark	40.7	0.274	4.17	1,414,000	2.10	3,363,000
leaves	21.6	0.007	0.75	51,926,000		
Quercus ithaburensis (6)						
wood	197.8	0.003	0.07	10,680,000		
bark	106.4	0.065	0.84	884,000	0.45	8,721,000
leaves	19.0	0.041	4.22	7,705,000		
husk	39.64	0.001	0.07	805,000		
caps	65.43	0.04	1.41	11,918,000		
Salix aemophylla (15)						
wood	145.3	0.002	0.14	393,000		
bark	24.0	0.009	0.36	2,395,000	0.25	793,400
leaves	16.2	0.026	1.65	5,520,000		
Styrax officinalis (12)						
wood	154.6	0.001	0.04	420,000		
bark	30.0	0.014	0.72	859,000	0.38	507,800
leaves	33.1	0.351	13.84	1,237,000		
Ziziphus spina-christy (2)						
wood	284.4	0.006	0.07	1,953,000		
bark	45.2	0.443	6.10	170,000	1.28	1,596,400
Average					0.75	2,350,815
HERBACEOUS DICOTS	*Starting weight*	*Final weight AIF*	*Weight % AIF*	*#phyt.1g.AIF*		
All the plant						
Ephedra (14) (branches)	23.4	0.108	4.50	2,396,000		
Asparagus aphyllus (20)	17.1	0.012	1.20	1,318,000		
Foeniculum vulgare (21)	9.2	0.004	0.48	3,951,000		
Linum pubescens (22)	8.6	0.012	3.23	1,034,000		
Sinapis alba (23)	18.8	0.006	0.75	429,000		
Pistacia lentiscus (24)	32.4	0.035	2.27	32,797,000		
Malva sylvestris (25)	20.0	0.109	4.16	389,000		
Pisum humile (26)	17.5	0.001	0.12	611,000		
Thymelea hirsuta (27)	29.9	0.205	13.40	333,000		
Myrtus communis (28)	20.3	0.010	0.64	2,729,000		
Lupinus varius (29)	26.7	0.061	2.90	135,000		
Lens orientalis (30)	17.3	0.023	2.54	958,000		
Average			3.01	3,923,333		
GRASSES						
Arundo donax (13)	*Starting weight*	*Final weight AIF*	*Weight % AIF*	*#phyt.1g.AIF*		*Average Arundo donax*
Stem	64.5	0.922	44.28	33,820,000		40,644,000
Leaves sheath	8.9	0.457	68.01	35,972,000		
Leaves	19.8	1.440	68.02	69,514,000		
Hordeum sp. (16)	4.1	0.104	37.53	55,647,000		
Hordeum vulgare (18)	6.5	0.080	31.85	57,186,000		
Triticum aestivum (17)	2.4	0.077	51.50	47,460,000		
Average			45.24	50,234,250		

Table 2 - Plant reference collection. Weight percent of the acid insoluble fraction (AIF) after treatment with acid and H2O2, and number of phytoliths per 1 g of AIF

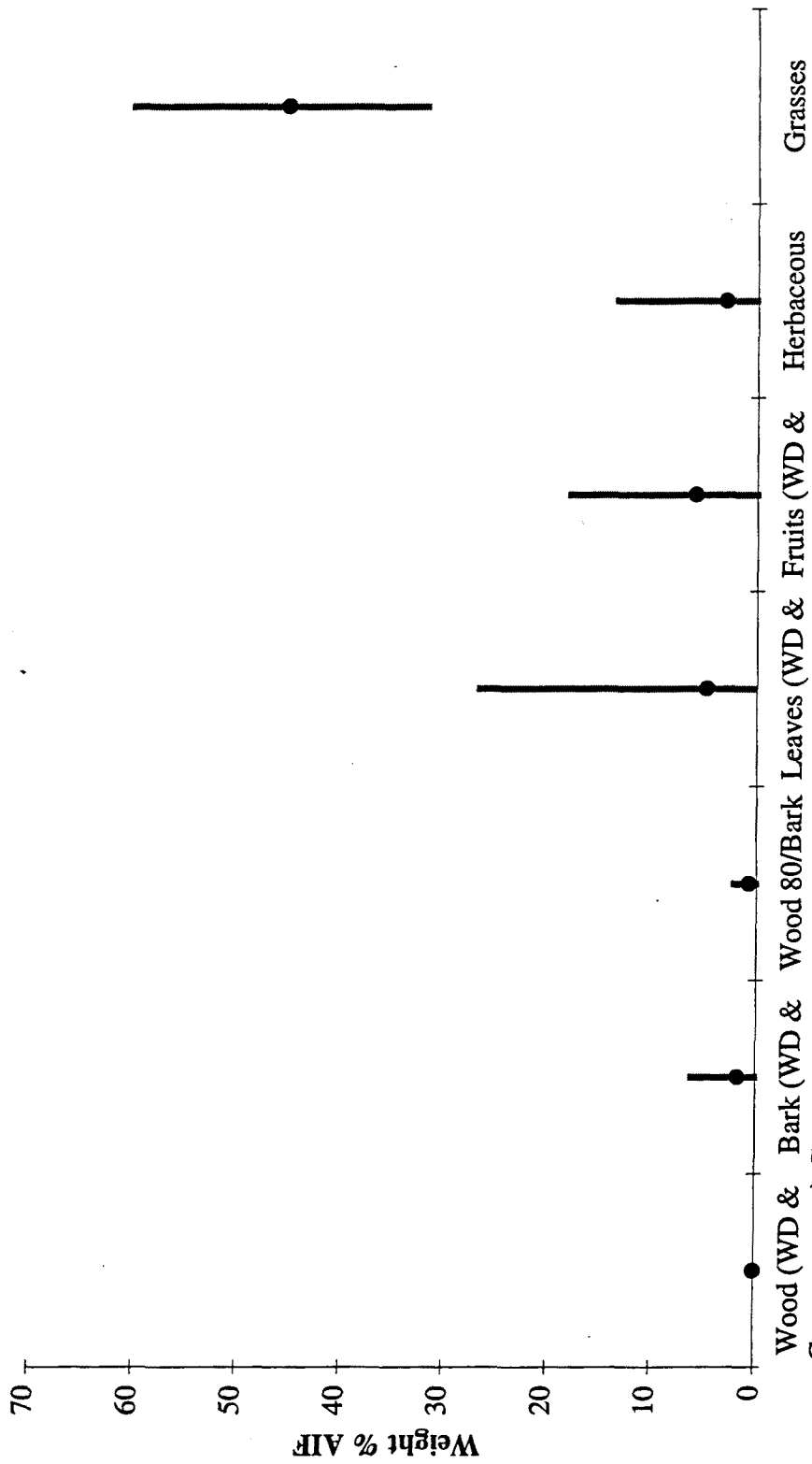

Figure 7 - Percentages of the Acid Insoluble Fractions (AIF) obtained from the reference collection of modern plants from the Mount Carmel area. Columns 1 and 2 shows the % AIF in wood and bark separately, whereas column 3 shows the % AIF in wood/bark together based on the weighted proportions of wood:bark 0.8/0.2.

Figure 8 shows the different number of phytoliths per 1 g of AIF in the different plant species. The amount of phytoliths in wood/bark per gram of AIF, is much lower than in the leaves from the same species, and in grasses. Leaves of woody dicotyledons and gymnosperms have a large variation in the number of phytoliths due mainly to the high number present in the needles of *Pinus halepensis* (Aleppo pine) and the leaves of *Quercus calliprinos* (Kermes oak) with 65 million and 52 million of phytoliths per 1 g of AIF respectively (Table 2). The rest of the species have an average number of phytoliths in leaves of 5.2 million. The major difference however, is between grasses and wood/bark. While in grasses the average number of phytoliths per gram of AIF is 50 million, in the wood/bark of woody dicotyledons and gymnosperms the average is 2.4 million (Table 2). The averages of the number of phytoliths per 1 g of AIF in wood and bark separately is 2.6 and 1.7 million, respectively. This means that grasses produce on the average about 20 times more phytoliths than the wood/bark of woody dicotyledons and gymnosperms.

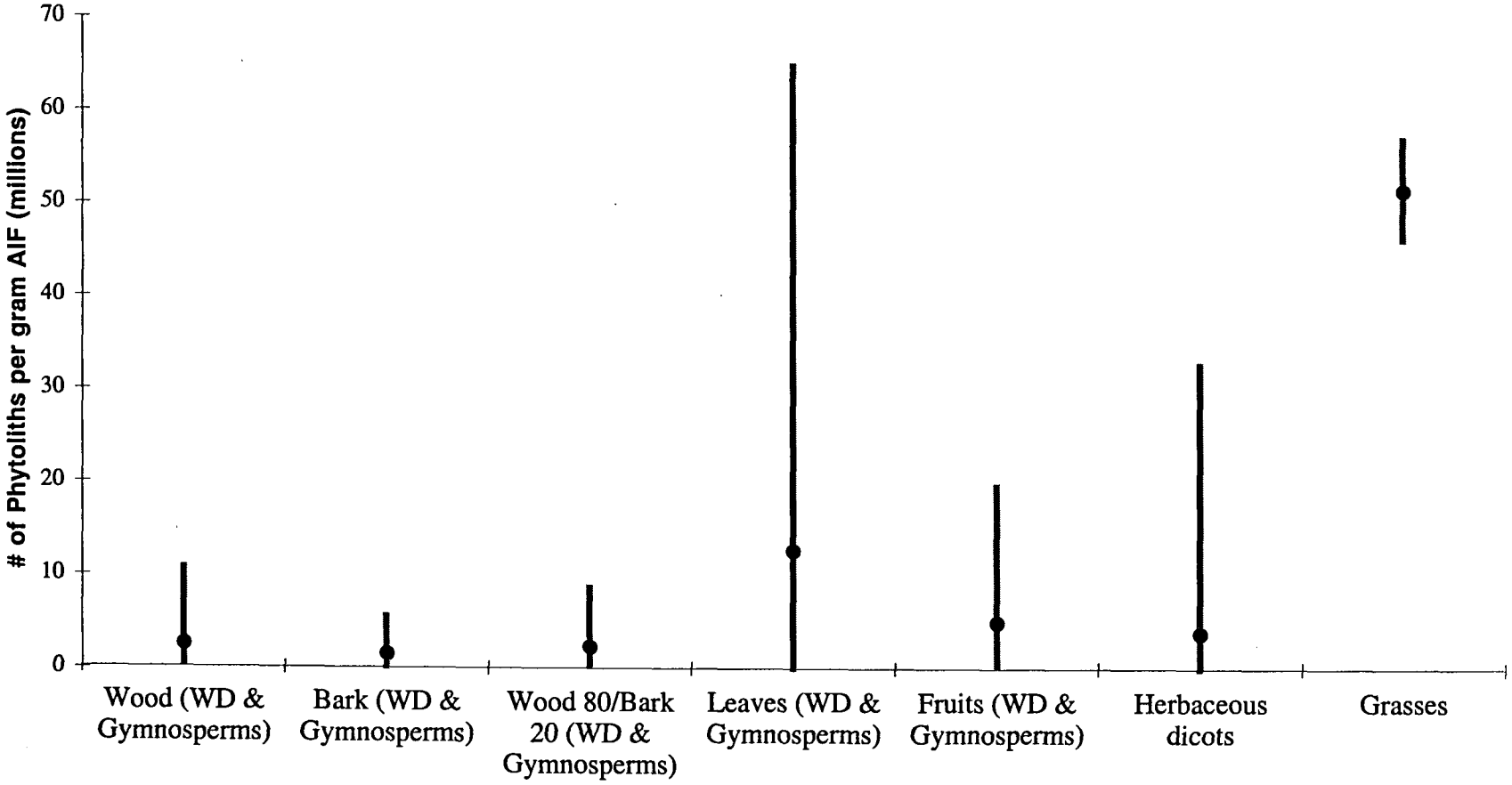

Figure 8 - Total number of phytoliths per 1 g of Acid Insoluble Fraction (AIF) produced in the reference collection of modern plants analysed from the Mount Carmel area. Columns 1 and 2 show the number of phytoliths per 1 g of AIF from wood and bark separately, whereas column 3 shows the number of phytoliths per 1 g of AIF in wood/bark based on the weighted proportion of wood:bark 0.8/0.2.

While studying the morphology of the phytoliths, it was observed that in wood and bark phytoliths with irregular, non-diagnostic morphologies are very common. These forms cannot be classified morphologically and were grouped together and named phytoliths with variable morphologies. These forms are not abundant in leaves and fruits this presence is variable according to different species. In grasses these irregular forms are almost absent.

The ratio between variable and consistent morphology phytoliths can be used, therefore, as a convenient indicator of the general source (wood *vs* grass) of the plant type used for fuel, when studying archaeological sediments. Table 3 shows the ratios between variable and consistent morphology phytoliths (v/c) obtained from the different plant species analyzed. Figure 9 shows the comparison of these ratios according to the different parts of the plants analyzed. A striking difference is observed between the wood/bark and grasses. The v/c ratio for 4 grasses, *Hordeum vulgare* (domesticated barley), *Hordeum vulgare* subsp. *spontaneous* (wild barley), *Triticum aestivum* (bread wheat) and *Arundo donax* (reed) are 0.06, 0.05, 0.15 and 0.10 respectively (Table 3). The leaves from the woody dicotyledon and gymnosperm groups also have a very low

v/c ratio of 0.22. In wood/bark (80/20) the average ratio is 4.97. Separately, the average v/c ratio for wood is much higher, 39.17, but this includes two species that contain almost no consistent morphology phytoliths (*Ceratonia siliqua* (Carob) and *Cupressus sempervirens* (Cypress)). Excluding these two, the average for wood is 7.02. For the bark of woody dicotyledons and gymnosperms the average ratio is 2.02 (Table 3).

This ratio can be applied to archaeological samples, together with the information on the number of phytoliths per 1 g AIF, to determine whether there is a greater proportion of wood/bark phytoliths over other parts of the same trees like leaves or other families, such as grasses.

Woody dicotyledons & Gymnosperms	Wood	Bark	Wood 80/bark 20	Fruits	Leaves
Amygdalus communis (9)	11.88	2.63	5.39		0.07
. -inner husk				1.29	
-outer husk				2.13	
Ceratonia siliqua (3)	245	1.04	8.49	3.42	0.23
Crataegus aronia (11)	3.31	0.84	1.99		0.30
Cupressus sempervirens (10)	187	1.16	6.83	4.87	0.48
Laurus nobilis (19)	2.45	3.28	2.49		0.08
Olea europaea (8)	20.42	9.5	17.44	4.56	0.22
Pinus halepensis (7)	2.97	0.33	1.25	0.15	0.08
Pistacia palaestina (4)	5.07	1.19	3.06		0.07
Quercus calliprinos (1)	4.71	0.98	2.86		0.22
Quercus ithaburensis (6)	4.44	0.81	2.96		0.37
-husk				0.6	
-caps				0.43	
Salix acmophylla (15)	12.53	2.61	6.89		0.08
Styrax officinalis (12)	6	0.82	1.82		0.41
Ziziphus spina christy (2)	3.4	1.05	3.16		
Average	**39.17**	**2.02**	**4.97**	**2.18**	**0.22**
Average excluding (3) and (10)	**7.02**				
Herbaceous dicotyledons	**Whole plant**				
Asparagus aphyllus (20)	5.45				
Ephedra (14)	2.83				
Foeniculum vulgare (21)	0.61				
Lens orientalis (30)	0.16				
Linum pubescens (22)	0.36				
Lupinus varius (29)	0.98				
Malva sylvestris (25)	1.26				
Myrtus communis (28)	0.16				
Pistacia lentiscus (24)	0.08				
Pisum syriacum (26)	18.50				
Sinapis alba (23)	0.93				
Thymelea hirsuta (27)	1.15				
Average	**2.71**				
Grasses		**Whole plant**			
Arundo donax (13)		0.10			
-stem	0.22				
-leaves sheath	0.06				
-leaves	0.02				
Hordeum vulgare (16)		0.06			
Hordeum v. subspontaneum (18)		0.05			
Triticum aestivum (17)		0.15			
Average		**0.09**			

Table 3 - Plant reference collection. Ratio variable to consistent (v/c) morphology phytoliths in the different species analyzed from the Mt. Carmel area.

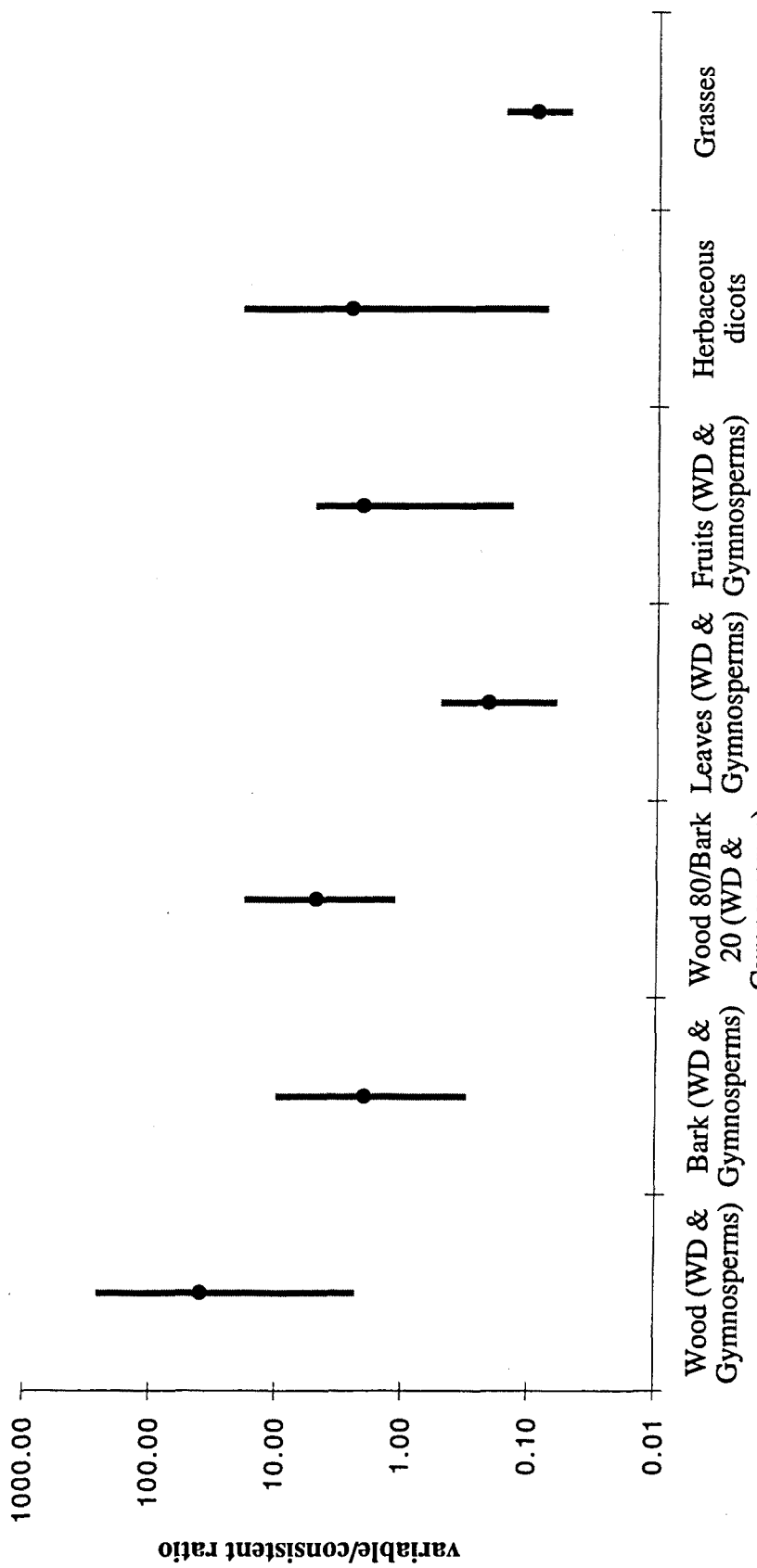

Figure 9 - Ratio between variable/consistent (v/c) morphology phytoliths produced in the reference collection of modern plants analyzed from the Mount Carmel area. Logarithmic scale. Columns 1 and 2 show the ratios of v/c phytoliths morphology for wood and bark separately, whereas column 3 shows the ratio of v/c phytolith morphology of wood/bark together based on the weighted proportions of wood:bark 0.8/0.2.

The next objective is to determine whether or not the consistent morphology phytoliths can be used to identify the plant from which the phytoliths are derived. For this purpose we counted, whenever possible, between 100 and 200 phytoliths with consistent morphology. This range is based on a test carried out using the bark of *Quercus calliprinos* (Kermes oak). The weighed samples were distributed on 6 microscope slides. Eight hundred phytoliths were counted, of which 417 were with consistent morphologies. Table 4 shows the cumulative compositions (in percent) as the counts from additional slides are combined. It also shows the differences in percentages for each of the slides or combination of slides in relation to the percent composition based on 417 phytoliths. The results show that the average error decreases, as expected, when more phytoliths are counted. Thus the composition (percent) of phytoliths with consistent morphologies calculated on a count of between 125 and 194 individual phytoliths has roughly a 20% error. The error decreases systematically to 12% when 265 phytoliths are counted. Note that when the proportion of a particular phytolith is below 2% it is not included in the calculation.

Name	*1 slide*	*2 slides*	*3 slides*	*4 slides*	*5 slides*	*6 slides*	*% diff.1 slide*	*% diff.2 slides*	*% diff.3 slides*	*% diff.4 slides*	*% diff.5 slides*	*% diff.6 slides*
C p	8.1	4	2.6	3	3.8	3.8	113	5	32	21	-	0
EA PR	5.4	4.8	6.2	6	6.7	6.2	13	23	0	3	8	0
E p	0	3.2	3.1	3.8	4.1	4.6	-	30	33	17	11	0
P El p	5.4	6.4	12.4	11.7	11	10.3	48	38	20	14	7	0
LC e	2.7	5.6	3.6	4.5	4.7	4.8	44	17	25	6	2	0
LC PO	8.1	6.4	7.2	6.8	6.7	6.5	25	2	11	5	3	0
LC p	0	0	0	0.8	1.2	1.7	-	-	-	-**	-	0
P Bk s se	24.3	23.2	22.7	23	23.8	24.2	-	4	6	5	2	0
P t p se	0	0	0	0	0.3	0.2	-	-	-	-	-	0
P t p re	0	0	0	0.4	0.6	0.7	-	-	-	-	-	0
PL	0	0	0	0.4	0.3	0.2	-	-	-	-	-	0
Shc	27	31.2	27.8	25.3	22.1	22.3	21	40	25	-	1	0
ShC Bi	2.7	4	4.6	3.8	3.2	2.9	7	38	59	31	10	0
Sp e	0	0.8	1.6	1.1	1.2	1.2	-	-	-	-	-	0
Sp p	16.2	10.4	8.2	9.4	10.5	10.3	57	1	20	9	2	0
Phytoliths counted	**37**	**125**	**194**	**265**	**344**	**417**	**37**	**125**	**194**	**265**	**344**	**417**
Average % diff.*							**41**	**20**	**23**	**12**	**5**	**0**

*** % slide x - % slide 6 / %slide 6**

**** less than 2% presence not included in the difference percentage**

Table 4 - Consistent morphology phytoliths from bark of *Quercus calliprinos* among 6 slides. Effect of phytolith number counted on the composition (%). The average % difference is an indication of the expected error.

Table 5 (a-f) shows the morphological results of the phytolith analyses for all the plants examined. These results have been grouped according to the different parts of the plants studied or groups of plants. In the samples where the amounts of phytoliths counted were below 50, the percentages were not noted, due to the lack of reliability in the results, as was shown in table 4, as these would have an error of 40% or more. Table 5a illustrate well the low proportion of phytoliths with consistent morphology in the wood of woody dicotyledons and gymnosperms. Most of the phytoliths identified in wood had variable morphology (Figure 10a). The opposite occurs in grasses where most of the phytoliths identified had consistent morphologies and there were almost no phytoliths with variable morphology (Table 5f) (Figure 10b). Leaves of woody dicotyledons also show a high amount of phytoliths with consistent morphologies (Table 5c). Ratios between variable and consistent morphology are shown in Table 3.

WOODY DICOTYLEDONS & GYMNOSPERMS																										
WOOD																										
Name (See Table 1 for key number)	*1a*		*2a*		*3a*		*4a*		*6a*		*7a*		*8a*		*9a*		*10a*		*11a*		*12a*		*15a*		*19a*	
Consistent morphologies	Sum	%	Sum	%	Sum	%	Sum	%	Sum	%	Sum	%	Sum	%	Sum	%	Sum	%	Sum	%	Sum	%	Sum	%	Sum	%
(C p Bu) Cylindroid psilate bulbous			1	1.1							1	-														
(C p) Cylindroid psilate	9	16.7	3	3.3							1	-													2	2.6
(C s) Cylindroid scabrate	1	1.9																								
(D p) Discoidal psilate									1	2.0																
(E p) Ellipsoid psilate	8	14.8	18	20.0			2	-	7	14.0	11	-	6	-	1	-			1	-			3	-	10	13.2
(E s) Ellipsoid scabrate	3	5.6	1	1.1											1	-							2	-	9	11.8
(EA H) Hair	3	5.6																								
(EA PR) Prickle	1	1.9	1	1.1																						
(LC p) Long cell psilate	1	1.9																								
(LC PO) Long cell polylobate			2	2.2																						
(P Bk p re) Parallelepiped blocky psilate rounded ends			4	4.4									1	-												
(P Bk s se) Parallelepiped blocky scabrate square ends	1	1.9	1	1.1	1	-	1	-															1	-		
(P El p) Parallelepiped elongate psilate	2	3.7									1	-														
(P t p re) Parallelepiped thin psilate rounded ends																					2	-				
(PL) Platelet	9	16.7																	3	-			1	-	4	5.3
(ShC Bi) Short cell-Bilobate	1	1.9	2	2.2																						
(ShC) Short cell	2	3.7	3	3.3							1	-													2	2.6
(Sp p) Sheroid psilate	13	24.1	53	58.9			12	-	42	84.0	16	-	5	-	5	-			12	-	5	-	5	-	35	46.1
(Sp s) Sheroid scabrate			1	1.1											1	-							3	-	14	18.4
(SS LC w) Silica skeleton long cells wavy																					1	-				
Total	54	100	90	100	1		15		50	100	31		12		8		0		16		8		15		76	100
Variable morphologies	*1a*		*2a*		*3a*		*4a*		*6a*		*7a*		*8a*		*9a*		*10a*		*11a*		*12a*		15a		19a	
(I ge) Irregular w/green elongates	106	54.9	189	61.8	200	81.6	44	57.9	182	82.0	70	76.1	185	75.5	50	52.6	67	35.8	15	28.3	28	58.3	104	55.3	72	38.7
(I p) Irregular psilate	57	29.5	115	37.6	45	18.4	32	42.1	39	17.6	22	23.9	60	24.5	40	42.1	120	64.2	38	71.7	20	41.7	83	44.1	108	58.1
(I s) Irregular scabrate	6	3.1	2	0.7											5	5.3									2	1.1
(IN) Indeterminated	2	1.0																								
(WM) weathered morphotypes	22	11.4							1	0.5													1	0.5	4	2.2
Total	193	100	306	100	245	100	76	100	222	100	92	100	245	100	95	100	187	100	53	100	48	100	188	100	186	100

Table 5a - Phytolith morphological results from wood from the plant reference collection. % of species with less than 50 phytoliths are not included due to the large error margin.

WOODY DICOTYLEDONS & GYMNOSPERMS																										
BARK																										
Name (See Table 1 for key number)	1b		2b		3b		4b		6b		7b		8b		9b		10b		11b		12b		15b		19b	
Consistent morphologies	Sum	%	Sum	%	Sum	%	Sum	%	Sum	%	Sum	%	Sum	%	Sum	%	Sum	%	Sum	%	Sum	%	Sum	%	Sum	%
(B) Bulliform*	1	0.6																								
(C p Bu) Cylindroid psilate bulbous					1	0.8			1	0.7	4	1.7					1	0.8			1	0.7	1	1.3		
(C p) Cylindroid psilate			6	-	14	11.0	5	7.8	4	2.9			2	-	11	14.7	7	5.3	11	15.1	12	9.0	20	25.3	1	-
(C s) Cylindroid scabrate	9	5.6	3	-	4	3.1			1	0.7							6	4.5	2	2.7	1	0.7	2	2.5		
(D p) Discoidal psilate	1	0.6							3	2.2					1	1.3			4	5.5	4	3.0	1	1.3		
(E p) Ellipsoid psilate	4	2.5			14	11.0	4	6.3	12	8.7	37	15.9	3	-	3	4.0	5	3.8			7	5.2	7	8.9		
(E s) Ellipsoid scabrate	15	9.3			8	6.3	7	10.9	6	4.3					3	4.0	6	4.5	2	2.7	1	0.7	3	3.8	3	-
(EA H a) Hair armed					1	0.8																				
(EA H) Hair	1	0.6	1	-	2	1.6															1	0.7				
(EA PA) Papillae*																							1	1.3		
(EA PR) Prickle*	8	5.0			4	3.1			1	0.7					2	2.7	5	3.8	4	5.5	1	0.7	5	6.3		
(HA Sp) Honeycomb spheroid																							1	1.3		
(LC d) Long cell dendritic*									1	0.7																
(LC e) Long cell echinate*	2	1.2	3	-	3	2.4									3	4.0	2	1.5	3	4.1	3	2.2				
(LC p) Long cell psilate*					3	2.4	5	7.8	1	0.7					6	8.0	16	12.1	2	2.7	4	3.0				
(LC PO) Long cell polylobate*	7	4.3	1	-	3	2.4			2	1.4					1	1.3	2	1.5	5	6.8	2	1.5	1	1.3		
(LC si) Long cell sinuous*									1	0.7																
(LC v) Long cell verrucate*			3	-																						
(LC w) Long cell wavy*			1	-					4	2.9							1	0.8			1	0.7				
(P Bk p se) Parallelepiped blocky psilate square ends	10	6.2	2	-	12	9.4	3	4.7	15	10.9	2	0.9	1	-	1	1.3	2	1.5	5	6.8	7	5.2	3	3.8		
(P Bk s se) Parallelepiped blocky scabrate square ends	14	8.7	3	-	8	6.3	2	3.1	9	6.5	1	0.4	2	-	7	9.3	7	5.3	15	20.5	23	17.2			2	-
(P El p) Parallelepiped elongate psilate	7	4.3	11	-	13	10.2	9	14.1	5	3.6	5	2.2			5	6.7	9	6.8	3	4.1	9	6.7				
(P El s) Parallelepiped elongate scabrate			1	-			1	1.6	1	0.7					1	1.3	3	2.3	2	2.7	1	0.7				
(P t p re) Parallelepiped thin psilate rounded ends	16	9.9																								
(P t p se) Parallelepiped thin psilate square ends	6	3.7	3	-					1	0.7																
(P t s se) Parallelepiped thin scabrate square ends			1	-					1	0.7																
(PL) Platelet	7	4.3	2	-	1	0.8	1	1.6	4	2.9	1	0.4			4	5.3	1	0.8							1	-
(ShC Bi) Short cell-Bilobate*	6	3.7			1	0.8	4	6.3	4	2.9			2	-	2	2.7	2	1.5	3	4.1	4	3.0			1	-
(ShC) Short cell*	30	18.6	6	-	19	15.0	6	9.4	14	10.1	1	0.4	1	-	14	18.7	43	32.6	10	13.7	27	20.1	6	7.6	4	-
(Sp e) Spheroid echinate					2	1.6			1	0.7							1	0.8								
(Sp p) Spheroid psilate	15	9.3			13	10.2	16	25.0	40	29.0	181	78.0	7	-	8	10.7	9	6.8			25	18.7	28	35.4	2	-
(Sp s) Spheroid scabrate	1	0.6			1	0.8	1	1.6	5	3.6					2	2.7	3	2.3	1	1.4					4	-
(Sp v) Spheroid verrucate																	1	0.8								
(SS LC p) Silica skeleton long cells psilate*															1	1.3			1	1.4						
(SS LC si) Silica skeleton long cells sinuous*	1	0.6																								
(SS LC w) Silica skeleton long cells wavy*									1	0.7																
Total	161	100	47		127	100	64	100	138	100	232	100	18		75	100	132	100	73	100	134	100	79	100	18	
Variable morphologies	1b				3b		4b		6b		7b		8b		9b		10b		11b		12b		15b		19b	
(I ge) Irregular w/green elongates	4	2.7	19	-	9	6.8	16	21.1	4	3.6	22	28.9	65	38.0	7	3.6	13	8.5	1	1.6			99	48.1	21	35.6
(I p) Irregular psilate	26	17.6	13	-	56	42.4	49	64.5	55	49.1	46	60.5	97	56.7	80	40.6	53	34.6	14	23.0	58	52.7	82	39.8	27	45.8
(I s) Irregular scabrate	67	45.3	3	-	15	11.4	6	7.9	15	13.4	1	1.3	1	0.6	42	21.3	17	11.1	7	11.5	16	14.5	10	4.9		
(IN) Indeterminated	10	6.8			32	24.2			18	16.1			8	4.7	17	8.6	28	18.3	10	16.4	13	11.8				
(WM) weathered morphotypes	41	27.7	8	-	20	15.2	5	6.6	20	17.9	7	9.2			51	25.9	42	27.5	29	47.5	23	20.9	15	7.3	11	18.6
Total	148	100	43		132	100	76	100	112	100	76	100	171	100	197	100	153	100	61	100	110	100	206	100	59	100

Table 5b - Phytolith morphological results from bark from the plant reference collection. % of species with less than 50 phytoliths are not included due to the large error margin.

WOODY DICOTYLEDONS & GYMNOSPERMS																								
LEAVES																								
Name (See Table 1 for key number)	1c		3c		4c		6c		7c		8c		9c		10c		11c		12c		15c		19c	
Consistent morphologies	Sum	%	Sum	%	Sum	%	Sum	%	Sum	%	Sum	%	Sum	%	Sum	%	Sum	%	Sum	%	Sum	%	Sum	%
(B) Bulliform	1	0.1																						
(C cl) Cylindroid clavate									1	0.2							1	0.6						
(C p Bu) Cylindroid psilate bulbous	71	8.3	3	0.9			13	3.3	148	23.2					2	2.5								
(C p DL) Cylindroid psilate with diagonal lines									46	7.2														
(C p) Cylindroid psilate			2	0.6			9	2.3	21	3.3	2	0.6			6	7.4	2	1.1	1	0.7	54	19.1	5	1.3
(C s) Cylindroid scabrate																	2	1.1						
(D p) Discoidal psilate																	1	0.6	1	0.7				
(E p) Ellipsoid psilate	26	3.0	9	2.7	10	5.1	31	7.9	64	10.0	6	1.7			15	18.5	5	2.8	8	5.8	2	0.7	8	2.2
(E s) Ellipsoid scabrate	5	0.6	4	1.2			13	3.3			8	2.3					6	3.4			2	0.7		
(E v) Ellipsoid verrucate																							4	1.1
(EA H b) Hair with base							1	0.3																
(EA H) Hair	2	0.2	6	1.8			4	1.0			4	1.2							49	35.3	1	0.4		
(EA Hb) Hair base							1	0.3									1	0.6						
(EA PA) Papillae											1	0.3												
(EA PR) Prickle							4	1.0			1	0.3							2	1.4	1	0.4		
(F) Fibre type	98	11.4	57	17.2	11	5.6	42	10.7			18	5.2	19	4.1					2	1.4			6	1.6
(HA El) Honeycombed elongate	2	0.2			6	3.1	2	0.5					1	0.2										
(HA Ph) Honeycomb polyhedral	1	0.1																						
(HA Sp) Honeycombed spheroid	1	0.1					4	1.0					9	1.9							6	2.1	1	0.3
(LC p) Long cell psilate	20	2.3					8	2.0									1	0.6	1	0.7			1	0.3
(LC PO) Long cell polylobate	1	0.1																						
(LC w) Long cell wavy	1	0.1					1	0.3																
(P Bk p re) Parallelepiped blocky psilate rounded ends							1	0.3					1	0.2										
(P Bk p se) Parallelepiped blocky psilate square ends	1	0.1	1	0.3			2	0.5			2	0.6							5	3.6	1	0.4		
(P Bk s se) Parallelepiped blocky scabrate square ends	1	0.1	1	0.3			3	0.8	5	0.8	1	0.3			1	1.2	1	0.6	1	0.7				
(P El in) Parallelepiped elongate Indeterminated									23	3.6														
(P El p) Parallelepiped elongate psilate	44	5.1	12	3.6	3	1.5	31	7.9	160	25.1	2	0.6							38	27.3				
(P El v) Parallelepiped elongate verrucate									94	14.7	2	0.6	3	0.6										
(P t p re) Parallelepiped thin psilate rounded ends							1	0.3																
(PL) Platelet	14	1.6	1	0.3	2	1.0	6	1.5	1	0.2									1	0.7				
(S) Stomata					81	41.3											2	1.1					25	6.7
(SC) Sclereid	6	0.7					2	0.5									1	0.6					3	0.8
(ShC Bi) Short cell-Bilobate			2	0.6	1	0.5					1	0.3			2	2.5			2	1.4	1	0.4		
(ShC) Short cell	2	0.2			1	0.5	5	1.3			4	1.2			2	2.5	14	7.8	9	6.5	1	0.4		
(Sp e) Spheroid echinate			1	0.3																				
(Sp p) Spheroid psilate	249	29.1	19	5.7	11	5.6	32	8.1	67	10.5	5	1.5	1	0.2	53	65.4	10	5.6	3	2.2			75	20.2
(Sp s) Spheroid scabrate			7	2.1																	1	0.4	3	0.8
(Sp v) Spheroid verrucate							1	0.3																
(SS C si) Silica skeleton cylindroid sinuous									1	0.2														
(SS C v) Silica skeleton cylindroid verrucate											12	3.5												
(SS LC p) Silica skeleton long cells psilate	1	0.1					6	1.5	6	0.9											6	2.1		
(SS LC w) Silica skeleton long cells wavy							1	0.3																
(SS LC) (S) Silica skeleton long cells w/Stomata	1	0.1																						
(SS LC) (EA PR) Silica skeleton long cells w/Prickles							2	0.5																
(SS ni) Silica skeleton not identifiable							6	1.5					20	4.3										
(SS Ph) Silica skeleton polyhedral	46	5.4	28	8.4	29	14.8	44	11.2			4	1.2	49	10.5			10	5.6	2	1.4			18	4.9
(SS Ph w) Silica skeleton polyhedral with wavy margin	1	0.1																						
(SS sl) Silica skeleton sensu lato	1	0.1	5	1.5			12	3.0	1	0.2	94	27.4	82	17.6			14	7.8	4	2.9	42	14.8	70	18.9
(SS Sp/E) (T) Silica skeleton spheroid/ellipsoid w/Tracheary													41	8.8										
(SS Sp/E) Silica skeleton spheroid/ellipsoid			34	10.2	23	11.7	4	1.0			29	8.5	56	12.0					1	0.7	145	51.2	4	1.1
(T) Tracheary	261	30.5	140	42.2	18	9.2	102	25.9			147	42.9	183	39.4			108	60.3	9	6.5	20	7.1	148	39.9
Total	857	100	332	100	196	100	394	100	638	100	343	100	465	100	81	100	179	100	139	100	283	100	371	100
Variable morphologies	1c		3c		4c		6c		7c		8c		9c		10c		11c		12c		15c		19c	
(I ge) Irregular w/green elongates	3	1.6	2	2.6	2	-	1	0.7			12	8.3	1	-	10	-	14	26.4	4	7.0	6	-		
(I p Pr) Irregular psilate w/protuberances					4	-																		
(I p) Irregular psilate	66	34.4	29	38.2	6	-	73	50.7	16	29.6	33	22.9	29	-	24	-	25	47.2	29	50.9	15	-	27	-
(I s Pr) Irregular scabrate w/protuberances			9	11.8																				
(I s) Irregular scabrate	8	4.2	15	19.7			23	16.0	1	1.9	3	2.1					9	17.0	9	15.8	3	-		
(IN) Indeterminated	15	52.1	2	2.6			15	10.4			5	3.5	2	-	1	-			4	7.0				
(WM) weathered morphotypes	100	7.8	19	25.0	1	-	32	22.2	37	55.6	23	16.0			4	-	5	9.4	11	19.3			1	-
Total	192	100	76	100	13		144	100	54	100	76	100	32		39		53	100	57	100	24		28	

Table 5c - Phytolith morphological results from leaves of trees from the plant reference collection. % for species with less than 50 phytoliths are not included due to the large error margin.

WOODY DICOTYLEDONS & GYMNOSPERMS																		
FRUITS/SEEDS, ETC.																		
Name (See Table 1 for key number)	3d		6e		6f		7d		8d		9d		9e		9f		10d	
Consistent morphologies	Sum	%	Sum	%	Sum	%	Sum	%	Sum	%	Sum	%	Sum	%	Sum	%	Sum	%
(B) Bulliform					1	0.1							2	1.0				
(C p Bu) Cylindroid psilate bulbous					4	0.5	20	5.4					3	1.5				
(C p) Cylindroid psilate					59	7.5							6	3.1	5	3.6	6	-
(C s) Cylindroid scabrate			2	2.5														
(C v) Cylindroid verrucate					4	0.5							1	0.5	1	0.7		
(D s) Discoidal scabrate					3	0.4									1	0.7		
(E p) Ellipsoid psilate	15	19.7	14	17.5	121	15.4	18	4.9	1	-			19	9.8	14	10.0		
(E PO) Ellipsoid polylobate	2	2.6																
(E s) Ellipsoid scabrate	4	5.3	1	1.3	34	4.3	18	4.9					17	8.8	21	15.0		
(EA H b) Hair with base					1	0.1												
(EA H) Hair					2	0.3												
(EA PR) Prickle					2	0.3							2	1.0	2	1.4		
(F) Fibre type					1	0.1	3	0.8	4	-								
(HA Sp) Honeycomb spheroid					2	0.3												
(LC e) Long cell echinate					18	2.3									2	1.4		
(LC p) Long cell psilate			2	2.5	14	1.8							15	7.7	2	1.4		
(LC PO) Long cell polylobate					11	1.4							51	26.3	9	6.4		
(LC w) Long cell wavy					2	0.3									2	1.4		
(P Bk p re) Parallelepiped blocky psilate rounded ends					72	9.2	11	3.0					2	1.0	4	2.9		
(P Bk p se) Parallelepiped blocky psilate square ends			1	1.3	31	4.0									7	5.0		
(P Bk s se) Parallelepiped blocky scabrate square ends	2	2.6			25	3.2							6	3.1	7	5.0	7	-
(P El in) Parallelepiped elongate indeterminated	7	9.2																
(P El p) Parallelepiped elongate psilate	2	2.6			21	2.7	1	0.3					4	2.1	6	4.3		
(P t p se) Parallelepiped thin psilate square ends					24	3.1									1	0.7		
(PL) Platelet			2	2.5	14	1.8	200	54.5	8	-			3	1.5	6	4.3		
(ShC Bi) Short cell-Bilobate													1	0.5				
(ShC) Short cell					18	2.3					2	-	15	7.7	13	9.3	2	-
(Sp e) Spheroid echinate					1	0.1									2	1.4		
(Sp p) Spheroid psilate	37	48.7	52	65.0	267	34.1	93	25.3	3	-			32	16.5	21	15.0		
(Sp s) Spheroid scabrate	6	7.9	3	3.8	27	3.4					1	-			10	7.1		
(Sp v) Spheroid verrucate			2	2.5	3	0.4							8	4.1	1	0.7		
(SS LC p) Silica skeleton long cells psilate					1	0.1							2	1.0				
(SS LC w) Silica skeleton long cells wavy					1	0.1							4	2.1				
(SS LC) (EA PR) Silica skeleton long cells with Prickles													1	0.5				
(SS ni) Silica skeleton no identifiable							1	0.3										
(SS Ph) Silica skeleton polyhedral			1	1.3			1	0.3										
(SS Sp/E) Silica skeleton spheroid/ellipsoid							1	0.3							1	0.7		
(T) Tracheary	1	1.3													2	1.4		
Total	76	100	80	100	784	100	367	100	16		3		194	100	140	100	15	
variable morphologies	3d		6e		6f		7d		8d		9d		9e		9f		10d	
(I ge) Irregular w/green elongates	161	61.9	15	-	8	2.3			31	42.5	49	70.0	10	4.0	25	8.4	48	65.8
(I p) Irregular psilate	65	25.0	19	-	155	45.5	14	25.9	41	56.2	20	28.6	119	47.4	87	29.2	23	31.5
(I s) Irregular scabrate	10	3.8	1	-	45	13.2	1	1.9					26	10.4	41	13.8	2	2.7
(IN) Indeterminated	1	0.4	1	-	16	4.7	1	1.9	1	1.4			16	6.4	12	4.0		
(WM) weathered morphotypes	23	8.8	12	-	117	34.3	38	70.4			1	1.4	80	31.9	133	44.6		
Total	260	100	48		341	100	54	100	73	100	70	100	251	100	298	100	73	100

Table 5d - Phytolith morphological results from fruits of trees from the plant reference collection. % for species with less than 50 phytoliths are not included due to the large error margin.

HERBACEOUS DICOTYLEDONS																						
Name (See Table 1 for key number)	20		21		22		23		24		25		26		27		28		29		30	
Consistent morphologies	Sum	%	Sum	%	Sum	%	Sum	%	Sum	%	Sum	%	Sum	%	Sum	%	Sum		Sum		Sum	
(C p Bu) Cylindroid psilate bulbous	1	-																				
(C p) Cylindroid psilate	5	-	3	2.3	4	3.0	6	-			4	4.3			12	18.8	4	2.0	6	-	109	59.9
(C s) Cylindroid scabrate															4	6.3			8	-	2	1.1
(C v) Cylindroid verrucate							1	-	1	0.4	1	1.1							3	-	7	3.8
(D p) Discoidal psilate															1	1.6						
(E p) Ellipsoid psilate	9	-	12	9.2	2	1.5			4	1.6	18	19.1	1	-	2	3.1	1	0.5				
(E PO) Ellipsoid polylobate			1	0.8	2	1.5																
(E s) Ellipsoid scabrate	1	-									15	16.0			1	1.6	1	0.5				
(EA H f) Hair foeniculum type			89	67.9																		
(EA H) Hair	1	-			14	10.6	2	-			1	1.1							11	-	8	4.4
(EA PR) Prickle							2	-			2	2.1							1	-		
(F l) Fibre net Linum type					68	51.5																
(F) Fibre type									3	1.2											1	0.5
(HA Sp) Honeycomb spheroid													1	-								
(LC e) Long cell echinate															1	1.6			1	-		
(LC p) Long cell psilate			1	0.8	3	2.3					1	1.1			5	7.8			5	-		
(LC PO) Long cell polylobate											1	1.1			1	1.6			1	-		
(LC w) Long cell wavy					2	1.5																
(P Bk p se) Parallelepiped blocky psilate square ends					1	0.8					2	2.1										
(P Bk s se) Parallelepiped blocky scabrate square ends	2	-	3	2.3	1	0.8	1	-			7	7.4							4	-		
(P El p) Parallelepiped elongate psilate	2	-			3	2.3	1	-			5	5.3	1	-	3	4.7						
(P El s) Parallelepiped elongate scabrate															1	1.6						
(P El v) Parallelepiped elongate verrucate									1	0.4												
(P t p se) Parallelepiped thin psilate square ends							2	-														
(PL) Platelet			2	1.5	1	0.8					2	2.1	1	-					2	-		
(S) Stomata									178	72.4												
(ShC Bi) Short cells-Bilobates			1	0.8	2	1.5							2	-	2	3.1					1	0.5
(ShC) Short cells	1	-	3	2.3	2	1.5	7	-			2	2.1			17	26.6	3	1.5				
(Sp e) Spheroid echinate																					1	0.5
(Sp p) Spheroid psilate	8	-	16	12.2	2	1.5					21	22.3	1	-	3	4.7	7	3.5	1	-	1	0.5
(Sp s) Spheroid scabrate											10	10.6	1	-	9	14.1			3	-		
(Sp v) Spheroid verrucate	2	-																				
(SS C v) Silica skeleton cylindroid verrucate																			1	-		
(SS LC p) Silica skeleton long cells psilate													1	-								
(SS LC w) Silica skeleton long cells wavy															1	1.6						
(SS Ph) Silica skeleton polyhedral					2	1.5	13	-	25	10.2	1	1.1					2	1.0				
(SS sl) Silica skeleton sensu lato					8	6.1	5	-	3	1.2							84	42.0				
(SS sl) Silica skeleton sensu lato with (T) Tracheary																	4	2.0				
(SS Sp/E) Silica skeleton spheroid/ellipsoid					15	11.4							3	-								
(T) Tracheary	1	-					3	-	31	12.6	1	1.1			1	1.6	94	47.0			52	28.6
Total	33		131	100	132	100	43		246	100	94	100	12		64	100	200	100	47		182	100
Variable morphologies	20	%	21	%	22	%	23	%	24	%	25	%	26	%	27	%	28	%	29	%	30	%
(I e) Irregular echinate	1	0.6																				
(I ge) Irregular w/green elongates	98	54.4	25	31.3	19	-	21	-	1	-	20	16.9	216	97.3	5	6.3	7	-	20	-	6	-
(I p) Irregular psilate	81	45.0	38	47.5	23	-	15	-	13	-	37	31.4	6	2.7	34	42.5	23	-	16	-	14	-
(I s) Irregular scabrate			5	6.3	1	-	1	-	3	-	23	19.5			8	10.0			6	-		
(IN) Indeterminated					2	-									3	3.8						
(WM) weathered morphotypes			12	15.0	3	-	3	-	2	-	38	32.2			30	37.5	2	-	4	-	10	-
Total	180	100	80	100	48		40		19		118	100	222	100	80	100	32		46		30	

Table 5e - Phytolith morphological results from herbaceous dicots from the plant reference collection. % for species with less than 50 phytoliths are not included due to the large error margin.

GRASSES												
Name (See Table I for key number)	**16**		**17**		**18**		***13a***		***13b***		***13c***	
Consistent morphology	**Sum**	**%**	**Sum**	**%**	**Sum**	**%**	***Sum***	***%***	***Sum***	***%***	***Sum***	***%***
(B) Bulliform							5	1.2	2	0.8	13	2.1
(E PO) Ellipsoid polylobate											8	1.3
(EA H) Hair	23	10.8	19	10.3	35	18.1					3	0.5
(EA PA) Papillae	32	15.0	17	9.2	27	14.0						
(EA PR) Prickle											2	0.3
(HA Sp) Honeycombed spheroid											2	0.3
(LC e) Long cell echinate	74	34.7	36	19.5	64	33.2			2	0.8		
(LC p) Long cell psilate	6	2.8			4	2.1	161	37.5	7	2.9	8	1.3
(LC v) Long cell verrucate							40	37.5			9	1.5
(LC w) Long cell wavy	5	2.3					35	17.5	3	1.2	3	0.5
(PL) Platelet							8	1.9				
(ShC Bi) Short cell. Bilobate									10	4.1	514	82.9
(ShC) Short cell	36	16.9	62	33.5	36	18.7	64	14.9	150	61.5	10	1.6
(SS LC e) Silika skeleton long cells echinate	7	3.3	4	2.2	5	2.6						
(SS LC p) Silica skeleton long cells psilate	13	6.1	9	4.9	8	4.1					23	3.7
(SS LC w) (ShC) Silica skeleton long cells wavy w/short cells							73	21.0	64	26.2	17	2.7
(SS LC w) Silica skeleton long cells wavy	10	4.7	38	20.5	14	7.3	17	21.0			1	0.2
(SS LC) (B) Silica skeleton long cells w/ Bulliforms											2	0.3
(SS LC) (EA PA) Silica skeleton long cells w/papillae	5	2.3										
(SS LC) (S) Silica skeleton long cells w/Stomata							1	0.2	6	2.5	5	0.8
(SS sl) Silica skeleton sensu lato	2	0.9					25	5.8				
Total	**213**	**100**	**185**	**100**	**193**	**100**	**429**	**100**	**244**	**100**	**620**	**100**
Variable morphologies	**16**		**17**		**18**		**13a**		**13b**		**13c**	
(I p Pr) Irregular psilate w/protuberances							21	22.1				
(I p) Irregular psilate	13	-	28	-	10	-	49	51.6	2	-	6	-
(I p) Irregular echinate							2	2.1				
(I s) Irregular scabrate							2	2.1	1	-	3	-
(IN) Indeterminated									2	-	1	-
(WM) Weathered morphotypes							21	22.1	9	-	2	-
Total	**13**		**28**		**10**		**95**	**100**	**14**		**12**	

Table 5f - Phytolith morphological results from grasses from the plant reference collection. % for species with less than 50 phytoliths are not included due to the large error margin

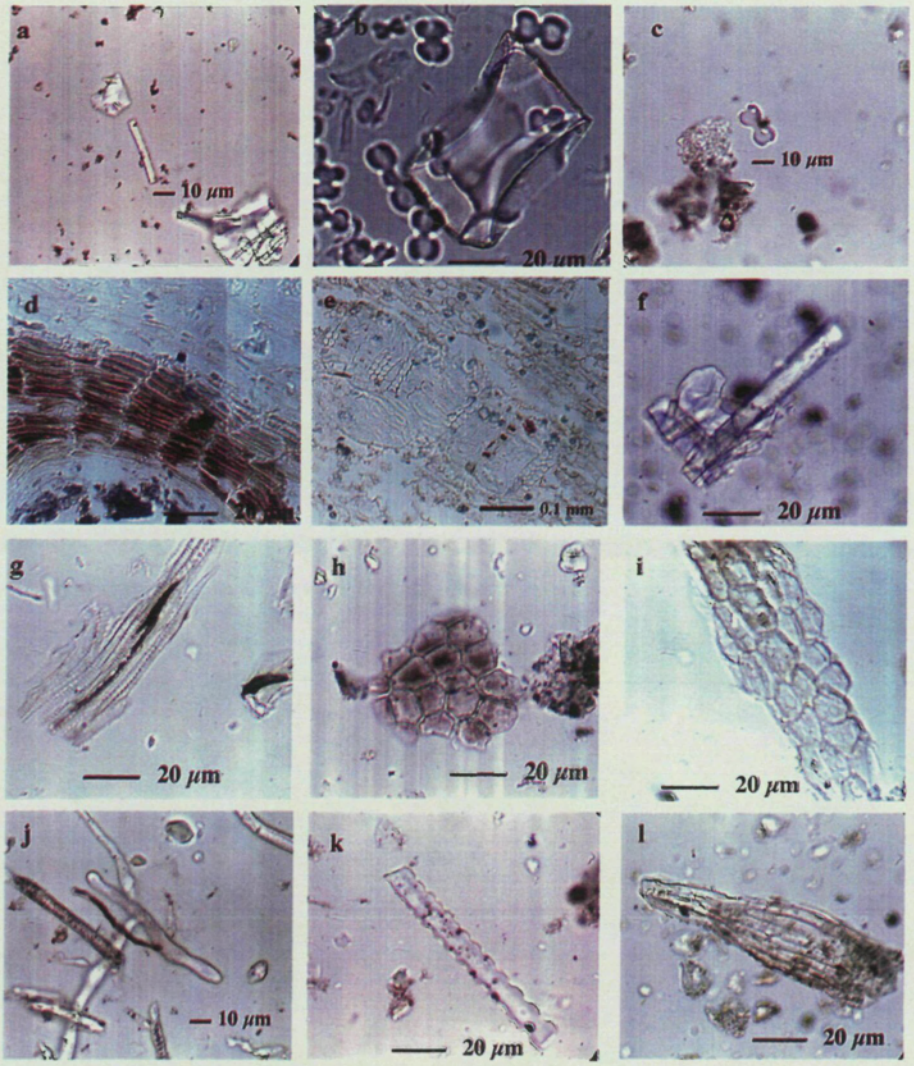

Figure 10 - Photomicrographs of phytoliths. Pictures taken at 400x. a) Irregular psilate from the wood of *Quercus ithaburensis* (Tabor oak). b) Short cells bilobates and Bulliform cells from the leaves of *Arundo donax* (Reed). c) Short cell characteristic of grasses identified in the bark of *Quercus calliprinos* (Kermes oak), probably contamination. d) Thick section of the bark of *Quercus calliprinos* (Kermes oak) with siliceous aggregates. e) Thick section of the leaves of *Quercus calliprinos* (Kermes oak) with the type of epidermal tissue characteristic (Picture taken at 100x). f) Green elongate form from the wood of *Quercus ithaburensis* (Tabor oak). g) Tracheary element from the leaves of *Quercus calliprinos* (Kermes oak). h) Silica skeleton polyhedral from the leaves of *Ceratonia siliqua* (Carob). i) Silica skeleton spheroid/ellipsoid from the leaves of *Amygdalus communis* (Almond). j) Cylindroid psilate bulbous from the leaves of *Pinus halepensis* (Aleppo pine). k) Long cell polylobate from the inner husk of *Amygdalus communis* (Almond). l) Epidermal appendage Hair from *Foeniculum vulgare* (Fennel).

While analyzing the phytoliths with consistent morphology from the bark of woody dicotyledons and gymnosperms we observed that, in most of the species there were phytoliths that according to the cell morphology, seemed to be a contamination from other families like grasses (Figure 10c). These are marked with an asterisk in Table 5b. In most of the cases these phytoliths constitute less than 10%. To check this possible contamination of phytoliths we carried out a test. We collected inner bark from different trees from the Mount Carmel area and we analyzed the phytolith morphologies. Table 6 shows the results obtained. The inner bark, has in general few phytoliths with consistent morphology. Among these consistent morphology phytoliths there is a predominance of spheroid and ellipsoid forms, which is consistent with the results obtained from the study of wood and bark. Phytoliths characteristics of grasses were very scarce and were only present in two samples.

WOODY DICOTYLEDONS & GYMNOSPERMS												
BARK												
Name (See Table 1 for key number)	1b		3b		6b		8b		9b		10b	
Consistent morphology	Sum	%	Sum	%	Sum	%	Sum	%	Sum	%	Sum	%
ShC Bi									1	-		
P El p							1	-				
LC e							1	-			1	
E p			2	-	2	-	1	-	1		1	
C p							2	-	1	-		
P Bk p se	1						2	-	1	-	1	
ShC							1	-			1	-
Sp p	2	-	2		9	-	4	-	5	-	5	
TOTAL	3		4		11		12		9		9	
Name (See Table 1 for key number)	1b		3b		6b		8b		9b		10b	
Variable morphology	Sum	%	Sum	%	Sum	%	Sum	%	Sum	%	Sum	%
I ge	67	64.4	89	57.8	41	78.8	47	52.2	77	51.3	63	54.8
I p	37	35.6	65	42.2	11	21.2	34	37.8	72	48.0	43	37.4
I s							3	3.3				
W M							6	6.7	1	0.7	9	7.8
TOTAL	104	100	154	100	52	100	90	100	150	100	115	45
phyt. consistent morphology	3	2.8	4	2.5	11	17.5	12	11.8	9	5.7	9	7.3
phyt. variable morphology	104	97.2	154	97.5	52	82.5	90	88.2	150	94.3	115	92.7
Total	107	100	158	100	63	100	102	100	159	100	124	100
Ratio	34.67		38.50		4.73		7.50		16.67		12.78	

Table 6 - Plant reference collection. Phytoliths counted in the inner bark of several plant species and the ratio obtained between v/c morphology of the phytoliths.

To check whether or not these and possibly other phytoliths are in fact present on the bark surface, thick paraffin embedded sections of bark were examined in the light microscope. The exterior surfaces were free of phytoliths. This however could not be regarded as conclusive that the phytoliths are formed in bark, as none of the sections revealed phytoliths within the bark tissue itself. Apparently the amounts are just too low to be found in the small volumes analyzed. We did however clearly observe siliceous aggregates, particularly in the section from *Quercus calliprinos* (Kermes oak) (Figure 10d). On the other hand, the cell tissue of the bark does not correspond to the morphology of the phytoliths identified as characteristic of grasses (Figure 10e). At present, and according to the cell morphology of grasses (Twiss, Suess & Smith, 1969; Brown, 1984; Mulholland & Rapp, 1992b), and due to the lack of evidence of real formation of these type of phytoliths in the bark, we assume that the phytoliths that resemble those of grasses, but are found in bark, are indeed contamination.

The morphological analyses of the phytoliths from wood of woody dicotyledons and gymnosperms, show a very low number of consistent morphology forms (Table 5a). Wood therefore, contributes with very few consistent morphology phytoliths to ash as

compared to bark. We will therefore confine the analyses of whether or not the distribution of consistent morphology phytoliths can be related to taxonomic affinity, to bark samples. Table 7 shows the results obtained for phytolith types identified in bark, in larger amount than 5%. Those forms with scabrate and psilate surfaces were combined, since in archaeological samples the differences in surface texture may relate to the quality of preservation. Three types characteristic of grasses are present, prickles (EA PR), long cells polylobate (LC PO) and short cells (ShC) (Table 7). Of these, only short cells are present above 10% and are distributed among most of the species analyzed. Short cells are usually quite small and are produced in huge numbers in the grass family. Their presence in the bark of trees could be due to wind-blown transportation. Figure 11 shows the differences in the morphological representations of the phytoliths in bark, after eliminating forms below 5 % and the possible grass contamination phytoliths. There are 4 forms that repeat themselves in most of the samples in relatively high percentage. Of these the spheroid form is the most abundant. Cylindroids, ellipsoids and parallelepiped blocky forms are also common.

Woody dicotyledons & Gymnosperms																				
Name (See Table 1 for key number	1b		3b		4b		6b		7b		9b		10b		11b		12b		15b	
Bark	Sum	%	Sum	%	Sum	%	Sum	%	Sum	%	Sum	%	Sum	%	Sum	%	Sum	%	Sum	%
C	9	5.6	19	15.0	5	7.8					11	14.7	13	9.8	13	17.8	13	9.7	22	27.8
D															4	5.5				
E	19	11.8	22	17.3	11	17.2	18	13.0	37	15.9	6	8.0	11	8.3			8	6.0	10	12.7
EA PR *	8	5.0													4	5.5			5	6.3
LC PO*															5	6.8				
P Bk	24	14.9	20	15.7	5	7.8	24	17.4			8	10.7	9	6.8	20	27.4	30	22.4		
P El			13	10.2	10	15.6					6	8.0	12	9.1	5	6.8	10	7.5		
P t	22	13.7			5	7.8														
PL											4	5.3								
ShC *	30	18.6	19	15.0	10	15.6	14	10.1			14	18.7	43	32.6	10	13.7	27	20.1	6	7.6
Sp	16	9.9	14	11.0	17	26.6	45	32.6	181	78.0	10	13.3	12	9.1			25	18.7	28	35.4
Total	128		107		63		101		218		59		100		61		113		71	
* Morphologies characteristics of grasses																				

Table 7 - Phytolith morphological results from bark from the plant reference collection, grouping surfaces psilate/scabrate and eliminating morphologies identified below 5%.

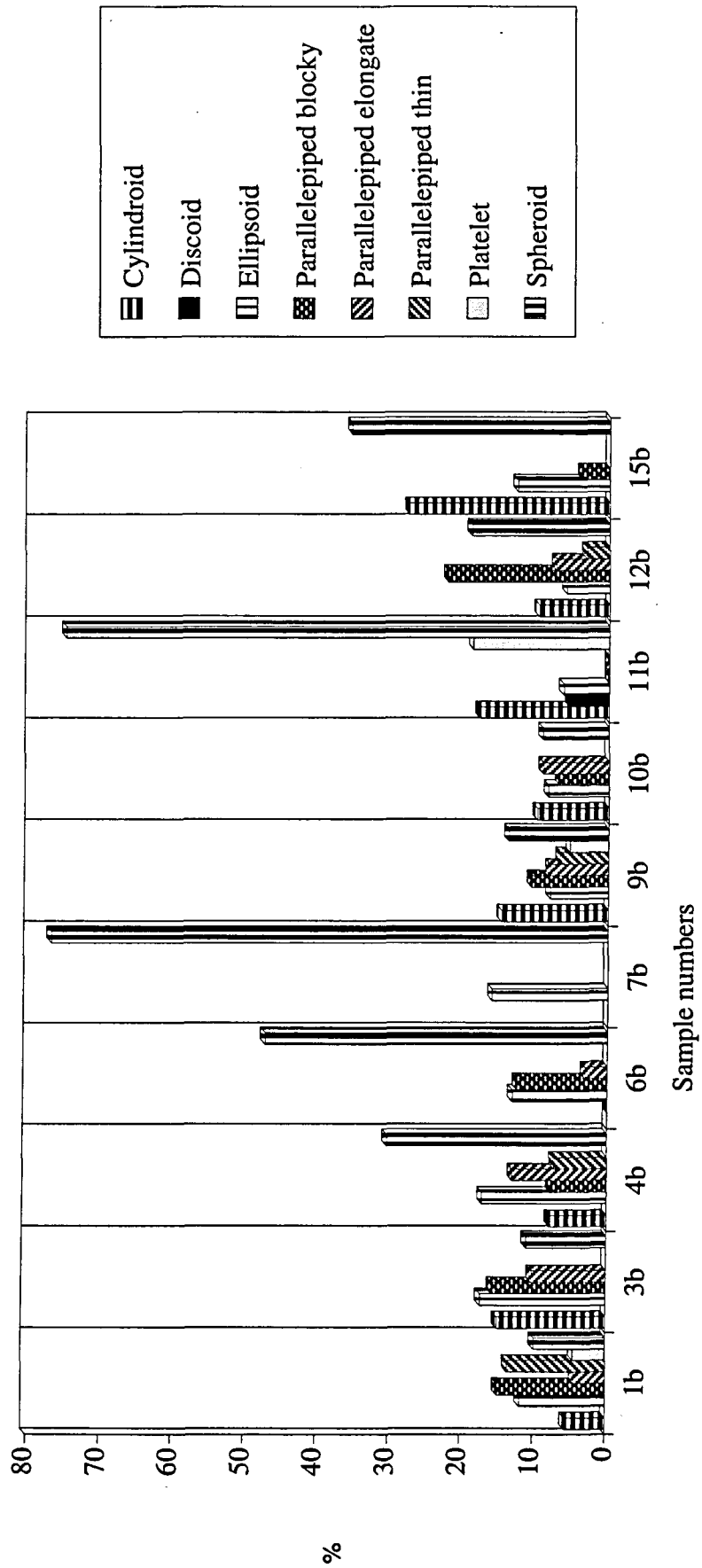

Figure 11 - Morphological results of phytoliths with consistent morphology from bark of woody dicotyledons and gymnosperms from the modern plant reference collection (percent).

The fact that so few phytolith types are present in bark limits the possibility of using them to identify the species of trees used for fuel for fires. If, however, under certain circumstances, wood and bark from mainly one species was used for fuel, then following Table 7 and Figure 11, absences of certain phytoliths types, or characteristic relative proportions, could be used for taxonomic identification. In general, however, we do not think that this will be possible for most archaeological samples.

Another difficulty arises from the enormous range in the amount of consistent morphology phytoliths present in the original wood/bark of the different species of trees analyzed (Table 8). The range is from 2,000 phytoliths/kg wood/bark to 1,231,000 phytoliths/kg. The most striking result is that of *Quercus calliprinos* (Kermes oak). Table 8 shows that per 1 kg of wood/bark burned there are 1.2 million phytoliths. This implies that, even if the bark/wood of *Quercus calliprinos* were used in a hearth in rather small quantities, this species would dominate the phytolith record. This is consistent with our results obtained through the morphological analyses of phytoliths of the samples analyzed for Tabun.

Name	*Initial weight (IW) 80:20*	*# Phytoliths IW*	*# Phyt. Consistent morphology IW*	*# phyt.consistent morphology (Wood/bark) IW*	*# Phyt. consistent morphology in 1kg of material*
Amygdalus communis (9)					
wood	212.6	1,500	100	23,000	**wood/bark 108,000**
bark	53.1	83,500	23,000		
Ceratonia siliqua (3)					
wood	286.9	9,800	50	78,000	**wood/bark 272,000**
bark	71.7	158,900	78,000		
Crataegus aronia (11)					
wood	161.7	1,200	300	70,000	**wood/bark 433,000**
bark	40.4	300,400	69,700		
Cupresus sempervirens (10)					
wood	197.4	1,600	0	65,300	**wood/bark 331,000**
bark	49.3	141,100	65,300		
Laurus nobilis (19)					
wood	152.2	5,200	1,500	3,000	**wood/bark 20,000**
bark	38.0	3,400	1,100		
Olea europaea (8)					
wood	348.5	7,000	300	700	**wood/bark 2,000**
bark	87.1	3,800	400		
Pinus halepensis (7)					
wood	187.9	2,500	600	14,000	**wood/bark 75,000**
bark	47.0	18,200	13,800		
Pistacia palaestina (4)					
wood	255.4	900	200	2,000	**wood/bark 8,000**
bark	63.9	4,500	2,100		
Quercus calliprinos (1)					
wood	109.7	3,800	700	135,000	**wood/bark 1,231,000**
bark	27.4	261,000	134,400		
Quercus ithaburensis (6)					
wood	197.8	32,000	5,900	21,000	**wood/bark 106,000**
bark	49.4	26,700	14,800		
Salix acmophylla (15)					
wood	145.3	800	100	9,000	**wood/bark 62,000**
bark	36.3	32,100	8,900		
Styrax officinalis (11)					
wood	154.6	400	100	9,000	**wood/bark 58,000**
bark	38.7	15,500	8,500		
Ziziphus spina-christy (2)					
wood	284.4	11,200	2,600	60,000	**wood/bark 211,000**
bark	71.1	118,500	57,800		

Table 8 - Plant reference collection. Number of phytoliths with consistent morphology in 1 Kg of wood 80/bark 20.

At present, *Quercus calliprinos* (Kermes oak) together with *Quercus ithaburensis* (Tabor oak) are the most common tree species in the area of Kebara and Tabun caves. The preliminary results obtained through the charcoal analyses of Kebara by Baruch, Werker & Bar-Yosef (1992) showed the presence of these two species as the most abundant in the archaeological record. Therefore, it is possible that the inhabitants of both Kebara and Tabun caves, would use oak for their fires.

During the microscopic analyses of the wood and bark of woody dicotyledons and gymnosperms, elongated forms with smooth surface and a distinct green color in wood and bark were observed (Figure 10f). Some of these forms sometimes appeared to be closely associated with phytoliths. Their refractive indices were different from those of silica phytoliths and none of these forms were observed in fossil samples. We therefore do not regard them as phytoliths and did not include them in the phytolith analyses.

The results of the morphological analyses of phytoliths with consistent morphology from leaves of woody dicotyledons and gymnosperms, are shown in Table

9. To facilitate the analysis of the most common forms, phytoliths with psilate and scabrate surface were grouped together, the morphological types below 3% representation and the forms that appear only in 1 species were removed. The distribution of the phytolith is also presented in Figure 12. Phytoliths with morphologies characteristic of grasses present in the original results (Table 5c) almost disappeared due to their low number, except for the short cells, that are present in 3 of the 12 species analyzed. The type that seems to be more characteristic of leaves is the tracheary form (Figure 10g). Unfortunately, these forms are not very common in this archaeological record, possibly because they are not well preserved in these sediments. Silica skeletons polyhedrals (Figure 10h) and silica skeletons spheroid/ellipsoids (Figure 10i) are also common in leaves. The needle phytoliths of *Pinus* (pine) have different morphologies from the rest of the genera. Phytoliths from pine are mostly elongated forms (cylindroids or parallelepipeds) and many of them are bulbous and very smooth (Figure 10j). Spheroids are also very common. In contrast to the leaves of the woody dicotyledons, tracheary elements and silica skeletons are almost totally absent from the two angiosperm species (*Pinus halepensis* & *Cupressus sempervirens*) (Aleppo pine and Cypress respectively) (Figure 12 & Tables 5d & 9).

Woody dycotiledons & Gymnosperms																								
LEAVES																								
Name See Table 1 for key number	*1c*		*3c*		*4c*		*6c*		*7c*		*8c*		*9c*		*10c*		*11c*		*12c*		*15c*		*19c*	
Consistent morphologies	Sum	%	Sum	%	Sum	%	Sum	%	Sum	%	Sum	%	Sum	%	Sum	%	Sum	%	Sum	%	Sum	%	Sum	%
C p Bu	71	8.3					13	3.3	148	23.2														
C									21	3.3					6	7.4					54	19.1		
E	31	3.6	13	3.9	10	5.1	44	11.2	64	10.0	14	4.1			15	18.5	11	6.1	8	5.8				
F	98	11.4	57	17.2	11	5.6	42	10.7			18	5.2	19	4.1										
P El	44	5.1	12	3.6			31	7.9	160	25.1									38	27.3				
S					81	41.3																	25	6.7
ShC															4	4.9	14	7.8	11	7.9				
Sp	249	29.1	24	7.2	11	5.6	32	8.1	67	10.5					53	65.4	10	5.6					78	21.0
SS JS/Ph/Sp/E	46	5.4	62	18.7	5	2.6	44	11.2			33	9.6	146	31.4			10	5.6			145	51.2	22	5.9
SS sl							12	3.0			94	27.4	82	17.6			14	7.8			42	14.8	70	18.9
T	261	30.5	140	42.2	18	9.2	102	25.9			147	42.9	183	39.4			108	60.3	9	6.5	20	7.1	148	39.9
Total	**800**		**308**		**136**		**320**		**460**		**306**		**430**		**78**		**167**		**66**		**261**		**343**	

Table 9 - Plant reference collection. Phytolith morphological results from leaves of trees grouping surfaces psilate/scabrate, eliminating morphologies below 3% and forms that appear in 1 specie.

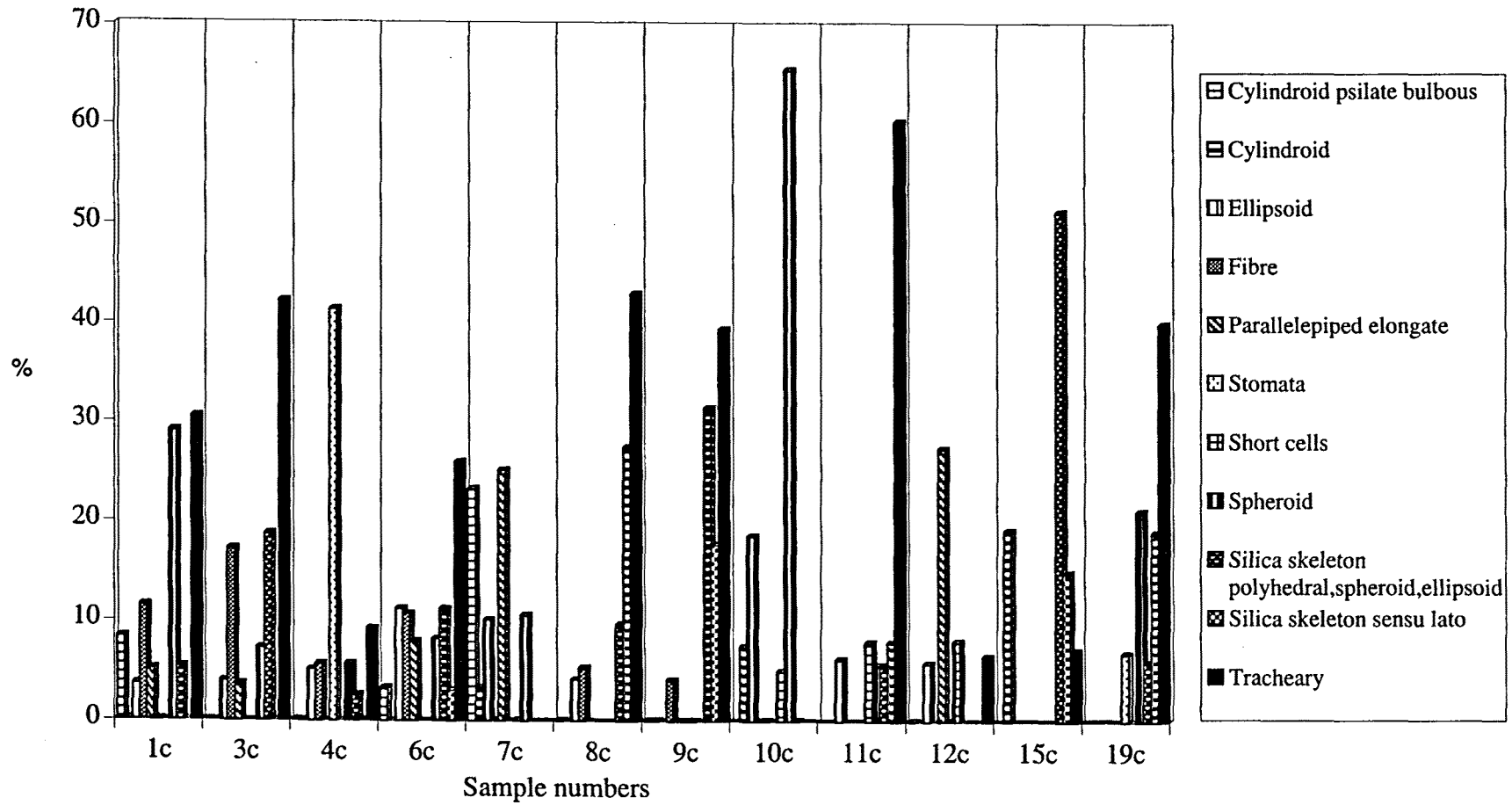

Figure 12 - Morphological results of phytoliths with consistent morphology from leaves of woody dicotyledons and gymnosperms from the modern plant reference collection (percent).

In summary, the phytoliths with consistent morphology characteristic of leaves of woody dicotyledons, are the tracheary elements and silica skeletons, mainly with polyhedral and spheroid/ellipsoid forms. This is not the case for the gymnosperm group where these forms are practically absent (Table 5c). Ellipsoid and spheroid forms are also common, although in lower quantities as compared to the bark of the same trees (Figure 12).

Table 10 shows the results of the morphological analyses of phytoliths with consistent morphologies from fruits of woody dicotyledons and gymnosperms. In general not many phytoliths were recovered. Only *Quercus ithaburensis* (Tabor oak) and *Pinus halepensis* (Aleppo pine) have large amounts of phytoliths. Once more, spheroids are the most common forms represented in all the samples (Figure 13). Ellipsoid forms are also very common. Platelets are characteristic of pine, constituting more than 50% of the total. Phytoliths with morphologies characteristic of grasses are only present in the husk (inner and outer) of *Amygdalus communis* (almond). Especially characteristic is the presence of long cells polylobate, in the inner husk, with more than 25% of the total. These forms are distinctively long and smooth (Figure 10k).

Woody dycotiledons & Gymnosperms												
FRUITS/SEEDS, ETC.												
Name See Table 1 for key number	*3d*		*6e*		*6f*		*7d*		*9e*		*9f*	
Consistent morphologies	*Sum*	*%*	*Sum*	*%*	*Sum*	*%*	*Sum*	*%*	*Sum*	*%*	*Sum*	*%*
C p Bu							20	5.4				
C					59	7.5						
E	19	25.0	15	18.8	155	19.8	36	9.8	36	18.6	35	25.0
LC									15	7.7		
LC PO									51	26.3	9	6.4
P Bk					128	16.3					18	12.9
P El	7	9.2										
PL							200	54.5				
ShC									16	8.2	13	9.3
Sp	43	56.6	55	68.8	294	37.5	93	25.3	32	16.5	31	22.1
TOTAL	**69**		**70**		**636**		**349**		**150**		**106**	

Table 10 - Plant reference collection. Phytolith morphological results from fruits of trees grouping surfaces psilate/scabrate and eliminating morphologies below 5%.

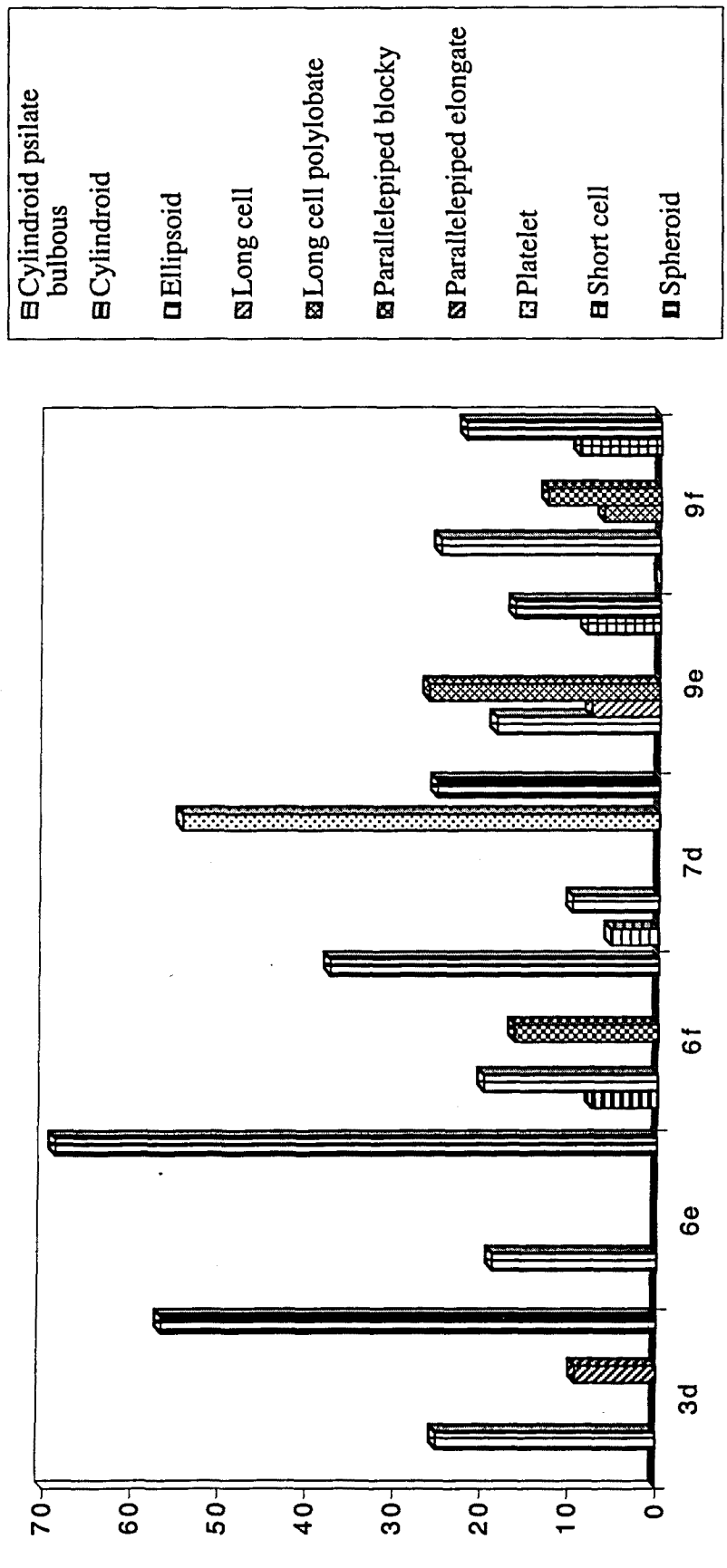

Figure 13 - Morphological results of phytoliths with consistent morphology from fruits of woody dicotyledons and gymnosperms from the modern plant reference collection (percent).

The morphological counts of phytoliths with consistent morphologies from herbaceous dicotyledons are shown in Table 11 and the distribution of the different morphologies in the species analyzed in Figure 14. The results show that there is a large variability of forms between species. However, phytoliths are not very abundant in herbaceous dicotyledons and inside different species there is a low variability of forms represented. From the Leguminoseae family only *Lens orientalis* (Lentil) has sufficient phytoliths to study the morphological characteristics. This species is represented only by cylindroid forms and tracheary elements, which would make its identification in the archaeological record difficult. Geis (1973), Koeppen (1980) and Piperno (1988) already observed the low amount of phytoliths recovered from this family. On the other hand, the presence (68%) of a very specific type of hair (named *foeniculum* type) identified in *Foeniculum vulgare* (fennel) (Figure 10l), and the fiber net type observed in *Linum pubescens* (Flax) (50%) (Figure 4d) could characterize these two species.

HERBACEOUS DICOTYLEDONS														
Name See Table 1 for key number	*21*		*22*		*24*		*25*		*27*		*28*		*30*	
Consistent morphologies	**Sum**	**%**	**Sum**	**%**	**Sum**	**%**	*Sum*	*%*	**Sum**	**%**	**Sum**	**%**	**Sum**	**%**
C									16	25.0			111	61.0
E	12	9.2					33	35.1						
EA H f	89	67.9												
EA H			14	10.6										
F l			68	51.5										
LC									5	7.8				
P Bk							9	9.6						
P El							5	5.3	4	6.3				
S					178	72.4								
ShC									19	29.7				
Sp	16	12.2					31	33.0	12	18.8				
SS sl			8	6.1							88	44.0		
SS Ph/Sp/E			17	12.9	25	10.2								
T					31	12.6					94	47.0	52	28.6
Total	**117**		**107**		**234**		**78**		**56**		**182**		**163**	

Table 11 - Plant reference collection. Phytolith morphological results from herbaceous dicotyledons grouping surfaces psilate/scabrate and eliminating morphologies below 5%.

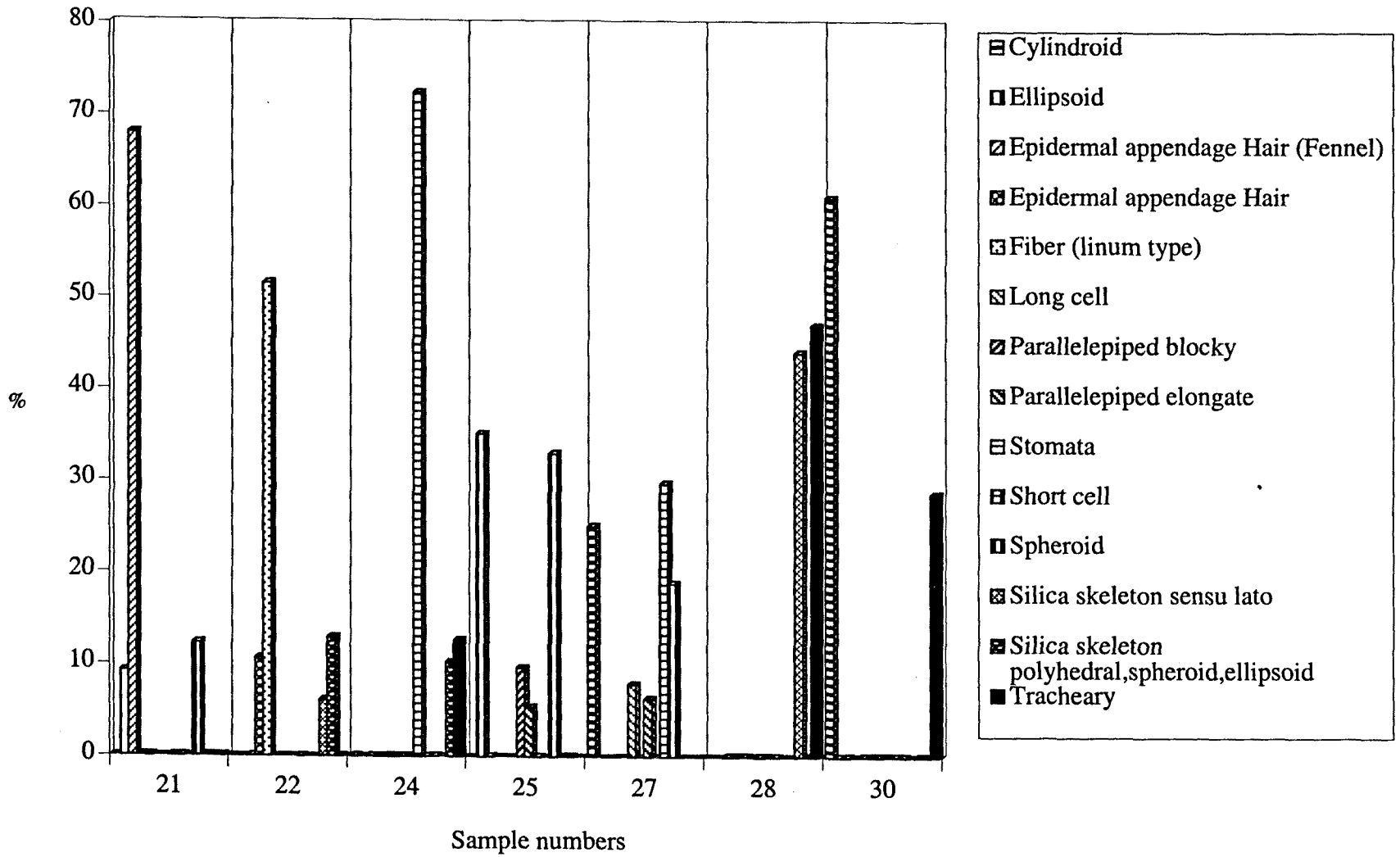

Figure 14 - Morphological results of phytoliths with consistent morphology from herbaceous dicotyledons from the modern plant reference collection (percent).

Phytoliths with consistent morphology from grasses were also analyzed. Table 12 shows the results obtained after removing forms present in less than 4%. In figure 15 it can be observed that there is homogeneity among samples 16, 17 and 18 (cereals) and they are different from sample 13 (*Arundo donax*), which is a reed. *Hordeum* (barley) and *triticum* (wheat) show the same phytolith types but with variations in the proportions. Echinate long cells and short cells are most common. Hairs and papillae, which are epidermal appendages are also present in these samples. On the other hand, the phytolith morphology in *Arundo donax* (Reed) is characterized by bilobates (Figure 16a), long cells with psilate surface, silica skeletons with a wavy margin (Figure 16b) and bulliforms (Figure 16c). The presence of bilobates forms in the reed is consistent with this grass belonging to the panicoid group. Panicoids grasses are characterized by the presence of bilobates forms (Mulholland & Rapp, 1992b; Twiss, Suess & Smith, 1969; Twiss, 1992). Epidermal appendages are absent from these samples. It should be noted that the study of grasses in this work was carried out primarily for comparing to those in woody dicotyledons and gymnosperms with respect to the same characteristics. No attempt was made to perform a full study.

GRASSES								
Name (See Table 1 for key number)	**16**		**17**		**18**		***13***	
Consistent morphology	**Sum**	**%**	**Sum**	**%**	**Sum**	**%**	**Sum**	**%**
EA H	23	10.8	19	10.3	35	18.1		
EA PA	32	15.0	17	9.2	27	14.0		
LC e	74	34.7	36	19.5	64	33.2		
LC p							176	13.6
ShC Bi							524	40.5
ShC	36	16.9	62	33.5	36	18.7	224	17.3
SS LC p	13	6.1	9	4.9	8	4.1		
SS LC w	10	4.7	38	20.5	14	7.3	172	13.3
Total	**188**		**181**		**184**		**1096**	

Table 12 - Plant reference collection. Phytolith morphological results from grasses, eliminating morphologies below 4%.

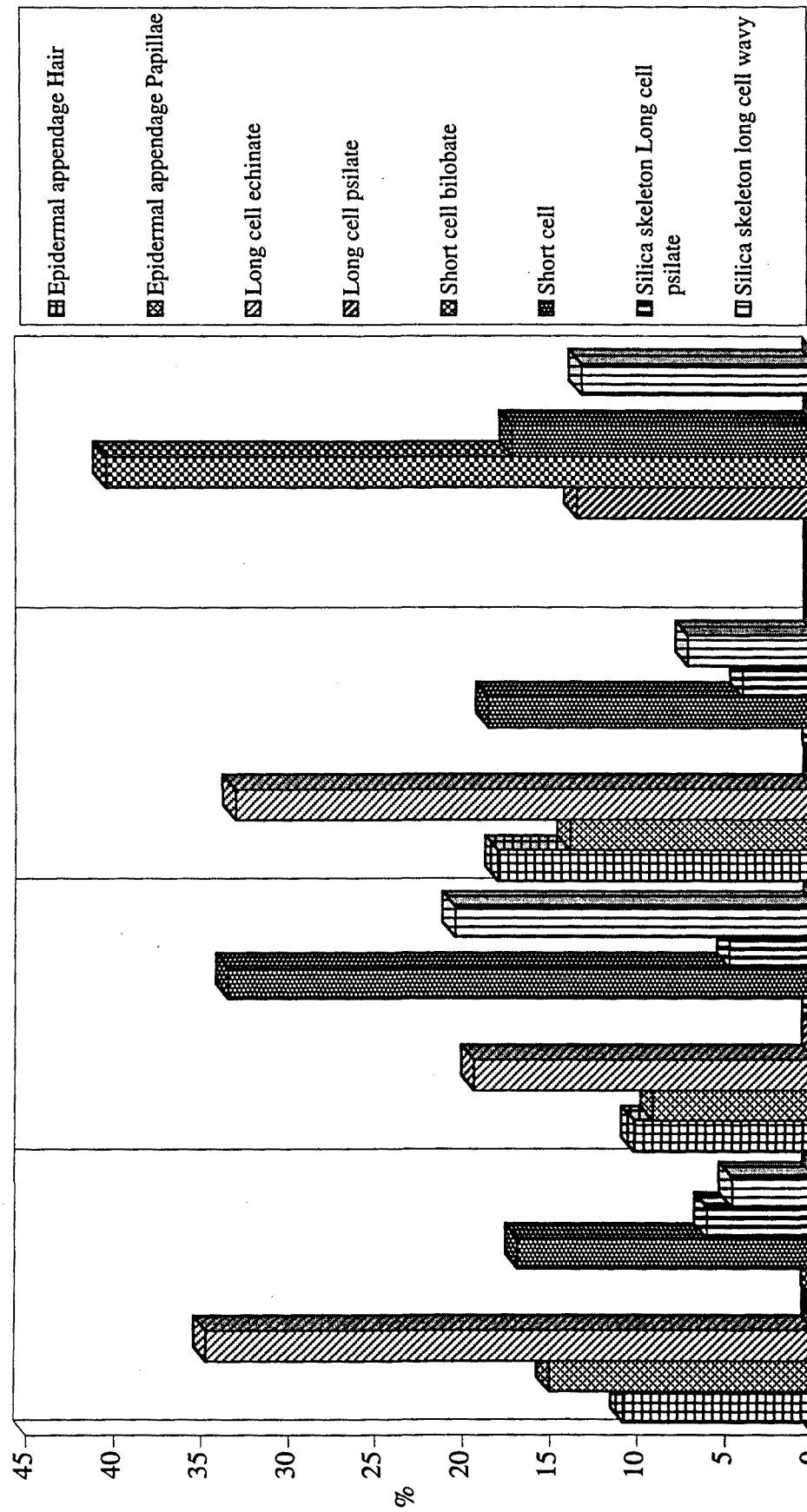

Figure 15 - Morphological results of phytoliths with consistent morphology from grasses from the modern plant reference collection (percent).

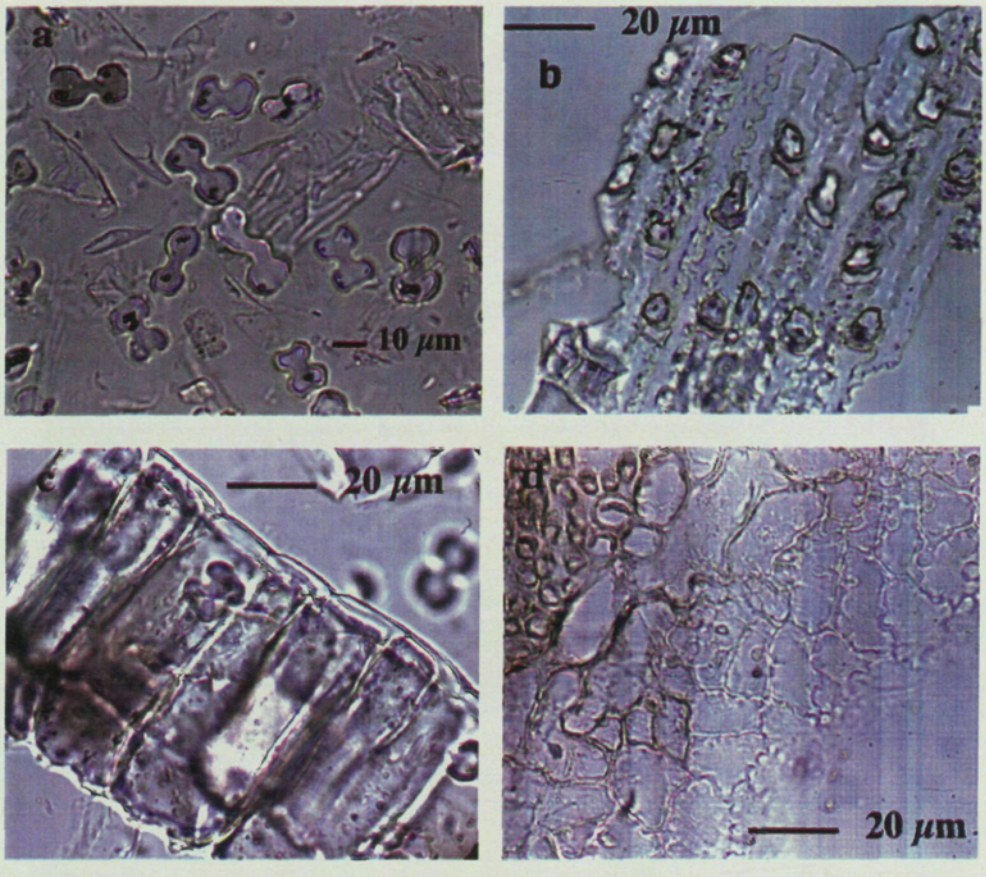

Figure 16 - Photomicrographs of phytoliths. Pictures taken at 400x. a)-c) Arundo donax (Reed). a) Short cells bilobate from the leaves. b) Silica skeleton long cells with wavy margin and short cells from the stem. c) Bulliform cells from the leaves. d) Thick section from the leaves of *Quercus calliprinos* with the epidermal cells with polyhedral and jigsaw forms.

B) Discussion

The phytolith analyses of the reference collection of modern plants from the Mount Carmel area, indicates that there is a big variety in the production of phytoliths, relating to the different species and within this relating to the different parts of the species analyzed (e.g. wood, bark, leaves, etc.). The largest difference observed is between wood and bark of woody dicotyledons and gymnosperms and the grass family. According to our results grasses produce about 20 times more phytoliths than wood and bark. These results are consistent with those obtained by Wilding & Drees (1971). This difference in the production of phytoliths must be taken into account when analyzing archaeological samples (Albert & Weiner, 1999).

The difference observed between wood and bark from dicotyledons and gymnosperms and the grass family is also evident when analyzing the ratio of variable and consistent morphology phytoliths. Wood and bark produce mainly phytoliths with variable morphology, while grasses produce almost exclusively phytoliths with

consistent morphology. Leaves of woody dicotyledons also show a very low ratio, with a much higher percentage of phytoliths with consistent morphology.

Phytoliths with consistent morphology from the wood of woody dicotyledons and gymnosperms could not be analyzed due to their very low concentrations. Phytoliths with consistent morphology from bark do not have a large variability, being very similar in all the species analyzed, and with a predominance of spheroid and ellipsoid forms. These results are consistent with the ones obtained by Amos (1952), Scurfield, Anderson & Segnit (1974), Ter-Welle (1976a,b), Espinoza (1987) and Carlsquit (1988). In general, the small amount of phytoliths with consistent morphology present in wood and bark, and the fact that the same forms repeat in most of the species analyzed, indicates that wood and bark are not taxonomically representative. However, the large presence of variable morphology phytoliths together with an abundant presence of spheroids and ellipsoids forms can help to identify the use of these part of the trees as fuel in archaeological hearths.

Phytoliths from leaves produce quite distinctive morphologies that make them identifiable from other parts of the plant and other plant taxa. Their taxonomic

significance lies in the presence of silica skeletons polyhedral, silica skeletons spheroid/ellipsoid, hair, hair bases, etc. In our reference collection phytoliths from leaves are morphologically dominated by tracheary elements, silica skeleton polyhedral and silica skeleton spheroid/ellipsoid. Spheroids and ellipsoid forms are also present although in smaller numbers than in wood and bark. Other identified forms were honeycombed assemblages (spheroids, elongates and polyhedral). Although Geis (1973) and Bozarth (1992) noted the presence of tracheary elements both in arboreal and herbaceous dicotyledons, these were not as abundant as in our samples. It is important to note, the absence, in our samples of the silica skeletons jigsaw puzzle (Bozarth, 1992) or anticlinal (Piperno, 1988). These phytoliths are produced in many deciduous tree leaves (Bozarth, 1992; Geis, 1973) and have wavy undulating walls. Geis (1973) suggests that jigsaw puzzle types are most common in mesophytic deciduous forests with wetter conditions. In our samples, these forms, although not silicified, were observed in the thick sections of leaves of *Quercus calliprinos* (Kermes oak) (Figure 16d). Therefore, it seems that silica skeletons jigsaw puzzle do indeed silicify after other forms, like silica skeletons polyhedral, have been silicified. However it has to be taken into account that *Quercus calliprinos* (Kermes oak) is not a deciduous tree and the leaves can live for several years. Therefore the presence of jigsaw puzzle could be due to the

accumulation of silica during the years, and not to wetter conditions to silicify as Geis (1973) already noted. These forms were observed in some of the archaeological samples from Kebara.

Our analyses of the needles of the Pinaceae differ from earlier investigations. The amount of silica observed in our reference collection is much higher than that obtained by others (Klein & Geis, 1978; Hodson, Williams & Sangster, 1997; Sangster, Williams & Hodson, 1997). However it has to be taken into account that, as Hodson, Williams & Sangster (1997) and Sangster, Williams & Hodson (1997) pointed out, gymnosperm needles are unusual since they remain on the tree for many years, and silica deposition increases with needle age. They also noted pronounced differences in deposition depending on the site. Therefore it is quite possible that our sample was composed of quite old needles that accumulated silica for several years. More samples from this family need to be studied in the Mt. Carmel area.

In relation to the morphology of the phytoliths identified in the needles of *Pinus halepensis* (Aleppo pine), we did not observe the characteristic tracheids (tracheary

elements with bordered pit impressions and tapering) noted by Klein & Geiss (1978), Hodson, Williams & Sangster (1997) and Sangster. Williams & Hodson (1997). However, we did observe elongate smooth forms and spheroid smooth forms, which were quite abundant in consistence with the results obtained by (Klein & Geiss, 1978; Bozarth, 1993). Klein and Geis (1978) suggest that the wide occurrence of these spheres is a common pattern of lumen infilling in taxonomically diverse plant material.

Phytoliths with consistent morphology from fruits and herbaceous dicotyledons are not very abundant and have no special characteristics apart from certain species like fennel and flax. These results are consistent with those obtained by Rovner (1971) who identified mainly rods, irregular fragments and spheroids, globules, etc.