UNIVERSITY OF ALBERTA

RECONSTRUCTION OF ENVIRONMENT IN EARLY BRONZE AGE SYRIA THROUGH PHYTOLITH ANALYSIS ON HUMAN DENTAL CALCULUS

by

SARAH CATHERINE WALSHAW ©

A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfillment of the requirements for the degree of MASTER OF ARTS.

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ABSTRACT

Aridification leading to crop failure has recently been hypothesized to explain the collapse of the Akkadian Empire in ancient Mesopotamia (~2300 and 2200 B.C.). Phytoliths from the dental calculus of 17 human skeletons excavated from Tell Leilan in northern Syria were investigated to test whether a change in floral dietary resources accompanied site abandonment. Multicelled phytoliths from Period III individuals (3000-2400 B.C.) were larger and more abundant than those from Period VI (5000-4100 B.C.) and Period II (2400-2200 B.C.) individuals. This increase in silicification during Period III signals the presence of humid growing conditions, while smaller phytoliths and reduced abundance during Period VI, and especially Period II, indicate that arid conditions prevailed. One adult female in Period III possessed remarkably large multicelled phytoliths; she probably had access to the irrigated cultigens grown in Southern Mesopotamia. Phytolith evidence supports the aridification hypothesis for the abandonment of Tell Leilan at 2200 B.C.

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CHAPTER 1. INTRODUCTION

1.1 INTRODUCTION

This thesis examines the diet of ancient Akkadians at Tell Leilan, Syria, using phytolith analysis, to test Weiss' hypothesis (1993; Weiss and Courty, 1993;Weiss *et al.*, 1993; Wright, 1998) that climate degradation was responsible for the abandonment of Tell Leilan between 2200 and 1900 B.C.. This chapter will introduce the reader to the Tell Leilan problem and the tenets of Weiss' hypothesis in order to provide a contextual background for this research.

1.2 EARLY BRONZE AGE MESOPOTAMIA AND TELL LEILAN

In the 3rd millennium B.C., the "Fertile Crescent" of ancient Syria and Iraq (see Figure 1.1) known as Mesopotamia supported sedentary farming communities with complex cultures and economies (Roux, 1992). Throughout much of its history Mesopotamia was divided into two halves, north (Subir) and south (Sumer), based on differences in language, geography, cultural spheres of influence and the use of irrigation. The northern plains received sufficient rainfall to sustain dry farming, while the parched south was fed through irrigation drawn from the Euphrates (Weiss, 1986a). The majority of Mesopotamian empires thrived first in the south, reaching the north only through long term residence and slow invasion (Weiss, 1983); trade routes were established early in the Copper Age, reinforcing ties between the two domains, but unification was a rare event (Crawford, 1991). The Akkadian Empire (~2300-2200 BC), established in 2317 B.C. by Sargon of Akkad, was the first to unite the south and the north (Liverani, 1993) and his legacy lives on in the literature of the time, which documents his triumphs as a conqueror of lands and people (Crawford, 1991). It is the demise of this powerful but short-lived empire that is the focus of this thesis.

Tell Leilan was an agricultural city on the northern plains of the Habur River, an eastern tributary of the Euphrates in present day Syria. It was already a well established Early Bronze Age city when the Akkadian Empire took over (Weiss, 1986b). The city itself as well as the surrounding agricultural villages experienced substantial and rapid population growth during the Ninevite V urbanization period (2600-2400 B.C., Tell Leilan IIId).

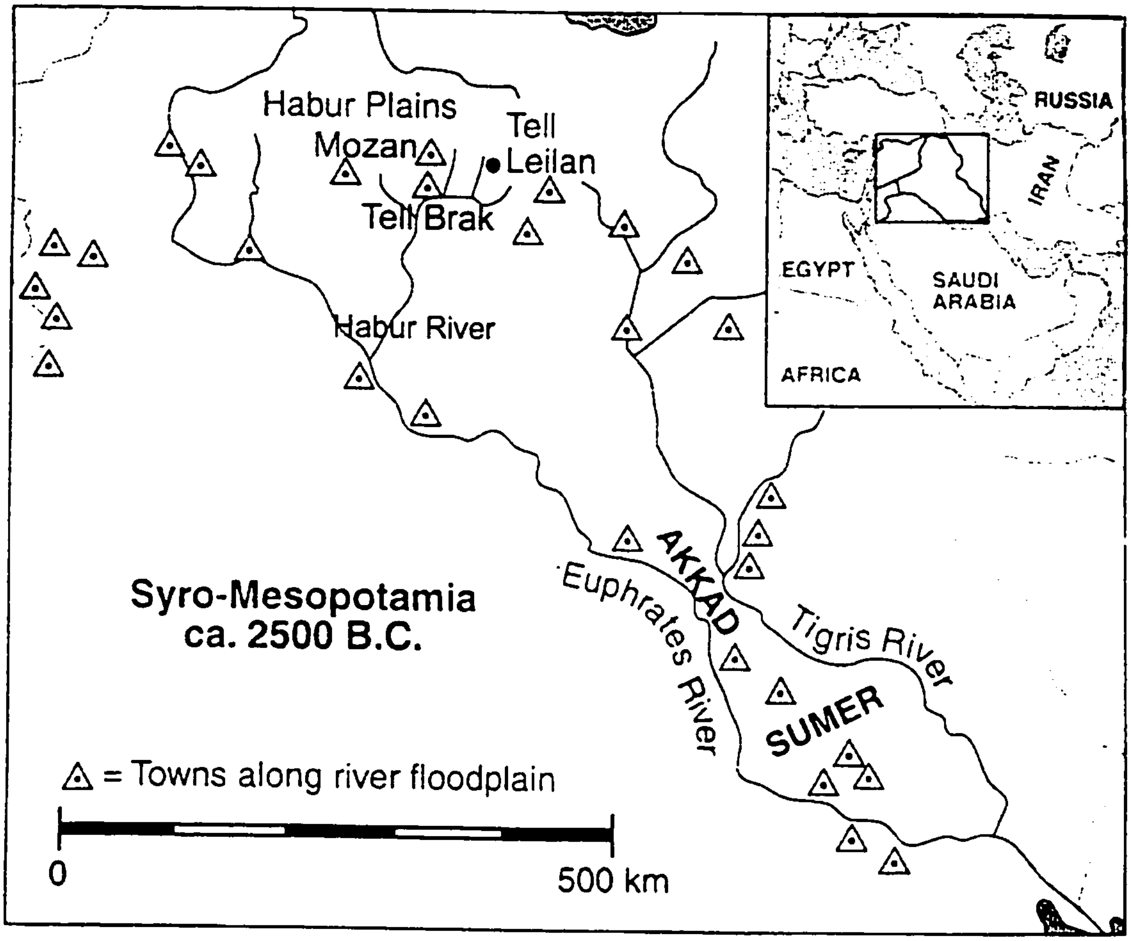

Figure 1.1 Map of Syro-Mesopotamia at 2500 B.C. showing location of Tell Leilan and the Habur plains (Habur River is the right-hand tributary branching off the Euphrates). Adapted from Gibbons (1993:985).

Most villages doubled in size, while Tell Leilan increased from 15 hectares to more than 90 hectares by 2400 BC, making it the largest urban centre on the Habur plains (Stein and Wattenmaker, 1990).

By the time of the Urban phase (2400-2200 B.C., Tell Leilan II), Tell Leilan was a major textiles centre through ovid pastoralism, and supported an agricultural subsistence base that included two-row barley (*Hordeum distichon*), emmer wheat (*Triticum dicoccum*), durum wheat (*T. durum*), and lentils (*Lens culunaris*) (Wetterstrom, n.d.a). Harvested crops were collected and redistributed through the complex Akkadian administration system, and pottery was mass-produced and used to distribute workers' rations of grain and oil (Wetterstrom, n.d.b). A massive city wall was erected between 2300 and 2200 B.C., with two concentric 8m thick mud brick walls protecting the inhabitants from outside intruders (Weiss and Courty, 1993;Weiss *et al.*, 1993). Thus, both archaeological and textual data sources reveal that by 2300 B.C. Tell Leilan boasted a "thriving imperial economy sustaining long-distance trade and construction of monumental buildings and massive agricultural projects" (Weiss *et al.*, 1993:999).

At approximately 2190 B.C., the Akkadian empire dissolved and Tell Leilan was abandoned: the entire city, and much of its neighbouring population, moved south, an event attested to both in archaeological and historic records (Weiss, 1993; Weiss and Courty, 1993). The large size and apparent stability of Tell Leilan during the Urban Period (Tell Leilan II, 2400-2200 B.C.) makes its sudden depopulation (Habur Hiatus I, 2100-1900 B.C.) all the more surprising to excavator Harvey Weiss of Yale University and colleagues (Weiss *et al.*, 1993). Habur hiatus I deposits at Tell Leilan are more than half a meter thick and are completely devoid of any cultural features, topped by the sudden appearance of Leilan Period I cultural materials dated to approximately 1900 BC.

1.3 The Environmental Degradation Hypothesis

Weiss (1986b, 1993; Weiss and Courty, 1993; Weiss *et al.*, 1993; Wright, 1998) blames drought resulting from high dust storm activity for this episode of cultural sterility, in a hypothesis referred to as the 'Environmental Degradation Hypothesis'. Geoarchaeologist Marie-Agnes Courty (1994; Weiss *et al.*, 1993) found evidence of an increase in wind-blown sediments at Tell Leilan and also high sediment loads in the Habur River beginning before the establishment of the Akkadian Empire. However, regional evidence from lake cores suggests that this storm period was just a stage in an overall aridification which took place after the Holocene thermal maximum at approximately 6,000 B.P. (e.g., Hotzl and Zotl, 1978; Kayan, 1999; Kelts and Shahrabi, 1986; Nutzel, 1976; Schyfsma, 1978; Van Zeist and Bottema, 1982; Wilkinson, 1999). Global signals have not detected the dust storm activity, but this is not surprising considering the spatial and temporal limitation of this climatic event (e.g., Stager and Mayewski, 1997).

The Environmental Degradation Hypothesis contradicts the common socio-political reasons cited for the fall of the Akkadian empire (e.g., Adams, 1981; Roux, 1992; Tainter, 1988; Yoffee, 1988). Most scholars have downplayed the "abandonment crisis" that Weiss postulates, and minimise the contemporaneity of the collapse of the other Old World cultures (e.g., Adams, 1981), leaving Weiss to defend his hypothesis in the face of the standard political explanations for culture collapse and change in Mesopotamia (Weiss, 1986b). My master's thesis is dedicated to testing the Environmental Degradation Hypothesis, using phytoliths recovered from human dental calculus to reconstruct diet in the three thousand years prior to the abandonment of Tell Leilan. My goal is to determine if a change in phytoliths accompanies or precedes the abandonment of Tell Leilan at 2200 B.C..

1.4 Phytolith Analysis and the Reconstruction of Ancient Akkadian Diet

Phytoliths are biogenic accumulations of hydrated opaline silica ($SiO_2 \cdot nH_2O$) in plants, which survive post-mortem organic decomposition. Because the silica from groundwater sources invades and eventually fills in a cell, phytoliths mimic original cell shapes and can be identified and classified according to size, surface ornamentation and shape (Pearsall and Dinan, 1992). Phytoliths have traditionally been used to reconstruct palaeodiet and palaeoenvironment, and are especially valued for their use in viewing the domestication of cereals, maize, beans and squashes, particularly in alkaline soil environments where pollen and macrobotanicals are poorly preserved (Piperno and Pearsall, 1998).

Phytolith analysts working on cereal agriculture have generated ways to differentiate between wild and domestic species (Ball *et al.*, 1996; Kaplan *et al.*, 1992; Rosen, 1992), and Rosen and Weiner (1994) have developed a way of determining ancient irrigation practices using multi-celled phytolith abundance statistics. When plants are grown in environments with plentiful water supplies, their phytoliths are more abundant, and appear more commonly in groups called "multi-celled phytoliths" than when plants are deprived of water.

Weiss' Environmental Degradation hypothesis for the abandonment of Tell Leilan presents an intriguing archaeological problem that can be tested using phytolith analysis. Macrobotanical investigations from the Tell Leilan samples have been carried out by Wetterstrom (Wetterstrom n.d.a, n.d.b), making available data regarding the presence of expected wild and domesticated plants I have obtained burial soil samples and human dental calculus samples from the Tell Leilan skeletal collection, curated by Dr. Nancy Lovell at the University of Alberta. The samples are from Periods II, III and VI, representing most of the three thousand years immediately preceding the population abandonment. By analyzing the phytoliths from these samples I will examine the variety and relative abundance of plant types consumed in the diet. Additionally, I will examine the cereal phytoliths in detail to examine shifts in cultigen dependence, if any. By reconstructing plant resource exploitation among the inhabitants of Tell Leilan prior to migration, I intend to investigate whether there existed a real or emically perceived environmental stimulus to abandon a thriving city of the Akkadian Empire at 4200 B.P.

CHAPTER 2. INTRODUCTION TO MESOPOTAMIAN CULTURE HISTORY AND THE ARCHAEOLOGY OF TELL LEILAN, SYRIA

2.1 LOCATION AND SETTING

Mesopotamia is geographically defined as a region of the Near East encompassing the floodplains of the Tigris and Euphrates north to Anatolia (southern Turkey) (Boren, 1976:23). Tell Leilan (see Figure 2.1) resides beside the Jarrah drainage system of the low altitude floodplains of the Habur River, a tributary of the Euphrates. Although the Habur river is presently insufficient to support irrigation[1], the average annual precipitation (450 mm/yr) received by this area is adequate to allow dry farming and satisfies the grazing requirements of ovid pastoralism (Akkermans, 1989). Tell Leilan boasts shallow but well drained Mediterranean red and brown alluvial soils, whose fertility is attested to by the fact that this region today supplies 25% of Syria's annual crop yields (Weiss, 1985). The modern vegetation is representative of steppe and steppe-forest environments, characterised by sagebrush (*Artemesia herba-alpa*), Chenopodiaceae, oak (*Quercus*) and pistachio (*Pistacia*) (Zohary, 1973), with cereals such as two-rowed barley (*Hordeum distichon*) and emmer wheat (*Triticum dicoccum*) commonly cultivated.

The Near East experiences a Mediterranean climatic regime, with moist winters and dry summers (van Zeist, 1969). The Habur triangle is fertile not only because of the high mean annual rainfall levels, but also because of the low (34%) interannual variability of rainfall, which means that the timing and volume of rainfalls is fairly predictable (Weiss *et al.*, 1990). Reliance upon dry farming in the north meant that crops were particularly sensitive to alterations in climate, especially in terms of the amount and timing of the winter rains and the intensity of summer insolation.

Mesopotamia can be divided into northern and southern halves on the basis of geography and rainfall: the north receives over 250mm of rain annually, supporting dry agriculture, whereas the drier south has larger rivers that support irrigation and transportation (Weiss, 1986a, 1990). This 200-250 mm threshold for annual rainfall decides

[1] average flow is $50m^3/s$, compared with the Euphrates at $840m^3/s$

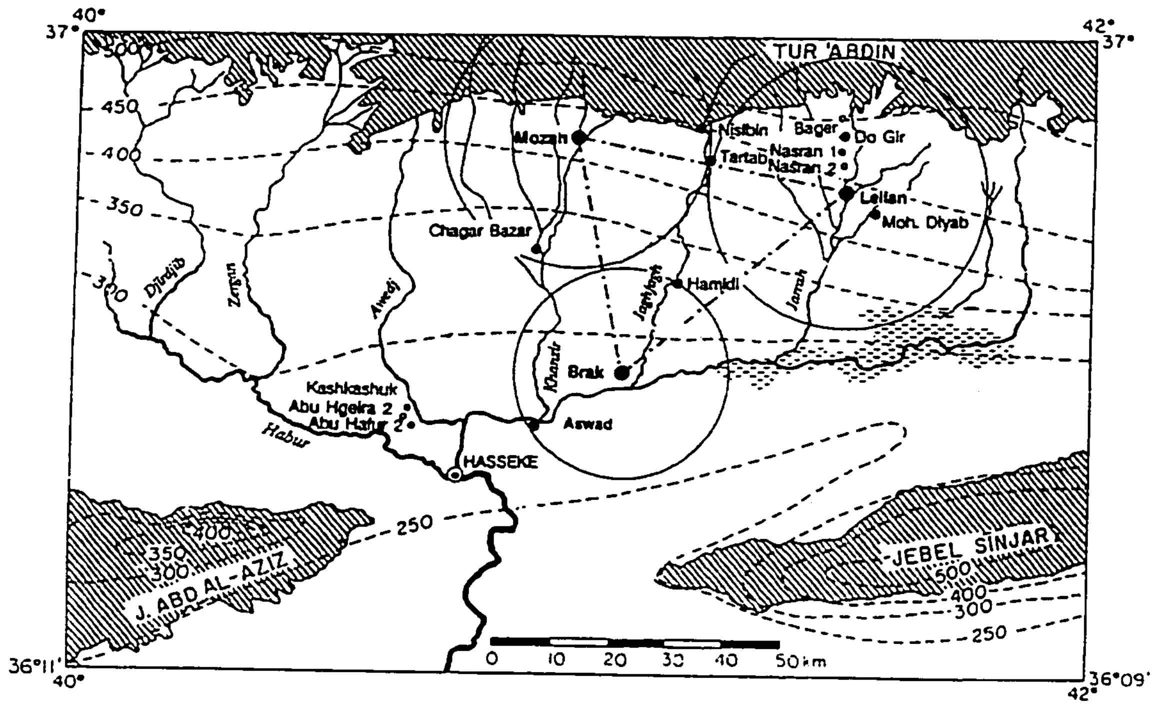

Figure 2.1 Map of the Ancient Near East showing modern rainfall isohyets (dotted lines connecting areas of equal annual rainfall) and archaeological sites mentioned in the text. Adapted from Weiss *et al.* (1993:996). Circles surrounding Mozan, Brak and Leilan indicate Early Bronze Age spheres of influence, and the triangle connecting them is the "Habur Triangle" referred to in the text. Hatched lines indicate uplands.

whether or not dry farming is a viable practice, and in Mesopotamia the 200 mm isohyet accurately delimits agricultural technologies. This difference in agricultural technology between the north (commonly called Subir) and the south (Sumer) has historically been considered by scholars to be the primary source for the differences between northern and southern cultural traditions in Mesopotamia (Roux, 1992). Weiss (1990) notes that southern Mesopotamian sites seem more interconnected than their dispersed and solitary northern counterparts, due to the co-operation and ease of travel (via rivers) between centres. Northern villages, on the other hand, display little co-operation, probably the result of a combination of ample crops and inefficient land-based modes of transportation.

Ancient Mesopotamia was culturally fertile, spawning many of the major accomplishments of our species including the first writing system (ancient cuneiform), the domestication of plants and animals, and urbanization (Thomas, 1982). Yet very little is known about the growth and decline of the cultures sustained by the "fertile crescent", particularly the Akkadian Empire, which unified the north and south for only one hundred years (2300-2200 B.C.) and then mysteriously dissolved. This chapter will summarise what is presently known about the various dynastic traditions that together comprise Mesopotamian prehistory, concentrating on the Akkadian dynasty. I will also discuss the various theories that have been put forward thus far regarding the rise and fall of walled urban centres such as Tell Leilan[2].

2.2 MESOPOTAMIAN CULTURE HISTORY

The culture chronology of the Mesopotamian Empire can roughly be broken down into the format displayed in Figure 2.2. Pottery style and architecture are the hallmarks of any cultural group in Near Eastern prehistory, because changes in subsistence were negligible after cereals and livestock were domesticated (~9000 B.C.). Thus cultures are named after pottery styles or the type site at which a diagnostic pottery tradition is found. Northern and southern Mesopotamia experienced distinct cultural histories, yet the transmission of ideas and goods that occurred between the two halves allows archaeologists to correlate chronologies through stratigraphic and culture material markers. For the purposes of this thesis, distinctions will be made between northern (Subarian/Akkadian) and southern (Sumerian) cultural phenomena when significant, with descriptions of Tell Leilan illuminating northern chronologies wherever possible.

2.2.1 Pre-Urban Mesopotamia – Hassuna, Halaf and Ubaid Cultures

Pre-urban Mesopotamia is sometimes overlooked in the archaeological literature in favour of the more dynamic Urban period. However, many important events transpired prior to the development of cities that enabled, and indeed could be considered preconditions for, urbanization. The Neolithic Revolution, dated in the Near East to ~9000

[2] A "tell" is a mound made from human activities, such as the construction of buildings; "tell" is also a common name for a settlement (city or village), either modern or archaeological, in this region (Rosen, 1986). Archaeological tells are often the result of hundreds, if not thousands, of years of human occupation, as new villages were built atop the older ones in antiquity.

	Southern Mesopotamia[1]	Northern Mesopotamia[2]	Tell Leilan[3]
1600 B.C.	1st Dynasty of Babylon	?	Leilan I
1800 B.C.	BC Isin-Larsa Dynasties	Mari	
1900 B.C.		Old Assyrian	Habur Hiatus I (*S4*)
2000 B.C.	Ur III Dynasty		
		Ur III	
	- - Gutium Interregnum - -	- - - - - - - - - - - - - - - - - - -	- - - - - - - - - - - - - -
2200 B.C.	Akkadian Dynasty	Akkadian Dynasty	Leilan IIb(*S3*)
2350 B.C.	Early Dynastic III	Ninevite V Period	Leilan IIa (*S2*)
			Leilan IIId (*S1*)
2600 B.C.	Early Dynastic II		Leilan IIIb-c
2750 B.C.	Early Dynastic I		Leilan IIIa
3000 B.C.	Jemdet Nasr		Leilan IV
3200 B.C.	Uruk Period	Uruk/Gawra Phase *Urbanization Period begins*	
			Leilan V
			Leilan VIb
4000 B.C.	Ubaid Period	Ubaid Period	
			Leilan VIb
5000 B.C.	▼ ?	Halaf Period	▼ ?
5600 B.C.		Hassuna Period	
6800 B.C.			

[1]from Postgate, 1992
[2] from Porada *et al.*, 1992
[3] from Weiss and Courty, 1993

Figure 2.2. Culture Chronologies for Southern and Northern Mesopotamia and Tell Leilan. Italicized codes (e.g., *S1*) refer to Weiss and Courty's stages of Akkadian control described in the text.

B.C., is defined by the origins of animal and plant domestication. Archaeologists traditionally envisioned domestication to have occurred as human groups took advantage of local wild flora and fauna (barley, wheat, sheep and goats) by slowly and uniformly cultivating crops and breeding culled herds (e.g., Childe, 1936; Saggs, 1984). However, modern research reveals that there is "far greater diversity in the pathways to food production" (Zeder, 1994:97) between the Neolithic and the Urban periods in the north, as individual communities responded to ecological and environmental pressures by blending agro-pastoralism with hunting and foraging to maintain flexible subsistence economies. This versatility is important to remember when interpreting the events, both climatic and socio-political, that contributed to the changes in Mesopotamian cultures in general, and specifically the fall of the Akkadian Empire.

The first permanent residential structures in Mesopotamia developed between 5800-5500 B.C., during the Hassuna Period in the northern, rain-fed plains, and appear to have housed individual families. Hassuna occupations are recognised by copper technology, long-distance trade of obsidian and semi-precious stones, cultivated cereals, domesticated sheep, goats, pigs and cattle, and a particular type of flat ceramic dish with corrugations on its inner surface, suspected to be useful in husking cereal grains (Saggs, 1984).

Hassuna assemblages are geographically restricted to northern Iraq, but temporally overlap with the more widespread Halaf assemblages found throughout northern Mesopotamia between 5600-5000 B.C. (Saggs, 1984). The Halaf period can be further subdivided into three stages of development signalling incipient cultural growth and development, the later stage of which is associated with beehive shaped architectural structures of supposedly religious significance. The Halafians were successful agriculturists and pastoralists, whose food surpluses and textile trade networks are often applauded in the archaeological literature for increasing both population size and quality of life in later periods, indicated by increasingly ornate and specialised pottery and jewellery. Halafian culture is predominantly identified on the basis of pottery type, as is the culture which succeeds it: the Ubaid Culture (~5000 - 4000 B.C.).

The subject of whether the adoption of Ubaid traditions was the result of human migration or technological diffusion remains controversial, and the fact that Ubaid cultural deposits are directly antecedent to the celebrated Sumerian cultural phenomenon is a cause for further contention. The continuity of other aspects of Halafian material culture upon the introduction of Ubaid pottery styles hints to passive diffusion of cultural traits rather than migration of foreigners and subsequent dissolution of Halafian culture (Roux, 1992).

Ubaid cultural traits are found widespread throughout Mesopotamia, with northern and southern trends in expression. In the south, clay is the medium of choice, not only for pottery but for architecture as well. In the south, mud-brick buildings abound alongside reed-mat structures, and mud-brick was used in the construction of altars and religious shrines, whereas northern Ubaid habitations are made exclusively of mud-brick (Roux, 1992). Southern Ubaid peoples grew barley and date palms, kept zebu and pigs, and obtained precious obsidian and bitumen through long-distance trade networks. Stone is commonly used, and is particularly significant in stamp seals which, while rare in the south, are abundant in the north. Pictograms first appear during this time period, and are considered to be the precursors to cuneiform, the known first writing system.

The most striking difference between the northern and southern manifestations of the Ubaid culture is seen in burial style. Southern burials are of one type only (supine extended burials were placed atop potsherds and covered with mud-brick), while in the north mortuary practices vary according to age (adult burials are predominantly flexed, with children's remains placed in urns) (Roux, 1992). Extended burials are rare in the north, resulting perhaps from incomplete cultural diffusion of Ubaid traditions.

The overall similarity in pottery traditions between the north and the south attest to the ubiquity of the Ubaid culture. The differences in other aspects of life (e.g., burial and housing material) foreshadow the regional variations of urbanization in the age to come: the Uruk period.

2.2.2 The Urban Revolution: the Uruk Period

The process of urbanization is a subject which has filled countless volumes in the archaeological literature, and the fact that the first cities arose on Mesopotamian soil makes it the frequent test-case of theories regarding urbanization (e.g., Adams, 1981; Gibson, 1972; Weiss, 1986). Mesopotamia experienced urbanization during the Uruk Period (~4000-3200 B.C.), in the form of a rapid increase in the rate of settlement and the establishment of a four-tiered hierarchical system of settlement including cities, towns, villages and hamlets (Crawford, 1991). With intensified urbanization came an increasingly stratified social system, thought to be the product of agricultural surpluses and demanded by division of labour and craft specialisation. Technological advances achieved during this time include the advent of metallurgical casting and the use of a "fast wheel" to mass-produce pottery (Crawford, 1991). Cylinder seals from this period, used primarily for the marking of property items, depict domestic and mythological scenes, and in their artistic renderings provide archaeologists with insights into the real and imagined dramas of life in ancient Mesopotamia. Monuments from this time are adorned with cone-mosaic print stamps in bright colours, and a penchant for rich hues can be seen in the pink walls of the "Red Temple" at E-Anna (Roux, 1992).

The most impressive cultural feat of the Uruk remains the adoption of the first writing system, cuneiform, an improvement on the pictograms of Ubaid fame. Inscribed into soft clay that was subsequently baked to rock-hardness, cuneiform scripts are as durable as pottery and serve as a cultural chronology marker in literate periods due to subtle changes in style through time. From its humble beginning as an accounting aid and business record, cuneiform writing quickly evolved into "an extremely sophisticated system which was used to record all mental activities, including a vast and admirable literature" (Roux, 1992:76). As with all Mesopotamian cultures, Uruk is best defined in terms of pottery styles, and archaeologists associate Uruk deposits with plain buff chaff-faced ware (Schwartz and Weiss, 1992).

Jemdat Nasr is a cultural phase associated with distinctive large jars with red and black geometrical or naturalistic designs painted into buff ware (Roux, 1992). It is generally considered to be an epilogue to the Uruk legacy, lasting from ~3200-2900 B.C., and many scholars place Jemdat Nasr phases into a context of late/terminal Uruk development (e.g., Saggs, 1984). Jemdat Nasr ware is absent from sites in the north, such as Tell Leilan and other locales within the Habur triangle. However, the continuous stratigraphy between late Uruk and early Ninevite V levels in northern sites prompts scholars to assume that southern Jemdat Nasr occupations are contemporaneous with early Ninevite V materials in northern sites (Schwartz and Weiss, 1992). Ninevite V (~3300-2500 B.C.) wheel-made pottery styles were first discovered in level V at Nineveh (Ninua) in northern Iraq and are characteristically finely incised, usually associated with a new type of painted pottery different from preceding Uruk styles. Due to its longevity and the observance of quantitative changes in pottery styles, this period is typically subdivided: at Tell Leilan, Ninevite V levels have been divided into four phases, called Leilan IIIa, IIIb, IIIc and IIId (Weiss and Courty, 1993).

While the Ninevites were ruling in the north, southern Mesopotamia slipped into its Early Dynastic Period (2900-2330 B.C.). Noted for the origin of the city-state, the Early Dynastic period is historically defined by the shifting of power between different centres ruled by an increasingly secular but largely theocratic governance (Crawford, 1991). It is during the Early Dynastic period that fully Sumerian styles develop and flourish, ranging from architecture to cylinder seals to pottery styles. The Sumerians are well known for the development of the "cire perdue" (lost wax) bronze casting technique, and the metallurgical artisans of the time produced some of the most celebrated pieces in the history of Mesopotamian art (Roux, 1992).

The urbanization process, begun during the Uruk period, reaches a new height with an abundance of cities fortified by walls, and the abandonment of smaller, rural settlements in favour of city life (Roux, 1992). Early Dynastic southern Mesopotamian city-states competed among themselves for the honour of being the seat of the king, but political enmity did not quell the socio-economic ties that bound each centre to the regional and dynastic whole (Postgate, 1992). Each city-state worshipped its own patron deity, and approximately one-third of all arable land surrounding a city was owned by the temple to sustain the multitude of workers and slaves devoted to temple life (Roux, 1992). The other influential institution was the palace, which housed the *en* (ruler) and the royal family, and was the site of official secular and religious activities. The independent governance of each city-state translated into self-maintenance but rarely expansion of political domains. Cities rose and fell in a kaleidoscope of changing political power structures, with many great rulers but few wielding powers beyond the confines of their city's domain.

2.2.3 The Akkadian Empire

Toward the end of the Early Dynastic period, several influential city-state rulers successively sought to expand their dominion beyond their city, and succeeded in unifying several of the major Sumerian centres. One such ruler, Sargon of Akkad, has been glorified in the ancient literature as the herald of a new age: his efforts to silence strife between Mesopotamian centres were unprecedented, and resulted in the unification and lauded expansion of the Mesopotamian empire under the Akkadian cultural influence (Roux, 1992). Sargon ruled between 2334 and 2279 B.C., and was succeeded by his sons Rimush (ruled 2279-2269 B.C.) and Manishtusu (ruled 2269-2255 B.C.), and then his grand-son Naram-Sin (ruled 2254-2218 B.C.) (Roux, 1992). The legacy of Sargon lives on in the literature of the time, which documents his triumphs as a conqueror of lands and people, but the brevity of this impressive empire precludes it from occupying a significant stratum in archaeological contexts. From textual evidence, it is known that Sargon was of northern, Semitic origin, and his linguistic legacy can be seen in the conversion from Sumerian to Semitic throughout the Empire.

Sargon also left a legacy of archaeological evidence of imperial control over both northern and southern Mesopotamia, leading researchers to consider his the first true Empire (Liverani, 1993). Irrigation agriculture in the south was evidently under imperial control, because textual and archaeological evidence show that production intensified and processed grains were shipped to and stored in centrally controlled structures (Weiss *et al.*, 1993). Northern rain-fed agricultural systems were also intensified under Akkadian rule with the stabilisation and management of channelled water courses; the fields yielded sufficient crops to allow the Empire to feed its workers with rationed wheat and barley. State organisational change is also seen through the increase in labour-intensive mass production of pottery and craft specialisation such as finely incised ceramics. The remains of large transport animals (horses, mules and onagers) are documented from urban areas, and these animals probably pulled harvest transport carts (Weiss *et al.*, 1993).

The majority of Mesopotamian cultures thrived first in the south, reaching the north only through long term residence and slow invasion; trade routes were established early in the Copper Age, reinforcing ties between the two domains, but unification was a rare event (Crawford, 1991). This is what makes the Akkadian Empire so impressive: the great Sargon of Akkad managed to unite the south and the north (Crawford, 1991). Sargon assumed power by 2334 BC, and left his successors an incredible legacy of dominion over the vast lands under Akkadian control, yet his empire fell just over a hundred and forty years later, by 2191 BC according to city records. The urban centre of Tell Leilan will be used as an example to illustrate the rise and decline of the Akkadian Empire, primarily because this is the source of the data employed by Weiss to construct his "Environmental Degradation" hypothesis to explain the fate of this short-lived empire (Weiss and Courty, 1993; Weiss *et al.*, 1993).

2.3 Tell Leilan and the Rise and Fall of the Akkadian Empire

Tell Leilan was already a well established Early Bronze Age city when the Akkadian Empire took over at approximately 2300 B.C. (Weiss, 1986b; Weiss and Courty, 1993). Weiss and Courty (1993; Weiss *et al.*, 1993) have developed a four-stage scenario for the growth and decline of Tell Leilan between 2600 and 1900, and that template will be used here to describe the changes occurring during this time period at Tell Leilan. The city itself as well as the surrounding agricultural villages experienced substantial and rapid population growth during the Ninevite V urbanization period (~2600-2400 B.C., Tell Leilan IIId), in what Weiss and Courty describe as "secondary state formation" (Stage 1, *S1* in Figure 2.2)). Most villages doubled in size, but Tell Leilan increased from a 15 hectare Acropolis to a more than 90 hectare city encompassing the Acropolis, Lower Town and surrounding settled areas by 2400 BC, making it the largest urban centre on the Habur plains (Stein and Wattenmaker, 1990). Tell Leilan grew not haphazardly, but according to prescribed edicts, exemplified by straight, paved streets throughout the Lower Town. Tell Brak and Mozan also grew to significant sizes during this time, and this trio (Leilan, Brak and Mozan) is thought to have wielded power over the circumscribed smaller towns and villages. Iconography of this period is standardised among the sites within the Habur Triangle, such as the shifting from local to "Subarian" cylinder seal styles. Secularisation of governance is seen in the replacement of temples with palaces, and the abolition of priestly rule in favour of city-state governance. The traditional Ninevite V incised ceramic tradition persists.

Stage 2 (Leilan IIa, ~2400-2300 B.C.) according to Weiss and Courty (1993) is characterised by the consolidation of state power. One of the more obvious characteristics of this stage is the abandonment of Ninevite V ceramic production in favour of mass-produced pottery techniques. Also, the first fortification at Leilan is built, a 2.5 meter-wide wall separating the elite and their wealth in the Acropolis from the residents of the Lower Town and nearby villages.

Akkadian conquest of Subir by Naram-Sin marks the beginning of Weiss and Courty's (1993) Stage 3, "Akkadian conquest and Imperialism", 2300-2200 B.C.. Five significant markers of Akkadian control have been identified in the Habur region. First, the Habur plains population was redistributed: the inhabitants of smaller centres concentrated into larger cities, while small villages remained dispersed and low in population (Weiss and Courty, 1993, contra Stein and Wattenmaker, 1990). This would have resulted in a constriction of authority and wealth to the cities with the removal of competing secondary centres. Second, these large centres required protection, and the Akkadians built a large city wall (comprising two 8m thick concentric mudbrick walls) to ward off potential thieves or invaders, although poorly controlled dating of this structure initially led excavators to hypothesise that the wall was erected to defend against the Akkadians themselves (Weiss, 1981, 1983; Weiss and Courty, 1993). Third, domesticated barley and lentil production, processing and storage became highly regulated under imperial control, and labourers received clean grains, relieved of the rachis, lemma and palea, ready for consumption (Wetterstrom, n.d.b). Fourth, a distinct pottery style called "sila-ware" makes its appearance. Standardised sila pottery from Leilan IIb period is green-ware that is found in three sizes, approximately 300mL, 1.0L and 1.5L respectively, from which archaeologists assume they were used in the rationing of food as payment by the Akkadian Empire (Senior and Weiss, 1992). The fifth and final hallmark of Akkadian imperial control on the Habur plains is the intensification of agricultural production. Water courses were stabilised through channelization, the "deepening and straightening of water channels... to counter the effects of rapid siltation and maintain an efficient water flow" (Weiss and Courty, 1993:141) and to prevent meandering.

Stage four of Weiss and Courty's (1993) template is the Habur Hiatus 1 event, dated from 2200-1900 B.C., during which Leilan and other Habur centres were deserted. Moreover, there appears to be a movement of northern peoples to Southern Mesopotamia: there is a sudden increase in the number of Hurrian (Habur sedentarist language) and Amorite (Habur nomad language) names in the records of southern cities. A 180km long wall is constructed at the northern end of the Akkadian portion of Southern Mesopotamia, and given the title "Repeller of the Amorites", but apparently it was not a sufficient deterrent, because the population of village-size settlements in the south doubled (Weiss and Courty, 1993).

The large size and apparent stability of Tell Leilan makes its sudden depopulation at approximately 2200 B.C. very surprising, particularly when viewed in conjunction with a contemporaneous population decline in adjacent towns and villages on the Habur plains (e.g., Tell Brak). Weiss correlates this decline with simultaneous cultural demises in other Old World civilisations such as the Egyptian Old Kingdom, the Minoans of Crete, the Palestinians, and the Indus cities of Harappa and Mohenjo-Daro (Weiss and Courty, 1993;

Weiss *et al*, 1993). Weiss and his colleagues have explained these felled societies as victims of a large-scale drought (desertification), beginning at approximately 2600 B.C. and intensifying close to 2200 B.C.. Dr. Courty[3] has examined the sediments of Tell Leilan and found evidence of strong dust winds, large sediment loads in the Habur river and a decrease in soil moisture, as well as a layer of volcanic ash (Courty, 1994, 1997; Weiss and Courty, 1993; Weiss *et al.*, 1993). This climatic episode left several remarkable strata in the Leilan sediments: Habur hiatus I deposits at Tell Leilan are more than half a meter thick and are completely devoid of any cultural features, topped by the sudden appearance of Leilan Period I materials dated to approximately 1900 BC. This geoarchaeological evidence will be examined in detail in Chapter Three, and the discussion here will move to an examination of various theories that have been put forth to explain the collapse of the Akkadian Empire.

2.4 THEORIES OF CULTURE CHANGE

Weiss' hypothesis that aridification created inhospitable conditions for the Leilan agricultural economy and ultimately undermined the Akkadian Empire is commonly referred to as the "Environmental Degradation Hypothesis". The premise of this theory is that aridification decreased crop yields to dangerously low levels, and that the residents of Leilan and other tells and villages on the Habur plains could not or would not alter their subsistence strategy to include hunting and wild plant foraging. Instead of adapting their subsistence strategy to their conditions, the Habur populations adapted to the situation by moving south in search of arable land. The movement of these peoples into southern villages taxed the resources available there, which were probably already sparse due to the same aridification, thus creating a double insult to the southern Akkadian economy and causing its eventual downfall. Weiss finds corroboration of his hypothesis that the climatic episode was geographically widespread in the political and economic crises experienced at around the second millennium B.C. by cultures in nearby regions: Egypt, Palestine, India and the Mediterranean.

Most scholars have downplayed the "abandonment crisis" that Weiss defends, and they minimise the contemporaneity of the collapse of the aforementioned Old World cultures (e.g., Adams, 1981; Tainter, 1988), leaving Weiss to defend his hypothesis in the face

[3] Geoarchaeologist at the Laboratoire d'Hydrologie et de Géochimie isotopique, CNRS (Centre National de Recherche Scientifique), Université de Paris-Sud, France.

of the standard political explanations for culture collapse and change in Mesopotamia. The majority of scholars (e.g., Potts, 1994) claim that the Akkadian empire was "destroyed by attacks from a group of tribesmen from the mountains, known collectively as the hordes of Gutium" (Crawford 1991:26). But the Gutian sphere of political influence was quite limited in comparison with the vast Akkadian Empire, and little attention is given to the practical aspects of how such a huge power could be conquered by this unprobable foe. A more plausible interpretation is that the same factors that persuaded the residents of Tell Leilan to abandon their city also forced the Gutians to flee their mountain base, and subsequent nomadic wandering led Gutian people into previously Akkadian territory, where the former ransacked and pillaged the remains of the latter. Roux (1992) takes into account the geographic extent of the Akkadian Empire, and blames localised, independent insurrections for the collapse of Akkad, giving the Gutians only minimal glory as the winners of "the last, decisive battle" (p. 158). Yoffee (1988) blames the Akkadians' demise on their preoccupation with the invasion of far-flung lands, resulting in ineffectual administration from a "distant, centralised Mesopotamian bureaucracy" (p.48). In summary, there is much support in the archaeological literature for a socio-political explanation for the demise of the Akkadian Empire.

There are also several scholars who, while accepting that climatic factors played a large role in the demise of the Akkadians, disagree with Weiss' environmentally deterministic slant. Rosen, whose phytolith work has been highly influential to this thesis, challenges Weiss' assumption that the Early Bronze Age economy was inflexible and fragile in the face of environmental change, using the downfall of the Canaanites as an example (Rosen, 1995a,). Garcia (1981) states that climatic changes may expose weaknesses already present within a culture or society, but are not by themselves prime movers of culture change. Considering this, Rosen does not just simply criticise Weiss, rather she puts forward several ideas regarding the social responses to such an environmental change. First, Rosen remarks how the administrative control over production may have left farmers with few options to change their agricultural strategies; early farmers may have in fact been more flexible than their rigidly controlled state-level counterparts. Also, because the elite may have their own personal reserves or access to convertible wealth, their concern with agricultural productivity may be less than the farmers who grow their daily bread. As a result, management strategies may have been unresponsive to the day to day conditions of the field, and ineffectual against along term aridification. Additionally, farmers in this region have historically experienced inclement growing conditions on a regular basis, and would have developed strategies for maximising crop yield: drought was a very real danger, as can be seen in numerous ancient texts, one that ancient farmers would have been attuned to and proactive against. Colson identifies several well-known drought-avoidance tactics, known from archaeological and ethnographic data, including crop and herd diversification, food storage, "cash" crops (trading of stored food for non-perishable valuables), social/trade networks to different regions, and traditional knowledge about famine foods (Colson, 1979; Rosen, 1995a). However, under the control of a largely unaware elite, farmers would not have been able to execute their judgement about optimising crop productivity. Rosen postulates that "central control by the urban elite over agricultural production might have served to protect the agrarian sector from short-term droughts by its redistributive function, but it would have also undermined the resilience of the common subsistence farmer" (p. 39). Finally, Rosen encourages archaeologists to interpret societal responses with an understanding of the cosmology of the culture in question. Only by comprehending how ancient societies interpreted the world around them and their role in it can archaeologists assess what factors motivate cultural phenomena such as the desertion of Tell Leilan and the collapse of the Akkadian Empire.

Weiss does have several supporters, though, including many collaborators and co-authors. His arguments regarding the decline of Tell Leilan and the impact of climatic events upon human prehistory have generated much discussion in the literature, and the occasional heated debate (e.g., Rosen, 1997a; Weiss, 1996, 1997). Issar (1995) uses Tell Leilan as an example of a situation in prehistory where climate was largely responsible for the dissolution of a cultural group. Kayan (1999) and Wilkinson (1999) mention the Akkadian demise in their analyses of Eastern Mediterranean Holocene environments and discuss geoarchaeological evidence for anthropogenic and environmental impacts upon the late Bronze Age Mesopotamian landscape. Rosen (1997b) addresses the Early Bronze Age desiccation and investigates human land use of a site in S.E. Turkey through geoarchaeology. Otterman and Starr (1995:127) even propose a mechanism for the aridification event, in which a transition from a "vegetative, crusted soil and convective precipitation" system to one characterised by "saltating-sands surface and extreme aridity" is deemed the cause of aridification at 2200 B.C.. The theory that environmental factors were the prime instigators of the Leilan hiatus episode deserves further investigation, such as the research presented in this thesis.

2.5 Testing the Environmental Degradation Hypothesis

Weiss' theory that aridification reduced Akkadian crop yields and forced the abandonment of Habur cities and villages is compelling, but needs further testing. The remainder of this thesis is dedicated to examining the diet of the residents of Tell Leilan during the 3000 years preceding abandonment using phytoliths recovered from human dental calculus. Phytoliths are opal silica bodies which form readily and predictably in the epidermal tissue of members of the Poaceae (Gramineae) family, which includes the cereal crops grown by Leilan farmers, and form silica skeletons (groups of cells silicified together) under wet/irrigation conditions. By examining the variety and abundance of phytoliths in the different time periods, alterations to the diet, and even the growing conditions, should be revealed.

CHAPTER 3. ENVIRONMENTAL HISTORY OF THE NEAR EAST

3.1 INTRODUCTION

A serious obstacle in correlating societal and environmental events is the use of different dating and calibration techniques in Quaternary research. Radiocarbon dates should be converted to calendar years using a calibration curve, which corrects for global and regional alterations to the amount of naturally occurring atmospheric ^{14}C. Some chronological methods produce calendric dates without calibration, such as dendrochronology or varve chronology, so care should be taken when comparing dates obtained from these differing methods – calendar dates cannot be strictly correlated with radiocarbon dates unless the latter are corrected. Thus, the dates presented in this chapter are only relatively comparable, as many of the radiocarbon dates have not been calibrated[4].

3.2 EVIDENCE OF CLIMATE CHANGE

There are myriad sources of information by which palaeoclimate can be inferred (Lowe and Walker [1997] is an excellent introduction to proxy indicators of past climates and environments). Studies referenced in this thesis use geomorphology, lithology, ice core signals, and the remains of fossil flora and fauna to study past climates and environments. Geomorphologists, who study landforms, can reconstruct where ancient glaciers lay or where past shorelines have resided. Lithologists and sedimentologists study the composition of sediments to determine their content and depositional environment: for example, coarse sand grains are deposited under high activity conditions such as fast moving rivers or wind. Ice cores such as GISP 2 from Greenland have been studied because their laminae contain chemical and physical clues of the environment in which the ice layer formed. Lastly, fossil taxa that have strict environmental requirements, such as certain species of diatoms that have specific salinity tolerances, can be used to reconstruct environments. All of these indicators of past environments are *proxy* indicators (associated with or believed to be the results of a certain

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[4] Historians and archaeologists refer to chronology in the B.C./A.D. framework, whereas palaeoclimatologists and geoarchaeologists in most cases use the "before present" (B.P.) designation. Thousands of years are abbreviated as ka, so 2200 B.C. is equivalent to 4.2 ka B.P.. Radiocarbon dates cited from sources other than Weiss (1993) and Courty (1994, 1997) may not have been converted to calendar dates, so unless otherwise specified consider the radiocarbon dates reported in this thesis to be uncalibrated.

environment) that are used to *infer* past climatic regimes.

Weiss *et al.* (1993) focused on local (site) and regional (Near Eastern) analyses of the chemistry, sedimentology and palaeoecology of sediments and lake cores. However a wider approach will be pursued in this thesis by including further archaeological data, additional regional studies, and global signals. By including a wider data set it is hoped that more evidence can be presented and that a more accurate picture of the climate and environment of northern Syria at 4200 B.P. can be achieved.

3.3 LOCAL EVIDENCE

Local evidence includes that derived from excavations and surveys at Tell Leilan and sites on the surrounding Habur plains. There is consensus that the Habur plains experienced aridification during the closing half of the third millennium B.C., although not all sites were as drastically depopulated as Tell Leilan.

3.3.1 Archaeological Evidence

Even before extensive archaeological excavations detected the Habur hiatus I episode, literary sources from southern Mesopotamia revealed an "influx of barbarians from the North", and told of a wall constructed to hold them back (Crawford, 1991). Cuneiform records from the southern city of Ur show an increase in the number of northern (Semitic, Hurrian) names registered, and Semitic peoples account for much of the population increase after 2100 B.C. (Crawford, 1991). The Curse of Akkad, an ancient literary text prophesying catastrophe for any invader of Nineveh (the regional Akkadian administration center) invokes images of " 'large fields [that] produced no grain...heavy clouds [that] did not rain' " (Wright, 1998:98). Most scholars appreciate only the metaphoric qualities of this passage, but Weiss interprets it to reveal actual climatic events in prehistory (Weiss, 1996).

3.3.2 Physical Anthropological Evidence

More tangible sources of archaeological evidence have come from the laboratory of Dr. Lovell, (Dawson, 1998; Feasby, 1998; McKenzie, 1999). Lovell and several of her students have found skeletal biological and dental evidence for physiological stress among the Tell Leilan population toward the end of the 3rd millennium B.C.. Hugh McKenzie examined the skeletal remains of 21 Leilan adults and found a low prevalence of osteoarthritis but a high incidence of periostitis, cribra orbitalia and enthesial lesions (McKenzie, 1999). These last three are skeletal manifestations of generalized physiological stress, including chronic infection, anaemia and biomechanical strain, respectively.

Studies of dental health and development also indicate stress prior to the abandonment of Tell Leilan. In particular, a high number of linear enamel hypoplastic defects were observed (Dawson, 1998). Enamel defects are correlated with episodes of physiological stress during childhood, when the enamel forms; however, the precise nature of the stress (e.g., dietary, climatic, emotional) is impossible to determine (Hillson, 1996).

Carbon stable isotope analyses on human bone samples revealed no significant change in amount of C_3 or C_4 plants in the diet (Feasby, 1998), so presumably barley and wheat (both C_3 plants) were sufficient to satisfy the Leilan subsistence economy. Furthermore, the $\delta^{13}C$ data imply that the environment had not changed sufficiently, or long enough, to encourage the immigration of C_4 plants into territory traditionally inhabited by C_3 flora. The differences between C_3 and C_4 plants and their geographic distributions will be discussed in detail in Chapter 4 (section 4.4.2).

3.3.3 Macrobotanical Data

Future investigations of the macrobotanical collections from Tell Leilan during the Period II may be informative, however at present there are no data published on this subject. Wetterstrom has kindly provided me with two unpublished manuscripts (n.d.a, n.d.b) describing plant remains from Tell Leilan, but they concentrate on the Ninevite V period, 2900-2400 B.C.. Remedying this lack of palaeobotanical data is the primary goal of this thesis, in which phytoliths from dental calculus were analyzed to determine if a change in the variety or abundance of plant taxa can be seen in dietary phytoliths at Leilan during the Early Bronze Age.

3.3.4. Geoarchaeology of Tell Leilan

Figure 3.1 summarizes the description of Habur Hiatus I sediments which follows. There have been three layers of sediment identified as part of the Leilan Collapse Phase (LCP) complex: an eolian deposit (referred to by Courty [1997] and Weiss *et al.* [1993] as a dust fall-out) comprising two facies (LCP1 and LCP2) and sediment derived from a mudbrick wall collapse phase (LCP3) at the time of abandonment (Courty, 1994; Courty 1997; Weiss *et al.*, 1993). Early publications documented the discovery of volcanic ash from LCP 1 sediments, and

Age (B.C.)	Leilan	Sediment Characteristics	Environmental Reconstruction
	Leilan I	Calc. loam, fine prismatic structure, ▲pedogenic carbonate, ▲ biol.act.	Soil stable, ▼winds , rainfall and seasonality as today
1900			
	Habur Hiatus I	Calc. loam, weak prismatic structure, ▼ biol.act., ▼pedogenic carbonates, ▲crusts, ▲windblown pseudosands	▼Soil stability, ▼soil moisture, ▲rains, surface runoff, ~winds
2200			
Building Collapse	IIb LCP3	Well sorted, well rounded calc. pseudosands, ▲crusts, building collapse	▲Winds, saltation, ▲rains, ▼vegetation
↑ *Dust Fall Out*	IIa LCP2	Fine pseudosands, volcanic glass, gypsum, calcitic loam, spherules, ▲sedimentary crusts	Horizontal winds, suspension eolian transport, ▲rains, ▼vegetation
↓	IIa LCP1	Well sorted, well rounded eolian pseudosands, volcanic glass, calcitic loam, ▲sedimentary crusts	Tephra fall, saltation, ▲rains, ▼vegetation
2400			
	IIId	Massive calc. loam, well developed pedogenic carbonates, ~biol.act., ▲pseudosands, ▲sedimentary crusts	~Stable soil, ~winds, ▲rains
2600			

Figure 3.1 Summary of Leilan stratigraphy from 2600-1800 B.C.. From Courty, 1994, 1997; Weiss *et al.*, 1993. Abbreviations: calc=calcareous; biol.act.=biological activity; ▲=high; ▼=low; ~=moderate; LCP=Leilan collapse phase.

directly linked a volcanic event to the abandonment of Tell Leilan (Weiss *et al.*, 1993). Courty has recently revised her interpretation and now divides the dust fall-out into a tephra-rich facies and a spherule-rich one (Courty, 1997). The tephra layer (LCP1) is a "thick sandy deposit remarkable by its complex and exogenous petrographical assemblage and the pseudo-sand morphology of the tephra" (Courty, 1997:7), indicative of a high-energy aeolian depositional environment not characteristic of a passive plume fall-out. The tephra shards themselves are slightly weathered (Weiss *et al.*, 1993), meaning that primary deposition from a volcanic origin is unlikely; they are probably from a distant erosional surface susceptible to wind gusts. Courty (1997) has not been able to locate the source vent for the tephra, but this is not surprising given the lack of historic literature on the subject, a dearth of geologic/geochemical data and the complexity of the air streams operating in this region (Zielinski *et al.*, 1994, Courty, 1997). Since the publication of Weiss *et al.* (1993), scholars have abandoned the hypothesis that a volcanic eruption triggered the drought implicated in Weiss' environmental degradation scheme, primarily due to the lack of evidence for volcanic eruptions causing climatic changes beyond a few years or decades (e.g., Sigurdsson, 1990). In general, this tephra-rich facies shows evidence of aeolian deflation and saltation, resulting from high velocity dust winds with high particle loads (Courty, 1997). Evidence of compaction demonstrates that Tell Leilan was inhabited at this time, and relative dating using artifacts places the beginning of the dust fall-out to the end of the Ninevite V period (around 2400 BC) (Court, 1997; Weiss *et al.*, 1993).

The second facies (LCP2) identified within the dust fall-out sediments is very thin (5mm) in comparison with the tephra-rich layer (20-40cm), but is more widespread in horizontal space than the isolated tephra facies. Characterized by a predominance of calcitic, siliceous, phosphatic and chrome-rich spherules, the minor coarse components are of exotic origin yet display a fresh aspect excluding the possibility of long-distance or alluvial transport (Courty, 1997). This spherule-rich layer contains a large number of 200-50 μm calcitic spherules possessing a fibrous-radiated fabric known only to originate from the immense impact of meteorites, suggesting an extra-terrestrial origin for these spherules (Courty, 1997). The only crater documented in the region during the mid-Holocene is located in the southwestern Arabian Peninsula (Grieve, 1997), and strong winds could have carried these exogenous sediments as far as Tell Leilan. This second facies of Leilan Collapse Phase is devoid of earthworm tunnels or other evidence of bioturbation, suggesting a parched soil inhospitable to burrowers and incapable of supporting much organic life (Courty, 1994).

This dust fall-out stage (LCP 1 and 2) appears to have brought heavy, destructive rains with it, capable of scouring vegetation from the exposed soil surface (Weiss *et al.*, 1993, Courty, 1997). Thus, while precipitation may have not decreased, its high intensity probably resulted in high run-off, meaning a decrease in soil moisture and a drop in groundwater levels. These rain storms could have caused crop failure, particularly in light of the Mediterranean precipitation pattern: if the soil is unable to absorb water during the winter months, then the vegetation has little chance of surviving the rainless summer, particularly if an increase in wind causes high evapotranspiration effects.

The collapse of buildings (LCP 3) occurred after deposition of the LCP 2, meaning that dry and windy conditions had prevailed since before the onset of Akkadian control (Courty, 1997). Courty (1994) interprets the collapse of mud-brick structures as a result of heavy rains, but without inhabitants there to upkeep the structures, they could have fallen easily by natural deterioration. There is no precise date associated with the abandonment of Tell Leilan, but the textual analysts and soil scientists alike place it just around 2200 B.C., so they are evidently in agreement about the timing of the onset of the Habur Hiatus 1 period. There is little evidence from nearby sites to correlate with the Leilan stages; however, sediment analyses at Abu Hgeira, approximately 75 km to the southwest, corroborate Courty's conclusion that high velocity dust storms prevailed between 2300 and 1900 B.C. (Weiss *et al.*, 1993). Generally, the Habur sediments at Tell Leilan indicate that heavy rains accompanied high winds loaded with dust between 2500-1900 B.C. (Courty, 1994).

In summary, local lines of evidence, including archaeological data and site sedimentology presented above, support the hypothesis that dry, dusty and windy conditions prevailed on the Habur plains between 4500 and 3900 B.P. However, there is no evidence to suggest that climatic conditions became more severe just prior to the abandonment of Tell Leilan at approximately 4200 B.P. Thus, the Akkadians experienced a harsh climate prior to as well as during the reigns of Sargon and his successors. While aridification may have contributed greatly to the downfall of Sargonic Mesopotamia, it was probably not the sole factor involved.

3.4 Evidence from Regional Studies

For the purposes of this study, I will consider Northern Africa, the eastern Mediterranean and southwest Asia including India to be "regional" sources of palaeoclimatic data, because the same forces propel their climatic regimes, with some degree of overlap. The Westerlies bring winter rains, the Siberian high-pressure system influences winter weather, and a tropical high-pressure system and the Indian monsoon system dominate summertime conditions (Roberts *et al.*, 1999).

Traditionally, studies by Near Eastern and European scholars have sought to explain

Holocene environmental changes within the framework of the Blytt-Semander system and nomenclature; for example, Nutzel (1976) describes a general warm stage occurring between 7.5-5.0 ka B.P., calling it the "Atlanticum", which precedes a dry "Sub-boreal" phase. Within the literature generated from North American scholars there is much regional support for the appearance of a warm, wet stage between 7.5-5.0 ka B.P., and an arid phase between 5.0-2.5/2.0 ka B.P. in the Near East. To avoid using value-laden terminology such as "climatic optimum", I will refer to the mid-Holocene warming phase as the "thermal maximum".

3.4.1. Near and Middle East

Before describing the data, it should be noted that there is lack of data pertaining to Near Eastern Holocene climates published in volumes available in North America. This may be due to: a) a lack of literature addressing the Holocene in general, b) Arabic studies not being translated into English, c) poor dating controls in the late Holocene due to human activities, and d) Middle Eastern studies waning due to lack of funds there and abroad. A recent special volume of *Quaternary Science Reviews* (1999 Vol. 18, issues 4-5) dedicated to the Late Quaternary of the Eastern Mediterranean contributes immeasurably to correcting this deficiency, however. An additional problem is that climate changes in the Near East are sensitive to, and reflect responses to, changes in adjacent regions, and some researchers believe that Near Eastern palaeoenvironmental data add little on their own to the understanding of Holocene climate changes (Roberts and Wright, 1993).

In Saudi Arabia, dune formation has been associated with aridification, and most scholars agree that after 6000 B.P. dune formation increased, alongside continental accumulations of aeolian sand (Anton, 1984). This is interpreted to be evidence of a general phase of aridity following the "semi-arid" phase between 11.0-6.0 ka B.P., also coined the "Neolithic pluvial" (Anton, 1984). At the onset of the aridification phase, the sea level had transgressed some 2-3 meters above present day sea level, and during the dry period regressed to present day levels (Hotzl and Zötl, 1978).

Ritchie and Haynes (1987) report evidence for what they call a "major pluvial episode" occurring in the eastern Sahara between 9.5 and 4.5 ka B.P. (calibrated radiocarbon years). Three sites in northern Sudan were sampled for pollen, and results show that the now-desert landscape was once savanna and desert grassland. Southern sites from this study show a higher percentage of arboreal pollen than northern sites, and the authors hypothesize that a northward movement of Sahelian woodlands (by 400-450 km) was responsible for this early to mid Holocene vegetation pattern (Ritchie and Haynes, 1987).

Goodfriend (1999) presented terrestrial stable isotope records from multiple biological and sedimentary sources in a recent study examining palaeoenvironment in the Levant. From stable carbon isotope analyses of land snail (*Trochoidea seetzeni*) shells, C_4 plants were latitudinally higher between 11.0–7.8ka B.P. and 7.0-3.2ka B.P., than during 7.8-7.0ka B.P., meaning that the same region was drier and perhaps hotter in the mid Holocene than at any other time in the last 10,000 years. Similarly, the $\delta^{18}O$ of the land snail carbonates, which closely resembles that of the regional precipitation, is highest in the mid-Holocene, between approximately 7.0-5.0ka B.P.

Many of the smaller lakes in the Near East are ephemeral (that is, they dry up and reappear cyclically), and thus are limited in scope and difficult to locate. Therefore, the few large lakes that exist have been studied extensively. Van Zeist and Bottema (1982) did a comprehensive palynological survey of 10 lakes in the Mediterranean region and in the Near East. All showed evidence of an increase in moisture between 7.5-5.0 ka B.P., after which the climate appeared to become cooler but not significantly drier. Lake Van in Turkey appeared to be the exception to this rule, showing an increase in moisture relatively late, after 6.0 ka B.P. Kelts and Shahrabi (1986) conducted a limnogeological (lake sediment) study of hypersaline Lake Urmia in northwestern Iran, and through palynology found that a playa (mud-flats) stage predominated prior to 9 ka B.P., with saline lake formation under cool, dry conditions. Following this, the shallow lake appears to grow slowly between 9.0-7.5 ka B.P., after which it expanded to attain present day size (maximum depth 12m, area 5000km^2) and has been fairly stable up until present times (Kelts and Shahrabi, 1986). This appears to contradict the findings of Degens *et al.* (1984), whose study of Lake Van in Turkey places its lowest lake levels between 10.0-6.0 ka B.P., increasing until up to 3.0 ka B.P.. Through the analysis of continuous varve sequences from Lake Van, Landmann *et al.* (1996) date the Holocene thermal maximum to between 6.2-4.0 ka B.P. on the basis of high opal content in the sediments and a high percentage of preserved organic matter, and observe an aridification immediately following this humid, warm phase.

Stratigraphic and geomorphologic studies have also contributed to our understanding of Near Eastern Holocene palaeoclimate. Kayan (1999) showed that three stages of coastline development occur along the Aegean coastal plains of Turkey. The early Holocene (~10-7ka B.P.) is characterized by post-glacial transgression, with shorelines reaching present-day levels by mid-Holocene (~7.0-3.5ka B.P.). Alluviation and deltaic progradation were prevalent during this transition from marine to terrestrial environment during the mid-Holocene. The late Holocene (~3.5ka B.P. to present) coastal sediments show evidence that deltaic progradation slowed and that delta plains were covered with floodplain sediments. Wilkinson (1999) looked at Holocene valley fills in Anatolia (southern Turkey) and northwestern Syria to examine channel development, and, by association, infer palaeoclimate. Wilkinson (1999) found that between 5000 and 3000 B.C., channels experienced moderate, perennial flow, while channels meandered and flow declined during 3000 to 500 B.C.. Rosen's (1998) geoarchaeological study of sediments from the Urfa Plain in Turkey reveal moist mid-Holocene conditions prevailing until the middle of the third millennium B.C., when water table levels dropped and channels became more incised during an arid climatic regime.

Apparently, the Gulf of Oman (located between Oman and Iran) has produced some reliable signals of aridification at ~4200 B.P., or so report Kerr (1998) and Wright (1998), who discussed the Leilan problem with palaeoclimatologists Peter de Menocal and Heidi Cullen. Cullen and de Menocal found a layer of increased dolomite deposition in the Oman core, dated to between 4200 and 3900 B.P., and trace the origin of this dolomite to the mountains and plains of Mesopotamia: exposure through dust-storms and subsequent long-distance aeolian transport is thought to be responsible.

In conclusion, some evidence from the Near East supports the hypothesis that the region experienced a period of aridification between approximately 5.0-2.0ka B.P., known in the literature as the Sub-boreal, following a stage of increased temperature and humidity called the Atlanticum. There is some regional variance observed in the timing, duration and severity of the Sub-boreal period, but if modern data are an adequate analog, then regional variance in Near Eastern climate expression is the norm and not the exception (e.g., Schyfsma, 1978).

3.4.2. North Africa

Data from North African sources consistently reveal an aridification after ~5500 B.P., similar to the Near Eastern data (e.g., Street-Perrott and Perrott, 1993). One of the most thorough studies was conducted by Gasse *et al.* (1987), who compiled lake core data from the Great Western Erg (Algeria). Their primary goal was to observe changes in the environment throughout the Holocene via lake geochemistry, stable isotope analysis and the analysis of biological remains, their most informative data source being diatoms. Through a comparison with the morphology and distribution of modern, known diatom taxa, Gasse *et al.* (1987) were able to construct a scale of hydrosalinity based upon the fossil diatom assemblage. Species with restricted salinity tolerances served as indicator taxa, and their waxing and waning presence through time allowed the authors to infer lake salinity and, by association, fresh-water flux, to reconstruct palaeoclimate. Between 4800-4000 B.P., thalassic (eusaline) diatom taxa predominate in the fossil record, indicating fairly low fresh-water flux: progressively during this time taxa incapable of surviving conditions of 25-30‰ (per mil) salinity disappear, and eurytopic (salt-adapted) species increase in abundance.

Gasse and van Campo (1994) examined several North African and West Asian sites to compare mid to late Holocene climate fluctuations as observed in the pollen, diatom, and limnochemical records. The North African lake cores, from both desert and rainforest vegetation zones, were purposefully taken from sites currently outside the influence of the present day Indian monsoon to determine if the extent of this system had expanded previously in the Holocene. The authors found strong evidence for two abrupt aridification phases within an overall humid phase, one occurring between ~8.0-7.0 ka B.P., the other contemporaneous with the Near Eastern aridification between 4.5-3.5ka B.P..

3.4.3 India

Gasse and van Campo's (1994) study also included sites from northern India (Rajasthan), wherein they found a signal comparable to that found in Northern Africa: two episodes of aridity (at 8,000-7,000 B.P. and 4,500-3,500 B.P.) within a warm, humid post-glacial phase. Bryson and Swain (1981) conducted a pollen study at Lake Lunkaransar in Rajasthan, now a desert region, and found that the maximum wet phase occurred here between 5.0-3.5ka B.P., coinciding with the rise of the Indus civilization. The authors defend their finding, which is contradictory to other such studies (e.g., Gasse and van Campo 1994), by noting that very different pollen records were collected from spatially close sites, and they invoke a highly variable monsoon as a probable factor for such otherwise inexplicable conflicts in the data. Data described by van Campo (1986) and Swain *et al.* (1983) provide corroborating evidence for a wet phase lasting until 3.5ka B.P., using information derived from palynological and lake level studies. The most recent study of this region to date (Kotlia *et al.*, 1997) describes a humid climate regime predominating between 9.3-6.0 ka B.P., during which time this region enjoyed the highest annual Holocene precipitation. This humid period was followed by a dune-building phase, accompanied by ephemeral lakes, from 4.2 ka B.P. onwards.

In conclusion, regional signals during the Holocene generally corroborate the local findings from Tell Leilan. A warm, humid phase predominated between approximately 7.5-5.0 ka B.P., followed by an aridification, which in some regions continues today. Variation in data sets from geographically proximal sites causes some concern particularly in terms of identifying the causal factors in climate change. However, today these regions experience quite a drastic variability in climate and environment within short spaces of geography and time, and it appears that this was true in the past as well. The focus of this paper will now turn to global signals, including data derived from China, Russia and the Greenland ice core, to determine if a reliable large-scale aridification is observable at ~4200 B.P.

3.5 GLOBAL CLIMATE SIGNALS

A survey of the global palaeoclimatic literature reveals no evidence for an aridification precisely at 4200 B.P. There is a consensus that the Blytt-Sernander stages of post-glacial climate change are maintained on a worldwide scale, so that after the Holocene thermal maximum at approximately 6.0 ka B.P. a slow transition to modern day conditions is observed. There are no Western Hemisphere or East Asian analogues to the rapid aridification of the Near East between 4500 and 3900 B.P. What little evidence there is I have presented below.

Cores from Lakes Sumxi and Bangong in Western Tibet reveal a series of dry spells between 6.0-1.5ka B.P., with maximum aridity occurring at approximately 3.8 ka B.P. (Gasse *et al.*, 1991; Gasse and Van Campo, 1994). A recently published Chinese loess record was examined to determine if mid to late Holocene patterns could be detected (Chen *et al.*, 1997). However, the authors were looking for evidence of orbital forcing (Dansgaard-Oeschger cycles and Heinrich events) and the data were not presented at a high enough resolution to observe small (less than 5ka long) climatic fluctuations. Demkin and Fedoroff (1997) observed an abrupt aridification within soils from the steppe region of southern (Ural) Russia, dated to the early Bronze Age (~4000 B.P.): cited as evidence is a soil enrichment in gypsum and carbonates, and a deflation in soil surface down to the B horizon. A recently analyzed drill core from the Yangtze Delta in China reveals a shift to a warmer, wetter environment at ~4000 B.P. (Stanley *et al.*, 1999). In summary, the literature revealed a general trend toward the modern climatic regime after the mid-Holocene thermal maximum at ~6000 B.P..

Geoarchaeologists often consult Arctic and Antarctic ice core data when reconstructing

Pleistocene climate histories. The annually deposited laminae of glacial ice possess physical and chemical signatures of past temperatures and air masses. There is no evidence from the Greenland ice core data (GISP2 core from the America-Greenland Ice Core Project) to support an aridification at 4200 B.P., however this does not take precedence over local or regional data. Climatic fluctuations of this scale and from this distance may not register at the poles, and most ice core studies employ 50-100 year core intervals instead of the more fine resolution 2.5 year intervals (e.g., Stager and Mayewski, 1997), thus short term fluctuations are unobservable. Moreover, the type of data retrieved from ice cores signals changes in temperature much more strongly than changes in precipitation patterns, so a desiccation in climate will not register as strongly as a global warming or cooling.

Lastly, computer simulations of past climate regimes through global circulation modeling (GCM) are commonly consulted when reconstructing palaeoenvironments (e.g., Kutzbach *et al.*, 1993; Webb *et al.*, 1993). However, GC models rely on changes in orbital forcings and models are constructed for multiples of 3000 years before present (e.g., 6000ka B.P., 9000ka B.P.). Therefore, the Habur hiatus event at 4200 B.P. falls outside the time scale addressed by GCM, and this source of information cannot be applied to the problem in question (A. Bush, Pers. Comm.).

3.6 Discussion and Conclusions: Contributions of Palaeoclimatic Data to Anthropological Questions

This investigation began as a question: did the climate of the Near East 4200 years ago deteriorate sufficiently to warrant site abandonment at Tell Leilan? Yes, it did. The author is satisfied that the local and regional data support a mid to late Holocene shift to a drier climate after a warm, wet phase alternately described as the "Atlanticum" the "Altithermal" or the "Holocene thermal maximum"(see Table 3.1 for a summary of climate changes). The variability seen between adjacent sites in terms of the timing, intensity and duration of climatic phases lends credence to a hypothesis that localized intense dust storms scoured the alluvial Habur plains, while nearby sites experienced less drastic yet arid weather patterns.

The anthropological aspect of the problem still remains, however. While we can reasonably conclude that the climate did indeed change after about 5,000 years ago, climate alone does not cause social change; rather, human cultural and political responses to climate change influence human societies (Rosen, 1986). The ancient residents of Tell Leilan left no written explanation for their desertion, nor do their successors indicate why they reinhabited the fallen city after a three hundred year hiatus. Was the soil inhospitable to staple cereals? Did animal fodder wane in abundance and quality? While the aridification did not seem to harm the residents of Tell Leilan physically, witnessed by adequate and stable dietary and health patterns,

Table 3.1 Summary of Local, Regional and Global Climate Trends for the Holocene.

Time	*Habur Plains*	*Regional Data*	*Global Data*
Late Holocene (4.5ka B.P. onwards)	Aridification	Aridification, though wetter in some areas	Change to modern sea levels and temperatures
Middle Holocene (7.0-4.5ka B.P.)	Semi-arid, more humid at 6.0ka B.P.	Warm, humid	Thermal maximum at ~6.0ka B.P.
Early Holocene (10.5-7.0 ka B.P.)	Dry	Humid with dry spells (Neolithic Pluvial)	Rising sea levels due to glacial melting

the impact of relentless dust storms, or of a catastrophic event such as a meteorite crash, on mental and societal health is not measurable. It is entirely conceivable that while the human being is capable of enduring extreme climatic events, human society may have been susceptible to the elements, and that social and religious conventions withered in the face of environmental catastrophe. Moreover, the scale of human change cannot easily be calibrated according to geologic time: events which are months or even days in duration are not often visible to a geologist or climatologist, and yet can be crucial in understanding events of importance to anthropologists. This is obvious in the case of prehistoric human migrations, where archaeologists cannot keep track of populations and oftentimes lose sight of them altogether.

In conclusion, the aridification postulated by Weiss for the Habur hiatus is corroborated by both local and regional palaeoenvironmental data. Whether this aridification is directly responsible for the migration of the population of an entire city in unknown, but it could easily be the indirect cause of political unrest: it is simple to envision environmental stress unraveling the fabric of society and causing dissolution of this urban center. Regardless of whether or not the late 3rd millennium aridification and abandonment at Tell Leilan can be linked causally, they are certainly coincidental.

Chapter 4. Phytolith Analysis: History, Theory and Methods

4.1 Introduction

This chapter will describe the history and theory of phytolith analysis, including the methods to be used in this thesis. Section 4.2 will provide a historical perspective with which to understand the current state of phytolith analysis in archaeology. Section 4.3 will examine silicon chemistry and the absorption and uptake of silica in higher plants. Section 4.4 will outline the role of phytolith analysis in archaeology, addressing theoretical concerns such as the identification and taxonomy of phytolith morphotypes. The concluding section of this chapter, section 4.5, will delineate the various methods currently employed to extract and analyze phytoliths from soil and dental calculus matrices.

4.2 Historical Considerations

The advent of the microscope effectively heralds the first recognition of "plant stones", commonly referred to as phytoliths (Mulholland and Rapp, 1992a). Von Loeuwenhoek described what are now known as calcium oxalate crystals, or calcium phytoliths, as early as 1675 (Arnott, 1976), however opal silica bodies would not be systematically examined for another 150 years (Rovner, 1983). German physician and botanist Christian Ehrenberg is credited with describing the first *phytolitharia* in 1841 as part of his massive contribution to exploring the microscopic universe of *infusoria* (tiny flora and fauna) (Powers, 1992). Ehrenberg examined the dust collected by Charles Darwin during his voyages aboard the Beagle (Darwin, 1846), and later sampled sediments from Europe and Asia, research which culminated in his classic textbook entitled Mikrogeologie (Powers, 1992). Important seminal works were also published by Gregory (1855) and Ruprecht (1866), whose investigations primarily concerned sediments and the identification of palaeoenvironments.

After several decades of initial interest, however, phytolith studies waned until the beginning of the 20th century (Rovner, 1983). When phytolith studies resurfaced from academic hibernation, researchers were more concerned with botanical taxonomy than their ecologically minded predecessors (Piperno, 1988; Powers, 1992). German and Eastern European scholars dominated the discipline (e.g., Netolitsky, Formanek, Frohnmeyer) in pre-war years, however Soviet and Western European researchers became prominent after World War II (Powers, 1992). In the 1950's phytolith analysis was furthered in both theory and method by several key British scholars, and the University College of North Wales was particularly instrumental in supporting phytolith research (e.g., Parry and Smithson, 1958a; 1958b). Phytolith analysis at this time was predominantly taxonomic in focus, with grasses and soils from various environments being classified on the basis of phytolith morphology (e.g., Blackman, 1971; Twiss *et al.*, 1969).

Irwin Rovner first applied phytolith analysis to archaeological problems (Rovner, 1971). Phytolith analysis occupies a familiar role in the science of archaeology: it is a technology borrowed from cognate disciplines, namely botany and geology. Rovner's application of phytolith analysis to archaeological problems in North America presented phytolith analysis with a new identity (Rovner, 1971); no longer solely the property of plant biologists and soil scientists, phytoliths were introduced to archaeologists as indicators of ancient diets and environments.

Archaeologists have further refined the original methods by adjusting for soil conditions and preservation factors, and have constructed regional taxonomic keys for the classification of phytoliths from sites around the globe (e.g., Mulholland and Rapp, 1992a). Due to the efforts of archaeologists and palaeoecologists during the past two decades, significant advances have been made in the recovery of phytoliths from areas previously thought to be impervious to palaeoethnobotany, such as the alkaline tropical environments of Panama (Piperno, 1983) and Ecuador (Pearsall, 1979). In addition, major theoretical and classificatory gains in phytolith analysis have been achieved by archaeologists, most notably in examining the domestication of cereals, beans and squashes, and other horticultural staples in prehistory (e.g., Pearsall 1979; Pearsall *et al.*, 1995; Piperno *et al.*, 1985; Rosen, 1987). Archaeologists are also becoming more aware of the contributions that phytoliths can make in reconstructing palaeoenvironments and palaeoclimates (e.g., Fredlund, 1993; Fredlund *et al.*, 1998) and are starting to use this procedure alongside more traditional techniques, such as palynology and sedimentology. Recent innovations in phytolith analysis include the use of opal silica bodies in forensic investigations (e.g., Marumo and Yanai, 1986), AMS radiocarbon dating (e.g., Mulholland and Prior, 1993), thermoluminescence dating (e.g., Rowlett and Pearsall, 1993), stable carbon isotope studies (e.g., Kelly *et al.*, 1991), palaeoclimatic reconstruction (e.g., Fredlund, 1993), and in the analysis of residue from lithics (e.g., Kealhofer *et al.*, 1999) and ceramic vessels (e.g., Jones, 1993; Tyree, 1994).

The innovative technique employed in this thesis allows palaeodietary plant use to be directly reconstructed by extracting and analyzing phytoliths embedded in dental calculus. This method was first performed on herbivore teeth by Armitage (Armitage, 1975), whose methods have been modified in recent years by Middleton (Middleton, 1990, 1992; Middleton and Rovner, 1994). Physical anthropologists and archaeologists are now beginning to utilize preserved monkey (e.g., Ungar, 1994), ape (e.g., Ciochon *et al.*, 1990) and human dental calculus (e.g., Danielson and Reinhard, 1998; Lalueza *et al.*, 1994, 1996; Middleton, 1993) to further understand diet and dental wear in primates and ancient humans. The Tell Leilan research contributes to the growing body of literature incorporating phytolith analysis into palaeoenvironmental and palaeodietary reconstruction by investigating prehistoric plant utilization at Tell Leilan, Syria (5000 B.P.) via phytolith analysis of human dental calculus.

With a rising interest in palaeoethnobotany among archaeologists, phytolith analysis has gradually gained the respect and trust of palaeobotanists, and has joined palynology and macrobotanical analysis in becoming a reliable tool of the environmental archaeologist. Several books on phytolith method and theory have been published (Pearsall, 1989; Piperno, 1988; Piperno and Pearsall, 1998), and several symposia have been dedicated to disseminating information from international phytolith research laboratories (Rapp and Mulholland, 1992; Pearsall and Piperno, 1993). Phytolith analysis has earned a respectable role in the modern science of archaeology, and future prospects for this burgeoning field are very bright (Rosen, 1995b). Evidence of this can be found in the recent success of the 2nd International Meeting on Phytolith Research (August 27-29, 1998, France), as well as by the recent prevalence of articles involving phytolith analysis in respected archaeology and palaeoethnobotany journals (e.g., Danielson and Reinhard, 1998; Kealhofer and Penny, 1998; Kealhofer *et al.*, 1999; Lentfer and Boyd, 1998; Madella *et al.*, 1998; Zhao and Pearsall, 1998; Zhao *et al.*, 1998).

4.3 Formation of Biogenic Opal Silica Bodies in Higher Plants

Phytoliths are biogenic accumulations of hydrated opaline silica ($SiO_2{\cdot}nH_2O$) in the epidermal "silica cells" of plants[5]. Because silica invades and eventually fills in a cell, phytoliths mimic original cell shapes and can be identified and classified according to size, surface ornamentation and shape (Pearsall and Dinan, 1992). The formation of phytoliths is a somewhat nebulous issue, owing to two factors: experimental studies have yet to identify the role of silicon in most higher plants, and the observed differential silicon uptake and absorption between species is not fully understood. This section will explore the contributions of chemistry and plant physiology to the elucidation of phytolith formation in higher plants.

4.3.1 Silicon Chemistry

Silicon (Si) is classified as a group IV p-block element, belonging to the same column as carbon, germanium, tin and lead in the periodic table (Atkins, 1989). After oxygen, silicon is by far the most abundant element in the earth's crust, being the primary component of such minerals as quartz, feldspars, pyroxenes, and amphiboles, (Press and Siever, 1986). In its ionic form, silicon is quadrivalent (Si^{4+}), but is most commonly bound to hydroxyl groups to form the monosilicic acid [H_4SiO_4] found in soil (Wollast and MacKenzie, 1983) or the silicon hydroxide ion found in groundwater solution (Simkiss and Wilbur, 1989).

4.3.2 Silica Absorption by Plants

The accepted interpretation of silica absorption among plant biologists is that monosilicic acid from groundwater sources enters the plant's root cortex (Sangster and Parry, 1981). Moving through the cortex to the endodermis, the unpolymerized monosilicic acid moves upward in the transpiration stream of the xylem to the stem, leaves and inflorescences (Simkiss and Wilbur, 1989). Polymerization to solid, hydrated oxide SiO_2-nH_2O (opal silica gel) may occur at tissue sites close to the transpiration stream (Sangster and Parry, 1981), most commonly in epidermal and hypodermal cells (Parry and Smithson, 1964). Silica polymerization is irreversible for all known vascular plants; once formed, the silica gel cannot be depolymerized and redistributed to other regions of the organism (Lewin and Reimann, 1969; Kaufman *et al.*, 1981).

The term phytolith is reserved for amorphous (non-crystalline, non-birefringent) silica gel deposits that have aggregated between cells, in cell membranes, or inside the cell lumen

[5] Cells other than "silica cells" also silicify, but less often and with more variability in morphology

(Sangster and Parry, 1981). Complete silicification of a cell results in a siliceous replica of the cell, whereas incomplete silicification produces a phytolith whose morphology only partially resembles the original cell structure (Piperno, 1988).

Silica uptake and aggregation within the plant is influenced by many physical and chemical factors, as well as time. The longer a plant specimen has been growing, the more phytoliths it will contain, and the larger and more complete those phytoliths will be (Simkiss and Wilbur, 1989). Furthermore, the amount of water moving through the plant system and the rate of transpiration influence phytolith formation (Rosen and Weiner, 1994). This may present problems in identifying relative and absolute abundance of opal silica morphologies; however this phenomenon has not been systematically addressed by phytolith analysts (Piperno, 1988). Additionally, soil alkalinity compromises silica solubility, resulting in a bias against phytolith formation and preservation in basic (pH>9) soil conditions (Lewin and Reimann, 1969). Laboratory experiments have shown that silicic acid concentrations within nutrient solutions are positively correlated with silica deposition in rice plants (Matsui and Takatoh, 1963), as well as rye, sunflowers, oats and horsetails (Lewin and Reimann, 1969), meaning that silica-enriched soil beds and groundwater sources are liable to encourage phytolith formation.

There has been considerable debate over the mode of transport of silica (active versus passive) in plants. Some plants appear to transport silica passively in the transpiration stream, while others actively regulate the uptake of monosilicic acid (Simkiss and Wilbur, 1989). Active or mediated transport has been demonstrated to occur under experimental conditions, when: a) plant silica concentrations are higher than $Si(OH)_4$ concentration in solution, b) the rate of silica absorption is faster than the transpiration rate, c) monosilicic acid is absorbed independently of water, and d) metabolic inhibitors do not reduce silica absorption (Matsui and Takatoh, 1963; Lewin and Reimann, 1969; Simkiss and Wilbur, 1989). It appears that silica is actively transported in *Oryza* (rice) and *Phaseolus* (bean) specimens, and probably in *Equisetum* (horsetail) species due to their relatively high Si concentration (Lewin and Reimann, 1969).

4.3.3 Silica Metabolism in Plants

While most plants grown in soil contain detectable amounts of silica, the role of silica in plant metabolism has eluded plant biologists despite a considerable number of experimental silicon-deprivation studies (Epstein, 1972). After four decades of laboratory research, it is generally accepted that silicon is essential for those plant species (e.g., *Equisetum* spp., grasses, *Oryza* spp.) which boast relatively high silica concentrations, but is non-essential for those species with low silica content (Chen and Lewin, 1969; Kaufman *et al.*, 1981). Grass, rice and horsetail shoots and leaves reportedly wilt and collapse upon themselves in silica-depleted environments, possibly indicating a structural role for silica in these plants. Kaufman *et al.* (1981) have posited a "window hypothesis" for the occurrence of silica cells in sugar cane: by allowing light rays to penetrate into the underlying photosynthetic mesophyll tissue, silica cells may offer the plant greater photosynthetic ability. Further support for this hypothesis comes from Rao *et al.* (1989) who report that increased potassium in the soil results in increased opal phytolith formation, which the authors credited for making the leaves more erect and creating a better "light environment" in rice (*O. sativa*) plants. Another hypothesis postulates that high phytolith content in grasses serves to deter grazing by herbivores through accelerated tooth wear and is therefore evolutionarily adaptive (McNaughton *et al.*, 1985).

To help solve this complex problem, plant biologists have examined the role of silica in other silica absorbing organisms, including a group of algae known as diatoms (Bacillariophyceae). Diatoms possess highly complex sculptured walls (frustules) composed of virtually pure hydrated silica in the form of $[SiO_2]_n \cdot nH_2O$ (opal) (Volcani, 1981). Studies have shown that, aside from being the primary component of frustules, silicon is biochemically essential for these algae because it plays a role in metabolism and in cell division, by facilitating DNA synthesis (Sullivan and Volcani, 1981). Silicon is not essential to fungi or to bacteria, and while it is found in trace amounts in most animals, silicon does not appear to serve any particular metabolic function (Orten and Neuhaus, 1970).

To summarize, the presence of silica in higher plants is ubiquitous, but its concentration is variable. Plants that possess higher amounts of silicates are expected to require Si for structural support or metabolic purposes, and have been hypothesized to transport monosilicic acid actively across the epidermal membrane. In contrast, plants with relatively low Si levels are thought to passively intake monosilicic acid from groundwater and absorb it from the transpiration stream; silicon is reported to be non-essential for these species. Because of the high degree of inter-plant variability with respect to the absorption and metabolism of monosilicic acid, phytolith analysts should ascertain the metabolic requirements of each plant within the sample. Only by being familiar with the formation of phytoliths within each species will analysts be able to make meaningful comparisons of relative and absolute phytolith abundance within and between archaeological samples. Research put forth in this thesis concentrates upon grass genera, which are known to accumulate large amounts of silicon and are reliable producers of phytoliths.

4.4 PHYTOLITHS IN ARCHAEOLOGY

To most archaeologists, phytolith analysis represents a microbotanical technique that provides information complementary to palynology, macrobotanical data, zooarchaeological research and other subsistence and palaeoenvironmental investigations. However, even when used independently, phytoliths can allow the archaeologist to answer important questions regarding plant availability and utilization in prehistory. Depending upon the original context of the sample, phytoliths can provide information about generalized palaeovegetation and palaeoclimate, plant domestication processes, palaeodiet, and the use of plants in textiles and non-dietary contexts (e.g., use of coca [Middleton, 1993]). Phytoliths have played an important role in studies of the domestication of maize, particularly in Mesoamerica (e.g., Piperno, 1983), and have been invaluable in reconstructing prehistoric plant use in alkaline soil sites, where organic preservation is poor.

Methodologically, phytolith analysis is highly analogous to palynology. Like pollen grains, phytoliths are microscopic in size (most are 5-60 microns) and are easily airborne, however they are typically deposited by "decay-in-place" mechanisms (Dimbleby, 1978:129). Pollen grains are lighter and are dispersed, by wind or animal action, and can be found up to several thousand kilometers from their origin (Horowitz, 1992). Thus, phytoliths are generalized indicators of prehistoric botanical resources that represent a smaller geographic area than pollen samples do. Phytoliths are highly resilient and often survive taphonomic insults that would destroy organic remains; only under very high temperatures (above 950 degrees Celsius) and high alkalinity (pH>9) does structural distortion of biogenic silica occur (Piperno, 1988).

4.4.1 Identification and Taxonomy

Phytolith shapes, especially in grasses, exhibit both multiplicity and redundancy (Mulholland, 1989; Rovner, 1971). 'Multiplicity' means the production of many phytolith types by one plant type, and 'redundancy' refers to the observation that many plant types may produce a certain phytolith morphotype. Moreover, not all plants form phytoliths, and of those that do, not all produce morphotypes which are diagnostic to a particular taxon (Piperno, 1988). Thus, accurate identification of opal silica bodies demands an extensive comparative collection and a seasoned analyst. The recognition and classification of discrete phytolith morphologies is the cornerstone of phytolith interpretation: the ability of the technician to make meaningful conclusions regarding plant species representation and differential abundance is predicated on the fact that diagnostic markers exist. Such markers may only identify a plant to a high taxonomic level (e.g., superfamily), but several types of grasses produce morphotypes that are distinctive at the subspecies level (e.g., maize variants). Therefore, it is essential that analysts be able to anticipate the taxa involved and have access to a comprehensive comparative collection to identify unknown morphotypes.

Phytoliths can be identified according to either the shape of the body (e.g., Rovner, 1971), or the corresponding plant cell in which it forms, or both (e.g., Piperno, 1988). Most modern phytolith systematists incorporate both shape and locus of origin into the identification of a phytolith because cellular origin can often be surmised from general morphology. Further identifying characteristics can then be applied, such as relative size, two-and three-dimensional shape, surface ornamentation, and wall thickness (Piperno, 1988; Mulholland and Rapp, 1992a). Recently, the lack of quantification in phytolith identification has been criticized by Rovner and Russ (1992), who advocate the use of stereoscopy to identify additional morphometric characters. These authors identify almost 60 parameters by which redundancy in identification could be reduced, grouped into measures of a) size, b) shape, c) topology, d) position and e) grey-scale (Rovner and Russ, 1992). Ball *et al.* (1993) successfully employed statistical tests to quantify differences in morphology between phytoliths from different plant tissues (laminae, inflorescence bracts and culms) of einkorn (*Triticum monococcum*).

While phytolith taxonomy remains controversial, important gains are being made which allow non-specialists to comprehend phytolith identification and nomenclature. With the publication of reference keys and diagrams, phytolith identification is becoming increasingly accessible to those without the facilities or resources to make proper reference collections (e.g., Pearsall and Piperno, 1993; Piperno and Pearsall, 1998; Mulholland and Rapp 1992b). Phytolith pictures and descriptions are now available on-line, as are chat groups and web pages discussing current research in the area.

4.4.2 Grass Phytoliths and the Identification of Cereals from Tell Leilan

As discussed above, phytolith analysts have long debated how to describe and name the phytolith forms they observe, and most use a system which combines both the shape of the cell and the suspected plant cell of origin (e.g., long hair cell). I consulted several sources when identifying and naming phytoliths during the analysis of the Leilan samples (Kaplan *et al.*, 1992; Mulholland and Rapp, 1992b; Piperno and Pearsall, 1998; Rosen, 1992, 1993; Twiss *et al.*, 1969). In the event of disagreement I deferred to the opinion of Rosen, a geoarchaeologist and phytolith analyst at Ben Gurion University of the Negev in Beer Sheva, Israel. Rosen's work in distinguishing between various Triticeae domesticated and wild cereals has proven valuable for this thesis (Rosen 1992, 1993; Rosen and Weiner, 1994).

Among grasses, most analysts distinguish between forms most commonly found in five grass subfamilies: Pooideae/Festucoideae, Chloridoideae, Panicoideae, Arundinoideae and Bambusoideae (Piperno and Pearsall, 1998; Twiss, 1992). The following description of this breakdown is from Twiss (1992) and is illustrated in Figure 5.1.

The subfamily Pooideae/Festucoideae contains C_3[6] grasses generally found at moderate to high latitudes and altitudes, and includes the economically important cereals wheat, barley, oats and rye. Pooid/Festucoid phytoliths are typically round/oval or rectangular/square, including the rondels, rectangles and long epidermal cells dominating Near Eastern phytolith assemblages (Rosen, 1993). The subfamily Chloridoideae comprises C_4 plants (e.g., short grasses) occupying arid zones at low latitudes, usually in areas where rainfall occurs in the summertime or where there is no rainfall season. Chloridoid plants contain long sinuous phytoliths (from the intercostal zone) and costal short cells such as saddles, and to a lesser extent crosses and dumbbells. The subfamily Panicoideae contains both C_3 and C_4 plants and has a wide geographic range. Epidermal costal phytoliths tend to be shaped like dumbbells and crosses, while intercostal elements contain rectangular wavy or sinuous cells. This subfamily contains the economically important sorghum, maize and sugarcane plants. The subfamily Bambusoideae, native to Southeast Asia, central Africa and South America, contains the supertribes Oryzanae and Bambusanae and produces mainly crosses and dumbbells (Oryzanae) and saddles (Bambusanae). Subfamily Arundinoideae is heterogeneous and widely distributed throughout the southern hemisphere, comprising mainly C_3 but also C_4 plants. Accordingly, many phytolith morphotypes are represented in this subfamily, including saddles, dumbbells,

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[6] During dark reactions, C_3 plants use the Calvin cycle to fix carbon, whereas C_4 plants use Hatch-Slack metabolism and succulents mostly employ crassulacean acid metabolism. C_3 plants accumulate less ^{13}C than C_4 plants do, and therefore have a lower $\delta^{13}C$ measurable by stable carbon isotope analysis of organic remains.

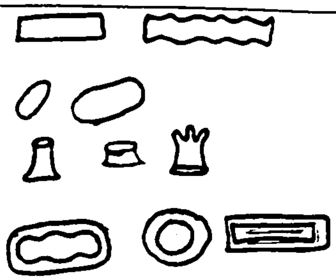
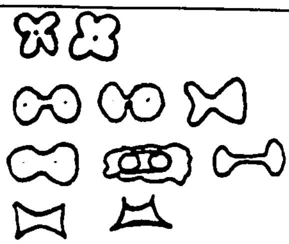
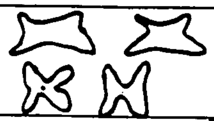
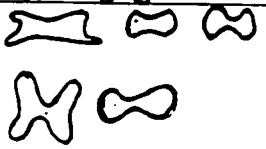
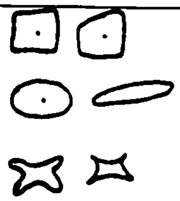
Gramineae Subfamily	**Characteristics**	**Predominant Phytolith Morphotypes (minor)**	**Illustrations**
Pooideae/ Festucoideae	C_3 plants Mid to high latitudes and altitudes	Rectangular Oval Rondel Trapezoid	
Panicoideae	C_3 and C_4 plants Wide geographic range	Crosses Dumbbells Bilobates (saddles)	
Chloridoideae	C_4 plants Low latitudes	Saddles (crosses, dumbbells)	
Bambusoideae	Bambusoid (C_3) and Oryzoid (C_3) S.E. Asia, C. Africa, C. and S. America	Elongate Saddles, Dumbbells and Crosses	
Arundinoideae	C_3, some C_4 S. Hemisphere	Square Oval (saddles, crosses, dumbbells)	

Figure 4.1 Illustrations of major grass short cell phytolith morphologies. Compiled from Brown (1984), Piperno and Pearsall (1998) and Twiss (1992).

crosses, ovals, rectangles and barrel-shapes. In the Leilan sample, Pooid/Festucoid and Panicoid grasses are expected to dominate the natural flora, due to geography and climate, with known Pooid/Festucoid cereals (barley, wheat) at the base of the subsistence economy. Although recent research (Mulholland and Rapp, 1992b) shows that this classificatory scheme may not hold true for all phytolith forms, it is generally accepted in the academic community (e.g., Piperno and Pearsall, 1998). The most controversial categories, dumbbells and saddles, are found minimally in the Leilan sample, reducing any concerns arising from the classification of these phytoliths in this thesis research.

It is important to consider the cell of origin for the different cereal phytolith morphologies. Silica skeletons (see Figure 4.2) are multi-celled phytolith sheets from epidermal tissue, and have been described in detail by Rosen (1992, 1993). Differences can be seen in the shape of the individual cells (wavy, straight), the size of each cell and the presence of any protuberances. Cereal silica skeletons possess long rectangular cells with dendritic protuberances (see Figure 4.3), and differences in the height and width of these branches allow the archaeologist to differentiate between the common cultigens (Ball *et al.*, 1996; Kaplan *et al.*, 1992; Rosen, 1992, 1993). Also, the number of cells per silica skeleton is informative of growing environment: the more cells, the more moist the soil, either through rainfall or irrigation (Rosen and Weiner, 1994). Small prickle cells, or trichomes, are conical cells, often with flat bases, which are found as "appendages" to long cells in the living plant (Kaplan *et al.*, 1992). The variation in tip dimension between small prickle cells is the basis for taxonomic differentiation. Large prickle cells have elongated cones and minimized bases compared with the small prickle variety, and macrohairs are even more elongate, having thin spiky cones. Papillae (also called trichome base cells) are epidermal sheet elements that serve as bases for trichome cells (see Figure 4.4). They are rounded and have differing margins that serve as distinguishing characters. For example, wheat papillae usually have a larger diameter and more pits than barley papillae (Rosen, 1992; Tubb *et al.*, 1993). Trapezoids (see Figure 4.5) are also found often in cereal plants, and these are distinctive in terms of shape (round, elongate), size and margin type (sinuous, lobed, straight).

4.4.3 Tell Leilan Phytolith Project

Weiss' Environmental Degradation hypothesis for the abandonment of Tell Leilan presents an intriguing archaeological problem that can be tested using phytolith analysis. Macrobotanical investigations from the Tell Leilan samples have been carried out by Wetterstrom (Wetterstrom n.d.a., n.d.b.), so information regarding the presence of expected wild and domesticated plants is available. However, these macrobotanical analyses of living floors and middens at Tell Leilan have concentrated upon Ninevite V levels (Wetterstrom n.d.a) and do not directly address the Leilan abandonment episode. It is known that by Period II wheat, barley and legumes were cultivated, and evidence from a living floor in Lower Town South suggests that cereal grains were cleaned and processed before distribution (Wetterstrom n.d.b). But there is no evidence, archaeological or historical, to support Weiss' claim that Leilan farmers could not produce enough food to feed their families. By examining phytoliths embedded in human dental calculus from Period II and comparing this with data from previous generations alive during more humid climatic episodes (Periods III and VI), the research presented here attempts to solve this mystery: did the residents of Tell Leilan grow enough food to sustain their population? If not, it is expected that wild resources obtained through hunting and gathering would have been added to the diet to mitigate low cultivar yields. Rosen (1995a) has identified several well-known drought-avoidance tactics, known from archaeological and ethnographic data, including crop and herd diversification and traditional knowledge about famine foods.

The skeletal material dates from Periods II-VI, representing the three thousand years preceding population abandonment (Habur hiatus I). By analyzing the phytoliths from these samples I will examine the variety and relative abundance of plant types consumed in the diet. By juxtaposing resource availability with resource exploitation among the inhabitants of Tell Leilan prior to migration, I will investigate whether there existed a real or emically perceived environmental stimulus to abandon a thriving city of the Akkadian Empire at 4200 B.P.

4.5 Research Methods

The methods involved in phytolith analysis are predicated on the isolation of opal silica bodies from their organic and inorganic matrices by physical and chemical means. The necessary laboratory equipment is readily located in most facilities designed for microbotanical research (e.g., a palynology lab), which are commonly equipped with the appropriate chemicals, equipment (e.g., centrifuge, muffle furnace, fume hood, hot plate) and microscope facilities.

4.5.1 Preparation of a comparative collection

The isolation of phytoliths from living plant tissues is normally accomplished via one of two procedures: wet oxidation and dry oxidation (ashing). Traditional botany techniques, such as epidermal peels, are rarely employed in modern laboratories as they involve complex procedures and the mechanical slicing of the epidermal layer (Pearsall, 1989). The process of oxidation removes much of the organic content, and can be done by chemical oxidizing agents or by incineration. The main difference between these two procedures is the inclusion of articulated phytoliths (spodograms) in incinerated samples; chemical oxidation reliably produces samples with disarticulated phytoliths, which are more easily recognizable and identifiable by the observer (Pearsall, 1989). I prefer dry ashing, as incineration may be safer than processing using the chemicals described by Rovner (1971) and Piperno (1988) for wet oxidation procedures. Also, samples can easily be left overnight if the oxidation process is slow (e.g., for coniferous specimens). Instructions for both methods can be found in Appendix A.

4.5.2 Extraction of Phytoliths from Sediments

Isolation of opal silica bodies from sediments is based on physical action rather than chemical reaction. The sample (at least 10 grams) is first deflocculated to remove clays and then sieved to remove sand and larger silt particles. Both chemical oxidation and ashing remove organics, and carbonates are liberated by addition of a weak HCl solution. The remaining sediments are settled via flotation with a heavy density liquid (2.3 g/mL) such as sodium polytungstate or cadmium iodide/potassium iodide (Zhao and Pearsall, 1998), and the floating phytoliths can be skimmed off the top, rinsed and mounted. The analyst can vary the order and timing of these procedures according to the physical and chemical properties of the sediment being analyzed : for example, sediments with high carbonate loads should be treated with acid before deflocculation. As with many palaeobotanical techniques, the end justifies the means, and the phytolith literature is filled with different techniques to suit a variety of depositional contexts. Detailed procedures can be found in Appendix A.

4.5.3 Extraction of Phytoliths from Dental Calculus

Supragingival calculus is mineralized plaque that normally grows at the base of a living plaque deposit. Calculus is most often found on the lingual surface of mandibular incisors and the buccal surface of molars, as these sites are close to salivary ducts. (Hillson, 1996). As plaque mineralizes, food and grit particles small enough to avoid dislodging are incorporated into this matrix, including phytoliths caught in the calculus during mastication. Addition of HCl dissolves much of the mineral component of calculus (apatite, whitlockite and octacalcium phosphate) and liberates biogenic silica particles for viewing under a light microscope. While the wet oxidation method described in Appendix A is recommended by Armitage (1975) and Middleton and Rovner (1994), dry ashing would also reduce the organic component of archaeological calculus. Ciochon *et al.* (1990) employ a strategy which allows them to examine the enamel surface with a scanning electron microscope, however post-mortem contamination may not be controlled for when viewing the phytoliths embedded in surface striations (Middleton and Rovner, 1994). For scanning electron microscopy, decontaminated calculus samples are removed from the tooth and plated in a carbide or gold-palladium mixture 200 Angstroms thick (Piperno, 1988:128). The protocol used in extracting phytoliths from the Leilan samples will be discussed in Chapter Five, alongside the results of this analysis.

4.6 CONCLUSION

Despite almost 30 years of archaeological application, phytolith analysis remains a relatively novel and somewhat suspect method in palaeoethnobotany. This is largely due to the need for the preparation of exhaustive comparative collections and the uncertainty regarding exactly how and why phytoliths form in the first place. However, when viewing the use of grass species in prehistory, namely cultigens such as wheat, barley, rye, maize and rice, phytolith analysis can be very useful. For example, phytolith analysis can be much more precise in determining species differences among cereals than pollen analysis, and phytoliths are more taphonomically resistant than macrobotanicals, even charred remains. Finally, by analyzing the phytoliths found on teeth or in dental calculus, archaeologists can examine plant food intake during an individual's lifetime, a time frame rarely achieved by macrobotanical analysis and palynology.

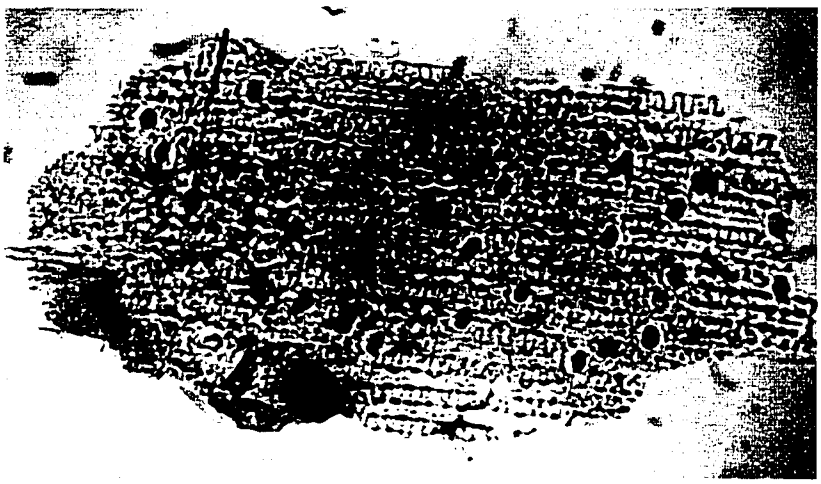


Figure 4.2 Silica skeleton of cereal from LC13 (Period III).
Field of view is approximately 200 x 350 μm.

Figure 4.3 Dendritic cereal phytoliths from LC29 (Period II). Each cell is approximately 9 x 50 μm.

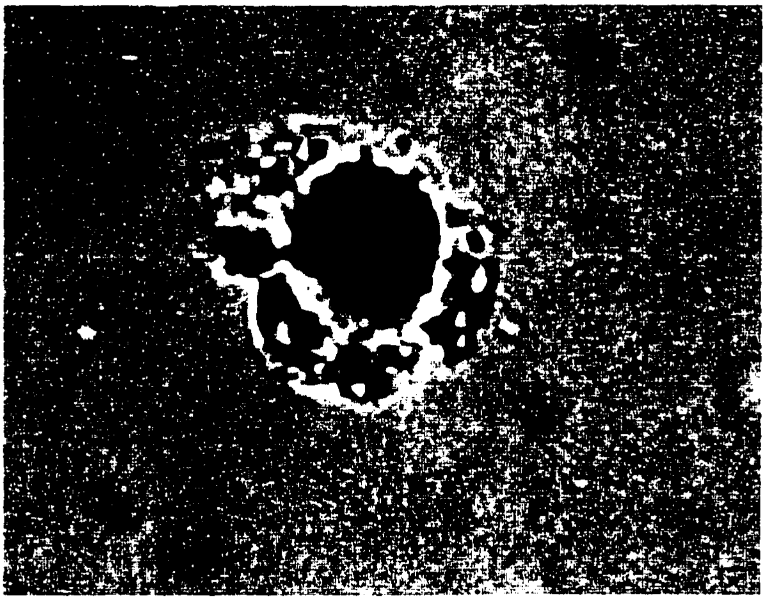


Figure 4.4 Papilla (trichome base cell) from LC/C.E.2 (Period II). Object is 25 μm wide.

Figure 4.5 Elongate trapezoid with wavy sides, from LC32 (Period II). Object is 60 x 15 μm.

CHAPTER 5. PHYTOLITH ANALYSIS OF LEILAN HUMAN DENTAL CALCULUS

5.1 INTRODUCTION

The abandonment of Tell Leilan between 2200 and 1900 B.C. is a complex problem with several hypothesized explanations. Weiss' theory that aridification led to crop failure and widespread food shortage has not been independently tested through botanical remains. Macrobotanical studies typically recover the remains of crop production and interpret subsistence activities from the discarded plant parts (McCorriston, 1994), thus providing information about what was grown rather than what was eaten. In contrast, phytoliths found in dental calculus signal the consumption of agricultural products. In societies that export or import large amounts of grain, there may be a discrepancy between production and consumption of goods, and therefore macrobotanical remains should be studied in tandem with dietary plant remains such as phytoliths from dental calculus. Wetterstrom (n.d.a, n.d.b) has examined Ninevite V period macrobotanical remains from storage facilities and household floors, but no data pertaining to the Period II abandonment are available. The research presented here examines phytoliths recovered from human dental calculus at Tell Leilan, and spans much of the three thousand years prior to the abandonment at ~2200 B.C..

If arid conditions prevailed in the years prior to the abandonment of Tell Leilan, archaeologists would expect to observe a shift towards drought tolerant crop species, specifically the dominance of barley over wheat, in the diet. Other known adaptations to famine, such as an increased reliance upon meat, would not be observed by palaeobotanical analysis alone, however a lowered concentration of plant matter in the diet, as seen through a reduction in absolute phytolith abundance in the dental calculus, could be expected in this instance. Expansion of subsistence strategy is also a common reaction to famine (Colson, 1979), so the introduction of new plant foods could signal staple crop shortages.

The results of the phytolith analysis performed on the Leilan human dental calculus samples are interesting and unique in several respects. First, more phytoliths were observed in this sample than in any other study published on dental calculus phytoliths to date (e.g., Ciochon *et al.*, 1990, Lalueza *et al.*, 1994, 1996). Second, only grass phytoliths were observed, whereas macrobotanical remains from the Near East often recover evidence of legumes and fruits in addition to the commonly cultivated cereals (Miller, 1991; Wetterstrom n.d.a, n.d.b). Third, Period III (3000-2400 B.C.) phytoliths are larger, more abundant and more complex than those recovered from Periods II (2400-2200 B.C.) and VI (5000-4100 B.C.).

5.2 METHODS AND MATERIALS

Thirty-three human dental calculus samples were made available for processing after dental calculus grades (on a scale of zero [absent] to three [heavy]) had been scored by Leslie Dawson (University of Alberta). Calculus from each tooth was then brushed with an acrylic paintbrush, scraped off the tooth using a bamboo stick and collected by quadrant (maxillary/mandibular; anterior/posterior) for storage in glass vials (Dawson, 1998). Beyond the initial removal of surface dust by brushing, no further measures were taken to remove surface contaminants from the samples once they were removed from the teeth. This is significant, because phytoliths are considered to be rare in dental calculus (Rosen 1999, pers. comm.; Juan 1999, pers. comm.), and loss of material through excessive abrasion is equally as problematic as contamination by burial soil environment. For example, in a study by Lalueza *et al.* (1996), calculus samples yielded no more than ten phytoliths per tooth.

Table 5.1 provides burial and osteobiographical data for each of the fourteen individuals sampled. Three time periods are represented, albeit unequally: two samples from Period VI (~5000-4100 B.C.), ten samples from Period III (~3000-2400 B.C.) and 21 samples from Period II (~2400-2200 B.C.). Both males and females were included (three males, three females, eight individuals of indeterminate sex), comprising eight adults, one young adult, four adolescents and one individual of unknown age. Samples were given a code according to the order in which they were processed and, because I used a "blind" approach, the Leilan Calculus codes (e.g., LC14) are not ordered relative to the burial context. In all tables, samples are placed in chronological order, however relative chronologies beyond the level of "period" are only available for two Period II Operations. In Operation 4a Lot 18, burial four (represented by samples LC 23-25) is the oldest in the feature, burial two (LC 17,18) is the youngest, and burial three (LC 7,8,21,22) is chronologically intermediate. Burial three (LC 5,6) in Operation 77G01 Lot 15 was deposited before burial two (LC 26,27). However, establishing relative chronologies

Table 5.1 Osteobiographical and Burial Data for the Individuals Sampled

Burial ID	Period	Age	Sex	Samples taken	Weight (g)[1]	Sample ID
L85 OP4a 18 B.2[2]	II	Adult	U	Max. Ant.	**0.007**	LC 17
				Max. Post.	**0.009**	LC 18
L85 OP4a 18 B.3	II	Adult	M	Mand. Ant.	**0.095**	LC 21
				Mand. Post.	**0.025**	LC 7
				Max. Ant.	**0.051**	LC 22
				Max. Post.	**0.050**	LC 8
L85 OP4a 18 B.4	II	Adult	U	Mand. Ant.	**0.007**/0.002	LC 23
				Mand. Post.	**0.015**/0.002	LC 24
				Max. Post.	**0.015**/0.005	LC 25
L87 77G01 B.1	II	Adult	U	Mand. Ant.	**0.020**	LC 19
				Mand. Post.	**0.014**	LC 20
L87 77G01 15 B.2[3]	II	15+/- 3yrs.	F	Mand. Ant.	**0.009**/0.001	LC 26
				Mand. Post.	**0.043**	LC 27
L87 77G01 15 B.3	II	15+/- 3yrs.	M	Mand. Post.	**0.018**	LC 5
				Max. Post.	**0.003**	LC 6
L89 76E20 B.6 Ind. 1	II	~18yrs	U	Mand. Post.	**0.025**/0.006	LC 28
L89 76E20 B.6 Ind. 2	II	15+/- 3yrs.	U	Mand. Post.	**0.009**/<0.001	LC 29
L89 76E20 Rm. 6 B.7	II	15+/- 3yrs.	U	Mand. Ant.	**0.010**/0.001	LC 30
				Mand. Post.	**0.040**/0	LC 31[4]
				Max. Ant.	**0.021**/0.005	LC 32
L89 76F20 112 B.5	II	Adult	U	Max. Ant.	**0.002**/0.001	LC 33
L80 OP1 61 B.1	III	Adult	M	Mand. Post.	**0.024**	LC 1
				Max. Ant.	0.011	LC 15
				Max. Post.	**0.018**	LC 2
L80 OP2 36 Ind 1	III	Adult	F	Mand. Post.	**0.007**	LC 3
				Max. Ant.	0.018	LC 16
				Max. Post.	**0.013**	LC 4
L80 OP1 108 B.2	III	Adult	F	Mand. Ant.	0.005	LC 11
				Max. Ant.	0.007	LC 12
				Mand. Post.	0.009	LC 13
				Max. Post.	0.013	LC 14
L80 OP 1C 26	VI	U	U	Max. Ant.	0.006	LC 9
				Max. Post	0.009	LC 10

[1] Bold indicates calculus weight, regular typeface indicates phytolith yield.

[2] This feature (L85 Operation 4a Lot 18) contained four burials; from stratigraphic context it appears that burial four is relatively older than the others, burial three is chronologically intermediate, and burial two is the youngest of those represented here.

[3] Burial two is relatively younger than burial three in this feature

[4] Sample 31 was destroyed during centrifugation and therefore does not appear in any further text or tables

between Operations is not possible as the archaeological data needed to do so is not available, thus I am not able to comment on the chronological relationships between individuals in different operations within the same time period.

Calculus samples were weighed before processing, and several were also weighed after processing to determine the actual amount of material being scanned. Weight measurements were initially taken using the Mettler P163N electronic balance in the Department of Anthropology's Palynology Lab, however samples were sufficiently small (less than 0.01 grams) to warrant using a more sensitive instrument. Dr. John Chang in the Department of Biological Sciences graciously allowed me access to the Metolius digital balance in his laboratory for weighing samples LC 23-33 and the contamination experiment samples (LC C.E. 1-4).

Dental calculus samples were processed according to a modified version of the protocol used by Lalueza *et al.* (1994, 1996). Samples were soaked in a 40g/L Calgon solution (active ingredient sodium hexametaphosphate) for 12-36 hours to loosen particles within the calculus matrix, then rinsed with distilled water and centrifuged. 10% Hydrochloric acid was then added to the samples to dissolve the calcium phosphates (apatite, brushite and octacalcium phosphate) that constitute the mineral fraction of dental calculus (Capasso *et al.*, 1995). Higher acid concentrations were used, or heat applied using a hot water bath, when reactions were slow or did not adequately dissolve the calculus. Samples were then cleaned with distilled water, centrifuged and dried with alcohol.

Microscope slides were prepared using Pro-Texx or Permount diluted with Xylene to achieve a moveable mount: phytoliths are often identified on the basis of a two-dimensional shape, but degraded forms and trapezoids are more easily identifiable when the analyst is able to rotate them. Three different microscopes were used: a light microscope (Leitz SM-Lux), a petrographic microscope (Leitz LaborLux 12 POL S) and a microscope (Leitz Dialux) with a Wild Photoautomat MPS 55 camera mount. Photographs were taken on Kodak EliteChrome 160T Tungsten colour slide film, and processed at Photographic Services at the University of Alberta. Selected slides were converted to colour prints for the purpose of documentation in this thesis.

Phytoliths mounted on microscope slides were viewed using a mechanical stage to prevent double counting of specimens. The entire mounted area was viewed at 250X magnification, and detailed identifications were made at 400X and 1000X. When phytolith tallies exceeded 200 items, the remainder of the slide was scanned at low magnification

(100X) for multiple phytoliths, which were scored separately for quantification purposes. Only a few slides bore phytoliths in sufficient concentration that 200 tallies were achieved, so as a result the majority of slides by far were scanned completely at high magnification.

To check errors in observation and identification, slides viewed early on in the research process were scanned again prior to data entry; some were even mounted again to ensure that all the calculus material was viewed. Dr. Deborah Pearsall of the University of Missouri at Columbia verified the identification of morphologies and generously allowed me access to her vast comparative collection. These precautionary measures contributed to ensuring the accurate assessment of the Leilan calculus phytolith assemblages.

5.3 Results

Table 5.2 presents the results of the phytolith analysis of the Tell Leilan dental calculus. Single cell tallies are separated from multiple cell tallies because the latter informs the researcher about environmental conditions, as will be seen in section 5.5. Like pollen, phytolith types are quantified and interpreted relative to each other and not by absolute value, so results are tabulated in relative percentage values (Pearsall, 1989; Piperno, 1988).

Domestic cereals differ only marginally from their wild counterparts. Phytolith analysts differentiate between the two by analyzing the width and pit number of papillae (Tubb *et al.*, 1993), by discriminant function analysis (Ball *et al.*, 1996) and also from taking measurements on each cell in a multi-celled phytolith and taking the average (Rosen, 1992, 1993). Length and width measurements for most wheat and barley species overlap, so only when the average lies inside one category and outside all others does a true identification take place. Qualitatively, barley phytoliths possess more regular waves while wheat phytoliths display waves of uneven amplitude. Therefore, in this thesis, wheat and barley are described as wavy-irregular and wavy-regular dendrite forms respectively, both in single and multiple cell categories.

Identifications were difficult to make considering the weathered condition of the phytoliths and the fact that many were obscured by being embedded in calculus fragments. Much of the phytolith material from Tell Leilan was degraded and the points of dendrite spicules had been broken off, making attempts at identification largely futile. Additionally, phytolith morphologies vary depending upon which portion of the culm or husk (inflorescence bract) is involved. For example, the lower husk emmer cells closely resemble middle husk barley

Table 5.2 Results of Phytolith Analysis of Leilan Calculus, in order of chronology. Period VI (5000-4100 B.C.) on the left is the oldest period, followed by Periods III (3000-2200 B.C.) and II (2400-2200 B.C.).

Sample	**LC 9**		**LC 10**		**LC 1**		**LC 2**		**LC 3**	
Period	**VI**		**VI**		**III**		**III**		**III**	
Number/Percentage	No.	%	No.	%	No.	%	No.	%	No.	%
Single Cells										
Long-Straight	20	2.9	20	12.2	20	17.7	1	5.3	2	3.5
Long-Wavy	1	2.9	24	14.6	8	7.1	0	0	1	1.8
Long-Misc.	0	0	1	0.6	2	1.8	0	0	0	0
Rods	1	2.9	8	4.9	0	0	0	0	0	0
Trapezoid	2	5.7	4	2.4	4	3.5	0	0	2	3.5
Trapezoid Wavy	2	5.7	7	4.4	4	3.5	1	5.3	0	0
Trapezoid Oval	1	2.9	2	1.2	0	0	0	0	1	1.8
Dendrite-Long	6	17	27	16.5	5	4.4	2	10.5	0	0
Dendrite-Short	3	8.6	12	7.3	24	21.2	3	15.7	7	12.3
Dendrite - Irreg.	0	0	0	0	0	0	0	0	0	0
Dendrite - Reg.	0	0	4	2.4	2	1.8	0	0	0	0
Papillae	3	8.6	2	1.2	2	1.8	1	5.3	0	0
Trichomes	0	0	0	0	2	1.8	0	0	0	0
Hairs	0	0	0	0	1	0.9	0	0	0	0
Bulliform	0	0	1	0.6	2	1.8	0	0	0	0
Saddles	1	2.9	8	4.9	1	0.9	0	0	3	5.3
Rondels	8	22.9	34	20.7	26	23	5	26.3	28	49.1
Rectangular	6	17	9	5.5	7	6.1	6	31.6	8	14
Oval	0	0	1	0.6	1	0.9	0	0	5	8.8
Stomata	0	0	0	0	2	1.8	0	0	0	0
Bilobes	0	0	0	0	0	0	0	0	0	0
Crosses	0	0	0	0	0	0	0	0	0	0
Total Single	**35**	**100**	**164**	**100**	**113**	**100**	**19**	**100**	**57**	**100**
Multiple Cells										
Straight	0	0	19	59.4	10	90.9	1	100	0	0
Wavy	2	66.7	13	40.6	1	9.1	0	0	0	0
Wavy - Irregular	0	0	0	0	0	0	0	0	0	0
Wavy - Regular	1	33.3	0	0	0	0	0	0	0	0
Dicot	0	0	0	0	0	0	0	0	0	0
Total Multiple	**3**	**100**	**32**	**100**	**11**	**100**	**1**	**100**	**0**	**100**

Table 5.2 Results of Phytolith Analysis of Leilan Calculus, in order of chronology. Period VI (5000-4100 B.C.) on the left is the oldest period, followed by Periods III (3000-2200 B.C.) and II (2400-2200 B.C.).

Sample	**LC 4**		**LC 11**		**LC 12**		**LC 13**		**LC 14**	
Period	**III**		**III**		**III**		**III**		**III**	
Number/Percentage	No.	%	No.	%	No.	%	No.	%	No.	%
Single Cells										
Long-Straight	6	15.8	19	10.6	8	8.0	4	3.9	0	0
Long-Wavy	2	5.3	17	9.5	5	5.0	3	2.9	0	0
Long-Misc.	0	0	6	3.4	2	2.0	3	2.9	3	1.7
Rods	2	5.3	0	0	1	1.0	0	0	0	0
Trapezoid	1	2.6	0	0	3	3.0	0	0	0	0
Trapezoid Wavy	2	5.3	4	2.2	7	7.0	0	0	0	0
Trapezoid Oval	1	2.6	1	0.6	2	2.0	0	0	0	0
Dendrite-Long	0	0.0	24	13.4	11	11.0	16	15.7	22	12.2
Dendrite-Short	1	2.6	13	7.3	7	7.0	9	8.8	9	5
Dendrite - Irreg.	0	0.0	0	0	0	0	0	0	0	0
Dendrite - Reg.	0	0.0	0	0	0	0	0	0	0	0
Papillae	0	0.0	0	0	2	2.0	0	0	0	0
Trichomes	0	0.0	0	0	1	1.0	0	0	0	0
Hairs	0	0.0	1	0.6	0	0	0	0	0	0
Bulliform	0	0.0	1	0.6	1	1.0	0	0	0	0
Saddles	0	0.0	12	6.7	2	2.0	2	2	3	1.7
Rondels	11	28.9	48	42.5	40	40.0	21	61.8	38	76.8
Rectangular	9	23.7	2	1.1	7	7.0	1	1	5	2.8
Oval	3	7.9	0	0	0	0	0	0	0	0
Stomata	0	0	0	0	1	1.0	0	0	0	0
Bilobes	0	0	1	0.6	0	0	1	1	0	0
Crosses	0	0	2	1.1	0	0	0	0	0	0
Total Single	**38**	**100**	**151**	**100**	**100**	**100**	**60**	**100**	**80**	**100**
Multiple Cells										
Straight	14	87.5	11	47.8	16	27.6	8	11.6	7	7.6
Wavy	2	12.5	12	52.2	42	72.4	61	88.4	85	92.4
Wavy - Irreg.	0	0	0	0	0	0.0	0	0	0	0
Wavy - Regular	0	0	0	0	0	0	0	0	0	0
Dicot	0	0	0	0	0	0	0	0	0	0
Total Multiple	**16**	**100**	**23**	**100**	**58**	**100**	**69**	**100**	**92**	**100**

Table 5.2 Results of Phytolith Analysis of Leilan Calculus, in order of chronology. Period VI (5000-4100 B.C.) on the left is the oldest period, followed by Periods III (3000-2200 B.C.) and II (2400-2200 B.C.).

Sample	**LC 15**		**LC 16**		**LC 23**		**LC 24**		**LC 25**	
Period	**III**		**III**		**II**		**II**		**II**	
Number/Percentage	No.	%	No.	%	No.	%	No.	%	No.	%
Single Cells										
Long-Straight	0	0	0	0	51	29.7	28	27.5	18	40.1
Long-Wavy	0	0	1	16.7	24	14	7	6.9	7	15.9
Long-Misc.	1	3.7	2	33.3	3	1.7	0	0	2	4.5
Rods	0	0	0	0	9	5.2	2	1.9	0	0
Trapezoid	0	0	0	0	2	1.2	1	1	0	0
Trapezoid Wavy	0	0	0	0	6	3.5	7	6.9	0	0
Trapezoid Oval	0	0	0	0	1	0.6	2	1.9	0	0
Dendrite-Long	11	40.7	3	50	10	5.8	11	10.8	2	4.5
Dendrite-Short	2	7.5	0	0	7	4.1	6	5.9	0	0
Dendrite - Irreg.	0	0	0	0	2	1.2	1	1	0	0
Dendrite - Reg.	0	0	0	0	1	0.6	0	0	0	0
Papillae	0	0	0	0	0	0	0	0	0	0
Trichomes	0	0	0	0	1	0.6	0	0	1	2.3
Hairs	0	0	0	0	0	0	0	0	0	0
Bulliform	0	0	0	0	2	1.2	4	3.9	0	0
Saddles	0	0	0	0	4	2.3	6	5.9	3	6.8
Rondels	8	29.6	0	0	43	25	23	22.5	8	18.2
Rectangular	5	18.5	0	0	4	2.3	2	1.9	0	0
Oval	0	0	0	0	1	0.6	1	1	3	6.8
Stomata	0	0	0	0	0	0	0	0	0	0
Bilobes	0	0		0	1	0.6	0	0	0	0
Crosses	0	0	0	0	0	0	0	0	0	0
Total Single	**27**	**100**	**6**	**100**	**172**	**100**	**102**	**100**	**44**	**99.1**
Multiple Cells										
Straight	2	100	3	60	4	80	4	100	1	50
Wavy	0	0	2	40	0	0	0	0	1	50
Wavy - Irreg.	0	0	0	0	0	0	0	0	0	0
Wavy - Regular	0	0	0	0	1	20	0	0	0	0
Dicot	0	0	0	0	0	0	0	0	0	0
Total Multiple	**2**	**100**	**5**	**100**	**5**	**100**	**4**	**100**	**2**	**100**

Table 5.2 Results of Phytolith Analysis of Leilan Calculus, in order of chronology. Period VI (5000-4100 B.C.) on the left is the oldest period, followed by Periods III (3000-2200 B.C.) and II (2400-2200 B.C.).

Sample	LC 7		LC 8		LC 21		LC 22		LC 17		LC 18	
Period	II		II		II		II		II		II	
Number/Percentage	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Single Cells												
Long-Straight	0	0	1	20	20	41.7	16	42.1	0	0	4	2.1
Long-Wavy	3	21.4	0	0	0	0	2	5.3	6	3.5	5	2.6
Long-Misc.	0	0	0	0	0	0	1	2.6	0	0	0	0
Rods	0	0	0	0	0	0	0	0	0	0	0	0
Trapezoid	0	0	0	0	0	0	0	0	0	0	0	0
Trapezoid Wavy	0	0	0	0	0	0	0	0	0	0	0	0
Trapezoid Oval	0	0	0	0	0	0	0	0	0	0	0	0
Dendrite-Long	0	0	0	0	12	25	2	5.3	27	15.8	53	27.7
Dendrite-Short	0	0	0	0	4	8.3	1	2.6	18	10.5	25	13.1
Dendrite - Irreg.	0	0	0	0	0	0	0	0	0	0	0	0
Dendrite - Reg.	0	0	0	0	0	0	0	0	0	0	0	0
Papillae	0	0	0	0	0	0	0	0	0	0	0	0
Trichomes	0	0	1	20	0	0	0	0	0	0	0	0
Hairs	0	0	0	0	0	0	0	0	0	0	0	0
Bulliform	0	0	0	0	0	0	0	0	0	0	0	0
Saddles	0	0	0	0	2	4.2	1	2.6	8	4.7	1	0.5
Rondels	2	14.3	2	40	10	20.8	12	31.6	70	40.9	58	30.4
Rectangular	2	14.3	1	20	0	0	0	0	40	23.4	45	23.6
Oval	7	50	0	0	0	0	3	7.9	2	1.2	0	0
Stomata	0	0	0	0	0	0	0	0	0	0	0	0
Bilobes	0	0	0	0	0	0	0	0	0	0	0	0
Crosses	0	0	0	0	0	0	0	0	0	0	0	0
Total Single	**14**	**100**	**5**	**100**	**48**	**100**	**38**	**100**	**171**	**100**	**191**	**100**
Multiple Cells												
Straight	0	0	0	0	2	66.7	7	77.8	9	52.9	4	30.8
Wavy	0	0	0	0	1	33.3	2	22.2	8	47.1	9	69.2
Wavy - Irreg.	0	0	0	0	0	0	0	0	0	0	0	0
Wavy - Regular	0	0	0	0	0	0	0	0	0	0	0	0
Dicot	0	0	0	0	0	0	0	0	0	0	0	0
Total Multiple	**0**	**0**	**0**	**0**	**3**	**100**	**9**	**100**	**17**	**100**	**13**	**100**

Table 5.2 Results of Phytolith Analysis of Leilan Calculus, in order of chronology. Period VI (5000-4100 B.C.) on the left is the oldest period, followed by Periods III (3000-2200 B.C.) and II (2400-2200 B.C.).

Sample	**LC 5**		**LC 6**		**LC 26**		**LC 27**		**LC 28**	
Period	**II**		**II**		**II**		**II**		**II**	
Number/Percentage	No.	%	No.	%	No.	%	No.	%	No.	%
Single Cells										
Long-Straight	47	22.1	11	15.6	37	18.3	38	19.8	42	18.7
Long-Wavy	12	5.7	0	0	46	22.8	32	16.6	35	15.4
Long-Miscellanec	1	0.5	0	0	0	0	22	11.5	7	3.1
Rods	9	4.2	5	7	0	0	0	0	14	6.2
Trapezoid	9	4.2	8	11.3	1	0.5	8	4.2	6	2.6
Trapezoid Wavy	46	21.7	9	12.7	14	6.9	6	3.1	21	9.3
Trapezoid Oval	10	4.7	2	2.8	3	1.5	1	0.5	1	0.4
Dendrite-Long	17	8	7	9.9	15	7.4	19	9.9	19	8.4
Dendrite-Short	13	6.2	4	5.6	18	8.9	4	2.1	8	3.5
Dendrite - Irreg.	2	1	0	0	3	1.5	4	2.1	2	0.9
Dendrite - Reg.	0	0	0	0	1	0.5	7	3.6	1	0.4
Papillae	1	0.5	3	4.2	2	1	0	0	0	0
Trichomes	3	1.4	0	0	1	0.5	1	0.5	19	4.4
Hairs	0	0	0	0	0	0	0	0	0	0
Bulliform	0	0	0	0	1	0.5	0	0	1	0.4
Saddles	3	1.4	0	0	13	6.4	9	4.7	5	2.2
Rondels	27	12.7	17	23.9	35	17.3	32	16.7	48	21.1
Rectangular	10	4.7	5	7	10	5	8	4.2	3	1.3
Oval	2	1	0	0	2	1	1	0.5	2	0.9
Stomata	0	0	0	0	0	0	0	0	0	0
Bilobes	0	0	0	0	0	0	0	0	0	0
Crosses	0	0	0	0	0	0	0	0	0	0
Total Single	**212**	**100**	**71**	**100**	**202**	**100**	**192**	**100**	**225**	**99.2**
Multiple Cells										
Straight	14	87.5	9	81.8	10	76.9	21	65.6	13	72.2
Wavy	2	12.5	2	18.2	2	15.4	10	31.3	5	27.8
Wavy - Irreg.	0	0	0	0	1	7.7	0	0	0	0
Wavy - Reg.	0	0	0	0	0	0	1	3.1	0	0
Dicot	0	0	0	0	0	0	0	0	0	0
Total Multiple	**16**	**100**	**11**	**100**	**13**	**100**	**32**	**100**	**18**	**100**

Table 5.2 Results of Phytolith Analysis of Leilan Calculus, in order of chronology. Period VI (5000-4100 B.C.) on the left is the oldest period, followed by Periods III (3000-2200 B.C.) and II (2400-2200 B.C.).

Sample	**LC 29**		**LC 30**		**LC 32**		**LC 33**		**LC 19**		**LC 20**	
Period	**II**		**II**		**II**		**II**		**II**		**II**	
Number/Percentage	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Single Cells												
Long-Straight	49	21.6	11	18.6	57	23.4	30	16.9	60	26.7	70	31
Long-Wavy	33	14.5	4	6.8	27	11.1	10	5.6	14	6.2	2	0.9
Long-Misc.	13	5.7	1	1.7	12	4.9	11	6.2	1	0.4	1	0.5
Rods	13	5.7	2	3.4	0	0	5	2.8	0	0	0	0
Trapezoid	8	3.5	2	3.4	5	2.1	3	1.7	0	0	0	0
Trapezoid Wavy	18	7.9	2	3.4	9	3.7	16	9	0	0	0	0
Trapezoid Oval	0	0	0	0	0	0	1	0.6	0	0	0	0
Dendrite-Long	22	9.7	5	8.5	22	9	18	10.1	30	13.3	36	16
Dendrite-Short	10	4.4	4	6.8	12	4.9	21	11.8	28	12.4	31	14
Dendrite - Irreg.	11	4.9	0	0	8	3.3	2	1.1	0	0	0	0
Dendrite - Reg.	0	0	1	1.7	8	3.3	2	1.1	0	0	0	0
Papillae	0	0	0	0	0	0	2	1.1	0	0	0	0
Trichomes	1	0.4	0	0	0	0	0	0	0	0	0	0
Hairs	0	0	0	0	0	0	0	0	0	0	0	0
Bulliform	0	0	1	1.7	0	0	0	0	0	0	0	0
Saddles	20	8.8	7	11.9	25	10.2	3	1.7	11	4.9	5	2.2
Rondels	28	12.3	18	30.5	56	23	44	24.7	77	34.2	76	34
Rectangular	0	0	0	0	1	0.4	1	0.6	0	0	0	0
Oval	0	0	1	1.7	2	0.8	4	2.2	1	0.4	3	1.3
Stomata	0	0	0	0	0	0	1	0.6	0	0	0	0
Bilobes	1	0.4	0	0	0	0	1	0.6	3	1.3	0	0
Crosses	0	0	0	0	0	0	0	0	0	0	0	0
Total Single	**227**	**99.8**	**59**	**100**	**244**	**100**	**178**	**100**	**225**	**99.8**	**224**	**100**
Multiple Cells												
Straight	14	87.5	6	85.7	13	92.8	6	50	1	20	3	100
Wavy	1	6.3	1	14.3	1	7.2	6	50	4	80	0	0
Wavy - Irreg.	1	6.3	0	0	0	0	0	0	0	0	0	0
Wavy - Regular	0	0	0	0	0	0	0	0	0	0	0	0
Dicot	0	0	0	0	0	0	0	0	0	0	0	0
Total Multiple	**16**	**100**	**7**	**100**	**14**	**100**	**12**	**100**	**5**	**100**	**3**	**100**

cells (Rosen, 1992). Thus, all unidentifiable cereal cells were scored as "dendrites", either large (more than three waves) or small (three or two waves). Difference in dendrite size may be related to degree of silicification or the maturity of the plant when harvested, so for this category only was size scored.

No non-grass single phytoliths were observed in the Leilan calculus samples. This is somewhat surprising considering that several phytolith-producing plants other than grasses were available to the residents of Tell Leilan. Wetterstrom (n.d.a, n.d.b) identified legumes in her analysis of the macroremains at Tell Leilan, and Cummings has demonstrated that legumes produce diagnostic phytolith forms (Cummings, 1992). Rosen (1992) identified date palm phytoliths in soils from archaeological sites in Israel, but these were from leaf elements only, and the edible portions of the plant may not produce opal silica bodies. Miller (1991) reports the presence of fruit (grapes, olives, figs and dates) at Near Eastern sites, as determined through macrobotanical analysis, yet no phytoliths from these fruits, known from Cummings (1992), were found the Leilan samples.

Straight and wavy long cells, dendrite cells (see Figure 5.2), rondels and rectangles dominated most samples. All of these phytolith forms are associated with Pooid/Festucoid grasses, including cereals, and this is to be expected considering they are the dominant grass vegetation type (C_3) in the Near East (Twiss, 1992). Since the edible (fruit) portion of a grain does not contain silicified cells, it is presumed that epidermal tissue breaks off and penetrates the soft grain during harvesting or fails to be discarded during cleaning (Rosen, Pers. Comm., 1999). The variation seen within the short-cell phytoliths in the Leilan samples largely reflects where in the plant silicification took place, as opposed to indicating different plant taxa. For example, stomatal cells (culm epidermal elements, see Figure 5.3) were identified in samples from all time periods, but could not be identified to genus or species because their morphology is not diagnostic. The few non-Pooid/Festucoid (saddle, bulliform, cross and dumbbell) types identified reflect the low natural abundance of Chloridoid, Bambusoid and Panicoid taxa in the prehistoric flora of northern Syria.

During the counting phase of this analysis, it quickly became apparent that no distinct pattern was emerging from the short cells in the phytolith assemblages observed. The most interesting pattern is seen not between the different time periods, as expected, but between samples from the same time period, and from Samples LC 11-14 (Period III) in particular. LC 11-14 all came from one adult female and had the highest concentration of phytoliths and the largest number and size of multi-celled phytoliths of all the individuals sampled. Other than being interred with an infant, there is scant burial data with which to interpret the mortuary context of this individual relative to the other samples. Suffice it to say, however, that this individual ate cultigens grown in an environment favorable to silicification. This will be discussed further in section 5.5.

There are several instances of high intra-individual variability with respect to the abundance and variety of phytoliths found in the dental calculus. Samples LC 9 and LC 10, which are from the same Period VI individual, produced remarkably differing phytolith assemblages from each other: the anterior calculus (LC 9) produced significantly less phytoliths than that from the molars (LC 10), even though both samples were especially small (<0.01g). Additionally, LC 10 produced several multi-celled phytoliths, whereas LC 9 produced none whatsoever. This phenomenon could be attributed to differential plant opal deposition during mastication, however not all anterior /posterior differences within an individual were as exaggerated as LC 9 and LC 10. For example, LC 26 and LC 27 are from anterior and posterior deposits respectively, and in this instance the samples are equally abundant in phytoliths. The same holds true for other anterior/posterior samples from the same individual, such as LC 17 and LC 18, and LC 19 and LC20.

5.3.1 Contamination Experiments

To determine possible contaminants, teeth and mandibles not previously cleaned were sampled for "background" phytolith assemblages. In addition, blank samples were processed alongside each batch of samples. These are standard procedures in most microscopic analyses: burial environment, excavation methods, and the circumstances of sample transport, curation and processing can all potentially introduce contaminants to the sample by surface contact or airborne particulates. Dental calculus is composed of virtually impenetrable mineral, so diagenesis, the "chemical and physical alteration in sediments during and after.... deposition" (Katzenberg, 1992:109) is probably not a significant factor. Additionally, because calculus forms only in the presence of saliva, the possibility of post-mortem inclusion of soil phytoliths in the calculus can be all but excluded (Middleton and Rovner, 1994). Despite the low expectation of contamination, precautions were taken to remove surface particles from each sample, and to eliminate potential contaminants from entering the sample during processing and analysis (for example, only metal and plastic implements were used).

Four samples (LC CE 1-4, from Period II) were processed to determine possible contaminants from the burial or storage environment: two bare tooth enamel surfaces and two bone surfaces were rinsed and processed according to the protocol used for the processing of dental calculus described above. Additionally, three blank samples were run, one with each group processed, to determine if the laboratory environment contributed any phytoliths. Finally, rinse residues were collected for samples LC 1-8, and mounted to see if any phytoliths were lost in the decanting of fluids during processing. The four CE samples produced phytolith assemblages remarkably similar in quantity and variety to those obtained from the calculus samples (see Table 5.3). This should not be surprising, considering that the local area surrounding Tell Leilan was largely dedicated to agriculture: in an intensely farmed region such as the Habur plains, cereals will dominate the local flora. There were few multi-celled phytoliths, consistent with other Period II samples

The blank samples (LCB1-3) produced assemblages largely devoid of biological entities and phytoliths; however, many fibers and mineral fragments were identified. Additionally, several "laboratory artifacts" were observable, such as Nalgene centrifuge tube scrapings produced by glass pipette action, and shattered glass fragments from glass-on-glass abrasion.

5.3.2. Loss Prevention

Rinse residues from LC 1-8 were collected and mounted to check phytolith loss during processing, as decanting of supernatants may displace phytoliths at the top of the pellet. While there is certainly potential for loss of phytoliths, observed in the presence of calculus matrix material and organic matter in the residue, no actual phytoliths were observed in these samples. The result of this exercise is the observation that samples from dental calculus are highly clumped, and phytolith material may be carried away during less than careful decanting. Samples should be centrifuged for longer than deemed necessary by normal processing standards (e.g., five to ten minutes), and measures should be taken to disaggregate the calculus matrix (by chemical rather than by physical means, such as the addition of Calgon described in the methods above) prior to processing.

5.3.3. Other Floral and Algal Finds

As expected from the mild processing methods used to extract phytoliths, several other types of biological entities were found in the dental calculus samples. Two types of pollen grains

Table 5.3 Results of Contamination Experiments

Sample	LC CE 1		LC CE 2		LC CE3		LC CE 4	
Period	II		II		II		II	
Number/Percentage	No.	%	No.	%	No.	%	No.	%
Single Cells								
Long-Straight	44	20.1	54	23.5	62	27.8	73	32.9
Long-Wavy	23	10.5	15	6.5	40	17.9	41	18.5
Long-Misc.	2	0.9	0	0	0	0	0	0
Rods	3	1.4	7	3	10	4.5	16	7.2
Trapezoid	12	5.5	20	8.7	13	5.8	11	4.9
Trapezoid Wavy	15	6.7	15	6.5	32	14.3	24	10.8
Trapezoid Oval	5	2.3	1	0.4	3	1.4	1	0.5
Dendrite-Long	23	10.5	21	9.1	3	1.4	11	4.9
Dendrite-Short	23	10.5	17	7.4	4	1.8	1	0.5
Dendrite-Irreg.	0	0	1	0.4	0	0	4	1.8
Dendrite-Reg.	2	0.9	0	0	0	0	0	0
Papillae	1	0.5	4	1.8	0	0	0	0
Trichomes	2	0.9	4	1.8	12	5.4	8	3.6
Hairs	0	0	0	0	0	0	0	0
Bulliform	1	0.5	0	0	0	0	0	0
Saddles	3	1.4	3	1.3	2	0.9	2	0.9
Rondels	57	26	66	28.7	31	13.9	22	9.9
Rectangular	1	0.5	0	0	3	1.4	2	0.9
Oval	2	0.9	2	0.9	7	3.1	6	2.7
Stomata	0	0	0	0	0	0	0	0
Bilobes	0	0	0	0	1	0.4	0	0
Crosses	0	0	0	0	0	0	0	0
Total Single	219	100	230	100	223	100	222	100
Multiple Cells								
Straight	3	75	3	100	5	100	3	75
Wavy	0	0	0	0	0	0	1	25
Wavy-Irregular	0	0	0	0	0	0	0	0
Wavy-Regular	0	0	0	0	0	0	0	0
Dicot	1	25	0	0	0	0	0	0
Total Multiple	4	100	3	100	5	100	4	100

were present: *Pinus* (J. Esdale, Pers. Comm., 1999), suspected to be a contaminant, and a vetch type (H. Friebe, Pers. Comm., 1999), probably *Astragalus*, which is common and economically important in the Near East (Townsend, 1974). The latter is believed to be indigenous to the sample, based on its geographic range and the weathered nature of the grains. Unidentified spores were ubiquitous within the samples, as were pinnate diatoms (A. Rhodes, Pers. Comm., 1999) that probably belong to the *Hantschia* genus (Ehrlich, 1995). Without the appropriate equipment identification of diatoms is difficult, however based on characteristics observable with a light microscope it is most probably *H. amphioxys*, which tolerates alkaline, slightly halitic and polluted marshes. Fungal hyphae and fibers were found, and are attributed to the laboratory or storage environment as they were also abundant in all three blank samples.

5.3.4 Minerals

Hundreds of mineral grains were found in each sample, most of which were birefringent (luminescent under crossed polars), although some quartz (which is pleochroic) was observed. Quartz grains were readily differentiated from opal phytoliths on the basis of morphology, and oftentimes colour, however in cases of uncertainty I made the conservative judgement and did not score the specimen as a phytolith. There was an abundance of mineral material recovered from the dental calculus, and while qualitative differences between slides was noted, no effort was made to quantify the mineral assemblages. This may be one area of study that future scholars wish to pursue in their analysis of archaeological dental calculus.

5.4 Interpretation of Results: Humidity and Aridity

While there is a lack of pattern with regards to short cell phytolith cell type among the three time periods in question, there is a significant difference in the amount and size of multi-celled phytoliths (see Figure 5.4) observed from samples found in Period III. Because the abundance of multiple phytoliths (also called spodograms) has been positively correlated with soil moisture during growth (e.g., Parry and Smithson, 1964; Rosen and Weiner, 1994), examining the quantities of multiple phytoliths in the Leilan sample may provide clues regarding environmental conditions in prehistory. Plants accumulate silica more readily in moist soils than in dry ones, and therefore a humid climate should produce more phytoliths in general and more multi-celled phytoliths in particular. This analysis will now focus on two parameters of this issue: the relative number of multiple phytoliths and the number of cells per multiple phytolith.

5.4.1 Silicification Index

One of the ways of quantifying cereal silica cell data is to compare the abundance of single cells with multiple cell phytoliths (i.e., the number of single cells vs. the number of multiple phytoliths). In one study, Rosen (1993) quantified silicification by dividing the number of multiple phytoliths by the total number of single cells, and she asserts that numerical values indicate the relative degrees of silicification, which in turn inform us about the moisture available in the growing environment. In this study I have opted to quantify silicification using long cell data only because short-cell phytoliths will mainly produce multi-celled phytoliths as a complex with long cells. Thus, the Silicification Index (expressed as a percentage, see Figure 5.1 and Table 5.4) used here represents the number of multiple phytoliths relative to the number of long cell single phytoliths (all long cells, barley, wheat and dendritic cells). A value of 100% means that all long cells were contained within spodograms and a value of zero means that all of the long cells were singular. As shown in Figure 5.1 and Table 5.4 the samples with the highest (above 33%) silicification percentages all belong to Period III (3100-2400 B.C.), while the very lowest SPs (below 10%) are generated by Period II samples. This trend becomes readily apparent when comparing the mean silicification percentages for each time period: the Period III mean was highest at 33%, followed by Period VI at 21% and Period II at 8%. While these values themselves do not hold any significance, the relationship between them does: plants growing during Period II received less water than those growing in Period VI, and especially Period III. This could be due to several factors, including higher rainfall, change in soil composition to enhance water retention, or irrigation practices.

5.4.2 Number of Cells per Spodogram

Another measure of silicification is quantifying the number of cells per multi-celled phytolith: the more cells present, on average, the relatively wetter the growing conditions. As the plant uptakes and transpires more water, a greater amount of dissolved silica moves through the plant and there is a greater chance that phytoliths will form. Under drier conditions, soluble silica in the groundwater precipitates out of solution and actually reduces the formation of phytoliths (Rosen, Pers. Comm., 1999). A study by Rosen and Weiner (1994) has shown that

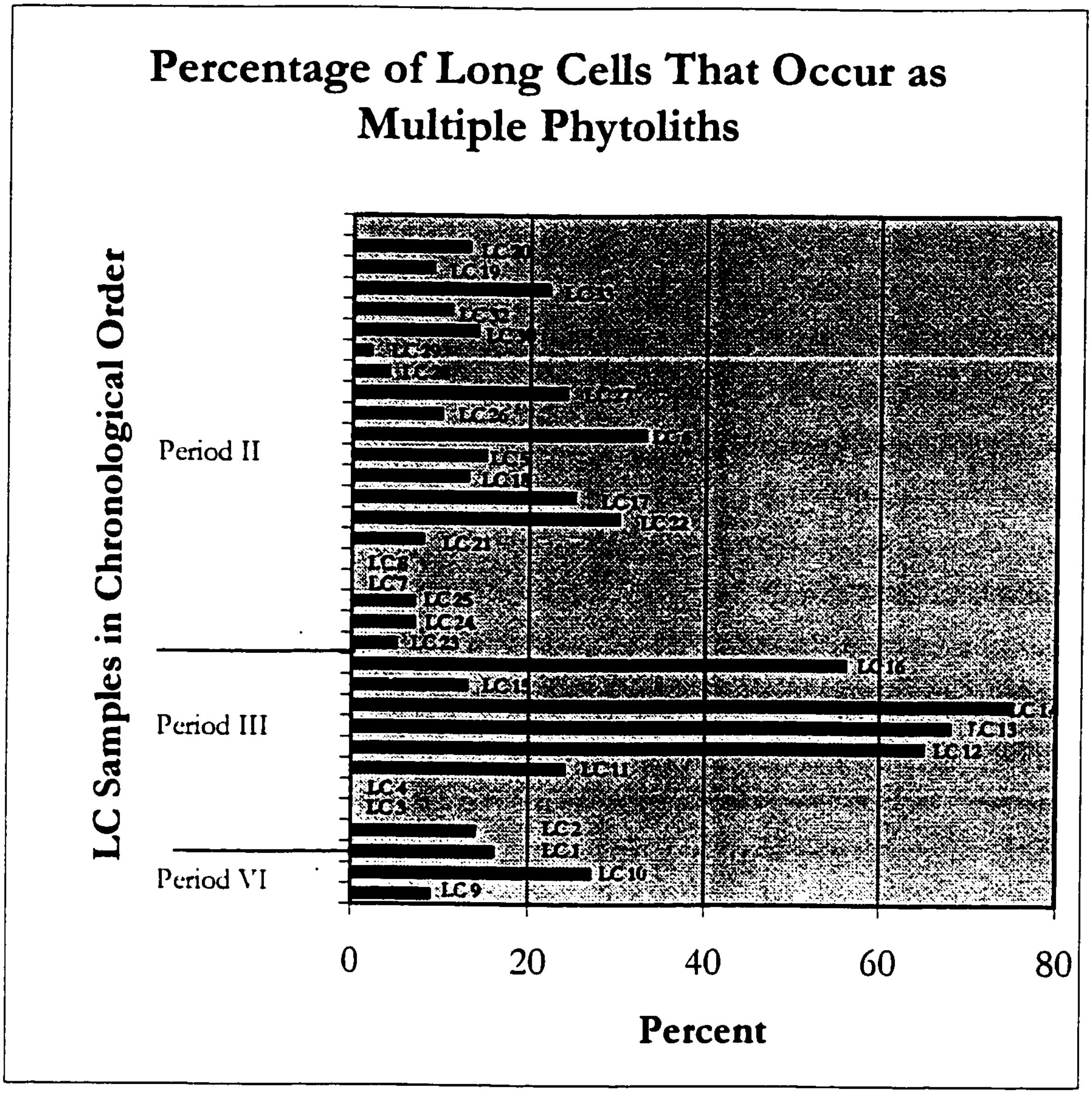


Figure 5.1 Graph showing the Silicification Index (percentage of long cells occurring as multiple phytoliths) of each Leilan calculus sample. Samples are listed in chronological order, with the oldest samples at the bottom of the y-axis and the youngest samples closest to the top.

Table 5.4 Silicification Index[1] for the Leilan Calculus Samples by Period.

Sample	Percentage	Sample	Percentage
	Period II		**Period III**
LC 19	4 %	**LC 16**	56 %
LC 20	2 %	**LC 15**	13 %
LC 33	13 %	**LC 14**	75 %
LC 32	10 %	**LC 13**	68 %
LC 30	22 %	**LC 12**	77 %
LC 29	11 %	**LC 11**	24 %
LC 28	14 %	**LC 4**	0 %
LC 26	10 %	**LC 3**	0 %
LC 27	24 %	**LC 2**	14 %
LC 5	15 %	**LC 1**	16 %
LC 6	33 %		
LC 18	13%	***Period III***	
LC 17	25 %	***Mean***	***33%***
LC 22	30 %		
LC 21	8 %		
LC 8	0 %		
LC 7	0 %		
LC 25	7 %		**Period VI**
LC 24	7 %	**LC 10**	27 %
LC 23	5 %	**LC 9**	14 %
Period II Mean	***8%***	***Period VI Mean***	***21%***

1. S.I. = number of multicelled phytoliths divided by total number of long celled phytoliths multiplied by 100%.

30% of multi-celled phytoliths from irrigated barley (*H. vulgare*) contained ten or more phytoliths, compared with only 6 % for dry-farmed barley. At Tell Leilan, where irrigation is not suspected to have been necessary due to sufficient rainfall (Weiss, 1986a, 1986b, *contra* Rosen, Pers. Comm., 1999), large spodograms in the archaeological record could signify abundant rainfall and/or the high evapo-transpiration rates of the plants in question.

Table 5.5 presents the tabulation of the number of cells within spodograms from the Leilan calculus samples. Only six samples produced spodograms containing ten or more cells, and many samples yielded no multiple phytoliths at all. Some impressive specimens were found, however: two samples produced multi-celled phytoliths with over fifty cells (LC 13 and LC 14), the largest spodogram comprising 119 cells. Again, the Period III samples produced the greatest number of large (more than nine cells) spodograms, consistent with the silicification index results presented above. Of interest is the degree of variability seen in samples from the same Period, and even from the same individual.

5.5 Conclusions

Although the short-cell data from the analysis of calcular phytoliths at Tell Leilan reveal little about the diet and environment in Syria at the end of the 3rd millennium B.C., long cell and multi-celled phytolith abundance and size data made some interesting contributions. Period III samples yielded the highest silicification indices, and also the highest average number of cells per spodogram, both of which are indications that Period III conditions were wetter than Period II. This is in accordance with Near Eastern palaeoenvironmental data, which report a moist climate regime at approximately 4000 B.C. by an aridification leading to modern semi-arid conditions. Additionally, the phytoliths with the largest number of cells are found in LC 13 and LC 14, samples from the same individual, suggesting that this individual enjoyed a different diet than the other individuals sampled in this study. This could be explained by high social status or migration from another area, such as the southern Habur plains, where irrigation is known to have occurred (Kühne, 1990).

5.6 Interpretation

From an analysis of the relative degree of silicification between the samples, it appears that Period III (3100-2400 B.C.) phytoliths are more silicified than Period VI phytoliths, and Period

Table 5.5 Number of Cells per Multiple Phytolith[1].

Sample	2-4	5-9	10-14	15-19	20-24	25+	
LC 20	3	0	0	0	0	0	
LC 19	4 (80%)	1 (20%)	0	0	0	0	
LC 33	8 (73%)	3 (27%)	0	0	0	0	
LC 32	20 (57%)	11 (31%)	1 (3%)	2 (6%)	0	1 (3%)	
LC 30	6 (86%)	1 (14%)	0	0	0	0	
LC 29	13 (72%)	6 (28%)	0	0	0	0	
LC 28	15 (88%)	2 (12%)	0	0	0	0	
LC 27	21 (75%)	7 (25%)	0	0	0	0	
LC 26	13	0	0	0	0	0	
LC 6	10 (91%)	1 (9%)	0	0	0	0	*Period II*
LC 5	35 (80%)	7 (16%)	2 (4%)	0	0	0	
LC 18	16	0	0	0	0	0	
LC 17	16 (89%)	1 (6%)	0	1 (6%)	0	0	
LC 22	10	0	0	0	0	0	
LC 21	2 (67%)	1 (33%)	0	0	0	0	
LC 8	0	0	0	0	0	0	
LC 7	0	0	0	0	0	0	
LC 25	2	0	0	0	0	0	
LC 24	2	0	0	0	0	0	
LC 23	3	0	0	0	0	0	
LC 16	5	0	0	0	0	0	
LC 15	2	0	0	0	0	0	
LC 14	40 (40%)	40 (40%)	5 (5%)	6 (6%)	3 (3%)	6 (6%)	
LC 13	12 (34%)	10 (29%)	5 (14%)	1 (3%)	0	7 (20%)	
LC 12	65 (66%)	28 (28%)	6 (6%)	0	0	0	*Period III*
LC 11	18 (86%)	3 (14%)	0	0	0	0	
LC 4	0	0	0	0	0	0	
LC 3	0	0	0	0	0	0	
LC 2	0	1	0	0	0	0	
LC 1	8 (73%)	3 (27%)	0	0	0	0	
LC 10	25 (86%)	2 (7%)	1 (3%)	1 (3%)	0	0	
LC 9	0	0	0	0	0	0	*Period IV*

1. Percentages indicated where appropriate

II phytoliths are the least silicified of all. One individual in Period III possessed particularly large multi-celled phytoliths, enough so to warrant an explanation: this adult had access to irrigated cultigens, either through importation of resources from the south, or travel/migration. While Weiss (1986a, 1986b) declares that irrigation practices were restricted to Southern Mesopotamia, Rosen (Pers. Comm, 1999) has observed archaeological evidence of irrigation in northern Mesopotamian sites nearby Tell Leilan. The most parsimonious explanation is that small-scale irrigation developed locally in response to occasional dry spells, but lacked the imperial support given to Sumerian irrigation practices. Kühne (1990) reports evidence supporting the existence of local irrigation systems along the lower Habur River during the early Bronze Age, though Weiss (1986a, 1986b) has found no such evidence at Tell Leilan. Anthropogenic channelization (the stabilization of water channels by building embankments of basalt blocks) was apparently the extent to which the residents of Tell Leilan altered the water system during Akkadian times (Weiss *et al.*, 1993).

The purpose of the research undertaken in this thesis was to determine if the residents of Tell Leilan experienced dietary stress resulting from aridification prior to the abandonment (Habur Hiatus I), as would be evidenced by a decrease in cultivar phytoliths and an increase in wild plant phytoliths (such as from famine foods) in the dental calculus. The results of this analysis, described above, do not directly verify or negate a food crisis at Tell Leilan at the close of the third millennium B.C., however the signals emitted by phytolith assemblages are invariably open to interpretation. By examining the short cell assemblage, no change in dietary strategy can be seen as the individuals in question relied heavily upon C_3 cereals, which all produce Pooid/Festucoid phytoliths. I am concentrating upon silicification as an indication of growing environment, and have highlighted the effect that aridification may have had on the solubility of groundwater silica in the fields surrounding Tell Leilan. This approach seems the most appropriate, given the environmentally focussed nature of the archaeological problem under investigation.

The small sample size of this research precludes me from making overzealous interpretations of Near Eastern palaeoclimate based upon the finding that Period III phytoliths appear larger and more abundant than those from other time periods. This issue of sample size becomes compounded when considering that chronologies below the "period' designation are often not possible to resolve, and thus differentiation between samples from the same period cannot be made. To aid in the interpretation of the dental calculus phytolith data presented here, other, complementary, data should be examined, such as macrobotanical remains from Period II contexts at Tell Leilan, and similar phytolith and macrobotanical studies at other Habur sites archaeological sites. This data is presently unavailable, and would help illuminate the issue of Early Bronze Age aridification in the Near East.

Figure 5.2 Two dentritic long cells (60 μm long) beside a plate of wavy long cells.

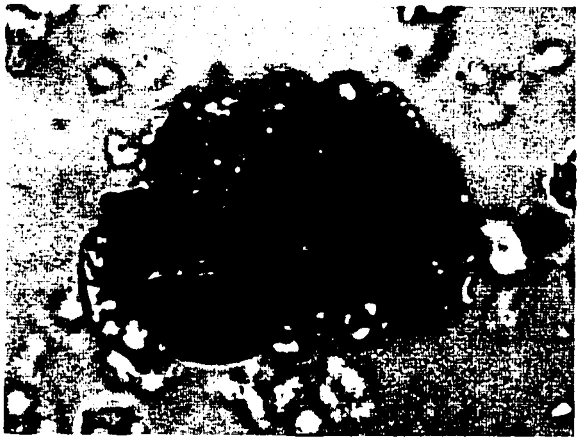


Figure 5.3 Stomatal complex from LC32 (Period II). Each cell is approximately 20 x 15 μm.

Figure 5.4 Multicelled phytolith showing variable cell morphology, from LC32 (Period II). Each long cell is approximately 10 μm wide and 20 to 40 μm long.

CHAPTER 6. CONCLUSIONS

6.1 ARIDIFICATION AT THE CLOSE OF THE THIRD MILLENNIUM B.C.

In Chapter Three, palaeoenvironmental evidence was presented that supports the theory that aridification prevailed in the Near East between approximately 2500-1500 B.C., following the mid-Holocene thermal maximum at ~4000 B.C.. The Leilan calculus phytolith data presented in Chapter Five are in agreement that Period III (3000-2400 B.C.) cereals were grown under more humid conditions than those grown in Periods II (2200-2400 B.C.) and VI (5000-4100 B.C.). In sum, the results of this research corroborate Weiss' hypothesis that aridification took place on the Habur Plains at the close of the third millennium B.C..

6.2 FAMINE AVOIDANCE STRATEGIES: IMPLICATIONS FOR THE RISE AND FALL OF THE AKKADIAN EMPIRE

Aridification itself is not sufficient to explain the collapse of the Akkadian Empire and the abandonment of a thriving urban city. Ethnographic evidence suggests that there are many ways societies and individuals mitigate and overcome resource depletion. Colson's (1979) review of the ethnographic literature revealed five strategies commonly employed by societies regularly confronted with food shortages. These include: 1) diversification of subsistence or money-earning strategies, 2) storage of foods, 3) storage and transmission of information regarding "famine foods" and famine avoidance tactics, 4) conversion of foodstuffs into non-perishable forms of wealth, and 5) development of relationships with individuals or societies in other regions. Migration is a hallmark of famine to ethnographers (Dirks, 1980), however in modern populations, migration is seen as an individual or family-level strategy to maximize productivity and/or income. Villages or larger social institutions wither under declining economies, and the family unit is the one responsible for making decisions as to whom shall migrate where and when (Hugo, 1998). Considering this observance that migration is a family-level decision, the mass movement of an entire town is difficult to explain. Either the residents of Tell Leilan moved in stages, or the Akkadian infrastructure provided a city wide decision-making body. Perhaps even the administrators themselves organized the abandonment.

Colson noted that subsistence farmers in particular were at a disadvantage with respect to food shortages due to their narrow breadth of diet, stating "(m)ost subsistence agriculturalists, therefore, plan food storage from harvest to harvest, and regard two bad years running as a major calamity" (1979:22). Modern farmers maintain optimal soil fertility by leaving fields fallow on a regular basis (e.g., Jacobsen, 1982; Watson, 1979), and can revert to drought-resistant crops when the need arises. But at Tell Leilan, where the economy was constricted to certain cereals and restricted by Akkadian imperial control, the ability of the farmer to grow more drought-tolerant species would have been quelled by the administrative power structure (Rosen, 1995a). Moreover, I expect that the demands of the Akkadian Empire were more adequately fed than those of local citizens during lean years, and when surplus yields failed to be achieved the elite retained their share while the workers went without. This is seen in ethnographic accounts of the rich getting richer and the poor becoming even poorer during times of food shortage, because the poor must sell goods or livestock at a reduced price to feed their families, and the rich obtain goods that increase in value after the crisis has passed (Colson, 1979; Dirks, 1980). Thus, famine exaggerates social status, and in doing so may differentially affect the health status, and even mortality, of members of a stratified society (Dirks, 1980).

The scenario I imagine for the rise and fall of the Akkadian Empire indeed depends upon drought, but not in the way that Weiss interprets it. According to palaeoclimatic data, the Near East became more arid after the Holocene thermal maximum (~4000 B.C.), and Tell Leilan experienced rapid aridification caused by severe storms before the onset of the Akkadian Empire. Phytolith evidence from human dental calculus at Tell Leilan corroborates these findings. It is my belief that the initial aridification laid the groundwork for the establishment of the Akkadian Empire by making the farmers dependent upon a central administration to redistribute foods. In terrain as varied as that found in the Near East, aridification was probably experienced variably, and therefore crops would have succeeded at some point in the Empire at all times (Jacobsen, 1982). Intense irrigation in southern Mesopotamia would have helped overcome low rainfall, while channel stabilization in the north maximized the natural rainfall experienced in this dry-farming zone. However, as aridification continued, repeated crop failure would have undermined the Akkadian establishment. Soil salinity, an ever present threat to Near Eastern farmland (Jacobsen, 1982), is a common culprit in modern crop failures, and would have stultified plant growth with prolonged aridification. Modern studies show that aridification itself produces increased land surface temperature by reducing plant cover, often perpetuating crop failure. For example, during the last half of this century in the Near and Middle East, a temperature increase of 0.07°C per decade was blamed on overgrazing and desertification (Nasrallah and Balling, 1995). Thus the late third millennium aridification could have been responsible for the success as well as the ultimate failure of the Akkadian Empire, which sufficed as a response to short-term crop failure but could not sustain itself under prolonged arid conditions.

6.3 Phytolith Analysis: comments, concerns and recommendations

Like all archaeologists studying the remnants of past life forms, phytolith analysts are a hybrid species to which both the social and the natural sciences contribute. Occasionally the archaeologist contributes methodologically or theoretically to cognate disciplines, but more often than not the reverse is true, leaving archaeologists in the role of applying, but not generating, scientific innovation. Phytolith analysis presents archaeology with a novel opportunity to change this phenomenon. Being mainly employed by soil scientists and archaeologists, phytoliths will only receive scientific examination when justified by a larger requirement that fulfills an application to an archaeological problem. However, phytoliths need to be examined on a more empirical level, one not seen commonly seen in archaeology laboratories. Many more questions need to be answered before phytolith analysis will gain the trust of archaeologists, because many gaps in knowledge currently exist. A greater understanding of the processes by which phytoliths form, and the circumstances that influence the size and shape of phytoliths, is required. In addition, problems arising from phytolith taxonomy need to be addressed. More plant types need to be studied to determine which, if any, phytoliths are regularly formed; only by knowing the full variety of opal silica morphotypes and the plants that produce them will phytolith analysts be able to unequivocally make plant identifications.

6.4 Recommendations for Future Work at Tell Leilan

The research described in Chapter Five of this thesis is a part of a larger body of research undertaken by scholars searching for the reasons why the Akkadian Empire fell and Tell Leilan was abandoned. Future work in this area may benefit from contributions that phytolith analysis of dental calculus has made, and there are several areas in particular that should be investigated.

First, a more extensive palaeobotanical study should be made of the various parts of Tell Leilan, and the natural landscape, both modern and ancient, should be sampled to provide a contrast to the palaeodietary data presented here. Modern samples should be processed for phytolith and other plant remains to determine the present association between botanical assemblages and environment. Also, phytolith and macrobotanical analyses of would be instructive. Also, phytolith analysis of herbivore dental calculus would contribute data regarding grazing and forage plants, and would be an appropriate complement to the research undertaken in this thesis.

Second, a geoarchaeological comparison should be made with other sites on the Habur plains - if the Leilan Collapse phase strata described by Courty (Weiss *et al.*, 1993) can be found in nearby sediments, Weiss' hypothesis would gain additional support. Methods in palaeoenvironmental and palaeoclimate reconstruction are currently not able to detect short-term climate changes. As observed ethnographically, periods of food shortage even months in length can be crucial to the survival of a human group, and geologically visible and important events may not be the ones that most influenced the course of prehistory. Palaeodietary reconstruction provides a biased view of prehistoric plant and animal resources, but when determined from skeletal remains can view resources available within a human's lifespan, which is a level of resolution ill attained by current methods in geoarchaeology.

Third, I would recommend that future researchers collect their own samples. My ability to interpret the results obtained through calcular phytolith analysis was constrained by a lack of context for the burials in question, and by the lack of control over the collection and storage of the specimens involved.

6.5 Final Remarks

Reconstructing past climates and environments is integral to archaeology and palaeoanthropology (Butzer, 1971; de Menocal, 1995). By understanding the resources available to ancient communities and the physical characteristics of the landscapes humans inhabited, archaeologists gain an appreciation for the natural opportunities and constraints faced by the cultures we study. Even in modern times, environmental factors shape human society and culture; those who study past human behaviors must appreciate and understand the geographic and climatic history of the area of interest in order to interpret ancient cultures and societies.

Yet, there are certain boundaries placed upon the reconstruction of past landscapes that limit the tools of the researcher. Surprisingly, ancient humans themselves pose the greatest limitation upon environmental reconstruction; because scholars aim to remove anthropogenic signals from the reconstruction of "pristine" past environments they eliminate human remains and material culture from palaeoenvironmental studies by sampling off-site. While physical anthropology has generated several tools with which to observe climatic adaptation, environmental archaeologists have traditionally not collaborated with physical anthropologists on this issue. The research presented here represents a novel approach to the Tell Leilan abandonment problem by marrying palaeoecological and physical anthropological methods. This combination of goals and methods has presented several obstacles, but has proven a worthwhile venture and one which should be embraced by future researchers. By using phytoliths found on human teeth to reconstruct diet, archaeologists can gain insight into short-term fluctuations in resource availability and attempt to determine how human resource procurement patterns change during periods of apparent environmental stress. It is only when archaeologists examine changes in climate that occur on the level of the human lifespan that we can claim to understand the impact that changes in prehistoric environments had on the lives and societies of ancient humans.

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APPENDIX A – PROCEDURES FOR EXTRACTING AND PROCESSING PHYTOLITHS

1. Preparation of a Comparative Collection using Chemical oxidation

Plants should be separated into fruits, leaves, stems and roots before being processed, as different plant parts may produce different phytolith morphologies. The purpose of this procedure is to chemically oxidize the organic components of plant tissue to isolate the inorganic opal silica bodies. The following is a wet oxidation procedure described by Piperno (1988).

1. Disinfection: Soak plant remains (>0.1 g) in a 1% Alconox (or 40 %Calgon) solution for several hours, then rinse repeatedly with distilled water. Place each 0.1g sample into a test tube.
2. Oxidation: Add 10mL of oxidizing agent to each test tube. Piperno advocates the use of Schulze solution (three parts concentrated nitric acid to one part saturated potassium chlorate), however several other successful oxidation agents have been identified in the literature, including chromic acid (Jones and Beavers, 1964), and a sodium chlorate Schulze solution (Pearsall, 1989:380).
3. Digestion: Place test tube into a boiling hot water bath, stirring frequently. If digestion has not occurred after 0.5 hours, add small quantities of solid potassium chlorate until all organic material has completely dissolved. Digestion is complete when all of the sediment has accumulated at the bottom of the tube, or when addition of more potassium chlorate meets no further reaction.
4. Isolation: Centrifuge for ten minutes at 1500rpm. The sediments will be packed into the bottom of the tube, while the phytoliths are suspended in solution in the supernatant. Decant, keeping supernatant. Rinse supernatant with distilled water and centrifuge treatment twice, and destroy any remaining carbonates by adding a 1M HCl rinse. Rinse again twice with distilled water, then wash in acetone to dry.
5. Slide preparation: The dried phytolith precipitate is mounted on clear microscope slides with Permount and viewed under a light microscope. Samples may be stored in a suspension of absolute ethanol.

2. Preparation of a Comparative Collection using Incineration

Incineration (dry ashing) isolates opal silica bodies by physical, rather than chemical, means. The procedure below is a modification of the Twiss, Suess and Smith (1969) method designed and advocated by Rosen (pers. comm., 1996).

1. Disinfection: Wash dried plant material in a detergent solution, agitating occasionally. Rinse in distilled water and dry. Place crumbled pieces of plant into crucibles; fill well, as about 8 full crucibles are required.
2. Incineration: Place crucibles in oven, starting cold and gradually bringing up the temperature over 2 hours. When 500 degrees C is reached, maintain for several hours. The sample may need to be stirred to ensure it is entirely burned, indicated by the presence of white ash.
3. Isolation: Add a small amount of 1M HCL to the ash to remove carbonates; reaction is complete when the fizzing completely stops. Centrifuge at 3000 rpm for five minutes, turning speed up gradually, and pour off supernatant: the sediment at the bottom of the tube is purely phytolith material. Wash this pellet in distilled water and centrifuge again, then repeat until the final rinse-off is clear. The final centrifuge is done with 70% methanol to dry. If the powder is still quite dark, remove this carbon-ash contaminant with household bleach; removal of organics should turn the mixture white. Rinse with distilled water again.
4. Slide preparation: Mount the dried powder onto a microscope slide with Permount or Entellan, as described above.

3. Extraction of Phytoliths from Sediments

This procedure is a combination of techniques advocated by Piperno (1988) and Rosen (1996, pers. comm.) and modified by the author.
1. Sieving: Phytoliths in agricultural sites may reach sizes of up to 0.5mm, so use a 0.25 - 0.50mm size screen to sieve sediments, depending upon the expected phytolith size. Sieve onto plastic or metallic surfaces, as paper theoretically contains phytoliths and could contaminate the sample. When sieved, make sure your sample is at least 2g in weight, as further procedures will decrease this amount further.
2. Removal of Carbonates: Cover sediments in 10% HCl and leave in fumehood until the reaction is complete, indicated by lack of fizzing. Wash ALL the sediment into a centrifuge tube with distilled water. To hasten this step, place tubes in a hot water bath, and /or increase

concentration of acid.

3. Centrifugation: To remove fine, light particles and to wash out the acid, centrifuge the sediments at 3000 rpm for 5 minutes. Decant supernatant and repeat this rinsing procedure until the supernatant is clear. NB: I advise keeping the first rinse (the HCl liquid decanted) to test and see if phytoliths are being discarded in this step.

4. Settling: Sediments are settled using a Calgon solution (40g/L ; active ingredient sodium pyrophosphate) and a tall beaker (over 8cm in height). Sand and silt fractions fall at 8cm/hour in this solution, so add enough liquid to make a mixture that is 8cm tall. Stir well to disaggregate clay particles, then let stand for one hour, after which the supernatant is pipetted off. This procedure removes the clays and fine silts, and any other particles under 5 microns in size (keep the first rinse to ensure no identifiable phytoliths were discarded). Repeat by adding more distilled water to the residue, up to the 8cm line again, stirring vigorously and letting it settle for one hour. Repeat until the supernatant is satisfactorily clear, signalling the removal of most of the clays and silts.

5. Ashing: To remove the organic material not flushed out by the above procedure, incinerate the sample at 500-550 degrees C for two hours. Grind the sample (very gently) before putting it into the oven, to stir up the aggregated materials.

6. Centrifugation: The ashed sample is then scooped into a heavy density liquid (specific gravity=2.3g/mL) and centrifuged at 2500rpm for five minutes. Sodium polytungstate in solution (70% powder to 30% distilled water by weight) is the recommended heavy density liquid, as it can be re-used for several samples. Pipette off the supernatant, which contains the biogenic silica particles, and pour into a new centrifuge tube. Wash the phytoliths in distilled water, and centrifuge again; this time the phytoliths will sink to the bottom. Repeat with another water wash, then with a drying methanol wash.

7. Mounting: Place phytolith powder evenly onto microscopic slide, then fix to the surface with Entellan or Permount (for a permanent slide); add coverslip and view under light microscope. Use a light microscope with crossed Nicholl's filters: biogenic opal silica is non-birefringent, whereas quartz crystals glow then extinguish when viewed at 90 degree angles.

4. Extraction of Phytoliths from Dental Calculus

This simple procedure is modified from Armitage (1975) and Middleton and Rovner (1994).

1. Decontamination: Post-mortem phytolith deposits are removed by lightly brushing the calculus deposit with a fine nylon bristle, and repeatedly rinsing with distilled water. Keep the rinse to identify possibly contaminant taxa. Scrape calculus deposit from the tooth using metal or plastic instruments.
2. Disaggregation: Soak calculus sample in 40g/L Calgon solution to help break up the mineralized calculus.
3. Oxidation: Dissolve the sample in 1M HCl (or hydrogen peroxide, or any other oxidizing agent. Rinse the specimen thoroughly in repeated distilled water rinses.
4. Mounting: Place the phytolith mixture evenly onto a microscope slide; cover with Entellan or Permount, and place a slipcover on top. View under a light microscope with cross nickel filters: biogenic opal silica is non-birefringent and will not glow under crossed Nicholl's filters.

APPENDIX B: SAMPLE DATA COLLECTION SHEET (created by Dr. Deborah Pearsall for use in the University of Missouri-Columbia Palaeoethnobotany Laboratory).

SHORT CELL COUNTING FORM

Project________ Scanner________ Date________

Slide #________ Scope/Obj________ Hours________

Taxon________ Rows________ St. pt./St. pt________

	TOTAL	PERCENT
PANICOID		
Bilobate		
Nodular		
Crenate		
3-lobed		
Cross		
Unilobate		
ALL PANICOID		
FESTUCOID		
Round/Oblong		
Rect/Square		
Long, Sinuous (crenate type)		
ALL FESTUCOID		
CHLORIDOID		
Saddle		
OTHER: Bambus.(B)/Arundi (A)/Pani (P)/Chlori(Ch)./Centothec (Ce)/Fest (F)		
saddle bottom:		
2-spike(short)		
Chusquea type, large lobes(B)		
2-spike top(most B)(2C;3C)		
2-spike top(P)I. arundinaceae(5C)		
2-spike(tall)		
2-spike top(A)P. communis (4C)		
4-spike		
4-spike top(B)S. sodiroana(1C;6C)		
rondel bottom:		
no spikes(short):		
concave/convex(B)C. delecata (1F)		
square or cone(B)Guadua(10f,11f)		
square with or w/out point top(B)P. latifolia(14f,20f)		
flat to triangle, irregular bottom(B,Ch)Leersia Distichlis(16f)		
no spikes(tall):		
narrow flat top(B)G. angustifolia(6F)		
flat top with triangle(B)G. amplexifolia(8f)		
2-spike(short)		
2-spike(A,Ch)Phragmites Distichlis(16f)		
2-spike(tall):		
2-spike top, flared bottom(B)Guadua(9f)		
2 or 3 spikes:		
2 or 3 spike(B,Ch)(4f,5f)		
2 or 3 spike, irregular bottom(Ch)D. spicata(19f)		
>2 spikes(short):		
3-spike top, elongate(B)P. latifolia(15f)		
>2 spikes(tall):		
3-many spikes, flared bottom(B,Ch)Guadua Distichlis(12f)		
Atypical:		
concave/angular convex(B)C. Scandens(2F)		
variable top(F,B)(7f)		
concave top and sides(B)P. latifolia(13f)		

irregular epid. w/ projections ________

rondel bottom, elongate, wavy top ________

QUICK SCAN FORM

Project:____________________ Scanner: ____________

Slice # ________________ Scope: _______ Date:______________

taxon: ____ #Rows scanned ____

Description ILLUSTRATION

TALLY

Total Abundance Code:

Description ILLUSTRATION

TALLY

Total Abundance Code:

Description ILLUSTRATION

TALLY

Total: Abundance Code: