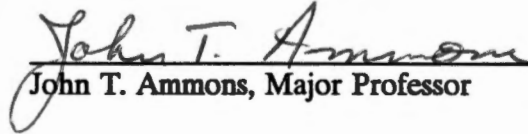
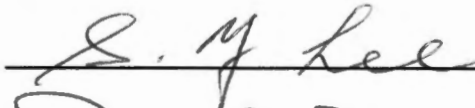


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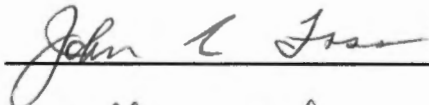
I am submitting herewith a dissertation written by Michael Wayne Morris entitled "A Pedological Investigation of Catchment Basins Below Late Minoan Period Archaeological Sites in Eastern Crete, Greece." I have examined the final copy of this dissertation for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Plant and Soil Science.

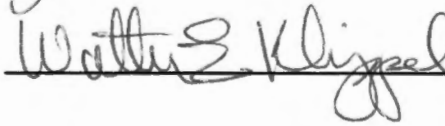

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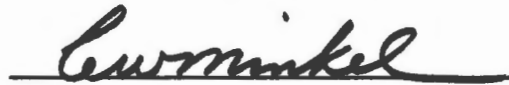








Accepted for the Council:



Associate Vice Chancellor
and Dean of the Graduate School

**A PEDOLOGICAL INVESTIGATION OF CATCHMENT BASINS
BELOW LATE MINOAN PERIOD ARCHAEOLOGICAL SITES
IN EASTERN CRETE, GREECE**

A Dissertation
Presented for the
Doctor of Philosophy
Degree
The University of Tennessee, Knoxville

Michael Wayne Morris

May 1994

AG-VET-MED.

Thesis

946

.M67

To Gabrielle, my wife and my best friend

Her presence brought memories of such things as Bourbon roses, rubies, and tropical midnights; her moods recalled lotus eaters and the march in *Athalie*; her motions, the ebb and flow of the sea; her voice, the viola. In a dim light, and with a slight rearrangement of her hair, her general figure might have stood for that of either of the higher female deities. The new moon behind her head, an old helmet upon it, a diadem of accidental dewdrops round her brow would have been adjuncts sufficient to strike the note of Artemis, Athena, or Hera respectively, with as close an approximation to the antique as that which passes muster on many respected canvases.

Thomas Hardy, *The Return of the Native*

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figures in this text, and also to Dr. Joanne Logan who helped me immensely with the statistical analysis and interpretation.

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and hospitality are all about.

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ABSTRACT

A series of soil pedons were investigated in conjunction with the Kavousi Archaeological Expedition in Eastern Crete, Greece. These soils were located in sediment catchment basins in landscape positions that were topographically below archaeological sites known to have been inhabited in the Late Minoan IIIc Period (1100-900 B.C.). The objective of this investigation was to use soil information in concert with available archaeological and chronological data to reconstruct the Late Pleistocene and Holocene landscape history of Eastern Crete. Four soil pedons were located near the archaeological site of Karphi which is in the Diktean Range north of the Lasithi Plateau. These four pedons included two sinkholes, one alluvial fan deposit, and one buried agricultural terrace. Three soil pedons were also investigated near the archaeological sites of Vronda and Kastro, which are near the village of Kavousi in the Siteia Range. These soil pedons included one buried colluvial deposit, one alluvial fan deposit, and one sinkhole. The soil morphology was described for each pedon, and particular attention was paid to existence of buried soils, discontinuities, and presence of artifacts. Samples were collected from the horizons in each pedon and were subjected to laboratory analysis. These analyses included total carbon content, organic carbon content, pH, CEC, particle size, total element, citrate-dithionite iron, and weak acid extractable element, as well as some selective clay mineralogy. Results from this investigation show that stable soils with argillic horizons existed prior to 3,000 yr B.P. and that soils developed after 3,000 yr B.P. show little evidence of weathering. This pattern may be related to moister conditions which occurred on the island prior to 3,000 yr. B.P. The analyses also indicate that an erosional episode, which could be related to human-influenced landscape destabilization, occurred after 3,000 yr. B.P. at Karphi and Kavousi. Additional investigations revealed that an eolian component was deposited at Karphi approximately 1,700 yr. B.P., and

clay rich sediments in the sinkhole at Kavousi exhibited vertic properties and translocated artifacts of Minoan age in the pedon.

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INTRODUCTION

The Department of Plant and Soil Science has conducted investigations in pedology and geomorphology in cooperation with the Kavousi Project under the supervision of the American School of Classical Studies in Athens, Greece. Project members include representatives of the Classics and Anthropology Departments from the University of Tennessee-Knoxville (UTK), Wabash College, and the University of Minnesota. The Late Minoan III C and Subminoan sites of Vronda and Kastro, near the village of Kavousi in eastern Crete, have been the focal points of these investigations. These archaeological sites are known as "refuge" sites because of their location in the higher elevations of the Siteia Mountain Range. They occupy relatively high positions on the landscape in comparison to the previous coastal settlements of the Minoan Palace Periods. These sites represent a unique period in Greek history for which there is no written history to verify the archaeological assemblages examined. A team of scientists including zooarchaeologists, paleobotanists, and human paleontologists were assembled to work in a manner modeled after a North American anthropological approach to prehistory (McMillan and Klippel, 1981). The UTK Department of Plant and Soil Science cooperated with the excavation in order to determine the soil resource base of the mountain settlements and to evaluate the potential attraction of these people to these locations on the basis of soil resources. The primary goals of these pedological investigations have been to 1) understand the geomorphic mechanisms of landscape development through time, 2) examine pedogenic development of these landscapes, 3) establish the chronologies of landscape stability and change, and 4) interpret the paleoenvironmental conditions governing the development of these landscapes, including the influence of human impact.

The research for this dissertation involves the examination of sediment catchment basins near the Late Minoan III C to Subminoan period refuge sites of Vronda and Kastro in eastern Crete; and the site of Karphi in the Lasithi Province of east-central Crete. It has been demonstrated through archaeological studies that humans have had a considerable impact on the landscape in relation to soil development (Griffith, 1980; Eidt, 1977). For example, land-clearance practices for agricultural purposes generally lead to increased erosion as deduced by the increase of sediment yield in catchment basins. Changes such as these can be detected through various means such as analysis of buried soil horizons or detection of change in sediment flux from colluvial or alluvial settings. Soils and landscapes are particularly sensitive to environmental changes, and environmental dynamics can be detected through pedological and geomorphological analyses.

PART 1

**THE ENVIRONMENTAL AND CULTURAL DYNAMICS OF CRETE
AND THE EASTERN MEDITERRANEAN**

INTRODUCTION

The Late Minoan III C period and subsequent Subminoan period (approx. 1100-900 B.C.) represents the final phase of the peoples and civilization of Minoan Crete. The previous cultural periods were represented by the Minoan palace phases, which was one of the most prosperous civilizations in the eastern Mediterranean. The following period, known as the Greek Dark Ages, was one of the cultural decline in human population, their stylistic components, and historical records. It has been speculated that this void in Greek history was compounded by a number of factors. Such wide ranging theories as a Dorian invasion (Kagan, 1969), the volcanic eruption of Thera (Ninkovich and Heezen, 1965), a climate change (Carpenter, 1966), and a period of severe economic depression (Betancourt, 1976) have been expounded by a variety of historians and scientists. However, truly conclusive evidence of any of these factors alone or in concert have not been established for Minoan Crete.

The approach for this assessment of broad scale changes in the Late Minoan environment is through a pedological investigation. Pedology is concerned with the development of a landscape, the stability of a landscape, and the physio-chemical alterations that occur during periods of landscape stability. The understanding of soils and soil systems as they are related to climate, organisms, parent material, topography, and time (Jenny, 1941) can be useful to archaeologists in their assessments of landscape development and post-depositional alteration processes (Wood and Johnson, 1978). The relationship between paleoenvironment and its effect on human populations has received considerable attention (Butzer, 1982). Pedology focuses on the soil system as the interface between the physical (parent material, climate) and the biological (vegetation, human influence) environment. By

examination of the variability in the properties of soil, one may be able to more fully assess the changes in climate, vegetation, and human impact that may have occurred during the past.

HISTORY OF THE EXCAVATIONS

The archaeological sites which were used in this study include the sites of Vronda and Kastro south of the present village of Kavousi on the northern slopes of the Siteia Range in eastern Crete. The site of Karphi was selected for this study because of its cultural affiliation which is contemporaneous with the Vronda and Kastro sites. The archaeological site proper was not disturbed for this study, but rather the sediment catchment areas situated topographically below these sites (including alluvial fans, sinkholes, and stream terraces) were the primary focus of this investigation.

Vronda was a settlement located south of the village of Kavousi atop a relatively level knoll of dolomitic limestones in the northern foothills of the Siteia Mountains at an elevation of approximately 440 m above mean sea level (AMSL). First excavated by Harriet Boyd in 1900, the site was left alone until the start of the Kavousi Project in 1978. Vronda was a sizable settlement spreading over an area of 61 m by 40 m. The settlement consisted of a number of rectangular houses situated on a series of terraces on the knoll. The settlement had a central paved street as well as several courtyards. The settlement also boasted a shrine, a pottery kiln, and a number of tholos tombs. The settlement was initiated around the beginning of the Late Minoan IIIc period (around 1100 B.C.) or possibly as early as the Early Minoan Period and was abandoned in the Early Protogeometric Period (around 800 B.C.). From the Early to Middle Protogeometric Period, Vronda was used as a cemetery by the inhabitants of the Kastro. The Vronda cemetery ceased in the Middle Geometric Period (Gesell et al., 1983; 1988; 1991; Day et al., 1986).

The site of Kastro is located south of Kavousi in the Siteia Range on a mountain promontory composed of hard phyllite at an elevation of around 710 m AMSL. The site was first excavated by Harriet Boyd in 1900, and excavations were begun anew in 1978 by the Kavousi Expedition. The Kastro is a Late Bronze/Early Iron Age settlement which overlooks the Avgo Pass in the Siteia Range. The site is composed of thirteen rooms on six terraces of differing elevations. The site of Kastro is believed to have begun in the Late Minoan III C Period and continued until the Late Protogeometric/Early Orientalizing Period (approximately 650 B.C.). After this time period, the human population in general left the Kavousi area (Gesell et al. 1985; Day et al., 1986).

The site of Karphi is located in the northern section of the Diktean Range above the Lasithi Plateau approximately 1 km north of the present village of Tzermiada. The site was excavated by John Pendlebury and teams from the British School in 1937-1938. The site occupies a saddle between two dolomite peaks with a good view of the sea to the north and the Plain of Lasithi to the south. The site consists of over 150 rectangular rooms and was believed to house 3,500 persons. The houses were built of shaped blocks of dolomite, and rectangular Minoan style and Megaron style buildings are present. The Minoan peak sanctuary at Karphi may have served as a religious center for the remaining Minoan inhabitants during the Mycenaean occupation of Crete. Pendlebury speculated that the inhabitants were Minoans who fled to this site to escape the Dorians who may have occupied the lower coastal plains around Knossos, Messara, and Pechiadha around 1100-900 B.C. (Students of the British School, 1937-1938). This site may have been attractive because of the cultivatable plains nearby. When the Dorian threat became less severe, the site was abandoned, probably for the nearby site of Papoura to the south which was closer to the Plain

of Lasithi (Students of the British School 1937-1938; Watrous, 1980; 1982; Desborough, 1972).

PREHISTORY OF CRETE

Neolithic Period (6,000-2,600 B.C.)

The Neolithic Period was the first for human habitation on the island of Crete. Peoples emigrating from Anatolia began to settle in the areas of Knossos, Phaestos, and Magasia. These permanent settlements practiced a mixed economy with a variety of livestock, legumes and cereals including the "exotic" cereals of emmer and bread wheat. Grain crops were primarily sown in the winter, and livestock consisted of smaller animals such as sheep and goats which were raised primarily for meat (Barker, 1985). Neolithic dwellings consisted of stone with upper stories of brick. Tool kits consisted of stone, bone, and obsidian (from Melos). Caves were used for worship as well as for burial (Kofou, 1990). Toward the end of the Neolithic Period a further diversification of agricultural crops was realized. Plant crops included emmer, einkorn and six-row barley as well as a wider range of legumes. Olives were grown and harvested on a minor scale (Barker, 1985). Livestock ratios changed with a decrease in sheep and goats and an increase in cattle and pigs from 6,000 to 3,000 B.C. with a subsequent increase in sheep and goats around 2,000 B.C. (Halstead, 1981). There is also evidence that these peoples may have had the technology for short sea voyages for the procurement of Melos obsidian, as well as deep water fish (Barker, 1985).

Pre-palace Period (Early Minoan, Middle Minoan Ia) 2,600-1,900 B.C.

The Pre-Palace Period or Early Minoan Period was one of a great number of innovations on Crete. Archaeological investigations from this period record the first use of bronze and the first use of the potters wheel in Crete. There was a general increase in the

human population at this time and the beginning of a more sedentary, structured society. The settlements of Palaikastro, Mochlos, Pseira, and Gournia are initiated around 2,900 B.C. The economy was based on fishing, farming, and pastoralism as well as shipping and trade. There is evidence for extensive trade with Egypt, the Cyclades, Asia Minor, the Levant, Libya, and possibly with the Greek mainland. Artisans and those engaged in trade and commerce comprised a new middle class. Chief exports included agricultural products, handicrafts, and livestock. Chief imports included tin and copper for bronze manufacture. Settlements, such as Vasiliki and Myrtos, consisted of houses which were wide, shallow and rectangular with flat roofs, wooden beam supports, covered with plaster, and surrounded by makeshift dwellings. In time, the houses became several stories high, with the lower parts consisting of rubble and the upper part of adobe. The Neolithic traditions of using caves for worship, particularly of the mother goddess, continued and peak sanctuaries are utilized at this time. Caves and rock crevices were utilized for burial. Settlements at Vasiliki and Myrtos were destroyed toward the end of this period and Vasiliki was rebuilt at a later time (Kagan, 1969; Kofou, 1990).

Old Palace Period (Middle Minoan Ib, II) 1900-1700 B.C.

This particular period in Minoan Crete represents a rather sudden transformation of power to several centralized locations with a few heads of state. The famous Minoan palace complexes were constructed at Phaestos, Malia, and Zakros with the largest palace at Knossos. The head of state (king) for the Minoan Empire most likely resided at the palace at Knossos. Several unfortified towns expanded around the palace complexes. The palaces and noble buildings were multistoried with square and rectangular rooms with many corridors around a central courtyard. The structure walls were built of a mixture of gypsum and limestone blocks with clay and wooden supports. The palaces had a host of storerooms, light wells, workshops, and sanctuaries. There were elaborate drainage systems within the palaces

as well as aqueducts such as the one from Mount Juktas to the palace at Knossos. Irrigation came into practice and a paved road was created between Knossos and Phaestos. Trade, taxes, and redistribution of goods were all under control by rulers of the palaces. There was evidence of trade with Egypt and Cyprus, and Minoan colonies developed on Milos and Kythera in the Aegean. Kamares ware was the popular ceramic style with floral decorations on a black background. Priests occupied high positions in the society and large areas of the palaces were dedicated to the Mother goddess. Linear A writing replaced the hieroglyphic scripts of the Neolithic. Around 1700 B.C., a series of powerful earthquakes shook the eastern Mediterranean causing destruction of the palace complexes (Kagan, 1969; Kofou, 1990).

New Palace Period (Middle Minoan III, Late Minoan I) 1700-1450 B.C.

The New Palace Period represents the zenith of the Minoan civilization on Crete. All of the palaces which were destroyed in the 1700 B.C. earthquake were rebuilt and the palace at Aghia Triada was added. Features of these new palace complexes included central and western courts, stairways, propylea, and light wells. Storage rooms were distributed where needed and religious, and royal rooms were located in the west wing. Buildings were constructed using a combination of gypsum and limestone blocks with wooden beams. Propylea were popular features with their columns composed of inverted Cypress trunks and floors paved with green slate. Country houses and farms appeared at Vathypetra, Gortyn, Plati, Siteia, and Zakros. These houses included tools for wine and olive pressing, clay kneading tables, looms and dyeing facilities. Towns included Malia, Zakros, Gournia, Palaikastro, Mochlos, and Pseira. Zakros was a wealthy trade center with Egypt, Gournia was a farming and trade center, and Pseira was a maritime settlement. Roads were developed throughout Crete with bridges, and guard houses. Minoan Crete controlled the center of the

Mediterranean Sea with many colonies as trade centers including Kythera, Kia, Rhodes, Thera, Melos, and Miletus. Trade was carried out with Africa, Asia, Cyprus, and Sicily. Agricultural products, including grain, wine and aromatic olive oil were chief exports, with principal imports including Lebanese cedar. Middle class artisans produced a large quantity of pottery, weavings, oils, perfumes, and pharmaceuticals. The kings were considered the political and religious heads of state. Cult areas in the palaces included lustral basins, fountains, stepped altars, and offering tables. The Snake Goddess was important and the Double Axe or "Labrys" was the important religious symbol for the Minoans. The dead were placed with burial goods in wooden bins or sarcophagi which were later replaced with clay and stone sarcophagi. Carved chamber tombs were also popular. Women held important positions in Minoan society particularly in the religion. Art reached its peak during this period with brilliant frescoes, floral and marine style pottery, steatite carving, bone and ivory working and gold working. The Linear A style of writing was popular during this period (Kagan, 1969; Kofou, 1990). The volcanic eruption of Thera occurred around 1500 B.C. and around 1450 B.C. the large cities were again destroyed. Some argue that the fall of ash and pumice served to poison the landscape and burn the villages and towns which led to the downfall of the Minoan Empire (Page, 1978). Others argue that it was not the ashfall but rather the earthquakes which occurred at a later time were particularly devastating to the society (Schiering, 1978) and occurred long after the Thera eruption (Soles and Davaras, 1990; Betancourt et al., 1990).

Post-Palace Period (Late Minoan II, III) 1450-1100 B.C.

After the eruption of Thera and the devastation of the Minoan palaces, the weakened Minoan power base succumbed to the Achaeans or Mycenaeans who took control of the island of Crete. The Achaean dynasty rebuilt parts of the palace at Knossos. Linear B

writing replaced Linear A and over 3,000 tablets of Linear B script were found at Knossos. Another earthquake hit Crete around 1380 B.C. and Mycenaean style Megara begin to appear in the architecture, a possible sign that the Minoan and Mycenaean peoples coexisted relatively well. Trade was still carried out with Africa and Egypt. Ceramic decorations became less free-form, like the Marine Style, and more stylized, like the ceramics from the Greek mainland. Although the art styles were considered to be in decline, bronze working approached its peak. The wealth of material goods in the royal tombs is evidence that Archons continued to be rather wealthy. The Snake Goddess with the upraised arms was still an important religious item and many were found in the peak sanctuaries at Karphi, Gournia, and Iraklio. Around 1200 B.C. there were reports of piracy in Egypt. The Hittites began to leave Anatolia, and peoples from Crete emigrated to Cyprus and the Levant. Piracy in the Mediterranean becomes commonplace and Crete may have still boasted a large fleet for that purpose (Kagan, 1969; Kofou, 1990; Watrous, 1980).

Protogeometric Period (Late Minoan III C, Subminoan) 1100-900 B.C.

The Protogeometric or Subminoan Period represents the last occurrence of the Minoan culture on Crete. A general depopulation occurred on Crete, and the Aegean area as well, in favor of resettlement in locations in Cyprus and the Levant to the east. Also, new immigrants (or at least those familiar with the manufacture of iron implements) began to settle on the island, primarily in central Crete. Older inhabitants, possibly the remnant Minoans, took refuge in the mountain villages in central and eastern Crete. Use of iron became prominent in construction of weapons and tools. In the 11th century, there was a move into the mountain villages or "refuge" sites of Karphi, Vrokastro, Vronta, and Kastri. It is believed that at least 3500 inhabitants lived on the Karphi site. The Karphi houses were single storied, built of hard limestone blocks with a dry stone technique. Iron implements and

a "megaron" style building are believed to be Mycenaean elements which appeared in this Minoan settlement. The Mycenaean cultural element was stronger in central Crete and at Kastri at this time. The important "fringe style" ceramic decoration was an archaeological marker for this time period. Other Early Iron Age settlements at this time included Knossos, Phaestos and a small settlement at Gortyn. The 10th century witnessed a period of separation of cultural elements between central Crete and eastern Crete. In central Crete there was the development of chamber tombs and cremation. Protogeometric Athens had a definite influence on the culture and imported Athenian vases appeared in central Crete. The culture in eastern Crete, though, held more to the Minoan traditions. Burial practices included inhumation in tholos tombs, and the Athenian protogeometric tradition had a limited influence on the eastern Crete ceramics. In the following Protogeometric and Orientalizing Periods (900-650 B.C.) political power became more centralized in Athens and the influence of the Athens geometric tradition became prevalent throughout Crete (Kagan, 1969; Kofou, 1990; Desborough, 1972; Coldstream, 1977).

PHYSIOGRAPHY OF CRETE

The island of Crete lies between 23°30' and 26°20' east longitude and 34°54'40" and 35°41'34" north latitude in the Southern Aegean region of the eastern Mediterranean Sea. The island is approximately 245 km long and 12-52 km wide with an area of 8,620 km². Crete is a remnant of a Tertiary arc of folds that extend from the southern Peloponese to southwest Anatolia. In the northern parts of the island, upraised ophiolitic sequences can be found and have been dated to the Cretaceous Period (Fortuin, 1977). The post-orogenic development of Crete is dominated by a complex system of block faults and thrusts creating a rather complicated mosaic of mountain ranges, including the Lefka Ori (White Mountains), Psiloritis (Ida), Lasithi (Dikte), and Siteia (Figure 1). Between these ranges lie a series of lower lying



Figure 1. Map of Crete showing physiographic areas, major cities and archaeological sites.

valleys, plateaus, and isthmuses. Approximately 10% of the island area has an elevation of less than 100 m; 35% 100-400 m; 30% 400-800 m; and 25% over 800 m. (Zohary and Orshan, 1965; Allbaugh, 1953). Post-orogenic deposition of limestones and marls overlie metamorphic rocks, which are separated by an angular unconformity. Upheaval and tilting of these beds toward the north and northeast lead to abrupt southern and less steep northern slopes.

Geology

The island of Crete represents the southernmost part of the Hellenides and has been referred to as a "drowned" mountain range. The Aegean arc overthrust and folded mainly during the Late Paleogene and Early Miocene. The oldest rocks of Crete are the cherty limestones and partially metamorphosed limestones of Permian to Oligocene age usually referred as the Plattenkalk or Talea-Ori series (Fortuin, 1977; Baumann et al., 1978). The lowest allochthonous unit is represented by the Phyllitic series which is Permian to Triassic in age. The Tripolitza Series comprises massive unbedded to thick bedded, dark grey, partly dolomitized limestones of Jurassic to Eocene in age. This unit overlies unconformably the Phyllitic series and underlies the Neogene or Tertiary chalks and marls particularly in the eastern portion of Crete. The Pindos Series consists of well bedded limestones with cherts and flysch sandstones of Eocene age. The highest allochthonous unit consists of a Serpentine-Amphibolite Association. This Volcano-Sedimentary complex consists of discontinuous strata of laterally non-persistent beds. The assemblage is represented by ophiolite sequences and granodiorite outcrops which underlie the Neogene in several places along fault zones (Fortuin, 1977; Baumann et al., 1978; Kopp, 1978).

The Neogene deposits on Crete were formed after a series of block-faulting episodes in Late Serravallian-Early Tortonian times where deposition drastically changed from a

terrestrial to an open marine environment (Fortuin, 1977; Baumann et al., 1978). At this time, tectonic tension caused the break up of the southern Aegean Region (Meulenkamp, 1985). From the Late Tortonian until the Pliocene, carbonate sedimentation took place. Unstable tectonic conditions controlled the sedimentation until the Early Pliocene, when great open marine sedimentation occurred (Buttner and Kowalczyk, 1978). In the early Late Pliocene, tectonic uplift started to separate as a horst from the surrounding seas (Fortuin, 1978).

Quaternary geology of Crete is dominated by Pleistocene "diluvial" deposits as well as Holocene alluvium and colluvium. Eustatic sea level changes congruent with major glacial and interglacial episodes are believed to be responsible for cycles of erosion and deposition, particularly along the sea coasts. Holocene alluvium and colluvium may have been influenced by early sea level changes, but the affect of humans on the landscape may have contributed to the extensive erosional features present on the current landscape.

Climate

The climate of Crete is Mediterranean or xeric with rainfall restricted primarily to the months of September to May with the highest rainfall occurring in December and January. There is a gradient extending from the western to the eastern portions of Crete with annual rainfall averaging around 600 mm in the coastal areas of northwestern Crete and 350 mm in northeastern Crete. There is an elevational orographic effect with precipitation. The Lasithi Plain, for example, receives around 900 mm of rainfall per year at an elevation of around 800 m. Nearby towns such as Neapoli and Agios Nikolaos receive 720 mm and 356 mm of precipitation at 400 m AMSL and 0 m AMSL respectively. Mean temperatures are on the average 2° to 3° cooler in the west as compared to the east. Temperatures in Ierapetra on

the south coast of eastern Crete generally range from a mean January temperature of 13.2° C to a mean August temperature of 27.2° C (Zohary and Orshan, 1965).

The Mediterranean climate is, quite appropriately, influenced by the Mediterranean Sea. During the summer, dry sirocco winds from the north of Africa dominate the weather pattern favoring evaporation over precipitation. During the winter, cold, dry continental air masses converge on a relatively warm sea (winter temperatures rarely drop below 16° C) resulting in strong evaporation and atmospheric instability leading to the deposition of winter rains (Gat and Magaritz, 1980). Atmospheric low pressure systems or depressions, develop over the Ionian Sea and deposit rainfall from west to east. The west-east running mountain ranges on Crete serve as a rainshadow favoring precipitation in the western regions over the east (Mariolopoulos, 1961). Table 1 summarizes climatic information for Iraklio, Crete.

Vegetation

The vegetation on Crete is typically Mediterranean. The vegetal cover is predominantly composed of maquis type and its derivatives (phrygana, garigue, and batha). The maquis is composed of evergreen xerophilous communities and is believed to have expanded due to human influence. It is possible that remnant forests of *Quercus pubescens*, *Quercus macrolepis*, *Pinus brutia*, and *Cupressus sempervirens* once dominated and covered the island (Zohary and Orshan, 1965).

Zohary and Orshan (1965), in their survey of the vegetation of Crete, divided the island into four major vegetation types; 1) Coniferous Forest, 2) Deciduous Forest, 3) Evergreen Maquis, and 4) Garigue and Batha (Phrygana).

Table 1. Climate information for Iraklio, Crete.

Source: Mariolopoulos, E.G. 1961. An outline of the climate of Greece. Pub. of the Meteorological Inst. of the Univ. of Athens, Athens.

Climate Measure	January	April	July	October	Year
Mean Air Temperature (°C)	12.4	16.9	25.8	20.9	19.0
Mean Maximum Air Temperature (°C)	15.7	21.5	29.6	25.0	22.9
Mean Minimum Air Temperature (°C)	9.0	12.3	21.9	16.9	15.0
Mean Relative Humidity (%)	71	61	60	67	65
Mean Cloudiness (Days)	6.8	4.2	0.6	4.5	4.2
Mean Rainfall (mm)	96.3	27.0	0.3	53.4	521.8
Days of Rain, Snow, Hail, and Thunderstorm	16.7	6.4	0.1	6.9	89.0
Prevailing Winds	S	NW	NW	NW	NW

Coniferous Forest

Remnant stands of *Pinus brutia* can be found on the island from 0 to 1,200 m AMSL mainly on marl or chalk rocks or rendzina soils. Stands of *Pinus brutia* tend to establish in areas where the dense evergreen maquis is removed because of the low shade tolerance of these pine seedlings. Other coniferous forest types include the cypress stands (*Cupressus sempervirens* var. *horizontalis*). These cypress stands have been observed from sea level to 1,500 m and substantial stands have been observed in the Lefka Ori and Lasithi mountain ranges. These conifers are also shade intolerant as seedlings and establish where dense maquis growth is limited.

Deciduous Forest

There are two remnant kinds of deciduous forests on Crete; one dominated by *Quercus pubescens* and the other dominated by *Quercus macrolepis*. *Quercus pubescens* is widely distributed throughout the northern half of the island and ranges in altitude from sea level up to 850 m. *Quercus pubescens* forests may have been originally limited to higher altitudes because it is usually limited to upper regions of the montane zone of the Mediterranean region. *Quercus macrolepis* is limited to the coastal area of northern Crete and is found in the lowlands and hills below 1,000 m AMSL. A third deciduous forest type on Crete is dominated by *Acer orientale* which mostly appears as a stunted shrub or tree and usually limited between the altitudes of 900 m and 1,500 m. It is often mixed with maquis trees and the main centers of the *Acer* forest are found in the Lefka Ori, Psiloritis and Lasithi mountain ranges.

The evergreen maquis is usually made up of low trees and higher shrubs, generally not exceeding 5 m in height. This vegetation association predominates in the 0-600 m zone. There are two major associations in the evergreen maquis. The *Pistacia lentiscus-Ceratonia siliqua* scrub is widely distributed all around the island in the lower zones and coastal plains. It is characteristically accompanied by *Olea europaea* var. *oleaster*. The other evergreen maquis association is the *Quercus coccifera* maquis. This association is usually limited to altitudes between 300-1,000 m but may descend to cooler valleys down to 100 m. In the western portion of Crete, *Quercus ilex* may be favored instead of *Quercus coccifera* because of the moister conditions.

Garigue and Batha (Phrygana)

The garigue and batha, sometimes known as the phrygana, consists of the medium and dwarf shrub formations. The garigue consists of a shrubbery up to 1 m in height whereas the batha attains a height of less than 60 cm. This association appears to be maintained by disturbance, both by frequent fires due to human influence, and by the extensive erosion that seems to be associated with the soils of this association.

Human Influenced Plant Communities

Based upon the archaeological record plants brought in by the human occupants of Crete in the Neolithic Period include spring barley (*Hordeum vulgare*), wheat (*Triticum dicoccum*), and lentil (*Lens esculenta*). Endemics that were cultivated included garden pea (*Pisum sativum*), broad bean (*Vicia faba*), chickling vetch (*Lathyrus sativus*), and olive (*Olea europea*). Cypress (*Cupressus sempervirens*) was used for the columns at the palace of Knossos and cypress and pine (*Pinus brutia*) were important for shipbuilding. Common forest trees used by the Minoans included Chestnut (*Castanea sativa*), Oak (*Quercus aegilops* var.

cretica), holly oak (*Quercus ilex*), juniper (*Juniperus oxycedrus* and *Juniperus macrocarpa*) and carob tree (*Ceratonia siliqua*) (Diapoulis, 1980).

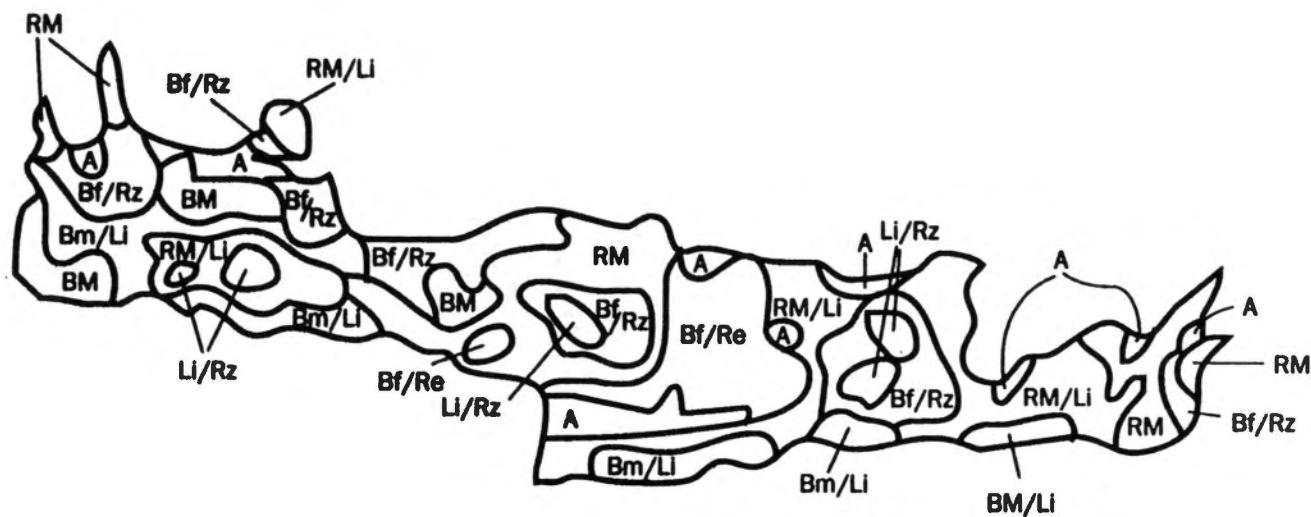
Soils

The soils of Crete are formed from six major parent material types; 1) basic-ultrabasic and acidic igneous formations, 2) metamorphic rocks, 3) hard (Mesozoic) limestone, 4) Tertiary and Quaternary chalks and marls, 5) flysch and conglomerates, and 6) alluvial formations (Nakos, 1983). Igneous rock types are found sparsely on the island. This parent material usually gives rise to acid soils. Metamorphic formations, including phyllites, slates, metaschists, and quartzites, form the bedrock basement of the island and are vastly exposed in areas where the overlying limestone has been truncated. Where not eroded these soils are relatively deep and moderately acid. It is in these metamorphic formations, particularly in the soft phyllites where one finds extensive construction of Minoan Period agricultural terraces on exposed slopes in eastern Crete. Hard limestones of Jurassic, Cretaceous and Eocene ages comprise the main mountain blocks of the island. From these limestones and dolomites one finds the development of residual red soils known as "terra rossa" which are generally shallow and high in clay content (Nevros and Zvorykin, 1939; Nakos, 1983). Caves, dolines and other karst features are common in these hard limestones. Tertiary chalks and marls of marine and terrestrial origin contain the light colored, high organic, high base "rendzina" soils (Nevros and Zvorykin, 1939) which were of great importance agriculturally particularly in the area of the palace site at Knossos. These soils are generally suited for dry farming and orchards (olive and vineyards) (Nakos, 1983). Flysch and conglomerates of Late Tertiary and Quaternary age are found in the footslope positions of the mountain ranges and are composed of clastic materials of variable origin. These deposits give rise to deep, moderately acid, loamy to clay loam soils. Holocene alluvium and colluvium is found throughout the drainages and valleys

loam soils. Holocene alluvium and colluvium is found throughout the drainages and valleys and were probably important to the agricultural production of cereals and grains during the Minoan Period because of their high base status and high water holding capacity (Yassoglou and Nobeli, 1972).

The soil-climate relationship is characterized by the effect of altitude on moisture, and longitude on temperature. Anastassiades (1949) divided Crete into two major climatic belts; the Chestnut belt and the Aegean belt. The Chestnut belt lies between 500 and 1,000 m AMSL and the Aegean belt which lies at 0-700 m AMSL, is restricted to the eastern and southeastern (drier) areas of Greece including Crete. Zinke (1973) recognized five different soil-vegetation catenas on most rock types in Italy, Greece, and California. These designations are 1) high elevation 1600+ m, ranker soils, moderately acid with associated high mountain pasture; 2) moderately high elevation 1,000-1,600 m, gray-brown podzolic with associated coniferous forests with *Abies* or *Pinus* and Hardwood Beech forests in Europe; 3) low elevation 500-1,000 m, brown forest soils with associated hardwood forest--lower beech forests, scrub oak forests, and closed cone pine forests; 4) lowest 0-500 m elevation, hard limestone, Mediterranean red soils (terra rossa), with *Quercus ilex* oak woodlands, *Quercus coccifera* maquis; and 5) lowest 0-500 m elevation, soft marls and chalks, xerorendzina or rendolls with associated annual grasses and herbs.

The following discussion focuses on the FAO (1966) soil mapping designations for the island of Crete and the associated USDA classification (Soil Survey Staff, 1975). The soils recognized by the FAO in Crete are 1) Lithosols and Rendzinas, 2) Brown Forest Soils and Rendzinas, 3) Brown Mediterranean soils and Lithosols, 4) Red Mediterranean Soils and Lithosols, 5) Brown Forest Soils and Regosols, 6) Brown Mediterranean soils, 7) Red Mediterranean Soils, and 8) Alluvial Soils (Figure 2).



Li/Rz: Lithosols and Rendzinas
 Bf/Rz: Brown Forest Soils and Rendzinas
 BM/Li: Brown Mediterranean Soils and Lithosols
 RM/Li: Red Mediterranean Soils and Lithosols
 Bf/Re: Brown Forest Soils and Regosols
 BM: Brown Mediterranean Soils
 RM: Red Mediterranean Soils
 A: Alluvial Soils

Figure 2. FAO soil map units for the island of Crete.

Source: FAO. 1966. Soil map of Europe: 1:2,500,000 explanatory text. Food and Agriculture Organization of the United Nations, Rome.

Lithosols and Rendzinas (Li/Rz–Lithic Udorthents and Lithic Rendolls)

These soils are formed from limestone and dolomite parent materials. This association occurs in mountainous regions with strongly dissected topography and steep to very steep slopes. These soils occur above 2,000 m in elevation. The climate is cold and humid with a mean annual temperature of 10° C and mean annual precipitation exceeding 1,200 mm. This soil association occurs in the White (Lefka Ori), Ida (Psiloritis), and Lasithi (Dikte) mountain ranges on Crete.

Brown Forest Soils and Rendzinas (Bf/Rz–Lithic Xerochrepts and Lithic Haploxerolls)

These soils are formed mainly from limestone and dolomite with some influence of loess. The physiography is generally mountainous to hilly with moderately steep to steep slopes. This association is found from 500 to 2,000 m AMSL. The climate is relatively mild, but drier with mean annual rainfall ranging from 600 to 1,000 mm. The seasonal rainfall and steep slopes of this association make the area more attractive for pastoralism than for crop or forest production. This association occurs in the northwest coastal areas and in the Ida and Lasithi mountain ranges.

Brown Mediterranean Soils and Lithosols (BM/Li–Lithic Haploxeralfs and Lithic Xerorthents)

These soils are formed from crystalline rocks, flysch deposits, and limestone. The association is found in hilly to mountainous regions with moderately steep to steep slopes with elevations ranging from 400 to 1,000 m. The climate is Mediterranean with mean annual precipitation ranging from 750 to 1,000 mm falling primarily in the winter months. These soils are moderately fertile, but highly erodible. Seasonal pasture can be maintained, but is not recommended. This association has potential for growing tree-fruits such as apples, pears,

prunes, and cherries. This association mainly occurs in the moister regions of west Crete and the south coast.

Red Mediterranean Soils and Lithosols (RM/Li—Lithic Rhodoxeralfs and Lithic Xerorthents)

These soils are composed mainly of shallow, stony, red soils. They are formed mostly from hard limestone and dolomite, calcareous sandstone, and calcareous shale. The association occurs on maturely dissected plateaus on moderately steep to steep slopes or on rough karst topography in which steep hills alternate with solution basins. Drainage is mainly subterranean. The climate is Mediterranean, warm and temperate with dry summers and humid winters. Annual precipitation generally ranges from 500 to 900 mm. The dry summers are the primary limiting factor agriculturally, but olives and dates can be cultivated with irrigation. Most of this association is suited primarily for pastoralism. This association mainly occurs in east-central and eastern Crete.

Brown Forest Soils and Regosols (Bf/Re—Rendollic Eutrochrepts and Typic Xerorthents)

This association consists of young soils developed from permeable calcareous parent materials. These permeable formations include chalks, soft limestones, marls, and calcareous clays. This association occurs on undulating to rolling low plateaus. The climate is humid temperate with variations occurring with altitude and latitude. Mean annual temperature is around 8° C with average annual rainfall ranging from 600 to 750 mm. This association is well suited for farm crops such as wheat, corn, and root crops. In Crete, this association occurs in the central area from the north coast south to the Messara Plain. This association was the primary agricultural soils of the Minoan palace at Knossos.

Brown Mediterranean Soils (BM–Typic Haploxeralfs)

This association occurs on a wide variety of parent materials including volcanic rocks, granite, shales, sandstones, and conglomerates. The physiography is varied from gently rolling relief to steep slopes. The association occurs generally from sea level to 800 m. The climate is Mediterranean with mean annual rainfall from 500 to 750 mm, occurring mostly in the winter months with a mean annual temperature of around 18° C. The natural vegetation is a mixture of mesophytic to xerophytic grass-tree cover with oak, wild pear, and elm. These soils have good moisture capacity and are more easily tilled than the Red Mediterranean soils. Principal crops are wheat, oats, corn, and olives. This soil unit is found mainly in the western areas of Crete.

Red Mediterranean Soils (RM–Typic Rhodoxeralfs and Lithic Rhodoxeralfs)

These soils are formed primarily from hard limestone, dolomite, calcareous sandstones, and calcareous sands and gravels. The association occupies sloping fans, undulating to rolling low plateaus and weakly dissected gentle to moderate slopes with gradients ranging from 8 to 20% slopes. The climate is Mediterranean with annual rainfall averaging from 500 to 750 mm, mainly falling in the winter months. Natural vegetation includes open forests of pine, oak, ash, chestnut, mulberry, and carob; however, most of the original forest cover has been destroyed and replaced with phrygana and maquis types. Soils are of moderate productivity and wheat, lentils, vines, olives, almonds, figs, and citrus are commonly grown. The more eroded and sloping areas are used for grazing. This association commonly occurs in west-central Crete.

Alluvial Soils (A–Typic Xerofluvents and Fluventic Xerochrepts)

These soils are found on relatively young alluvial deposits. They are varied in composition and origin and can consist of coastal and valley alluvium, deltaic and estuarine deposits, and lake and lagoon sediments. These soils can occur in valleys of large and small streams, on coastal strips, deltas, estuaries and lake basins. They are generally very productive and are the primary agricultural soils producing a variety of crops including olives, wheat, cotton, flax, and vegetables. In Crete they are found in the alluvium of the Messara Plain, the Cha Gorge, and the Lasithi Plateau, and on river and beach deposits near Chania, Iraklio, Siteia, and Palaikastro.

PALEOENVIRONMENT

The reconstruction of paleoenvironments is of critical importance in assessing the effects of climate on the resource base of past human populations. Much of the work on paleoclimates in the eastern Mediterranean has been conducted in the Nile Valley (Butzer and Hansen, 1968), the Levant (Farrand, 1979), various deep sea cores (Emiliani, 1955), northwest Greece (Bottema, 1979), and most extensively in the southern Peloponese (McDonald and Rapp, 1972; Rapp and Aschenbrenner, 1978). These studies include information gathered from a variety of sources including sedimentology, pollen analysis, geomorphology, geoarchaeology, and pedology in their attempts to correlate climatic dynamics in the eastern Mediterranean. A summary of the chronology of the following paleoenvironmental events is recorded in Figure 3.

Deep Sea Cores and Stable Isotopes

Sediment cores collected from various parts of the Mediterranean document changes in planktonic and benthic foraminifera assemblages and the $18/16\text{O}$ compositions of their

YEARS BEFORE PRESENT	MEDITERRANEAN SEA	VEGETATION	GEOMORPHOLOGY	PREHISTORY
12,000	Southernmost extent of Mediterranean winter rainbelt 5° to 10° cooler than present Increase in effective moisture			
11,000	Incursion of meltwater from the Black Sea			
10,000	Salinity decrease	Pine forest (<i>Pinus brutia</i>)		
9,000		Expansion of oak forest	25 m of sea level rise over last 9,000 years	
8,000		Dominant oak forest	Channel incision	Neolithic Period
7,000	Period of stagnation End of meltwater influx			
6,000		Decrease in oaks		
5,000	Northward shift of Mediterranean winter rainbelt Climatic optimum	Onset of xerophytic vegetation assemblage		Pre-palace Period
4,000				Old Palace Period New Palace Period Post-palace Period
3,000	End of wet phase in the Mediterranean			Protogeometric Period Geometric Period
2,000			Deposition of "younger fill"	
1,000				
0				

Figure 3. Chronology of environmental and cultural events for Crete and the eastern Mediterranean.

carbonate shells which serve as paleothermometers and give some indication of the temperature and composition of seawater. Mineralogical assemblages have also led to clues to the circulation of the waters in the Mediterranean in reference to fresh water inputs, sea level fluctuations and the ability to exchange with other bodies of water. For example, the increase in anhydrite and dolomite composition in Late Miocene-Early Pliocene (Messinian) times indicate a Mediterranean basin closed from the Atlantic Ocean, concentrating soluble salts in the Mediterranean Sea, therefore lowering the vapor pressure of the Atlantic seawater and aiding in the development of continental ice masses. This phenomenon was known as the Messinian Salinity Crisis and represented a period when the Straits of Gibraltar were closed and there was no exchange between the Atlantic and Mediterranean (Lloyd and Hsu, 1972; Meulenkamp, 1977). This phenomenon was responsible for the deposition of the gypsum beds exposed on the island of Crete today (Meulenkamp et al., 1977).

Analyses of a number of deep sea cores in the Mediterranean cover at least the last glacial and interglacial cycle. Thiede (1978), through reconstruction of a number of cores, points to an influx of cool, fresh water from the Black Sea into the Aegean around 18,000 yr B.P. which disrupted the natural west to east temperature gradient of Mediterranean sea surface temperatures. Emiliani (1955) reported on a complete core taken between Crete and Cyprus that spanned some 100,000 years. The findings based on faunal analysis and oxygen isotope studies indicated that the waters of the Mediterranean were more dilute around 35,000 yr. B.P. with a salinity decrease of 1‰ to 5‰, and that the temperature was 5° to 10° cooler during the period between 30,000 and 12,000 yr. B.P. The study also points to repeated layers of black muds prior to 50,000 yr. B.P. which was interpreted as a lowering of sea level and the closing of the Mediterranean basin during peak glacial times.

Holocene variations in climate in the eastern Mediterranean are recorded in several sea studies. Herman (1972) studied several deep sea cores; one which spans the last 120,000 years. Her findings show that the mean surface water temperatures between the present and past interglacials were similar, and a period of marine stagnation was recorded about 7,000 yr. B.P. Buckley et al. (1982) studied a series of cores around the eastern Mediterranean. Analyses of the planktonic foraminifera indicate a slow warming from about 24,000 yr. B.P. to a climatic optimum at 4,700 yr. B.P. Planktonic foraminifera productivity was highest at 9,000 and 4,700 yr. B.P. and benthonic foraminifera activity was greatest in the late glacial between 12,000 to 10,000 yr. B.P. caused by incursion of fresh meltwater into the saline Mediterranean. A decrease in the amount of montmorillonite from 12,000 yr. B.P. coincides with the addition of meltwater in the Mediterranean from the Black Sea and an increase in montmorillonite at 6,700 yr. B.P. indicates the end of meltwater influx. A salinity decrease recorded at 10,000-9,000 yr. B.P. may be evidence for increased precipitation in the Nile river valley. Gat and Magaritz (1980) report from oxygen isotope measurements of shellfish off of the coast of Israel that a particularly wet phase is evident from the time period of the early Holocene to about 3,000 yr. B.P.

Pollen and Paleovegetation Analyses

Vegetational dynamics during the last glacial period document two major changes. The first is a forested vegetational regime reflective of the moister and cooler conditions of the Late Pleistocene which grades into one of a more warmer and drier forest vegetation in the early Holocene. The second is the onset of more xerophytic vegetational types which is interpreted as the influence of human landscape use or the onset of drier climatic conditions.

Analysis of the core at Tenaghi Philippon in northern Greece yielded four major vegetation types (Wijmstra et al., 1990). The first 86 meters of the Tenaghi Philippon core

covers the last 960,000 years. The general glacial/interglacial cycle interpreted from these data indicate that; 1) at the beginning of the interglacials a warm period with wet summers and winters is indicated by an open forest vegetation dominated by *Pistacia* sp., 2) summers began to dry shortly thereafter forcing an evergreen oak forest to develop, 3) during the second half of the interglacials, a deciduous forest developed in the cooler, moister conditions, and 4) at glacial maxima a dry continental climate with cold winters accompanied by steppe vegetation is indicated. This pattern seems to be consistent throughout history until the influence of humans led to some deforestation around 2,000 yr. B.P. (Turner and Greig, 1975). Pollen diagrams also show that olive cultivation appeared in the Tenaghi Philippon area during the Middle Bronze Age and during the Later Dark Age-Early Classical Periods (Greig and Turner, 1974).

The northern part of the Greek mainland shows similar patterns as the pollen spectra at Tenaghi Philippon. The Gavrouna core from Thrace shows that an oak forest which had developed by 9,000 B.C. showed little change until Medieval times when deforestation and a change to a more open vegetation is observed (Greig and Turner, 1974). In the Kopais core near Athens an open steppe vegetation with grasses, chenopods, and mugwort dominate during the last glacial period until about 10,000 yr. B.P. Afterwards, a deciduous forest dominated by oak, with minor constituents of pine, hazel, ash, elm, birch, lime, and hornbeam appears. The deciduous forest was affected by human impact during Final Neolithic times. During the Bronze Age, pollen grains of olive, grape, walnut and chestnut were found (Turner, 1978; Turner and Greig, 1975; Greig and Turner, 1974).

The Osmanaga lagoon pollen core was taken from the southwest Peloponese near Pylos (Wright, 1972). Prior to the Mycenaean Bronze Age occupation an *Aleppo* pine forest is evident. After 4,000 yr. B.P., it was believed that deforestation by the Mycenaean

inhabitants led to a mixed shrubland of maquis along with an increase in agricultural weeds and the appearance of walnut, chestnut, olive and grape pollen (Wright, 1985). An increase in *Olea* pollen by 40% occurs around 1,000-600 B.C., after the main Mycenaean cultural period. Wright believes that this drastic change in vegetation is attributed solely to the activities of man and that human impact has done more to alter the vegetation communities in Greece than any inferred post-glacial climatic change (Wright, 1968).

The only pollen core reported for the island of Crete was taken from the mouth of the Platys River near Aghia Galini in south-central Crete (Bottema, 1980). The early record for Crete indicates a pine and a deciduous oak forest preceded the open maquis and phrygana that exists today. This study indicates that around 10,000 yr. B.P. a pine forest (probably *Pinus brutia*) was present with few deciduous oaks and no xerophytic vegetation. From 9,500 to 8,000 yr. B.P. there was an increase in oaks although pine was still dominant. Around 7,500 yr. B.P., oak expanded at the expense of the pine forest and *Platanus* could be found in the river valleys. Between 7,500 to 7,300 yr. B.P. an open vegetation predominates over the oak forest. At around 7,300 yr. B.P. a re-expansion of the oak forest takes place. Around 5,000 yr. B.P. the area must have been largely devoid of trees with arboreal pollen percentages dropping to modern values. There is a marked pollen gap between 7,300 and 5,000 yr. B.P. and the 5,000 year date may be somewhat erroneous. It is believed that the current xerophytic assemblage has dominated since 4,600 yr. B.P.

The following summary for the last 20,000 years for the eastern Mediterranean was presented by Van Zeist and Bottema (1982). In Greece precipitation increased around 20,000 yr. B.P. and decreased again around 18,000 yr. B.P. Between 18,000 to 16,000 yr. B.P. temperatures dropped to a minimum with dry steppe vegetation predominantly (*Artemisia* and *Chenopodiaceae* and some scattered tree stands) in Greece. From 12,000 to 11,000 yr. B.P.

there was continuous forest cover in northeast Greece. Around 8,000 yr. B.P. there was continuous forest cover over all of Greece, and around 4,000 yr. B.P. the present day distribution of vegetation had become established.

Geomorphology

Geomorphological evidence for landscape evolution during the last glacial cycle has been presented in various areas of Greece. Many of these investigations have explored the validity of the Vita-Finzi (1969) model of alluviation in the Mediterranean region. The model encompasses two major cycles of alluviation in the last 100,000 years. One episode, the Pleistocene "Older Fill" is exemplified by the "Red Beds" of Greece which contain Mousterian and Upper Paleolithic artifacts. The "Younger Fill" contains sherds from the 2nd and 3rd centuries A.D. to the present. The younger fill episode was preceded by a channel incision episode from 8,000 to 2,000 yr. B.P. The forcing factor for these episodes is climatic change. Davidson (1980) supported the Vita-Finzi hypothesis, in particular on the chronology of the Younger Fill, because of the burial of Classical period sherds in the tell mounds of Sitagroi in the plain of Drama in Macedonia. Davidson's continuing work on Melos and Santorini also showed erosional episodes occurring during the Late Bronze Age, immediately preceding the eruption of Thera on Santorini. Subsequent deposition may or may not coincide with the Vita-Finzi synchronous Younger fill episodes (Davidson and Tasker, 1982; Davidson et al., 1976; Davidson, 1978). Bintliff (1975) also supported the Vita-Finzi hypothesis. With work in alluvial valleys in Greece and on Crete, Bintliff has demonstrated that two major alluvial aggradation episodes have occurred. The older fill universally overlaid Pliocene or earlier formations and descend sharply at the coast to a former (glacial) low sea-level. The younger fill was deposited as a result of a cool, moist phase from late Roman and Medieval times to

around 200 yr. B.P. (Bintliff 1975; 1977). Vita-Finzi attributed this climatic cooling to a southward shift in the atmospheric depression belts of Europe (Vita-Finzi, 1976).

There have been a number of critics of the Vita-Finzi model. Wagstaff (1981) argued that detailed studies of these fill sequences and their sedimentary and pedogenic characteristics have not been performed. He suggested that studies of Vita-Finzi supporters failed to regard immediate location of the deposits or whether they consist of alluvium or colluvium. Van Andel et al. (1986) documented an erosional sequence which began around 4,500 yr. B.P. in the southern Argolid. There were two events which consisted of debris flows that were interpreted as clearing of steep slopes of marginal soils. Two other events laid down stream flood deposits which commenced after the abandonment and subsequent failure of agricultural terraces. Land stabilization occurred when agricultural terraces and check dams were maintained, and when the area was completely abandoned and the maquis and pine assemblage reinvaded the landscape. Their conclusion was that the younger fill was more a situation of human impact than climate change in the Late Holocene (Pope and Van Andel, 1984). Landscape destabilization episodes seemed to follow within 500 to 1,000 years the introduction of farming in Greece (Van Andel and Zangger, 1990). Lewin et al. (1991), through a study of the geomorphology in the Voidomatis basin, Epirus, northwest Greece, identified several Quaternary alluvial valley fills that range in age from middle Pleistocene to the Historic period. Major periods of alluviation were associated with valley glaciation (26,000-20,000 yr. B.P.), and deglaciation (20,000-15,000 yr. B.P.) in the Pindus Mountains. The more recent aggradation episode is believed to be linked to overgrazing sometime before the 11th century A.D. The authors concluded that the "older fill-younger fill" model of Vita-Finzi is inadequate for interpreting Quaternary valley aggrading episodes.

Another area of geomorphology one should consider is that of sea level changes and its effect on depositional regimes. Several factors effecting these changes in sea level include tectonics and glacioeustatic factors (Fairbridge, 1972; Flemming, 1972). Kraft et al. (1975; 1980) studied the effects of sea level rise over the past 9,000 years in the area of the Bay of Navarino, southern Greece. There was a general rise in sea level of 25 m over the past 9,000 years. This was accompanied by a major marine transgression into the embayment over 4 km north of the present shoreline. During the Mesolithic and Neolithic Periods, humans occupied the area at a time of rapid sea level rise with no significant alluvial plain. By Helladic times, humans were occupying the developing alluvial plain at the southern shore. Rapp and Kraft (1978) estimated a sea level rise from two to four meters since the Bronze Age in the southern Peloponnese. Van Andel and Lianos (1983) estimated that post-glacial sea level rise reduced the amount of bottomland in the southern Peloponnese to about one-third from the early Holocene to the Mesolithic Period and about one-fifth of that which is available today. Zangger (1991) attributes sea level rise and fall to Neolithic settlement patterns in the Dimini Bay area. The post-glacial sea level rise near Argos served to separate Lake Lerna near Argos from the encroaching sea. Rapid sedimentation into Lake Lerna commenced due to the effect of deforestation by the Early Bronze Age inhabitants and the rise in base level due to sea level rise.

Paleopedology

Pedological studies have been conducted in association with Bronze Age archaeological sites in the southern Peloponnese. Yassoglou and Nobeli (1972) have divided these soil systems into four major types: 1) residual soils formed on consolidated rocks (Alfisols), 2) residual soils formed on Tertiary marine marl, clay, sand, and silt (Mollisols), 3) older alluvial soils (Alfisols), and 4) recent alluvial soils. The first two categories refer to the

"terra rossa" and "rendzina" soils respectively. The remaining categories are important because they represented sequences of alluviation that contained buried horizons and archaeological materials. The findings of Haidouti and Yassoglou (1982) demonstrated that argillic horizons (subsurface horizons which exhibit translocation of weathered clay minerals from the surface horizons) could be developed in 2,000 to 3,000 years in a xeric climate. Cambic horizons (horizons formed by removal of carbonates) could be developed in less than 900 years. Soils that developed in a period longer than 3,000 years exhibit a sepic microstructure and a lower ratio of amorphous to crystalline iron oxides in the argillic horizon. Yassoglou and Haidouti (1978) refer to work conducted by Nettleton et al. (1975) on the development of argillic horizons in the drier areas of the western United States, and observe that these argillic horizons formed during the pluvial conditions of the Late Pleistocene. There has also been no argillic development in these desert soils for the past 12,000 years and these argillic horizons are considered to be climatic relics. Yassaglou and Haidouti (1978) however, believe that argillic horizons can form in the present xeric regimes of the Mediterranean. These soil morphological characteristics can be used as relative time markers in examining landscape evolution.

The development of the "terra rossas" and the red and brown Mediterranean soils have been suggested by some as being relict in origin (Davidson, 1980). It has been speculated that these soils have formed under the interstadial conditions of the last glacial episode and correlate with the stability associated with the developments of the red beds of Greece. Khan (1959) studied rendzina, terra rossa and red-brown soils using zirconium as a weathering index. It was determined that the terra rossa showed more extensive weathering due to loss of iron, aluminum, titanium and silica from the solum in comparison to the rendzina soils. Comparative studies of the translocation of elements between terra rossas and

red-brown soils developed on English limestone show no significant difference, indicating a similar pedogenic history. Timpson (1992) demonstrated that alluvial terraces near the village of Pacheia Ammos in Crete exhibited maximum clay accumulation in the surface and translocation of carbonates which reflected a moister climate for these pedogenic processes. His interpretation was that a Late Pleistocene to Early Holocene episode which correlated with an expansion of a pine-oak forest was the most likely time frame in which these pedogenic processes could take place. Tarzi and Paeth (1975) compared the pedogenic development between a red Mediterranean soil and a rendzina soil from Lebanon. The comparison showed the red Mediterranean soil was almost decalcified, exhibited illuvial clay horizons (argillic), accumulation of organic matter, and enrichment of sesquioxides, and kaolinite as the major processes in the development of the soil. The rendzina soil was more retarded in soil development because of its high carbonate content. As a result it had a weakly developed soil profile, with little release of sesquioxides and little translocation of clays. These soils did exhibit great accumulation of organic matter (melanization). Nevros and Zvorykin (1936, 1937) have noted similar patterns in terra rossa and rendzina developments and conclude that the terra rossa and the red Mediterranean soils are relict from a previously moister climatic regime. These authors also noticed that terra rossas formed only on hard limestone, whereas the rendzina soils formed on the softer chalks and marls.

One of the more compelling arguments concerning the pedogenesis of the terra rossa soils are whether or not these soils are developed from eolian deposits. Macleod (1980), in an examination of the terra rossa and underlying limestone in Epirus found that, due to the low amount of insoluble residue in the native limestone, approximately 130 m of limestone would be required to form a 40 cm profile. The particle size distribution would indicate a

heavy silt component which would be consistent with an eolian deposition, and that the iron content of the limestone would be insufficient for the terra rossa soils to inherit. Macleod concludes that a significant North African dust influence from sirocco winds lead to the development of the terra rossas. This tenet is supported by a number of studies in Europe and the Mediterranean (Danin and Gerson, 1983; Yaalon, 1987; Prodi and Fea, 1979; Rapp, 1984; Nihlen and Solyom, 1986; Jackson et al, 1982; Yaalon and Ganor, 1973).

One aspect of pedogenesis that has not been completely addressed is the influx of pyroclastic materials from the Theran eruption on the landscape of Crete and its subsequent pedogenesis. The best available evidence indicates that the Minoan tephra fall on Crete did not exceed 5 cm in thickness, and much of eastern Crete received less than 2.0 cm (Blong, 1980; Watkins et al., 1978). Analysis of some soil samples from the Late Minoan IA levels at Pyrgos in south Crete showed evidence of some tephra from the Theran eruption. Trace amounts of volcanic glass shards ($n = 1.509 \pm 0.001$), accessory minerals (including amphiboles and pyroxenes), and moderate amounts of smectite in the clay fraction closely match tephra from the 1500 B.C. Theran eruption (Cadogan and Harrison, 1978). Evidence of Theran tephra has also shown up in the Late Minoan IA levels of Pseira (Betancourt et al., 1990) and Mochlos (Soles and Davaras, 1990).

Synthesis

The major climatic forcing factors in the eastern Mediterranean seem to stem from the effects of continental glaciation in the European mainland. During the last glacial maximum, mean temperatures in the area were lowered some 5° to 7° and there was an increase in effective moisture (Farrand, 1971). A southward shift in the Mediterranean winter rain belt contributed to increased precipitation evidenced by the heavy alluviation in the Nile River Valley (Butzer and Hansen, 1968). The areas of northern Greece may have been

unaffected by this phenomenon because they may have been under the influence of dry continental air masses during the Late Pleistocene. The influx of glacial meltwater effectively lowered the sea temperatures of the eastern Mediterranean during the Late Pleistocene and Early Holocene, and may have been a climatic factor (Thiede, 1978). The northward shift of the Mediterranean belt during deglaciation would have effected the climatic regimes of the area throughout the Holocene.

It is the north and south shift in rain belts that can be used to explain the vegetation patterns for the glacial/interglacial cycles in the eastern Mediterranean. The vegetational record as recorded through pollen analyses seem to indicate that colder and drier adapted plant assemblages in the north may be contemporaneous to moister adapted plant assemblages reflective of pluvial regimes in the south including Crete, the Levant, and North Africa. An alteration of glacial steppes and cool forests in the north can be compared to deciduous assemblages which occur in succession with xerophytic assemblages in the south (Bertolani-Marchetti, 1985). Studies in the Dead Sea Basin show that pluvial conditions that occurred during the last interglacial and lasted up to the Early Holocene correlates very well with the onset and decline of pluvial conditions in the Great Basin of the western United States (Farrand, 1971). An early to mid-Holocene humid episode was recorded in the sediments of a series of buried lake muds in north-west Sudan in the eastern Sahara (Ritchie et al., 1985). Pollen analysis of these sediments record a tropical savannah woodland vegetation that existed 8,900 to 4,900 yr. B.P.

This early to mid-Holocene humid trend could have important implications in interpreting Late Bronze Age cultural dynamics. Carpenter (1966) believed that the decline in Late Bronze Age population in the Aegean may have been facilitated by a period of drought. Bryson et al. (1974) presented evidence of a spatial drought pattern which occurred

in January 1955 which may have been used to explain the movements of Aegean peoples into Cyprus and the Levant. Weiss (1982) used climate data from 35 Greek, Turkish, Cypriot, and Syrian weather stations for the period 1951-1976. Using the Palmer drought index, a principal component analysis showed that the 4th January eigenvector could be used to explain an area of increased drought potential over the Aegean Sea, and areas of greater moisture over Southern Anatolia and the Levant. This pattern seems to match a pattern of migration which is believed to have occurred in the early 12th century B.C. corresponding to the onset of the Greek Dark Ages.

PEDOLOGY AND ARCHAEOLOGY

The use of the science of "pedology" has had a significant impact in archaeological studies (Foss, 1977; Wood and Johnson, 1978; Griffith, 1980; Haidouti and Yassoglou, 1982; Holliday, 1985; Pendall and Amundson, 1990). In contrast, archaeological studies centered around geomorphology, sedimentology, and geochemistry have been much more prolific (Hassan, 1979; Gladfelter, 1981; Butzer, 1982; Rapp, 1987; Stein, 1987). Pedology is the study of the weathering of material at the earth's surface. Particular attention is given to weathering processes which coincide with the stability of the landscape and the development of soils. Jenny (1941) described the formation of a soil as a function of climate, parent material, relief, organisms, and time. Pedology focuses on the soil system as the interface between the physical and the biological environments. Changes in the factors of soil formation over time can effectively alter the extant soil system. By examining the variability in the soil environment one may be able to more fully assess changes in climate, vegetation, or anthropogenic impact which may have occurred in the past. Such assessments can be valuable in archaeological research.

Models of Pedogenesis

One of the earlier models of pedogenesis was actually a culmination of a century of empirical observations and processual theories. The "factorial" model was synthesized by Jenny (1941) from tenets first aired by the Russian scientist Dokuchaev. The factorial approach views soil formation as a function of five major factors; climate, organisms, relief, parent material, and time plus a few unspecified subsidiary factors.

$$S = f(\text{cl, o, r, p, t, ...})$$

Jenny proposed that variability within these factors would lead to different pedogenic results. For example, two soils formed on similar parent materials, of similar relief, at the same time, with a similar vegetational suite but in different climates should vary because of this difference. Joffe (1936) divided these factors into active (climate, organisms), and passive (parent material, relief, and time) soil forming factors.

Criticisms of Jenny's model stem from the attempt to solve the model mathematically. Chesworth (1976) argued that the model was invalid because the equation can be true if and only if all the factors in the model are independent variables. When one examines, for example, the effect of climate on organisms, or parent materials on relief, one can conclude that these factors do not behave independently. Huggett (1976) argued that the soil forming factors are basically external to the soil system and can only be examined as univariate factors. One can then only correlate the factors with morphological properties rather than directly measure driving forces of pedogenesis (e.g. precipitation, evaporation, radiation, etc.). Yaalon (1976) defended Jenny's model as one that is solvable, either univariately or multivariately. The external nature of the factors insinuates a driving force behind the observable and measurable morphological features.

The system-process approach was first proposed by Simonson (1959). The approach utilized four interacting processes; additions, losses, translocations, and transformations. Simonson proposed that soil genesis be considered as two overlapping steps; 1) accumulation of parent materials, and 2) the differentiation of horizons. The four interacting processes serve to develop differentiation in soil horizons. Yaalon (1971) suggested a modification of the systems approach where soil-forming processes are viewed as a part of two groups; 1) those approaching a state of dynamic equilibrium at a fast or slower initial rate, and 2) the irreversible or self-terminating processes, where the balance of input or output is not maintained with gains greater than losses or gains less than losses. Huggett (1975) proposed a systems model in the context of an integrated soil-landscape system defined by the extent of the drainage basin which undergoes progressive dissection and vertical weathering. Huggett (1976) argued that the systems approach deals with the exchange of material and energy between a soil system and its environment. These fluxes are directly measurable and more relevant to explaining pedogenic development than the factorial approach.

Runge (1973) proposed the "energy model" which integrated the factorial approach with the systems approach. In this model, parent material and vegetation are combined as a single factor (o, or organic matter production), and climate and relief are combined as a single factor (w, or water available for leaching). The model is expressed as

$$S = f(o, w, t)$$

Organic matter production is the major retarding vector in dynamic pedogenesis, and water available for leaching (gravitational water) is the major organizing vector. One problem with this model is that organic matter production, such as in Spodosols, acts as an organizing vector because of the effect of organic acids on the translocation of sesquioxides. Therefore the factors do not always behave independently.

The "Residua-Haplosol" model of Chesworth (1973) explains the dynamics of pedogenesis as a function of the change in the chemical composition of soils through time. This model stresses the relative losses and gains of constituents as a function of time. For example, time favors the accumulation of aluminum and the loss of silica. Chesworth (1976) argues that this approach is more realistic because the nature of the variables (chemical constituents) means that they are direct measurements taken on the soil system, and not extrinsic factors that may or may not be relevant to soil development.

The "Evolution" model of pedogenesis has been proposed by Johnson and Watson-Stegner (1987). This model is based on the observation that soils develop along two interactive pathways, according to the equation

$$S = f(P,R)$$

where "P" is the progressive pathway, and "R" is the regressive pathway. The progressive pathway incorporates those processes that promote horizonation, assimilative upbuilding, or subsurface deepening. The regressive pathway involves haploidization, retardant upbuilding, and/or surface removal. One pathway usually will predominate over the other, but the effects of both are continually functioning in a soil system.

Chronosequences

One of the methods for solving Jenny's (1941) soil forming factors equation is the analysis of sequences. These sequences are studied by finding suitable soil-landscape relationships where four of the soil forming factors are held constant and one factor varies between soil units. The most common of these sequences is the "chronosequence" where all conditions of parent materials, climate, organisms, and relief are constant and the major difference is the length of time the soil unit has remained stable (Stevens and Walker, 1970). Traditionally, river and stream floodplain and terrace levels have been studied as

chronosequences (Harris et al., 1980; McFadden and Hendricks, 1985). Other sequences include lithosequences, biosequences, clinosequences, and climosequences which are also solved in a univariant manner, although multivariate (more than one factor) methods have been attempted (Yaalon, 1975).

There have been a number of chronosequence studies conducted in river and marine terrace situations. Harris et al. (1980) examined a chronosequence of New River alluvium in Virginia for four soils formed on successively older terraces. The study found that with time, there was increasing clay illuviation and an increase in citrate-dithionite extractable iron with depth in older landforms. The clay mineralogy indicated a weathering progression from mica-vermiculite to hydroxy interlayered vermiculite to kaolinite. Birkeland (1978) found with Quaternary age deposits in Baffin Island that a chronosequence developed from a slightly altered parent material (Cox) in a 200 year old soil to the development of a strong cambic horizon in a 100,000 year old soil. A chronosequence of loess derived soils in southeastern Iowa demonstrated increased cation eluviation and increased formation and movement of clay with a soil solum with increasing age (Hutton, 1951). Muhs (1982) studied a chronosequence on marine terraces on San Clemente Island which ranged in age from less than 3,000 years to more than 1,000,000 years. Soils less than 200,000 years in age were Alfisols and Mollisols, and soils greater than 200,000 years in age were Vertisols and Alfisols with slickensides. Clay, soluble salts from aerosol additions, citrate-dithionite extractable aluminum, smectite/mica ratios in the clay fraction and quartz/plagioclase ratios in the silt fraction increased with age.

Glacial landforms have also been used as important models for studying soil chronosequences. Ruhe (1956) studied a chronosequence in a Wisconsinan loess landform, a Late Sangamon soil, and a Kansan till. The study found that with increasing age there was an increase in thickness of the soil solum, an increase in thickness of the B-horizon, and an

increase in clay content. In a comparison of soils developed in Kansan, Illinoian, and Wisconsinan age drifts in New Jersey and Pennsylvania, Novak et al. (1971) found an increase in the clay size fraction, and an increase in the extractable iron content with age. Levine and Ciolkosz (1983) found in a comparison of Woodfordian (15,000 yr. B.P.), Altonian (75,000-28,000 yr. B.P.), and pre-Wisconsinan (>75,000 yr. B.P.) tills in northeastern Pennsylvania that extractable iron oxide, extractable aluminum, clay, kaolinite, gibbsite, and fine clay content increased through time, whereas extractable silica content decreased through time.

There have been a number of attempts to quantify and find solutions to chronofunctions. Bockheim (1980) analyzed 32 chronosequences from 27 areas which ranged in latitude between 66° N and 78° S and represented 7 climatic regions ranging from tropical rainy to cold desert with 7 types of parent materials. The study showed that the rates of decrease of pH and base saturation decreased similarly regardless of the nature of the parent material. The rates of increase in solum thickness, oxidation depth, soluble salt content of the salt enriched horizon, and clay content in the B-horizon are positively correlated with mean annual temperature, and rates of increase of total nitrogen in the surface is negatively correlated with mean annual temperature. Sondheim and Standish (1983) examined 60 pedons collected from a sequence of moraines located in front of the Robson Glacier, Mt. Robson, British Columbia. They found that soil properties which varied significantly with depth and moraine age were organic carbon, nitrogen, and pH. These variable fit with one or two significant factors of a multivariate factor analysis. Calcium carbonate equivalent, pyrophosphate extractable iron and aluminum, citrate-dithionite extractable iron and aluminum, percent sand, and percent clay showed generally little or no relationship to depth and age and was considered the result of a high degree of variability with the parent materials. Harden and Taylor (1983) examined a number of chronosequences from different

climatic regimes from California, New Mexico, and Pennsylvania. Ten soil properties including clay films, texture plus wet consistence, rubification, structure, dry consistence, moist consistence, color value and pH (Harden, 1982) were utilized along with soil depth as part of a Soil Profile Index. In soil moisture regimes that ranged from udic to aridic, it was concluded that soil profile properties develop systematically in different climates, and that the Soil Profile Index increases significantly with age. Other rating scales that have been used to study chronosequences include the field morphology scale of Bilzi and Ciolkosz (1977) and the redness rating scale of Torrent et al. (1983).

Discontinuities and Buried Soils

Buried soils and discontinuities can be important to archaeological research because many archaeological contexts are associated with these discontinuities. Buried archaeological sites are often located on buried surfaces representing former stable landforms. These buried landforms are also referred to as paleosols which are soils formed in the past. There are three major types of paleosols; relict soils, buried soils, and exhumed soils. Relict soils are soils which formed on pre-existing landscapes but were never buried by younger sediments. Formation processes date from the time of the original landscape. Buried soils were formed on pre-existing landscapes and were subsequently buried by younger sediments. Exhumed soils are soils that were buried by younger sediments and re-exposed by removal of the younger overburden (Ruhe, 1965). Paleosols can be used to aid in the determination of past environments. By comparing paleosols with soils of recent environments it may be possible to determine the soil forming conditions of the past (Valentine and Dalrymple, 1976). Buried paleosols can be recognized by the relict A-horizon or organic accumulation of a former surface (Ruhe, 1969). Discrepancies in lithology can be used to assess a multisequel profile (Ruhe and Daniels, 1958) indicating buried surfaces. Stone lines which occur in a profile may

also indicate a buried surface (Ruhe, 1959). While chronosequences are generally time variable sequences that are examined across space, buried soils and discontinuities are time variable sequences that are examined vertically. Bronger and Catt (1989) have suggested that paleosols or relict soils be defined by a set of properties that are reflective of past climatic conditions regardless of age.

The measurement and determination of discontinuities in a vertical soil profile has been a continuing problem met with a variety of solutions. Chapman and Horn (1968) studied 15 soils overlying various geologic materials in northwest Arkansas. A comparison of titanium and zirconium ratios between the silty material and the parent material showed no significant difference and therefore it was concluded that the silt fraction was derived from local parent material and not from loess. Rostad et al. (1976) studied argillic horizons overlying coarse textured calcareous gravels to determine if the two materials were similar. Titanium:zirconium ratios between the upper and lower materials exhibited a less than 58% variability and it was concluded that these fine textured argillic horizons did form from the calcareous gravel parent materials. Rabenhorst and Wilding (1986) used quartz grain morphology, particle size distribution, elemental assay and mineralogical data to indicate lithological discontinuities between loess and underlying limestone in the Edwards Plateau, Texas. Ajmone Marson et al. (1988a) analyzed the uniformity of parent material and degree of weathering of the soils of a chronosequence developed during the Pleistocene. Mobile elements (phosphorus and sodium) were compared to zirconium concentrations as a weatherable:non-weatherable element ratio to determine parent material uniformity. Clay-free ratios (e.g. fine sand:total sand + total silt) have also been used to examine a possible change in depositional regimes. The clay-free ratio eliminates the possible pedogenic effects and relies strictly on the depositional component, because clays are more likely to move

through a profile through time than sand or silt. These clay-free ratios have been used to determine the presence of discontinuities in a vertical profile (Raad and Protz, 1971; Thompson, et al. 1981; Asady and Whiteside, 1982; Ajmone Marsan et al. 1988b).

Pedological Archaeology

Discontinuities in regard to archaeological site location has been an important part in integrating pedology and archaeology. Foss (1977) in a study of Paleoindian sites in the Shenandoah River Valley of northern Virginia and the Delaware River Valley of eastern Pennsylvania, showed that appreciable horizonation, clay and iron accumulation in the B-horizon, clay coatings on ped surfaces, and moderately developed structure in the B-horizon had transpired since the deposition of Paleoindian artifacts. Discontinuities found within these Pleistocene age profiles proved important from an archaeological standpoint because of the different age relationships and activities associated with breaks in sedimentary patterns. Studies by Holliday (1985, 1992) demonstrated how correlation with buried soils of early and middle Holocene sediment at the Lake Lubbock archaeological site in Yellowhouse Draw, Texas and archaeological chronology helped to decipher periods of aggradation and stability in the site situation. Bettis (1992) showed how Holocene alluvium developed soil morphological characteristics according to the age of the former surface. Early to Middle Holocene (>4,000 yr. B.P.) alluvium in the upper Midwest United States generally consists of Mollisols and Alfisols with well developed argillic horizons. Late Holocene (after 3,500 yr. B.P.) alluvium consist of Mollisols or Inceptisols with cambic horizons or Entisols that lack subsurface B-horizons. By concentrating on the morphology Bettis was able to develop a predictive archaeological-landscape model in which the development of the soil morphology was consistent with the age of the archaeological assemblage.

Archaeological discontinuities can also be recognized by analysis of extractable metals from a soil profile. Various metals can be immobilized and recycled in the soil system by plants. Cations such as manganese, copper, zinc, strontium and barium can be extracted from the soil solution by mass flow or diffusion into root cells. Manganese, copper, and zinc are common plant micronutrients and strontium and barium, although not recognized as micronutrients, can also be extracted from the soil solution. These metals in cation form can be retained in surface soil horizons by processes such as adsorption onto clay mineral surfaces, adsorption by organic matter, and complexation by residual organic compounds. The use of extractable metal concentrations (lead, in particular) to delineate archaeological sites has been employed in several archaeological projects in the Mediterranean (Davies et al., 1988; Foss et al., 1990; 1991; Foss, 1990).

One of the more common approaches to delineation of human influence in a vertical profile is the determination of phosphorus. Non-metals such as phosphorus are a major component of the organic materials that are added to the soil system by plant recycling and deposition of organic materials. All organisms contain a significant amount of phosphorus. Phosphorus is a constituent in many proteins, coenzymes, nucleic acids, and metabolic substrates in plants and animals. Vertebrates store a large quantity of phosphorus in the form of hydroxy-apatite in their bone tissues. Once in the soil environment, organic phosphate compounds tend to mineralize rapidly (e.g. into H_2PO_4^- form), react with cations (such as calcium, iron, and aluminum), and precipitate out of solution. Therefore, phosphorus loss by weathering is minimal in comparison to other non-metal compounds (such as nitrates). Plant and animal remains deposited in a soil environment by human activity will generally promote higher phosphorus concentrations in those soil horizons. Various extracts of phosphorus and

phosphate compounds have been used to delineate areas of human activity (Eidt, 1977; Proudfoot, 1976; Sjoberg, 1976; Mattingly and Williams, 1962; Griffith, 1980).

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PART 2

**SEDIMENTATION AND PEDOGENESIS NEAR THE KARPHI
ARCHAEOLOGICAL SITE**

INTRODUCTION

The Karphi archaeological site in eastern Crete, Greece represents a human settlement which was inhabited for a relatively short period of time (around 1100-900 B.C.) and was permanently abandoned. This archaeological site allowed this investigation the opportunity to observe short term human impact on a soil system some 3,000 years ago. An effort was made to concentrate on depositional basins which existed around and topographically below the present site of Karphi. These depositional basins, including dolines, and an alluvial fan, have a tendency to preserve within their sedimentary matrices the depositional history of the area. The interpretation of this depositional history can provide insights into understanding the dynamics of landscape development. In this manner, one may be able to assess the impact of humans, vegetation, and/or climate on the landscape history.

The first objective for this study was to locate paleosols within the depositional basins and on the landscape which would correlate with the period of the Minoan inhabitation of the Karphi site. The second objective was to document the depositional episodes and use artifacts and radiocarbon analyses to record Minoan archaeological levels in order to determine the extent of human influence on the landscape. The third objective was to determine the type of sedimentation involved and interpret how the landscape was developing through time. These objectives are outlined to understand the natural history of the Karphi area.

SITE SETTING

Karphi is located approximately 2 km northwest of the present village of Tzermiada in east-central Crete (Figure 1). The site is located in the northern Diktean range (highest

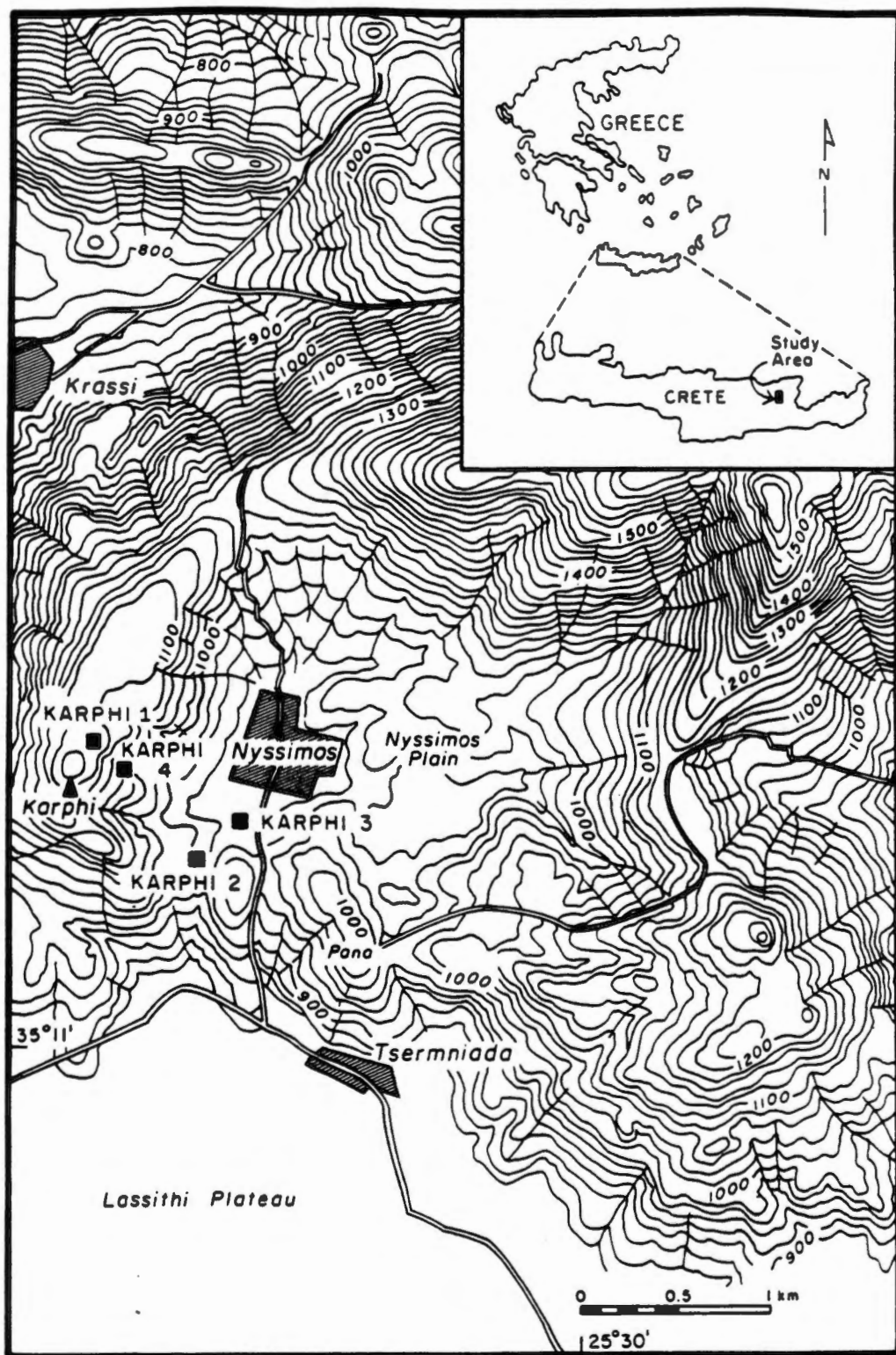


Figure 1. Plan view of the Karphe archaeological site and location of the study pedons.

elevation Mount Dikte--2,148 m AMSL) above the plain of Lasithi. Karphi is situated between two mountain peaks in which the northern peak has an elevation of 1148 m AMSL. A number of sinkholes or dolines are located along the ridge of these northern peak ranges and an exposure of phyllites located to the east of Karphi contain a number of agricultural terraces of Minoan origin (Plate 1). At the base of this phyllite exposure is the Nyssimos plain situated about 920 m AMSL which measures approximately 1.0 km north to south and 0.75 km east to west (Plate 2). The plain of Lasithi is directly to the south of Karphi and is approximately 840 m AMSL (Plate 3). The Lasithi plain is approximately 11 km east to west and 6 km north to south, and is characterized as a karstic basin in the Diktean range. The Lasithi plain is one of the most intensively farmed areas of Crete, and has the highest elevation of any area of Crete which is inhabited year-round (Watrous, 1982).

The geology of the area around Karphi consists of limestones and dolomites of the Gavrono-Tripoliza series which range in age from Jurassic to Eocene (Figure 2). It is described as a thick bedded to massive unit, usually grey limestones and dolomites of shallow water origin. Two thrust faults, one located on the eastern scarp, and the other located to the east, separate this limestone formation from an underlying Phyllite series. The Phyllite-Quartzite series is considered a tectonic unit rather than a stratigraphic unit and is underlain by the Plattenkalk series limestones (Jurassic to Eocene in age) and usually overlain by the Gavrona-Tripoliza series. The main part of the Phyllite-quartzite series consists of Permo-Triassic phyllites, quartz-phyllites, and quartzites (Creutzburg et al., 1977). Springs are known to emerge from these phyllite exposures in a number of areas around the Lasithi plain (Watrous, 1982). Alluvial deposits on the Nyssimos plain consist of rounded phyllite gravels originating from the phyllite exposure east of Karphi. The sediment within the Lasithi plain consist of alluvium and diluvium which originated from the limestone slopes. Deposits of



Plate 1. Phyllite "cove" with associated Minoan age agricultural terraces near the Karphi archaeological site with Randy Loftis in the foreground, view facing northwest.



Plate 2. View of the Nyssimos Plain from the Minoan age agricultural terraces near Karphi, facing east.



Plate 3. View of the Plain of Lasithi near the village of Tzermiada, facing south.

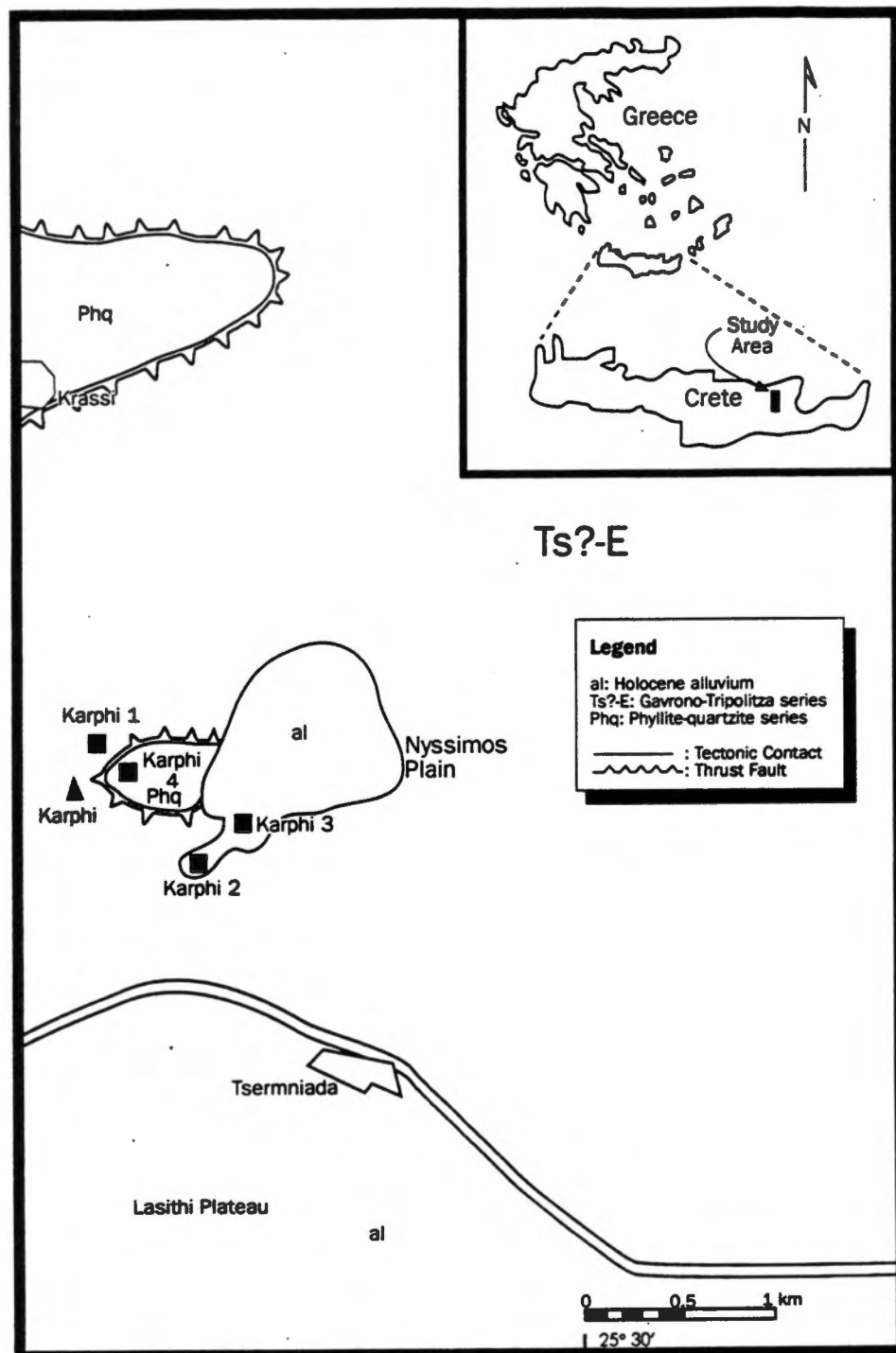


Figure 2. Bedrock geology of the Karpfi study area.

Source: Creutzburg, N., C.W. Drooger, J.E. Meulenkamp, J. Papastamatiou, W. Sannemann, E. Seidel, A. Tataris. 1977. General geological map of Greece, Crete island: 1:200,000. Section of Geological Mapping, Institute of Geological and Mining Research, Athens.

red-brown sediment derived from the terra rossa soils comprise these alluvial deposits. The depth of this alluvium has ranged from 30 to 70 m in the Lasithi plain (Watrous, 1982).

The climate of the Lasithi plateau is generally cooler, and moister than the typical Mediterranean climate. Rainfall averages around 900 to 1,150 mm yr⁻¹ and occurs primarily between the months of October and February (Rosenan, 1965; Watrous, 1982). Summers are cool averaging 20° to 30° C and winters are cold averaging 5° to 10° C. The Lasithi plain receives an average of 380 mm yr⁻¹ of snowfall which can cover the ground for up to a week at a time (Watrous, 1982).

The vegetation in the Lasithi area have been divided into two major plant communities (Zohary and Orshan, 1965). The first is the garigue and batha communities which form on the thin soils of the hard limestones of the sloping areas. Dominant taxa in this community include *Cytisus creticus*, *Anthyllis hermanniae*, *Genista acanthoclada*, *Euphorbia characias*, *E. Acanthothamnus*, *Cistus parviflorus*, *Phlomis lanata*, *P. Cretica*, *P. Fruticosa*, *Ballota pseudodictamnus*, *Hypericum empetrifolium*, and some species of *Teucrium*, *Origanum* and others. The second plant community is limited to elevations from 800 to 1,500 m AMSL in the mountains of Crete. This association consists of a *Cupressus-Acer* forest with dominant taxa including *Acer orientale*, *Cupressus sempervirens*, *Berberis cretica*, *Rosa agrestis*, *Daphne oleoides*, *Cyclamen hederifolium*, *Anemone hortensis*, and *Cerastium comatum* (Zohary and Orshan, 1965). The foothills of the Lasithi area which consist of limestone and phyllite exposures are cultivated for a variety of crops including wheat, barley, pulses, and grapes. Arboreal crops such as almonds, walnuts, apples, pears, plums, and cherries are also cultivated on these landscapes. The Lasithi plain itself has a relatively fertile soil which produces many crops such as wheat, legumes, and truck crops such as potatoes and cabbage (Watrous, 1982).

SITE HISTORY

The archaeological site of Karphi (Plates 4 and 5) represents a settlement which was occupied during the last vestige of the Minoan culture on Crete. The site was excavated by John Pendlebury and the British School in 1937-1938. The Karphi site was a Late Minoan III C to Subminoan Period (ca. 1100-900 B.C.) site which was settled during the general depopulation of the island as well as other areas of the Aegean. The mountain "refuge" sites which included Karphi were believed to be settled by older remnant Minoans at a time when the use of iron rather than bronze was becoming popular in weapon and tool manufacture. It is believed that 3,500 inhabitants lived in the 150 rooms of the village. The houses at Karphi were single storied, rectangular, and built of hard limestone blocks with a dry stone technique. Iron implements and a "megaron" style building are believed to be Mycenaean elements which appeared in this Minoan settlement. The important "fringe style" appears in the ceramic motifs. The Minoan peak sanctuary at Karphi may have been a religious center for the remaining Minoan inhabitants during the Mycenaean occupation of Crete. It is believed that the inhabitants were Minoans who fled to this site to escape the Dorians who may have settled the lower coastal plains around Knossos, Messara, and Pedhiadha around 1100-900 B.C. It is believed this site was attractive because of the nearby plains suitable for cultivation. When the Dorian threat became less severe, the site was abandoned, probably for the nearby site of Papoura to the south which was closer to the plain of Lasithi (Students of the British School, 1937-1938; Watrous, 1980; 1982; Desborough, 1972).



Plate 4. Archaeological site of Karphi with the Lasithi Plain in the background and Walter E. Klippel in the foreground, facing southeast.



Plate 5. Archaeological site of Karphi with John T. Ammons (left) and Walter E. Klippel (right) in the foreground, facing south.

MATERIALS AND METHODS

Field Methods

The area around Karphi was surveyed to find suitable soil sites for sampling. Depositional basins including two sinkholes and one alluvial fan were located which were believed to contain buried soil horizons suitable for analysis. One buried agricultural terrace was located as well to determine the effect of human impact on the pedogenic development of the soil system. These sites were then sampled and described according to methods outlined in the Soil Survey Manual (Soil Survey Staff, 1984). The following is a description of the sites selected for this study.

Karphi 1

The Karphi 1 pedon was located in a sinkhole comprised of a closed basin located approximately 0.30 km north of the site of Karphi at 25°28'16" E Long, 35°12'53" N Lat (Figure 1, Plate 6). This doline is situated at approximately 1100 m AMSL in elevation. The alluvial fill which comprises the base of the sinkhole measures 37 m north to south, and 21 m east to west. Three auger holes were drilled across the site and the depth to bedrock of the alluvium ranged from 46 to 57 cm. A spot was selected in the center of the sinkhole, and a 3.5" bucket auger was used to collect samples from the soil surface to bedrock. Samples of the terra rossa and limestone of the surrounding basin were collected at 10 m north and 10 m east of the edge of the alluvium in the basin. The terra rossa was sampled to a depth of approximately 5 cm. The samples were described and double-bagged for shipment to the soil characterization laboratory in the Department of Plant and Soil Science at the University of Tennessee, Knoxville.

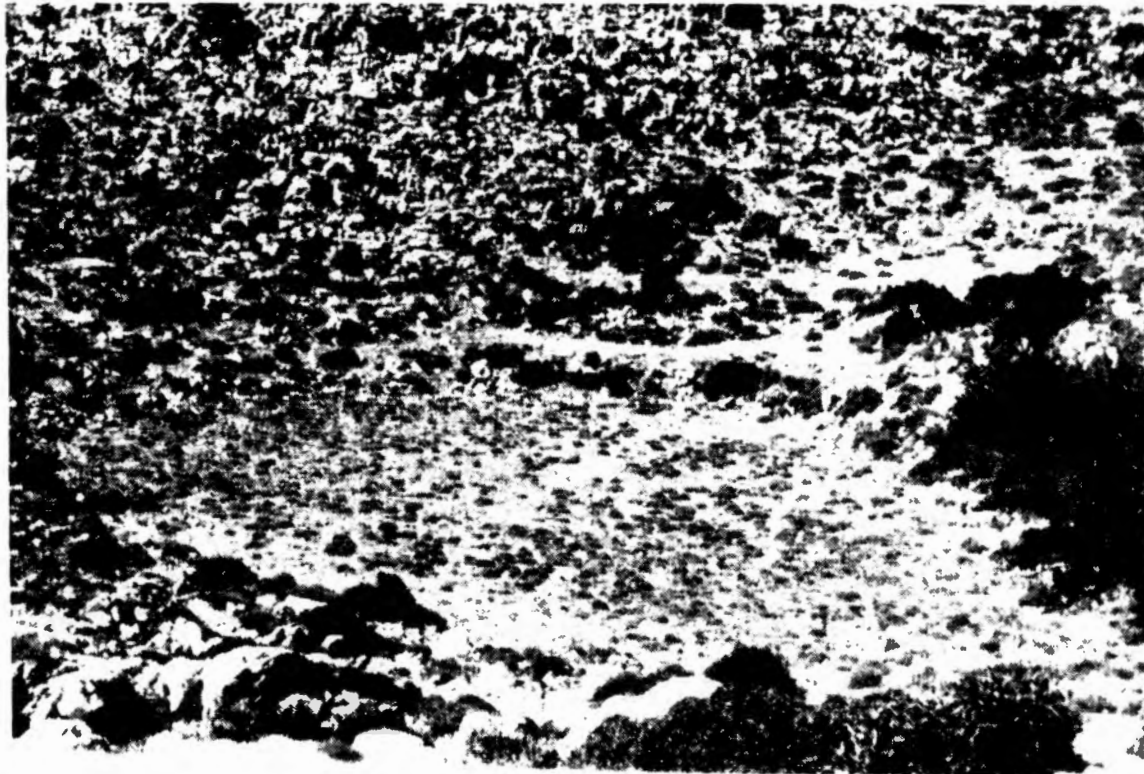


Plate 6. The sinkhole of the Karphi 1 pedon, facing east.

Karphi 2

The site of the Karphi 2 pedon was located approximately 0.75 km southeast of the present site of Karphi at an elevation of approximately 920 m AMSL at 25°28'40" E Long, 35°12'35" N Lat (Figure 1, Plates 7 and 8). Karphi 2 is a sinkhole and can be found by taking the road which runs behind the Tzermiada hospital. One can follow this road past the butcher's house to the Nyssimos plain. As one reaches the surface of the Nyssimos plain, approximately 3.4 road km from the Tzermiada hospital, the sinkhole will be directly on the west side of the road. The sinkhole is roughly circular with dimensions of 121 m north to south and 138 m east to west. A soil pit was placed 22 m in from the far western side of the alluvium of the sinkhole. A depth of 55 cm below the surface was reached before it became apparent that digging implements were inadequate. The remaining samples were collected by use of a 3.5" bucket auger. The bottom of the sinkhole was never reached. Samples were collected from the soil pit and from the bucket auger corings. Samples were described and bagged in a similar fashion as Karphi 1.

Karphi 3

The Karphi 3 pedon was located in the phyllite alluvium of the Nyssimos plain (Figure 1, Plates 9 and 10). Karphi 3 was separated from Karphi 2 by a limestone spur which bisects the plain. Karphi 3 was located approximately 0.9 km east of the present site of Karphi at 25°28'56" E Long, 35°12'46" N Lat. A transect was run from the mouth of the phyllite cove east across the Nyssimos plain. A representative core was selected at 282 m and 293° west to the mouth of the phyllite cove. The site was cored with a 3.5" bucket auger. Samples were collected from the bucket auger corings, and were bagged in a similar fashion as Karphi 1.



Plate 7. The sinkhole of the Karphi 2 pedon, facing south.



Plate 8. Michael W. Morris sampling the Karphi 2 pedon, facing northeast.

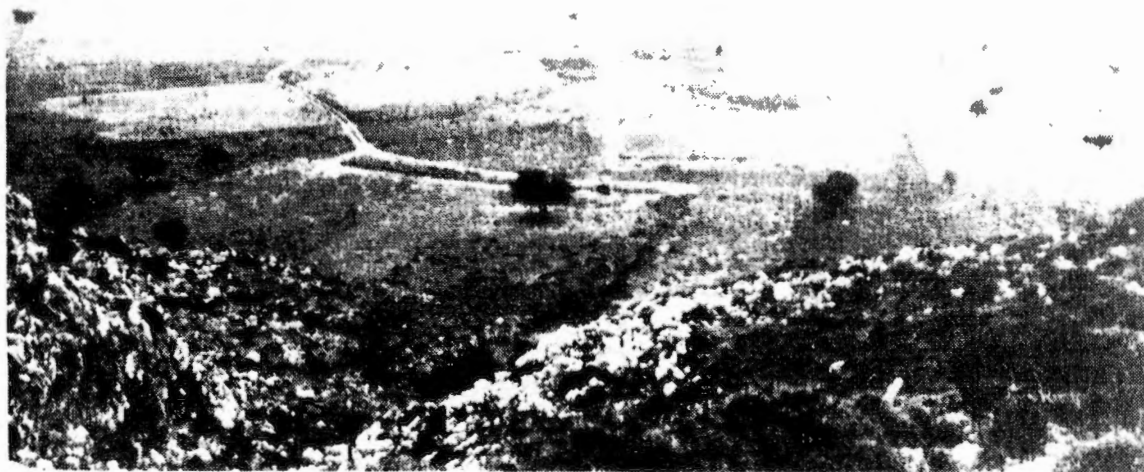


Plate 9. View of the Nyssimos plain of the Karphi 3 pedon, facing east.



Plate 10. Sampling at the Karphi 3 pedon on the Nyssimos plain with the phyllite "cove" and agricultural terraces in the background, facing west.

Karphi 4

The Karphi 4 pedon was an exposure from an agricultural terrace located about 1,020 m AMSL and approximately 0.30 km east of the present site of Karphi at 25°28'24" E Long, 35°12'50" N Lat (Figure 1, Plate 11). One has to enter the mouth of the phyllite cove and follow a goat trail which skirts the south side of the phyllite exposure. One will reach a spring and water trough on this trail. If one follows the contour of the landscape from the spring, and travel north approximately 100 m, one will reach this exposure. The profile was cleaned and photographed. Samples were collected by the soil horizons described, collected from the base of the pedon to the surface to avoid as much interhorizon contamination as possible, and bagged in a manner similar to the samples of Karphi 1. Approximately 500 g of sample was collected from each horizon. Additional samples of charcoal were collected from some of the root channels in the exposed profile.

Laboratory Methods

Soil samples collected from Crete were first subjected to a freezing treatment of -80° C for 48 hrs to destroy any organisms which may have been present. The samples were removed from the freezing treatment and allowed to thaw. Representative pedis were collected from each sample and set aside. The remaining samples were then air dried and ground to pass a 10 mesh sieve (2.00 mm limiting diameter). The fraction > 2.00 mm was collected and weighed. The fraction $\leq$ 2.00 mm was quartered and one quarter was ground to 60 mesh and finer.

Total carbon content for each sample was determined by using a LECO CR-12 carbon analyzer on the $\leq$ 60 mesh portion of the sample. Each sample was tested with 1 M HCl for presence of inorganic carbon (CO_3^{2-}). Soil horizons with high organic carbon contents are believed to have been surface horizons into which plant material such as roots had been



Plate 11. Profile view of the Karphi 4 pedon in the agricultural terraces of the phyllite exposure, facing west.

incorporated. Subsurface horizons with high carbon contents are believed to represent former stable surfaces that had been buried by additions of new parent material. Carbon analysis has been used to locate and delimit buried archaeological sites on former stable surfaces (Stein, 1982; Ahler, 1973; Foss, 1977).

Measurements of pH were made on each sample using a pH meter equipped with a chloride combination electrode. A 1:1 ratio of soil to distilled-deionized water, and a 2:1 ratio of 0.1 M CaCl_2 to soil were used in the preparation, and pH's were measured according to the procedure outlined in McLean (1986). The measurement of pH can provide some insight into the relative weathering status of a soil sample which can give the relative base saturation of the sample. Because of the relationship between high base saturation and optimal preservation of archaeological materials, pH measurements have been used in several archaeological studies (Deetz and Dethlefsen, 1963; Gordon and Buikstra, 1981).

A particle size analysis was performed on all samples using a combination of sand sieving and sedimentation techniques as outlined in Gee and Bauder (1986). Samples with $\geq 1.0\%$ organic carbon were pretreated with a 30% H_2O_2 solution, and samples which reacted to 1 M HCl were treated with a 1 M Na-acetate solution buffered at pH 4.5. Approximately 10 g of the <2.00 mm fraction of each sample was dispersed in a Na-hexametaphosphate--Na-carbonate solution, and the sand size fraction of each sample was separated from the smaller fractions by wet sieving. The sand fraction was dried and fractionated by dry sieving into very coarse sand (VCoS, 2.00-1.00 mm), coarse sand (CoS, 1.00-0.50 mm), medium sand (MS, 0.50-0.25 mm), fine sand (FS, 0.25-0.10 mm), and very fine sand (VFS, 0.10-0.050 mm) fractions. The remaining silt and clay size fractions of each sample were retained in a 1000 ml capacity sedimentation cylinder and placed in a water bath. Pipette analysis was performed on these samples to determine their coarse silt (CoSi, 50-20

μm), fine silt (FSi, 20-2 μm), and clay (C, <2 μm) fractions. A combination of centrifugation and pipette methods were used to determine the fine clay fraction (FC, <0.2 μm). Distribution of clay-size particles with depth was used as a weathering indicator for this study (Foss, 1977; Bilzi and Ciolkosz, 1977; Hall et al., 1982). Data from the particle size analyses were also converted to clay-free ratios to document changes in depositional regimes and assess the uniformity of the parent material (Raad and Protz, 1971; Thompson et al., 1981; Asady and Whiteside, 1982; Ajmone Marsan et al., 1988). The clay-free ratios chosen for this study included: 1) Fine silt/(total sand + total silt) [FSi:(TS+Si)], and 2) Fine sand/(total sand + total silt) [FS:(TS+Si)].

Elemental analyses were performed with the aid of a Thermo Jarrel Ash Model 61 Inductively Coupled Argon Plasma Atomic Emission spectrometer (ICAP-AES), which has the capacity for analyzing 26 different elements simultaneously. A total element analysis was performed by digesting about 0.2000 g of the <60 mesh sample in an aqua-regia/concentrated hydrofluoric acid/microwave oven treatment neutralized with boric acid according to the procedure outlined by Nadkarni (1984). Extractable element analysis was performed by using approximately 2 g of the <2 mm fraction which was extracted with a 5:1 HCl:HNO₃ solution adjusted to 0.75 M according to a procedure outlined in Lewis et al. (in press).

The elements from the total analysis were converted to weight percentage oxides. These oxides were then converted to molar ratios and molar indices which were used as weathering indices. These indices will theoretically decrease with increased weathering or age of the sediment. The indices chosen for this study include: 1) $\text{SiO}_2/\text{R}_2\text{O}_3$, where R_2O_3 is equal to Fe_2O_3 (determined by citrate-dithionite extraction) + Al_2O_3 (total) + TiO_2 (total) (Birkeland, 1984), 2) Parker's Weathering Index which is defined as $100(\text{K}_2\text{O}/0.25 + \text{Na}_2\text{O}/0.35 + \text{CaO}/0.7 + \text{MgO}/0.9)$ where the values in the denominator refer to the relative

strengths of the cation-oxygen bond (Parker, 1970), and 3) $\text{TiO}_2\text{:ZrO}_2$ (Chapman and Horn, 1968; Rostad et al., 1976).

Free iron oxides were determined using the citrate-dithionite procedure as outlined by Holmgren (1967). Concentrations were determined by atomic absorption spectrophotometry using a Perkin-Elmer Spectrophotometer. Free iron oxides are considered iron compounds which are not associated with silicate iron. The generalized reaction in soils is defined as:



where silicate iron (usually ferrous iron) is oxidized into ferric iron form which is most easily described by the Free Iron (Fe_d): Total Iron (Fe_T) ratio (Schwertmann, 1985). A number of studies have demonstrated a positive correlation between the amount of free iron oxides in a soil system and the relative age of the system (Blume and Schwertmann, 1969; Alexander, 1974; Singer, 1977; Torrent et al., 1980; Arduino et al., 1986).

A statistical analysis was performed on the samples from each pedon. Each pedon was analyzed as a unit or as a series of formations within the pedon. Where applicable, these formations were compared with the terra rossa samples collected from the rims of the appropriate sinkholes. A group means analysis of variance procedure was utilized to determine whether the means of the various indices between groups were significantly different. The variables chosen for these comparisons included the molar ratios of $\text{SiO}_2\text{:R}_2\text{O}_3$ molar ratio, the $\text{TiO}_2\text{:ZrO}_2$ molar ratio, Parkers weathering index, and the $\text{Fe}_d\text{:Fe}_T$ free to total iron ratio. The clay-free ratios of $\text{FS:}(\text{TS}+\text{Si})$ and $\text{FSi:}(\text{TS}+\text{SI})$ were also used. The Ryan-Einot-Gabriel-Welsch Multiple Range test was used to compare the means in each pedon using the PC-SAS® statistical software package. This all pairwise comparison controls for the Type I experimentwise error rate. Because duplicates were analyzed for each sample

for the total element analysis, the number of degrees of freedom for the molar ratios are double those for the clay-free ratios. The $\alpha=0.05$ significance level was selected for this analysis.

Extractable elements were used to document whether there were buried surfaces in the pedons studied. The elements Mn, Cu, Zn, Sr, Ba, and P were used for this procedure. Elements such as Mn, Cu, and Zn are common plant nutrients. Barium and Sr can be extracted from the soil solution by mass flow or diffusion into root cells and recycled by leaf, root, and other plant tissues. These metals can be retained in the surface of a soil by processes such as adsorption onto clay mineral surfaces, adsorption by organic matter, and complexation by residual organic compounds. Increased concentrations of these extractable metals in subsurface horizons can be indicative of former stable surfaces which are now buried (Foss et al., 1990; 1991; Foss, 1990). Phosphorus is a major component of organic materials and can be concentrated in the soil system due to human activity (Eidt, 1977; Proudfoot, 1976; Sjöberg, 1976; Mattingly and Williams, 1962; Griffith, 1980).

Cation exchange capacity (CEC) and base saturation were determined using NH_4OAc pH 7 and NaCl vacuum-extraction replacement procedures. The <2 mm fraction of soil sample was vacuum extracted with a 1 M NH_4OAc solution adjusted to pH 7, and the extractant was analyzed for extractable Ca and Mg using atomic absorption. Extractable Na and K were analyzed by flame emission. After two ethanol washes, the 10% NaCl-0.005 M HCl replacement solution was used for extraction and the extractant was distilled and titrated with 0.01 M HCl to determine NH_3 concentration and, therefore, measure the CEC of the soil sample (Roads, 1986; Thomas, 1986; Hammer and Lewis, 1987). This procedure was performed primarily for classification purposes.

RESULTS

The pedons selected at the Karphi site were analyzed to understand the development of the landscape over time. A number of buried horizons and discontinuities were found as documented by the soil morphology and by the laboratory procedures; several were associated with archaeological assemblages. The following is a site by site discussion of each of the pedons, their morphology, and their physical and chemical characteristics.

Karphi 1

The Karphi 1 soil pedon was developed in a shallow alluvial deposit in the base of a sinkhole of a closed basin. The total depth of the pedon was 54 cm and limestone bedrock was found directly underneath. Colors of the soil horizons ranged from 5YR 3/4 to 5YR 4/4 moist indicating that some rubification and melanization had occurred (Table 1). Textures ranged from silty clay in the surface horizon to clay in the bottom horizon, with a gradual increase in total clay with depth from 43.9% in the A horizon to 55.5% in the Bt3 horizon and a similar increase in fine clay from 12.9% to 18.8% (Table 2, Figure 3, Appendix A). The samples were subjected to testing with 1 M HCl and no effervescence was noted. Total carbon contents in the pedon decreased gradually from 2.44% at the surface to 1.94% in the Bt3 horizon (Table 3, Figure 3). A whole soil radiocarbon sample was extracted from the Bt3 horizon. The results of this determination yielded a ^{14}C date of 1100 ± 70 yr B.P. (Beta 66572). Because of the extent of dark colors and the fact that one depositional sequence is in evidence, this determination likely represents a mean residence time for the age of the soil rather than a firm absolute date. There was some possible gilgai relief noted across the surface of the alluvium of the sinkhole and Late Minoan period artifacts were noted on the surface as well.

Table 1. Morphology of soil pedons investigated near the Kaphi archaeological site.

Horizon	Lower Depth	Color			Texture	Structure	Boundary	Consistence		
		Dry	Moist					Moist	Dry	
cm										
Kaphi 1										
A	9	5YR 4/6	5YR 3/4	SiC	n.d.	n.d.	n.d.	n.d.	n.d.	
Bt1	27	5YR 5/4	5YR 3/4	SiC	2fsbk	n.d.	n.d.	n.d.	n.d.	
Bt2	36	5YR 4/4	5YR 3/4	SiC	2fsbk	n.d.	n.d.	n.d.	n.d.	
Bt3	54	5YR 5/6	5YR 4/4	C	2fsbk	n.d.	n.d.	n.d.	n.d.	
R	54+									
Kaphi 2										
Ap	23	10YR 6/4	7.5YR 4/4	SiCL	2mgr	as	vfr	fr	fr	
Bw	55	10YR 6/6	7.5YR 4/4	SiCL	1msbk	as	fr	fr	fr	
2Ab	77	7.5YR 4/4	7.5YR 3/4	SiCL	2msbk	n.d.	fr	fr	fr	
2Bw1b	85	7.5YR 4/6	7.5YR 4/4	SiCL	2msbk	n.d.	fr	fr	fr	
3Bw2b	93	5YR 4/6	5YR 3/4	CL	1msbk	n.d.	fr	fr	fr	
3Bw3b	101	5YR 4/4	5YR 3/4	CL	1csbk	n.d.	fr	fr	fr	
3BC1b	109	5YR 4/6	5YR 4/6	CL	1csbk	n.d.	fr	fr	fr	
3BC2b	117	5YR 4/6	5YR 4/4	SiCL	1csbk	n.d.	fr	fr	fr	
Kaphi 3										
Ap	23	10YR 5/4	10YR 4/4	vg SL	1mgr, Osg	n.d.	vfr	vfr	vfr	
BA	28	10YR 6/4	10YR 4/4	vg SL	Osg	n.d.	l	l	l	
Bw	52	10YR 6/4	7.5YR 4/6	vg SL	Osg	n.d.	l	l	l	
2Bt1b	61	7.5YR 5/6	7.5YR 4/4	vg SL	Osg, 1mgr	n.d.	l	l	l	
2Bt2b	81	7.5YR 5/4	7.5YR 4/6	vg SL	Osg, 1mgr	n.d.	l	l	l	
2Bt3b	102	7.5YR 5/6	7.5YR 4/6	vg SL	Osg, 1mgr	n.d.	l	l	l	

Table 1. continued.

Horizon	Lower Depth	Color		Texture	Structure	Boundary	Consistence	
		Dry	Moist				Moist	Dry
	cm							
Karphi 4								
A	14	10YR 6/3	10YR 4/3	L	2mgr	as	fr	fr
Bw1	23	10YR 6/4	10YR 4/4	g SL	1msbk	cs	fr	fr
Bw2	35	10YR 6/4	10YR 4/4	vg SL	1msbk	as	fr	fr
2Bt1b	49	5YR 4/6	5YR 4/4	CL	2msbk	cs	fr	fi
2Bt2b	60	5YR 3/4	5YR 3/3	CL	2csbk	cs	fr	vfi
R	60+							

Table 2. continued.

Horizon	Lower Depth	Gravel (>2.00 mm)	Sand (2.00-0.05 mm)					Silt (50-2 μm)			Clay (<2 μm)	
			VCoS	CoS	MS	FS	VFS	CoSi	FSi	CoC	FC	
Kaphi 2												
Ap	23	0.0	0.4	0.1	0.5	3.5	5.0	10.2	49.3	21.6	9.4	
Bw	55	0.1	0.5	0.6	0.3	3.6	5.2	8.9	45.6	27.5	7.8	
2Ab	63	0.5	1.0	0.7	0.6	5.3	7.2	11.5	34.8	30.2	8.7	
	70	1.2	1.2	0.9	0.9	5.4	7.5	11.4	34.0	28.9	9.8	
	77	2.5	1.5	1.3	0.9	5.9	8.5	10.4	33.7	28.9	8.9	
2Bw1b	85	1.2	1.1	1.1	1.0	6.1	8.6	11.6	33.2	28.1	9.2	
3Bw2b	93	1.0	1.4	0.8	1.2	7.5	9.4	11.3	34.7	24.1	9.6	
3Bw3b	101	0.7	1.0	1.3	1.3	8.1	10.8	13.0	33.8	21.9	8.8	
3BC1b	109	0.8	1.3	1.1	1.1	7.4	10.5	14.2	34.6	20.6	9.2	
3BC2b	117	1.2	1.3	0.9	0.9	5.8	7.8	13.0	37.3	22.7	10.3	
Terra Rossa												
	5	0.3	0.6	1.6	2.8	10.7	7.5	11.5	18.8	30.3	16.2	
Terra Rossa	5	5.0	0.5	0.5	1.0	7.0	8.3	11.4	21.3	34.9	15.1	

Table 2. continued.

Horizon	Lower Depth	Gravel (>2.00 mm)	Sand (2.00-0.05 mm)				Silt (50-2 μm)		Clay (<2 μm)			
			VCos	Cos	MS	FS	VFS	CoSi	FSi	CoC	FC	
Karpni 3	Ap	12	40.7	25.8	11.2	5.5	13.5	7.8	4.5	18.3	10.9	2.5
	BA	28	56.8	28.7	11.8	5.7	10.8	5.9	7.6	15.3	11.5	2.7
		36	56.6	29.1	14.0	6.1	9.9	4.8	7.1	15.0	12.0	2.0
	Bw	44	46.3	28.6	15.2	6.2	10.5	6.6	7.3	12.8	10.7	2.1
		52	50.9	28.4	14.4	5.9	9.4	7.0	8.0	13.9	10.6	2.4
	2Bt1b	61	50.3	21.3	10.7	5.7	18.1	11.6	8.9	12.2	8.9	2.6
	2Bt2b	70	43.9	21.4	14.4	7.4	18.5	10.3	6.8	9.2	9.2	2.8
	2Bt3b	81	48.0	23.9	12.9	5.6	16.5	11.2	7.0	8.3	11.1	3.5
		87	50.8	27.7	11.6	5.0	14.3	10.6	6.8	9.0	11.9	3.1
		93	60.5	34.6	15.5	5.4	8.1	4.8	4.2	14.4	10.0	3.0
	102	59.8	30.8	16.2	6.4	10.0	5.1	5.6	13.5	10.8	1.6	

Table 2. continued.

Horizon	Lower Depth	Gravel (>2.00 mm)	Sand (2.00-0.05 mm)					Silt (50-2 μ m)		Clay (<2 μ m)	
			VCoS	CoS	MS	FS	VFS	CoSi	FSi	CoC	FC
			cm	%							
Karphi 4											
A	14	2.5	6.8	5.0	3.1	10.2	10.9	14.9	24.5	17.8	6.8
Bw1	23	25.1	16.1	10.9	5.4	13.1	9.0	9.8	16.3	13.4	6.0
Bw2	35	33.8	15.4	9.8	4.4	12.3	8.5	9.8	20.7	15.7	3.4
2Bt1b	49	4.3	7.1	5.6	3.1	7.7	8.5	10.8	23.0	25.4	8.8
2Bt2b	60	1.4	7.0	4.6	2.3	6.6	7.7	12.8	27.0	23.8	8.2

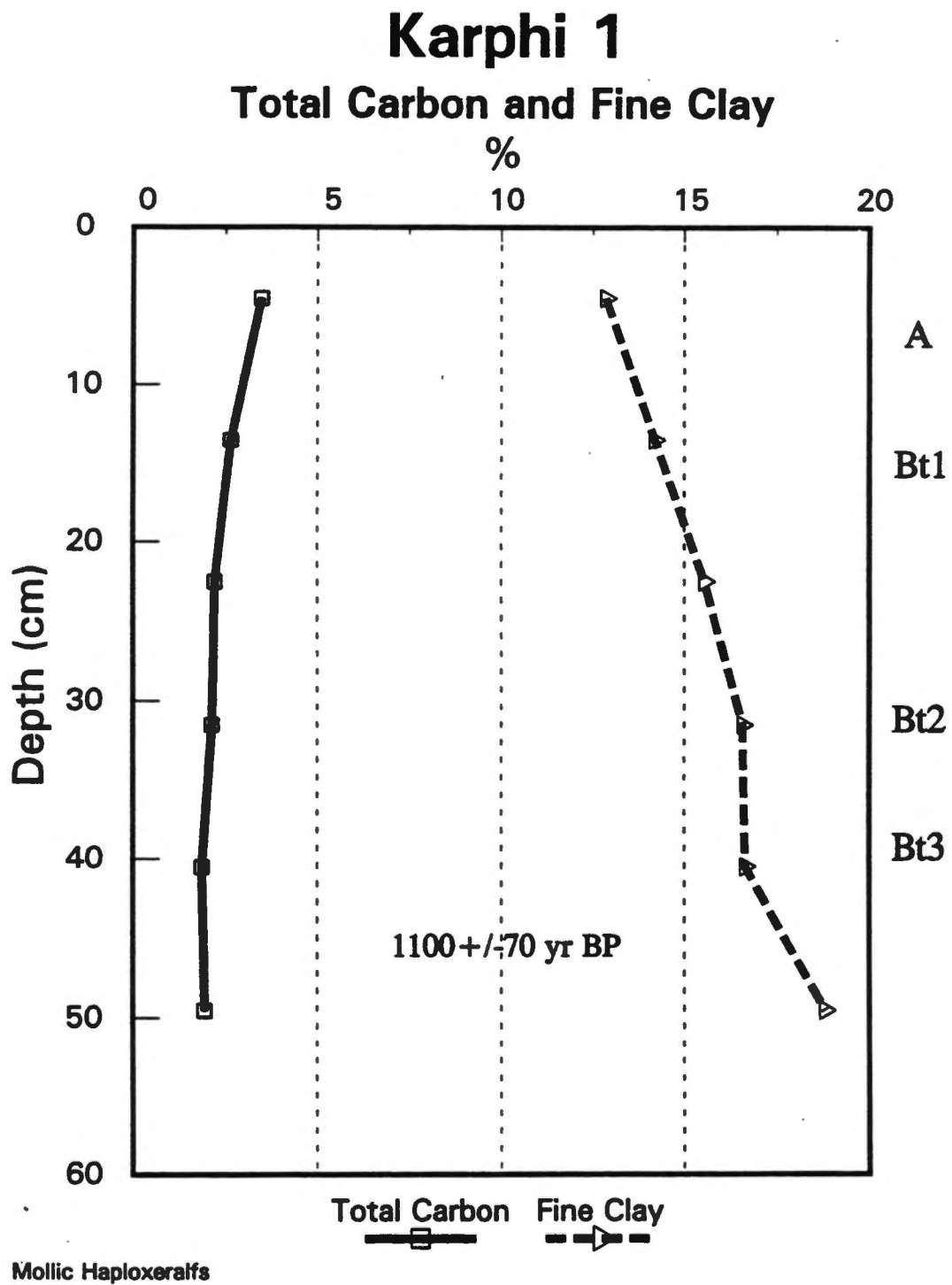


Figure 3. Total carbon and fine clay distribution vs. depth for the Karphi 1 soil pedon.

Table 3. Chemical properties including carbon, exchangeable cations, and pH of soil pedons investigated near the Karphi archaeological site.

Horizon	Lower Depth	Total Carbon	NH ₄ OAc Extractable Cations				NH ₄ OAc CEC	Base Saturation	pH	
			Ca	Mg	Na	K			1:1 H ₂ O	2:1 CaCl ₂
			cmol _c kg ⁻¹							
	cm	%					%			
Karphi 1										
A	9	3.47	23.2	3.36	0.36	1.96	28.2	102.2	7.10	6.72
Bt1	18	2.65	19.9	2.70	0.34	1.62	27.2	90.0	7.15	6.51
	27	2.22	20.3	2.46	0.37	1.19	27.1	89.8	6.99	6.51
Bt2	36	2.14	21.3	2.48	0.36	1.06	27.4	92.3	6.69	6.44
Bt3	45	1.86	20.2	2.51	0.37	0.93	27.4	87.6	6.91	6.59
	54	1.94	19.8	2.39	0.36	0.97	26.5	88.7	7.12	6.60
Terra Rossa	5	5.27	42.1	3.48	0.42	2.00	36.9	130.2	7.44	7.11
Terra Rossa	5	4.86	30.0	3.17	0.31	2.08	33.8	105.3	7.20	6.90

Table 3. continued.

Horizon	Lower Depth	Total Carbon	NH ₄ OAc Extractable Cations					pH			
			Ca	Mg	Na	K	NH ₄ OAc CEC	Base Saturation	1:1 H ₂ O	2:1 CaCl ₂	
cm											

Table 3. *continued.*

Horizon	Lower Depth	Total Carbon	NH ₄ OAc Extractable Cations					NH ₄ OAc CEC	Base Saturation	pH	
			Ca	Mg	Na	K	1:1 H ₂ O			2:1 CaCl ₂	
			cm	%	cmol _c kg ⁻¹					%	
Karphi 3											
Ap	12	1.49	1.3	0.56	0.21	0.55	8.63	30.8	4.94	4.48	
	23	1.08	1.1	0.53	0.11	0.53	7.85	28.3	4.84	4.40	
BA	28	0.98	1.4	0.63	0.13	0.52	7.59	35.3	5.08	4.55	
	36	0.54	1.5	0.61	0.10	0.37	6.50	39.5	5.30	4.70	
Bw	44	0.35	1.4	0.52	0.10	0.24	5.85	39.1	5.32	4.80	
	52	0.32	1.4	0.58	0.09	0.23	5.54	40.8	5.40	4.88	
2Bt1b	61	0.25	1.0	0.63	0.10	0.20	4.96	38.8	5.45	4.95	
	70	0.14	1.0	0.74	0.09	0.17	4.83	39.3	5.53	5.00	
2Bt2b	81	0.15	1.1	0.86	0.09	0.18	5.12	42.9	5.59	5.00	
	87	0.16	1.3	0.92	0.10	0.17	5.63	44.9	5.61	5.12	
2Bt3b	93	0.13	1.2	0.93	0.10	0.16	5.62	42.7	5.69	5.12	
	102	0.18	1.1	0.88	0.11	0.18	5.73	39.6	5.60	5.10	

Table 3. continued.

Horizon	Lower Depth	Total Carbon	NH ₄ OAc Extractable Cations				NH ₄ OAc CEC	Base Saturation	pH	
			Ca	Mg	Na	K			1:1 H ₂ O	2:1 CaCl ₂
			cmol _c kg ⁻¹							
	cm	%					%			
Karphi 4										
A	14	2.22	11.8	2.66	0.26	0.49	15.6	97.5	6.82	6.41
Bw1	23	0.91	9.1	1.29	0.14	0.30	10.2	106.5	7.55	6.90
Bw2	35	0.77	8.4	0.97	0.15	0.30	10.4	94.5	6.51	6.80
2Bt1b	49	0.51	11.9	0.96	0.21	0.41	15.5	86.6	7.51	6.98
2Bt2b	60	0.55	13.6	1.01	0.31	0.35	17.8	85.6	7.52	7.02

The base saturation above bedrock was 88.7% (NH_4OAc pH 7) (Table 4) and the increase of clay with depth indicated the presence of an argillic horizon and therefore an Alfisol. The xeric moisture regime and simple horizonation placed the pedon in the Haploxeralfs great group. Moist soil color value of 3 or less in the upper 10 cm and $> 0.7\%$ organic carbon content place this pedon in the Mollic Haploxeralfs subgroup. A mesic temperature regime is assumed for this elevation and a mixed mineralogy is also assumed. The pedon is therefore classified as fine, mixed, mesic Mollic Haploxeralfs at the family level (Soil Survey Staff, 1990).

Clay-free ratios from the particle size analysis for this pedon seem to indicate a rather uniform parent material (Table 4, Figure 4). The $\text{FSi}:(\text{TS}+\text{Si})$ ratio ranges from 0.634 to 0.674 with a mean of 0.659 and a coefficient of variation (CV) of 2.25%. Samples tested for the terra rossa on the surrounding basin exhibit a mean of 0.615 and a CV of 10.34%. The high fine silt component in this sediment suggests the possibility that there is significant eolian influence in the sinkhole. However, the amounts of fine silt in the sediments at the bottom of the sinkhole and in the terra rossa are comparable. There have been suggestions that the terra rossa is developed from eolian sediments from North Africa (Macleod, 1980; Yaalon, 1987; Rapp, 1984; Nihlen and Solyom, 1986). If this is the case then there may be a significant eolian component to the deposits in Karphi 1, however, the clay-free ratios suggest that the sediments in Karphi 1 are similar to the surrounding terra rossa soils and an alluvial deposition of reworked loess may be plausible.

Examination of the molar ratios and weathering indices used in this study tend to confirm the uniform nature of the parent material (Tables 4 and 5, Figure 5). The $\text{SiO}_2:\text{R}_2\text{O}_3$ ratios for this pedon ranged from 4.54 to 2.06 with an average of 3.48 and a CV of 25.52%. The $\text{SiO}_2:\text{R}_2\text{O}_3$ ratio for the surrounding terra rossa soils exhibit an average of 3.32 with a CV

Table 4. Weathering indices and clay-free ratios determined for soil pedons investigated near the Karphi archaeological site.

Horizon	Lower Depth	Weathering Indices				Clay-free Ratios	
		SiO ₂ :R ₂ O ₃	TiO ₂ :ZrO ₂	Parker's Weathering Index	Fe _d :Fe _T	FS:(TS+Si)	FSi:(TS+Si)
	cm						
Karphi 1							
A	9	3.66	71.7	17.5	0.502	0.036	0.634
Bt1	18	3.28	73.7	18.1	0.476	0.026	0.661
	27	2.06	70.9	17.9	0.555	0.019	0.673
Bt2	36	4.54	69.7	17.7	0.471	0.026	0.674
Bt3	45	3.57	79.2	17.0	0.433	0.020	0.652
	54	3.00	69.0	18.0	0.439	0.030	0.657
Terra Rossa	5	3.13	68.5	19.7	0.207	0.029	0.659
Terra Rossa	5	3.41	73.5	18.8	0.245	0.050	0.570

Table 4. continued.

Horizon	Lower Depth	Weathering Indices				Clay-free Ratios	
		SiO ₂ :R ₂ O ₃	TiO ₂ :ZrO ₂	Parker's Weathering Index	Fe _d :Fe _t	FS:(TS+Si)	FSi:(TS+Si)
	cm						
Karphi 2							
Ap	23	3.42	94.8	17.1	0.363	0.051	0.715
Bw	55	4.19	95.2	18.0	0.379	0.055	0.706
2Ab	63	3.54	82.2	17.4	0.440	0.086	0.570
	70	4.23	81.2	17.5	0.330	0.088	0.556
	77	3.83	78.6	16.8	0.356	0.088	0.542
2Bw1b	85	3.98	79.5	17.0	0.342	0.095	0.530
3Bw2b	93	5.96	93.2	16.0	0.337	0.113	0.524
3Bw3b	101	5.91	107.1	15.4	0.330	0.117	0.488
3BC1b	109	4.99	118.2	15.2	0.349	0.105	0.493
3BC2b	117	5.39	103.1	17.5	0.301	0.086	0.556
Terra Rossa	5	2.84	86.1	16.0	0.231	0.200	0.351
Terra Rossa	5	3.65	86.3	17.3	0.217	0.139	0.426

. Table 4. continued.

Horizon	Lower Depth	Weathering Indices				Clay-free Ratios	
		SiO ₂ :R ₂ O ₃	TiO ₂ :ZrO ₂	Parker's Weathering Index	Fe _d :Fe _t	FS:(TS+Si)	FSi:(TS+Si)
	cm						
Karphi 3							
Ap	12	5.58	531.5	15.6	0.118	0.156	0.212
	23	5.67	750.6	15.3	0.154	0.144	0.204
BA	28	5.46	—	17.9	0.129	0.134	0.189
Bw	36	5.31	—	19.8	0.153	0.115	0.174
	44	4.75	—	19.9	0.095	0.120	0.147
	52	4.33	—	19.7	0.093	0.108	0.160
2Bt1b	61	4.62	—	17.6	0.083	0.204	0.138
2Bt2b	70	3.99	—	18.4	0.092	0.211	0.104
	81	3.70	—	19.3	0.098	0.194	0.097
2Bt3b	87	3.63	417.4	19.9	0.110	0.168	0.105
	93	3.04	—	20.7	0.072	0.093	0.166
	102	3.74	—	20.8	0.078	0.114	0.154

. Table 4. continued.

Horizon	Lower Depth	Weathering Indices				Clay-free Ratios	
		SiO ₂ :R ₂ O ₃	TiO ₂ :ZrO ₂	Parker's Weathering Index	Fe _d :Fe _t	FS:(TS+Si)	FSi:(TS+Si)
	cm						
Karphi 4							
A	14	5.70	314.5	19.6	0.082	0.135	0.326
Bw1	23	3.50	560.6	22.4	0.078	0.162	0.202
Bw2	35	4.43	281.1	19.7	0.081	0.152	0.256
2Bt1b	49	4.96	108.0	18.4	0.164	0.117	0.482
2Bt2b	60	5.67	103.8	18.4	0.221	0.097	0.397

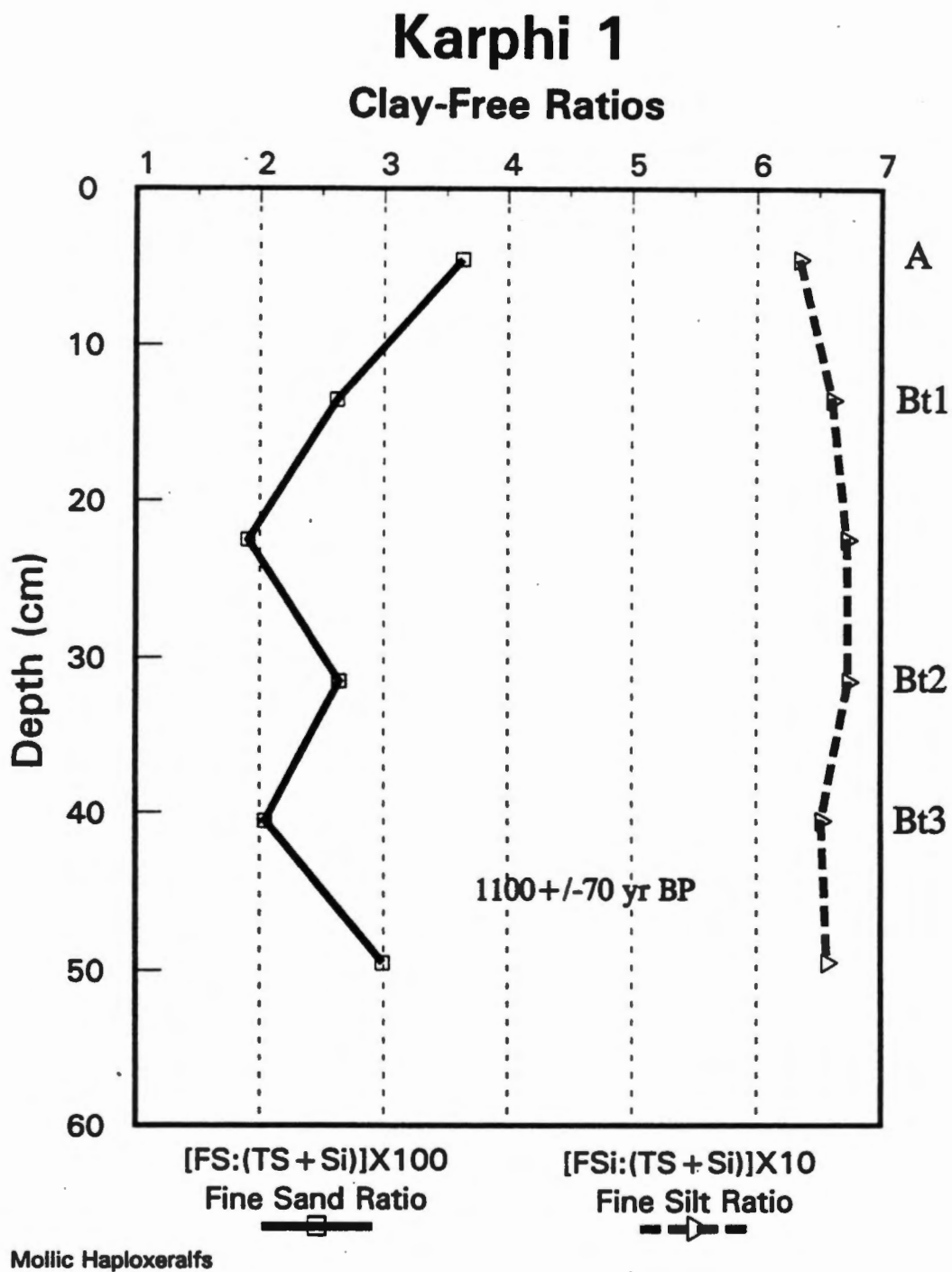


Figure 4. Distribution of clay-free ratios, as determined by particle size analysis, vs. depth for the Karphi 1 soil pedon.

Table 5. Statistical results of Ryan-Einot-Gabriel-Welsch multiple range tests for weathering indices and clay-free ratios for soil pedons investigated near the Karchi archaeological site.

	Molar Ratios				Clay-free Ratios	
	SiO ₂ :R ₂ O ₃	TiO ₂ :ZrO ₂	Parker's Weathering Index	Fe _d :Fe _t	FS:(TS+Si)	FSi:(TS+Si)
Karchi 1						
0-54 cm						
$\bar{x}$	3.48a†	72.5a	21.0a	0.473a	0.026a	0.659a
SD	0.89	5.9	0.6	0.039	0.006	0.015
CV (%)	25.52	8.11	2.88	8.22	24.05	2.25
<i>n</i>	11	11	11	11	6	6
Terra Rossa						
$\bar{x}$	3.32a	72.0a	22.7b	0.232b	0.039a	0.615a
SD	0.64	3.8	0.8	0.022	0.015	0.064
CV (%)	19.29	5.25	3.32	9.56	38.01	10.34
<i>n</i>	3	3	3	3	2	2
LSD	1.21	7.9	0.9	0.052	0.017	0.059
df	12	12	12	12	6	6
α	0.05	0.05	0.05	0.05	0.05	0.05

† Group means with the same letter(s) are not significantly different at the $\alpha=0.05$ level

Table 5. continued.

	Molar Ratios				Clay-free Ratios	
	$\text{SiO}_2:\text{R}_2\text{O}_3$	$\text{TiO}_2:\text{ZrO}_2$	Parker's Weathering Index	$\text{Fe}_d:\text{Fe}_t$	$\text{FS}:(\text{TS}+\text{Si})$	$\text{FSi}:(\text{TS}+\text{Si})$
Karphi 2						
0-55 cm						
$\bar{x}$	3.93a†	95.2ab	20.9a	0.373a	0.053a	0.710a
SD	0.77	4.5	0.8	0.010	0.003	0.007
CV (%)	19.47	4.75	3.62	2.60	5.88	0.92
<i>n</i>	3	3	3	3	2	2
55-85 cm						
$\bar{x}$	3.90a	80.5c	20.2a	0.368a	0.089ab	0.549b
SD	0.57	1.7	0.7	0.048	0.004	0.017
CV (%)	14.52	2.10	3.39	12.93	4.58	3.13
<i>n</i>	8	8	8	8	4	4
85-117 cm						
$\bar{x}$	5.57b	105.5a	18.9a	0.332a	0.105b	0.515b
SD	1.03	10.0	1.6	0.035	0.014	0.032
CV (%)	18.48	9.43	8.62	10.66	13.01	6.17
<i>n</i>	8	8	8	8	4	4
Terra Rossa						
$\bar{x}$	3.11a	86.3bc	18.9a	0.227b	0.169c	0.388c
SD	0.46	0.9	0.9	0.009	0.043	0.053
CV (%)	14.90	1.09	4.75	3.90	25.46	13.73
<i>n</i>	3	3	3	3	2	2
LSD	1.51	12.4	2.2	0.071	0.049	0.081
df	18	18	18	18	8	8
α	0.05	0.05	0.05	0.05	0.05	0.05

† Group means with the same letter(s) are not significantly different at the $\alpha=0.05$ level

Table 5. continued.

	Molar Ratios				Clay-free Ratios	
	$\text{SiO}_2\text{:R}_2\text{O}_3$	$\text{TiO}_2\text{:ZrO}_2$	Parker's Weathering Index	$\text{Fe}_d\text{:Fe}_T$	$\text{FS:}(\text{TS}+\text{Si})$	$\text{FSi:}(\text{TS}+\text{Si})$
Karphi 3						
0-52 cm						
$\bar{x}$	5.19a†	—	22.0a	0.124a	0.130a	0.181a
SD	0.94	—	2.8	0.026	0.018	0.025
CV (%)	18.06	—	12.53	20.84	14.01	13.96
<i>n</i>	12	—	12	12	6	6
52-102 cm						
$\bar{x}$	3.79b	—	23.8a	0.089b	0.164a	0.127b
SD	0.72	—	1.6	0.013	0.049	0.029
CV (%)	18.89	—	6.76	5.01	30.15	22.82
<i>n</i>	12	—	12	12	6	6
LSD	0.71	—	1.9	0.017	0.048	0.035
df	22	—	22	22	10	10
α	0.05	—	0.05	0.05	0.05	0.05

† Group means with the same letter(s) are not significantly different at the $\alpha=0.05$ level

Table 5. continued.

	Molar Ratios				Clay-free Ratios	
	SiO ₂ :R ₂ O ₃	TiO ₂ :ZrO ₂	Parker's Weathering Index	Fe _d :Fe _t	FS:(TS+Si)	FSi:(TS+Si)
Karphi 4						
0-35 cm						
$\bar{x}$	4.85a†	355.7a	24.6a	0.080a	0.150a	0.261a
SD	0.91	125.4	1.3	0.004	0.014	0.062
CV (%)	18.86	35.25	5.09	5.18	9.34	23.70
<i>n</i>	5	5	5	5	3	3
35-60 cm						
$\bar{x}$	5.32a	106.1b	22.3b	0.192b	0.107b	0.440b
SD	1.11	2.7	0.5	0.033	0.014	0.060
CV (%)	20.75	2.56	2.09	17.04	13.34	13.71
<i>n</i>	4	4	4	4	2	2
LSD	1.59	150.4	1.6	0.034	0.041	0.178
df	7	7	7	7	3	3
α	0.05	0.05	0.05	0.05	0.05	0.05

† Group means with the same letter(s) are not significantly different at the $\alpha=0.05$ level

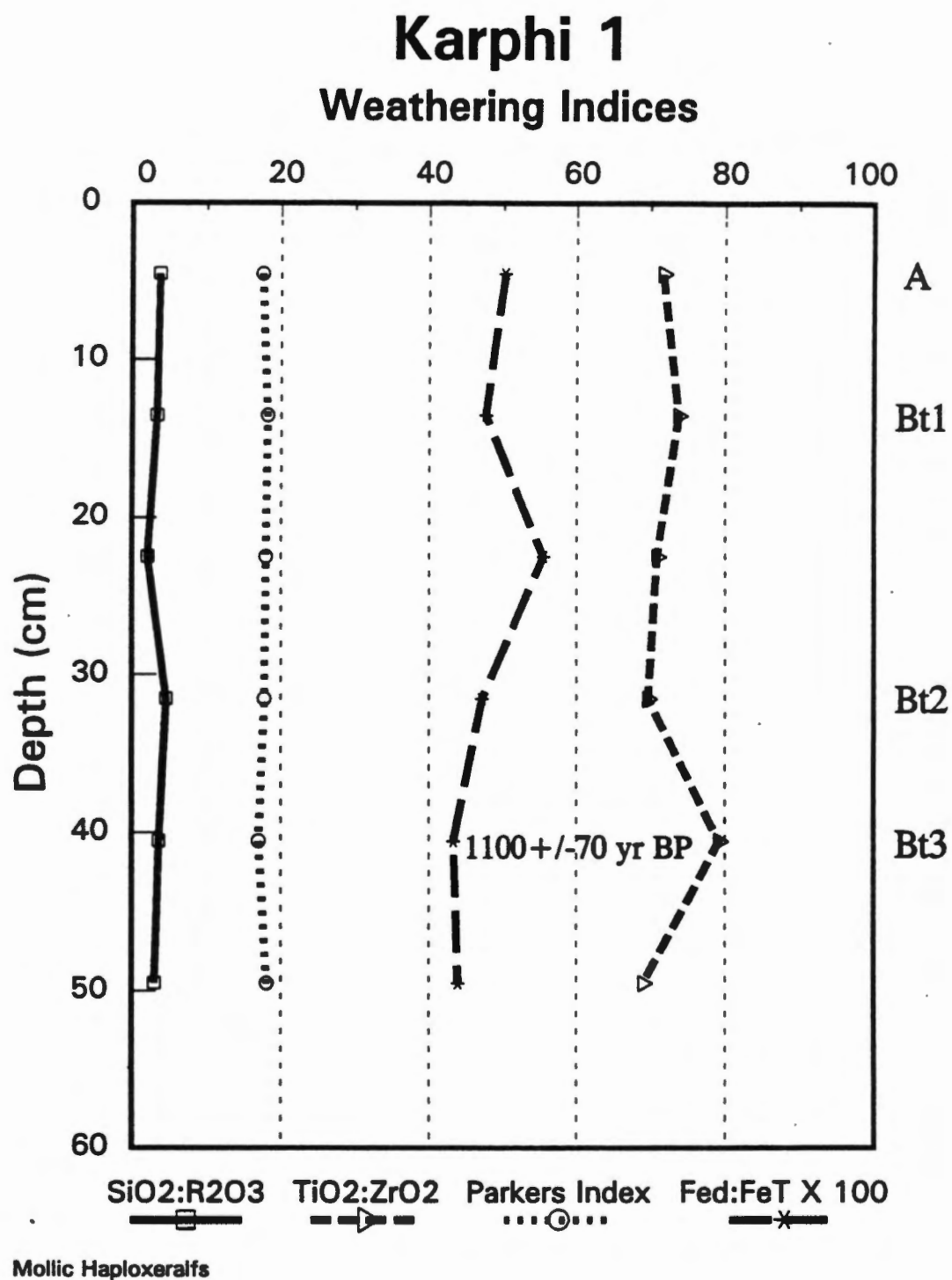


Figure 5. Plot of weathering indices, as determined by total element analysis and citrate-dithionite extraction, vs. depth for the Karphi 1 soil pedon.

of 19.29% which is statistically similar to the pedon ratios. The Parker's weathering index and the Ti:Zr ratios exhibit a similar pattern. For the Parker's weathering index, the average for the pedon is 21.0 with a CV of 2.88% and the average for the terra rossa is 22.7 with a CV of 3.32% which shows a slight but significant difference. For the Ti:Zr ratios, the mean for the pedon is 72.5 with a CV of 8.11%, and the mean for the terra rossa is 72.0 with a CV of 5.25% which is not significantly different. The chief differences between the pedon and the terra rossa is in the $Fe_d:Fe_T$ ratios. The average $Fe_d:Fe_T$ for the pedon was 0.473 with a CV of 8.22%, and for the terra rossa averages 0.232 with a CV of 9.56% which is significantly lower.

An examination of the extractable elements in this pedon show that there is some recycling of these elements at the soil surface (Table 6, Figure 6). Extractable P is greatest at the surface at 30.5 mg kg⁻¹ and decreases steadily to 7.86 mg kg⁻¹ in the Bt3 horizon with a slight increase above bedrock. Extractable Pb, Mn, and Sr exhibit similar patterns with the greatest concentrations of these elements at the surface (7.31, 386, and 10.4 mg kg⁻¹ respectively) and a gradual decrease with depth (6.07, 149, and 8.12 mg kg⁻¹ respectively). There is a slight increase in extractable Pb and Mn just above bedrock in the Bt3 horizon. Extractable Ba and Cu exhibit an increase in concentration from the surface to the lower section of the Bt1 horizon and a decrease with depth. Barium and Cu do not seem to exhibit the increased concentration at the surface as the other elements analyzed, and seem more homogeneous through the profile. The distribution of these elements seems to indicate a single sequence of deposition with the present surface as the only stable surface in the history of this pedon.

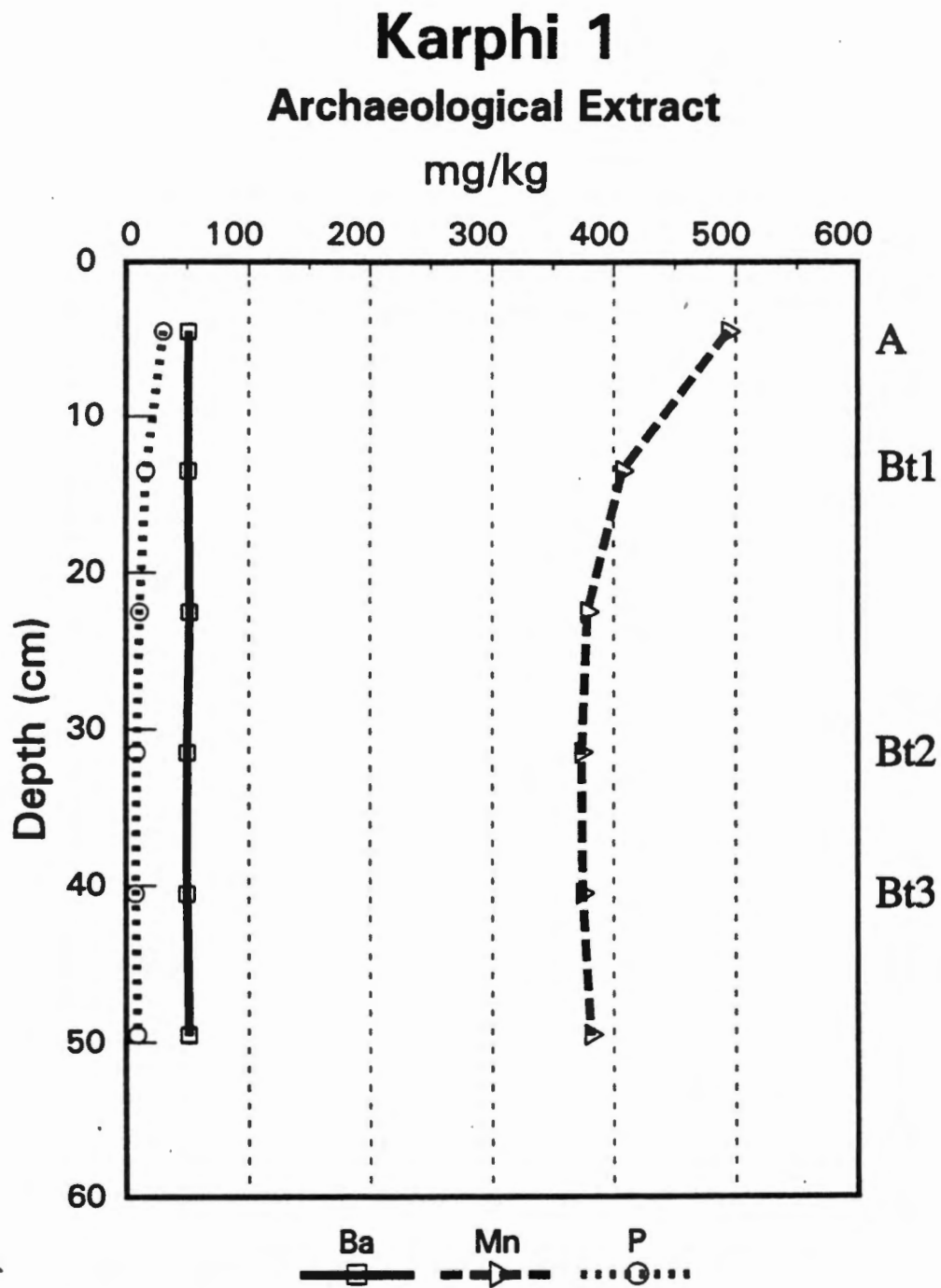
Karphi 1 represents an alluvial pedon in which the parent material was derived primarily from the surrounding terra rossa soils. The presence of Late Minoan artifacts on

Table 6. Elemental concentrations determined by archaeological extract method for soil pedons investigated near the Karphi archaeological site.

Horizon	Lower Depth	Extractable Elements					
		Ba	Cu	Mn	P	Pb	Sr
	cm	mg kg ⁻¹					
Karphi 1							
A	9	50.9	7.94	386	30.5	7.31	10.40
Bt1	18	50.7	8.46	300	16.3	6.88	8.93
	27	51.8	9.13	229	11.2	6.30	8.75
Bt2	36	50.1	8.14	197	8.6	5.55	8.69
Bt3	45	49.7	6.47	149	7.9	4.99	8.26
	54	51.3	7.06	197	9.5	6.07	8.12
Terra Rossa	5	47.7	6.01	409	58.3	13.3	10.9
Terra Rossa	5	50.7	8.50	413	34.6	12.8	10.1
Karphi 2							
Ap	23	33.3	6.10	179	24.6	5.06	5.56
Bw	55	36.4	4.95	82.4	3.1	4.49	4.36
2Ab	63	40.2	4.73	76.2	2.7	4.52	4.34
	70	43.0	4.64	78.0	1.5	4.41	4.47
	77	48.8	4.88	75.1	0.1	4.41	4.99
2Bw1b	85	50.4	4.33	61.9	0.0	3.96	4.99
3Bw2b	93	50.6	3.98	64.1	0.0	3.62	4.53
3Bw3b	101	47.6	3.28	65.8	0.0	3.48	3.95
3BC1b	109	46.2	3.37	57.8	0.0	3.90	3.92
3BC2b	117	44.7	3.05	50.5	0.0	3.79	4.00
Terra Rossa	5	36.8	4.14	310	9.1	7.34	6.86
Terra Rossa	5	37.5	4.77	418	15.4	9.02	7.84

Table 6. continued.

Horizon	Lower Depth	Extractable Elements						
		Ba	Cu	Mn	P	Pb	Sr	
								mg kg ⁻¹
Kaphi 3								
Ap	12	17.8	1.93	163	120.0	3.36	1.60	
	23	17.9	1.91	137	45.5	2.87	1.25	
BA	28	16.0	1.49	99.5	48.9	2.48	1.78	
Bw	36	11.6	1.26	33.4	13.9	1.58	1.90	
	44	9.1	0.80	16.9	4.8	1.46	1.67	
	52	8.8	0.88	22.0	6.3	1.46	1.60	
2Bt1b	61	7.1	1.28	14.1	4.3	1.26	1.39	
2Bt2b	70	7.0	1.12	10.3	1.8	1.61	1.71	
	81	8.2	0.79	12.2	1.3	1.57	1.77	
2Bt3b	87	8.2	1.07	12.1	1.3	1.70	1.78	
	93	8.8	0.84	11.9	0.8	1.65	1.62	
	102	8.8	0.89	11.8	2.2	1.53	1.54	
Kaphi 4								
A	14	26.0	3.36	259	31.3	3.54	5.60	
Bw1	23	19.0	2.50	142	20.4	2.58	3.79	
Bw2	35	20.2	2.70	128	8.9	3.05	3.58	
2Bt1b	49	29.9	3.07	71.6	0.0	3.50	5.29	
2Bt2b	60	39.9	4.94	97.3	0.0	3.36	6.92	



Mollic Haploxeralfs

Figure 6. Distribution of extractable elements, as determined by archaeological extraction method, vs. depth for the Karphi 1 soil pedon.

the surface indicate that the surface of this pedon was stable at least 3,000 years ago. A radiocarbon date of 1100 yr B.P. (Beta 66572) in the Bt3 horizon represents a mean residence time for the whole soil and the date is likely underestimated. The presence of an argillic horizon seemed to indicate that the present soil probably formed in a moist climate or at least moist enough to promote illuviation of clays. According to Foss and Collins (1987) it would take at least 3,500 to 4,000 years to form an argillic horizon in a udic moisture regime. The presence of Late Minoan artifacts on the surface of this pedon seems to indicate that the archaeological context is consistent with the soil morphology but not with the radiocarbon analysis.

Karphi 2

Karphi 2 differs from the pedon at Karphi 1 in two major respects; 1) Karphi 2 has no archaeological context and, 2) Karphi 2 is a pedon with more than one depositional sequence. Pendlebury reported that a charcoal layer could be found below the surface on the Nyssimos plain which led him to believe that the Karphi site was well wooded at one time (Students of the British School, 1937-1938). Karphi 2 represents a pedon which comes closest to meeting the conditions which Pendlebury observed on the Nyssimos plain.

The first 55 cm of the Karphi 2 pedon represents a relatively modern sequence (Table 1, Appendix A). Moist colors of this upper portion consist of 7.5YR 4/4, and textures of the Ap and Bw horizons are silty clay loams. There is some soil development with a moderate medium granular structure in the surface to a weak medium subangular blocky structure in the cambic horizon, and moist consistence changes from very friable to friable in the cambic horizon.

There is a thick buried A horizon (2Ab) which extends from 55 to 77 cm below the surface. Radiocarbon analysis of this buried horizon performed on a bulk soil sample yielded

a mean residence time date of $1,790 \pm 50$ yr. B.P. (Beta-63172). This 2Ab exhibits moist colors of 7.5YR 3/4, silty clay loam textures, and moderate medium subangular blocky structure. Charcoal is common in the 2Ab and there are few fragments of limestone on the surface of the 2Ab. There are common very thin and patchy discontinuous clay skins on the peds of the 2Ab and the 2Bw1b horizons. Colors in the 2Bw1b horizon brighten to 7.5YR 4/4 (moist).

A second discontinuity designating a third sequence in this pedon occurs at 85 cm below the surface. The moist colors change abruptly to 5YR 3/4 in the 3Bw2b, and 3Bw3b horizons. The 3BC1b and 3BC2b horizons are brighter with 5YR 4/6 and 5YR 4/4 colors respectively. Textures change to clay loams with silty clay loam in the 3BC2b horizon. Structures change from a weak medium subangular blocky in the 3Bw2b, to weak coarse subangular blocky in the 3Bw3b, to weak coarse subangular blocky to structureless massive in the 3BC1b and 3BC2b horizons. There are very few rounded phyllite fragments found in this third sequence and there are few fine discontinuous clay coatings on the peds in the horizons of this sequence.

The first buried soil in this pedon is more than 50 cm below the surface and therefore the surface of the pedon is used in the classification. The presence of a cambic horizon, an ochric epipedon and a xeric moisture regime places this pedon in the Xerochrepts great group. The presence of the 2Ab horizon creates a situation where there is an irregular decrease in carbon with depth (Table 3, Figure 7) and the soil slope is $< 25\%$, thus placing this pedon into the Fluventic Xerochrepts subgroup. A fine-silty particle size class, a mixed mineralogy, and a mesic temperature regime places this pedon in the fine-silty, mixed, mesic Fluventic Xerochrepts family (Soil Survey Staff, 1990).

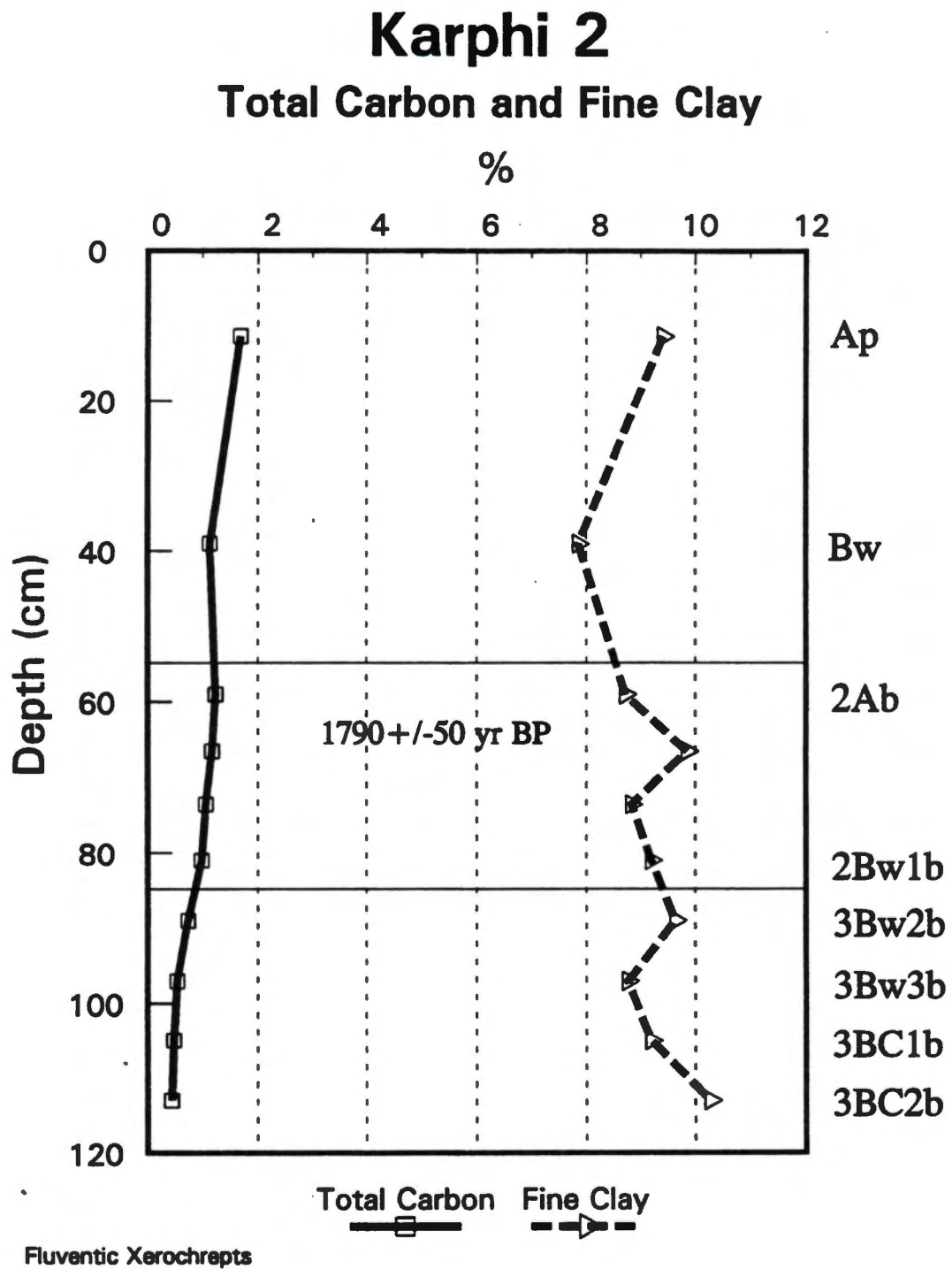


Figure 7. Total carbon and fine clay distribution vs. depth for the Karphi 2 soil pedon.

Although the clay content in this pedon does not increase with depth, there is some evidence of clay illuviation within the sequences (Table 2, Figure 7). The clay content in the 2Ab is highest at 38.9% and decreases regularly to 37.3 in the 2Bw1b horizon. Likewise, in the third sequence the highest clay content is in the 3Bw2b at 33.7% and decreases regularly to 29.8% in the 3BC1b horizon and increases slightly to 33.0% in the 3BC2b horizon. The presence of few and very few thin discontinuous clay skins in the horizons below the 2Ab indicate that there is some clay movement, although not enough to qualify as argillic. The evidence appears in the fine clay content where two increases of 9.8% and 9.2% are found in the second sequence, and two increases of 9.6% in the 3Bw2b and 10.3% in the 3BC2b horizons are found in the third sequence. These fine clay peaks in the distribution of the profile may indicate some initial illuviation in these sequences.

Analysis of the clay-free ratios show that the discontinuities defined by the soil morphology can be independently confirmed. The FS:(TS+Si) ratio indicates that three different depositional events confirm the variability between the three sequences (Tables 4 and 5, Figure 8). The first sequence (Ap to Bw) has a mean ratio of 0.053 with a CV of 5.88%, the second sequence (2Ab to 2Bw1b) exhibits an average ratio of 0.089 with a CV of 4.58%, and the third sequence (3Bw2b to 3BC2b) has a mean ratio of 0.105 with a CV of 13.01%. The first sequence is significantly different than the third sequence, but both are similar to the second sequence. The terra rossa exhibits a mean ratio of 0.169 with a CV of 25.46%, which is significantly different from the ratios in the pedon. An increase of fine sand with depth follows a trend of increased sand content with each successive sequence. The sand content of the terra rossa shows that the third sequence is most like the terra rossa sand distribution and, therefore, exhibits more terra rossa character than the other two sequences.

Karphi 2

Clay-Free Ratios

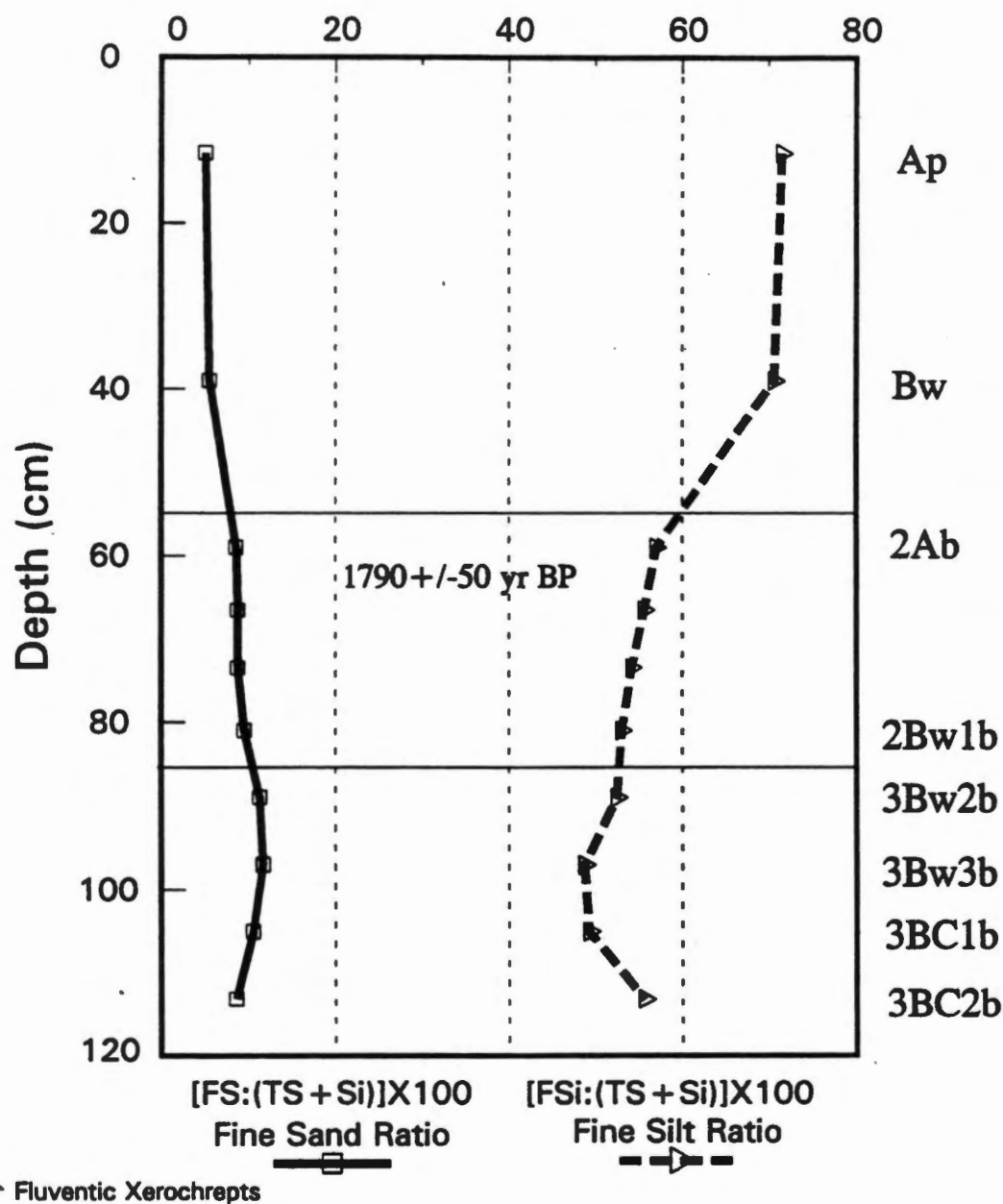


Figure 8. Distribution of clay-free ratios, as determined by particle size analysis, vs. depth for the Karphi 2 soil pedon.

The FSi:(TS+Si) ratio shows what may be interpreted as episodes of eolian influence in this pedon (Tables 4 and 5, Figure 8). The first sequence (Ap to Bw) exhibits a mean ratio of 0.710 and a CV of 0.92%. This indicates that the fine silt in these samples average 71% of the clay-free fraction. The lower two sequences have average fine silt ratios of 0.549 (CV of 3.13%) and 0.515 (CV of 6.17%) which are statistically similar to each other. The terra rossa fine silt ratios average 0.388 with a CV of 13.73% which is significantly different from the pedon. This relationship seems to indicate that there may be a greater eolian influence exhibited in the Karphi 2 pedon, and that the greatest eolian influence may be found in the upper sequence which was deposited after $1,790 \pm 50$ yr B.P.

The weathering indices and molar ratios also tend to confirm the existence of three depositional sequences. The $\text{SiO}_2\text{:R}_2\text{O}_3$ molar ratios for the first two sequences have means of 3.93 (CV 19.47%) and 3.90 (CV 14.52%), respectively (Tables 4 and 5, Figure 9). The third sequence, however, has a mean ratio of 5.57 with a CV of 18.48% which is significantly different from the first two sequences. In theory, the $\text{SiO}_2\text{:R}_2\text{O}_3$ ratio should decrease with increased weathering or age. This particular pattern seems to indicate that the upper sequences were probably weathered before the sediments were deposited in the sinkhole. The terra rossa exhibits a molar ratio of 3.11 with a CV of 14.90%. This suggests that the terra rossa is more highly weathered and is more consistent with the upper two sequences.

The use of Parker's weathering index does not show much difference in any of the three sequences or in the terra rossa (Tables 4 and 5, Figure 9). The mean values (and CV's) for each of the three sequences are 20.9 (3.62%), 20.2 (3.39%), and 18.9 (8.62%) respectively which indicates that the lower sequence shows a greater loss of bases than the upper two sequences. The Parker's index values for the terra rossa show a mean of 18.9 with a CV of

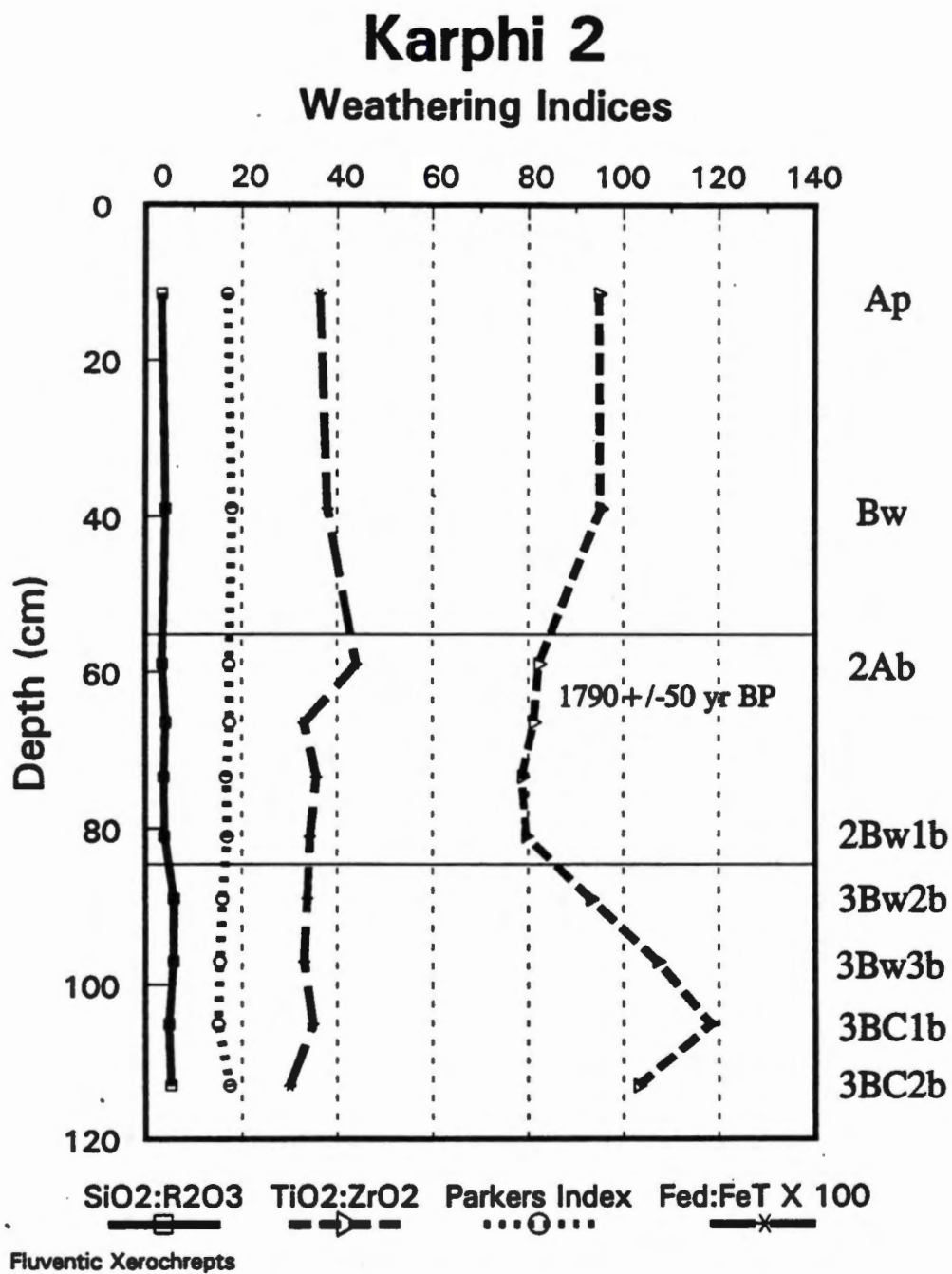


Figure 9. Plot of weathering indices, as determined by total element analysis and citrate-dithionite extraction, vs. depth for the Karphi 2 soil pedon.

4.75%. In this case Parker's weathering index of relative loss of bases does little to discriminate these formations.

Iron ratios used as a weathering index are also poor at discriminating between these sequences (Tables 4 and 5, Figure 9). The average $\text{Fe}_d:\text{Fe}_T$ ratio for each of the sequences (and CV's) are 0.373 (2.60%), 0.368 (12.93%), and 0.332 (10.66%) respectively. Although these values do little to discriminate the three sequences, the mean ratio for the terra rossa is 0.227 with a CV of 3.90% which is significantly different from the values in the pedon.

The $\text{TiO}_2:\text{ZrO}_2$ ratios for Karphi 2 serve to discriminate these sequences (Tables 4 and 5, Figure 9). The mean values for this molar ratio for each of the three successive sequences (with associated CV's) are 95.2 (4.75%), 80.5 (2.10%), and 105.5 (9.43%) respectively. In regard to other weathering indices, the $\text{TiO}_2:\text{ZrO}_2$ molar ratio should also decrease with increased weathering. I interpret the data to indicate that the lower sequence is less weathered, and that the upper two sequences, especially the second, were weathered before they were deposited in the sinkhole. The terra rossa tested exhibited a molar ratio average of 86.3 with a CV of 1.09%. This value suggests that the second sequence is most closely related to the terra rossa values and perhaps exhibited a similar weathering history. The first sequence is also statistically similar to the terra rossa.

The extractable element distribution from the Karphi 2 pedon exhibits some variability due to the multi-sequel nature of the profile (Table 6, Figure 10). The concentrations of extractable Cu, Mn, Pb, P, and Sr are all greatest at the surface of the pedon, probably due to the recycling of these elements by plant roots. Manganese shows two subsurface peaks at 78.0 mg kg^{-1} in the 2Ab horizon and 65.8 mg kg^{-1} in the 3Bw3b horizon which may also indicate some recycling of Mn by plant material in the lower two sequences. Lead also shows an increased concentration in the 2Ab horizon at 4.52 mg kg^{-1} and in the

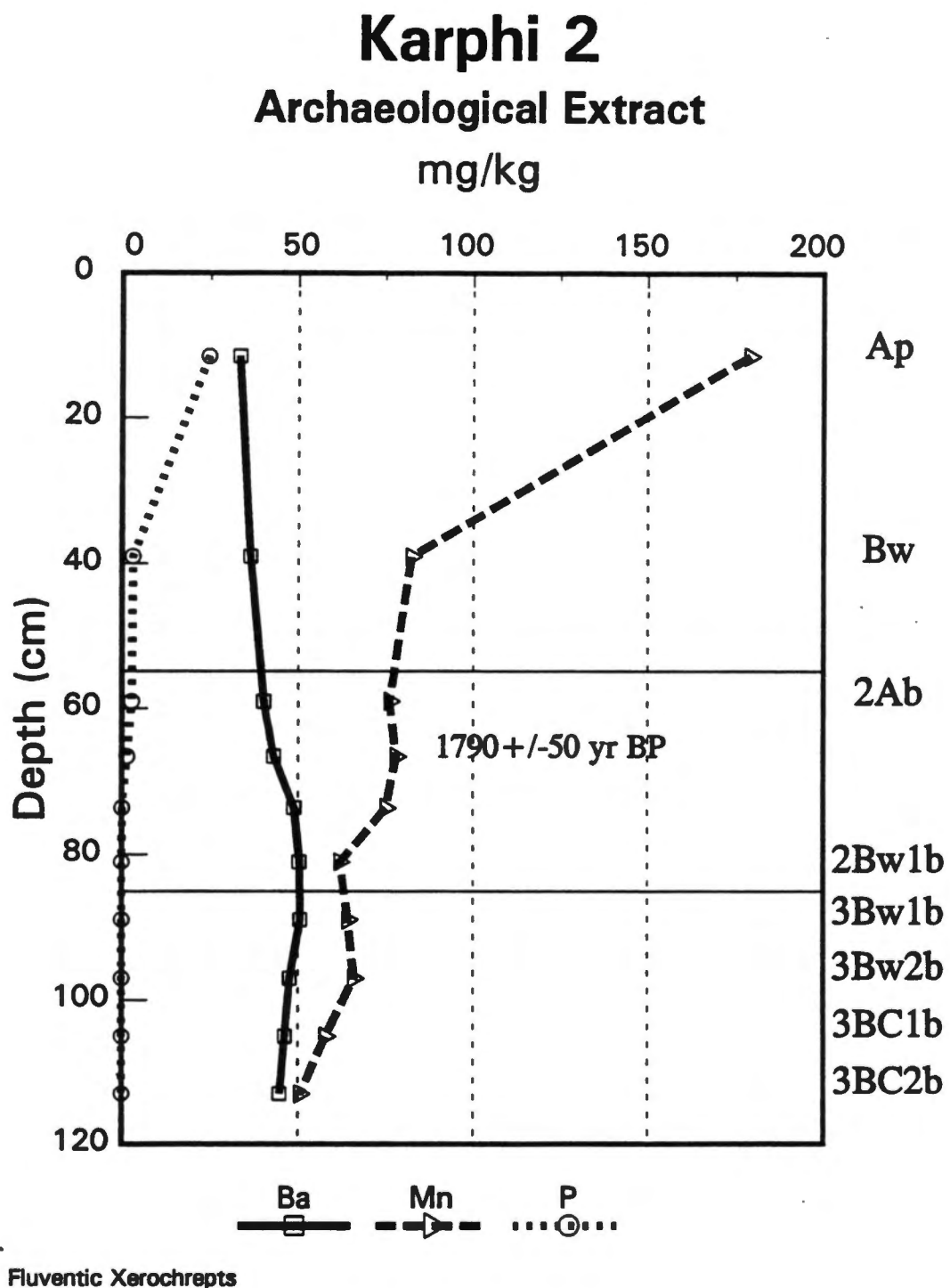


Figure 10. Distribution of extractable elements, as determined by archaeological extraction method, vs. depth for the Karphi 2 soil pedon.

3BC1b horizon at 3.90 mg kg^{-1} . Strontium also shows two subsurface peaks in the 2Ab horizon at 4.99 mg kg^{-1} and in the 3BC2b horizon at 4.00 mg kg^{-1} . On the other hand P concentrations are highest in the surface at 24.6 mg kg^{-1} and decreases sharply to 0.051 mg kg^{-1} in the base of the 2Ab horizon, and remains below detectable limits throughout the remaining profile. Copper exhibits two peaks in the lower sequences at 4.88 mg kg^{-1} in the 2Ab horizon and 3.37 mg kg^{-1} in the 3BC1b horizon. Barium does not follow the pattern of the other extractable elements. Barium gradually increases from the surface at 33.3 mg kg^{-1} to a peak of 50.6 mg kg^{-1} in the 3Bw2b horizon, and gradually decreases to 44.7 mg kg^{-1} in the 3BC2b horizon.

The pedon at Karphi 2 represents at least three different episodes of deposition. The lowest sequence seems to be an alluvial deposition with some evidence of weathering. The A horizon is missing from the lowest sequence, and one might assume that the soil was truncated at one time. Another depositional episode occurred, probably alluvial, in which a Roman age soil had developed. The weathering indices seem to indicate that this parent material was weathered prior to deposition. Another depositional sequence occurred which buried the Roman age soil. The particle size distribution is evidence that this soil has a higher fine silt content, and may be of eolian origin. There is the question of whether the lower sequence was of Minoan age (3Bw2b). There were no artifacts associated with this profile, and Pendlebury's charcoal level was Roman in age rather than Minoan. The pedons of Karphi 3 and Karphi 4 exhibit truncated buried soils that are likely contemporaneous with the Minoan inhabitation of Karphi. The pedons at Karphi 3 and Karphi 4 exhibit development of an argillic horizon which is absent in the Karphi 2 pedon. Therefore, the context of the lowermost sequence is still open to conjecture.

Karphi 3

Karphi 3 represents the most representative pedon from a transect which was run in a westerly direction from the mouth of a phyllite cove across the Nyssimos plain. The common aspect to every core in the transect was that a paleosol consisting of rounded phyllite gravels with argillans was found in each core. In half of the cores taken, Late Minoan pottery fragments were found directly above the paleosol. It became necessary to test whether there was a real discontinuity in this pedon and whether some aspect of landscape development could be interpreted from this information.

The description of the soil morphology provided the first clues that a discontinuity existed between two depositional episodes (Table 1, Appendix A). An Ap horizon, 23 cm in depth, was described with moist color of 10YR 4/4, weak medium granular to structureless single-grained structure, very friable moist consistence, and a very gravelly sandy loam texture with many rounded and subrounded phyllite fragments. A BA horizon is found 23-28 cm below the surface with the primary difference of a loose moist consistence and a structureless single-grained structure. A cambic horizon is found between 28-52 cm. There is a brightening of this "color-B" horizon with moist colors of 7.5YR 4/6 and dry colors of 10YR 6/4, but similar properties as the horizons above. At 52 cm below the surface, a discontinuity with an associated paleosol was encountered. The primary distinguishing factor was the thin, discontinuous clay coatings on the surface of the phyllite fragments. The 2Bt1b horizon exhibited 7.5YR 4/4 moist and 7.5YR 5/6 dry colors. Texture was still a very gravelly sandy loam with many rounded and subrounded phyllite fragments, the structure was structureless single-grained, and the moist consistence was loose. The 2Bt2b horizon had 7.5YR 5/4 dry and 7.5YR 4/6 moist colors with some weak fine granular structure between the phyllite fragments. The 2Bt3b horizon exhibited 7.5YR 5/6 dry colors and some weak fine granular

structure between the phyllite fragments, but was similar to the description of the upper 2Btb horizons.

The classification of this pedon involved the upper 52 cm and the paleosol was not considered for soil taxonomy. The presence of a cambic horizon, an ochric epipedon and a xeric moisture regime placed this pedon in the Xerochrepts great group. The pedon had a base saturation <60% between the depths of 25 and 75 cm, had an irregular carbon distribution with depth, and had a slope < 25% (Table 3, Figure 11). These characteristics place the pedon in the Dystric Fluventic Xerochrepts subgroup. A loamy skeletal particle size class, a mixed mineralogy, and a mesic temperature regime place this pedon in the loamy skeletal, mixed, mesic Dystric Fluventic Xerochrepts family (Soil Survey Staff, 1990).

The particle size analysis for the Karphi 3 pedon aided in distinguishing between the two sequences separated by the discontinuity (Table 2, Figure 11). The clay content in the upper sequence exhibits a rather irregular distribution with depth. In the lower sequence, the clay content is 11.5% in the 2Bt1b, increases to 15.0% in the 2Bt3b horizon and decreases regularly to 12.4% at the base of the pedon. This indicates illuviation of clay-sized particles in the lower sequence, and therefore, the lower sequence is characterized by an argillic horizon. The fine clay distribution also mirrors this relationship.

The clay-free ratios of FS:(TS+Si) and FSi:(TS+Si) serve to further distinguish the two sequences (Tables 4 and 5, Figure 12). One major difference is that the upper sequence has a lower FS:(TS+Si) ratio in comparison to the lower sequence. The upper sequence has a mean ratio value of 0.130 with a CV of 14.01%, and the lower sequence has a mean ratio value of 0.164 with a CV of 30.15% which are statistically similar. What is particularly interesting is that the clay-free ratios for the fine sand tend to decrease regularly for each sequence. This appears to be a result of two distinct alluvial depositional episodes. The

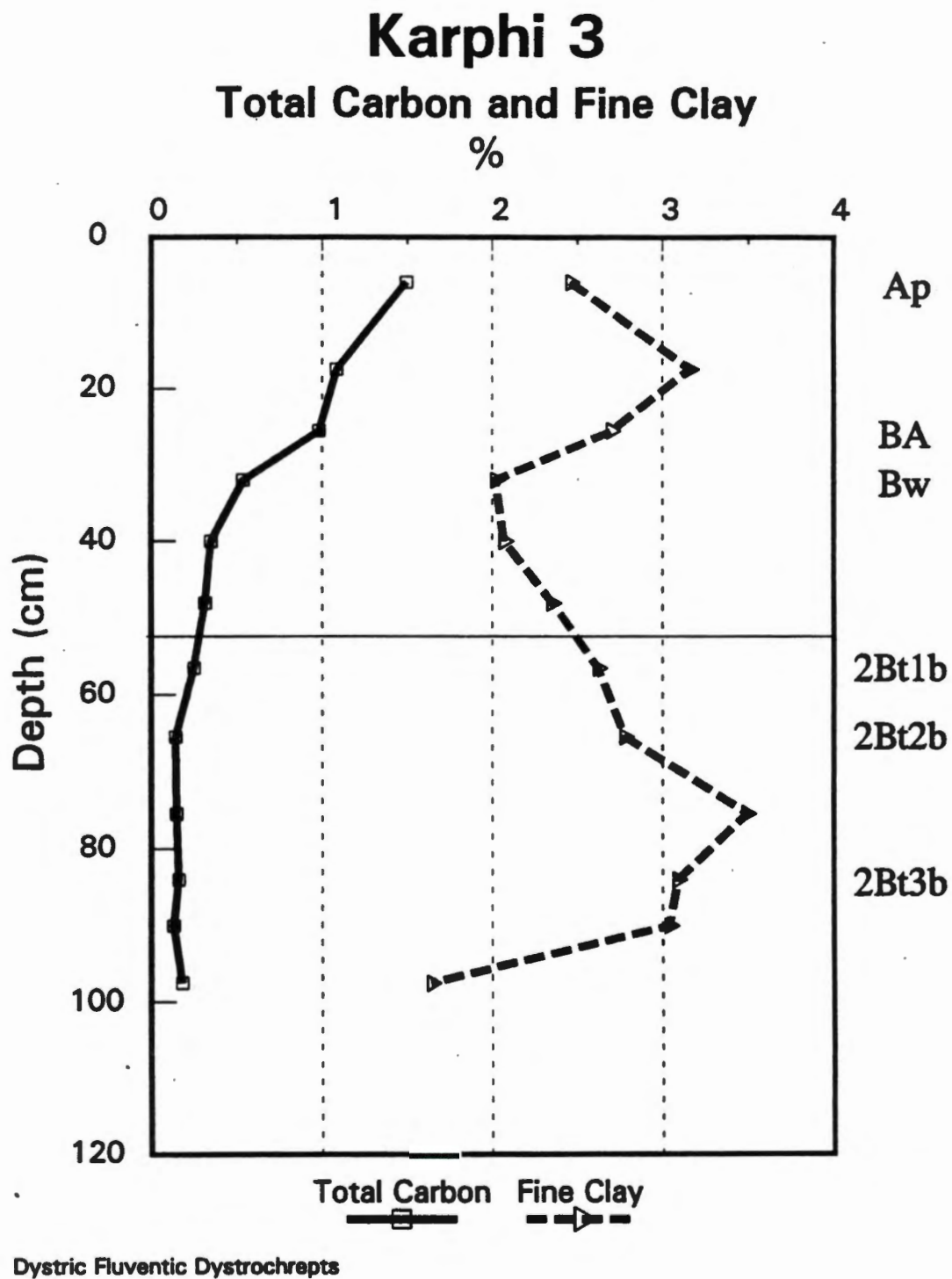


Figure 11. Total carbon and fine clay distribution vs. depth for the Karphi 3 soil pedon.

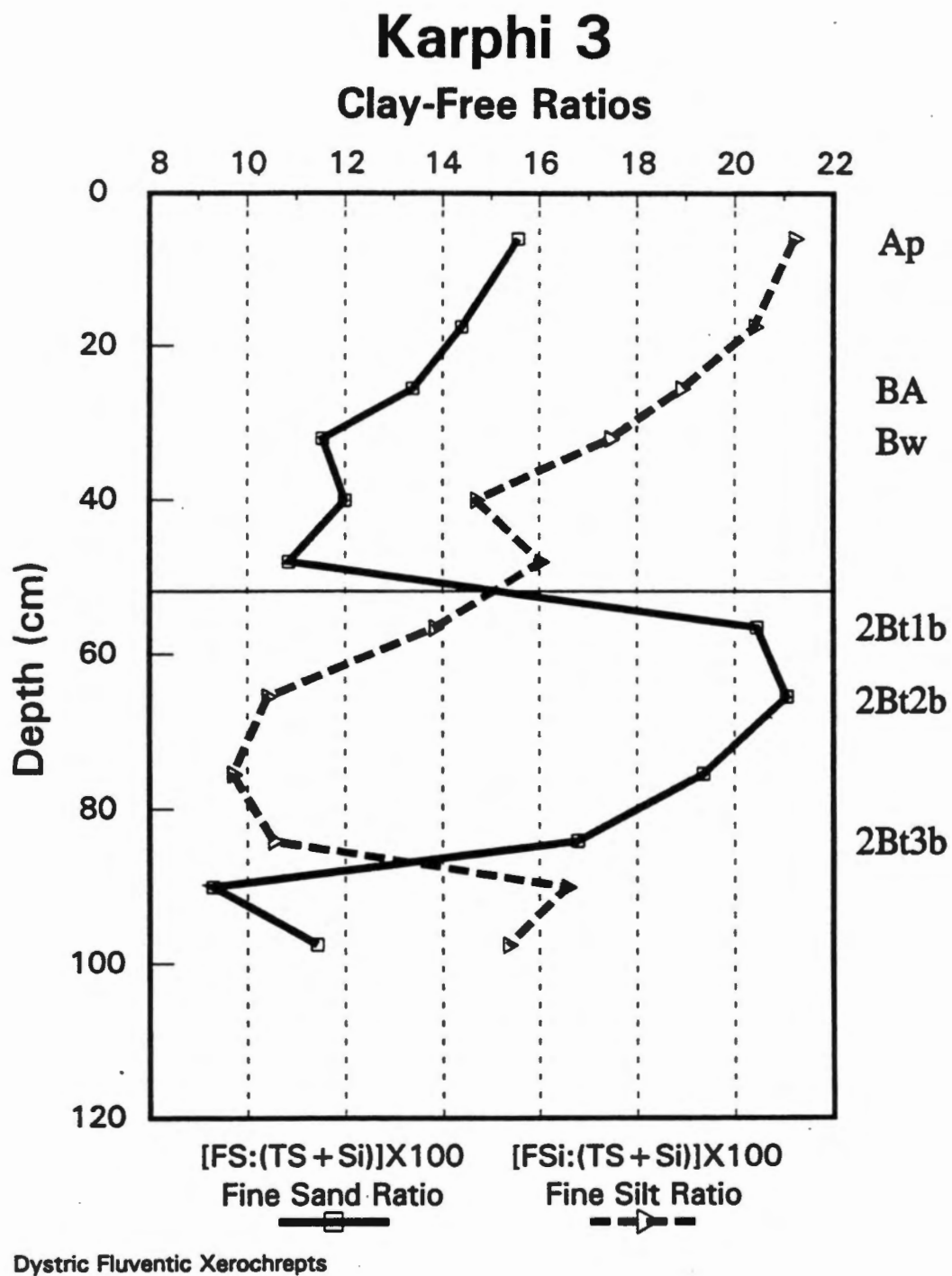


Figure 12. Distribution of clay-free ratios, as determined by particle size analysis, vs. depth for the Karphi 3 soil pedon.

FSi:(TS+Si) ratios show that there is an enrichment of fine silt in the upper sequence. The mean ratio for the upper sequence is 0.181 with a CV of 13.96% and the lower sequence has a mean ratio of 0.127 with a CV of 22.82% which is significantly different. The fine silt ratios decrease somewhat regularly in the upper sequence with depth, however these ratios tend to increase regularly in the lower sequence with depth. There may be an alluvial influence at work here, however, there may be some enrichment of fine silt in the upper sequence by eolian additions.

Weathering indices can also be used to distinguish between the two depositional sequences in Karphi 3 (Tables 4 and 5, Figure 13). The $\text{SiO}_2:\text{R}_2\text{O}_3$ molar ratio shows this difference. The upper sequence exhibits a mean molar ratio of 5.19 with a CV of 18.1%, and the lower sequence exhibits a mean molar ratio of 3.79 with a CV of 18.9% which are significantly different. These data represent evidence that the lower sequence is more weathered in regards to loss of Si and relative gains of Ti, Al, and Fe. Examination of Parker's weathering index shows an opposite trend. The upper sequence has an index that averages 22.0 and a CV of 12.53% and the lower sequence averages 23.8 with a CV of 6.76%. Although these numbers are not significantly different, the general trend is for an enrichment of bases (Ca, Mg, Na, K) in the lower sequence. According to the data on exchangeable bases, there is a slight enrichment of Mg in the lower sequence (Table 3). An examination of the $\text{Fe}_d:\text{Fe}_T$ ratios also show a trend similar to Parker's weathering index. The average Fe ratio in the upper sequence is 0.124 with a CV of 20.84%, and the average for the lower sequence is 0.089 with a CV of 5.01% which are significantly different. This trend shows a greater amount of weathering in the upper sequence. There is a great possibility that the parent material in the upper sequence was weathered prior to deposition in the alluvial fan.

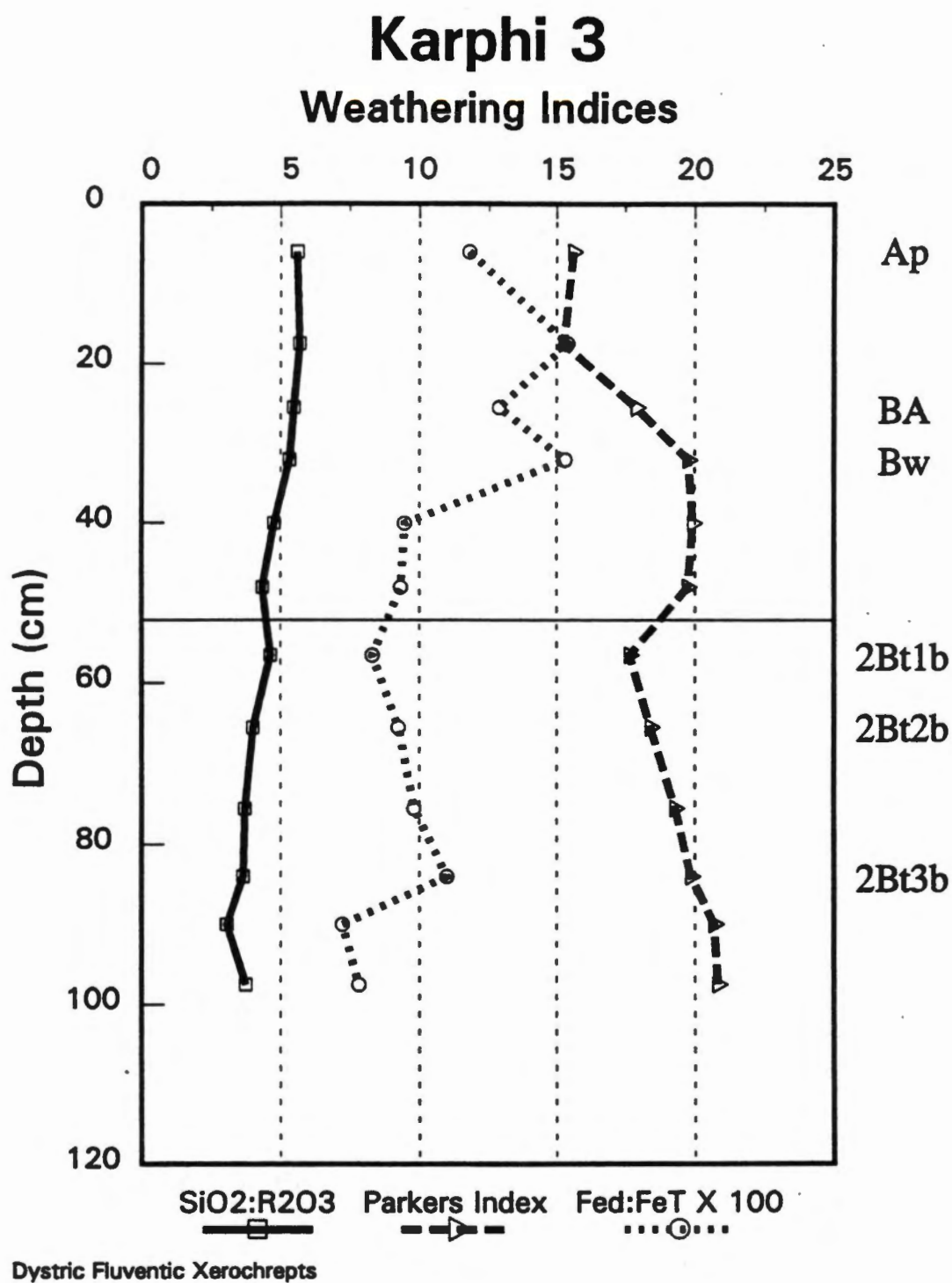
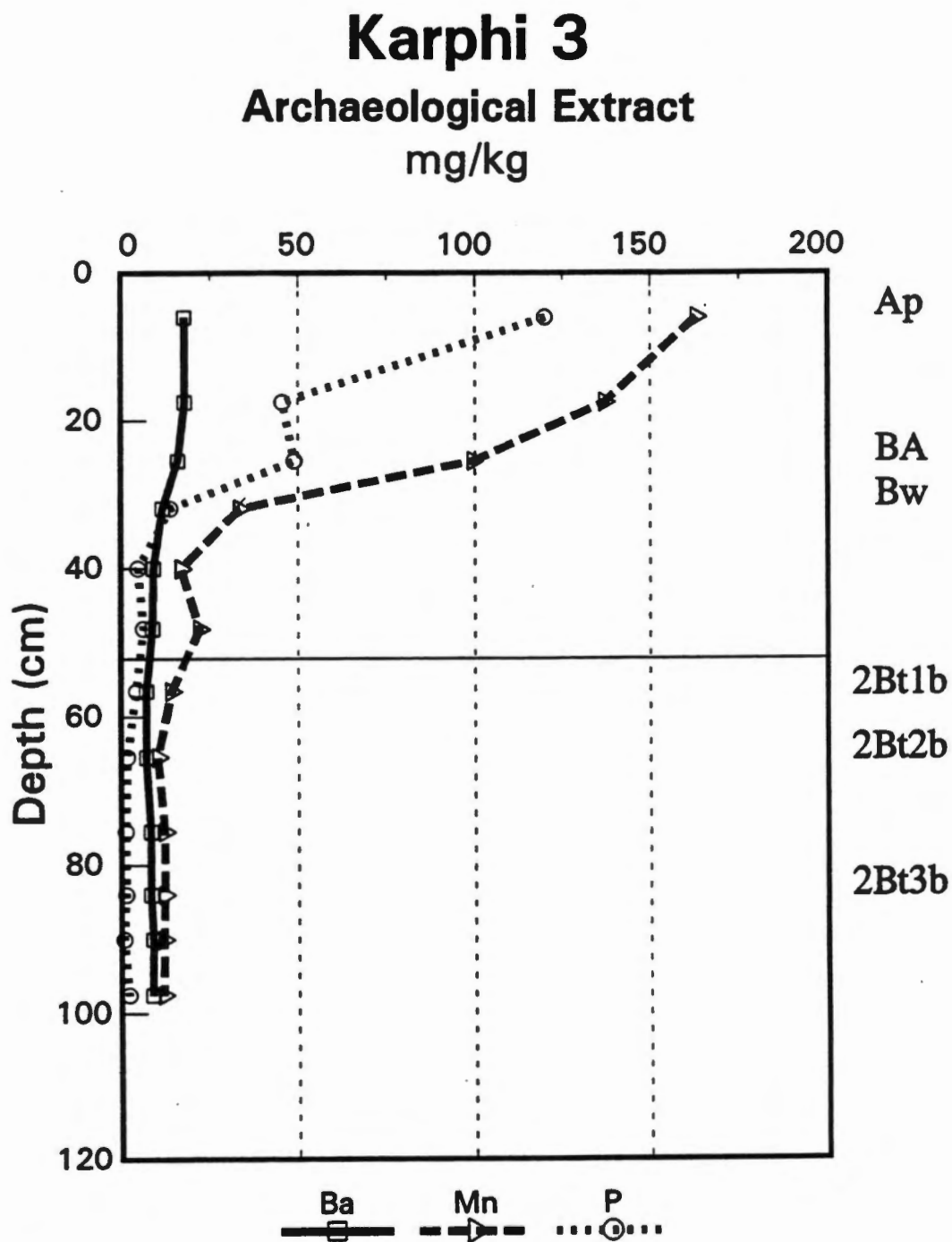


Figure 13. Plot of weathering indices, as determined by total element analysis and citrate-dithionite extraction, vs. depth for the Karphi 3 soil pedon.

There was insufficient zirconium contents in the total element analysis to calculate $\text{TiO}_2\text{:ZrO}_2$ molar ratios for this pedon.

The distribution of extractable elements in this pedon show some relationships that may be related to the presence of the discontinuity (Table 5, Figure 14). The elements Ba, Cu, Mn, P, and Pb are all highly concentrated at the surface of the pedon. Barium decreases regularly from 17.8 mg kg^{-1} at the surface to 7.04 mg kg^{-1} at the 2Bt2b horizon, and increases to 8.84 mg kg^{-1} at the base of the pedon. Copper decreases from 1.93 mg kg^{-1} at the surface to 0.88 mg kg^{-1} at the base of the Bw horizon. Two Cu peaks are 1.28 mg kg^{-1} at the top of the 2Bt1b horizon and another of 1.07 mg kg^{-1} in the 2Bt3b horizon, which may be related to some metal recycling. Manganese decreases from a value of 163 mg kg^{-1} at the surface to 16.9 mg kg^{-1} in the Bw. A definite increase in Mn of 22.0 mg kg^{-1} directly above the 2Bt1b horizon may be the result of some recycling of this metal. A part of a buried A horizon may have been missed when the soil-profile morphology was described. Phosphorus shows a similar pattern with 120 mg kg^{-1} at the surface, a decrease with depth to 4.78 mg kg^{-1} and an increase to 6.27 mg kg^{-1} directly above the 2Bt1b horizon. Increases of Pb and Sr in the lower sequence seems to be correlated with clay content. The high value for Pb (1.70 mg kg^{-1}) and Sr (1.78 mg kg^{-1}) in the lower sequence correlates with the peak clay content. Perhaps some translocation of these metals occur with clay illuviation. This would indicate that with time and argillic development, metals that have been recycled by vegetation may move at a later time, blurring the relative position of the buried surface.

The morphology, physical and chemical characteristics of the pedon at Karphi 3 indicate two episodes of deposition with enough stability in between for a paleosol to develop in the lower sequence. This buried soil exhibits argillic development which means that the soil was stable for a time sufficient for this pedogenic phenomenon. The presence of Late



Dystic Fluventic Xerochrepts

Figure 14. Distribution of extractable elements, as determined by archaeological extraction method, vs. depth for the Karphi 3 soil pedon.

Minoan artifacts on the surface of this paleosol indicates that a period of stability coincided with the time of Minoan habitation. The relative absence of a distinct buried A horizon can be interpreted as an episode of truncation, and subsequent burial by deposition.

Karphi 4

The Karphi 4 pedon is the only soil unit described that was not part of a depositional basin. The Karphi 4 pedon was located in an agricultural terrace that has been subsequently buried by colluvium. These agricultural terraces were cut into the softer phyllite exposure east of the Karphi archaeological site. The presence of Minoan artifacts on the surface of a residual paleosol illustrate that the agricultural terraces were of Minoan origin, and would serve as a representative pedon of a soil with a direct Minoan impact.

The morphology of the Karphi 4 pedon is a phyllite-derived colluvium over a phyllite residuum (Table 1, Appendix A). There are some scattered pieces of limestone on the surface of this phyllite colluvium. The elevation is approximately 1,020 m AMSL and the aspect of the site is 91° East. The pedon is situated on a 52% slope in a 295° northwesterly direction. However, if one follows the terrace contour, the slope is 11% at an azimuth of 152° southeast. The A horizon is 14 cm thick with a moist color of 10YR 4/3, a loam texture, a moderate medium granular structure, an abrupt smooth boundary, and a friable moist consistence. The cambic horizons (Bw1 and Bw2) below the A are somewhat brighter in color and show some development of structure. These horizons have 10YR 4/4 moist colors, weak medium subangular blocky structure, friable moist consistence, and have common angular phyllite and limestone fragments. The texture of the Bw1 horizon is a gravelly sandy loam, and the Bw2 horizon has a very gravelly loam texture. An abrupt smooth lower boundary at 35 cm marks a lithologic discontinuity between the colluvium and the residuum.

A paleosol had developed in the residuum as evidenced by an argillic horizon. The 2Bt1b horizon (35-49 cm) has a moist color of 5YR 4/4, a clay loam texture, a moderate medium subangular blocky structure, a friable moist consistence, and thin discontinuous clay skins. The 2Bt2b horizon has a 5YR 3/3 moist color with common 5YR 5/8 mottles, clay loam texture, moderate coarse subangular blocky structure, friable moist consistence, and thin discontinuous and continuous clay skins. The phyllite residuum grades into phyllite bedrock around 60 cm below the surface. The striking features that distinguish the residuum from the colluvium is the argillic horizon, the redder colors, and the relative lack of coarse fragments. Charcoal samples were collected from root channels at 54 cm below the surface. This charcoal sample was composited with soil samples from the 2Bt1b and the 2Bt2b horizons and a bulk soil radiocarbon sample was submitted. This sample yielded a mean residence time date of $2,730 \pm 50$ yr B.P (Beta-65969). This gives an estimated age of 780 B.C. which would be about 120 years after the abandonment of the site of Karphi. The presence of Late Minoan ceramics and this radiocarbon date are compatible with a Late Minoan context for the agricultural terrace, and confirms the association of these terraces with the archaeological site of Karphi.

The classification of the pedon at Karphi 4 is relatively straight-forward. The upper mantle of 35 cm is more than half the combined thickness of the pedon, and therefore the upper mantle bears the brunt of the classification. The presence of a cambic horizon, an ochric epipedon and a xeric moisture regime places this pedon in the Xerochrepts great group. The pedon does not exhibit any ancillary characteristics to place it in a subgroup other than Typic Xerochrepts. The family level classification is fine-silty, mixed, mesic Typic Xerochrepts (Soil Survey Staff, 1990).

The particle size analysis aided in characterizing the Karphi 4 pedon (Table 2, Figure 15). The most striking aspect is the dramatic increase in clay content between the buried paleosol and the colluvial overburden. The clay content increases from 19.1% in the Bw2 horizon to 34.2% in the 2Bt1b horizon. A decrease to 32.0% in the 2Bt2b horizon may indicate that this soil unit was truncated. The surface horizon for the paleosol is missing and the profile may have been truncated at the point of clay maxima in the argillic horizon. I interpret the argillic horizon in the paleosol as evidence that the landscape may have been relatively stable at the time of Minoan inhabitation of the Karphi site.

Clay-free ratios were used to interpret the distinction between the colluvial overburden and the buried paleosol at Karphi 4 (Tables 4 and 5, Figure 16). The FS:(TS+Si) ratio for the colluvial overburden averages 0.150 with a CV of 9.34% and the average for the paleosol is 0.107 with a CV of 13.34% which are significantly different. This distinction indicates that the two soil units were formed from different depositional regimes and/or parent materials. The FSi:(TS+Si) ratio also exhibits the same effect. This ratio averages 0.261 with a CV of 23.70% in the overburden and averages 0.440 with a CV of 13.71% in the paleosol which is a significant difference. This relationship supports the contention that the lower paleosol is enriched in fine silt in comparison to the colluvial overburden. The fine silt content in the A horizon at the surface is higher at 24.5% than in the Bw1 and Bw2 horizons (16.3% and 20.7% respectively). This may indicate that there is some eolian influence in the upper horizon as there seems to be at other Karphi pedons.

The weathering indices for the Karphi 4 pedon yielded mixed results as far as distinguishing the colluvial overburden from the residual paleosol (Tables 4 and 5, Figure 17). The $\text{SiO}_2:\text{R}_2\text{O}_3$ ratio for the overburden yielded an average of 4.85 with a CV of 18.86% and the residual paleosol had an average of 5.32 with a CV of 20.75% which are not significantly

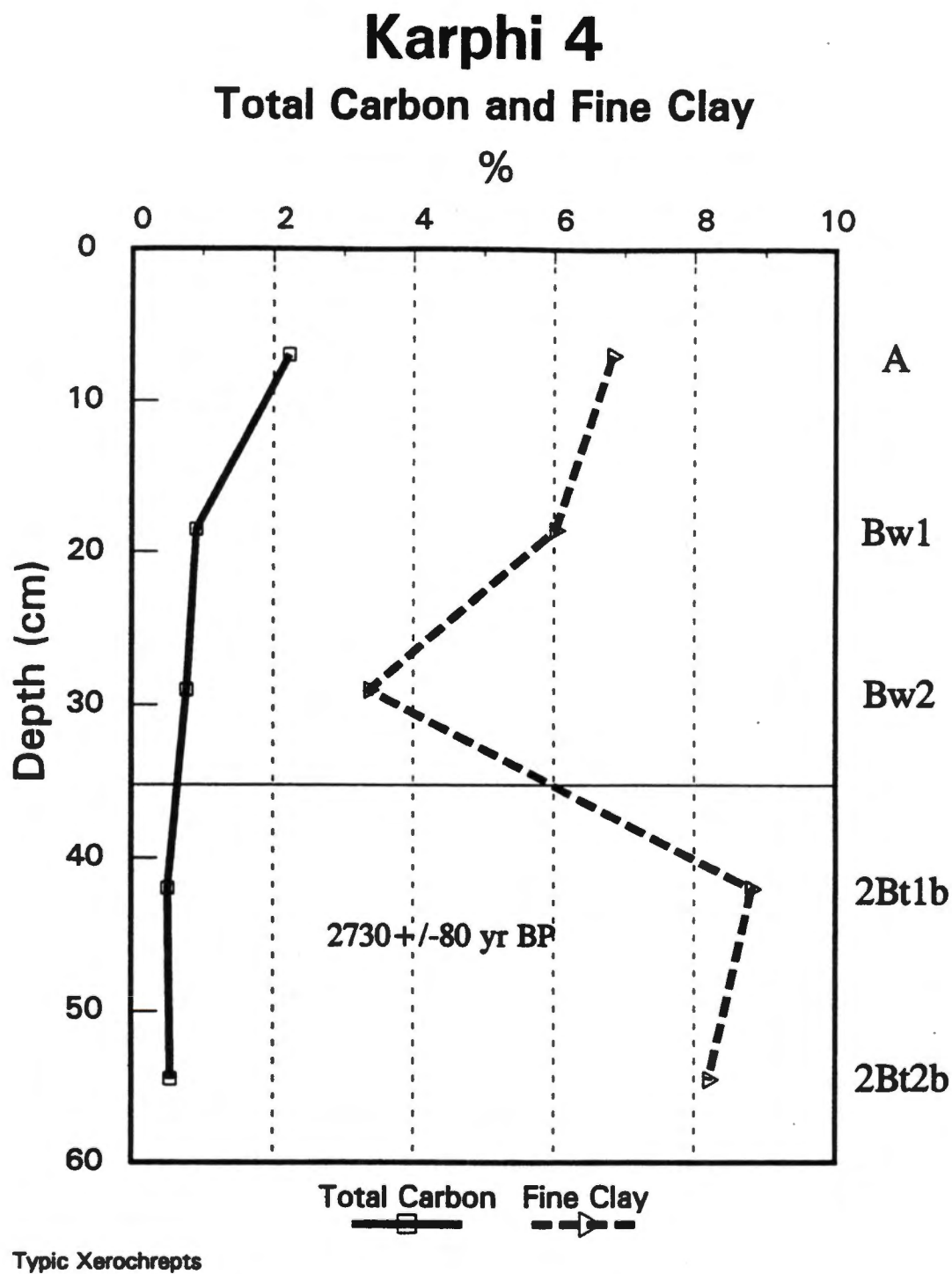


Figure 15. Total carbon and fine clay distribution vs. depth for the Karphi 4 soil pedon.

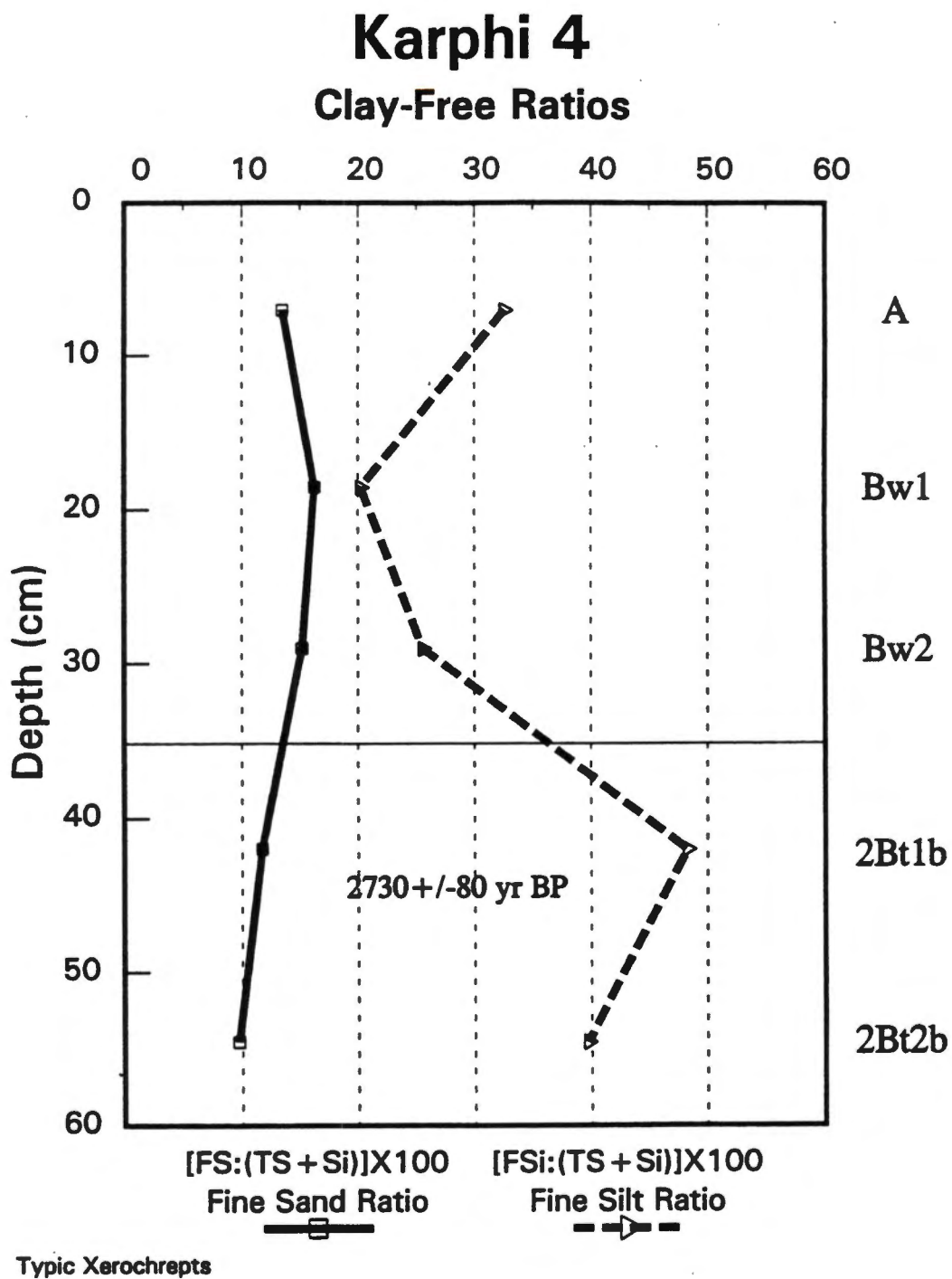


Figure 16. Distribution of clay-free ratios, as determined by particle size analysis, vs. depth for the Karphi 4 soil pedon.

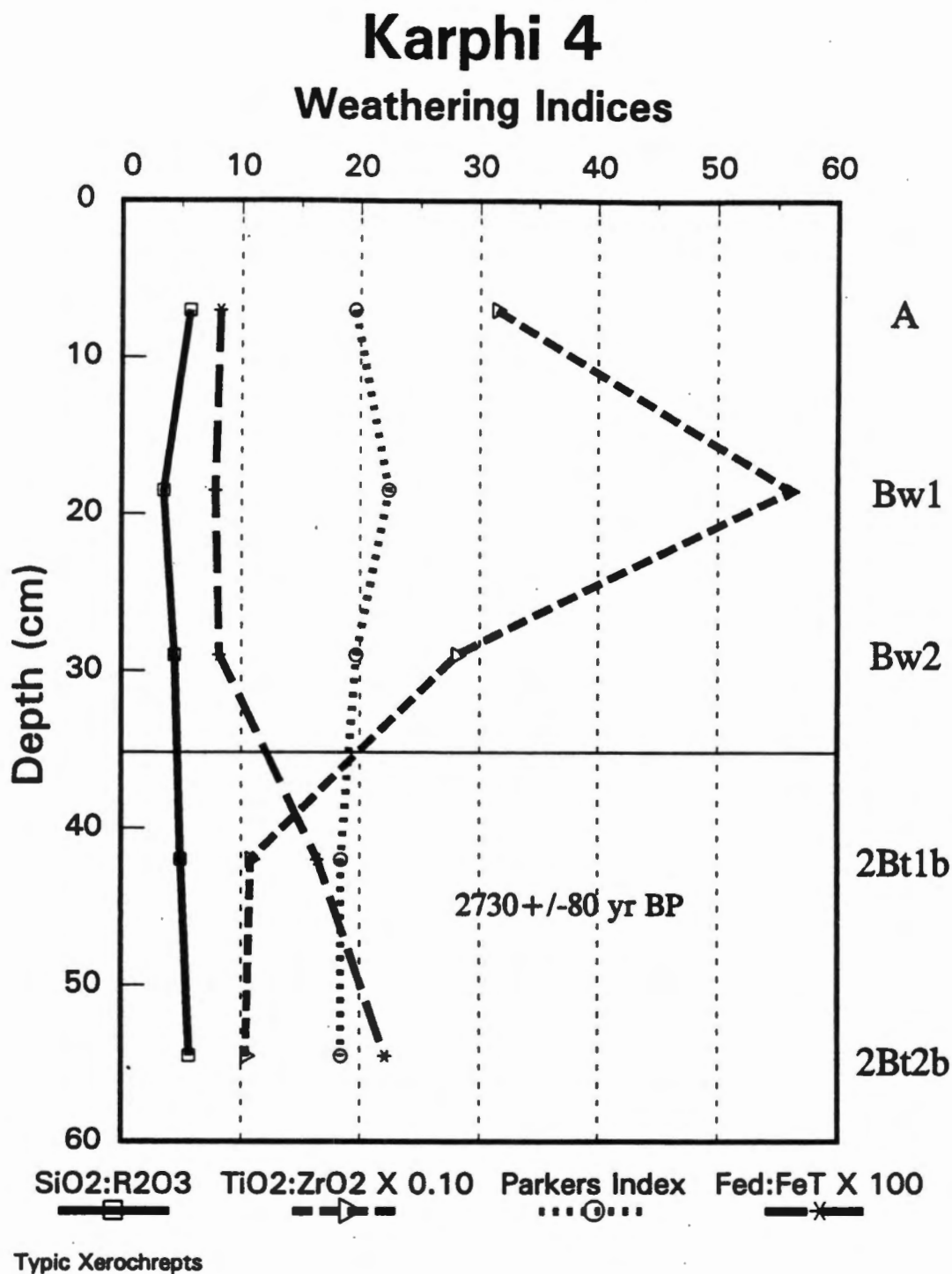


Figure 17. Plot of weathering indices, as determined by total element analysis and citrate-dithionite extraction, vs. depth for the Karphi 4 soil pedon.

different. These figures show that the data overlap and does little to discriminate between these two soil systems, even though the morphology indicates a definite discontinuity. Parker's weathering index shows a significant difference. The overburden had an average index of 24.6 with a CV of 5.09%, and the residual paleosol had an average index of 22.3 with a CV of 2.09%. As predicted, the older soil yielded a smaller index than the younger soil. The $\text{TiO}_2\text{:ZrO}_2$ ratios show a similar pattern. The average index for the overburden is 355.7 with a CV of 32.25%, and the residual soil has an average index of 106.1 with a CV of 2.56% which is a significant difference. As predicted, the index is less for the older paleosol than it is for the colluvial overburden. The $\text{Fe}_d\text{:Fe}_T$ ratios are most helpful in discriminating between these landforms. the colluvial overburden has an average ratio of 0.080 with a CV of 5.18%, and the paleosol has an average ratio of 0.193 with a CV of 17.0%. This relationship signifies that there are more free iron oxides in the paleosol which is consistent with the older age in comparison to the colluvial overburden.

The analysis of extractable elements shows some interesting patterns in the comparison of the colluvial overburden with the residual paleosol (Table 5, Figure 18). Initially, one observes the enrichment of each of the elements studied in the A horizon. For example, extractable P has its highest level at the surface at 31.3 mg kg^{-1} and decreases to 8.89 mg kg^{-1} in the Bw2 horizon. However, extractable P drops below detectable limits in the paleosol which indicates that the evidence for human influence on this terrace has been removed or perhaps eroded downslope. On the other hand, some of the extractable elements observed are enriched in relation to the paleosol. Barium, Cu and Sr have some of the highest levels in the buried paleosol, and are particularly enriched in the 2Bt2b horizon. For example, extractable Sr exhibits an enrichment on the surface of 5.60 mg kg^{-1} , decreases to 3.58 mg kg^{-1} in the Bw2 horizon, jumps to 5.29 mg kg^{-1} in the 2Bt1b horizon, and further

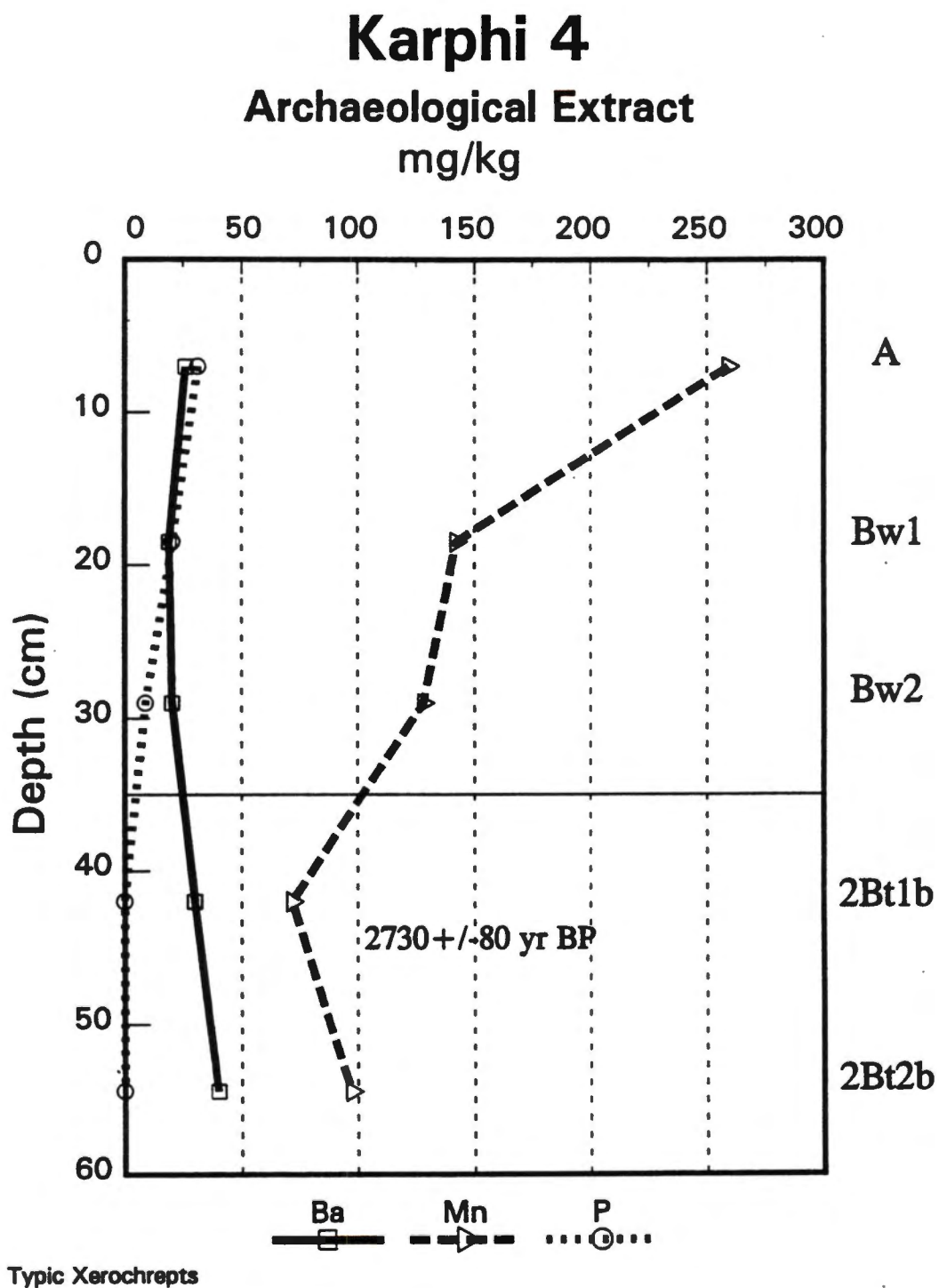


Figure 18. Distribution of extractable elements, as determined by archaeological extraction method, vs. depth for the Karphi 4 soil pedon.

increases to 6.92 mg kg^{-1} in the 2Bt2b horizon. Extractable Mn is not enriched in regard to the paleosol. Because of the observation that there were a number of root channels filled with charcoal in the 2Bt2b horizon, the enrichment of these extractable elements could be related to the recycling of these elements by roots. There may be some mobility of these elements through the profile, and one needs to consider the processes of illuviation with clays or chelating organic acids from vegetative decay as possible sources for error in distinguishing buried surfaces.

The Karphi 4 pedon is an example of the utility in distinguishing between parent materials of differing processes and ages. The presence of a discontinuity and the archaeological association was clear from the analysis of soil properties and morphology. The pattern seems to indicate that the phyllite residuum in which the agricultural terraces were placed was stable at the time of the Late Minoan occupation of Karphi. The redder colors and the presence of an argillic horizon tells one that there was at least several thousand years of stability, and perhaps a moister climate with forest vegetation to produce this soil. The landform became unstable after the Minoan occupation, and an episode of erosion removed the A horizon and part of the argillic B horizon. Later, the site was covered with colluvium derived from the phyllite and limestone upslope which buried the paleosol. Minimal development in the overburden shows only the expression of a cambic horizon.

DISCUSSION

The development of the landscape around the Karphi archaeological site was a function of a number of formational factors. The variability of parent materials did not allow for a thorough comparison between sites. The climate and vegetation had effects on the development of the morphology. The influence of human impact also left its mark on the

landscape. An attempt to correlate these factors can give some indication of how the landscape at Karphi developed over a period of time.

The soils in and around the archaeological site of Karphi are dominated by the terra rossas which are dominant on the hard limestones of the Tripoliza series. These soils are generally well weathered and exhibit advanced morphological development such as illuvial clay horizons, sequioxide enrichment, organic matter accumulation, and enrichment in kaolinite (Khan, 1959; Nevros and Zvorykin, 1936; 1937; Tarzi and Paeth, 1975). It has been speculated that these soils formed during the moister conditions of the last interstadial and are relict in origin (Davidson, 1980; Nevros and Zvorykin, 1936; 1937). In addition, other studies have shown that it is a possibility that the parent material for the terra rossa soils is eolian in origin, and derived primarily from loess deposits from North Africa (Jackson et al., 1982; Nihlen and Solyom, 1986; Rapp, 1984; Danin and Gerson, 1983; Macleod, 1980; Yaalon and Ganor, 1973). In any case, the sinkholes around the Karphi archaeological site have been influenced by the surrounding terra rossa soils of the rims.

The phyllite exposure represents a parent material type that contrasts to the hard and soft limestone landscapes. The soils developed from phyllite are generally silt loam to loamy in texture, acid to very acid in reaction, and usually low in Ca, Mg, and K, particularly at high elevations. This parent material type yields soils that are usually low in biological activity due to potentially toxic levels of Al and Mn (Nakos, 1979; 1983; 1984). One may begin to wonder why this landscape at Karphi was utilized for agricultural terracing. What may be of a great deal of interest is the mechanism of the formation of this phyllite cove. According to Rapp (1984) mountains in south Europe exhibit the formation of nivation hollows on east facing slopes at altitudes greater than 1,000 m. When one examines the phyllite cove, one may consider the possibility that a nivation hollow might explain this particular landform. The

"cirque-like" shape of the hollow, the softer phyllite parent material, the elevation of 1,000 m or more, and the east facing aspect indicate that a nivation hollow may be a possibility and that Pleistocene periglacial phenomena affected the landscape development at Karphi.

The late glacial climate of the Karphi area, and for Crete has been open to conjecture. The eastern Mediterranean was about 5° to 10° cooler between 30,000 and 12,000 yr. B.P. due to the influx of cool, fresh water from receding glacial masses into the Aegean sea (Thiede, 1978; Emiliani, 1955). A gradual warming is indicated from 24,000 yr. B.P. to a climatic optimum at 4,700 yr. B.P. (Buckley et al., 1982). Late glacial vegetation patterns for mainland Greece show a late glacial cold open steppe environment existed (Wijmstra et al., 1990; Turner and Greig, 1975; Greig and Turner, 1974; Turner, 1978). However, some areas in the eastern Mediterranean show that pluvial conditions existed around the time of the late glacial (Farrand, 1971; Bertolani-Marchetti, 1985). The only pollen core reported from Crete shows that an early Holocene pine forest with deciduous oaks dominated the landscape from 10,000 to 7,300 yr. B.P. Modern pollen assemblages indicate that the current Mediterranean conditions had set in by 4,600 yr. B.P. (Bottema, 1980). Stable isotope studies provide documentation that moist conditions existed in the eastern Mediterranean up to 3,000 yr. B.P. (Gat and Magaritz, 1980).

Three of the four pedons at the Karphi site exhibited argillic horizons in the soil morphology. Identification of argillic horizons in the morphology has been used to determine the stability of a soil pedon (Foss, 1977; Bilzi and Ciolkosz, 1977; Hall et al., 1982). Argillic horizons have been shown to develop in moist climates and have been used as indicators of previously moist conditions (Nettleton et al., 1975). It has been estimated that argillic horizons will form in around 3,500 years in a humid (udic) climate (Foss and Collins, 1986). The site of Karphi 1 exhibits an argillic horizon which has been stable at least for 3,000 years

because of the presence of Minoan artifacts on the surface. The Karphi 3 site has an argillic horizon which developed in a gravel deposit. The site of Karphi 4 had an argillic horizon developed in a paleosol derived from phyllite residuum. If the phyllite cove were developed as a nivation hollow, the deposition of gravels in the alluvial plain below may have been triggered by this periglacial event. The spalling of the phyllite material from the cove would have to cease in order to develop a good residual soil. It is therefore suggested that the argillic horizons of these soils were formed during the moister and more stable conditions of the Late Pleistocene/Early Holocene.

Around 3,100 yr. B.P., the Minoans began to settle at the site of Karphi. The evidence of human impact includes a series of agricultural terraces in the phyllite cove of Karphi. The artifact assemblages were found in three pedons; Karphi 1, Karphi 3, and Karphi 4. The artifacts at Karphi 1 were located on the surface of the pedon and the lack of discontinuities in this pedon indicates the soil surface was stable at the time of the Minoan occupation. The artifacts at Karphi 3 were located directly above the discontinuity over a sequence that has an argillic horizon. Extractable element concentrations with depth show there may have been some of the original surface horizon left due to the enrichment of elements known to be recycled with organic matter in a soil profile. The artifacts at Karphi 4 are also located at a discontinuity directly above a paleosol with an argillic horizon. A Late Bronze/Early Iron age radiocarbon date in the Karphi 4 paleosol confirms the Minoan context. This evidence supports the observation that these soils were stable at the time of the Minoan occupation of Karphi.

The pedons of Karphi 3 and Karphi 4 show evidence of truncation with the A horizons of the paleosols missing from the profile record. Subsequent deposition of alluvial and colluvial materials above these paleosols is evidence that the landforms became unstable

at or after the time of human occupation at Karphi. Van Andel et al., (1986), have proposed that the abandonment of agricultural terraces has led to increased erosion in the valleys of the southern Argolid. Perhaps, the truncation of the landforms due to erosion and subsequent deposition was initiated by landscape abandonment. The third paleosol below the second discontinuity at Karphi 2 may have a Minoan correlation, but no artifacts or absolute dates are associated with this unit.

The first discontinuity at the Karphi 2 pedon has yielded a radiocarbon date that would be associated with the Roman period. There was no evidence for Roman activity at the Karphi site although there are a considerable number of Roman period sites in the Lasithi plateau (Watrous, 1982). What could be most interesting in the enrichment of fine silt in the overburden above this Roman age paleosol. Although the sediments at Karphi 1 and in the lower two sequences of Karphi 2 exhibit characteristics that suggest they were derived from the surrounding terra rossa, the upper sequence is the unit most likely influenced by eolian additions. Ritchie et al., (1985) reported the existence of pluvial conditions and a tropical savannah woodland vegetation in north-west Sudan from 8,900 to 4,900 yr. B.P. The onset of desertification may have led to increased eolian activity from the north African deserts which may have led to eolian deposits in Europe. Considering the American dust bowl, and the use of north Africa as a major wheat producing area for the Roman empire, could one speculate that a Roman dust bowl situation was created during the first millennium A.D. and the evidence for this eolian activity is located in a sinkhole at Karphi?

Can the soil evidence from Karphi aid in interpreting the previous climatic conditions? The presence of the argillic horizons may indicate that moister and more stable conditions were present prior to the occupation of Karphi. Using the Minoan artifacts as a marker,

there is no evidence for the development of argillic horizons in stratigraphic sections that were developed after the Minoan occupation. According the Haidouti and Yassoglou (1982) an argillic horizon can develop in a xeric moisture regime in around 3,000 years and a cambic horizon in 900 years. There is no evidence at Karphi that an argillic can form in 3,000 years. The argillic horizons at Karphi were developed prior to 3,000 years ago, and the overburden which may have been deposited during or shortly after the Minoan occupation show little or no argillic development. It is the opinion of this investigation that there is a climatic difference with moister conditions prevalent prior to the Minoan occupation around 3,000 years ago, and drier conditions are evident after the Karphi settlement was abandoned.

CONCLUSIONS

The investigation of discontinuities and paleosols at the Karphi archaeological has helped in developing a landscape chronology, and aided in documenting the effect of human interaction on the landscape. The use of clay-free ratios, molar ratios, and extractable element distributions are effective in documenting the existence of discontinuities and paleosols. Examination of the development of soil morphology from field descriptions and laboratory characterization aid in documenting the pedogenic processes at work. Developing a chronology from artifact distributions and radiocarbon analyses help to place the development of soil morphology with time. The following sequence of events is inferred from the field and laboratory observations of the selected pedons at the Karphi archaeological site.

1. Evidence of Pleistocene periglacial activity at the Karphi site is present in the form of a possible nivation hollow which developed in a sequence of an uplifted phyllite exposure.
2. Alluvium derived from this nivation hollow is deposited in an alluvial fan on the Nyssimos plain, probably near the time of the Late Pleistocene/Early Holocene transition.

3. A soil develops on the freshly exposed phyllite residuum in the phyllite cove, on the surface of the alluvial gravel deposits in the Nyssimos plain, and in the alluvium of a sinkhole located adjacent to the Karphi archaeological site. Soil morphology of argillic horizon development is consistent with the moister, forested regime of the early- to mid-Holocene epoch.
4. Humans inhabit the Karphi archaeological site around 1100-900 yr. B.P. Major influence on the landscape is the construction of agricultural terraces in the phyllite cove. There is evidence of truncation of the landscape with the erosion of A horizons of the soils in the phyllite cove and on the Nyssimos plain. Artifacts deposited on the surface of these soils plus radiocarbon analyses date the agricultural terraces and the paleosol of the Nyssimos plain as Minoan in origin.
5. Extensive erosion of the agricultural terraces buries the Minoan terraces and the paleosol in the Nyssimos plain. This event could have been compounded by agricultural terrace abandonment as well as a change to a drier (or more xeric) climate.
6. Eolian additions to the landscape may have been most dominant during the 1st millennium A.D. The burial of a Roman age paleosol on the Nyssimos plain may have been due to increased eolian activity.
7. Subsequent pedogenesis for soils derived from parent materials that post-date the Minoan levels at Karphi exhibit only development of cambic horizons. This phenomenon may indicate a change in climate to a drier regime than the one in which the paleosols had formed.

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PART 3

**AN INVESTIGATION OF A VERTISOL IN EASTERN CRETE WITH
IMPLICATIONS
REGARDING ARCHAEOLOGICAL SITE PATTERNING**

INTRODUCTION

Soil studies conducted by the Department of Plant and Soil Science, University of Tennessee, in eastern Crete focused on the attempt to locate, describe, and characterize depositional basins in order to understand the dynamics of landscape development over time. One such depositional basin was found in the northern coastal hills northwest of the present village of Kavousi. This landform was a rather large sinkhole with an alluvial fill of considerable depth. Two distinct artifact lines were located in a borrow pit which had been placed in the sinkhole prior to the investigation. It was believed that these artifact assemblages would help to establish the time in which the surface of the alluvium was stable and the amount of deposition which would have occurred between cultural assemblages.

Two artifact lines were encountered in the profile of the borrow pit; one at 30 cm, and one at 110 cm below the present surface. Ceramic sherds dating to the Middle Minoan period were found on the surface of the alluvium. Upon identification of the ceramic sherds found in the profile, the investigation was to learn that the buried ceramic sherds were Middle Minoan period as well. Upon further investigation of this profile, soil morphological features such as deep vertical cracks extending from the surface, intersecting slickensides, and a high clay content were discovered. It was surmised that a Vertisol was encountered and that the artifacts were "redeposited" as a result of the opening and closing of the vertical cracks by the shrink-swell activity for which Vertisols are noted.

Archaeological disturbance processes have been noted for a number of factors. One of these disturbance processes has involved the vertical movement of artifacts through a vertical profile. Therefore, it is the objective of this investigation to examine the soil properties of a Vertisol and document the effect of a pedogenic process in the disturbance of an archaeological context.

BACKGROUND

Vertisols form on a wide variety of parent materials in a great number of climates. Parent materials range from basaltic intrusions, calcareous rocks, gneisses, sandstones, shale, gabbro, diabase, dolerite, serpentine, volcanic ash rich in feldspars, marine and lagoonal clays, and alluvium. The climatic conditions are also quite variable but generally there needs to be some seasonality of precipitation leading to episodes of wetting and drying of the profile (Ahmad, 1983; Soil Survey Staff, 1975). Ahmad outlined some of the more common aspects of the Vertisol profile.

Some of the outstanding features of the profile are the development of minimal horizon differentiation due to pedoturbation, high clay content, pronounced changes in volume with changes in water content resulting in deep, wide cracks in the dry seasons, and very plastic and sticky soil consistency when wet. The profile has a high bulk density when dry and very low hydraulic conductivity when wet, and when it dries some subsidence occurs and cracks develop. As a result of internal stresses due to overburden pressure and swelling and shrinking of the subsoil, a peculiar type of wedge-shaped platy structure develops in which the peds have greater horizontal dimensions than vertical. The upper and lower-ped surfaces instead of being parallel, are inclined away from each other at 20-30°, forming wedges. The particular type of orientation of the clay on the ped surfaces due to stress is known as "slickensides". The physical behavior of Vertisols commonly results in "gilgai" microrelief which consists of slight depressions and mounds, in an irregular pattern or ridges and valleys oriented normal to the slope gradient (Ahmad, 1983, p. 92).

Other features that are common to Vertisols include a generally high cation exchange capacity, montmorillonite as the dominant clay mineral, low organic matter content, and a generally dark color. These soils are usually found at an elevation less than 1,000 m AMSL and on slopes of less than 5%. One of the major characteristics is the self-swallowing aspect of the profile. Shrink and swell conditions tend to cycle materials from the surface into the interior of the profile through the vertical cracks that extend from the surface. This process has been termed "pedoturbation" as is described as follows.

In Vertisols there are two main causes of pedoturbation and development of slickensides. One is the effect of swelling pressures upon wetting and the resolution of horizontal and vertical stress components. The other is the "self-swallowing" concept in which surficial soil material is continuously being incorporated into the subsoil through stress cracks, thus increasing the volume of subsoil material at depth. If some of the main stress cracks are semi-permanent as evidence suggests, the continuous loss of surface soil at the locations in dry seasons and the heaving which occurs in the wet season due to swelling would eventually lead to the development of *gilgai* micro-relief. Swelling pressures at depths below the depth of cracking are not as easily resolved by soil heaving due to greater overburden pressure and in most cases, the formation of slickenside features must be related to lateral swelling pressures which exceed the shear strength of the soil under overburden-pressure confinement (Ahmad, 1983, p. 112).

The effects of pedoturbation and the genesis of Vertisols have been examined in a number of studies. Southard and Graham (1992) measured the ^{137}Cs activity in a Chromic Pelloxerert in the central valley of California. Their findings showed that an irregular distribution of ^{137}Cs activity with depth demonstrated that pedoturbation had occurred primarily in the upper 20-30 cm. Muhs (1982) showed in a chronosequence on San Clemente Island in a Mediterranean climate that soil surfaces >200,000 yr were generally Vertisols and Alfisols with vertic properties; whereas, younger soils generally consisted of Mollisols and Alfisols. The conclusion was that Alfisols and Mollisols with natric B horizons may be the genetic precursors to Vertisols. Graham and Southard (1983) found that a particular non-eroded areas in the Wasach Mountains of northern Utah sported Pellexerolls on the northern slopes while the eroded soils were generally Chromoxererts on the south facing slopes. Datta and Sastry (1981) found that the differences between the Alfisols and Vertisols of the Mysore Plateau of India were primarily a function of the increased montmorillonite content in the Vertisols. Gustavson (1991) found buried Vertisols which had formed in the Late Tertiary paleoclimate of west Texas and Chihuahua Mexico. A former lake basin or playa had been subjected to wet and dry periods, and the presence of gypsum beds and calcic soil horizons indicated that this parent material, dominated by alluvial fans and fan deltas, accumulated in

an arid to semiarid climate. Zein el Abedine et al. (1969) demonstrated a similar pedogenic process was responsible for formation of Vertisols derived from basaltic materials in the Gezira area in the Republic of Sudan.

The vertical movement of artifacts through a soil profile has been documented in a number of studies. Wood and Johnson (1978) identified a number of disturbance processes, based on the evolution model of pedogenesis (Johnson and Watson-Stegner, 1987), which would tend to redistribute artifacts and thus blurring the archaeological context. One of the processes Wood and Johnson (1978) refer to is one directly related to the shrink-swell properties of Vertisols and soils with vertic morphology which is termed "argilliturbation." Many of the studies of vertical artifact movement occur in sandy and silty deposits unrelated to Vertisol development. Lamov and Ranov (1984) noted that the irregular vertical distribution of Paleolithic artifacts in the silty profiles of Tadzhikistan could be explained either by disturbance by burrowing animals or successive occupational layers rapidly buried by loess. Cahen and Moeyersons (1977), in a study of post-Achulean industries at Gombe Point in Zaire, found vertical movement of artifacts in a refitting study in a homogeneous sandy alluvium. The mechanism of artifact movement is believed to be initiated by faunal activity, and artifacts with high movement indices travel through the profile more rapidly than artifacts with smaller movement indices. Hofman (1986) documented vertical movement of artifacts, by refitting analysis, in alluvium of the Duck River in Middle Tennessee. Hofman notes a 40% clay content and massive vertical cracks which extend some 2 m from the surface into the profile. Although a Vertisol was not described, the observations are consistent of a soil with vertic morphology.

SITE SETTING

The Vertisol is located in the coastal hills of the Bay of Mirabello in eastern Crete, and is referred to as Kavousi 3 pedon (Figure 1, Plate 1). The site is a sinkhole located approximately 2 km west of the present village of Kavousi at 35°50'08" E Long, 35°07'37" N Lat. The dimension of the alluvial fill in the sinkhole is approximately 280 m north to south and 410 m east to west, and is roughly triangular in shape (Plate 2). The sinkhole has an outlet to the west into the Bay of Mirabello and the pedon is a little less than 100 m AMSL in elevation. The alluvium in the sinkhole is red, stone free, and fine textured. A borrow pit was placed in the center of the sinkhole, and a maximum depth to bedrock was noted at around 5 m below the surface.

The geology of the area around Kavousi 3 consists of a Triassic age dolomite of the Tripolitza series (Papastamatiou et al., 1959; Creutzburg et al., 1977) (Figure 2). The unit is described as a gray, dark gray, or black dolomite of tidal to shallow-marine origin that is sometimes oolitic or crystalline, usually massive bedded, rarely thick bedded or blocky, and fossils are hardly conserved (Papastamatiou et al., 1959). The sinkhole has been mapped as Holocene alluvium within a karstic basin in this dolomite unit. There is a tectonic contact with the Phyllite-quartzite series to the north, a probable fault to the east which runs at the base of these dolostone and phyllite coastal hills through an area of Quaternary alluvium. The dolostone unit is bounded to the south by an upper Cretaceous dark-grey to black thickly bedded limestone (Papastamatiou et al., 1959)

The climate of Kavousi is a typical Mediterranean climate, and is considered as one of the drier areas of Crete. Precipitation is restricted primarily to the months of September to May with highest precipitation in December and January. Rainfall is rare between the months of May to August. Average rainfall in Ierapetra, about 7 km to the south at sea level,

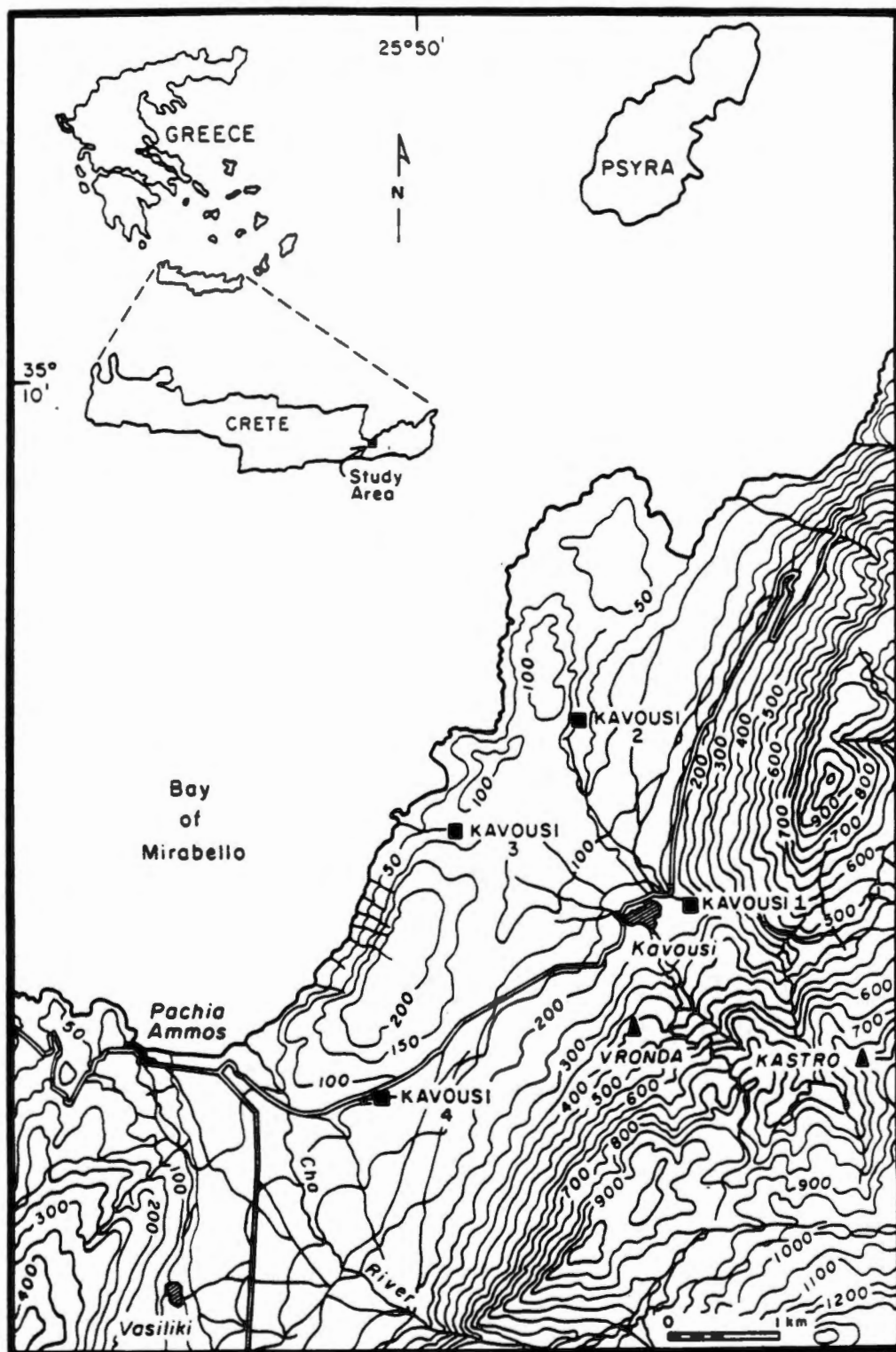


Figure 1. Plan view of the Kavousi area including the Vronda and Kastro archaeological sites and the Kavousi study pedons.



Plate 1. View of the village of Kavousi and the Kavousi 3 pedon and sinkhole, taken from the Kastro archaeological site, facing west.

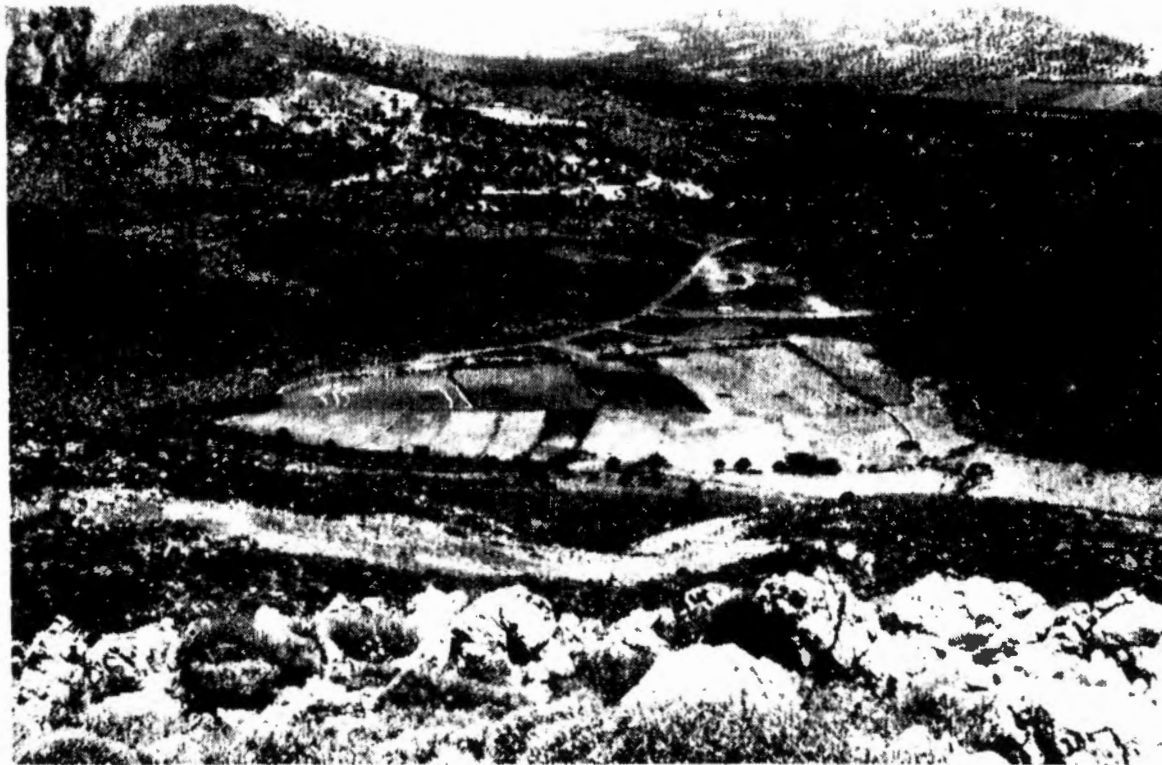


Plate 2. View of the sinkhole at Kavousi 3 with the outlet to the sea at the far left, facing north.

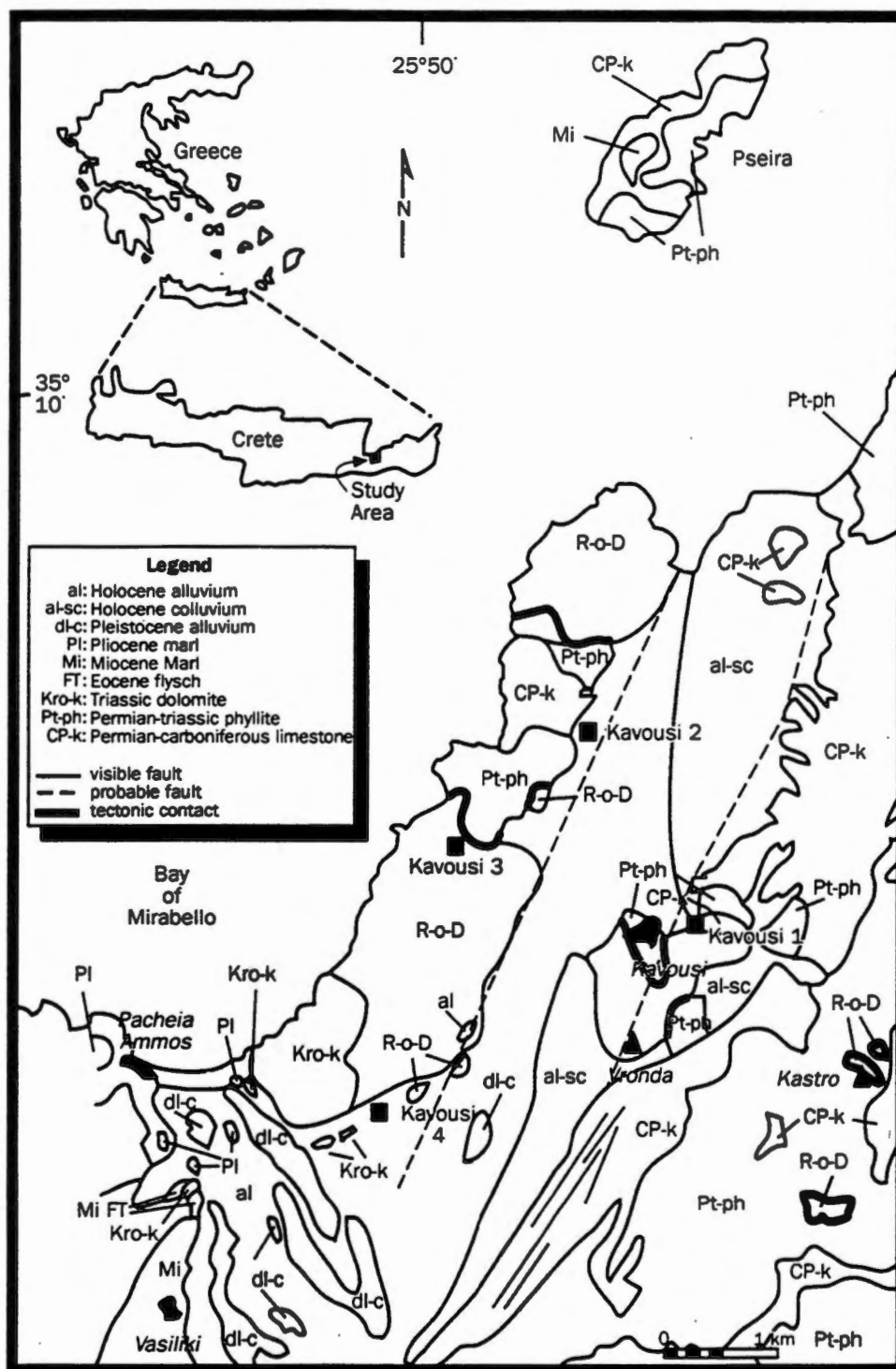


Figure 2. Bedrock geology of the Kavousi study area.

Source: Papastamatiou, J., D. Vetoulis, A. Tataris, J. Borovas, G. Christodoulos, and G. Katsikatsos. 1959. Geologic map of Greece, Ierapetra sheet. Inst. for Geol. Subsurface Res., Athens.

is 380 mm yr⁻¹. Mean monthly temperatures for Ierapetra are 13.2° C in January and 27.2° C in August (Zohary and Orshan, 1965).

The vegetation of the area around Kavousi 3 has been mapped by Zohary and Orshan (1965) as two major plant communities; the Ceratonieto-Pistacietum and the Hyparrhenieto-Thymetum. The Ceratonieto-Pistacietum Lentisci community is a maquis type which occupies the lower slopes of the hills throughout Crete up to 300-400 m in elevation. This association occurs on terra rossa and rendzina soils. The typical plants of this community include *Ceratonia siliqua*, *Pistacia lentiscus*, *Olea europaea* var. *oleaster*, *Rhamnus prunifolia*, *Coridothymus capitatus*, *Hyparrhenia hirta*, and *Calycotome villosa*. *Juniperus phoenicea* occurs as a codominant particularly in the area of northeastern Crete. The Hyparrhenieto-Thymetum comprises garigue and batha (phrygana or low chaparral) communities which occur from sea level to 300 or 400 m AMSL. Species which are typical of this association are *Cytisus creticus*, *Anthyllis hermanniae*, *Genista acanthoclada*, *Euphorbia characias*, *Euphorbia acanthothamnus*, *Cistus parviflorus*, *Phlomis lanata*, *Phlomis cretica*, *Phlomis fruticosa*, *Ballota pseudodictamnus*, *Hypericum empetrifolium* and some species of *Teucrium* and *Origanum* (Zohary and Orshan, 1965).

Archaeological sites which were contemporaneous with the artifacts found in the Kavousi 3 pedon include a number of Middle Minoan and Late Minoan Period sites. Middle Minoan to Late Minoan I sites are located at Pseira (an island 6 km north of Kavousi 3), Vasiliki (village 5 km south of Kavousi 3), and Gournia (archaeological site 5 km west of Kavousi 3). The sites in the Kavousi study area of Vronda and Kastro were inhabited during the Late Minoan IIIc Period and later and may not have contributed to the ceramic assemblage found in the Kavousi 3 sinkhole although Vronda may have been inhabited during the Middle Minoan Period.

MATERIALS AND METHODS

Field Methods

The sinkhole at Kavousi 3 was deliberately sought out for sampling purposes. A borrow pit approximately 50 m x 50 m had been placed in the center of the alluvial deposit of the sinkhole by a local brick-making company. Two continuous profiles with a north and an east facing aspect had been exposed with up to 3 m of depth from the surface to the base. A 1 m profile section of the east facing exposure was selected. This pedon was sampled and described according to methods outlined in the Soil Survey Manual (Soil Survey Staff, 1984). Artifacts which were located in the 1 m section of the profile were mapped *in situ* with the relative depth and orientation of the ceramic sherds noted (Figure 3). Upon return to the site the following year, a deeper section of the borrow had been excavated exposing an area of redoxymorphic features. This was described and carbonate nodules were collected from the new exposure. Samples of terra rossa and limestone were collected 50 m south of the edge of the alluvium up the rim and 50 m west of the alluvium up the rim of the sinkhole. Samples from the profile were collected and double bagged for shipment to the soil characterization laboratory in the Department of Plant and Soil Science, University of Tennessee, Knoxville.

Laboratory Methods

Soil samples collected from Crete were first subjected to a freezing treatment of -80° C for 48 hrs to destroy any organisms which may have been present. The samples were removed from the freezing treatment and allowed to thaw. Representative pedis were collected from each sample and set aside. The remaining samples were then air dried and ground to pass a 10 mesh sieve (2.00 mm limiting diameter). The fraction > 2.00 mm was

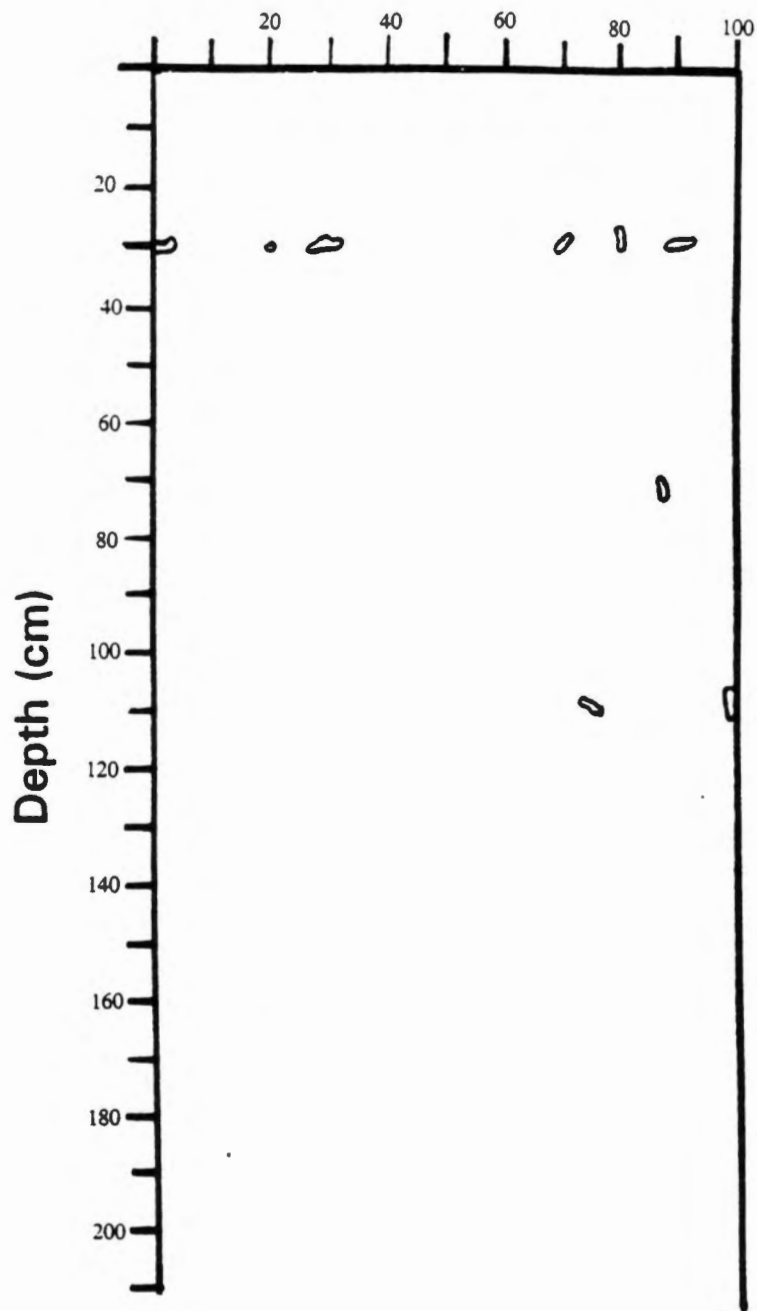


Figure 3. Distribution of Minoan ceramic artifacts in a 1 m x 2.1 m profile section at the Kavousi 3 soil pedon.

collected and weighed. The fraction ≤ 2.00 mm was quartered and one quarter was ground to 60 mesh and finer.

Total carbon content for each sample was determined by using a LECO CR-12 carbon analyzer on the ≤ 60 mesh portion of the sample. Each sample was tested with 1 M HCl for presence of inorganic carbon (CO_3^{2-}). The organic carbon content in each sample was determined by use of the Walkley-Black method (Nelson and Somers, 1986). Soil horizons with high organic carbon contents are believed to have been surface horizons into which plant material such as roots had been incorporated. Subsurface horizons with high carbon contents are believed to represent former stable surfaces that had been buried by additions of new parent material. Carbon analysis has been used to locate and delimit buried archaeological sites on former stable surfaces (Stein, 1982; Ahler, 1973; Foss, 1977).

Measurements of pH were made on each sample using a pH meter equipped with a chloride combination electrode. A 1:1 ratio of soil to distilled-deionized water, and a 2:1 ratio of 0.1 M CaCl_2 to soil were used in the preparation, and pH's were measured according to the procedure outlined in McLean (1986). The measurement of pH can provide some insight into the relative weathering status of a soil sample which can give the relative base saturation of the sample. Because of the relationship between high base saturation and optimal preservation of archaeological materials, pH measurements have been used in several archaeological studies (Deetz and Dethlefsen, 1963; Gordon and Buikstra, 1981).

A particle size analysis was performed on all samples using a combination of sand sieving and sedimentation techniques as outlined in Gee and Bauder (1986). Samples with $\geq 1.0\%$ organic carbon were pretreated with a 30% H_2O_2 solution, and samples which reacted to 1 M HCl were treated with a 1 M Na-acetate solution buffered at pH 4.5. Approximately 10 g of the < 2.00 mm fraction of each sample was dispersed in a Na-

hexametaphosphate--Na-carbonate solution, and the sand size fraction of each sample was separated from the smaller fractions by wet sieving. The sand fraction was dried and fractionated by dry sieving into very coarse sand (VCoS, 2.00-1.00 mm), coarse sand (CoS, 1.00-0.50 mm), medium sand (MS, 0.50-0.25 mm), fine sand (FS, 0.25-0.10 mm), and very fine sand (VFS, 0.10-0.050 mm) fractions. The remaining silt and clay size fractions of each sample were retained in a 1000 ml capacity sedimentation cylinder and placed in a water bath. Pipette analysis was performed on these samples to determine their coarse silt (CoSi, 50-20 μm), fine silt (FSi, 20-2 μm), and clay (C, <2 μm) fractions. A combination of centrifugation and pipette methods were used to determine the fine clay fraction (FC, <0.2 μm). Distribution of clay-size particles with depth was used as a weathering indicator for this study (Foss, 1977; Bilzi and Ciolkosz, 1977; Hall et al., 1982). Data from the particle size analyses were also converted to clay-free ratios to document changes in depositional regimes and assess the uniformity of the parent material (Raad and Protz, 1971; Thompson et al., 1981; Asady and Whiteside, 1982; Ajmone Marsan et al., 1988). The clay-free ratios chosen for this study included: 1) Fine silt/(total sand + total silt) [FSi:(TS+Si)], and 2) Fine sand/(total sand + total silt) [FS:(TS+Si)].

Elemental analyses were performed with the aid of a Thermo Jarrel Ash Model 61 Inductively Coupled Argon Plasma Atomic Emission spectrometer (ICAP-AES), which has the capacity for analyzing 26 different elements simultaneously. A total element analysis was performed by digesting about 0.2000 g of the <60 mesh sample in an aqua-regia/concentrated hydrofluoric acid/microwave oven treatment neutralized with boric acid according to the procedure outlined by Nadkarni (1984). Extractable element analysis was performed by using approximately 2 g of the <2 mm fraction which was extracted with a 5:1 HCl:HNO₃ solution adjusted to 0.75 M according to a procedure outlined in Lewis et al. (in press).

The elements from the total analysis were converted to weight percentage oxides. These oxides were then converted to molar ratios and molar indices which were used as weathering indices. These indices will theoretically decrease with increased weathering or age of the sediment. The indices chosen for this study include: 1) $\text{SiO}_2/\text{R}_2\text{O}_3$, where R_2O_3 is equal to Fe_2O_3 (determined by citrate-dithionite extraction) + Al_2O_3 (total) + TiO_2 (total) (Birkeland, 1984), 2) Parker's Weathering Index which is defined as $100(\text{K}_2\text{O}/0.25 + \text{Na}_2\text{O}/0.35 + \text{CaO}/0.7 + \text{MgO}/0.9)$ where the values in the denominator refer to the relative strengths of the cation-oxygen bond (Parker, 1970), and 3) $\text{TiO}_2:\text{ZrO}_2$ (Chapman and Horn, 1968; Rostad et al., 1976).

Free iron oxides were determined using the citrate-dithionite procedure as outlined by Holmgren (1967). Concentrations were determined by atomic absorption spectrophotometry using a Perkin-Elmer Spectrophotometer. Free iron oxides are considered iron compounds which are not associated with silicate iron. The generalized reaction in soils is defined as:



where silicate iron (usually ferrous iron) is oxidized into ferric iron form which is most easily described by the Free Iron (Fe_d): Total Iron (Fe_T) ratio (Schwertmann, 1985). A number of studies have demonstrated a positive correlation between the amount of free iron oxides in a soil system and the relative age of the system (Blume and Schwertmann, 1969; Alexander, 1974; Singer, 1977; Torrent et al., 1980; Arduino et al., 1986).

A statistical analysis was performed on the samples from each pedon. Each pedon was analyzed as a unit or as a series of formations within the pedon. Where applicable, these formations were compared with the terra rossa samples collected from the rims of the appropriate sinkholes. A group means analysis of variance procedure was utilized to

determine whether the means of the various indices between groups were significantly different. The variables chosen for these comparisons included the molar ratios of $\text{SiO}_2\text{:R}_2\text{O}_3$ molar ratio, the $\text{TiO}_2\text{:ZrO}_2$ molar ratio, Parkers weathering index, and the $\text{Fe}_d\text{:Fe}_T$ free to total iron ratio. The clay-free ratios of $\text{FS:}(\text{TS}+\text{Si})$ and $\text{FSi:}(\text{TS}+\text{SI})$ were also used. The Ryan-Einot-Gabriel-Welsch Multiple Range test was used to compare the means in each pedon using the PC-SAS® statistical software package. This all pairwise comparison controls for the Type I experimentwise error rate. Because duplicates were analyzed for each sample for the total element analysis, the number of degrees of freedom for the molar ratios are double those for the clay-free ratios. The $\alpha=0.05$ significance level was selected for this analysis.

Extractable elements were used to document whether there were buried surfaces in the pedons studied. The elements Mn, Cu, Zn, Sr, Ba, and P were used for this procedure. Elements such as Mn, Cu, and Zn are common plant nutrients. Barium and Sr can be extracted from the soil solution by mass flow or diffusion into root cells and recycled by leaf, root, and other plant tissues. These metals can be retained in the surface of a soil by processes such as adsorption onto clay mineral surfaces, adsorption by organic matter, and complexation by residual organic compounds. Increased concentrations of these extractable metals in subsurface horizons can be indicative of former stable surfaces which are now buried (Foss et al., 1990; 1991; Foss, 1990). Phosphorus is a major component of organic materials and can be concentrated in the soil system due to human activity (Eidt, 1977; Proudfoot, 1976; Sjoberg, 1976; Mattingly and Williams, 1962; Griffith, 1980).

Cation exchange capacity (CEC) and base saturation were determined using NH_4OAc pH 7 and NaCl vacuum-extraction replacement procedures. The <2 mm fraction of soil sample was vacuum extracted with a 1 M NH_4OAc solution adjusted to pH 7, and the

extractant was analyzed for extractable Ca and Mg using atomic absorption. Extractable Na and K were analyzed by flame emission. After two ethanol washes, the 10% NaCl-0.005 M HCl replacement solution was used for extraction and the extractant was distilled and titrated with 0.01 M HCl to determine NH_3 concentration and, therefore, measure the CEC of the soil sample (Roads, 1986; Thomas, 1986; Hammer and Lewis, 1987). This procedure was performed primarily for classification purposes.

Clay mineralogy was analyzed on samples in the mineralogical control section of the soil pedon. Samples of clay were collected from the particle size analysis procedure. The clay sample was split with one part saturated with KCl solution and the other saturated with MgCl_2 solution and both samples were treated with sodium citrate-dithionite to remove the iron oxides. The clay samples were subjected to a filter peel technique and placed on a glass slide according to a procedure outlined by Drever (1973). The K-saturated slides were subjected to air dry, 105° C, 300° C, and 550° C treatments. The Mg-saturated slides were subjected to air dry and ethylene-glycol treatments. X-ray diffraction analysis was performed on a Scintag XDS 2000 X-ray diffractometer at the Oak Ridge National Laboratories in a procedure outlined by Whittig and Allardice (1986).

RESULTS

The morphology at Kavousi 3 represents a profile of relatively deep alluvium which was first described in the summer of 1991 (Table 1, Appendix A, Plate 3). There is an Ap horizon at the surface which extends from the surface to 30 cm. The moist color is a 2.5YR 3/4 and the dry color is a 2.5YR 3/6. The horizon exhibits moderate medium granular and weak medium subangular blocky structure. The lower boundary is clear and smooth and the moist consistence is friable. The texture of the Ap as well as for the entire profile is a clay. The Bw horizon (30-40 cm) has a moist color of 2.5YR 3/6, a weak medium subangular

Table 1. Morphology of the Kavousi 3 soil pedon.

Horizon	Lower Depth	Color		Texture	Structure	Boundary	Consistence	
		Dry	Moist				Moist	Dry
cm								
Kavousi 3								
Ap	30	2.5YR 3/6	2.5YR 3/4	C	2mgr 1msbk	cs	vfr	fr
Bw	40	2.5YR 4/6	2.5YR 3/6	C	1msbk	n.d.	fr	fi
Bss1	100	2.5YR 4/4 2.5YR 3/6 2.5YR 4/6	2.5YR 3/4	C	2mabk 1cpr 1mabk	n.d.	fr	vfi
Bss2	120	2.5YR 4/6	2.5YR 4/4	C	3vcpr	n.d.	fi	vfi
Bss3	200	2.5YR 4/6	2.5YR 3/6	C	3vcpr	cs	fi	vfi
Bk	210+	2.5YR 3/6	10R 4/6	vg C	2csbk	n.d.	fr	fi



Plate 3. The soil profile of Kavousi 3, facing south.

blocky structure and a friable moist consistence. The lower boundary is gradual and smooth. The Bss1 horizon extends from 40-100 cm. The moist color is a 2.5YR 3/4. The structure of this horizon ranges from moderate and weak medium angular blocky to weak coarse prismatic. The consistence is firm moist and very firm dry. There are a few slickensides which appear in this horizon. The Bss2 horizon (100-120 cm) has a moist color of 2.5YR 4/4, a very coarse prismatic structure, a diffuse smooth boundary and a firm moist consistence. Large slickensides are noted in this horizon (Plate 4). The Bss3 horizon (120-200 cm) has a 2.5YR 4/6 moist color, a strong very coarse prismatic structure, a diffuse smooth lower boundary, and a firm moist consistence. Large cracks, slickensides, and pressure faces are noted in the horizon. The Bk horizon (200-210+ cm) is distinguished from the rest of the profile by the presence of common fine and medium carbonate nodules in the matrix. The moist color is a 10R 4/6, with a moderate coarse subangular blocky structure, and a friable moist consistence. There was evidence of clay flows between the carbonate nodules which was noted as not being pedogenic but the effect of flocculation in the portion of the profile with high cation concentrations. Field tests with 1 M HCl showed that this was the only horizon in the profile which exhibited a reaction to the acid.

When the investigators returned to the sinkhole in 1992, it was discovered that new and deeper areas of the borrow pit had been excavated. A deeper portion of the pit had revealed a small exposure in the center of the borrow pit which exhibited redoxymorphic features. This vertical exposure was located 25.9 m and 40° east from the Kavousi 3 pedon. The profile was 355 to 425 cm below the surface of the alluvium in the sinkhole. There were tongues of gleyed material around the angular blocky peds. Carbonate nodules about 3 cm in diameter were recorded at 425 cm below the surface. The dominant moist color of the matrix was 10R 3/6 with common 10YR 7/2 (about 20% material around peds), and few



Plate 4. Slickensides from the Kavousi 3 pedon at 110 cm below the surface.

7.5YR 5/8 (about 5% of matrix) mottles. Soil properties include a strong medium angular blocky to prismatic structure, and a clay texture. Carbonate nodules comprise about 5% of the matrix. Limestone fragments were found across the surface of the excavated area, but none could be found in profile. The nodular, rounded morphology and the hard consistence of these nodules are similar to a polymorphous type described by Gladfelter (1992) (Plate 5). This carbonate nodule is formed by migration of interstitial groundwater in the capillary fringe of the vadose zone in alluvial and marl deposits. Groundwater was noted at places in the bottom of the excavation. It seems that the carbonate nodules formed above a fluctuating water table at the base of the Kavousi 3 pedon, and are geogenic rather than pedogenic in origin. Similar redoxymorphic features have been found in red alluvium (Kokkinopilos formation) in the area of a fluctuating water table in Epirus, Greece (Macleod and Vita-Finzi, 1982).

Some of the chemical characteristics from Kavousi 3 aid in the interpretation of the soil morphology (Table 2, Figure 4). Organic carbon exhibits a decrease from 1.26% at the surface to 0.19% at the base at 210 cm below the surface, with two minor peaks at 80-100 cm and 160-180 cm. The distribution of inorganic carbon (total carbon - organic carbon) exhibits a somewhat irregular distribution from the surface to 180 cm (mean = 0.09%), but increases dramatically to 0.22% at 180-200 cm and 2.48% at 200-210 cm. This is interpreted as the precipitation of carbonate above the capillary fringe of the water table, perhaps due to some evapotranspiration during the dry season. Exchangeable Ca exhibits a similar pattern. A somewhat irregular distribution of exchangeable Ca (mean = 19.8 cmol_c kg⁻¹) is observed from the surface to 180 cm. A dramatic increase in Ca is found at 24.9 cmol_c kg⁻¹ at 180-200 cm and another increase at 42.6 cmol_c kg⁻¹ at 200-210 cm below the surface. Exchangeable Na shows a different, but important pattern. There is a gradual increase of exchangeable Na



Plate 5. Redoxymorphic features and carbonate nodules (note point of knife) observed in an open pit near the Kavousi 3 pedon.

Table 2. Chemical properties including carbon fractions, exchangeable cations, and pH of the Kavousi 3 soil pedon.

Horizon	Lower Depth cm	Inorganic Carbon	Organic Carbon	Total Carbon	NH ₄ OAc Extractable Cations					pH	
					Ca	Mg	Na	K	NH ₄ OAc CEC	Base Saturation	1:1 H ₂ O 2:1 CaCl ₂
			%				cmol _e kg ⁻¹			%	
Ap	30	0.06	1.26	1.32	19.8	11.1	1.03	1.73	28.3	119	7.89
Bw	40	0.11	0.67	0.78	20.6	14.1	1.19	0.74	30.2	121	8.28
Bss1	60	0.15	0.58	0.73	20.4	13.0	1.31	0.68	29.4	121	8.21
	80	0.11	0.42	0.53	19.7	11.3	1.53	0.61	29.7	112	8.14
	100	0.03	0.47	0.50	19.8	10.7	1.82	0.63	29.4	112	7.99
Bss2	120	0.08	0.35	0.43	19.4	9.7	2.50	0.65	28.9	112	8.08
Bss3	140	0.11	0.29	0.40	20.2	10.2	3.48	0.67	28.2	123	8.05
	160	0.08	0.28	0.36	19.4	11.6	5.22	0.70	28.6	129	7.65
	180	0.04	0.30	0.34	18.5	11.4	4.65	0.67	28.8	122	7.92
	200	0.22	0.21	0.43	24.9	11.2	4.38	0.64	28.3	145	8.20
Bk	210	2.48	0.19	2.67	42.6	10.8	3.47	0.46	25.2	227	8.30
Terra Rossa	5	n.d.	n.d.	3.62	29.8	13.2	1.06	2.29	32.9	141	7.90
Terra Rossa	5	n.d.	n.d.	4.51	35.7	12.6	1.17	2.12	30.9	167	7.80
											7.50

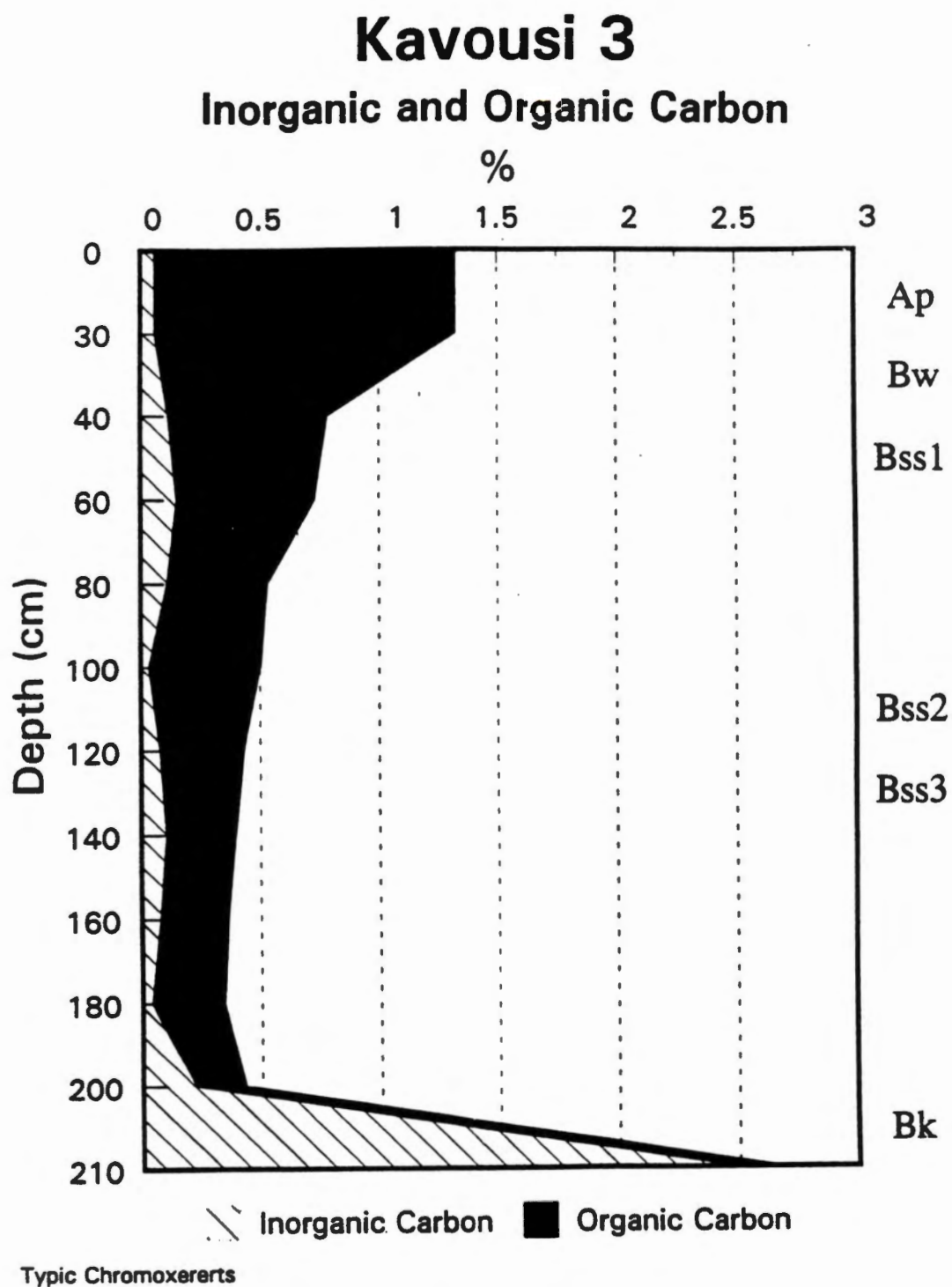


Figure 4. Distribution of inorganic and organic carbon vs. depth for the Kavousi 3 soil pedon.

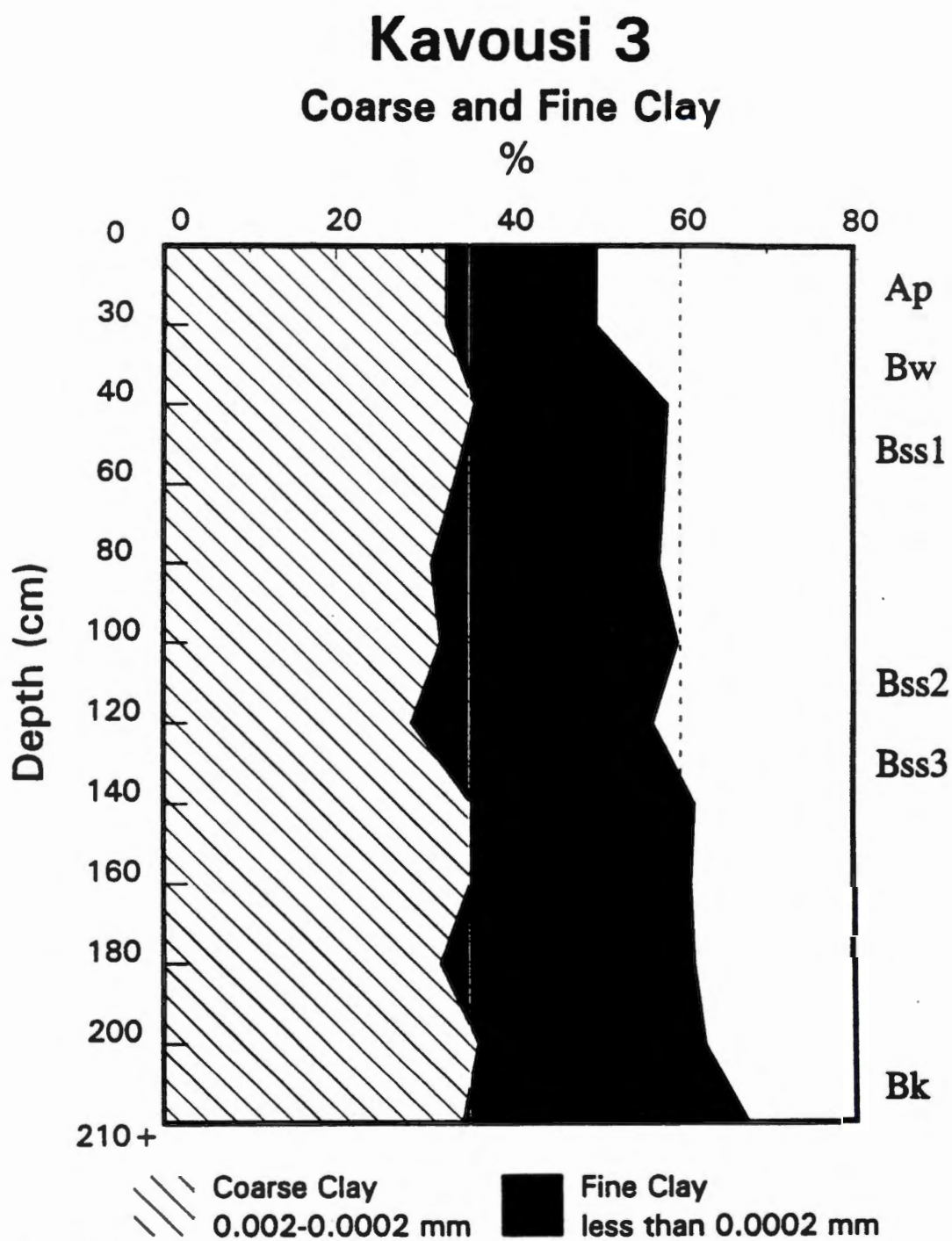
from 1.03 cmol_c kg⁻¹ at the surface to 1.82 cmol_c kg⁻¹ at 100 cm below the surface. At this point the exchangeable Na increases sharply to 2.50 cmol_c kg⁻¹ in the Bss2 horizon and continues to increase to 5.22 cmol_c kg⁻¹ at 160 cm. The exchangeable Na decreases steadily to 3.47 cmol_c kg⁻¹ at 210 cm below the surface. It is interesting to note that this Na increase occurs in the Bss2 and Bss3 horizons which exhibit the greatest expression of slickensides and pressure faces. Muhs (1982) found that Alfisols with natric B horizons could be precursors to Vertisols on San Clemente Island, California. Perhaps the hydrophyllous nature of the Na ion in the interlayer position of the clay minerals serve to facilitate the shrink-swell properties of the Vertisol.

An examination of the particle size distributions shows that most of the profile is rather homogeneous (Table 3, Figure 5). The clay content increases from 50.3% to 58.6% from the surface to the Bw horizon. There is also a decrease in sand content from 14.5% to 11.9% as well, and sand content decreases to 8.8% at 200 cm and again to 3.3% at 210 cm. From this point there is a rather regular increase in clay from 58.6% to 62.9% at 200 cm. There is a substantial increase in clay from 62.9% at 200 cm to 68.0% at 210 cm. Fine clay at this point increases from 26.5% to 33.4% as well. This increase in clay content over a short distance could be ascribed to the flocculation of clay due to an increase in exchangeable Ca.

The analysis of clay-free ratios demonstrates that discontinuities that may exist are below the areas of artifact concentrations (Tables 4 and 5, Figure 6). The FS:(TS+Si) ratio shows a decrease in fine sand content from the surface at 0.108 to 0.061 at 200 cm. The ratio then decreases dramatically to 0.035 in the Bk horizon. The FSi:(TS+Si) ratio shows an increase in the ratio from 0.448 in the surface to 0.580 at 200 cm and a drastic increase to 0.774 in the Bk horizon. Clay-free ratios calculated for the terra rossa samples show that the

Table 3. Particle size distribution of the Kavousi 3 soil pedon.

Horizon	Lower Depth	Gravel (>2.00 mm)	Sand (2.00-0.05 mm)					Silt (50-2 μm)		Clay (<2 μm)	
			VCOS	CoS	MS	FS	VFS	CoSi	FSi	CoC	FC
Ap	30	0.8	1.2	1.4	1.5	5.4	5.0	12.9	22.3	32.7	17.6
Bw	40	0.1	1.6	1.2	0.9	3.9	4.3	9.5	20.0	36.0	22.6
Bss1	60	0.2	1.2	1.5	1.1	3.4	4.7	8.3	21.6	33.7	24.5
	80	0.0	0.8	1.5	1.1	4.0	3.6	10.3	21.0	31.1	26.6
	100	0.1	1.1	1.1	0.8	3.7	3.1	9.9	20.5	32.1	27.7
Bss2	120	0.1	0.7	1.4	1.1	2.6	4.6	9.5	23.3	28.7	28.1
Bss3	140	0.0	0.8	1.1	0.8	3.5	3.1	9.2	19.8	35.6	26.1
	160	0.1	0.5	1.2	0.9	2.9	2.7	9.9	20.6	35.5	25.8
	180	0.8	0.5	0.8	0.8	2.6	2.3	11.0	20.4	32.0	29.6
Bk	200	2.6	1.1	1.1	0.9	2.3	3.4	6.8	21.5	36.4	26.5
	210	26.8	0.0	0.3	0.5	1.1	1.3	4.0	24.8	34.6	33.4
	Terra Rossa	5	19.8	1.4	2.1	2.8	5.2	2.4	8.8	20.2	35.3
Terra Rossa	5	15.7	1.4	1.2	0.8	2.7	3.5	12.4	27.1	37.5	13.4



Typic Chromoxererts

Figure 5. Distribution of coarse and fine clay, as determined by particle size analysis, vs. depth for the Kavousi 3 soil pedon.

Table 4. Weathering indices and clay-free ratios determined for the Kavousi 3 soil pedon.

Horizon	Lower Depth	Weathering Indices				Clay-free Ratios	
		SiO ₂ :R ₂ O ₃	TiO ₂ :ZrO ₂	Parker's Weathering Index	Fe _d :Fe _T	FS:(TS+Si)	FSi:(TS+Si)
	cm						
Ap	30	2.80	70.9	18.1	0.516	0.108	0.448
Bw	40	3.72	66.3	18.4	0.590	0.094	0.484
Bss1	60	3.12	67.5	18.7	0.560	0.082	0.517
	80	3.70	70.0	17.6	0.596	0.094	0.496
	100	4.55	70.6	18.0	0.556	0.091	0.509
Bss2	120	3.73	70.7	16.0	0.594	0.060	0.539
Bss3	140	3.50	67.6	15.6	0.714	0.091	0.517
	160	3.48	60.6	16.4	0.531	0.075	0.512
	180	3.91	72.8	17.0	0.568	0.067	0.532
	200	3.29	71.6	17.1	0.665	0.061	0.580
Bk	210	3.84	80.7	41.7	0.717	0.035	0.774
Terra Rossa	5	3.67	68.3	30.0	0.371	0.122	0.471
Terra Rossa	5	2.99	63.7	25.0	0.362	0.055	0.554

Table 5. Statistical results of Ryan-Einot-Gabriel-Welsch multiple range tests for weathering indices and clay-free ratios for the Kavousi 3 soil pedon.

	Molar Ratios				Clay-free Ratios	
	SiO ₂ :R ₂ O ₃	TiO ₂ :ZrO ₂	Parker's Weathering Index	Fe _d :Fe _t	FS:(TS+Si)	FSi:(TS+Si)
0-210 cm						
$\bar{x}$	3.62a†	70.9a	22.6a	0.603a	0.078a	0.537a
SD	0.53	4.0	7.2	0.069	0.021	0.085
CV (%)	14.72	5.69	31.99	11.39	26.73	15.90
<i>n</i>	21	21	21	21	11	11
Terra Rossa						
$\bar{x}$	3.34a	66.1b	30.8b	0.367b	0.089a	0.512a
SD	0.64	3.0	2.9	0.005	0.047	0.059
CV (%)	19.14	4.46	9.43	1.39	53.37	11.51
<i>n</i>	4	4	4	4	2	2
LSD	0.62	4.4	7.7	0.072	0.041	0.141
df	23	23	23	23	11	11
α	0.05	0.05	0.05	0.05	0.05	0.05

† Group means with the same letter(s) are not significantly different at the $\alpha=0.05$ level

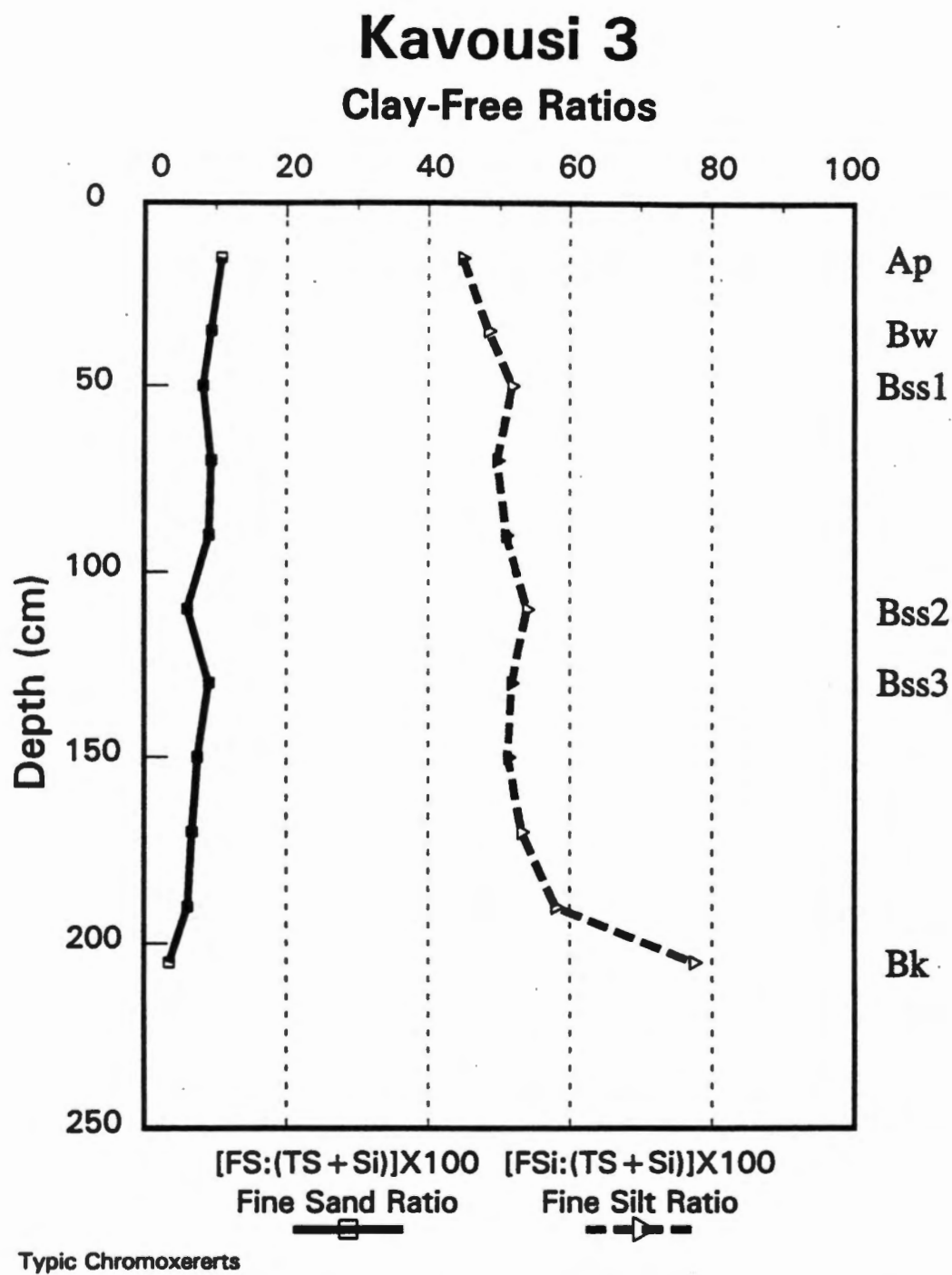


Figure 6. Distribution of clay-free ratios, as determined by particle size analysis, vs. depth for the Kavousi 3 soil pedon.

materials in the Kavousi 3 pedon are not statistically different than the terra rossa parent material. The $FS:(TS+Si)$ ratio average for the pedon is 0.078 with a coefficient of variation (CV) of 26.73%. The average $FS:(TS+Si)$ ratio for the terra rossa is 0.089 with a CV of 53.37%. The $FSi:(TS+Si)$ ratio exhibits a similar pattern. The average fine silt ratio for the pedon is 0.537 with a CV of 15.90% and the average for the terra rossa is 0.512 with a CV of 11.51% which is also statistically different. It can therefore be concluded that the alluvium for the sinkhole was derived from the terra rossa according to the clay-free ratios.

An examination of weathering indices in the pedon and the terra rossa shows the homogeneity of the parent material of each (Tables 4 and 5, Figure 7). The $SiO_2:R_2O_3$ ratios for the pedon has an average of 3.62 with a CV of 14.72%. The average for the $SiO_2:R_2O_3$ ratio in the terra rossa is 3.34 with a CV of 19.14%. There is no clear trend in the distribution of the $SiO_2:R_2O_3$ ratio with depth in the pedon to indicate any clear discontinuity, and the mean for the pedon does not differ significantly from the terra rossa mean. The Parker's weathering index distribution, on the other hand, seems to show a discontinuity at 200 cm in the Bk horizon. There is a somewhat irregular but uniform distribution of this index with depth from 18.1 at the surface to 17.1 at 200 cm with an increase to 41.7 in the Bk horizon. This implies that the lower horizon is enriched in regard to bases than the profile above. A comparison with the terra rossa shows that the pedon is more depleted in regard to bases. The average index for the profile is 22.6 with a CV of 31.99% and the average index for the terra rossa is 30.8 with a CV of 2.91% which is a significant difference. The $TiO_2:ZrO_2$ ratios show there is a close relationship between the terra rossa and the pedon. The average $TiO_2:ZrO_2$ ratio for the pedon is 70.9 with a CV of 4.04% and the average for the terra rossa is 66.1 with a CV of 2.95% which is a significant difference. By examining the distribution of the $TiO_2:ZrO_2$ ratio of the pedon, one can see that there is a

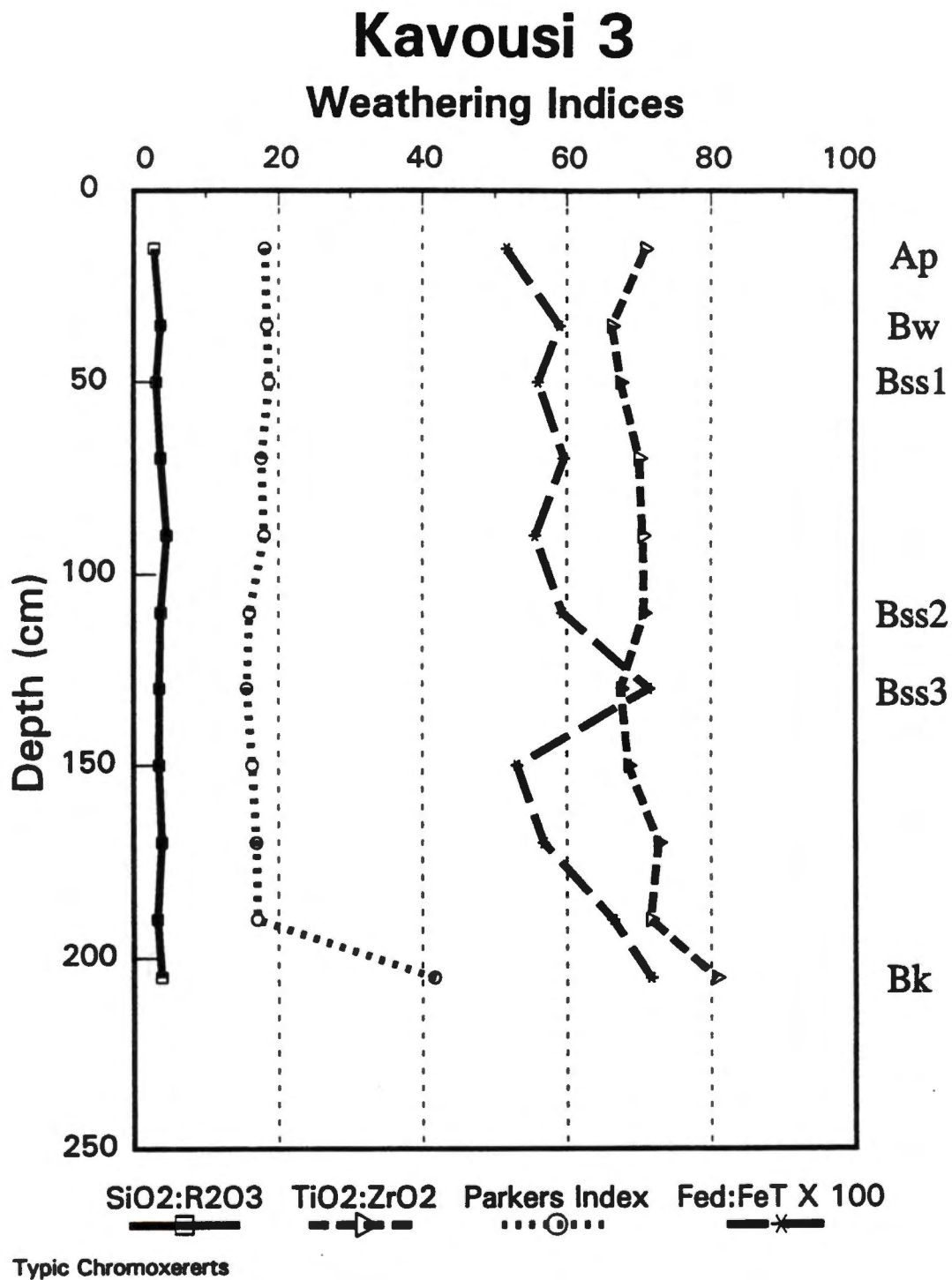


Figure 7. Plot of weathering indices, as determined by total element analysis and citrate-dithionite extraction, vs. depth for the Kavousi 3 soil pedon.

great increase in the Bk horizon of a 80.7 ratio value which may indicate a discontinuity here. The $\text{Fe}_d:\text{Fe}_T$ ratios are weathering indices which also show a difference between the pedon and the terra rossa. The average $\text{Fe}_d:\text{Fe}_T$ ratio for the pedon is 0.603 with a CV of 11.39% and the terra rossa shows a smaller ratio averaging 0.367 with a CV of 1.39%. The terra rossa exhibits a smaller free iron oxide content than the pedon similar to results from the Karphi archaeological site (Part 2--this dissertation).

The extractable element distributions do not confirm any discontinuities which may be represented by artifact distributions (Table 6, Figure 8). Most of the extractable elements analyzed have their greatest concentrations at the surface and a gradual decrease with depth. Extractable Mn decreases from 394 mg kg^{-1} at the surface to 133 mg kg^{-1} in the Bk horizon with two minor peaks at 80-100 cm and 160-180 cm. Extractable P is only detectable in the surface horizon at 3.00 mg kg^{-1} , which may indicate that human influence is restricted to the surface. Extractable Cu decreases regularly from 8.32 mg kg^{-1} in the surface to 3.58 mg kg^{-1} in the Bk horizon with a slight peak at 140-160 cm. Extractable Ba is more concentrated in the upper part of the pedon (0-120 cm) with values ranging from 77.6 mg kg^{-1} to 73.0 mg kg^{-1} . The lower part of the pedon (120-210 cm) has extractable Ba values that range from 68.7 mg kg^{-1} to 35.8 mg kg^{-1} . This relationship could possibly indicate that the surface material containing some residual organic material is being recycled in the upper 120 cm of the profile, which is the depth to the major slickensides. Extractable Pb is concentrated at the surface at 5.38 mg kg^{-1} and decreases somewhat irregularly to 4.39 mg kg^{-1} at 200 cm. Extractable Pb then increases to 6.93 mg kg^{-1} in the Bk horizon. Extractable Sr does not follow the pattern in the other extractable element distributions. Extractable Sr increases from 10.9 mg kg^{-1} at the surface to 34.6 mg kg^{-1} in the Bk horizon. In this case, extractable Sr may be reflecting the concentration in carbonates which increases in the profile with depth. In any case, none

Table 6. Elemental concentrations determined by archaeological extract method for the Kavousi 3 soil pedon.

Horizon	Lower Depth	Extractable Elements					
		Ba	Cu	Mn	P	Pb	Sr
	cm	mg kg ⁻¹					
Ap	30	75.1	8.32	394	3.00	5.38	10.9
Bw	40	74.4	7.38	227	0.00	4.92	11.6
Bss1	60	75.6	7.11	203	0.00	4.85	12.6
	80	73.0	6.45	158	0.00	4.47	13.7
	100	77.6	6.34	188	0.00	4.51	14.8
Bss2	120	76.6	6.25	164	0.00	4.25	15.5
Bss3	140	68.7	6.09	146	0.00	4.69	16.3
	160	56.1	6.30	138	0.00	4.25	17.0
	180	60.7	5.47	144	0.00	4.13	18.3
	200	55.7	4.39	111	0.00	4.39	22.4
Bk	210	35.8	3.58	133	0.00	6.93	34.6
Terra Rossa	5	58.7	6.59	316	16.8	6.38	12.8
Terra Rossa	5	69.2	9.46	479	66.5	8.47	15.5

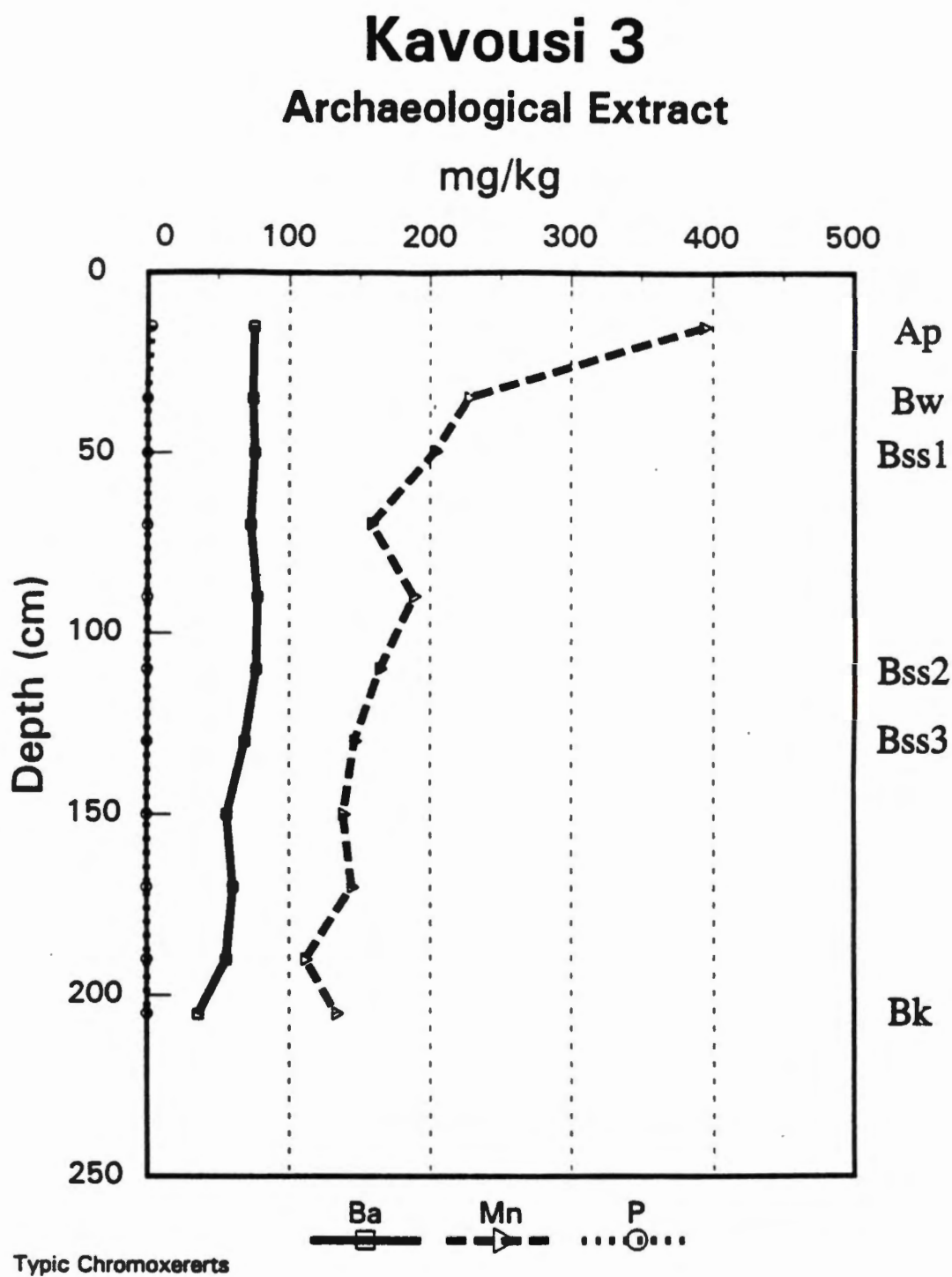


Figure 8. Distribution of extractable elements, as determined by archaeological extraction method, vs. depth for the Kavousi 3 soil pedon.

of these elements shows any discontinuities where the artifact lines were found in the profile at 30 cm and 110 cm.

The clay mineral analysis performed on the Bss2 horizon (100-120 cm) demonstrated a lack of expandable clay minerals (Figure 9). A comparison of the K saturated air-dried sample and the K saturated 550° C treatment shows that kaolinite is present at 7.2 angstroms and 3.54 angstroms because these peaks disappear as kaolinite is destroyed at 550° C. A comparison between the Mg saturated air-dried and Mg saturated ethylene-glycol treatment show that an illite peak at 10.0 angstroms does not increase, and therefore does not expand upon glycolation. This is unusual for a Vertisol since almost every one reported has at least some expandable minerals (Ahmad, 1983). The remaining X-ray diffraction peaks are an illite peak at 5.0 angstroms, and a quartz peak at 3.34 angstroms. Therefore, kaolinite and illite are the major clay minerals in the control section of this Vertisol.

The pedon at Kavousi 3 is classified according to the following characteristics outlined in the Keys to Soil Taxonomy (Soil Survey Staff, 1990). The pedon has a depth ≥ 50 cm, has $\geq 30\%$ clay content in all horizons and exhibits open cracks in the summer at least 1 cm wide from the surface to 170 cm. The pedon also has slickensides close enough to intersect between 25 and 100 cm, and has wedge shaped structural aggregates tilted 10° to 60° from the horizontal between 25 and 100 cm. These characteristics designate the pedon as a member of the Vertisol order. The Vertisol has a xeric moisture regime, a thermic temperature regime, and exhibits cracking during the summer months. This places this soil in the Xererts suborder. The pedon has a dominant chroma, moist, of 2 or more in the upper 30 cm, and is therefore placed in the Chromoxererts great group. Lack of any other diagnostic characteristics place this pedon in the Typic Chromoxererts subgroup. The pedon exhibits a clay content between 30% and 59% in the control section (25-100 cm), has a mixed

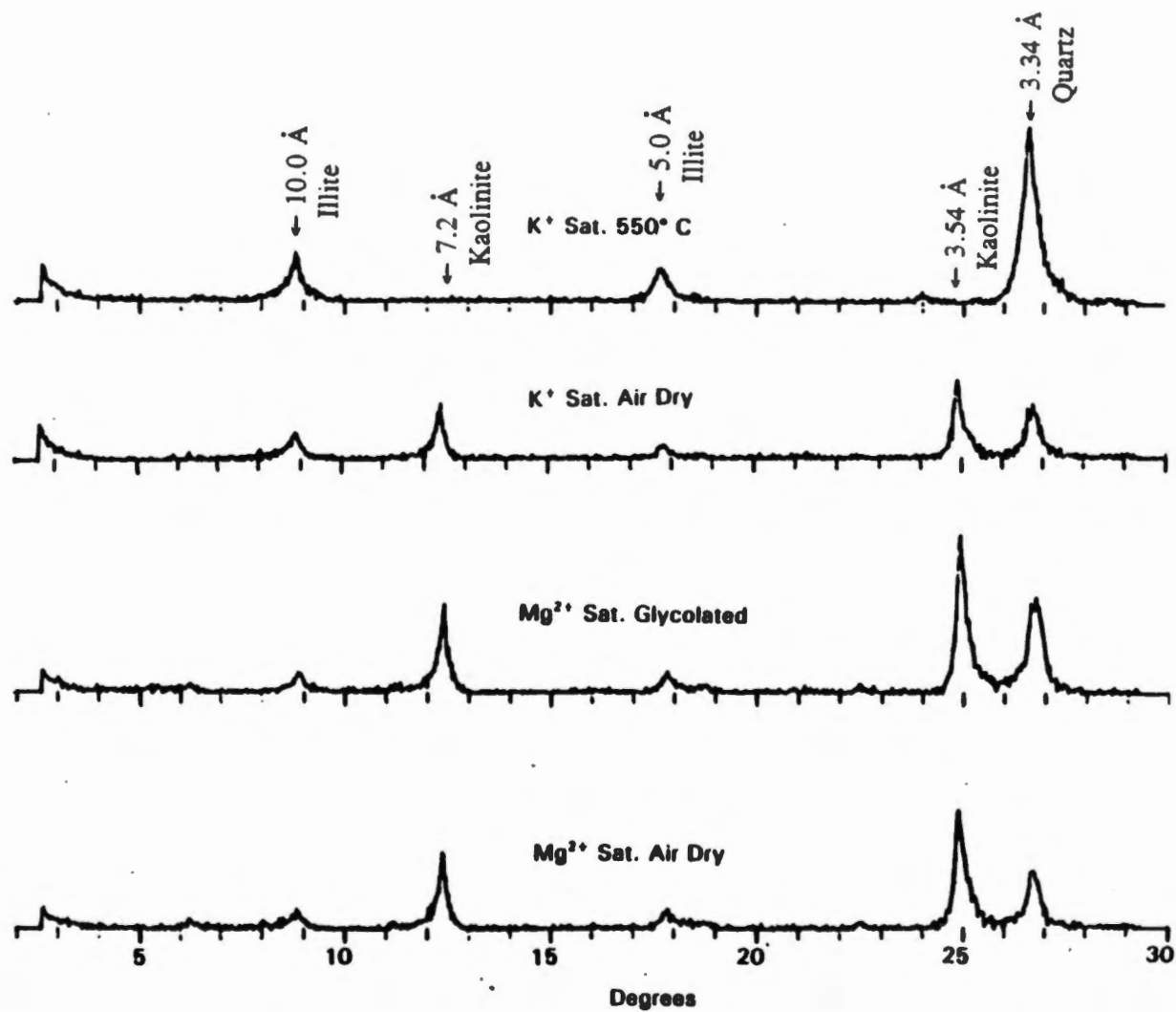


Figure 9. X-ray diffractograms of a clay sample from the Bss2 horizon (100-120 cm) of the Kavousi 3 soil pedon.

mineralogy of kaolinite and illite, and a thermic temperature regime. Therefore, the family classification is fine, mixed, thermic Typic Chromoxererts.

DISCUSSION

One of the most striking features about the pedon at Kavousi 3 is that the sediments are relatively homogeneous, particularly in the upper 200 cm. The use of clay-free ratios and molar ratios indicates that the upper 200 cm of the pedon is relatively uniform. These sediments are apparently derived from the terra rossa of the surrounding rim and were redeposited in the sinkhole as alluvium. The free iron ratios, though, are the only indices which are not comparable between the pedon and the terra rossa. There were no buried soils in the profile as evidenced by a lack of accumulation of organic carbon or extractable elements in the depth of the profile. The Bk horizon (200-210 cm) seems to represent a pedogenic and a possible lithological discontinuity. The effect of carbonate accumulation as a result of being within the capillary fringe of a fluctuating water table has developed a horizon with different morphological properties. The clay-free ratios also indicate that the parent material may be somewhat different than the upper portion of the profile. However, there is no indication of a discontinuity or buried soil which correlates with the artifact lines in the profile.

Artifact lines which are mapped in profile have been used to indicate buried surfaces and paleosols in archaeological studies (Turner et al., 1982; Turner and Klippel, 1989). This principle is consistent with the development of stone lines which are recognized as evidence of buried surfaces in a profile (Ruhe, 1959). Artifacts that have been recognized as having been translocated in a profile are generally not associated with the development of discrete artifact lines in profile (Cahen and Moeyerson, 1977; Hofman, 1986). In the case of the pedon at Kavousi 3, there seems to be a development of discrete artifact lines as a function

of the translocation of these artifacts by argilliturbation (Wood and Johnson, 1978). The artifact line at 30 cm below the surface correlates with the base of a plow zone in the alluvium of the sinkhole (Plate 6). Perhaps the extent of the vertical cracking was interrupted by this plow activity and the 30 cm depth represents the depth to which the continuous cracking was disturbed. The artifact line at 110 cm conforms to the depth of the wedge shaped aggregates with fluted slickensides and oriented at an approximate 45° angle. This artifact line could be explained by the depth to which straight vertical cracking exists between the surface and the subsoil. Although vertical cracks at least 1 cm wide were noted to a depth of 170 cm, these wedges may have provided an obstacle limiting the depth of artifact translocation. Because many of the artifacts exhibit vertical orientation and some were found between the 30 cm and 110 cm depths, there is more evidence for artifacts movement through the profile as an argument to the development of these artifact lines.

The Vertisol at Kavousi 3 has most of the characteristics that are common in Vertisols around the world. The clay content is sufficiently high, the relief is relatively level, the climate has distinct wet and dry seasons, and the profile exhibits vertic morphology. The main difference between this profile and most all Vertisols around the world is the lack of smectites in the clay minerals. Ahmad (1983) noted that Vertisols formed in alluvium have a mineralogy that has abundant illite. Ahmad (1983) also noted that continental Vertisols in Australia commonly have higher kaolinite contents than smectite. D'Hoore (1968) did report that several African Vertisols had low swelling clay contents, but were high in amorphous gels of Al_2O_3 and SiO_2 in the clay fraction. Usually the non-crystalline content of Vertisols are less than 20% of the clay size fraction (Ahmad, 1983). It is perhaps possible that the presence of amorphous gels in the Vertisol at Kavousi 3 could explain the development of vertic morphology without the benefit of expandable clays although the non-crystalline

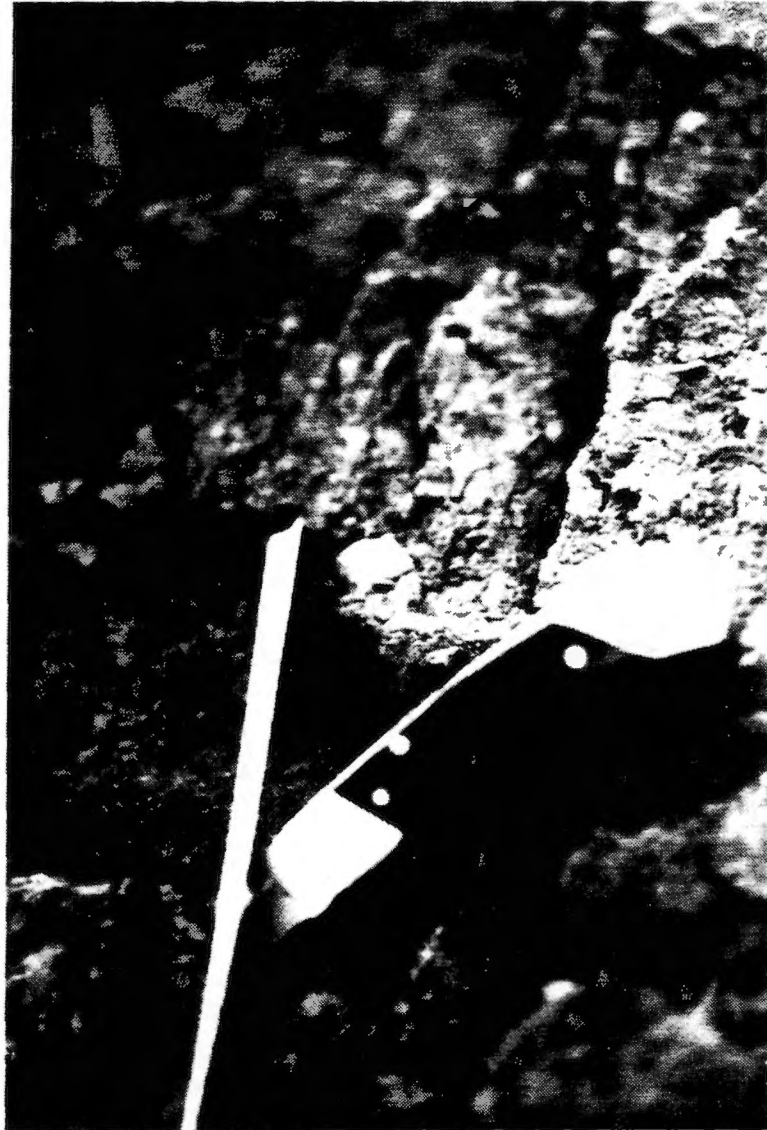


Plate 6. Minoan age ceramic fragment at 30 cm below the surface at Kavousi 3. Note the vertical orientation of the artifact.

amorphous gels were not determined in this study. It is the opinion of this investigator that the development of vertic morphology in this pedon is primarily a result of the extremes in wet and dry periods of the xeric climate in this area. Therefore, the climate is the primary soil forming factor in the pedogenesis of this Vertisol.

The presence of Middle Minoan artifacts on the surface of the Kavousi 3 pedon, and the evidence that Middle Minoan artifacts have moved through the profile indicates that the surface of this alluvium was stable at least 4,000 yr. B.P. (Plate 7). The question remains of when did the sediments in this sinkhole accumulate and by what mechanism? The chemical evidence indicates that this soil was formed from the terra rossa soils of the surrounding basin. Davidson (1980) noted that the terra rossa soils may be relict in origin and a product of the climate of the last glacial period. The fineness of the sediments in the sinkhole reflect a depositional regime that was relatively slow moving or still such as in a slackwater environment. It is quite possible that this was a Pleistocene or Early Holocene lake and these sediments represent a lacustrine environment. Pluvial conditions have been reported in the areas of the Levant and North Africa (Farrand, 1971). Ritchie et al. (1985) reported on pluvial conditions in north-west Sudan between 8,900 to 4,900 yr. B.P. Could pluvial conditions have existed as a product of shifting Mediterranean winter rain belt during the Late Pleistocene--Early Holocene? Bertolani-Marchetti (1985) suggested that these pluvial conditions could have been in place in this part of the Mediterranean. Dermitzakis and Sondaar (1978) point out that pluvial fauna such as the pygmy hippopotamus has been found in Late Pleistocene deposits on Crete. The sinkhole at Kavousi 3 may then represent a Late Pleistocene--Early Holocene lake in this part of Crete and stand as a relic of a previous climatic regime.



Plate 7. Minoan age ceramic fragments on the surface of the Kavousi 3 pedon. Note proximity of artifact to vertical cracks.

CONCLUSIONS

One of the classic observations in pedology is the demarcation of discontinuities and buried soils by locating stone lines in a soil profile (Ruhe, 1959). This technique has been further implemented in archaeological studies by observation of artifact lines in a profile as an indicator of past living surfaces (Turner et al., 1982; Turner and Klippel, 1989). The appearance of two artifact lines at the Kavousi 3 pedon in eastern Crete could possibly be explained by the development of living surfaces with deposition of artifacts and their subsequent burial. However, field observations and laboratory analyses from this pedon appear to indicate a lack of evidence of buried surfaces to correlate with the pottery lines at 30 cm and 110 cm. The pottery line at 30 cm seems to indicate the base of a plow layer at the site. Because of the evidence of vertic properties including open cracks from the surface downward, the existence of a pottery line at 110 cm seems to demarcate the extent of intersecting slickensides. Movement of artifacts through the profile seems to be dependent on the limiting diameter of the artifact and the morphology of the vertical cracks. The observation that a few artifacts were located between the 30 and 110 cm depths and the vertical orientation of many of the artifacts lend credence to the translocation model. The shrink-swell properties of this Vertisol seem to be a function of the Mediterranean or xeric climate where the episodes of wet conditions fall between episodes of very dry conditions, rather than the shrink-swell properties of the clays. It is therefore concluded that in some cases, artifacts can move a considerable vertical distance through a profile from their original depositional context.

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PART 4

DEPOSITION, EROSION, AND PEDOGENESIS OF

ALLUVIAL AND COLLUVIAL SOILS NEAR

THE VRONDA AND KASTRO ARCHAEOLOGICAL SITES

INTRODUCTION

The Late Minoan III C archaeological sites of Vronda and Kastro were the focus of the Kavousi expedition near the village of Kavousi in eastern Crete, Greece. Bringing Americanist prehistoric techniques to Greece as part of their archaeological investigations, the Kavousi expedition enlisted the services of soil scientists from the University of Tennessee to understand the natural environment of the area. These soils investigations were conducted in the framework of an interdisciplinary effort to study the interaction of the lifeways of the Minoan Period peoples who inhabited the area and the natural setting of that period. It was hoped that cultural and environmental dynamics in the Kavousi area be understood in the context of the past.

The focus of this soil study was an investigation of a series of buried soils that were located topographically below these archaeological sites in the Avgo gorge and the alluvial fans emanating from the gorge. Some of these soils exhibited morphology indicative of stability and *in situ* weathering. Other soil profiles had buried soils with Minoan Period artifacts within the sediment matrix. It was believed that an investigation of these soils would provide clues as to the degree of stability and instability as well as the chronological sequence in which these events occurred. It was the purpose of this investigation to understand the sequence of these events and the correlation with the archaeological context of the area.

BACKGROUND

Geomorphological evidence for landscape evolution during the last glacial cycle has been presented for various areas of Greece. Many of these investigations have explored the validity of the Vita-Finzi (1969) model of alluviation in the Mediterranean region. The model encompassed two major cycles of alluviation over the last 100,000 years. One episode, the Pleistocene "Older Fill" is exemplified by the "Red Beds" of Greece, a rubified alluvium which

contained Mousterian and Upper Paleolithic artifacts. The "Younger Fill" is an alluvium which contained sherds from the 2nd and 3rd centuries A.D. to the present. The younger fill episode was preceded by a channel incision episode from 8,000 to 2,000 yr. B.P. The forcing factor for these episodes was climatic change; a cool, moist interstadial climate for the older fill, and a cool, moist (Little Ice Age) Late Holocene climate for the younger fill.

Davidson (1980) supported the Vita-Finzi hypothesis, in particular on the chronology of the younger fill, because of the burial of Classical Period sherds in the tell mounds of Sitagroi in the plain of Drama in Macedonia. Davidson's continuing work on Melos and Santorini also showed erosional episodes occurring during the Late Bronze Age, immediately preceding the eruption of Thera on Santorini. Subsequent deposition may or may not have coincided with the Vita-Finzi synchronous younger fill episodes (Davidson and Tasker, 1982; Davidson et al., 1976; Davidson, 1978).

Bintliff (1975) also supported the Vita-Finzi hypothesis. Bintliff demonstrated that two major alluvial aggradation episodes had occurred in a study of alluvial valleys in Greece and on Crete. The older fill universally overlaid Pliocene or earlier formations and descended sharply at the coast to a former (glacial) low sea-level. The younger fill was deposited as a result of a cool, moist phase from late Roman and Medieval times to around 200 yr. B.P. (Bintliff, 1975; 1977). Vita-Finzi attributed this climatic cooling to a southward shift in the atmospheric depression belts of Europe (Vita-Finzi, 1976).

There have been a number of critics of the Vita-Finzi model. Wagstaff (1981) argued that detailed studies of these fill sequences and their sedimentary and pedogenic characteristics had not been performed. He suggested that studies of Vita-Finzi supporters failed to regard immediate location of the deposits or whether these deposits consisted of alluvium or colluvium. Van Andel et al. (1986) documented an erosional sequence which

began around 4,500 yr. B.P. in the southern Argolid. There were two events which consisted of debris flows that were interpreted as clearing of steep slopes of marginal soils. Two other events laid down stream flood deposits which commenced after the abandonment and subsequent failure of agricultural terraces. Land stabilization occurred when agricultural terraces and check dams were maintained, and when the area was completely abandoned after which the maquis and pine assemblage reinvaded the landscape. Their conclusion was that the younger fill was more a result of human impact than climate change in the Late Holocene (Pope and Van Andel, 1984). Landscape destabilization episodes seemed to follow within 500 to 1,000 years the introduction of farming in Greece (Van Andel and Zangger, 1990).

Lewin et al. (1991), through a study of the geomorphology in the Voidomatis basin, Epirus, northwest Greece, identified several Quaternary alluvial valley fills that range in age from middle Pleistocene to the Historic period. Major periods of alluviation were associated with valley glaciation (26,000-20,000 yr. B.P.) and deglaciation (20,000-15,000 yr. B.P.) in the Pindus Mountains. The more recent aggradation episode was believed to be linked to overgrazing sometime before the 11th century A.D. The authors concluded that the "older fill-younger fill" model of Vita-Finzi was inadequate for interpreting Quaternary valley aggrading episodes.

Pedological studies have been conducted in association with Bronze Age archaeological sites in the southern Peloponnese. Yassoglou and Nobeli (1972) have divided these soil systems into four major types: 1) residual soils formed on consolidated rocks (Alfisols); 2) residual soils formed on Tertiary marine marl, clay, sand, and silt (Mollisols); 3) older alluvial soils (Alfisols); and 4) recent alluvial soils. The first two categories referred to the "terra rossa" and "rendzina" soils respectively. The remaining categories were important because they represented sequences of alluviation that contained buried horizons and

archaeological materials. The findings of Haidouti and Yassoglou (1982) demonstrated that argillic horizons (subsurface horizons which exhibit translocation of weathered clay minerals from the surface horizons) could be developed in 2,000 to 3,000 years in a xeric climate. Cambic horizons (horizons formed by removal of carbonates) could be developed in less than 900 years. Soils that developed in a period longer than 3,000 years exhibited a sepic microstructure and a lower ratio of amorphous to crystalline iron oxides in the argillic horizon.

Yassoglou and Haidouti (1978) referred to work conducted by Nettleton et al. (1975) on the development of argillic horizons in the drier areas of the western United States, and observed that these argillic horizons formed during the pluvial conditions of the Late Pleistocene. There had also been no argillic development in these desert soils for the past 12,000 years and these argillic horizons are considered to be climatic relics. Yassoglou and Haidouti (1978) however, believe that argillic horizons can form in the present xeric regimes of the Mediterranean. This evidence contrasts with the study by Foss and Collins (1986) which indicated that a weak argillic horizon takes at least 3,500 years to develop in the udic (humid) moisture regimes of the eastern United States. Because water is the primary agent for solution and translocation of soil constituents (McKeague and St. Arnaud, 1969), it is difficult to understand how an argillic horizon can form in a drier climate in less time than in a moister regime.

SITE SETTING

Two soil pedons were located for this study. The first, Kavousi 1, was located in the Avgo gorge approximately 0.36 km east of the village of Kavousi (Figure 1, Plates 1 and 2). The pedon was a bisquel profile with a mixed phyllite and chalk sediment derived from a phyllite unit mixed with a soft limestone marl located upslope. This rendzina soil was buried

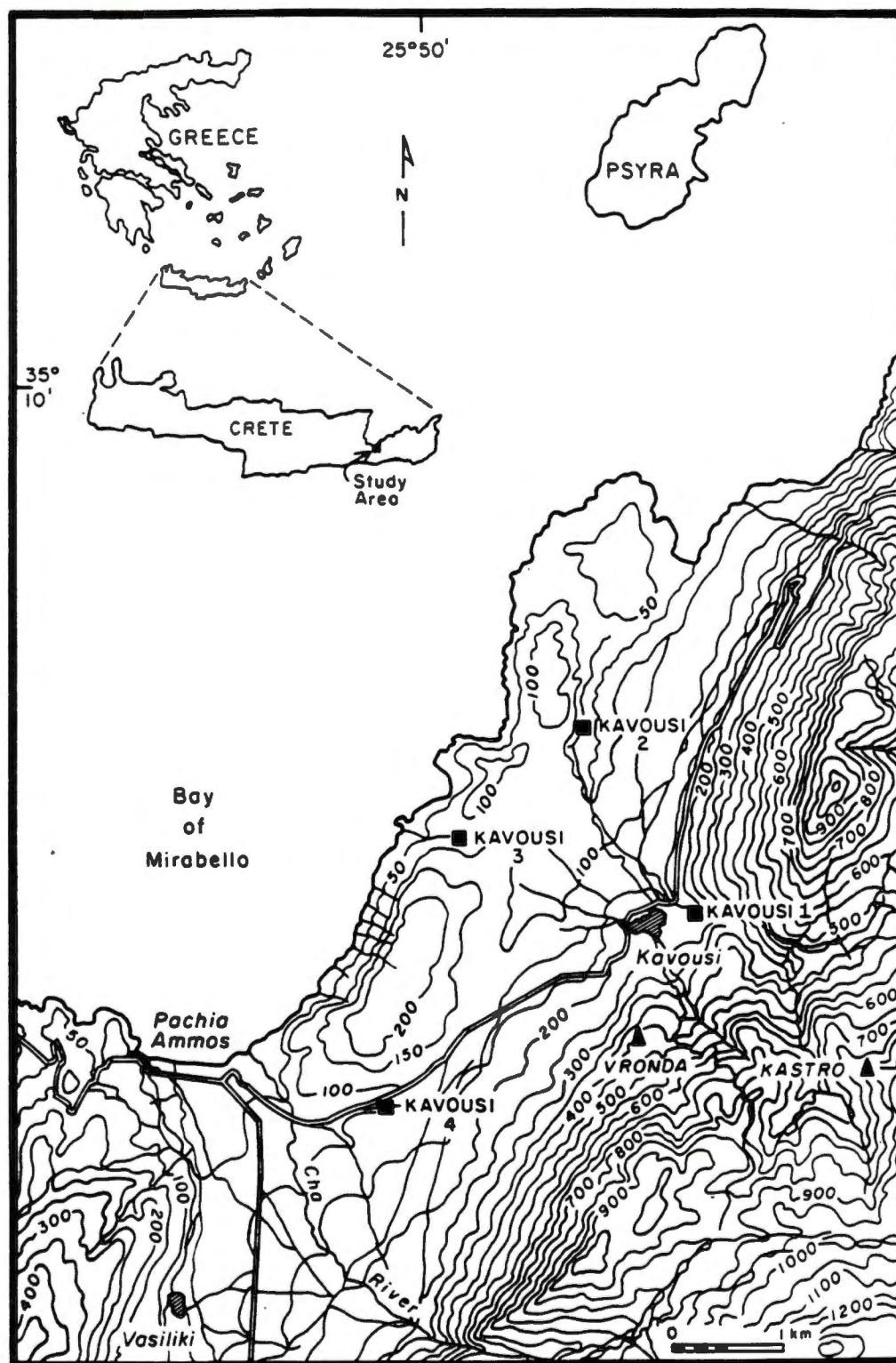


Figure 1. Plan view of the Kavousi area including the Vronta and Kastro archaeological sites and the Kavousi study pedons.

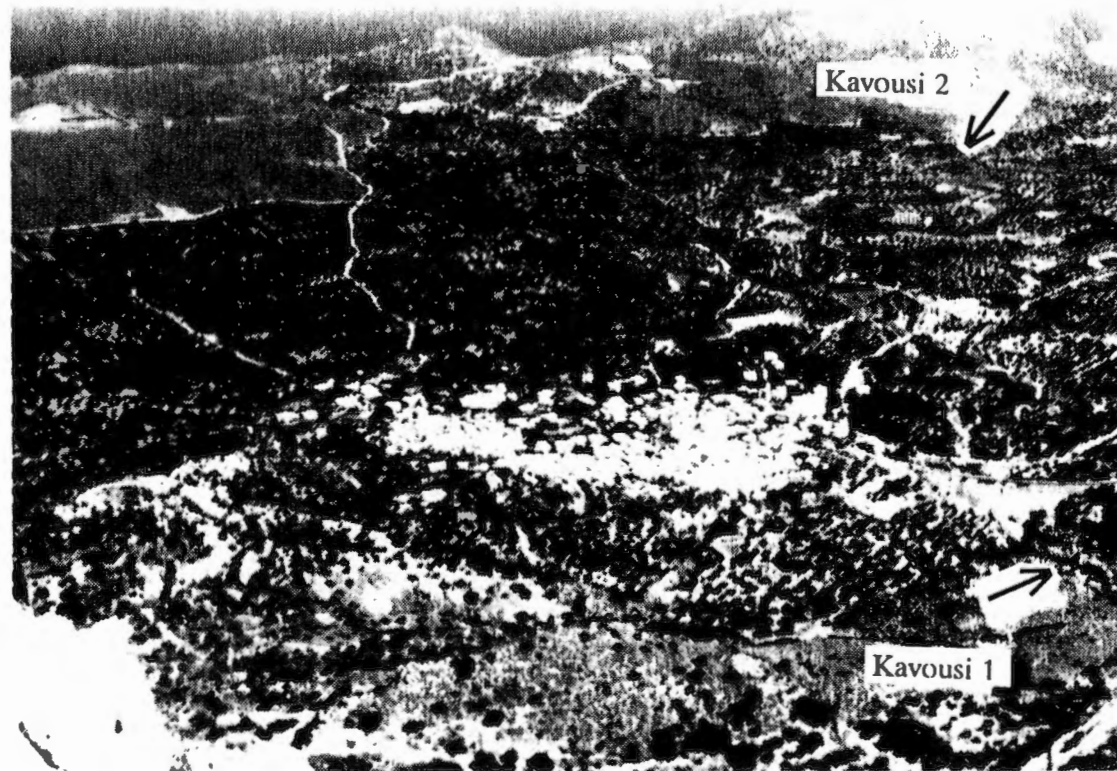


Plate 1. View of the village of Kavousi and the Kavousi 1 and 2 pedons, taken from the Kastro archaeological site, facing west.

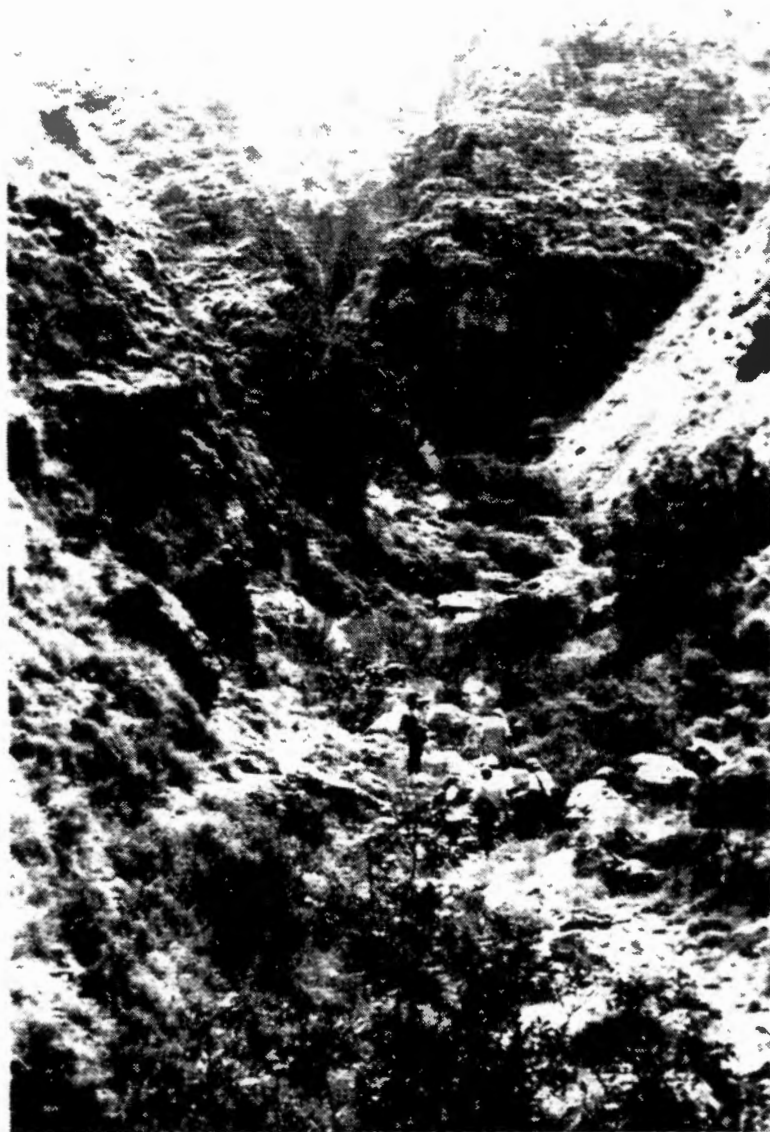


Plate 2. View of the Avgo Valley Gorge near the village of Kavousi, facing south.

by over 2 m of a cobbly mixed phyllite and limestone sediment also derived from upslope (Plate 3). Kavousi 2 was a pedon located in an alluvial fan deposit emanating from the Avgio gorge and was located approximately 1.8 km north of the village of Kavousi (Figure 1, Plates 1 and 4). The pedon consisted of two sequences of alluvium. Each sequence had a relatively silty overbank matrix which overlaid a gravelly lag channel deposit. The lower sequence contained ceramic artifacts that were identified as part of either Late or Middle Minoan contexts.

The geology of the immediate area around the Kavousi 1 and 2 pedons was governed by two probable faults (Figure 2). The sediments are mapped as Holocene alluvium and colluvium. One probable fault runs the length of the scarp to the west of Mount Kapsas, and the other runs the length of the alluvial valley west of Kavousi along the western flank of the coastal hills. Phyllite exposures east of Kavousi 1 and in the coastal hills west of Kavousi 2 are described as mainly a tectonic unit rather than a stratigraphic unit underlain by the Plattenkalk series limestones (Jurassic to Eocene in age) and usually overlain by the Gavrona-Tripolitza series. The main part of the phyllite-quartzite series consists of Permo-Triassic phyllites, quartzphyllites, and quartzites (Creutzburg et al., 1977). Exposures of the Plattenkalk series east of Kavousi 1 and west of Kavousi 2 consisted of average bedded, usually bluish, crystalline limestone, with flaggy intercalations or nodules of very fine grained chert. Exposures of Triassic age dolomite of the Gavrona-Tripolitza series can be found in the hills south of Kavousi 1 where the Vronda site is located, and west of Kavousi 2 in the coastal hills. This unit consists of dark-gray or black dolomite, thick bedded to massive, generally of shallow water origin (Papastamatiou et al., 1959; Creutzburg et al., 1977). The marls in the Kavousi 1 pedon are not currently mapped but could have been derived from one of the various marl deposits more common to the west near the villages of Vasiliki and



Plate 3. Profile view of Kavousi 1, facing west.

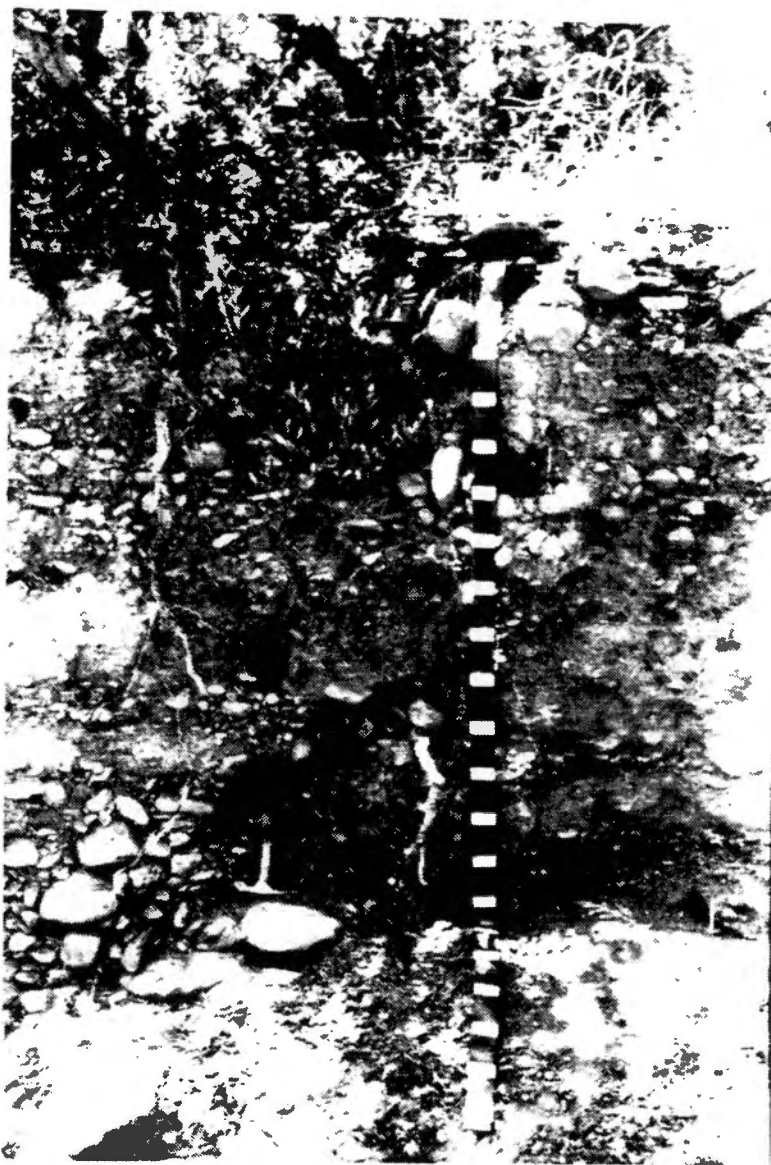


Plate 4. Profile of Kavousi 2, facing north.

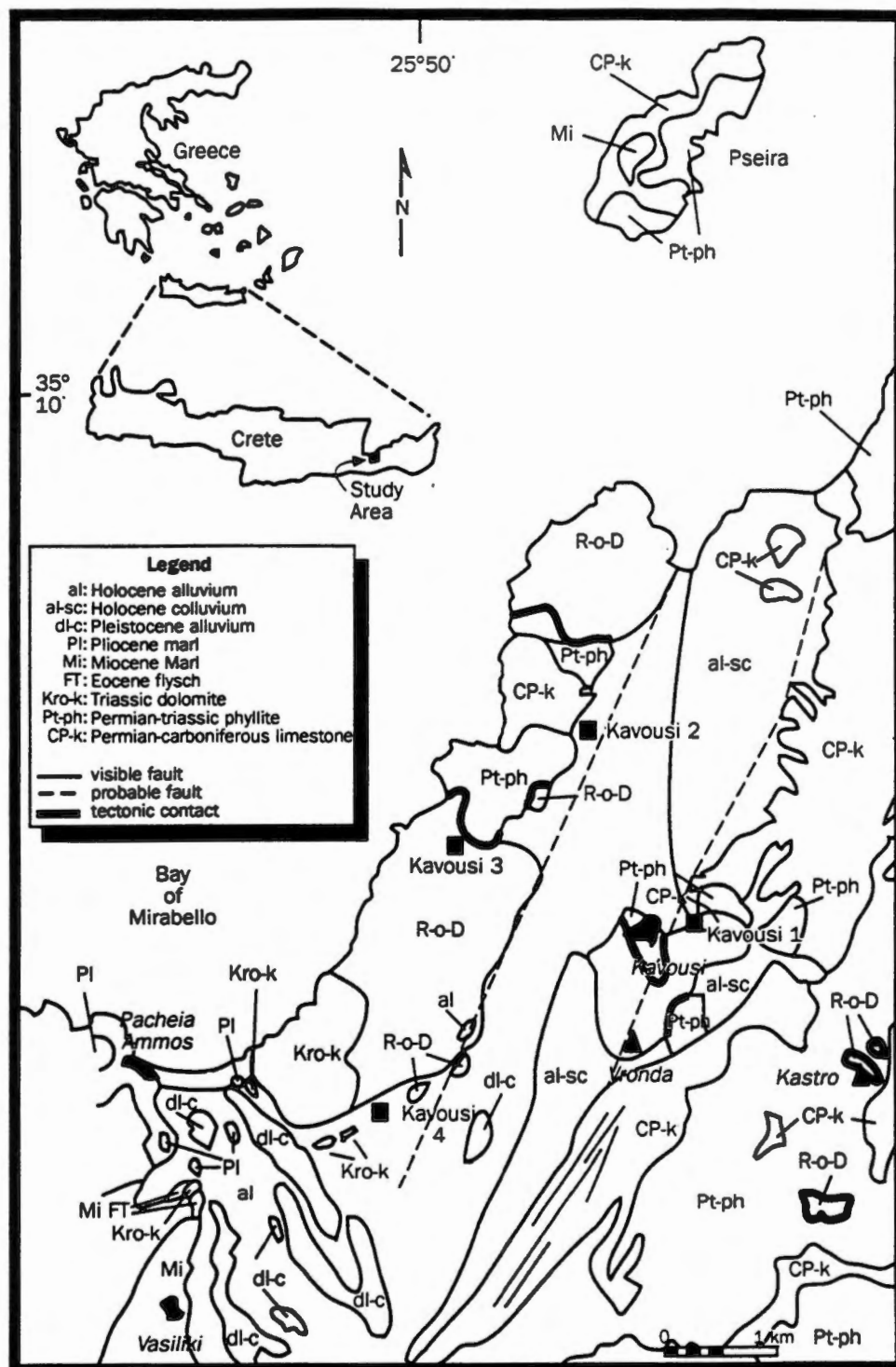


Figure 2. Bedrock geology of the Kavousi study area.

Source: Papastamatiou, J., D. Vetoulis, A. Tataris, J. Borovas, G. Christodoulos, and G. Katsikatsos. 1959. Geologic map of Greece, Ierapetra sheet. Inst. for Geol. Subsurface Res., Athens.

Pacheia Ammos (Fortuin, 1977). There could be a number of marl deposits buried in the areas of heavy colluvium in this alluvial valley.

The climate of the Kavousi area is a typical Mediterranean climate, and is considered as one of the drier areas of Crete. Precipitation is restricted primarily to the months of September to May with highest precipitation in December and January. Rainfall is rare between the months of May to August. Average rainfall in Ierapetra, about 7 km to the south at sea level, is 380 mm yr⁻¹. Mean monthly temperatures for Ierapetra are 13.2° C in January and 27.2° C in August (Zohary and Orshan, 1965).

The vegetation of the area of Kavousi has been mapped by Zohary and Orshan (1965) as two major plant communities; the Ceratonieto-Pistacietum and the Hyparrhenieto-Thymetum. The Ceratonieto-Pistacietum Lentisci community is a maquis type which occupies the lower slopes of the hills throughout Crete up to 300-400 m in elevation. This association occurs on terra rossa and rendzina soils. The typical plants of this community include *Ceratonia siliqua*, *Pistacia lentiscus*, *Olea europaea* var. *oleaster*, *Rhamnus prunifolia*, *Coridothymus capitatus*, *Hyparrhenia hirta*, and *Calycotome villosa*. *Juniperus phoenicea* occurs as a codominant particularly in the area of northeastern Crete. The Hyparrhenieto-Thymetum comprises garigue and batha (phrygana or low chaparral) communities which occur from sea level to 300 or 400 m AMSL. Species which are typical of this association are *Cystisus creticus*, *Anthyllis hermanniae*, *Genista acanthoclada*, *Euphorbia characias*, *Euphorbia acanthothamnus*, *Cistus parviflorus*, *Phlomis lanata*, *Phlomis cretica*, *Phlomis fruticosa*, *Ballota pseudodictamnus*, *Hypericum empetrifolium* and some species of *Teucrium* and *Origanum* (Zohary and Orshan, 1965).

The archaeological sites which were used in this study include the sites of Vronda and Kastro south of the present village of Kavousi on the northern slopes of the Siteia Range

(Figure 1). Other archaeological sites of the Middle and Late Minoan I Periods include the sites of Pseira (an island 7 km north of the village of Kavousi), Vasiliki (a village 5.3 km southwest of the village of Kavousi), and Gournia (archaeological site 6 km west of the village of Kavousi). According to the artifact assemblages found in the Kavousi 2 pedon, the people of these sites may have utilized the alluvial valley below Kavousi.

Vronda was a settlement located south of the village of Kavousi atop a relatively level knoll of dolomitic limestones in the northern foothills of the Siteia Mountains at an elevation of approximately 440 m AMSL (Figure 1, Plate 5). First excavated by Harriet Boyd in 1900, the site was left alone until the start of the Kavousi project in 1978. Vronda was a sizable settlement spreading over an area of 61 m by 40 m. The settlement consisted of a number of rectangular houses situated on a series of terraces on the knoll. The settlement had a central paved street as well as several courtyards. The settlement also boasted a shrine, a pottery kiln, and a number of tholos tombs. The settlement was initiated around the beginning of the Late Minoan IIIc Period and went out of use in the Early Protogeometric Period (around 1100-800 B.C.). From the Early to Middle Protogeometric Period, Vronda was used as a cemetery by the inhabitants of the Kastro. The Vronda cemetery ceased in the Middle Geometric Period (Gesell et al., 1983; 1988; 1991; Day et al., 1986).

The site of Kastro is located south of Kavousi in the Siteia Range on a mountain promontory composed of hard phyllites at an elevation of around 710 m AMSL (Figure 1, Plate 6). The site was first excavated by Harriet Boyd in 1900, and excavations were begun anew in 1978 by the Kavousi Expedition. The Kastro is a Late Bronze/Early Iron Age settlement which overlooks the Avgo Pass in the Siteia Range. The site is composed of thirteen rooms on six terraces of differing elevations. The site of Kastro is believed to have begun in the Late Minoan III C Period and continued until the Late Geometric/Early



Plate 5. View of the Vronda archaeological site, facing northwest.



Plate 6. View of the Kastro archaeological site, facing north.

Orientalizing Period (approximately 650 B.C.). After this time period, the human population in general left the Kavousi area (Gesell et al., 1985; Day et al., 1986).

MATERIALS AND METHODS

Field Methods

The area around Kavousi was scouted for suitable sites for sampling. Areas where the potential for buried soils and paleosols were surveyed and suitable profiles in stream cuts were located. Once located, these sites were sampled and described according to methods outlined in the Soil Survey Manual (Soil Survey Staff, 1984). The following is a description of the sites selected for this study.

Kavousi 1

The Kavousi 1 pedon was located on a walking trip from Kavousi to the Avgo gorge at 25°52'16" E Long, 35°07'12" N Lat (Figure 1). The site can be reached by walking from the bridge on the main highway, which crosses the Avgo gorge in the village of Kavousi, approximately 100 m to the south. A mixed chalky marl and phyllite colluvial deposit can be found on each side of the gorge. The pedon is located on the east facing exposure, and represents a truncated rendzina soil which was buried by over 2 m of a mixed limestone and phyllite colluvium. The profile was cleaned and samples were collected from the base of the profile upwards. Only 10 cm of the colluvium overlying the rendzina soil and the surface 10 cm were sampled for this investigation. The samples were described in the field and packaged for shipment for the soil characterization laboratory in the Department of Plant and Soil Science, University of Tennessee, Knoxville.

Kavousi 2

The Kavousi 2 pedon can be reached by taking the road from the Tholos beach north of Kavousi and driving west on the gravel road at the base of the coastal hills at 25°51'02" E Long, 35°08'10" N Lat (Figure 1). One can drive 2.4 km from the Roman tholos and a stream cut will be immediately to the south. A south facing stream cut profile is located here that exhibits two sequences of silty overbank deposits with associated rounded gravel lag channel deposits in an alluvial fan. The stream originates in the Avgo gorge and follows a fault at the base of the coastal hills. The lower sequence contained Minoan ceramic sherds. The pedon was described in the field and sampled from the base of the pedon to the surface. The samples were double bagged for shipment to the soil characterization laboratory at the Department of Plant and Soil Science, University of Tennessee, Knoxville.

Laboratory Methods

Soil samples collected from Crete were first subjected to a freezing treatment of -80° C for 48 hrs to destroy any organisms which may have been present. The samples were removed from the freezing treatment and allowed to thaw. Representative peds were collected from each sample and set aside. The remaining samples were then air dried and ground to pass a 10 mesh sieve (2.00 mm limiting diameter). The fraction > 2.00 mm was collected and weighed. The fraction $\leq$ 2.00 mm was quartered and one quarter was ground to 60 mesh and finer.

Total carbon content for each sample was determined by using a LECO CR-12 carbon analyzer on the $\leq$ 60 mesh portion of the sample. Each sample was tested with 1 M HCl for presence of inorganic carbon (CO_3^{2-}). Soil horizons with high organic carbon contents are believed to have been surface horizons into which plant material such as roots had been incorporated. Subsurface horizons with high carbon contents are believed to represent former

stable surfaces that had been buried by additions of new parent material. Carbon analysis has been used to locate and delimit buried archaeological sites on former stable surfaces (Stein, 1982; Ahler, 1973; Foss, 1977).

Measurements of pH were made on each sample using a pH meter equipped with a chloride combination electrode. A 1:1 ratio of soil to distilled-deionized water, and a 2:1 ratio of 0.1 M CaCl_2 to soil were used in the preparation, and pH's were measured according to the procedure outlined in McLean (1986). The measurement of pH can provide some insight into the relative weathering status of a soil sample which can give the relative base saturation of the sample. Because of the relationship between high base saturation and optimal preservation of archaeological materials, pH measurements have been used in several archaeological studies (Deetz and Dethlefsen, 1963; Gordon and Buikstra, 1981).

A particle size analysis was performed on all samples using a combination of sand sieving and sedimentation techniques as outlined in Gee and Bauder (1986). Samples with $\geq 1.0\%$ organic carbon were pretreated with a 30% H_2O_2 solution, and samples which reacted to 1 M HCl were treated with a 1 M Na-acetate solution buffered at pH 4.5. Approximately 10 g of the <2.00 mm fraction of each sample was dispersed in a Na-hexametaphosphate--Na-carbonate solution, and the sand size fraction of each sample was separated from the smaller fractions by wet sieving. The sand fraction was dried and fractionated by dry sieving into very coarse sand (VCoS, 2.00-1.00 mm), coarse sand (CoS, 1.00-0.50 mm), medium sand (MS, 0.50-0.25 mm), fine sand (FS, 0.25-0.10 mm), and very fine sand (VFS, 0.10-0.050 mm) fractions. The remaining silt and clay size fractions of each sample were retained in a 1000 ml capacity sedimentation cylinder and placed in a water bath. Pipette analysis was performed on these samples to determine their coarse silt (CoSi, 50-20 μm), fine silt (FSi, 20-2 μm), and clay (C, <2 μm) fractions. A combination of centrifugation

and pipette methods were used to determine the fine clay fraction (FC, $<0.2 \mu\text{m}$). Distribution of clay-size particles with depth was used as a weathering indicator for this study (Foss, 1977; Bilzi and Ciolkosz, 1977; Hall et al., 1982). Data from the particle size analyses were also converted to clay-free ratios to document changes in depositional regimes and assess the uniformity of the parent material (Raad and Protz, 1971; Thompson et al., 1981; Asady and Whiteside, 1982; Ajmone Marsan et al., 1988). The clay-free ratios chosen for this study included: 1) Fine silt/(total sand + total silt) [FSi:(TS+Si)], and 2) Fine sand/(total sand + total silt) [FS:(TS+Si)].

Elemental analyses were performed with the aid of a Thermo Jarrel Ash Model 61 Inductively Coupled Argon Plasma Atomic Emission spectrometer (ICAP-AES), which has the capacity for analyzing 26 different elements simultaneously. A total element analysis was performed by digesting about 0.2000 g of the <60 mesh sample in an aqua-regia/concentrated hydrofluoric acid/microwave oven treatment neutralized with boric acid according to the procedure outlined by Nadkarni (1984). Extractable element analysis was performed by using approximately 2 g of the <2 mm fraction which was extracted with a 5:1 HCl:HNO₃ solution adjusted to 0.75 M according to a procedure outlined in Lewis et al. (in press).

The elements from the total analysis were converted to weight percentage oxides. These oxides were then converted to molar ratios and molar indices which were used as weathering indices. These indices will theoretically decrease with increased weathering or age of the sediment. The indices chosen for this study include: 1) $\text{SiO}_2/\text{R}_2\text{O}_3$, where R_2O_3 is equal to Fe_2O_3 (determined by citrate-dithionite extraction) + Al_2O_3 (total) + TiO_2 (total) (Birkeland, 1984), 2) Parker's Weathering Index which is defined as $100(\text{K}_2\text{O}/0.25 + \text{Na}_2\text{O}/0.35 + \text{CaO}/0.7 + \text{MgO}/0.9)$ where the values in the denominator refer to the relative

strengths of the cation-oxygen bond (Parker, 1970), and 3) $\text{TiO}_2\text{:ZrO}_2$ (Chapman and Horn, 1968; Rostad et al., 1976).

Free iron oxides were determined using the citrate-dithionite procedure as outlined by Holmgren (1967). Concentrations were determined by atomic absorption spectrophotometry using a Perkin-Elmer Spectrophotometer. Free iron oxides are considered iron compounds which are not associated with silicate iron. The generalized reaction in soils is defined as:



where silicate iron (usually ferrous iron) is oxidized into ferric iron form which is most easily described by the Free Iron (Fe_d): Total Iron (Fe_T) ratio (Schwertmann, 1985). A number of studies have demonstrated a positive correlation between the amount of free iron oxides in a soil system and the relative age of the system (Blume and Schwertmann, 1969; Alexander, 1974; Singer, 1977; Torrent et al., 1980; Arduino et al., 1986).

A statistical analysis was performed on the samples from each pedon. Each pedon was analyzed as a unit or as a series of formations within the pedon. Where applicable, these formations were compared with the terra rossa samples collected from the rims of the appropriate sinkholes. A group means analysis of variance procedure was utilized to determine whether the means of the various indices between groups were significantly different. The variables chosen for these comparisons included the molar ratios of $\text{SiO}_2\text{:R}_2\text{O}_3$ molar ratio, the $\text{TiO}_2\text{:ZrO}_2$ molar ratio, Parkers weathering index, and the $\text{Fe}_d\text{:Fe}_T$ free to total iron ratio. The clay-free ratios of FS: (TS+Si) and FSi: (TS+SI) were also used. The Ryan-Einot-Gabriel-Welsch Multiple Range test was used to compare the means in each pedon using the PC-SAS® statistical software package. This all pairwise comparison controls for the Type I experimentwise error rate. Because duplicates were analyzed for each sample

for the total element analysis, the number of degrees of freedom for the molar ratios are double those for the clay-free ratios. The $\alpha=0.05$ significance level was selected for this analysis.

Extractable elements were used to document whether there were buried surfaces in the pedons studied. The elements Mn, Cu, Zn, Sr, Ba, and P were used for this procedure. Elements such as Mn, Cu, and Zn are common plant nutrients. Barium and Sr can be extracted from the soil solution by mass flow or diffusion into root cells and recycled by leaf, root, and other plant tissues. These metals can be retained in the surface of a soil by processes such as adsorption onto clay mineral surfaces, adsorption by organic matter, and complexation by residual organic compounds. Increased concentrations of these extractable metals in subsurface horizons can be indicative of former stable surfaces which are now buried (Foss et al., 1990; 1991; Foss, 1990). Phosphorus is a major component of organic materials and can be concentrated in the soil system due to human activity (Eidt, 1977; Proudfoot, 1976; Sjoberg, 1976; Mattingly and Williams, 1962; Griffith, 1980).

Cation exchange capacity (CEC) and base saturation were determined using NH_4OAc pH 7 and NaCl vacuum-extraction replacement procedures. The <2 mm fraction of soil sample was vacuum extracted with a 1 M NH_4OAc solution adjusted to pH 7, and the extractant was analyzed for extractable Ca and Mg using atomic absorption. Extractable Na and K were analyzed by flame emission. After two ethanol washes, the 10% NaCl-0.005 M HCl replacement solution was used for extraction and the extractant was distilled and titrated with 0.01 M HCl to determine NH_3 concentration and, therefore, measure the CEC of the soil sample (Roads, 1986; Thomas, 1986; Hammer and Lewis, 1987). This procedure was performed primarily for classification purposes.

RESULTS

Kavousi 1

The morphology at Kavousi 1 is representative of the bisequel nature of the pedon (Table 1, Appendix A). The profile consisted of 213 cm of a colluvial overburden of rounded phyllite and limestone pebbles and cobbles that buries an older soil. The underlying pedo-stratigraphic unit is a colluvium derived from a marl deposit upslope mixed with angular and tabular phyllite fragments. The morphology of the overburden exhibits a massive, single-grained structure with some evidence of weak subangular blocky structure between the rock fragments. The moist color is 10YR 4/4 and the unit has soil textures which range from sandy loam to gravelly sandy clay loam. There was a strong reaction with 1 M HCl. The boundary at the base of the C horizon at 213 cm was abrupt and smooth. Although the logistics of the field investigation prohibited detailed observation above 203 cm, it was inferred that minimal soil development had taken place in this unit and a cambic horizon below the A horizon was probably the extent of pedogenic development.

The lower sequence represented a rendzina soil with a relict argillic horizon and a truncated surface. There was no evidence of a buried A horizon associated with this unit. The moist color of the matrix ranged from a 2.5Y 6/4 to a 10YR 5/8. Redoxymorphic features were found between the ped faces and were generally 7.5YR 5/8 in color suggesting some segregation of iron due to movement of water between the ped faces. The structure of the horizons in this unit was moderate medium angular blocky in the 2Bt1b and 2Bt2b which changed to moderate medium subangular blocky, moderate medium prismatic, to massive in the 2BC1b and 2BC2b horizons. In the argillic horizons there is evidence of clay movement with the existence of thin clay skins on the ped faces. The textures ranged from gravelly clay loams in the argillic horizons, and very gravelly sandy clay loams in the lower

Table 1. Morphology of soil pedons investigated in the valley below the Vronda and Kastro archaeological sites.

Horizon	Lower Depth	Color		Texture	Structure	Boundary	Consistence	
		Dry	Moist				Moist	Dry
cm								
Kavousi 1								
A	20	n.d.	n.d.	SL	2mgr	n.d.	fr	n.d.
A-C	203	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
C	213	10YR 6/4	10YR 4/4	g SCL	0sg 1fsbk	as	fr	fi
2Bt1b	237	2.5Y 7/6	2.5Y 6/4	g CL	2mabk	cs	fr	fi
2Bt2b	275	2.5Y 7/4	2.5Y 6/4	g CL	2mabk	cs	fr	fi
2BC1b	340	2.5Y 7/4	2.5Y 5/4	vg SCL	2msbk 2mpr	cs	fr	fi
2BC2b	360+	10YR 6/8	10 YR 5/8	vg SCL	0m 1csbk	n.d.	fr	fi
Kavousi 2								
Ap	15	10YR 5/2	10YR 4/2	g SL	2mgr	aw	vfr	fr
Bw	47	10YR 6/4	10YR 4/6	vg L	1msbk	cs	fr	fi
C	61	10YR 6/4	10YR 4/6	vg SL	0sg 1msbk	cs	fr	fi
2Ab1	88	10YR 5/4	10YR 4/4	vg SL	1msbk	cs	fr	fi
2Ab2	116	10YR 5/4	10YR 4/4	L	1msbk	cs	fr	fi
2Cb	136+	10YR 5/3	10YR 4/3	vg SL	0sg 1msbk	n.d.	vfr	vfr

transitional horizons. The coarse fragments in the matrix consisted of angular and tabular phyllite fragments which were disoriented in the matrix. The lower sequence had a strong reaction to 1 M HCl.

The soil classification of the pedon at Kavousi 1 was not determined because the upper 203 cm was not adequately described in the field. From general field observations it appears that the pedon consists of two sequences; a truncated colluvium derived rendzina soil which was buried by a more recent colluvium that may have been derived from an alluvial formation upslope. The best field classification of the pedon at Kavousi 1 is a Xerochrept which overlies an old Rendoll.

The pedogenic development of this pedon can be described in the carbon and clay distributions (Tables 2 and 3, Figures 3 and 4). The organic carbon distribution is relatively high in the surface at 1.43% and decreases to 0.02% in the 2Bt1b horizon. The inorganic carbon distribution on the other hand increases dramatically in the lower sequence. From the C horizon to the 2Bt1b horizon, the inorganic carbon content increased from 1.51% to 4.52%. This reflects the high carbonate content in the colluvium derived from a marl deposit. The clay distribution in this profile shows some pedogenic development in the lower sequence. The overall clay content increases from 27.9% in the 2Bt1b horizon to 33.7% in the 2Bt2b horizon. There was also another increase from 21.7% in the 2BC1b horizon to 27.2% in the 2BC2b horizon. When the fine clay distribution is examined, one notices that there is an increase from 4.6% in the 2Bt1b horizon to 7.2% in the 2Bt2b horizon. This relationship correlates well with the presence of clay skins on the ped faces as noted in the soil morphology. The fine clay content decreases to 3.0% and 3.4% in the 2BC1b and 2BC2b horizons respectively. This relationship suggests that the lower portion of the pedon has not experienced the degree of weathering as the upper segment of the discontinuity.

Table 2. Particle size distribution of soil pedons investigated in the valley below the Vronda and Kastro archaeological sites.

Horizon	Lower Depth	Gravel (>2.00 mm)	Sand (2.00-0.05 mm)					Silt (50-2 μm)			Clay (<2 μm)	
			VCOS	COS	MS	FS	VFS	COSi	FSi	CoC	FC	
												cm
Kavousi 1												
A	20	12.6	12.0	13.4	7.9	12.8	11.8	11.4	15.0	11.0	3.8	
C	213	34.4	20.2	18.8	8.4	10.4	3.8	5.8	8.6	19.6	4.4	
2Bt1b	237	29.6	12.2	8.4	4.2	9.4	7.5	10.8	19.6	23.3	4.6	
2Bt2b	275	22.9	11.3	6.6	3.1	6.9	6.0	8.8	23.6	26.5	7.2	
2BC1b	340	42.0	16.3	12.8	6.7	13.1	7.8	8.6	13.0	18.7	3.0	
2BC2b	360+	46.5	15.7	11.9	5.1	10.8	6.3	8.0	15.0	23.8	3.4	
Kavousi 2												
Ap	15	27.5	6.9	13.7	11.2	20.2	7.8	8.7	12.8	13.8	4.9	
Bw	47	40.7	8.3	10.5	7.2	12.6	6.0	12.7	17.8	20.8	4.1	
C	61	44.1	12.0	14.1	9.1	17.2	9.6	9.5	11.5	14.6	2.4	
2Ab1	88	39.8	10.0	10.6	6.4	15.7	10.6	14.5	13.9	15.7	2.6	
2Ab2	116	13.8	5.0	4.0	3.9	13.9	14.1	16.2	19.3	20.4	3.2	
2Cb	136+	38.0	17.6	14.2	9.7	22.2	8.1	8.1	8.9	9.7	1.5	

Table 3. Chemical properties including carbon fractions, exchangeable cations, and pH of soil pedons investigated in the valley below the Vronda and Kastro archaeological sites.

Horizon	Lower Depth	NH ₄ OAc Extractable Cations										pH		
		Inorganic Carbon	Organic Carbon	Total Carbon	Ca	Mg	Na	K	NH ₄ OAc CEC	Base Saturation	1:1 H ₂ O	2:1 CaCl ₂		
	cm		%				cmol _c kg ⁻¹			%				
Kavousi 1														
A	20	0.85	1.43	2.28	25.0	0.83	0.29	0.43	8.49	313	7.60	7.33		
C	213	1.51	0.35	1.86	31.9	0.79	0.96	0.16	7.82	433	8.39	7.41		
2Bt1b	237	4.52	0.02	4.54	40.2	1.26	0.41	0.10	10.74	391	8.27	7.80		
2Bt2b	275	5.05	0.21	5.26	38.4	1.88	0.99	0.11	8.63	479	8.10	7.80		
2BC1b	340	3.80	0.00	3.80	43.5	2.84	0.98	0.10	9.94	477	8.45	7.60		
2BC2b	360+	4.39	0.19	4.58	39.6	2.57	0.43	0.11	5.02	851	8.23	7.75		
Kavousi 2														
Ap	15	2.14	2.10	4.24	27.9	1.69	1.33	1.10	8.23	389	7.70	7.49		
Bw	47	2.18	0.47	2.65	30.9	0.65	0.41	0.24	7.59	424	7.99	7.61		
C	61	3.21	0.26	3.47	32.6	0.55	0.31	0.12	5.73	586	8.69	7.79		
2Ab1	88	3.00	0.42	3.42	33.6	0.80	1.77	0.13	6.51	558	7.89	7.59		
2Ab2	116	3.50	0.49	3.99	39.1	1.87	2.80	0.09	7.14	614	7.60	7.61		
2Cb	136+	4.13	0.34	4.47	32.9	1.43	3.32	0.07	4.28	881	7.70	7.50		

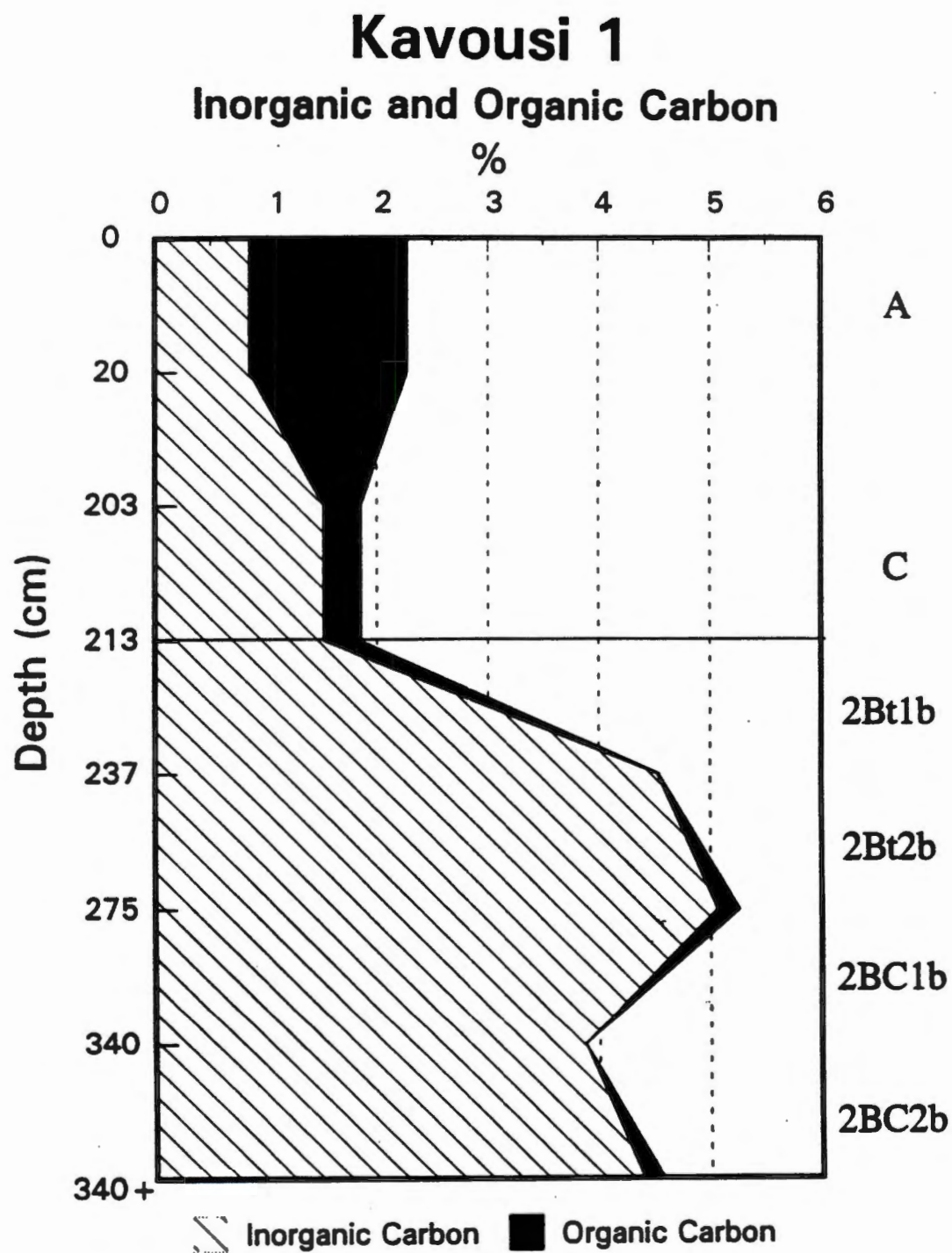


Figure 3. Distribution of inorganic and organic carbon vs. depth for the Kavousi 1 soil pedon.

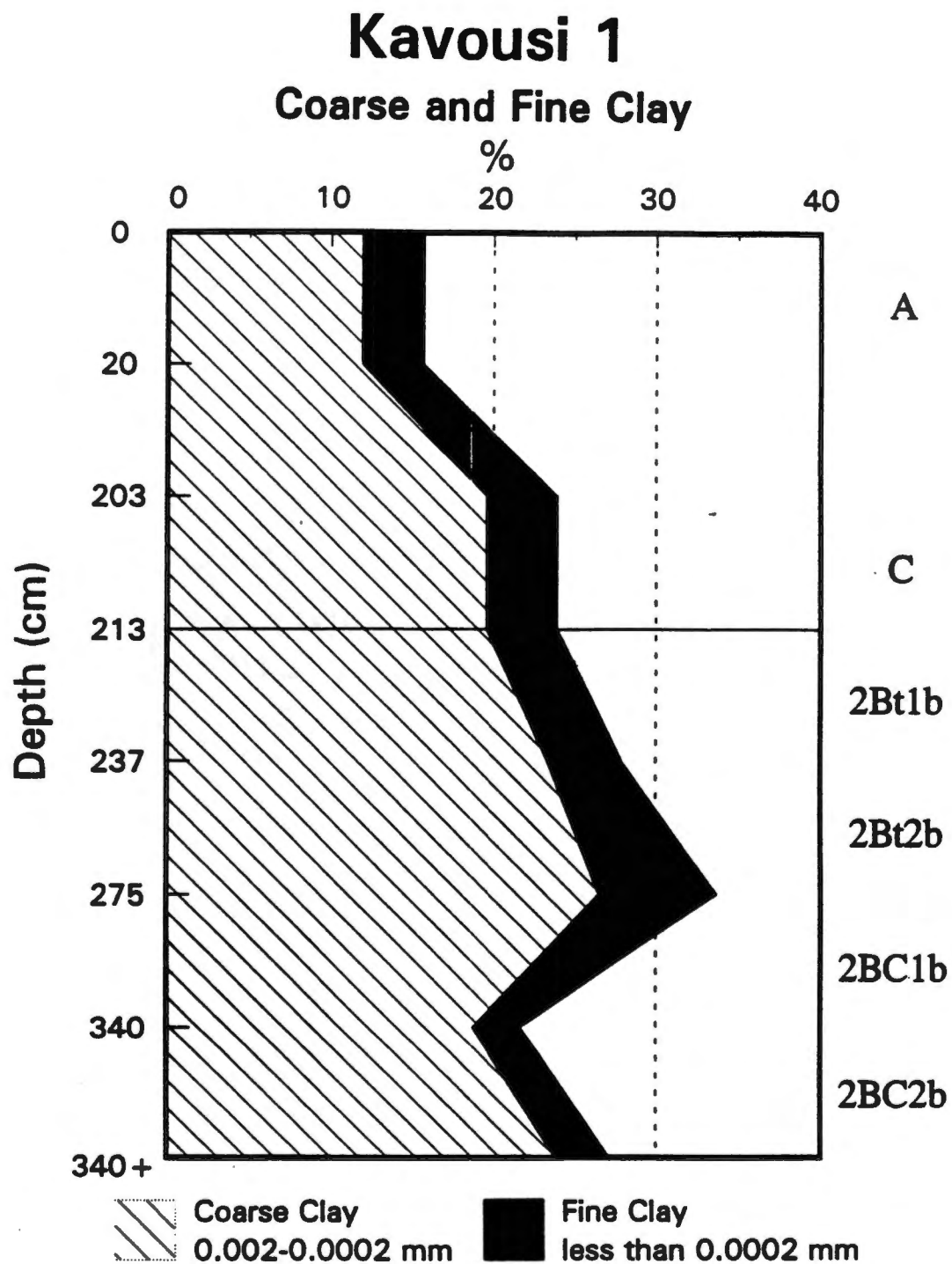


Figure 4. Distribution of coarse and fine clay, as determined by particle size analysis, vs. depth for the Kavousi 1 soil pedon.

Examination of other chemical properties also aid in characterizing the pedon at Kavousi 1 (Table 3). The pH's of the pedon are relatively high ranging from 7.60 to 8.45 (1:1 soil:water). The exchangeable cations, analyzed by NH_4OAc adjusted to pH 7 extraction, are going to be overrepresented in terms of the amount of Ca and Mg in the sample. This is reflected in the observation that the base saturation calculated for each horizon well exceeds 100%. Nevertheless, the exchangeable Ca increases from $31.9 \text{ cmol}_c \text{ kg}^{-1}$ in the C horizon to $40.2 \text{ cmol}_c \text{ kg}^{-1}$ in the 2Bt1b horizon. The Mg content also increases from $0.79 \text{ cmol}_c \text{ kg}^{-1}$ in the C horizon to $1.26 \text{ cmol}_c \text{ kg}^{-1}$ in the 2Bt1b horizon. In general, the amount of exchangeable Ca is $10 \text{ cmol}_c \text{ kg}^{-1}$ higher in the lower sequence and the exchangeable Mg is more than double in the lower sequence in comparison to the upper sequence. This relationship reflects the carbonatic nature of the rendzina soil represented in the lower sequence.

Clay-free ratios were used to examine the nature of the discontinuity between the colluvial overburden and the underlying rendzina (Tables 4 and 5, Figure 5). The fine sand ratio ($\text{FS}:\text{TS} + \text{Si}$) does little to discriminate between these two formations. The overburden had a ratio of 0.145 with a coefficient of variation (CV) of 7.28% and the rendzina had an average ratio of 0.138 with a CV of 19.37% which is not significantly different. The distribution of the fine sand ratio with depth shows a fairly regular distribution and little variability with values ranging from 0.105 to 0.168. The fine silt ratio ($\text{FSi}:\text{TS} + \text{Si}$), on the other hand, demonstrates more of the variability between the two units. An average fine silt ratio of 0.14 with a CV of 31.89% in the overburden is contrasted with an increase to 0.272 in the 2Bt1b and 0.356 in the 2Bt2b horizons. This relationship seems to show an enrichment of fine silt in the upper portions of the rendzina and is a pattern similar to the Karphi 4 pedon (chapter 2 this dissertation). The average fine silt ratio for the rendzina is 0.250 with

Table 4. Weathering indices and clay-free ratios determined for soil pedons investigated in the valley below the Vronda and Kastro archaeological sites.

Horizon	Lower Depth cm	Weathering Indices				Clay-free Ratios	
		SiO ₂ :R ₂ O ₃	TiO ₂ :ZrO ₂	Parker's Weathering Index	Fe _d :Fe _T	FS:(TS+Si)	FSi:(TS+Si)
Kavousi 1							
A	20	5.16	396.6	32.8	0.067	0.152	0.179
C	213	4.57	—	44.2	0.067	0.137	0.113
2Bt1b	237	4.76	—	71.8	0.060	0.131	0.272
2Bt2b	275	4.45	—	80.6	0.107	0.105	0.356
2BC1b	340	5.18	—	68.4	0.047	0.168	0.166
2BC2b	360+	4.91	—	77.0	0.049	0.148	0.206
Kavousi 2							
Ap	15	5.14	—	50.0	0.073	0.249	0.157
Bw	47	4.53	263.3	50.7	0.071	0.168	0.237
C	61	5.26	—	61.7	0.062	0.207	0.139
2Ab1	88	5.14	—	60.9	0.064	0.200	0.170
2Ab2	116	4.83	—	67.2	0.075	0.182	0.253
2Cb	136+	6.66	—	75.0	0.060	0.250	0.101

Table 5. Statistical results of Ryan-Einot-Gabriel-Welsch multiple range tests for weathering indices and clay-free ratios for soil pedons investigated in the valley below the Vronda and Kastro archaeological sites.

	Molar Ratios				Clay-free Ratios	
	SiO ₂ :R ₂ O ₃	TiO ₂ :ZrO ₂	Parker's Weathering Index	Fe _d :Fe _T	FS:(TS+Si)	FSi:(TS+Si)
Kavousi 1						
0-213 cm						
$\bar{x}$	4.86a†	—	42.3a	0.067a	0.145a	0.146a
SD	0.71	—	6.8	0.001	0.011	0.047
CV (%)	14.57	—	16.16	1.31	7.28	31.89
<i>n</i>	4	—	4	4	2	2
213-340 cm						
$\bar{x}$	4.82a	—	77.6b	0.061a	0.138a	0.250a
SD	0.39	—	4.7	0.018	0.027	0.083
CV (%)	8.02	—	5.99	28.79	19.37	33.17
<i>n</i>	8	—	8	8	4	4
LSD	0.69	—	7.36	0.020	0.057	0.182
df	10	—	10	10	4	4
α	0.05	—	0.05	0.05	0.05	0.05

† Group means with the same letter(s) are not significantly different at the $\alpha=0.05$ level

Table 5. continued.

	Molar Ratios				Clay-free Ratios	
	$\text{SiO}_2:\text{R}_2\text{O}_3$	$\text{TiO}_2:\text{ZrO}_2$	Parker's Weathering Index	$\text{Fe}_a:\text{Fe}_T$	$\text{FS}:(\text{TS}+\text{Si})$	$\text{FSi}:(\text{TS}+\text{Si})$
Kavousi 2						
0-61 cm						
$\bar{x}$	4.98a†	—	57.6a	0.068a	0.208a	0.178a
SD	0.40	—	5.9	0.005	0.040	0.052
CV (%)	8.04	—	10.20	7.69	19.32	29.35
<i>n</i>	6	—	6	6	3	3
61-116 cm						
$\bar{x}$	5.55a	—	70.8b	0.066a	0.211a	0.175a
SD	0.95	—	6.6	0.008	0.036	0.076
CV (%)	17.11	—	9.35	11.46	16.92	43.76
<i>n</i>	6	—	6	6	3	3
LSD	0.94	—	8.05	0.008	0.086	0.148
df	10	—	10	10	4	4
α	0.05	—	0.05	0.05	0.05	0.05

† Group means with the same letter(s) are not significantly different at the $\alpha=0.05$ level

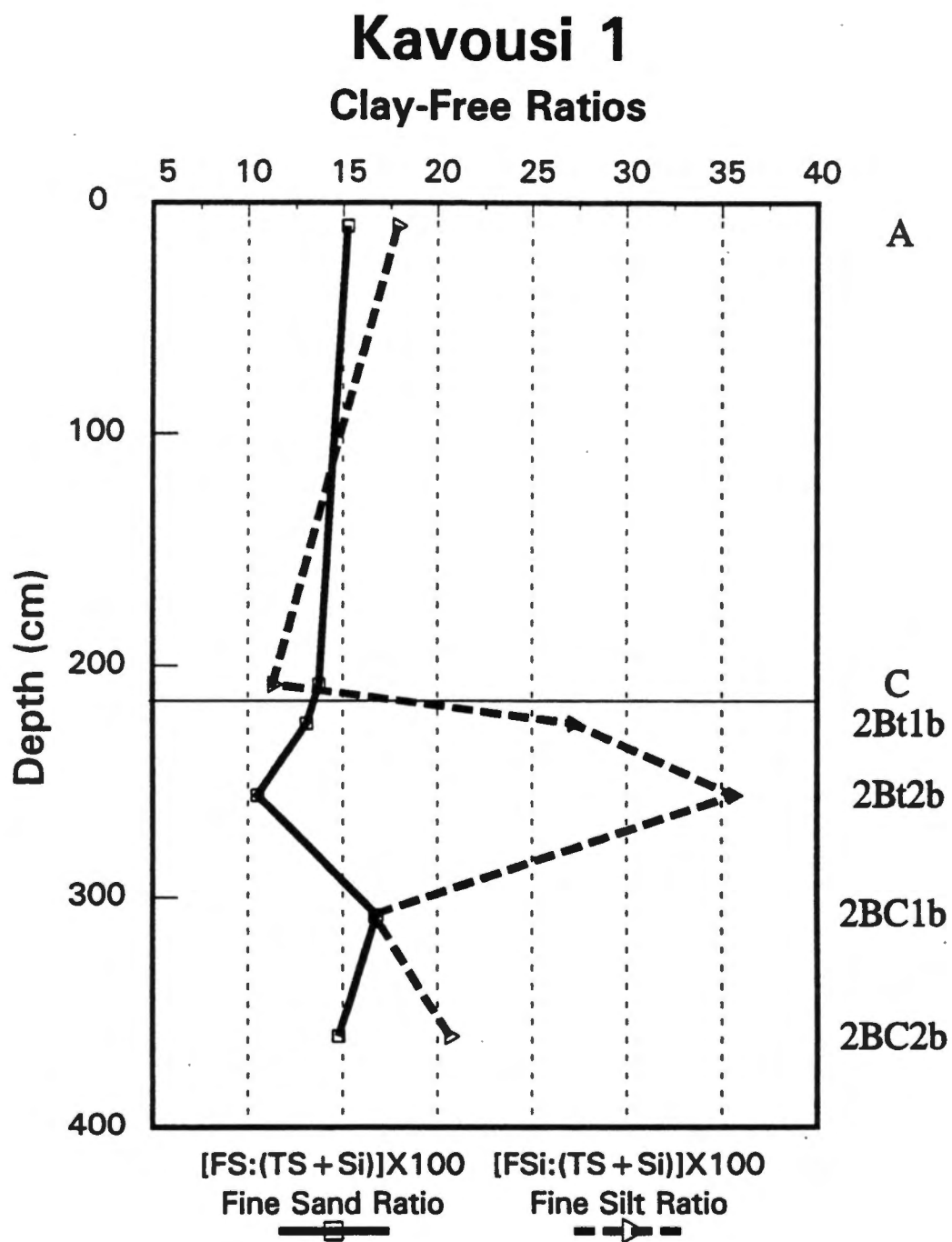


Figure 5. Distribution of clay-free ratios, as determined by particle size analysis, vs. depth for the Kavousi 1 soil pedon.

a CV of 33.17% which is not significantly different from the colluvial overburden. However, the distribution of this ratio with depth shows the discontinuity relatively well.

An analysis of the weathering indices calculated for the samples at Kavousi 1 show that some of these values aid in discriminating the two soil units better than others (Tables 4 and 5, Figure 6). The $\text{SiO}_2\text{:R}_2\text{O}_3$ ratio and the $\text{Fe}_d\text{:Fe}_T$ ratios do little to show the differences in the two sequences. The upper part of the soil profile has an average $\text{SiO}_2\text{:R}_2\text{O}_3$ ratio of 4.86 with a CV of 14.57%, and the rendzina has an average ratio of 4.82 with a CV of 8.02% which is not significantly different. The average $\text{Fe}_d\text{:Fe}_T$ ratio for the overburden is 0.067 with a CV of 1.31% and the average ratio for the rendzina is 0.061 with a CV of 28.79% which is also not significantly different. The Zr values were generally below detectable limits, and $\text{TiO}_2\text{:ZrO}_2$ ratios could not be analyzed for the pedon. However, the use of Parkers Weathering Index helped to discriminate between the two sequences. The overburden had an average index of 42.3 with a CV of 16.16% and the rendzina had an average index of 77.6 with a CV of 5.99%. A statistical test of these means show that they are significantly different. The high values in the rendzina show that this unit is enriched in regard to Ca, Mg, Na, and K. Because the parent materials of this sequence were probably derived from some chalks and marls located upslope, the enrichment of these weatherable elements in the rendzina is reasonable. A plot of the Parker's Weathering Index with depth shows that there is a rather clear discontinuity between these two units particularly between the C horizon (44.2) and the underlying 2Bt1b horizon (71.8).

An examination of the distribution of extractable elements with depth aid in distinguishing between the character of the colluvial overburden and the colluvial rendzina (Table 6, Figure 7). The distribution of Ba shows an enrichment of this element in the colluvial overburden with 109 and 142 mg kg⁻¹ in the A and C horizons respectively, and a

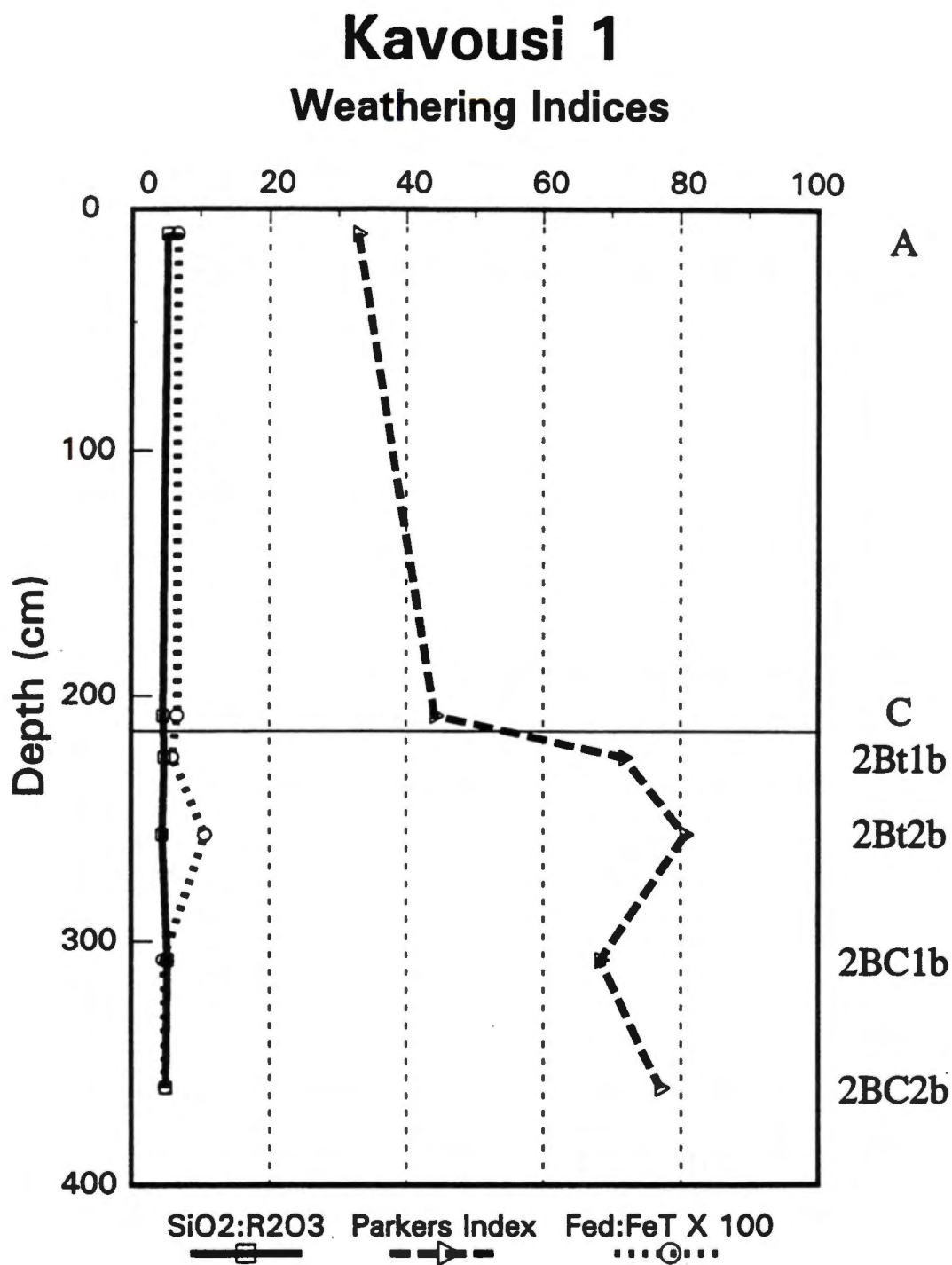


Figure 6. Plot of weathering indices, as determined by total element analysis and citrate-dithionite extraction, vs. depth for the Kavousi 1 soil pedon.

Table 6. Elemental concentrations determined by archaeological extract method for soil pedons investigated in the valley below the Yronda and Kastro archaeological sites.

Extractable Elements							
Horizon	Lower Depth	Ba	Cu	Mn	P	Pb	Sr
		mg kg ⁻¹					
Kavousi 1							
A	20	109	15.1	764	190	5.48	274
C	213	142	7.56	394	73.3	2.34	326
2Bt1b	237	88.8	6.60	398	59.9	0.00	734
2Bt2b	275	42.2	6.18	365	0.0	0.00	747
2BC1b	340	37.5	6.55	405	108	0.00	767
2BC2b	360+	31.9	7.27	360	40.8	0.00	820
Kavousi 2							
Ap	15	105	8.57	552	105	3.82	162
Bw	47	143	11.7	656	100	1.44	180
C	61	105	8.96	451	107	1.82	208
2Ab1	88	87.2	9.32	495	133	1.61	188
2Ab2	116	62.2	11.2	329	101	1.82	204
2Cb	136+	48.1	8.09	383	61.3	1.01	272

Kavousi 1

Archaeological Extract

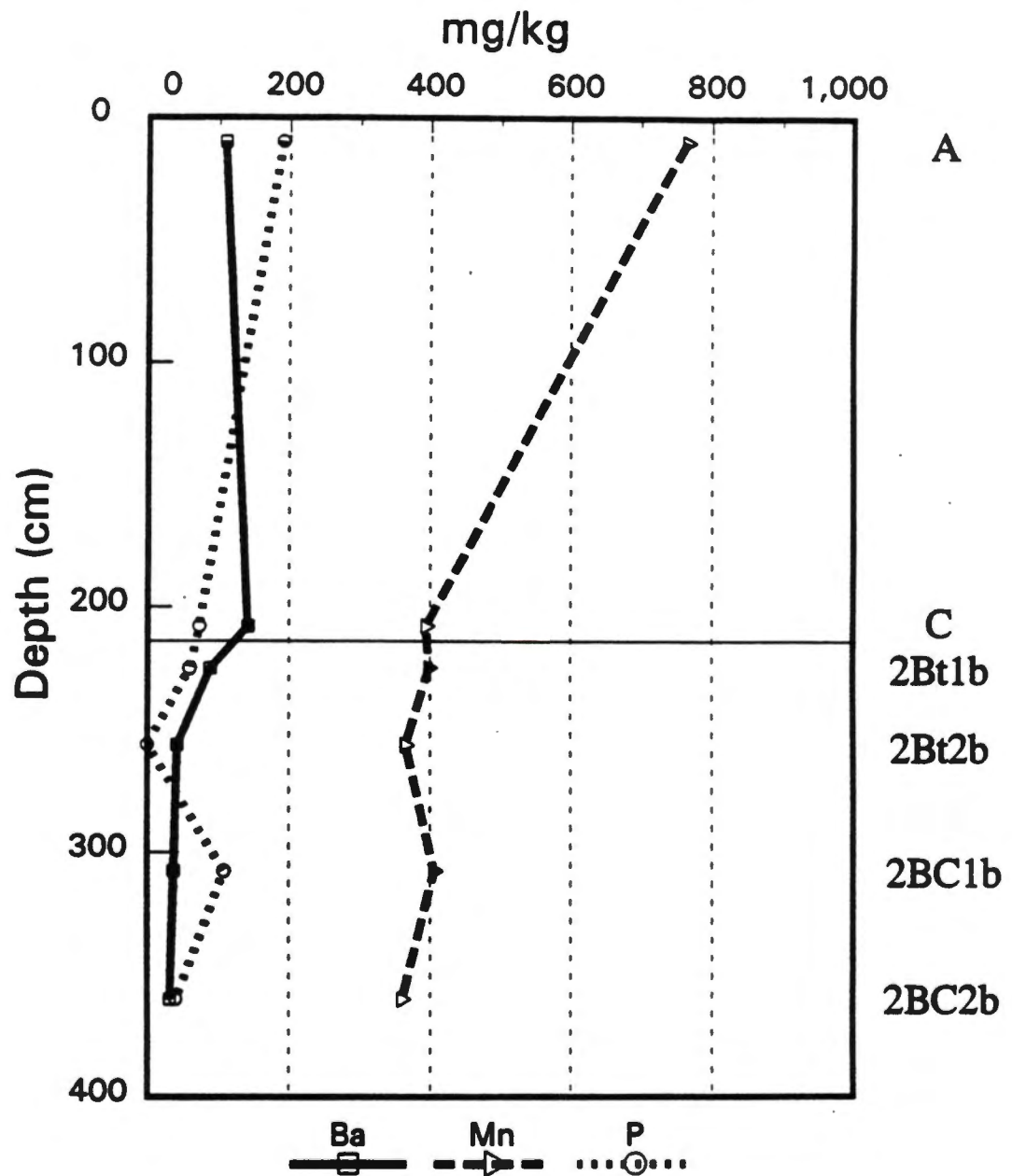


Figure 7. Distribution of extractable elements, as determined by archaeological extraction method, vs. depth for the Kavousi 1 soil pedon.

regular decrease from 88.8 mg kg⁻¹ in the 2Bt1b to 31.9 mg kg⁻¹ in the 2BC2b horizon. The distribution of Cu in the profile shows an enrichment in the surface A horizon of 15.1 mg kg⁻¹ and a dramatic drop to 7.56 mg kg⁻¹ in the C horizon. The Cu concentration then decreases gradually to 6.18 mg kg⁻¹ in the 2Bt2b horizon and a gradual increase to 7.27 mg kg⁻¹ in the 2BC2b horizon. The relatively elevated values in the surface may be indicative of some recycling of Cu by vegetation at the surface. The same relationship can be observed in the Mn distribution. There is a concentration of 764 mg kg⁻¹ in the A horizon which decreases by almost one-half in the C horizon of 394 mg kg⁻¹. The remaining values range from 405 mg kg⁻¹ to 360 mg kg⁻¹ which may indicate little recycling of this element. A similar relationship can be observed with the distribution of P with depth. The highest value is 190 mg kg⁻¹ in the surface which again declines by almost one-half to 73.3 mg kg⁻¹ in the C horizon. The values decrease to undetectable in the 2Bt2b horizon, increase to 108 mg kg⁻¹ in the 2BC1b horizon and again decline to 40.8 mg kg⁻¹ in the 2BC2b horizon. Because P is sometimes associated with human influence one can conclude that only the present surface may have been effected by human activity. The values of Pb are only detectable in the colluvial overburden, and this relationship may be due to human influence as well. The values of Sr are 274 and 326 mg kg⁻¹ in the A and C horizons of the colluvial overburden. These values nearly double to 734 mg kg⁻¹ in the 2Bt1b horizon and gradually increase to 820 mg kg⁻¹ in the 2BC2b horizon. This relationship is likely due to the enrichment of Sr in the rendzina, perhaps as a carbonate as a part of the chalk or marl matrix.

The general observation of the pedon at Kavousi 1 is that the morphology of the unit most clearly defines the discontinuity and alludes to the pedogenic history. The buried rendzina soil exhibits a distinct argillic horizon and soil structure. The development of argillans on the ped faces as well as redoxymorphic features between the ped faces attest to

a period of stability and pedogenesis that occurred in the past. The buried soil had no buried surface horizon (Ab) associated with it. The colluvial overburden in contrast showed minimal development of soil structure and little pedogenic weathering. This particular pattern was noted at two pedons at the Karphi archaeological site (Part 2 this dissertation). The recurring theme seems to be a distinct period of stability where an argillic horizon is formed followed by an episode of truncation where the surface A horizon is systematically removed. This soil is then subsequently buried by a colluvium or alluvium that shows little or no pedogenic development. By use of artifacts and radiocarbon dates, the two soils at the Karphi site exhibit a Late Minoan association about 3,000 years ago for the buried soil. Although no artifacts were found or radiocarbon dates were taken, it may be plausible to believe that the buried soil was the original surface during the Minoan occupation of the Kavousi area. The truncated A horizon may then be related to human induced erosion in the Avgos valley gorge, perhaps due to landscape denudation.

Kavousi 2

The soil pedon of Kavousi 2 was located north of the village of Kavousi in the exposed section of a dissected alluvial fan (Figure 1). The alluvial fan is now occupied by an extensive olive grove in the valley below Kavousi. Sediments of the alluvial fan originated from the Avgos gorge and the sediments very likely correspond to the upper section of the Kavousi 1 pedon. The pedon at Kavousi 2 consisted of two sequences of alluvium. The upper sequence was separated from the lower sequence by a lag gravel deposit. The second alluvial sequence contained Minoan age ceramic fragments and was believed to be part of a soil system which dated to that period.

The soil morphology helped in distinguishing the two sequences from each other (Table 1, Appendix A). The upper sequence exhibited a young soil. The Ap horizon was

relatively dark with a moist color of 10YR 4/2 and the Bw and C horizons showed brighter 10YR 4/6 colors below. The textures ranged from a gravelly sandy loam in the Ap to a very gravelly loam in the Bw and a very gravelly sandy loam in the C or lag channel deposit. Structures were moderate medium granular in the surface to weak subangular blocky in the Bw horizon, and weak medium subangular blocky between the rock fragments in the C horizon. One of the more important features was that there were no artifacts found in the matrix of the upper alluvial sequence.

The second alluvial sequence at Kavousi 2 begins at 61 cm below the surface and is overlain by the first sequence. Darker moist colors of 10YR 4/4 in the 2Ab1 and 2Ab2 horizon, and 10YR 4/3 in the 2Cb horizon help distinguish this sequence from the overlying alluvium. Textures range from very gravelly sandy loam in the 2Ab1 and 2Cb horizons to loam in the 2Ab2 horizon. The soil structure in this sequence is a weak medium subangular blocky. There were no argillans observed on the ped faces in any of the horizons. Particularly notable was the presence of Minoan pottery fragments in the 2Ab1 and 2Cb horizons. A radiocarbon whole soil sample consisting of a composite of approximately 1,500 g of soil from the 2Ab1 and 2Ab2 horizons yielded a ^{14}C date of $3,040 \pm 90$ yr. B.P. (Beta-68290). This date is consistent with a Late Minoan association and it is believed that this soil was the surface during the Minoan inhabitation of the Kavousi area.

The soil classification of this pedon involved the upper 61 cm and the paleosol was considered to be too deeply buried for the characterization. The presence of a cambic horizon, an ochric epipedon, and a xeric moisture regime placed this pedon in the Xerochrepts great group. The pedon had an irregular carbon distribution with depth and had a slope less than 25% (Table 3, Figure 8). These characteristics place the pedon in the Fluventic Xerochrepts subgroup. A loamy skeletal particle size class, a mixed mineralogy, and

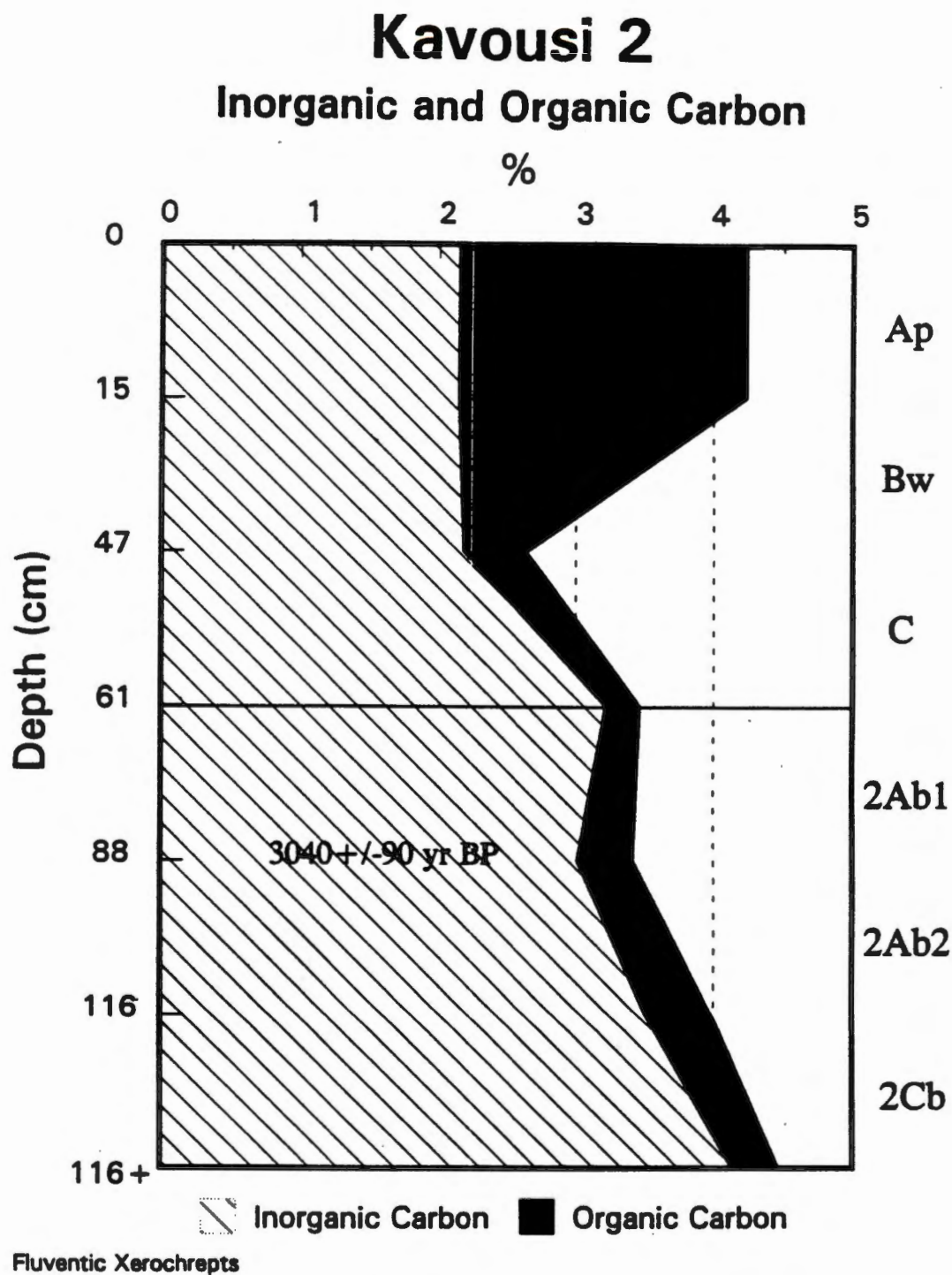
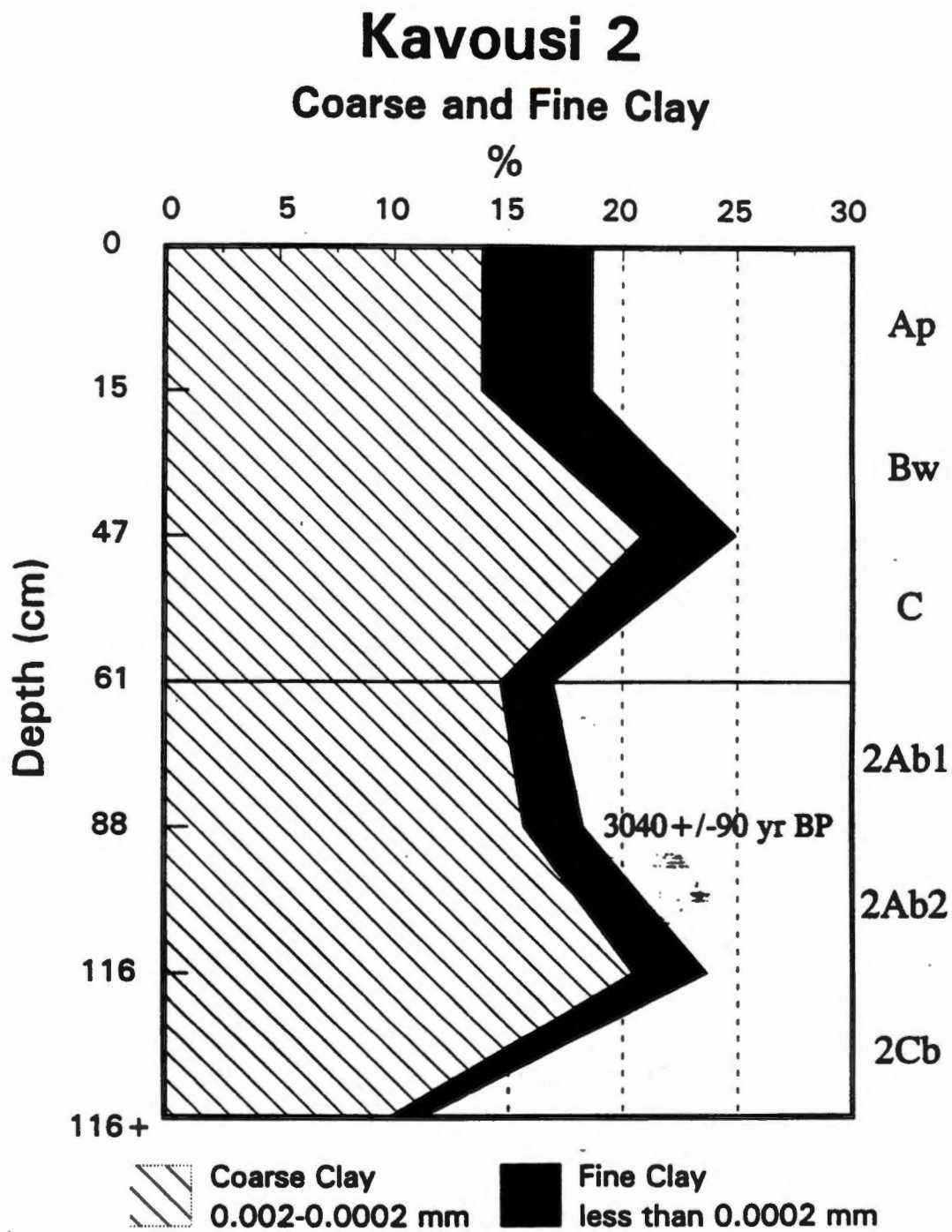


Figure 8. Distribution of inorganic and organic carbon vs. depth for the Kavousi 2 soil pedon.

a thermic temperature regime place this pedon in the loamy skeletal, mixed, thermic Fluventic Xerochrepts family (Soil Survey Staff, 1990).

An examination of the distribution of clay in the profile aids in the characterization of the sequences (Table 2, Figure 9). The distribution of clay in the profile suggests that two episodes of illuviation had occurred. The total clay content increases from 18.7 to 24.9% from the Ap to the Bw horizon. There is another increase of 18.3 to 23.6% from the 2Ab1 to the 2Ab2 horizon. Although the increase in clay content in both sequences are sufficient to define an argillic horizon, there are two fundamental characteristics that do not define these horizons as argillic. First, the ratio of fine clay to coarse clay does not increase in the lower horizon in comparison to the upper horizon as is common in illuvial horizons. Second, there was no evidence of clay illuviation in the form of clay skins or argillans on the ped faces in the Bw or the 2Ab2 horizons. This increase in clay content is related to alluvial stratification and not illuviation. Therefore, the horizons were not defined as argillic and only a cambic horizon can be defined in the upper sequence.

The distribution of carbon in the profile helps to illustrate the bisquel nature of the pedon (Table 2, Figure 8). The organic carbon content decreases uniformly from 2.10% in the Ap horizon to 0.26% in the C horizon. An increase in organic carbon can be observed with a value of 0.42% in the 2Ab1 and 0.49% in the 2Ab2 horizons denoting buried surfaces. Inorganic carbon contents seem to have accumulated in the lower sequence. The inorganic carbon content increases from 2.14% in the Ap horizon to 3.21% in the C horizon. A decrease in inorganic carbon content to 3.00% in the 2Ab1 horizon could be explained by the weathering and subsequent loss of carbonates in a former surface soil. The inorganic carbon content increases to 4.13% in the 2Cb horizon.



Fluventic Xerochrepts

Figure 9. Distribution of coarse and fine clay, as determined by particle size analysis, vs. depth for the Kavousi 2 soil pedon.

An examination of the exchangeable cations can also provide insight into the development of the two soil sequences in this pedon (Table 2). The NH_4OAc pH 7.0 vacuum extraction method for this pedon has more than likely overestimated the exchangeable Ca and Mg contents. This explains the greater than 100% base saturations calculated for the profile and is evidenced by the high inorganic carbon concentrations throughout the profile. Calcium and Mg carbonates likely contribute to the high base saturation measurements. The one striking difference between the upper sequence and the lower sequence is the two-fold difference in exchangeable Na. Exchangeable Na decreases from $1.33 \text{ cmol}_\text{c} \text{ kg}^{-1}$ to $0.305 \text{ cmol}_\text{c} \text{ kg}^{-1}$ between the Ap and the C horizons. The exchangeable Na content increases from $1.77 \text{ cmol}_\text{c} \text{ kg}^{-1}$ in the 2Ab1 horizon to $3.32 \text{ cmol}_\text{c} \text{ kg}^{-1}$ 2Cb horizon. A similar pattern was observed in the Kavousi 3 pedon (Part 3 this dissertation) where the explanation was movement of cations by capillary water activity in the lower portions of the section. A similar situation may explain this pattern at the Kavousi 2 pedon. There is also the possibility salt spray from the Mediterranean plays a role in exchangeable Na enrichment, particularly in the surface horizon.

A comparison of the clay-free ratios do little to help define the differences between the two sequences represented in the Kavousi 2 pedon (Tables 4 and 5, Figure 10). An analysis of the means of the clay-free ratios shows that the two sequences are not statistically different. The average fine sand value for the upper sequence is 0.208 with a coefficient of variation (CV) of 19.32% while the average value for the lower sequence is 0.211 with a CV of 16.92%. The fine silt ratio in the upper sequence averages 0.178 with a CV of 29.35% and the average for the lower sequence is 0.175 with a CV of 43.76%. This evidence seems to indicate that the two sequences are similar in their modes of deposition as measured by their particle sizes.

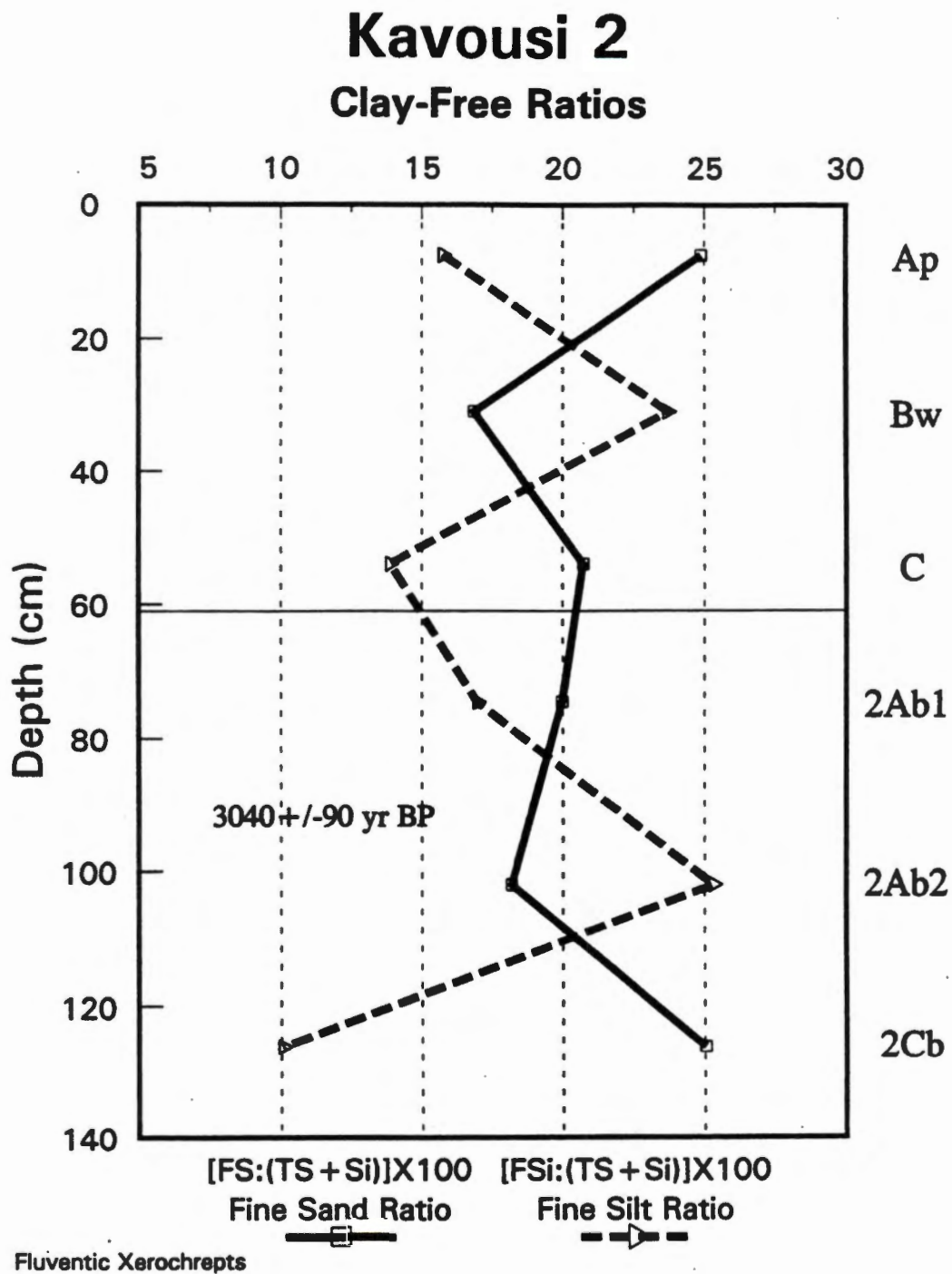


Figure 10. Distribution of clay-free ratios, as determined by particle size analysis, vs. depth for the Kavousi 2 soil pedon.

An examination of the clay-free ratios with depth yields an interesting pattern (Figure 10). There seems to be a fine silt peak in the second horizon of each sequence. There also seems to be a decrease in the fine sand component in the same horizons. The fine silt ratio (FSi:TS + Si) value in the upper sequence increases from 0.157 in the Ap horizon to 0.237 in Bw horizon. The fine sand ratio decreases from 0.249 to 0.168 in the same horizons. Likewise, the fine silt ratio increases from 0.170 in the 2Ab1 horizon to 0.253 in the 2Ab2 horizon. Also the fine sand ratio decreases from 0.200 to 0.182 in the same horizons. The fine silt ratios also decrease for the two lag channel deposits (C and 2Cb horizons) and the fine sand ratios increase for the same horizons. This evidence seems to indicate that the variability in the clay-free ratios in this pedon is primarily within the two sequences rather than between the two. The depositional characteristics for each sequence are likely due to similar depositional processes; one which occurred prior to 3,000 yr. B.P. and one which occurred at a later time.

In a manner similar to the clay-free ratios, the weathering indices calculated for the horizons in the Kavousi 2 pedon also do little to discriminate between the two sequences (Tables 4 and 5, Figure 11). The mean $\text{SiO}_2\text{:R}_2\text{O}_3$ ratio for the upper sequence is 4.98 with a CV of 8.04% and the mean $\text{SiO}_2\text{:R}_2\text{O}_3$ ratio for the lower sequence is 5.55 with a CV of 17.11% which is not significantly different. The mean $\text{Fe}_d\text{:Fe}_T$ ratio for the upper sequence is 0.068 with a CV of 7.69% and the lower sequence has a mean $\text{Fe}_d\text{:Fe}_T$ ratio of 0.066 with a CV of 11.46% which is also not significantly different. This relationship may indicate that pedogenic processes operating on the pedon have not significantly altered the characteristics of the profile in 3,000 years. The major difference between the sequence is with the Parkers Weathering Index. The upper sequence exhibits a mean Parkers Index of 57.6 with a CV of 10.20% and the lower sequence has a mean Parkers Index of 70.8 with a CV of 11.46% which

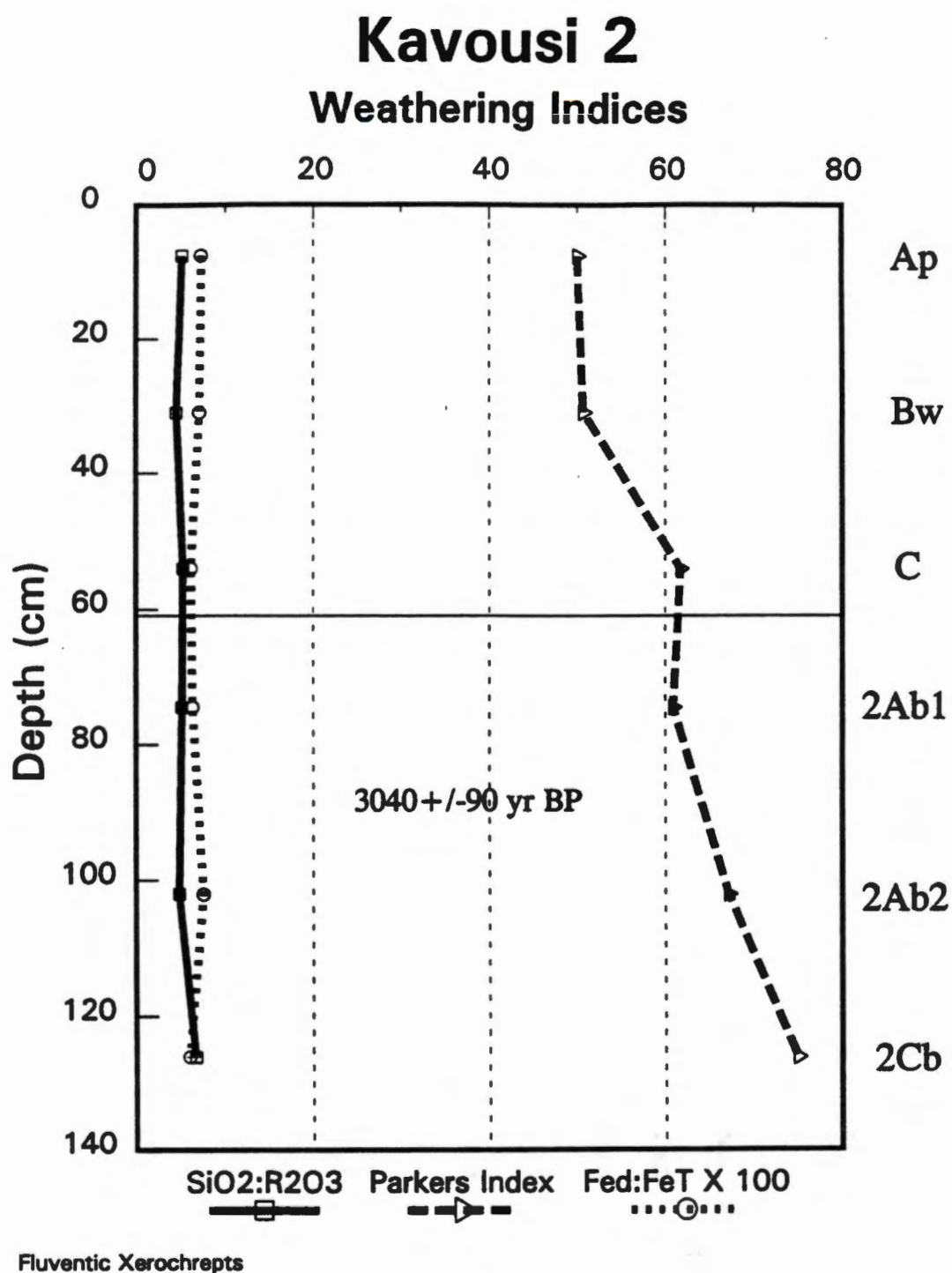


Figure 11. Plot of weathering indices, as determined by total element analysis and citrate-dithionite extraction, vs. depth for the Kavousi 2 soil pedon.

is significantly different. The reason for this discrepancy is the high total Ca values in the lower sequence in comparison to the upper sequence (Appendix B). There seems to be some accumulation of carbonates in the lower sequence, perhaps due to some capillary activity for the CaO values increase with depth from 15.4% in the 2Ab1 horizon to 20.5% in the 2Cb horizon. An alternative explanation would be that some weathering had occurred in the lower sequence and the Ca in the form of CaCO_3 had been leached out of the surface and redeposited in the lower horizons. This relationship can be observed in plot of Parkers Weathering Index with depth which shows an increase of the index from 50.0 in the Ap horizon to 75.0 in the 2Cb horizon (Figure 11).

The nature of the pedon at Kavousi 2 is best characterized by an examination of the distribution of extractable elements using the Archaeological extract (Table 6, Figure 12). The distribution of extractable Sr with depth seems to correspond with the inorganic carbon content. Sr values increase from 162 mg kg^{-1} in the Ap horizon to 208 mg kg^{-1} in the C horizon. There is a slight decrease to 188 mg kg^{-1} in the 2Ab1 horizon and another gradual increase to 272 mg kg^{-1} in the 2Cb horizon. Extractable Pb values decrease irregularly from a peak of 3.82 mg kg^{-1} in the Ap horizon to 1.01 mg kg^{-1} in the 2Cb horizon. This concentration of Pb in the surface could be explained by some retention of Pb in the organic compounds and plant roots at the surface or perhaps by the use of lead products (e.g. gasoline) in modern times. Extractable Cu values tend to follow the pattern of accumulation of the element by soil surfaces. The extractable Cu values increase from 8.57 mg kg^{-1} in the Ap horizon to 11.7 mg kg^{-1} in the Bw horizon. A similar pattern is found with a value of 9.32 mg kg^{-1} in the 2Ab1 horizon to 11.2 mg kg^{-1} in the 2Ab2 horizon. This seems to show some recycling of Cu in the soil surface and the buried surface. Extractable Mn exhibits a similar pattern. Manganese values increase from 552 mg kg^{-1} in the Ap horizon to 656 mg kg^{-1} in

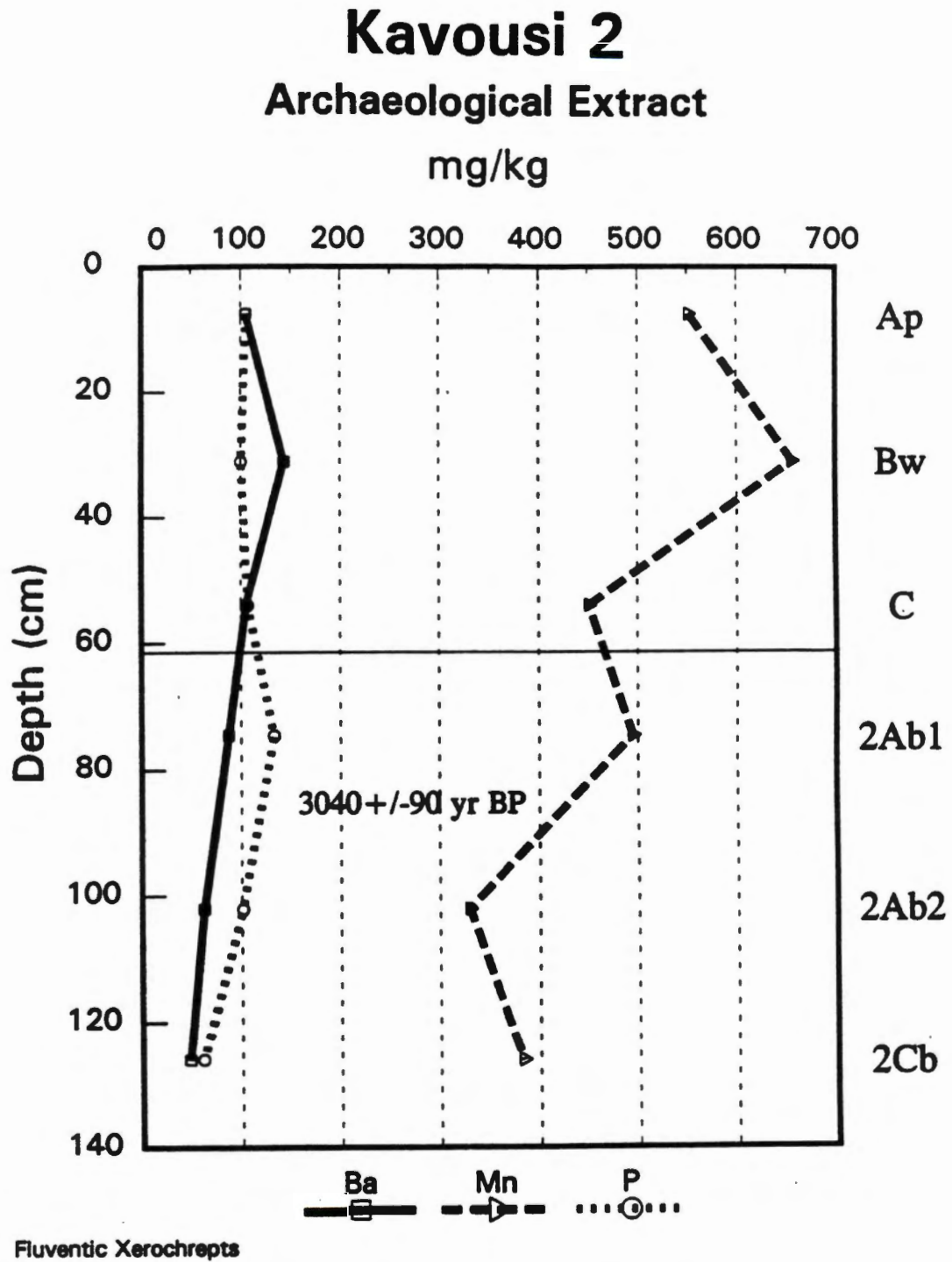


Figure 12. Distribution of extractable elements, as determined by archaeological extraction method, vs. depth for the Kavousi 2 soil pedon.

the Bw horizon and decreases to 451 mg kg⁻¹ in the C horizon. There is another increase in Mn of 495 mg kg⁻¹ in the 2Ab1 horizon and a steady decrease to 329 mg kg⁻¹ in the 2Ab2 horizon. Extractable Ba values do not show an accumulation in the surfaces of the pedon. There is an increase in extractable Ba from 105 mg kg⁻¹ in the Ap horizon to 143 mg kg⁻¹ in the Bw horizon, and a steady decrease to 48.1 mg kg⁻¹ in the 2Cb horizon. Extractable P seems to define the nature of the pedon more than any of the other extractable elements. An irregular distribution of P from 105 mg kg⁻¹ in the Ap horizon to 107 mg kg⁻¹ in the C horizon is observed. A concentration of P of 133 mg kg⁻¹ is observed in the 2Ab1 horizon which correlates well with the position of Minoan period artifacts in the profile. There is a decrease in extractable P to 61.3 mg kg⁻¹ in the 2Cb horizon. This seems to indicate that there is not only a buried soil at this depth, but that there was likely human influence as well.

The important characteristic of the pedon at Kavousi 2 is that it consisted of two depositional sequences which seem to be intact. The nature of the grain sizes in the horizons show that each sequence represents a silty overbank deposits over a lag gravel deposit. The chemical nature of the profile shows that there has been little or no measurable weathering that has taken place over the past 3,000 years in the pedon. The fact that Minoan ceramic fragments were found in the buried A horizon of the second sedimentary sequence plus a compatible ¹⁴C date indicates that this surface was present at the time of Minoan inhabitation of the area. The major difference between the two sequences is an accumulation of weatherable bases in the lower sequence. Also, the fact that these bases seem to increase with depth may indicate an upward movement of these elements with a fluctuating water table plus evaporation. In any case, the character of each sequence is similar to the extent that the same pedogenic processes have been operating on this profile for the past 3,000 years.

DISCUSSION

The climate or paleoclimate of an area has a distinct effect on the development of a soil system. In examining the profiles at Kavousi, one observes that the Kavousi 1 profile exhibits a greater amount of soil development in the form of argillic horizons than Kavousi 2. Argillic horizons commonly form in udic climates, such as in eastern North America. Several studies in the Mediterranean have suggested that the terra rossa soils so commonly found in the hard limestone areas of Crete are relicts of an age when there was significantly more available moisture for pedogenesis than are obvious today (Nevros and Zvorykin, 1936; 1937; Davidson, 1980). It may be possible to interpret the changing climatic conditions of the eastern Mediterranean by examining the development of soil profiles through time.

Holocene variations in climate in the eastern Mediterranean are recorded in several sea studies. Herman (1972) studied several deep sea cores; one which spans the last 120,000 years. Her findings show that the mean surface water temperatures between the present and past interglacials were similar, and a period of stagnation was recorded about 7,000 yr. B.P. Buckley et al. (1982) studied a series of cores around the eastern Mediterranean. Analyses of the planktonic foraminifera indicate a slow warming from about 24,000 yr. B.P. to a climatic optimum at 4,700 yr. B.P. Planktonic foraminifera productivity was highest at 9,000 and 4,700 yr. B.P. and benthonic foraminifera activity was greatest in the late glacial between 12,000 to 10,000 yr. B.P. caused by incursion of meltwater into the Mediterranean. A decrease in the amount of montmorillonite from 12,000 yr. B.P. coincides with the addition of meltwater in the Mediterranean from the Black Sea and an increase in montmorillonite at 6,700 yr. B.P. indicates the end of meltwater influx. A salinity decrease recorded at 10,000-9,000 yr. B.P. may be evidence for increased precipitation in the Nile river valley. Gat and Magaritz (1980) report from oxygen isotope measurements of shellfish off of the coast of

Israel that a particularly wet phase is evident from the time period of the early Holocene to about 3,000 yr. B.P.

Vegetational dynamics during the last glacial period document two major changes. The first is a forested vegetational regime reflective of the moister and cooler conditions of the Late Pleistocene which grades into one of a more warmer and drier forest vegetation in the early Holocene. The second is the onset of more xerophytic vegetational types which is interpreted as the influence of human landscape use or the onset of drier climatic conditions. The only pollen core reported for the island of Crete was taken from the mouth of the Platys River near Aghia Galini in south-central Crete (Bottema, 1980). The early record for Crete indicates a pine and a deciduous oak forest preceded the open maquis and phrygana that exists today. This study indicates that around 10,000 yr. B.P. a pine forest (probably *Pinus brutia*) was present with a few deciduous oaks and no xerophytic vegetation. From 9,500 to 8,000 yr. B.P. there was an increase in oaks although pine was still the dominant vegetation type. Around 7,500 yr. B.P., oak expanded at the expense of the pine forest and *Platanus* could be found in the river valleys. Between 7,500 to 7,300 yr. B.P. an open vegetation predominated over the oak forest. At around 7,300 yr. B.P. a reexpansion of the oak forest takes place. Around 5,000 yr. B.P. the area must have been largely devoid of trees with arboreal pollen percentages dropping to modern values. There is a marked pollen gap between 7,300 and 5,000 yr. B.P. and the 5,000 year date may be somewhat tenuous. It is believed that the current xerophytic assemblage has dominated the area since 4,600 yr. B.P.

The question remains as to how these soils data can help interpret the climatic information for the island of Crete. Timpson (1992) had addressed the formation of old alluvial terraces near the village of Pacheia Ammos as a functions of the Pleistocene conditions that prevailed during their pedogenesis (Figure 1, marked as Kavousi 4). The

reddened colors (rubification) of the terraces and the translocation of pedogenic carbonates were interpreted as pedogenic processes which took place in the moister conditions of the Late Pleistocene in eastern Crete. Tarzi and Paeth (1975) noted that the development of a red Mediterranean soil and a rendzina showed that the red soil was almost decalcified, exhibited illuvial clay horizons (argillic), showed accumulation of organic matter, and exhibited enrichment of sesquioxides, plus kaolinite. The development of the rendzina soil, because of its high carbonate content, showed retarded pedogenic effects with a weakly developed soil profile, little release of sesquioxides, and little translocation of clays. The fact that the buried rendzina soil in the Kavousi 1 pedon exhibited an argillic horizon could indicate that this soil formed during a moister period than exists today in that area. Perhaps as early as the Late Pleistocene or during the early Holocene when Crete was forested could a soil such as this develop. It is therefore believed that the buried rendzina soil at Kavousi 1 is a climatic relict of soil formed during a moister period which may have had a forest cover.

Another question that needs to be addressed is the mechanism and interpretation of the deposition of sediments in the alluvial fan north of the Avgo gorge and the village of Kavousi. One model that needs to be addressed is the Vita-Finzi model which documents two major alluvial fill episodes of the last 100,000 years; one "older fill" which occurred around 30,000 yr. B.P. and contains Mousterian and Upper Paleolithic artifacts, and the other "younger fill" which contains sherds from the 2nd and 3rd centuries A.D. to the present (Vita-Finzi, 1969). The "younger fill" episode was preceded by a channel incision episode from 8,000 to 2,000 yr. B.P. This model of alluviation has been supported by a number of studies (Davidson, 1978; 1980; Davidson and Tasker, 1982; Davidson et al., 1976; Bintliff, 1975; Bintliff, 1977). While Vita-Finzi's model is a climate based model, alternative models such

as the model of Van Andel et al. (1986) emphasizes the importance of human impact on the landscape as of primary importance.

An examination of the soils information in the Kavousi area may shed some light on the interpretation of these models. The fact that Minoan Period artifacts were found in a buried soil in the Kavousi 2 pedon indicates that the Vita-Finzi model needs adjustment. With the artifact assemblages plus a ^{14}C date of $3,040 \pm 90$ yr. B.P. means that an aggradation episode occurred when there should have been a downcutting episode according to the Vita-Finzi model. The question remains as to whether this aggradation episode is related to agricultural terrace abandonment according to the Van Andel model. The ^{14}C information, plus the identification of artifacts as being Late Minoan Period (Donald Haggis, personal communication) indicates that the artifacts were deposited on a former stable surface and that this buried surface was the living surface at the time of Late Minoan occupation. Another point of interest is that a surface survey of the Kavousi valley showed that no Late Minoan I Period artifacts were found on the surface in the area north of the mouth of the Avgo gorge covered by the alluvial fan in the area of the Kampos (Haggis, 1992). This can be interpreted as a major aggradation event occurring after the Minoan occupation of the area which subsequently buried a former living surface in the valley. Other archaeological sites have documented completely buried living surfaces in alluvial valleys (Turner and Klippel, 1989). The episode which deposited the upper sequence at Kavousi 2 could possibly have occurred due to terrace abandonment after the general population left the Kavousi area in the Geometric Period.

Another area of pedogenic interpretation concerns the length of time necessary for the development of an argillic horizon. Foss and Collins (1986) have shown through several archaeological studies that the development of weak argillic horizons take about 3,500 years

in moist climates. Nettleton et al. (1975) observed that argillic horizons formed during the pluvial conditions of the Late Pleistocene in the southwestern United States. It was determined that these argillic horizons have not been forming for the past 12,000 years and the Argids in this area were climatic relics of a pluvial Pleistocene condition. Haidouti and Yassoglou (1982) have shown that argillic horizons, described in the southern Argolid in relation to several Bronze age archaeological sites, could have developed in 2,000 to 3,000 years in a xeric climate.

The pedon at Kavousi 2 seems to be inconsistent with the findings of Haidouti and Yassoglou (1982). Although there was an increase in clay content in two different alluvial sequences, the morphological characteristics were not indicative of an illuvial episode. There was no evidence of argillans to any degree on the ped faces in the pedon. The fine clay:coarse clay ratio, which usually increases from the eluvial to the illuvial horizon, decreased in this case. The fact that a ^{14}C date of $3,040 \pm 90$ yr. B.P. was recorded in the second sequence also seems to disagree with the findings of Haidouti and Yassoglou. Some of the measures commonly used for distinguishing the amount of pedogenesis in a pedon (molar ratios) showed that there was little difference between the lower and upper sequence in the Kavousi 2 pedon. From the information collected from the pedon, one can conclude that very little pedogenic development has taken place for the past 3,000 years in the alluvial fan. It is therefore concluded that the present xeric climate is not conducive to soil weathering processes, and the present xeric conditions have probably been in place for at least the past 3,000 years.

Based on the evidence collected on these two pedons, a history of landscape development is presented. The oldest unit is the rendzina which is currently buried in the Kavousi 1 pedon. This chalk deposit with mixed phyllite colluvium had a stable surface in

which a soil had developed. The development of soil structure, the segregation of iron, and the development of argillans in the profile indicate that this soil formed in a moister climate, probably under a forest vegetation. This was likely to occur during the Late Pleistocene-early Holocene when pollen evidence indicates that the island was forested and the climate was moister. An episode of truncation occurred where the surface of the rendzina was removed. A similar pattern where a soil with an argillic horizon was truncated was observed at the Karphi archaeological site (Part 2, this dissertation). One ^{14}C date taken from one of these profiles at Karphi showed the soil was stable at around 3,000 years ago. It is possible that the truncation episode may be correlated with deforestation of the landscape. This deforestation could have occurred by a climate change or by human impact.

An episode of aggradation had occurred in the valley north of Kavousi prior to 3,000 yr. B.P. A soil developed in this alluvial deposit which consisted of a lag channel overlain by silty overbank deposits. The question remains as to whether this deposition was triggered by landscape destabilization from upslope in the Avgo gorge. The ^{14}C date and the artifacts in the profile are consistent with the period of Minoan inhabitation of the site of Vronda during the Late Minoan III C Period. There is the possibility that the aggradation episode was triggered by deforestation due to human activity. A soil developed on this alluvial fan where one observes the accumulation of organic matter (melanization) as the primary pedogenic process with some loss of carbonates from the surface. The surface was occupied by the Minoan peoples, and it is believed that this valley was farmed the same way that the alluvial valleys were farmed in the southern Argolid (Haidouti and Yassoglou, 1982). This surface was subsequently buried sometime after 3,000 years ago by another lag channel-silty overburden alluvial episode. Because the Kavousi area was abandoned sometime during the Geometric Period, it is possible that this abandonment lead to another landscape

destabilization which buried the Minoan soil. Perhaps in the Van Andel et al. (1986) model, the abandonment of the agricultural terraces above the Avgo gorge near the Vronda and Kastro archaeological sites lead to the development of this alluvial formation downslope. The morphology of the colluvial overburden at Kavousi 1 is consistent with the morphology at the Kavousi 2 pedon. It is possible that this colluvial episode is concurrent with one of the alluvial aggradation episodes below.

The general pattern of landscape development at Kavousi seems to be the following set of events:

1. A soil develops in a moister climate with a forested vegetation. This soil shows the development of an argillic horizon, soil structure, and segregation of iron. In the Kavousi example, a rendzina soil developed from a mixed chalk-phyllite colluvium reflects these features.
2. An episode of truncation takes place in which the soil exhibiting the features of pedogenesis are truncated and the soil surfaces are removed.
3. Sediments are deposited in the valley below the Avgo gorge and a soil develops in this alluvium which has a mean residence time of around 3,000 yr. B.P. Artifacts of Late Minoan origin are deposited on this soil surface. In the time of 3,000 years, there is little evidence of soil weathering and development of morphology such as the formation of an argillic horizon is not evident.
4. This alluvial soil is buried by another alluvial sequence exhibiting a lag channel-silty overbank deposit pattern. This event occurs sometime after 3,000 yr. B.P. The most likely event may be the abandonment of the Kastro settlement during the Geometric period and the destabilization of the agricultural terraces.

CONCLUSIONS

The investigation of buried soils below the Minoan period archaeological sites of Vronda and Kastro near the village of Kavousi provide a look into the environmental conditions which prevailed at the time of the inhabitation of the area. First of all, the buried rendzina in Kavousi 1 more than likely formed in a climate moister than the present which

was probably forested. A pedological investigation of a buried soil in an alluvial fan deposit which contained Late Minoan artifacts showed that little pedogenesis has taken place on this fan for over 3,000 years. This outcome is likely due to the onset of the xeric climate that prevails in the area today. The fact that the artifacts were *in situ* and extractable P values were sufficiently elevated shows that the Late Minoan peoples were utilizing the alluvium below the Vronda and Kastro sites for agriculture in concert with the agricultural terraces on the north facing slopes of the Siteia Range. The findings in this study are in conflict with the Vita-Finzi "older fill-younger fill" hypothesis and the Haidouti and Yassoglou "formation of argillic horizons in less than 3,000 years in a xeric climate" hypothesis. The primary conclusion from this pedological study is that the soil morphology shows that there was a climate moister than the present prior to the Late Minoan occupation of the Kavousi area, and that the climate of the area during the Late Minoan period was similar to that of today.

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APPENDICES

APPENDIX A

SOIL PROFILE DESCRIPTIONS

Appendix A-1. Soil profile description for the Karphi 1 pedon.

PEDON: Karphi 1

AREA: Karphi, Lasithi Province, Crete, Greece

CLASSIFICATION: Mollic Haploxeralfs, fine, mixed, mesic

LOCATION: 25°28'16" E Long, 35°12'53" N Lat

NATIVE VEGETATION: Donkey Thorn, Thorny Bramlin, Thyme, Oregano

PHYSIOGRAPHY: Sinkhole in Gavrona-Tripolitza series dolomites and limestones

PARENT MATERIAL: Alluvium and Loess

ELEVATION: Approximately 1100 m AMSL

INFILTRATION: Moderate

AVAILABLE WATER: Low

HYDRAULIC CONDUCTIVITY: Moderate

SOIL WETNESS CLASS: Class 1

SOIL SLOPE: Nearly Level

EROSION: None to slightly eroded

SURFACE RUNOFF: Very slow

SAMPLED BY: Michael W. Morris and John T. Ammons, July 30, 1991.

- | | |
|-----|---|
| A | 0-9 cm; 5YR 4/6 dry, 5YR 3/4 moist; silty clay texture, the horizon was auger drilled, therefore structure, lower boundary, and consistence were not determined; reaction pH=6.5. |
| Bt1 | 9-27 cm; 5YR 5/4 dry, 5YR 3/4 moist; silty clay texture; moderate fine subangular blocky structure; indeterminate lower boundary and consistence; reaction pH=6.5; common fine mica flakes. |
| Bt2 | 27-36 cm; 5YR 4/4 dry, 5YR 3/4 moist; silty clay texture; moderate fine subangular blocky structure; indeterminate lower boundary and consistence; reaction pH=6.5; common fine mica flakes. |
| Bt3 | 36-54 cm; 5YR 5/6 dry , 5YR 4/4 moist; clay texture; moderate fine subangular blocky structure; indeterminate lower boundary and consistence; reaction pH=6.5; common fine mica flakes; few fine limestone fragments. |
| R | 54+ cm |

Additional Notes: The ground surface is covered by about 20% angular and slightly rounded limestone fragments. An auger transect run across the sinkhole revealed depths to bedrock as 46 cm, 52 cm, and 57 cm. Late Minoan period ceramic fragments noted on the surface of the unit. All samples showed no reaction with 1 N HCl. Gilgai relief noted on the surface. The need for Ti:Zr ratios was noted.

Appendix A-2. Soil profile description for the Karphi 2 pedon.

PEDON: Karphi 2

AREA: Karphi, Lasithi Province, Crete, Greece

CLASSIFICATION: Fluventic Xerochrepts, fine-silty, mixed, mesic

LOCATION: 25°28'40" E Long, 35°12'35" N Lat

NATIVE VEGETATION: Donkey Thorn, Thorny Bramlin

PHYSIOGRAPHY: Sinkhole in Gavrona-Tripolitza series dolomites and limestones

PARENT MATERIAL: Alluvium and Loess

ELEVATION: Approximately 920 m AMSL

INFILTRATION: Moderate

AVAILABLE WATER: High

HYDRAULIC CONDUCTIVITY: Moderate

SOIL WETNESS CLASS: Class 1

SOIL SLOPE: Nearly Level

EROSION: None to slightly eroded

SURFACE RUNOFF: Very slow

SAMPLED BY: Michael W. Morris, Randy Loftis, John T. Ammons, and Photeinos Santas,
July 16, 1992.

Ap	0-23 cm; 10YR 6/4 dry, 7.5YR 4/4 moist; silty clay loam texture, moderate medium granular structure; abrupt smooth boundary; very friable moist and friable dry consistence; common very fine mica flakes; many fine, very fine, and medium roots; no coarse fragments.
Bw	23-55 cm; 10YR 6/6 and 5YR 4/3 dry, 7.5YR 4/4 moist; silty clay loam texture; weak medium subangular blocky structure; abrupt smooth boundary; friable moist and friable dry consistence; no coarse fragments; few medium, fine, and very fine roots.
2Ab	55-77 cm; 7.5YR 4/4 dry and 7.5YR 3/4 moist; silty clay loam texture; moderate medium subangular blocky structure; indeterminate lower boundary; friable moist and friable dry consistence; limestone fragments on the surface on the horizon; few fine and very fine roots; common charcoal fragments; very thin discontinuous clay coatings on the ped faces; few very fine manganese nodules.
2Bw1b	77-85 cm; 7.5YR 4/6 dry with few 7.5YR 5/6 mottles, 7.5YR 4/4 moist; silty clay loam texture; moderate medium subangular blocky structure; indeterminate lower boundary; friable moist and friable dry consistence; common thin discontinuous clay coatings; few very fine roots; few very fine manganese nodules.
3Bw2b	85-93 cm; 5YR 4/6 dry, 5YR 3/4 moist; clay loam texture; weak medium subangular blocky structure; indeterminate lower boundary; friable moist and

friable dry consistence; few thin discontinuous clay coatings; few very fine roots; few very fine manganese nodules; very few rounded phyllite fragments.

- 3Bw3b 93-101 cm; 5YR 4/4 dry, 5YR 3/4 moist; clay loam texture; weak coarse subangular blocky structure; friable moist and friable dry consistence; few thin discontinuous clay coatings; very few fine roots; few fine manganese nodules; very few rounded phyllite fragments.
- 3BC1b 101-109 cm; 5YR 4/6 dry, 5YR 4/6 moist; clay loam texture; weak coarse subangular blocky structure to structureless massive; indeterminate lower boundary; very few thin discontinuous clay coatings; very few fine roots; very few rounded phyllite fragments; few manganese nodules.
- 3BC2b 109-117 cm; 5YR 4/6 dry, 5YR 4/4 moist; silty clay loam texture; weak coarse subangular blocky structure to structureless massive; indeterminate lower boundary; friable moist and friable dry consistence; very few thin discontinuous clay coatings; no roots; very few rounded phyllite fragments; few manganese nodules.

Additional Notes: The pedon was excavated to a depth of 55 cm and auger drilled for the remainder. There was no archaeological materials associated with this pedon. Darker colors found in the old root channels and insect burrows of the Bw horizon. These colors may be due to translocation of materials from the surface, otherwise no clay skins were noted here. Mass of surface materials may have occurred through the Bw horizon. Colors are likely to be due to differential water flow through macropores which darkened portions of the horizon.

Appendix A-3. Soil profile description for the Karphi 3 pedon.

PEDON: Karphi 3

AREA: Karphi, Lasithi Province, Crete, Greece

CLASSIFICATION: Dystric Fluventic Xerochrepts, loamy skeletal, mixed, mesic

LOCATION: 25°28'56" E Long, 35°12'46" N Lat

NATIVE VEGETATION: Dominantly phrygana vegetation

PHYSIOGRAPHY: Alluvial fan developed from phyllite gravels emanating from an exposed phyllite "cove"

PARENT MATERIAL: Alluvium

ELEVATION: Approximately 920 m AMSL

INFILTRATION: Moderate

AVAILABLE WATER: Low

HYDRAULIC CONDUCTIVITY: High

SOIL WETNESS CLASS: Class 1

SOIL SLOPE: Gently sloping

EROSION: None to slightly eroded

SURFACE RUNOFF: Medium

SAMPLED BY: Michael W. Morris and Randy Loftis, July 28, 1992.

Ap	0-23 cm; 10YR 6/4 dry, 10YR 4/4 moist; very gravelly sandy loam texture; weak medium granular structure to structureless single-grained; indeterminate lower boundary; very friable moist and very friable dry consistence; common fine and very fine roots; common rounded phyllite gravels.
BA	23-28 cm; 10YR 6/4 dry, 10YR 4/4 moist; very gravelly sandy loam texture; structureless single-grained structure; loose dry and loose moist consistence; common very fine and few fine roots; common rounded to subrounded phyllite fragments.
Bw	28-52 cm; 10YR 6/4 dry, 7.5YR 4/6 moist; very gravelly sandy loam texture; structureless single-grained structure; indeterminate lower boundary; loose dry and loose moist consistence; common rounded and subrounded phyllite fragments; few very fine roots.
2Bt1b	52-61 cm; 7.5YR 5/6 dry, 7.5YR 4/4 moist; very gravelly sandy loam texture; structureless single-grained to weak medium granular structure; loose dry and loose moist consistence; common rounded and subrounded phyllite fragments; few very fine roots; thin discontinuous clay coatings on the phyllite fragments.
2Bt2b	61-81 cm; 7.5YR 5/4 dry, 7.5YR 4/6 moist; very gravelly sandy loam texture; structureless single-grained to weak medium granular structure; indeterminate lower boundary; loose dry and loose moist consistence; common rounded and subrounded phyllite fragments; thin, discontinuous clay coatings on the phyllite fragments.

2Bt3b

81-102 cm; 7.5YR 5/6 dry, 7.5YR 4/6 moist; very gravelly sandy loam texture; structureless single-grained to weak medium granular structure; indeterminate lower boundary; loose moist and loose dry consistence; common rounded and subrounded phyllite fragments; thin discontinuous clay coatings on the phyllite fragments.

Appendix A-4. Soil profile description for the Karphi 4 pedon.

PEDON: Karphi 4

AREA: Karphi, Lasithi Province, Crete, Greece

CLASSIFICATION: Typic Xerochrepts, fine-silty, mixed, mesic

LOCATION: 25°28'24" E Long, 35°12'50" N Lat

NATIVE VEGETATION: Dominantly phrygana vegetation

PHYSIOGRAPHY: Late Minoan period agricultural terrace in an eroded phyllite "cove"

PARENT MATERIAL: Colluvium over residuum

ELEVATION: Approximately 1020 m AMSL

INFILTRATION: Moderate

AVAILABLE WATER: Very low

HYDRAULIC CONDUCTIVITY: Moderate

SOIL WETNESS CLASS: Class 1

SOIL SLOPE: Sloping along terrace (11%), steep in the cove (52%)

ASPECT: 91° east

EROSION: Moderately eroded

SURFACE RUNOFF: Rapid

SAMPLED BY: Michael W. Morris and Randy Loftis, August 1, 1992.

- | | |
|-------|---|
| A | 0-14 cm; 10YR 6/3 with few 7.5YR 6/6 mottles dry, 10YR 4/3 with few 7.5YR 5/6 mottles moist; loam texture; moderate medium granular structure; abrupt smooth boundary; friable moist and friable dry consistence; many fine, very fine and medium roots. |
| Bw1 | 14-23 cm; 10YR 6/4 dry, 10YR 4/4 moist; gravelly sandy loam texture; weak medium subangular blocky structure; clear smooth boundary; friable moist and friable dry consistence; common fine, very fine and medium roots; common angular phyllite and limestone fragments. |
| Bw2 | 23-35 cm; 10YR 6/4 dry, 10YR 4/4 moist; very gravelly sandy loam; weak medium subangular blocky structure; abrupt smooth boundary; friable moist and friable dry consistence; common angular phyllite and limestone fragments; few medium and common fine and very fine roots. |
| 2Bt1b | 35-49 cm; 5YR 4/6 dry, 5YR 4/4 moist; clay loam texture; moderate medium subangular blocky structure; clear smooth boundary; friable moist and firm dry consistence; few angular phyllite fragments; few fine and very fine roots; thin discontinuous clay coatings. |
| 2Bt2b | 49-60 cm; 5YR 3/4 with common 5YR 5/8 mottles, 5YR 3/3 with 5YR 5/8 mottles; clay loam texture; moderate coarse subangular blocky structure; clear smooth boundary; friable moist and very firm dry consistence; no coarse fragments; thin and thick discontinuous clay coatings; few fine pieces of charcoal; few very fine roots. |

R

60+ cm

Additional Notes: Pottery sherd oriented vertically at 56 cm below the surface. This sherd probably fell behind the terrace wall. Phyllite bedrock exposed approximately 30 m uphill and 20 m downhill. Massive charcoal sample taken 54 cm below surface in 2Bt2b horizon. Limestone fragments found on the surface of the pedon. Ceramics noted on the surface of the buried soil in other agricultural terraces in this eroded phyllite exposure.

Appendix A-5. Soil profile description for the Kavousi 1 pedon.

PEDON: Kavousi 1

AREA: Kavousi, Ierapetra Province, Crete, Greece

CLASSIFICATION: Xerochrepts

LOCATION: 25°52'16" E Long, 35°07'12" N Lat

NATIVE VEGETATION: Olive grove, maquis, and phrygana. Oleander, thyme, *Phlomis*, *Erichaceae*, *Genista acanthoclada*

PHYSIOGRAPHY: Eroded terrace or bench, exposed profile in drainageway

PARENT MATERIAL: Young colluvium (rounded limestone) over old colluvium (phyllite and marl "mud flow")

ELEVATION: Approximately 150 m AMSL

INFILTRATION: Moderate

AVAILABLE WATER: Moderate

HYDRAULIC CONDUCTIVITY: Moderate

SOIL WETNESS CLASS: Class 1

SOIL SLOPE: Gently sloping

EROSION: Moderately eroded

SURFACE RUNOFF: Medium

SAMPLED BY: Michael W. Morris, John T. Ammons, and Photeinos Santas, July 18, 1991.

- | | |
|-------|---|
| A | 0-20 cm; 10YR 4/3 moist; sandy loam texture; moderate medium granular structure; friable moist consistence. |
| A-C | 20-203 cm; many rounded limestone, dolomite, and phyllite gravels and cobbles, up to 60 and 70% of the matrix; green schist fragments present from 2 mm to 20 mm in diameter; weakly developed soil structure; coarse fragments are oriented with the slope of the gorge. |
| C | 203-213 cm; 10YR 6/4 dry, 10YR 4/4 moist; gravelly sandy clay loam structure; structureless single-grained to weak fine subangular blocky structure between the rock fragments; abrupt smooth boundary; friable moist and firm dry consistence; strong reaction with 1 N HCl; no roots; common medium pores. |
| 2Bt1b | 213-237 cm; 2.5Y 7/6 dry with common 7.5YR 5/8 mottles, 2.5Y 6/4 moist with common 7.5YR 5/8 mottles between the ped faces; gravelly clay loam texture; moderate medium angular blocky structure; clear smooth boundary; friable moist and firm dry consistence; common medium tabular phyllite fragments; few fine and very fine roots concentrated along ped faces; low chroma mottles near ped faces; few very fine pores; common thin continuous clay coatings. |
| 2Bt2b | 237-275 cm; 2.5Y 7/4 dry with common 7.5YR 5/8 mottles, 2.5Y 6/4 moist with common 7.5YR 5/8 mottles between ped faces; gravelly clay loam texture; moderate medium angular blocky structure; clear smooth boundary; friable dry and firm moist consistence; common tabular phyllite fragments; very fine roots |

concentrated between ped faces; common thin discontinuous clay coatings on the ped faces and on some phyllite fragments.

- 2BC1b 275-340 cm; 2.5Y 7/4 dry, 2.5Y 5/4 moist; very gravelly sandy clay loam texture; moderate medium subangular blocky and moderate medium prismatic structure; clear smooth boundary; friable moist and firm dry consistence; common angular and tabular phyllite and schist coarse fragments, very few limestone coarse fragments; few very fine roots along the ped faces; very few discontinuous clay coatings.
- 2BC2b 340-360+ cm; 10YR 6/8 dry, 10YR 5/8 moist; very gravelly sandy clay loam texture; structureless massive to weak coarse subangular blocky structure; friable moist and firm dry consistence; many angular and tabular phyllite and schist coarse fragments, few limestone coarse fragments; very few fine roots along the ped faces.

Additional Notes. Entire profile exhibited strong reaction with 1 N HCl.

Appendix A-6. Soil profile description for the Kavousi 2 pedon.

PEDON: Kavousi 2

AREA: Kavousi, Ierapetra Province, Crete, Greece

CLASSIFICATION: Fluventic Xerochrepts, loamy-skeletal, mixed, thermic

LOCATION: 25°51'02" E Long, 35°08'10" N Lat

NATIVE VEGETATION: Olive grove and maquis vegetation including thorny bramlin, oleander, and wheat-grass

PHYSIOGRAPHY: Dissected alluvial fan

PARENT MATERIAL: Alluvium

ELEVATION: Approximately 50 m AMSL

INFILTRATION: Moderate

AVAILABLE WATER: Low

HYDRAULIC CONDUCTIVITY: Moderate

SOIL WETNESS CLASS: Class 1

SOIL SLOPE: Nearly level

EROSION: None to slightly eroded

SURFACE RUNOFF: Slow

SAMPLED BY: Michael W. Morris and John T. Ammons, July 19, 1991.

- | | |
|------|--|
| Ap | 0-15 cm; 10YR 5/2 dry, 10YR 4/2 moist; gravelly sandy loam texture; moderate medium granular structure; abrupt wavy boundary; very friable moist and friable dry consistence; approximately 30% surface covered by pebbles and cobbles; few coarse and common medium and fine roots. |
| Bw | 15-47 cm; 10YR 6/4 dry, 10YR 4/6 moist; very gravelly loam texture; weak medium subangular blocky structure; clear smooth boundary; friable moist and firm dry consistence; common rounded limestone, dolomite and phyllite fragments; common medium, fine, and very fine roots; few snail shell on the profile wall. |
| C | 47-61 cm; 10YR 6/4 dry, 10YR 4/6 moist; very gravelly sandy loam texture; structureless single-grained to weak medium subangular blocky structure; clear smooth boundary; friable moist and firm dry consistence; many rounded limestone, dolomite, and phyllite coarse fragments which are oriented with the slope of the pedon surface; common fine and very fine roots. |
| 2Ab1 | 61-88 cm; 10YR 5/4 dry, 10YR 4/4 moist; very gravelly sandy loam texture; weak medium subangular blocky structure; clear smooth boundary; friable moist and firm dry consistence; common coarse fragments of rounded limestone, dolomite, and phyllite gravels and cobbles which are oriented with the pedon surface; few medium, fine and very fine roots; few pottery sherds found mostly on the surface of the horizon oriented horizontally. |
| 2Ab2 | 88-116 cm; 10YR 5/4 dry, 10YR 4/4 moist; loam texture; weak medium subangular blocky structure; clear smooth boundary; friable moist and firm dry |

consistence; few rounded limestone, dolomite, and phyllite fragments; few medium, fine, and very fine roots; very few pottery sherds.

2Cb 116+ cm; 10YR 5/3 dry, 10YR 4/3 moist; very gravelly sandy loam texture; structureless single-grained and weak medium subangular blocky structure; very friable moist and very friable dry consistence; few fine and very fine roots; many rounded limestone, dolomite, and phyllite fragments oriented with the pedon surface; few pottery fragments.

Additional Notes: Every horizon exhibits a very strong reaction with 1 N HCl.

Appendix A-7. Soil profile description for the Kavousi 3 pedon.

PEDON: Kavousi 3

AREA: Kavousi, Ierapetra Province, Crete, Greece

CLASSIFICATION: Typic Chromoxererts, fine, mixed, thermic

LOCATION: 25°50'08" E Long, 35°07'37" N Lat

NATIVE VEGETATION: Wheat-grass and other phrygana vegetation

PHYSIOGRAPHY: Large sinkhole in the north coastal limestone hills **PARENT**

MATERIAL: Alluvium possibly lacustrine

ELEVATION: Approximately 75 m AMSL

INFILTRATION: Moderate

AVAILABLE WATER: High

HYDRAULIC CONDUCTIVITY: Moderate

SOIL WETNESS CLASS: Class 1

SOIL SLOPE: Nearly level

EROSION: None to slightly eroded

SURFACE RUNOFF: Slow

SAMPLED BY: Michael W. Morris and John T. Ammons, July 24, 1991.

Ap	0-30 cm; 2.5YR 3/6 dry, 2.5YR 3/4 moist; clay texture; moderate medium granular and weak medium subangular blocky structure; clear smooth boundary; very friable moist and friable dry consistence; common fine manganese nodules; few limestone fragments; common fine and very fine roots.
Bw	30-40 cm; 2.5YR 4/6 dry, 2.5YR 3/6 moist; clay texture; weak medium subangular blocky structure; friable moist firm dry consistence; few rounded limestone fragments; common very fine roots; few worm casts, few tubers.
Bss1	40-100 cm; 2.5YR 4/4, 2.5YR 3/6, and 2.5YR 4/6 dry, 2.5YR 3/4 moist; moderate medium angular blocky, weak coarse prismatic, and weak medium angular blocky structure; few fine slickensides oriented approximately 30° from the horizontal; common vertical cracks approximately 1 cm wide; friable moist and very firm dry consistence; common manganese nodules; common very fine roots.
Bss2	100-120 cm; 2.5YR 4/6 dry, 2.5YR 4/4 moist; clay texture; strong very coarse prismatic structure; common coarse slickensides oriented approximately 30° from the horizontal; common stress cutans on the prism heads; firm moist and very firm dry consistence; few fine manganese nodules; very few very fine roots on the faces of the slickensides; common vertical cracks approximately 1 cm wide.
Bss3	120-200 cm; 2.5YR 4/6 dry, 2.5YR 3/6 moist; clay texture; strong very coarse prismatic structure; common coarse and medium slickensides oriented approximately 30° from the horizontal; common stress cutans on the prism

heads; firm moist and very firm dry consistence; few fine carbonate nodules; very few very fine roots on prism faces.

Bk 200-210+ cm; 2.5YR 3/6 dry, 10R 4/6 moist; very gravelly clay; moderate coarse subangular blocky structure; friable moist and firm dry consistence; strong reaction with 1 N HCL; many fine and medium carbonate nodules.

Additional Notes: The Bk horizon was the only horizon which had any reaction with 1 N HCl. Vertical cracks of 1 cm width or greater were observed from the surface of the pedon to approximately 170 cm. Minoan ceramics noted at 30 cm below the surface to the depth of the plowzone and at 110 cm below the surface to the depth of the first large broad slickensides. Minoan ceramics were also noted on the surface of the pedon. There were a number of snails on the face of the borrow pit.

APPENDIX B

RESULTS OF TOTAL ELEMENT ANALYSIS

Appendix B. Results of total analysis for pedons from the Karphi and Kavousi investigations reported as weight percent oxides.

Horizon	Lower Depth	Oxides													
		Al ₂ O ₃	BaO	CaO	Fe ₂ O ₃	K ₂ O	MgO	MnO	Na ₂ O	P ₂ O ₅	SO ₃	SiO ₂	SrO	TiO ₂	ZrO ₂
								%							
	cm														
Karphi 1															
A	9	17.8	0.342	1.067	6.95	1.98	1.46	0.196	0.512	0.076	0.149	44.7	0.009	0.556	0.012
Bt1	18	18.4	0.036	0.871	7.27	2.18	1.57	0.200	0.508	0.124	0.168	41.4	0.009	0.588	0.012
	27	19.0	0.036	0.829	7.34	2.20	1.52	0.196	0.495	0.098	0.151	27.1	0.009	0.592	0.013
Bt2	36	18.9	0.035	0.832	7.40	2.15	1.59	0.192	0.459	0.096	0.157	58.6	0.009	0.571	0.013
Bt3	45	21.2	0.037	0.815	7.93	2.07	1.55	0.200	0.399	0.102	0.150	50.9	0.010	0.626	0.012
	54	20.4	0.041	0.850	7.95	2.16	1.65	0.209	0.474	0.111	0.142	41.2	0.009	0.600	0.013
Terra Rossa	5	21.4	0.035	1.574	7.18	2.19	1.61	0.195	0.420	0.203	0.254	42.7	0.010	0.613	0.014
Terra Rossa	5	23.2	0.035	1.107	7.19	2.31	1.48	0.165	0.454	0.147	0.221	50.1	0.009	0.590	0.012
Limestone	0	0.2	0.000	64.470	0.04	0.00	0.67	0.003	0.000	0.000	0.034	0.4	0.024	0.000	0.000
Limestone	0	0.4	0.000	36.020	0.11	0.07	18.84	0.001	0.000	0.000	0.717	0.3	0.007	0.000	0.000

Appendix B. continued.

Horizon	Lower Depth	Oxides													
		Al ₂ O ₃	BaO	CaO	Fe ₂ O ₃	K ₂ O	MgO	MnO	Na ₂ O	P ₂ O ₃	SO ₃	SiO ₂	SrO	TiO ₂	ZrO ₂
		cm							%						
Karphi 2															
Ap	23	16.8	0.030	0.658	6.73	1.86	1.47	0.215	0.743	0.059	0.062	38.2	0.007	0.467	0.008
Bw	55	18.0	0.035	0.517	7.02	2.09	1.52	0.243	0.781	0.048	0.064	50.2	0.007	0.480	0.008
2Ab	63	17.6	0.040	0.573	6.66	1.93	1.47	0.255	0.803	0.065	0.071	41.8	0.007	0.464	0.009
	70	17.4	0.042	0.587	6.58	1.92	1.45	0.271	0.833	0.053	0.060	48.4	0.008	0.476	0.009
	77	17.0	0.037	0.558	6.26	1.87	1.39	0.259	0.781	0.018	0.045	42.9	0.007	0.452	0.009
2Bw1b	85	16.6	0.043	0.598	6.27	1.79	1.48	0.252	0.825	0.025	0.055	43.5	0.007	0.455	0.009
3Bw2b	93	15.9	0.031	0.538	6.15	1.72	1.42	0.239	0.735	0.004	0.049	62.4	0.006	0.453	0.008
3Bw3b	101	14.5	0.028	0.478	5.67	1.66	1.38	0.225	0.739	0.005	0.025	56.4	0.006	0.390	0.006
3BC1b	109	15.5	0.028	0.417	5.66	1.70	1.31	0.169	0.712	0.000	0.037	50.8	0.006	0.394	0.005
3BC2b	117	16.6	0.034	0.465	6.79	2.05	1.45	0.184	0.795	0.000	0.010	58.7	0.007	0.427	0.006
Terra Rossa	5	18.5	0.037	1.122	7.42	1.48	1.45	0.170	0.626	0.075	0.107	34.0	0.008	0.556	0.010
Terra Rossa	5	19.3	0.027	1.535	7.23	1.58	1.52	0.179	0.545	0.096	0.176	45.1	0.009	0.553	0.010
Limestone	0	0.1	0.000	62.950	0.03	0.00	0.40	0.001	0.000	0.000	0.037	0.0	0.015	0.000	0.000
Limestone	0	0.1	0.000	62.500	0.02	0.00	0.44	0.001	0.000	0.000	0.011	0.0	0.021	0.000	0.000

Horizon	Lower Depth	Oxides														cm		
		Al ₂ O ₃	BaO	CaO	Fe ₂ O ₃	K ₂ O	MgO	MnO	Na ₂ O	P ₂ O ₅	SO ₃	SiO ₂	StO	TiO ₂	ZrO ₂			
Karpni 3	Ap	12	13.8	0.021	0.175	5.30	2.02	1.08	0.099	0.782	0.023	0.030	47.3	0.004	0.185	0.001		
		23	13.5	0.021	0.133	4.83	1.99	1.04	0.103	0.785	0.005	0.028	47.6	0.004	0.188	0.000		
	BA	28	15.7	0.021	0.118	4.99	2.48	1.14	0.064	0.846	0.000	0.019	52.4	0.004	0.159	0.000		
	Bw	36	16.2	0.023	0.084	4.95	2.86	1.10	0.039	0.948	0.000	0.012	52.6	0.004	0.153	0.000		
		44	19.4	0.027	0.103	5.91	2.88	1.22	0.038	0.886	0.000	0.013	55.9	0.005	0.166	0.000		
		52	18.7	0.028	0.092	6.20	2.84	1.27	0.049	0.856	0.000	0.018	49.4	0.005	0.229	0.000		
	2Bt1b	61	16.3	0.024	0.151	5.53	2.38	1.14	0.037	0.870	0.000	0.011	45.9	0.005	0.245	0.000		
	2Bt2b	70	17.5	0.025	0.129	5.55	2.54	1.18	0.035	0.872	0.000	0.025	42.5	0.005	0.219	0.000		
		81	17.4	0.025	0.114	5.50	2.67	1.27	0.041	0.902	0.000	0.014	39.3	0.005	0.243	0.001		
	2Bt3b	87	18.8	0.027	0.137	6.23	2.71	1.26	0.046	0.976	0.000	0.000	41.8	0.005	0.286	0.000		
Phyllite		93	20.8	0.029	0.072	7.38	2.98	1.45	0.052	0.837	0.000	0.000	38.4	0.005	0.271	0.001		
		102	20.0	0.029	0.080	7.41	2.99	1.47	0.057	0.835	0.000	0.009	45.7	0.005	0.292	0.000		
	0	21.8	0.028	0.290	8.56	2.74	1.80	0.076	0.563	0.006	0.007	42.8	0.004	0.287	0.000			

Appendix B. continued.

Horizon	Lower Depth	Oxides													
		Al ₂ O ₃	BaO	CaO	Fe ₂ O ₃	K ₂ O	MgO	MnO	Na ₂ O	P ₂ O ₅	SO ₃	SiO ₂	SrO	TiO ₂	ZrO ₂
		cm						%							
Kavousi 2															
Ap	15	11.5	0.048	10.760	5.47	2.16	3.34	0.150	0.915	0.019	0.074	36.4	0.023	0.154	0.000
Bw	47	13.0	0.040	10.740	5.86	2.29	3.32	0.178	0.961	0.012	0.028	36.1	0.022	0.201	0.001
C	61	11.7	0.045	15.100	5.55	2.12	3.64	0.150	0.911	0.000	0.023	37.6	0.032	0.146	0.000
2Ab1	88	12.3	0.037	15.350	5.54	1.99	3.49	0.159	0.807	0.002	0.033	38.6	0.031	0.150	0.000
2Ab2	116	11.4	0.044	17.670	5.08	1.96	3.36	0.158	0.995	0.004	0.085	33.6	0.033	0.139	0.000
2Cb	136+	10.2	0.032	20.460	5.06	1.97	3.87	0.128	0.838	0.016	0.092	41.4	0.042	0.121	0.000

Appendix B. continued.

Horizon	Lower Depth	Oxides															
		Al ₂ O ₃	BaO	CaO	Fe ₂ O ₃	K ₂ O	MgO	MnO	Na ₂ O	P ₂ O ₅	SO ₃	SiO ₂	SrO	TiO ₂	ZrO ₂		
																cm	%
Kavousi 3																	
Ap	30	17.5	0.036	1.112	7.57	1.93	1.88	0.196	0.405	0.023	0.067	34.2	0.008	0.670	0.015		
Bw	40	19.9	0.042	1.213	8.04	2.06	1.74	0.205	0.382	0.000	0.030	52.1	0.009	0.703	0.016		
Bss1	60	20.6	0.042	1.188	8.22	2.09	1.78	0.201	0.403	0.000	0.031	44.8	0.009	0.720	0.016		
	80	20.5	0.043	0.954	8.39	2.05	1.68	0.208	0.410	0.000	0.019	53.9	0.010	0.780	0.017		
	100	20.8	0.051	0.968	8.64	2.06	1.69	0.212	0.465	0.000	0.032	66.5	0.010	0.784	0.017		
Bss2	120	20.1	0.043	0.798	8.33	1.91	1.48	0.203	0.382	0.000	0.026	53.2	0.010	0.752	0.016		
Bss3	140	19.0	0.040	0.762	7.69	1.85	1.42	0.165	0.412	0.000	0.025	48.3	0.009	0.722	0.016		
	160	19.2	0.044	0.746	7.83	1.89	1.50	0.172	0.504	0.000	0.055	46.8	0.010	0.764	0.017		
	180	19.3	0.053	0.752	7.80	1.94	1.53	0.164	0.555	0.000	0.040	53.3	0.010	0.756	0.016		
	200	19.6	0.038	1.255	7.72	1.87	1.45	0.147	0.425	0.000	0.019	46.1	0.010	0.732	0.016		
Bk	210	17.2	0.026	12.240	6.28	1.44	1.26	0.056	0.196	0.000	0.006	46.5	0.010	0.577	0.011		
Terra Rossa	5	19.7	0.045	3.997	7.49	2.10	3.35	0.139	0.358	0.070	0.103	48.5	0.010	0.704	0.016		
Terra Rossa	5	20.7	0.040	2.786	7.78	2.10	2.63	0.166	0.381	0.079	0.151	41.1	0.011	0.668	0.016		
Limestone	0	0.1	0.000	34.030	0.02	0.00	19.40	0.001	0.000	0.000	0.013	0.0	0.008	0.000	0.000		
Limestone	0	3.7	0.006	51.010	1.13	0.34	2.48	0.027	0.032	3.070	0.042	7.8	0.009	0.095	0.001		

APPENDIX C

PERMITS

FROM THE DIRECTOR

BRITISH SCHOOL AT ATHENS

52 ODOSS SOUEDIAS
GR - 106 76 ATHENS
GREECE

13th June 1991

Professor W. Coulson,
ASCS.

Dear Professor Coulson,

Thank you for your letter of June 12th. The British School welcomes the work of the soil scientists from your Kavousi excavations and will be glad if comparative data can be found near sites that we have excavated.

As this is not work on site you do not require the formal permission of my Managing Committee. We would however be grateful to receive copies of any reports they may make, even preliminary. We would not, of course, make any use of them without permission.

Yours

A handwritten signature in dark ink, appearing to read 'Elizabeth French', with a stylized, flowing script.

Elizabeth B. French

FIRST NAME...PHOTENOS
SURNAME...SANTAS
INSTITUTION...SOUTHEASTERN
COLLEGE
ADDRESS.....
.....

IO: I.G.M.F.
Public Relations Office
70 Messogiou Str.
115 27 Athens
G R I C C F

The issue of work - permit No 4231/6-5.91 by the Institute of Geology
and Mineral Exploration for a geological research in the Greek area of
.....EASTERN CRETE - LASITHI COUNTY.....

is subject to the following terms and conditions:

- a) to co-operate with the I.G.M.F. at all times
- b) to declare the commencement of the field work to the nearest Police Station
of the study area, as well as to the local Department of the Greek Archaeolo-
gical Service (Museum)
- c) to submit a report in duplicate to the I.G.M.F.'s Public Relations Office
- d) to send 20 copies of scientific papers to the I.G.M.F.'s Public Relations Office
- e) to show the responsible of the I.G.M.F. all samples collected during field work
- f) to avoid collecting rock samples from archaeological areas subsurface speleolo-
gical sites, and submerine areas of scientific interest.

If the above terms and conditions are not observed, the IGME reserves the
right to revoke the work permit.

This work permit is valid only for the stipulated area, for the period from
.....1/6/91.....to.....30/8/91.....

Topographical maps can only provided by the Military Geographical Service,
under their responsibility, Av. Evelpidon 11362, Pedion Areos

I agree to abide by the above terms and conditions.

Signature

Date...13/6/91.....



ΙΝΣΤΙΤΟΥΤΟ ΓΕΩΛΟΓΙΚΩΝ ΚΑΙ ΜΕΤΑΛΛΕΥΤΙΚΩΝ ΕΡΕΥΝΩΝ

ΜΕΣΟΓΕΙΩΝ 70 - ΑΘΗΝΑ Τ.Κ. 115 27 - ΤΗΛ. 77 96 412 - ΤΕΛΕΞ: 21 6357 ΙΓΜΕ GR

ΥΠΗΡΕΣΙΑ ΤΕΚΜΗΡΙΩΣΗΣ,
ΔΙΕΘΝΩΝ ΚΑΙ ΔΗΜΟΣΙΩΝ ΣΧΕΣΕΩΝ

Πληροφορίες: Κλαίρη Χειλάκου
Τηλέφωνο: 7709553

Αθήνα 15-4-92
Αριθμ. Πρωτ. 2829

Θ Ε Μ Α : Παροχή διευκολύνσεων σε
αλλοδαπούς γεωλόγους.

Προς: Υπ. Αρχές του Νομού Λασηθίου

- Κοιν: 1) Υπουργ. Πολιτισμού και Επιστημών
Δ/ση Αρχ/των Αριστείδου 14 101 86
2) Υπουργ. Δημ. Τάξης Δ/ση Κρατ. Ασφ.
Τμήμα Γ. Κατέχακη 1 101 77
3) Ανωτ. Δ/ση Τμήμ. Ασφ. Ν. Λασηθίου
4) Εφορεία Αρχ/των Ν. Λασηθίου
Κ. Παλαιολόγου 74 72 100
5) ΓΕΣ 2ον ΕΓ/1β
6) ΓΕΣ 2ον ΕΓ/3

Σύμφωνα με την υπ' αριθμ. 846/10-2-1973 τριφυπουργική απόφαση των Υπουργών Βιομηχανίας, Πολιτισμού και Επιστημών και Εθνικής Παιδείας, χορηγούμε άδεια ερευνητικής εργασίας στον γεωλόγο Michael Morris του Πανεπιστημίου Tennessee των U.S.A., ο οποίος θα συνοδεύεται από τους Dr. Photeinos Santas, Dr. J.E. Foss, Dr. J.T. Ammons και ομάδα Ελλήνων σπουδαστών.

Οι ανωτέρω πρόκειται να εργαστούν στην περιοχή του Νομού Λασηθίου από 1-6-92 μέχρι 30-8-92 σχετικά με γεωλογικές-γεωμορφολογικές μελέτες.

Οι ανωτέρω υποχρεούνται να:

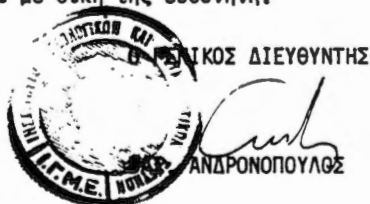
- α) συνεργάζονται μετά του ΙΓΜΕ
- β) ενημερώνουν το πλησιέστερο Αστυνομικό Τμήμα της περιοχής, καθώς και την τοπική Αρχαιολογική Υπηρεσία (Μουσεία), για την έναρξη των εργασιών τους
- γ) στέλνουν κατά καιρούς στην Υπηρεσία Τεκμηρίωσης, Διεθνών και Δημοσίων Σχέσεων του ΙΓΜΕ ικανό αριθμό αντιτύπων της επιστημονικής εργασίας που εκπονούν
- δ) επιδεικνύουν στον αρμόδιο υπάλληλο όλα τα δείγματα που συγκεντρώνουν από την υπαίθρια εργασία τους πριν την αποστολή τους στο εξωτερικό
- ε) μην προσεγγίζουν αρχαιολογικούς χώρους ή χώρους σπηλαίων για λήψη δειγμάτων πετρωμάτων και
- στ) απέχουν από κάθε αρχαιολογική ανασκαφή υποθαλάσσια, ή σπηλαιολογική έρευνα.

Η άδεια ισχύει μόνο για το αναφερόμενο χρονικό διάστημα και μόνο για την αναφερόμενη περιοχή και έρευνα.

Το τοπογραφικό και αεροφωτογραφικό υλικό είναι χρήσιμο στους ενδιαφερομένους και διατίθεται αποκλειστικά από την Γ.Υ.Σ. και με δική της ευθύνη.

Κοινοποίηση:

- Βιβλιοθήκη
- Δ.Γ.Γ.Χ.
- Υ.Τ.Δ.Δ.Σ.



FIRST NAME...PHOTEINOS
SURNAME...SANTAS
INSTITUTION...SOUTHEASTERN
ADDRESS...53 TATOLOU ST.
...KIFISSA, ATHENS 14561

TO: I.G.M.E.
DOCUMENTATION, INTERNATIONAL
AND PUBLIC RELATIONS SERVICE
70, Messoghion str.
115 27 Athens
G R E E C E

The issue of work - permit No 2929/15-4-92 by the Institute of Geology
and Mineral Exploration for a geological research in the Greek area of.....

is subject to the following terms and conditions:

- a) to co-operate with the I.G.M.E. at all times
- b) to declare the commencement of the field work to the nearest Police Station
of the study area, as well as to the local Department of the Greek Archaeolo-
gical Service (Museum)
- c) to submit a report in duplicate to the I.G.M.E.'s Documentation, International
and Public Relations Service
- d) to send 20 copies of scientific papers to the I.G.M.E.'s Documentation, Inter-
national and Public Relations Service
- e) to show the responsible of the I.G.M.E. all samples collected during field work
- f) to avoid collecting rock samples from archaeological areas subsurface speleologic-
al sites, and submarine areas of scientific interest.

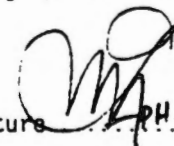
If the above terms and conditions are not observed, the IGME reserves the
right to revoke the work permit.

This work permit is valid only for the stipulated area, and the period from
1 JUNE 92 to 30 AUGUST 92

Topographical maps can only provided by the Military Geographical Service,
under their responsibility, Av. Evelpidon 11362, Pedion Areos.

I agree to abide by the above terms and conditions.

Signature

 PH. SANTAS

Date...7/5/92

VITA

Michael Wayne Morris was born in Winchester, Virginia on March 23, 1959. He attended the Frederick County School until 1968 when he moved to Culpeper, Virginia. He attended the public school system in Culpeper and graduated from Culpeper County High School in June 1977. In the fall of 1977 he entered the College of William and Mary in Williamsburg, Virginia. He began his archaeological experience as a volunteer for the Governor's Land Project in Jamestown, Virginia and the Shirley Plantation Project in Charles City County, Virginia. He became interested in soil studies while working for a land development company in Manassas, Virginia for which he mapped drain fields, dug ditches, and stabilized slopes on roadways. He received his Bachelor of Arts degree in Anthropology in May 1981.

Michael entered the University of Tennessee, Knoxville in September 1981 to pursue a Master of Arts degree in Anthropology. While in attendance, he worked for several archaeological projects including the Big South Fork Archaeological Project of the Big South Fork National River and Recreation Area in Tennessee and Kentucky; the Shelby Bend Archaeological Project in Maury County, Tennessee; and numerous smaller projects. He completed his M.A. in Anthropology from the University of Tennessee in August 1989.

Michael entered the graduate program in Plant and Soil Science at the University of Tennessee, Knoxville in January 1990. He married Gabrielle Gianna Santore of Greeneville, Tennessee on October 20, 1990. He served as a graduate research assistant in the soil genesis program and participated in numerous projects including the Ames Water Quality Study in Grand Junction, Tennessee. He also served as an assistant coach for the University's soil judging team. His primary research was on the island of Crete where he helped coordinate a pedological investigation as a part of the Kavousi Archaeological Expedition. He currently

holds memberships in the American Society of Agronomy, Soil Science Society of America, Society for American Archaeology, American Quaternary Association, Sigma Xi, and Gamma Sigma Delta. He is presently employed as an Archaeologist and Pedologist in the Environmental Department of Lockwood Greene Technologies in Oak Ridge, Tennessee.

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