Evidence for Subsurface Translocation of Ceramic Artifacts in a Vertisol in Eastern Crete, Greece

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A Chromic Haploxerert was investigated in cooperation with a soil survey of the Kavousi Archaeological Expedition near the village of Kavousi in Eastern Crete, Greece. This Vertisol was found in a sinkhole formed in Triassic age dolomite in a coastal hill range on the Bay of Mirabello. The Vertisol developed in low energy deposits, and parent material was derived from the "terra rossa" soils (Lithic Ruptic Xerochreptic Rhodoxeralfs and Lithic Ruptic Rhodic Xerochrepts) of the surrounding uplands. A Middle Minoan Period (2000 to 1550 B.C.) archaeological ceramic deposit was located on the surface of this soil. Ceramics dating to the same period were discovered in the profile between the depths of 30 and 110 cm The soil profile was described and sampled. Soil samples were subjected to particle size, total carbon, organic carbon, and extractable metals analyses to examine the possibility of discontinuities and buried soil horizons as an explanation for the appearance of artifacts deep in the profile. X-ray diffraction analysis was performed to identify the clay minerals in the profile. Vertical cracks of 1 cm in width or more were observed in the profile from the surface to 170 cm in depth. The majority of the intersecting slickensides were observed at 110 cm, but some slickensides were recorded at a depth of 200 cm. Particle size analysis showed no discernible discontinuities associated with the pottery. There was a increase in clay content from 50.3% in the surface to 68.0% at the base of the profile. Carbon increased at 140 cm below the surface, but no discernible increase at the depths of the pottery fragments. Extractable element analyses showed a gradual decrease of Ba and Mn from the surface to the base of the profile indicating an absence of buried surfaces. Clay mineral analysis revealed the predominant clay-sized minerals to be illite, kaolinite, and quartz. This evidence indicated that the ceramic artifacts had been translocated from the surface of the landform to as far as 110 cm into the profile due to the shrink-swell of Vertisol pedogenesis. The primary driving force behind the vertic morphology is the seasonal wet and dry conditions indicative of the xeric climate of the eastern Mediterranean.

A team of soil and biological scientists from the University of Tennessee and the College of Southeastern Europe worked in cooperation with archaeologists from the Kavousi Project in Eastern Crete, Greece. The Kavousi Project, an archaeological expedition sponsored by the American School of Classical Studies in Athens, Greece, focused on excavations in the Late Bronze Age/Early Iron Age sites of Vronda and Kastro on the southern aspects of the Siteia Range in Eastern Crete. Soil studies conducted in cooperation with the Kavousi Project focused on locating, describing, and characterizing depositional basins in order to understand the dynamics of landscape development over time. One such depositional basin was located in the northern coastal hills northwest of the present village of Kavousi. This landform consisted of a large sinkhole with an alluvial fill of considerable depth. Artifacts were noted in the profile walls of an excavated borrow pit. It was believed that these artifact assemblages would help to establish the time during which the surface of the alluvial landscape was stable and to estimate the amount of sediment deposition that would have occurred between the depositions of these assemblages.

Artifacts were encountered in the profile of the borrow pit from 30 to 110 cm below the surface. These artifacts, which consisted of ceramic sherds dating to the Middle Minoan Period (2000-1550 B.C), were found on the surface of the alluvium. Upon identification of these ceramic sherds, the investigation learned that the buried ceramic sherds were from the Middle Minoan Period as well. Soil morphological features such as deep vertical cracks extending from the surface, intersecting slickensides, and a high clay content were described. It was surmised that this soil unit was a Vertisol and the artifacts may have been "redeposited" as a result of the opening and closing of the vertical cracks by the shrink-swell activity of this Vertisol.

The objective of this study was to determine if there were evidence for buried soils and/or discontinuities in the soil profile that would explain the presence of artifacts deep in the soil profile. A number of techniques were employed to determine the presence of discontinuities. Soil descriptions were made to note any changes in the soil morphology of the pedon. Soil samples were collected from the pedon for particle size, carbon, and extractable element analyses. Particle size analysis was used to note changes in the particle size distribution with depth where variability in particle size distribution would characterize changes in the lithology (e.g., the presence of stone lines or multisequel argillic horizons) and would locate discontinuities. Carbon analyses were used to determine if buried soil surfaces were present in this pedon. Buried soils can be identified by increases in organic carbon and decreases in inorganic carbon due to recycling of organic materials and leaching of carbonates at a soil surface. Extractable element analyses were performed to denote changes in the distribution of metals in the profile and to help in locating buried surfaces where such metals as Ba and Mn and non-metals such as P would be concentrated. By observing these changes in the soil profile and correlating them with the buried artifacts, the presence of buried surfaces associated with these artifacts was determined. If no discontinuities were found, it could be determined that the artifacts were translocated and not in their original depositional context.

BACKGROUND

Vertisols form on a wide variety of parent materials in a number of climates. Vertisol parent materials can include 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 for Vertisol formation 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, 1983:92).

Other features that are common to Vertisols include a high cation exchange capacity, montmorillonite as the dominant clay mineral, low organic matter content, and a dark color. These soils are usually found at an elevation less than 1000 m AMSL and on slopes of less than 5%. One of the major characteristics of Vertisols 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" and 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 soils under overburden-pressure confinement (Ahmad, 1983:112).

The vertical movement of artifacts through a soil profile has been documented in other archaeological 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, thus blurring the archaeological context. One of the processes to which Wood and Johnson (1978) refer is directly related to the shrink-swell properties of Vertisols and soils with vertic morphology, which was termed "argilliturbation." Hofman (1986) documented vertical movement of artifacts, by refitting analysis, in Holocene alluvium of the Duck River in Middle Tennessee. Hofman noted a 40% clay content and massive vertical cracks that extended from the surface to 2 m into the profile. Although a Vertisol was not described, the observations were consistent of soils with vertic morphology.

SITE SETTING

The Vertisol was located in the coastal hills of the Bay of Mirabello in Eastern Crete, and is referenced as the Kavousi 3 pedon (Figs. 1 and 2). The site was a sinkhole formed in Triassic age dolomite of the Tripolitza series and located approximately 2 km west of the present village of Kavousi at 35°50'08" E Long., 35°07'37" N Lat. Dimensions of the alluvial fill in the sinkhole were approximately 280 m north to south and 410 m east to west, and it was roughly triangular in shape. The sinkhole had an outlet to the west into the Bay of Mirabello, and the pedon was slightly less than 100 m AMSL in elevation. Alluvium in the sinkhole was 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 approximately 5 m below the surface.

The climate of Kavousi is typical of the Mediterranean area and is considered one of the drier areas of Crete. Precipitation is restricted primarily to the months from September until May with the highest precipitation occurring in December and January. Rainfall is rare between the months of May and August. Average rainfall in Ierapetra, a village approximately 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). Figure 3 shows the temperature and precipitation averages of selected months for the city of Iraklio, Crete.

Archaeological sites that are contemporaneous with the artifacts found in the Kavousi 3 pedon include a number of Middle Minoan and Late Minoan Period (1900-1450 B.C.) sites. Middle Minoan to Late Minoan I sites are located at Pseira (an island 6 km north of Kavousi 3), Vasiliki (a village 5 km south of Kavousi 3), and Gournia (an archaeological site 5 km west of Kavousi 3). The archaeological sites in the Kavousi study area of Vronda and Kastro were inhabited during the Late Minoan IIIc and Protogeometric Periods (1100-900 B.C.) and probably did not contribute to the artifact assemblage found in the sinkhole.

METHODOLOGY

Field Methods

The sinkhole at Kavousi 3 was located during a soils mapping reconnaissance. A borrow pit approximately 50 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. The profiles had 3 m of exposure in places from the surface downward. A 1-m profile section of the east-facing exposure was selected for sampling purposes. This pedon was sampled and described according to methods outlined in the *Soil Survey Manual* (Soil Survey Staff, 1984). Artifacts located in a 1-m section of the described profile were mapped in situ with the relative depth and orientation of the ceramic sherds noted (Fig. 4).

Laboratory Methods

The soil samples were 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 ≤2.00 mm was quartered, and one-quarter was ground to 60 mesh and finer.

Total carbon content for each sample was determined using a LECO CR-12 carbon analyzer on the ≤60-mesh portion of the sample. Each sample was tested with 1M HCl for the 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).

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 ≥1.0% organic carbon were pretreated with a 30% H_2O_2 solution, and samples that 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 were 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 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 silt (50-2 µm) and clay (<2 µm) fractions.

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 to analyze 26 different elements simultaneously. Extractable element analysis was performed by using approximately 2 g of the <2-mm fraction of the soil sample. This sample was extracted with a 5:1 $HCl:HNO_3$ solution adjusted to 0.75 M according to a procedure outlined in Lewis *et al.* (1994).

Extractable elements were used to document the presence of buried surfaces in the pedon. 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. Non-metals, such as P, are major

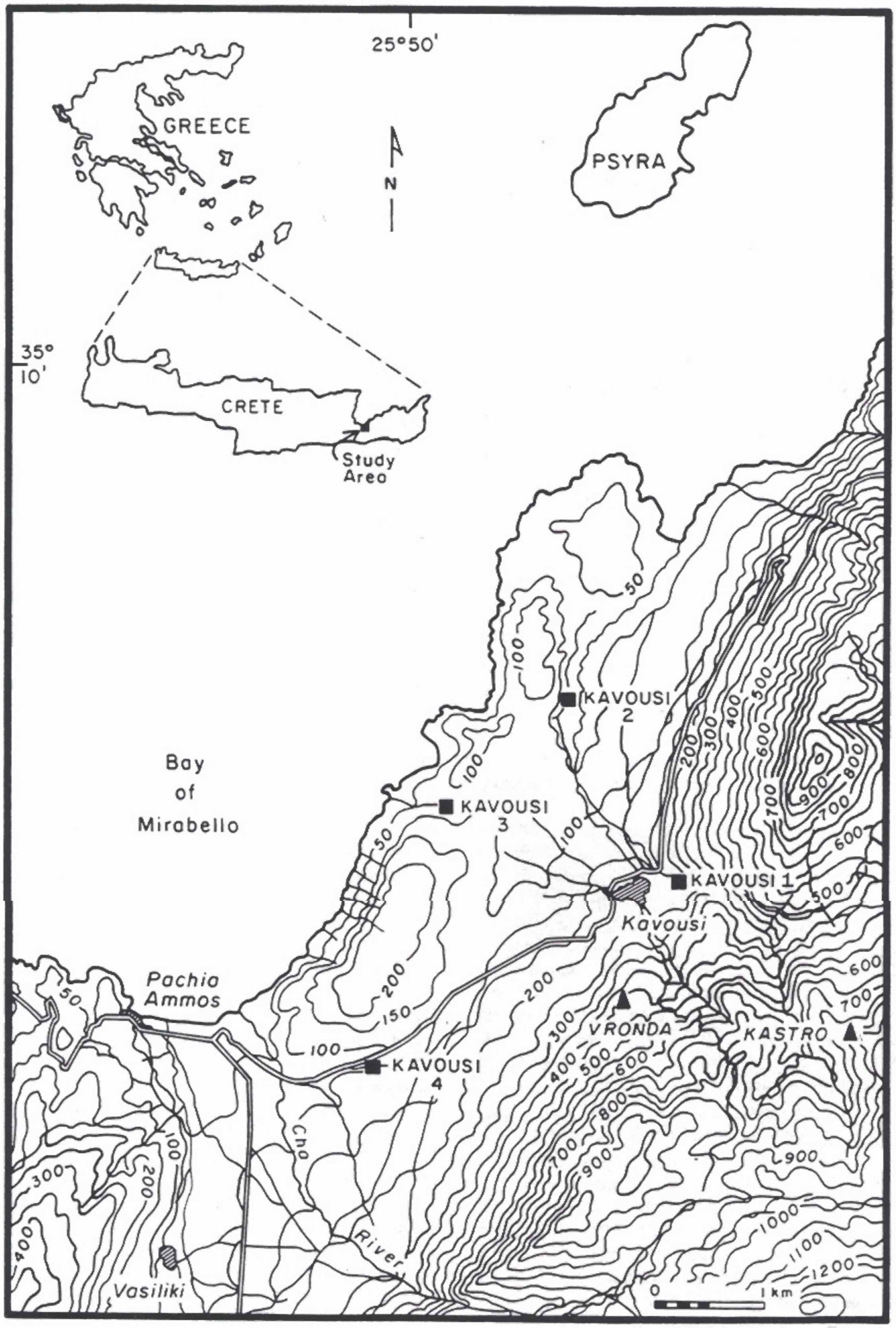

FIG. 1. Plan of the Kavousi area including the Vronda and Kastro archaeological sites and the Kavousi study pedons. Kavousi 3 is located in the center of the drawing.

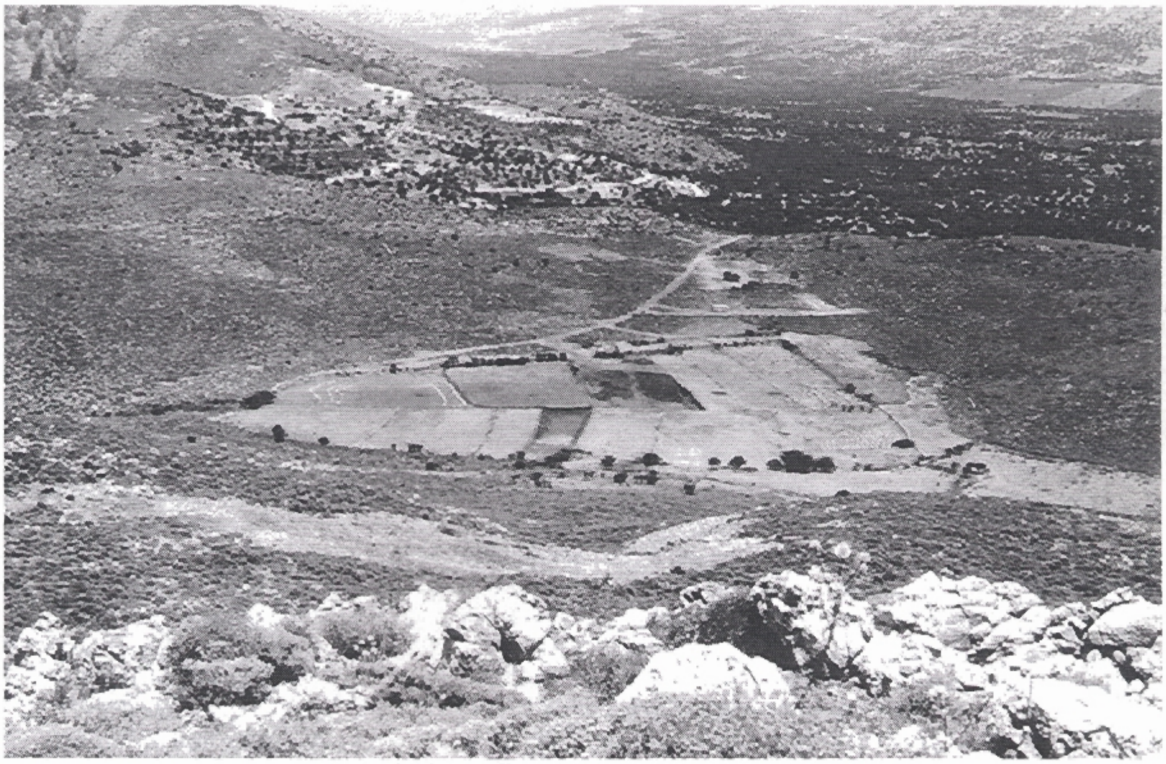

FIG. 2. View of the sinkhole at Kavousi 3 with the outlet to the sea at the far left, facing north.

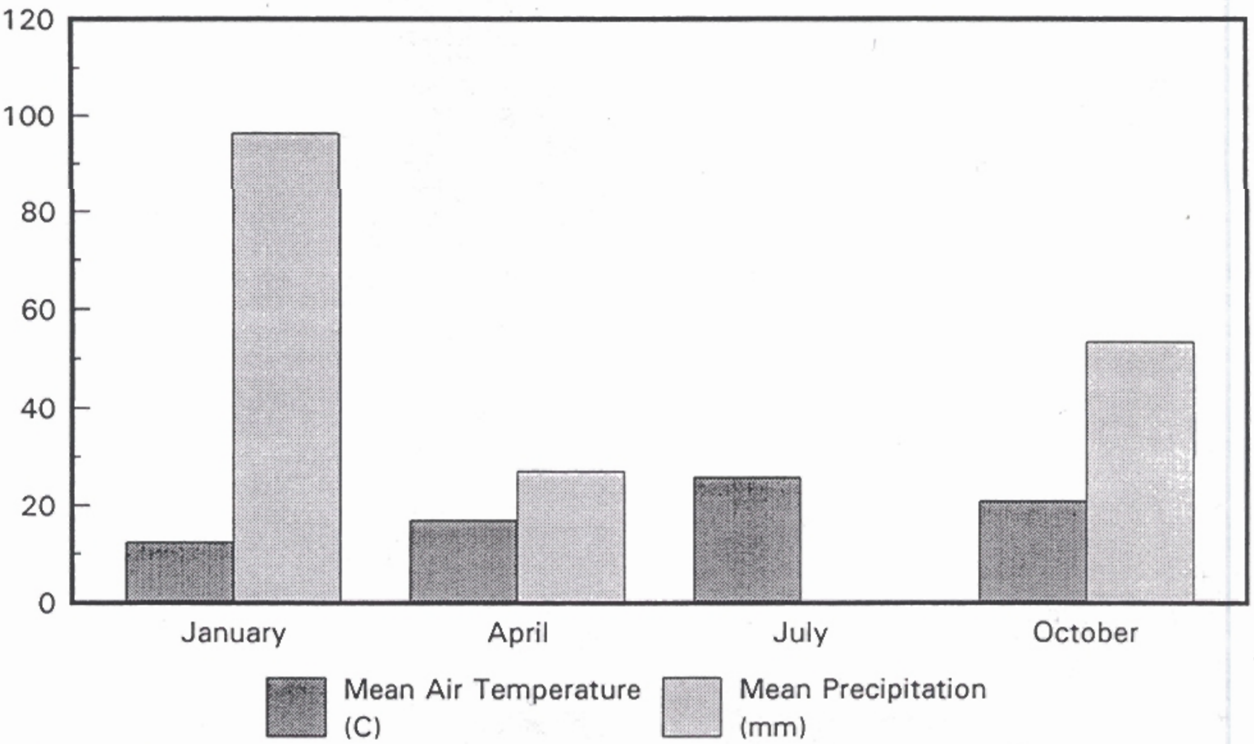

FIG. 3. Mean Air Temperature (°C) and Mean Precipitation (mm) for selected months for Iraklio, Crete, Greece. Source: Mariolopoulos (1961).

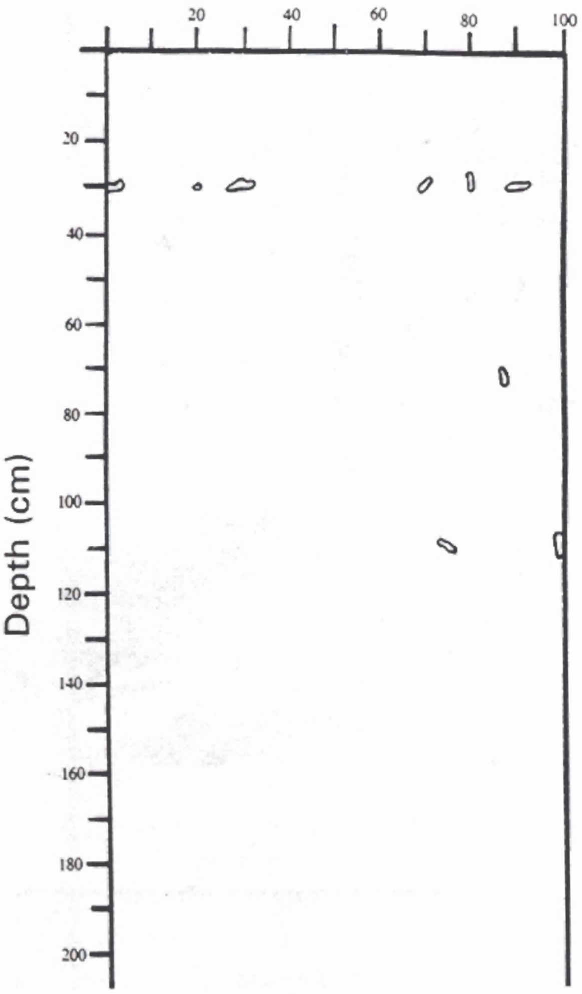

FIG. 4. Distribution of Minoan ceramic artifacts in a 1 x 2.1-m profile section at the Kavousi 3 soil pedon.

components of organic materials and can be concentrated in the soil system where organic materials are located, primarily in the surfaces.

Clay mineralogy was analyzed on samples in the mineralogical control section of the soil pedon. Samples of clay were collected in the particle size analysis procedure. Each clay sample was split, and one part was saturated with KCl solution and the other part was saturated with $MgCl_2$ solution. Both samples were treated with Na-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 Laboratory in a procedure outlined by Whittig and Allardice (1982).

RESULTS

The soil morphology at Kavousi 3 represented a profile of deep alluvium (Table 1, Fig. 5). Some of the more notable aspects of the soil morphology were the vertic properties associated with this soil. The texture of the entire profile was clay, and the colors were dark red and red ranging from 2.5YR 3/6 to 2.5YR 4/6. The profile exhibited stress cutans or slickensides from 40 to 200 cm below the surface in the Bss horizons (Fig. 6). The peds were subangular blocky to prismatic in structure, and the dry consistence ranged from friable in the surface to very firm at a depth of 200 cm. The Bk horizon (200-210+ cm) was distinguished from the rest of the profile by the presence of common fine and medium carbonate nodules in the matrix. The moist color was a 10R 4/6 (light red) with a moderate, coarse subangular blocky structure, and a friable moist consistence. There was evidence of clay flows between the carbonate nodules which formed by flocculation of clays in the Bk horizon due to high cation concentrations. Field tests with 1 M HCl showed that this was the only horizon in the profile that exhibited a reaction to the acid.

FIG. 5. The soil profile of Kavousi 3, facing south.

TABLE 1
Soil Morphology of the Kavousi 3 Soil Pedon

Horizon	Lower Depth (cm)	Color		Texture	Structure	Boundary	Consistence	
		Dry	Moist				Moist	Dry
Ap	30	2.5YR 3/6	2.5YR 3/4	C	2mgr 1msbk	cs	vfr	fr
Bw	40	2.5YR 4/6	2.5YR3/6	C	1msbk	n.d.	fr	fi
Bss1	100	2.5YR 4/4 2.5YR 3/6 2.5YR 4/6	2.5YR3/4	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

Some of the chemical characteristics from Kavousi 3 aided in the interpretation of the soil morphology (Fig. 7). Organic carbon exhibits a decrease from 1.26% at the surface to 0.19% 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) exhibited a somewhat irregular pattern from the surface to 180 cm in depth (mean = 0.09%), but increased to 0.22% at 180-200 cm and to 2.48% at 200-210 cm. This pattern was interpreted as the precipitation of carbonates above the capillary fringe of a water table, perhaps due to some evapotranspiration during the dry season.

An examination of the particle size distributions showed that most of the profile was homogeneous (Fig. 8). The clay content increased from 50.3 to 58.6% from the surface to the Bw horizon. There was also a decrease in sand content from 14.5 to 11.9% as well, and the sand content decreased to 8.8% at 200 cm and again to 3.3% at 210 cm. There was an increase in clay from 62.9% at 200 cm to 68.0% at 210 cm. This increase in clay content over a short distance could be ascribed to the flocculation of clay due to an increase in exchangeable cations.

Extractable element distributions did not identify any discontinuities that may be represented by artifact locations (Fig. 9). Most of the extractable elements that were analyzed had their greatest concentrations at the surface and gradually decreased with depth. Extractable Mn decreased from 394 mg kg^{-1} in the Bk horizon with two lesser peaks at 80-100 cm and 160-180 cm. Extractable P was only detectable in the surface horizon at 3.00 mg kg^{-1}, which indicated that biological activity was restricted to the surface. Extractable Ba was more concentrated in the upper part of the pedon (0-120 cm) with values ranging from 77.6 to 73.0 mg kg^{-1}. The lower part of the pedon (120-210 cm) had extractable Ba values that ranged from 68.7 to 35.8 mg kg^{-1}. This relationship indicated that the surface material containing some residual organic material was being recycled in the upper 120 cm of the profile, which was the depth of the major slickensides. The clay mineral analysis performed on the Bss2 horizon (100-120 cm) showed the horizon had no expandable clay minerals (Fig. 10). A comparison of the K saturated air-dried and the K saturated 550° C treatments showed kaolinite to be present at 7.2 Å and 3.54 Å because these peaks disappear as kaolinite is destroyed at 550° C. A comparison between the Mg saturated air-dried and Mg saturated ethylene-glycol treatments showed that an illite peak at 10.0 Å did not increase and therefore, did not expand upon glycolation. This was unusual for a Vertisol since most reported Vertisols have at least some expandable minerals (Ahmad, 1983). The remaining X-ray diffraction peaks were an illite peak at 5.0 Å and a quartz peak at 3.34 Å. Therefore, kaolinite and illite were the major clay minerals in the control section of this Vertisol.

DISCUSSION

Artifact lines 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 Moeyersons, 1977; Hofman, 1986). In the case of the pedon at Kavousi 3, there seemed to be a development of 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 correlated with the base of a plow zone in the alluvium of the sinkhole.

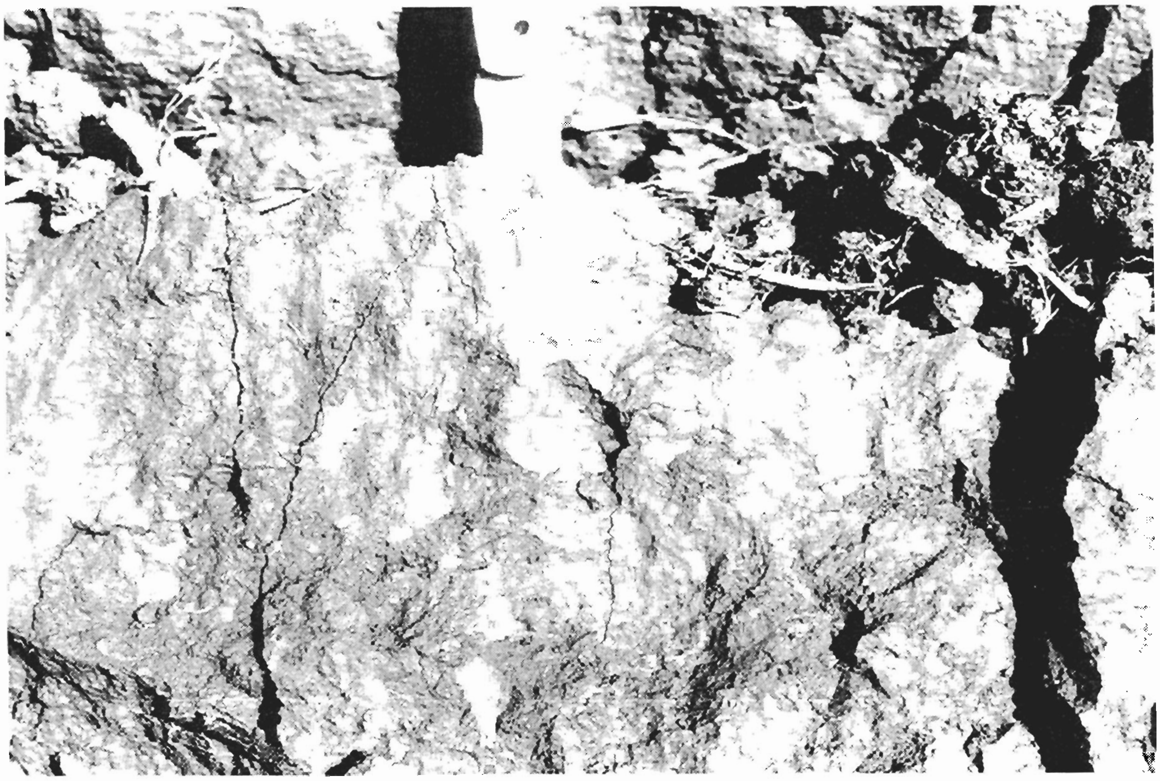

FIG. 6. Slickensides from the Kavousi 3 pedon at 110 cm below the surface.

FIG. 7. Distribution of inorganic and organic carbon *vs.* depth for the Kavousi 3 soil pedon.

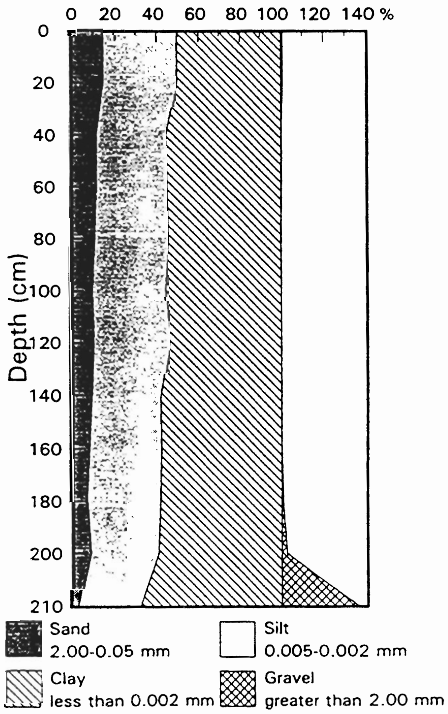

FIG. 8. Distribution of gravel, sand, silt, and clay, as determined by particle size analysis, *vs.* depth for the Kavousi 3 soil pedon.

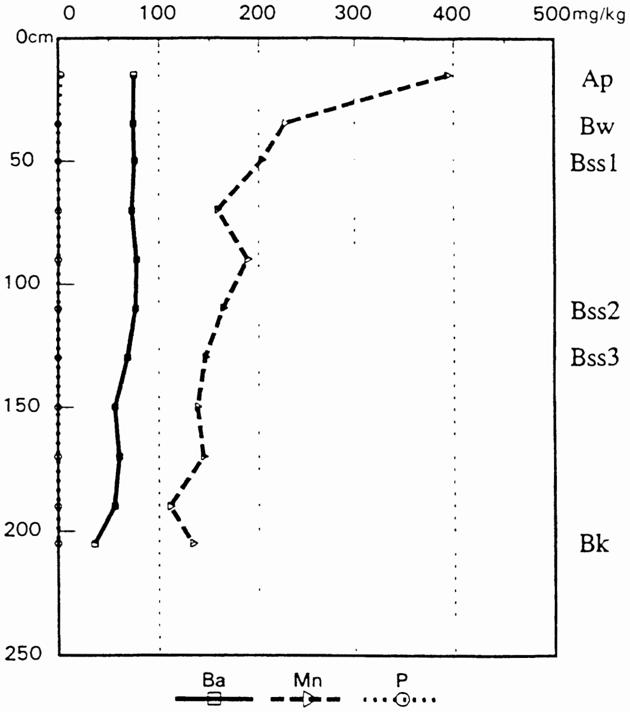

FIG. 9. Distribution of extractable elements, as determined by archaeological extraction method, *vs.* depth for the Kavousi 3 soil pedon.

Perhaps the extent of the vertical cracking was interrupted by this activity, and the 30-cm depth represented the depth to which the continuous cracking was disturbed. The depths of the artifacts at 110 cm conformed to the depth of the wedge-shaped aggregates with fluted slickensides that were oriented at an approximate 45° angle. This artifact distribution could be explained by the depth to which straight vertical cracking existed 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.

The Vertisol at Kavousi 3 had most of the characteristics common to Vertisols. The clay content was sufficiently high, the relief was relatively level, the climate had distinct wet and dry seasons, and the profile exhibited vertic morphology. The main difference between this profile and most Vertisols was the absence of smectites in the clay mineral suite. Ahmad (1983) noted that Veritsols formed in alluvium had a mineralogy abundant in illite. Ahmad (1983) also noted that continental Vertisols in Australia commonly had 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 is less than 20% of the clay-size fraction (Ahmad, 1983). Although it was not tested for these components, the Vertisol at Kavousi 3 may reflect this composition as well.

The presence of Middle Minoan Period artifacts on the surface of the Kavousi 3 pedon, and the evidence that Middle Minoan artifacts had moved through the profile, indicated that the surface of this alluvium was stable at least 4000 yr B.P. (Fig. 11). The questions that remain are when did the sediments in this sinkhole accumulate, and by what mechanism did they accumulate? The parent material for the alluvium was derived from the terra rossa soils (Lithic Ruptic Xerochreptic Rhodoxeralfs and Lithic Ruptic Rhodic Xerochrepts) 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 reflected a depositional regime that was of relatively low energy, such as in a slackwater environment. It is 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 8900 and 4900 yr. B.P. Bertolani-Marchetti (1985), through paleovegetation reconstruction, suggested that these pluvial conditions could have been in place in the eastern Mediterranean during the Late Pleistocene. Pluvial conditions can be explained by the southward shift of the Mediterranean winter rain belt during the last glacial episode. The sinkhole at Kavousi 3 may represent a Late Pleistocene/Early Holocene lake in this part of Crete and stand as a relic of a previous climatic regime.

CONCLUSION

The appearance of artifacts between the depths of 30 and 110 cm in a profile could have been explained as the presence of living surfaces with deposition of artifacts and their subsequent burial. However, field observations and laboratory analyses from this pedon indicated a lack of evidence of buried surfaces to correlate with these artifact distributions. An artifact line at 30 cm below the surface indicated the base of a plow layer at the site. The distribution of artifacts to a depth of 110 cm was related to the vertic morphology of the pedon. Artifacts on the surface of the pedon were incorporated into the profile during the summer months when the extent of the cracks from the surface downward were the greatest. Movement of artifacts through the profile was dependent upon the limiting diameter of the artifact and the morphology of the vertical cracks. The shrink-swell properties of this Vertisol were determined 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 a function of the shrink-swell

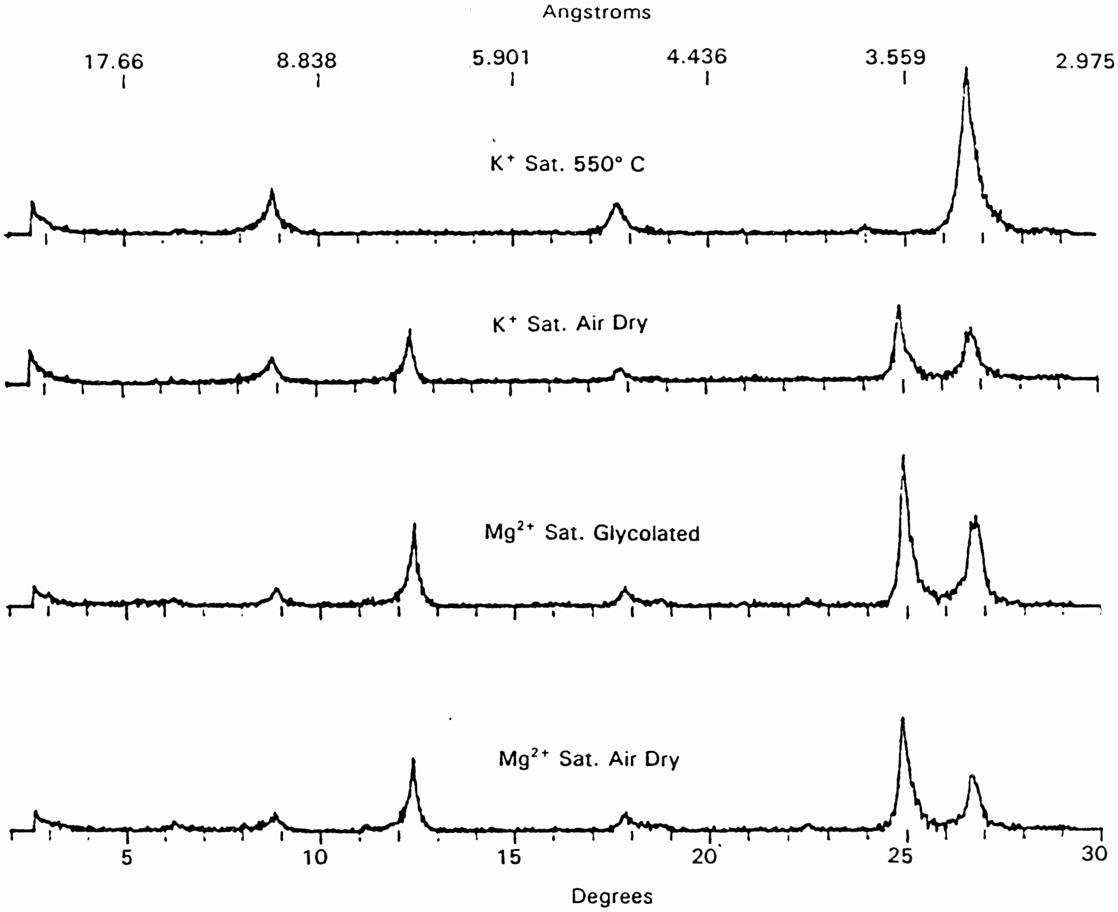

FIG. 10. X-ray diffractograms of a clay sample from the Bss2 horizon (100-120 cm) of the Kavousi 3 soil pedon.

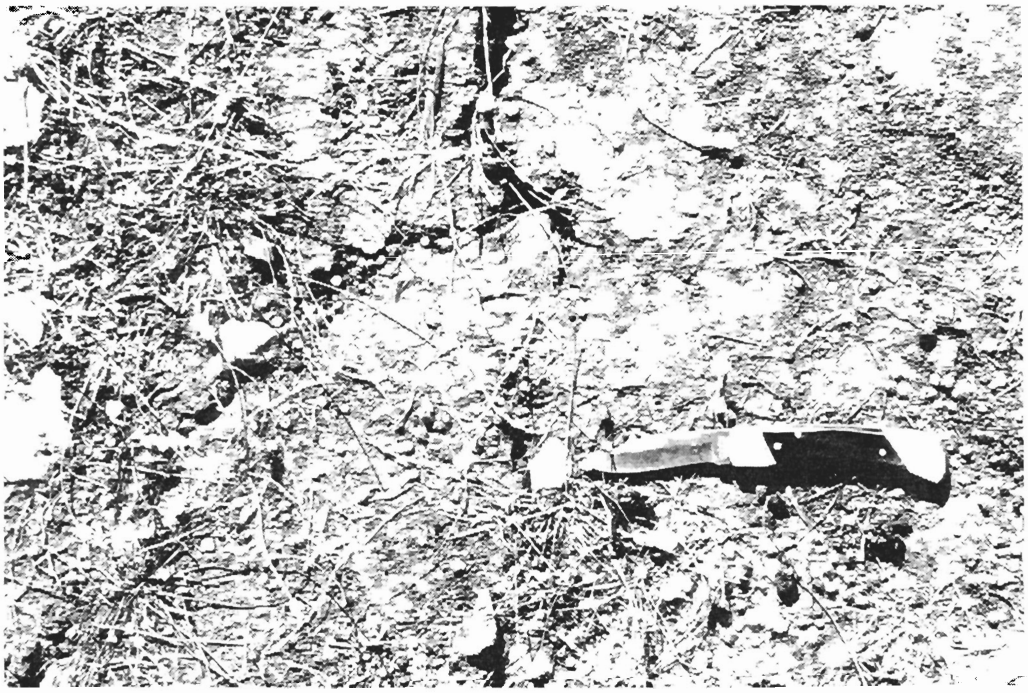

FIG. 11. Minoan-age ceramic fragments on the surface of the Kavousi 3 pedon. Note proximity of artifact to vertical cracks.

properties of the clays. It is concluded that artifacts in a Vertisol can move a considerable distance through a soil profile from their original depositional context.

ACKNOWLEDGMENTS

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