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8

Microfacies Analysis Assisting Archaeological Stratigraphy

MARIE-AGNÈS COURTY

1. Introduction

Accurate construction of archaeological stratigraphy has long been recognized as crucial in providing a solid chronocultural framework for discussing past behavioral activities and their linkages with geological processes (Gasche and Tunca, 1984; Harris, 1979). As a consequence, a major effort during excavation has been directed toward the definition of individual strata and their spatial variations. This goal has been accomplished through careful observation of the properties of the sedimentary matrix and its organization in three-dimensional space. The interfering effects of natural agents and human activities on the accumulation of the sedimentary matrix has been considered by some to conform to the principle of stratigraphic succession—as elaborated by earth scientists—and thus conforming to geological laws (Renfrew, 1976; Stein, 1987). Others have strongly argued that the rules and axioms of geological sedimentation cannot be applied to archaeological layers because they are produced by people and thus constitute an entirely distinct set of phenomena (Harris, 1979; Brown and Harris, 1993). Understanding the processes involved in the formation of archaeological stratification has also long been a question of passionate debate, with the views of human or natural deposition being opposed to the theory of biological mixing (Johnson and Watson-Stegner, 1990). These contradictory perceptions have been

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tentatively reconciled by the recognition of the inherent general complexity of archaeological stratigraphy, that can be isolated into its lithostratigraphic, chronostratigraphic, and ethnostratigraphic components (Barham, 1995; Gasche and Tunca, 1984). Archaeologists have thus been alerted to the difficulty in describing strata objectively—as routinely done by geologists—and the necessity to continuously evaluate the significance of lateral and vertical stratigraphic changes.

The various analytical techniques used in the earth sciences that for a long time have been routinely applied to archaeology (e. g., particle size analysis or geochemistry) have not provided much support for deciphering sediment characteristics and for distinguishing cultural manifestations from natural ones. As a consequence, context analysis, evaluation of site preservation, and reconstruction of past lifeways have not been enhanced greatly above the level of detailed field observations of the sedimentary properties. These analyses are generally debated on the basis of artifact assemblages, including ecofacts and micro artifacts, and the presence of identifiable archaeological features (Bar-Yosef, 1993).

The understanding of the interplay between human activities and natural agents has benefited significantly from the application of microscopic techniques to the study of archaeological sediments— this is known as soil micromorphology (Courty et al., 1989). Similar to sedimentary petrography, soil micromorphology uses thin sections of intact sediments and soils in order to infer their entire depositional and postdepositional history. Originally, the use of microscopic tools was conceived as part of the excavation strategy, and it was expected to refine the criteria traditionally used for establishing archaeological stratigraphy. This technique, however, is still viewed as a difficult and unpractical option: it is conducted by specialists as it is not accessible to every field project, and it is constrained by the lack of a proper methodology for transfering data from the microscope to the field (Barham, 1995; Bar-Yosef, 1993; Matthews et al., 1997). High costs and lack of practitioners have, undoubtedly, constrained the generalized use of microscopic techniques to study archaeological sediments. In addition soil micromorphology—which is derived from petrography—is not a routine procedure used in studying soils. Finally, recognition and interpretation of soil fabrics in thin sections following soil micromorphological principles implies acceptance of the basic concepts of pedology. This latter discipline has given priority to the concept of soil genesis in most soil classification systems (Chesworth et al., 1992). Thus, study of vertical (horizonation) and lateral variations of soil morphology at all analytical levels has focused on properties that reflect the nature of the soil environment and the imprint of the dominant soil-forming processes. However, the complexity of processes involved in the formation of archaeological sediments and soils does not permit simple application of the concepts and methods of soil micromorphology as defined in pedology. Therefore, from its very beginning, the application of microscopic techniques to the study of archaeological soils and sediments was clearly presented as an adaptation of soil micromorphology—as used in pedology—in order to better match the uniqueness of the archaeological context (Courty et al., 1989). Finally, soil micromorphology differs from the approach of soil macromorphology. The latter tends to emphasize descriptive parameters in the field that have genetic overtones (after all, the designation of soil horizons in the field implies a certain realm of pedogenesis); micromorphological criteria are utilized to be as descriptive as possible, with no genetic significance.

The concepts and microscopic methods used in archaeology are in fact more similar to the routine procedures long established in sedimentary geology for studying rocks and sediments. The aim of sedimentary geology is to unravel the comprehensive complex history of depositional environments as based on the classification of sedimentary facies and the sequential analysis of their variability through space and time (Carozzi, 1960). In geology, facies denotes sediments or rocks that are characterized by a unique set of properties related to lithology, texture, structure, and organic remains (Martini and Chesworth, 1992; Miall, 1990; Walker, 1984). This facies concept differs from that of fabric used in soil micromorphology by the absence of any genetic connotation. The idea of facies was introduced in order to help the practical surveyor in the field recognize rocks and sediment (Chesworth et al., 1992). Therefore, facies analysis at the microscopic level has been aimed at providing valuable information for refining criteria visible with the naked eye. In addition, a few sedimentologists concerned with the interplay between sedimentation and pedogenesis introduced the concept of pedofacies in order to better understand how various scales of sediment accumulation across space (particularly in alluvial settings), influence the lateral variability of paleosol morphology (Brown and Kraus, 1987). Facies-based methodologies, however, have been used in archaeology only with timidity (Gilbertson, 1995), although their application to archaeological stratigraphy has been proposed to offer great potential for interpreting the genesis of cultural deposits (Barham, 1995).

The aim of the chapter is to explain how concepts and methods of sedimentary geology—particularly microfacies analysis—can be applied to archaeological settings in order to provide a better integration of microscopic techniques in the excavation. Beyond methodological aspects, we illustrate how analysis at microscopic scales provides important keys to the understanding of the formation of archaeological strata and of their spatiotemporal variability. Knowledge of these factors is an essential requirement for evaluating the integrity of the archaeological record and of site preservation. We intend to emphasize that this methodological orientation is not only important for efficiently assisting archaeological stratigraphy, but is also vital for the future of the discipline, and of geoarchaeology in general. Also considered is the potential of the microscope to illuminate the stratigraphic archaeological record. This strategy impels earth scientists to study geological processes at all temporal and spatial scales compatible with human events. These scales range from daily activities to those of a few generations, and from small habitations, to occupations over a large region.

2. Basic Concepts and Definitions

2.1. Anthropogenic Processes

What makes archaeological strata unique is the interference of humans with natural sedimentation and with pedological processes and their associated post-depositional transformations (Courty et al., 1989). In pedology, anthropogenic processes have been embodied into specific modifications of soil properties that result in the anthropic epipedon (Soil Survey Staff, 1975) without a clear definition of human-related mechanisms. This has lead the pioneers of soil micromorphology to make use of the concepts of cultural processes introduced with the emergence of behavioral archaeology (Schiffer, 1976). This author broadly defined cultural processes at the sedimentary level as the basic physical actions exerted by humans on their living sphere, and more particularly at the surface of occupation: accumulation, transformation, and redistribution. In fact, these new concepts were identical to the one used for artifacts, giving major importance to the intent of past humans in their actions and not to its mechanical nature. The terms *primary*, *secondary*, and *tertiary refuse* that are still in use (Schiffer, 1995) illustrate this anthropological perception of archaeological sediments. We have progressively realized that a definition implying intent is confusing and therefore have given priority to a broad notion referring to all types of actions that are directly or indirectly related to human activities. The diversity of these actions, however, is far from being completely explored (Courty et al, 1994; Matthews et al., 1997). This situation contrasts sharply with most manifestations of sedimentary and pedogenic processes, which are already well known at the microscopic level. Therefore, anthropogenic (i.e., cultural) processes should better be defined as everything not linked to natural factors. This characterization is adopted only to better match the specific objectives of archaeology, and it is not meant to be a philosophical position that counters human agency with "natural" ones. The need to adopt well-defined concepts for anthropogenic processes and cultural layers when studying archaeological stratigraphy should not obscure the fact that any archaeological site has been part of a depositional environment, and that at every moment of its life it has been the stage of natural processes. Therefore, the concept of anthropogenic facies can be theoretically accepted, although they practically never exist in reality, except for materials that suffered irreversible transformations by humans, such as ceramics, baked floors, and bricks.

2.2. Archaeological Facies and Facies Patterns

The definition of facies in sedimentary geology is directly applicable to archaeological layers, although in archaeology lithology is a result of deposition both by natural and anthropogenic processes. Similarly, contacts between facies are not only geogenic or pedogenic (for the pedofacies) limits, but they can also be of anthropogenic origin and complex (Courty et al., 1989). Stratigraphic units identified in the field can be characterized by one or several facies, depending on the homogeneity of each strata and the accuracy of field observations. Therefore, geologist's facies assemblage concepts can be readily extended to archaeological contexts.

Horizontal facies associations refer to lateral variations within each strata, for example, an occupation entity formed of different use areas (e.g., room, court yard, passage, street) or different sub areas within a larger depositional environment (e.g., microdepression, terrace, base of slope). *Vertical facies sequences* relate to the changes of the use of space and site configuration through time in response

to occupation dynamics and geomorphic processes. In order to avoid the confusion that commonly occurs in sedimentary geology (Martini and Chesworth, 1992), the terminology used for facies should avoid mixing description and interpretation and should not refer to the product of a process (e.g., "anthropogenic or natural facies") or to a specific activity area (e.g., "courtyard facies").

3. Methodology

3.1. Problems

Many archaeologists often enlist the help of an expert in soil micromorphology when specific problems encountered during excavation or survey remain unsolved. Such problems include the duration and function of a hearth; the presence of questionable archaeological features (e. g., weak traces of combustion suggesting the existence of a poorly preserved fire place); processes producing a certain color of a stratum; difficulty in defining the exact boundary between successive layers; or difficulty in establishing stratigraphic correlations over short distances because of rapid changes in color, texture, or cohesion (Fig. 8.1). After explaining how the aspects of the stratigraphic study performed in the field can benefit from observations at microscopic scales, the specialist can undertake a more comprehensive study. This ideal situation is facilitated when a full-time specialist—whose duties include involvement in the excavation strategies, and responsibility for the gathering of the stratigraphic database—is an integral part of the field project.

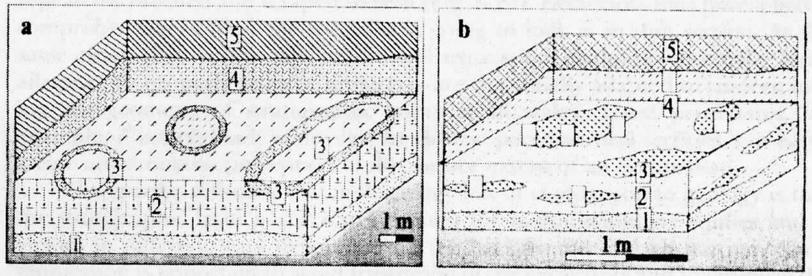

Figure 8.1. Typical situations requiring application of micromorphological study for a particular problem. (a) Circular and elongated ditches evidenced by an uncommon soil material filling with few scattered artifacts suggested to be funerary structures in an open-air site; questions to be solved: origin of the ditch-filling materials, rapidity of the deposition. The small rectangles indicate sampling position. (b) Shelter occupation sequence with four archaeological strata of distinct facies; layer 2 shows diffuse ashy lenses (3) interpreted as poorly structured fireplaces; questions to be solved: mode of deposition and environmental conditions specific to each occupation phase; function of the fireplaces.

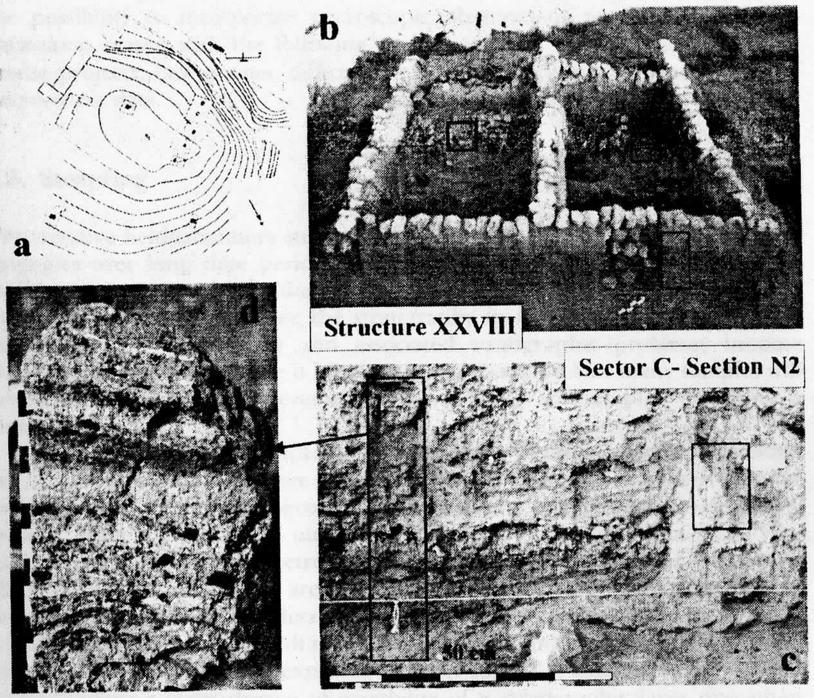

Figure 8.2. Example of an archaeological situation where soil micromorphology is exploited to its fullest in the field: Tell Dja'dé, sequence of the Pre-Pottery Neolithic (Middle Euphrates valley, Syria). (a) Topographic map of the site showing the different areas successively excavated and extensively sampled. (b) Mud–brick structures and stone architecture after excavation: samples were taken during the course of excavation to characterize the succession of room fills and the types of construction materials (see Fig. 8.10c, a room fill in thin section). (c) Domestic activity area devoid of massive architecture showing a finely stratified succession of floors and rapid lateral variability. The black rectangles indicate location of samples. (d) Fresh cut of the undisturbed sample displaying clear microstrata that are difficult to identify during excavation (see Fig. 8.10b, the thin section from this sample). (Courtesy of Eric Coqueugniot)

Within the site itself, these duties include the following (Fig. 8.2):

1. Assistance in constructing and correlating stratigraphic sequences (Cammas, 1994)
2. Investigation of the role of human agencies on the production, transport, and transformation of sediments, as well as the effects of humans on bringing about landscape changes (Wattez et al., 1990)
3. Assistance in defining site limits, the spatial configuration of habitation structures and occupation surfaces, and in determining the function of activity areas and their evolution through time (Cammas et al., 1996; Courty et al., 1991; Matthews et al. 1997; Rigaud et al., 1995; Simpson and Barrett, 1996)
4. Evaluation of the integrity of the archaeological record and the degree of site preservation with respect to the countervailing effects of natural factors (Gé et al., 1993)
5. Reconstructing palaeoenvironmental conditions—along with other environmental specialists—during each phase of occupation and evaluating the evolution of occupations through time in response to climate and environmental changes (Courty, 1989; Wattez and Courty, 1996).

In the off-site context, which is also concerned with archaeological stratigraphy, an important concern of the soil micromorphologist is to better define the exact nature and spatial extent of human-induced landscape transformations. These transformation can be broadly characterized as direct effects, such as changes in soil properties caused by cultivation, or indirect ones that refer to anthropogenic forcing of past geomorphic functioning (Courty and Weiss, 1997; Davidson et al., 1992; Gebhardt, 1988; Macphail et al., 1990)

3.2. Research Strategy

The practice of excavation ideally consists of a strategy of alternating fieldwork and laboratory work in order to continuously evaluate and refine the relevant and easily accessible attributes used to recognize spatial and vertical facies changes in the field. Because most members of a regular archaeological team do not have personal access to the microscope, the specialist is continuously concerned with explaining the information collected under the microscope. Observation of an impregnated, undisturbed block, for example, illustrates how a fresh cut can reveal a much clearer picture of the stratigraphic record than one exhibited by a repeatedly brushed and scraped section (Fig. 8.2d). Excavators thus have a better comprehension of what the specialist is going to look at in thin section. At the same time, they realize why traditional excavation methods—normally quite adequate to properly retrieve artifacts—are not usually adapted to understanding the geometry of stratigraphic layers at all scales. These procedures, for example, if not regularly controlled by closely spaced vertical sections, can easily create an erroneous perception of the surface extent of an occupation.

The specific difficulty that archaeology has in comparison to geology is that the stratigraphic layer is the starting point for multidisciplinary studies and is viewed in different ways depending on the background of each partner. Communication is important to avoid frustration of the excavators and to optimize the use of microscopic data. Accomplishments made by microscopic analysis are strongly dependent on the quality of the sampling, which itself is constrained by archaeological problems that arise from field perceptions. As shown by long experience in the earth sciences, an important difficulty for improving efficiency is to decrease the time lag between fieldwork and laboratory analysis. This lag is one month at a minimum but is generally longer because of a series of practical constraints. The problem is less crucial for long-term excavations where there is the possibility to incorporate microscopic observations produced after each excavation season with the following one. Short-term excavations, particularly rescue projects, face greater difficulty in making efficient and dynamic use of microscopic data.

3.3. Sampling

The iterative field/laboratory strategy offers the possibility of planning sampling strategies over long time periods, which ultimately reduces costs. In general, initial sampling is guided by the need to answer specific problems or to establish the main facies that constitute the stratigraphy in the field. As the excavation progresses, the stratigraphy and associated stratigraphic problems become clearer, and as a consequence it becomes easier to realize how many samples will be needed in order to be certain that the range of stratigraphic variability is covered (Fig. 8.3).

The ideal number of samples to be taken for a successful micromorphological study is a delicate question, often raised by beginners. Those with broader experience, and who are unconstrained by practical limitations, will simply answer, "Take the maximum number of samples. " This query is in fact a very basic principle known to all petrographers: the more samples you take, the more efficient and less speculative are your inferences under the microscope, simply because the "unknown" is reduced to a minimum. However, when working at an archaeological site, it is difficult to adjust sampling to match the spatial complexity of the deposits and the expected level of spatial resolution. For example, understanding a large degree of variability of a stratigraphic layer may often require sampling at <50 cm intervals (see Fig. 8.2 b & 8.2c). Such sampling would undoubtedly create severe damage to the layer and would conflict with the need to retrieve *in situ* artifacts over wide surfaces, which is necessary for understanding intrasite activities. A common solution is to sample a series of sections or pedestals left around the excavated area; this strategy facilitates the extraction of undisturbed blocks with minimum disturbance. It is, however, not ideal for a proper integration of field and microscopic data because the undisturbed samples are taken from a non-excavated area, and, therefore, cannot help test the reality of spatial boundaries or structures as recognized during the excavation.

Sampling is an imperative step, involving a series of choices that can be made only according to the comprehension of the stratigraphy at a certain time, and it requires close collaboration between all field participants. Jointly describing undisturbed, freshly extracted blocks often offers the possibility of confronting different perceptions and of fixing a common view of the field reality that will serve as a solid basis for a joint elaboration of the archaeological stratigraphy.

The novelty of archaeological sites and soil/depositional-related archaeological problems makes irrelevant a standardized sampling procedures for routine soil investigations. To the contrary, sampling requires flexibility, intuition, and the ability to accept the fact that errors will be later revealed under the microscope.

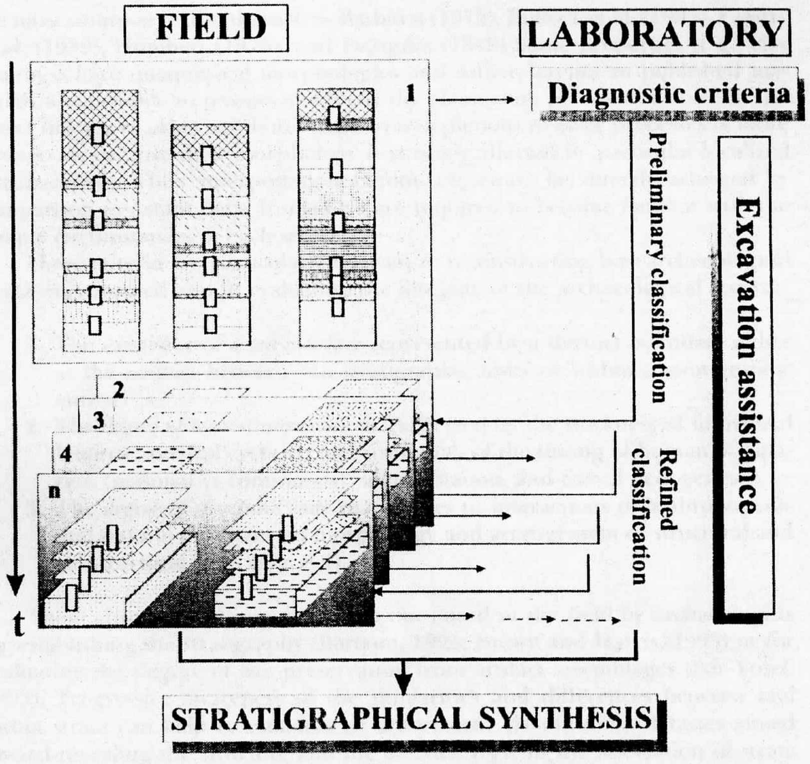

Figure 8.3. Sampling procedure employing an iterative strategy in which excavation and laboratory constraints are continually weighed against each other. Numbers 1 to *n* represent successive excavation seasons.

3.4. Analytical Procedure

3.4.1. Theoretical Basis

The basic description of depositional environments, associated sediments, and soils has long been recognized to be a difficult task because they are heterogeneous, spatially variable, time dependent, and controlled by nonlinear processes that interact at different spatial and temporal levels (de Marcily, 1996; Perrier and Cambier, 1996). Two scenarios are possible in light of our ability to observe these processes : (1) global changes of the system related to a particular phenomenon can be quantified at a specific operating level, by selecting appropriate indicators even though understanding of causality and the interactions with other phenomena remain speculative; or (2) the measurement of selected "diagnostic" properties does not permit characterization of the global functioning of a system. This situation stems from its great complexity, which necessitates searching for individual processes. This is achieved through objective description of the system coupled with constant elaboration of explanations intended to match our observations.

The global approach is widely applied in soils for quantifying all effects of agricultural practices and is extensively used with isotopic indicators in palaeoclimatological studies of marine, ice, and lake cores. In sedimentary geology this "elementary" approach has long been successfully applied to perform facies analysis of sedimentary basins and to establish a general theory of evolution of geological systems (Bathurst, 1971; Humbert, 1972; Walker, 1984). Due to the interaction of sedimentary, pedogenic, and cultural processes, archaeological depositional environments are extremely complex and it is not yet possible to isolate easily measured indicators that would provide rapid and simple answers to the large range of questions raised in archaeology. Although often presented as a routine analysis in archaeological survey and site interpretation, the exact potential of phosphate analysis for differentiating site function needs to be more deeply explored (Quine, 1995). Therefore, the "disentangled approach" combined with facies analysis is currently the only methodology that can help produce a structural logic in various geomorphic and cultural contexts that are notorious for their unique origin (Brown and Harris, 1993).

3.4.2. Practice

The need to utilize facies analysis as a tool generally depends on the number of samples. This is crucial when a large number of samples is being investigated. Samples used in facies analysis are collected in two basic ways: either extensively across horizontal layers to study the spatial variability of facies and their archaeological significance, particularly for well preserved living floors (see e.g., Fig. 8.2b & 8.2c), or systematically from all strata across the different vertical sections in order to study the evolution through time of their mode of formation.

In both cases, the first stage of the facies analysis requires a systematic comparison of all the thin sections, generally at low levels of magnification. Two objectives should be kept in mind during this stage:

- To establish relationships among field properties and microscopic scales. In particular, to attempt to understand the criteria that the excavators selected for identifying each archaeological strata and its lateral changes;
- To discriminate between: (1) the properties common throughout all the archaeological strata, or at least, a great number of them; these properties are likely to reflect a general trend in the origin, mode and/or conditions of deposition; and (2) the properties encompassed in vertical and lateral changes. This second group can be subdivided into (B1) the ones that change between individual strata, and (B2) those that change within each strata.

Microscopic properties are described according to standard terminology in use for rocks, sediments, soils, and archaeological deposits that are easily available in the most common textbooks such as Bathurst (1975), Bullock et al. (1985), Courty et al. (1989), Humbert (1976), and Pettijohn (1949) Some properties (e.g., clay coatings) have unequivocal morphologies and with reference to published materials it is possible to recognize directly the elementary processes involved. The direct linkage of other attributes (e.g., iron depletion) to basic processes is more ambiguous because their morphology is strongly affected by particular localized circumstances. Their interpretation cannot, therefore, be directly achieved by comparison to extant data. Instead we are required to become familiar with the unique circumstances of each setting.

Three criteria are particularly relevant to reconstructing how archaeological strata were formed and in evaluating the integrity of the archaeological record:

1. The existence of a *soil interface* represented by a distinct boundary either at the contact between two stratigraphic units or within a stratigraphic entity;
2. The *degree of microstratification* as expressed by the thickness of individual laminae, vertical cyclicity, and continuity of the timing of human occupation (seasonal vs continuous), sedimentation, and coeval pedogenesis;
3. The *degree of structural state* that relates to interactions of anthropogenic and natural processes on morphology and arrangement of structural and substructural units (Fig. 8.4).

These criteria can be coupled with ones used in the field by archaeologists for establishing the stratigraphy (Barham, 1995; Brown and Harris, 1993) or for evaluating the degree of site preservation from artifact assemblages (Bar-Yosef, 1993). Progressive awareness of the similarities and differences between and within strata can help to establish an arborescent classification of facies aimed toward revealing the structure and the internal logic of the association of strata toward different levels of organization (Humbert, 1972). The main groups of the classification are defined on the basis of their general properties, whereas different subgroups are distinguished according to the type and intensity of changes in properties. For the classification to be operational in the field, we must be able to choose between unambiguous criteria that can be easily recognized in the field with the naked eye. Facies sharing close morphological similarities at different microscopic levels are assumed to have similar origins and relate to the same mode of deposition. Construction of a strictly descriptive classification implies both the tentative identification of the basic processes as well as their interactions. The classification can be accepted when successive subdivisions in groups and subgroups can be genetically linked (Fig. 8.5). These linkages enable us to interpret sequence of events expressed in the lateral and vertical facies changes.

3.5. Synchronization with Other Techniques

Various analytical techniques performed on bulk samples (e.g., granulometry, organic matter and carbonate contents, pH, phosphorus) have generally been

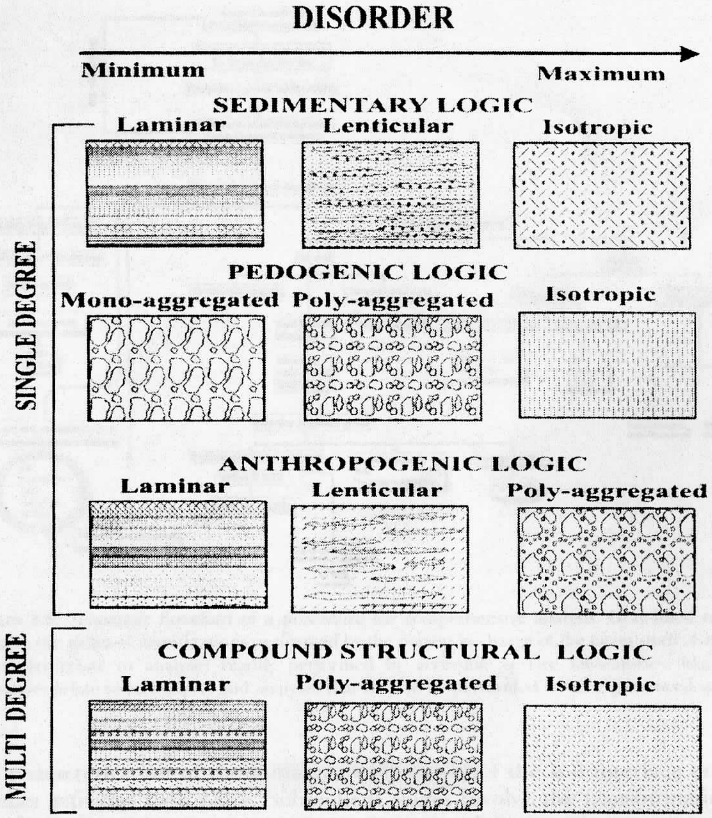

Figure 8.4. Schematic representation of the different types and degrees of structural logic for archaeological strata. This figure illustrates that morphologically similar structures and fabrics can have different origins. For example, for a pedogenic logic the polyaggregated structure can result from both wetting-drying and biological activity, for an anthropogenic logic a similar structure can result from dumping and trampling, and for a compound logic, gravity desegregation, trampling and biological activity can interact.

borrowed from pedology and sedimentology and have been commonly applied to archaeological soils and sediments (for examples see many reports in the archaeological "gray literature"; also Stein and Farrand, 1985; Lasca and Donahue, 1990). These techniques are often presented by the geoarchaeological community as alternative to micromorphological study, and they are often considered to be more rapid, cheaper and statistically reliable to a certain extent (Canti, 1995).

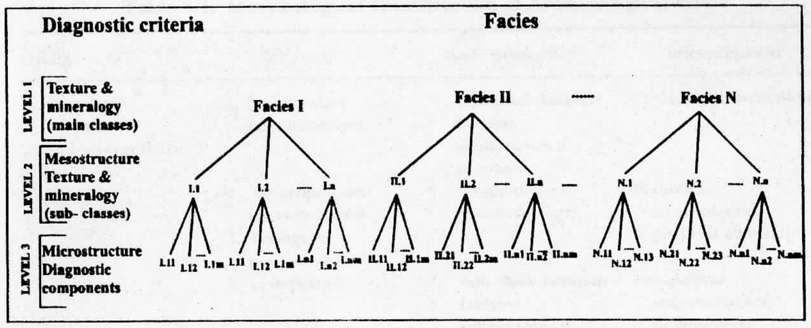

Figure 8.5. Schematic framework of an arborescent classification for interpreting lateral and vertical affiliation between strata: Level 1 groups relate to distinct classes of parent materials used to describe the principle changes in sedimentation or temporal changes of human-used soil materials; Level 2 subgroups detail significant changes of environmental conditions through time or major changes of human activities; Level 3 subdivisions concern lateral spatial variations of local factors or human activities.

The inherent complexity of stratigraphic archaeology and our insufficient understanding of archaeological strata does not, however, allow us to use these techniques on a routine basis independent of microscopic study and to extract relevant conclusions from their statistical analysis. In many cases, the exact significance of the measurement obtained (e.g., particle size data or calcium carbonate content) can be established with the help of microscopic observations.

Choices of analytical techniques may vary widely according to the nature of the problem at hand and the degree of resolution required. However, in order to successfully interpret the data we must adopt a logical progression in the understanding of the levels of organization of the constituent properties. The proposed guideline (Fig. 8.6) emphasizes the difference between two groups of analytical results: (1) easily accessible ones generally obtained from service laboratories and interpreted by the same person who is in charge of the facies study; (2) ones not available on a routine basis that are generally in the hands of a specialist and not the person in charge of the stratigraphic/facies study. The latter, however, keeps a pivotal role in helping link the analytical results with microscopic data and maintaining their relevance to the questions raised in the field.

4. Formation of Archaeological Strata

4.1. General Principles

Application of facies analysis permits the construction of a general model to describe the formation of archaeological strata, including the evaluation of the integrity of the archaeological record. An important aspect of the model lies in

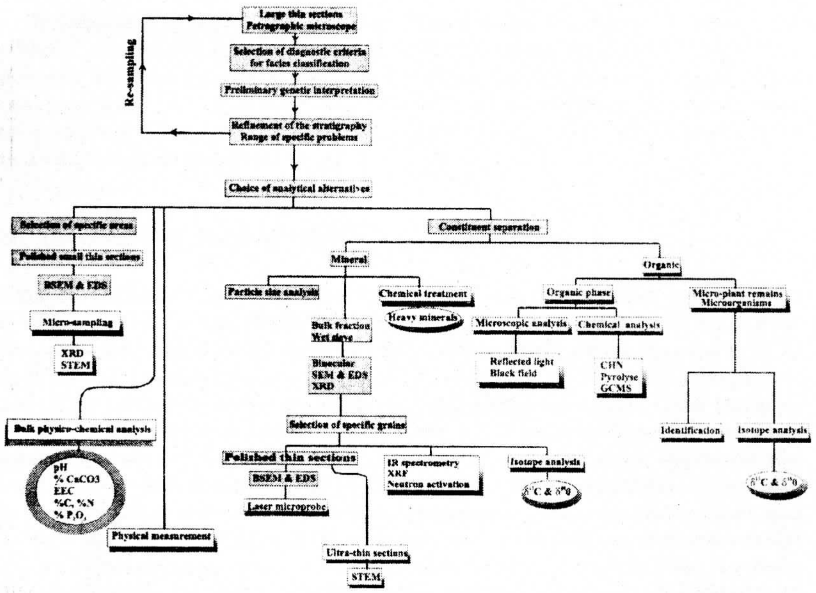

Figure 8.6. Schematic flowchart of a procedure for comprehensive analysis. Gray-filled rectangles indicate the series of investigations performed by the person in charge of the facies study; Gray raised rectangles relate to analyses readily performed by accessible service laboratories; black raised rectangles relate to techniques and analyses that have to be performed by an experienced specialist.

the characterization of the initial state (Phase 0) of the soil interface on which human activities took place. Subsequent stages involve the transformation of a two-dimensional entity into a three-dimensional body. These stages can be subdivided into two phases:

1. Phase 1 represents the period during which anthropogenic processes are dominant, although they interact with sedimentation and pedogenesis. Thus, this phase records human activities in their environmental settings.
2. Phase 2 integrates all the transformations that occurred after site abandonment and includes deterioration of the archaeological signal that was recorded during Phases 0 and 1.

This simplified view aims to illustrate that the evolution of archaeological strata follows general rules that link their morphology, genesis, and their archaeological significance (Table 8.1). Regularly ordered strata display the finest quality temporal signal, as would be the case for Phases 0 and 1 above, with minimal subsequent distortion as (i. e., no Phase 2). They characterize well-preserved strata with good integrity of the archaeological record, and they are ideal for performing sequential analysis.

Table 8.1. Morphological Classification of Archaeological Strata

Group	Subgroup	Basic properties	Interpretation
Ia. Regularly ordered (microstratified)	1. Sedimentary microstratified	• mm thick laminae • Distinct subhorizontal interface	Cyclical sedimentation
	2. Anthropogenic microstratified	• Single degree structural logic	Periodical accumulation
	3. Pedogenic microstratified		Superficial alteration
	4. Compound	• mm thick laminae • Distinct subhorizontal interface • Relict interface	Polycyclical sedimentation/ pedogenesis/ occupation
Ib. Regularly ordered	Anthropogenic	Massive, single degree structural logic	Careful human preparation
II. Weakly ordered	1. Pedosedimentary	Sedimentary microstructures and pedogenic features	Discontinuous sedimentation/ pedogenesis
	2. Anthropogenic	Anthropogenic structural logic. Relict interface	Human accumulation/ reworking
	3. Compound	Multidegree structural logic	Intermittent sedimentation/ pedogenesis/ occupation
III. Randomized	1. Sedimentary	• Single degree structural logic • No sedimentary microstructures	Massive deposition
	2. Pedogenic	Homogeneous Gradual limits Single degree structural logic	High pedogenic maturity
	3. Pedosedimentary	Homogeneous Gradual limits Multidegree structural logic	Redeposited soil horizons
	4. Compound	Homogeneous Gradual limits Erratic structural logic	Human deposition of soil horizons

Weakly ordered strata do not offer a high-quality temporal signal: the record of Phase 0 is generally obscured; that of Phase 1 is present but often not easily accessible, although effects of Phase 2 are moderate. Weakly ordered strata characterize rather well-preserved strata with a medium integrity of the archaeological record.

In randomized strata, the record of Phases 0 and 1 has been totally erased by Phase 2 transformations. Study of their facies cannot be expected to provide information on the original anthropogenic processes and natural events contemporaneous with the occupation, but instead aims at clarifying the nature and environmental significance of the events that strongly obscured the integrity of the archaeological setting.

4.2. Dynamics of the Soil Interface

Archaeologists have long associated high-quality site preservation with the idea of well-preserved living floors, particularly as viewed as the intact record of occupation left after abandonment (Schiffer, 1995). Evidence for minimal vertical dispersion and subhorizontal orientation of artifacts, as well as conjoined pieces, have all been used to recognize these intact surfaces (Bar-Yosef, 1993; David et al., 1973; Leroi-Gourhan and Brézillon, 1966). Analysis at microscopic scales has revealed the physical reality of these occupation surfaces, which appear in the form of inframillimetric layers (Gé et al., 1993) and whose identification provides the opportunity to test their existence independently from field observations and archaeological interpretation. The occurrence of these surfaces is not restricted to special circumstances, such as slow accretion, or rapid burial, as often has been suggested (Bar-Yosef, 1993; Schiffer, 1995), and they appear in all sedimentary contexts (e. g., Fig. 8.7). The high resistance of these surfaces to disturbance is linked to the dynamics of the different processes that originally produced them. Often, intense transit or careful maintenance of habitation and activity areas for prolonged periods has preserved the surfaces from plant colonization, therefore favoring natural agents that are active on bare surfaces (Bresson and Boiffin, 1990; Valentin, 1991). Thus, the induration of ancient surfaces, commonly noticed in the field, appears in thin section to result from hard setting and physical strengthening of interaggregate bonds caused by repeated trampling and alternating wetting–drying. In other contexts, surfaces have remained exposed to splash effects of raindrops at the bare surface and to repeated drying, as expressed by their laminar structure. These processes have induced a surficial compaction that has strongly constrained vertical root penetration and biological mixing, as exhibited by the presence of common very fine subhorizontal channels. Because soils react strongly to atmospheric conditions, well-preserved ancient soil surfaces provide information on the microconditions at the time of occupation.

Living surfaces formed from very resistant materials of concretelike hardness that have been carefully maintained offer a unique situation where the soil interface has remained strictly as a two-dimensional entity, possibly over long periods of time (Fig. 8.8). These exceptions aside, in thin section, soil interfaces of archaeological contexts always express a vertical dimension created by the combined effect of physical actions on the living substrate, production of human microdebris, and the accumulation of dust from various sources. Because these factors operate at very short (i.e., at diurnal) human time scales, viewing the soil interface as a plane surface with irregularities is correct only for instantaneous moments of

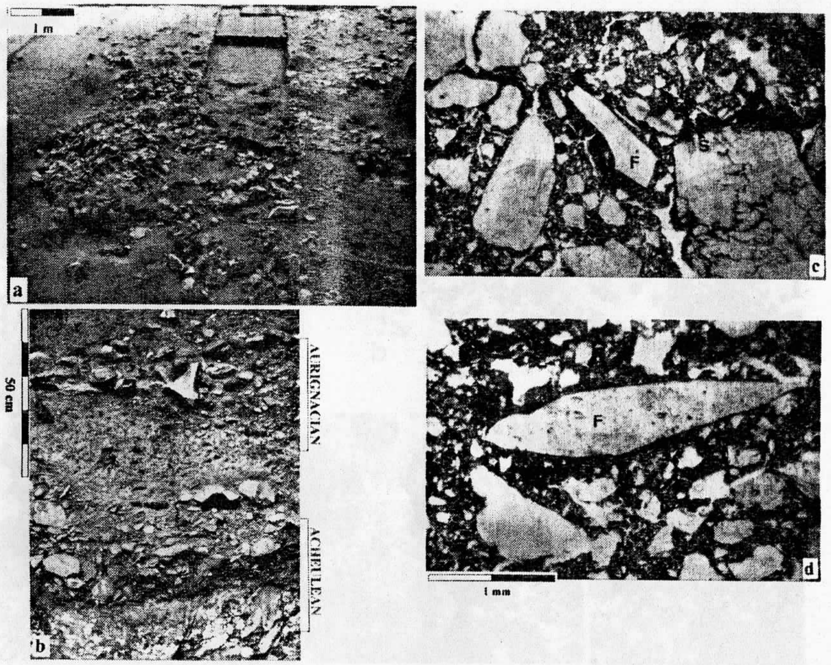

Figure 8.7. The open-air Palaeolithic site of Barbas, Dordogne Valley, southwest France. (a) Field view showing a well-preserved Aurignacian (early Upper Palaeolithic, ca. 35000 yr BP) occupation surface, extensively excavated in one part of the site (Barbas III). (b) Stratigraphic sequence from Barbas I showing evidence of surface flow during deposition of the Acheulean and Aurignacian levels. These flows, however, have not disturbed the archaeological assemblages and interface with associated soil. (c) Microscopic view of the locally well-preserved soil interface (sample 1) on which artifacts are lying; the thin surface illustrates a microstratified pedogenic facies with finely laminated silty clay (S) resulting from water percolation through an impervious material, possibly an animal-skin floor covering, with common microflakes (F) incorporated into the subsoil by trampling. (d) Lateral variations of the same surface (sample 2) showing the slight compaction of a weakly distinct soil interface with subhorizontally layered microflakes. (Photos (a) and (b) courtesy of Eric Boëda)

a few hours. In general, individual ancient soil surfaces are not easily identified during excavation because they are thin and form only patchy physical discontinuities. The field perception of a single, well-preserved living floor appears, in most cases, to correspond to polyphased living floors that represent longer occupation episodes, probably of a few years' duration (Gé et al., 1993).

Human actions have created a unique situation that has nearly no equivalent in natural conditions. An exception occurs in arid regions where soils, weakly protected by an open vegetation cover, have remained exposed to the effects of rain splash and to the effects of surface slaking and crusting. In regions of greater humidity, weakly or nonvegetated surfaces are restricted to zones of active

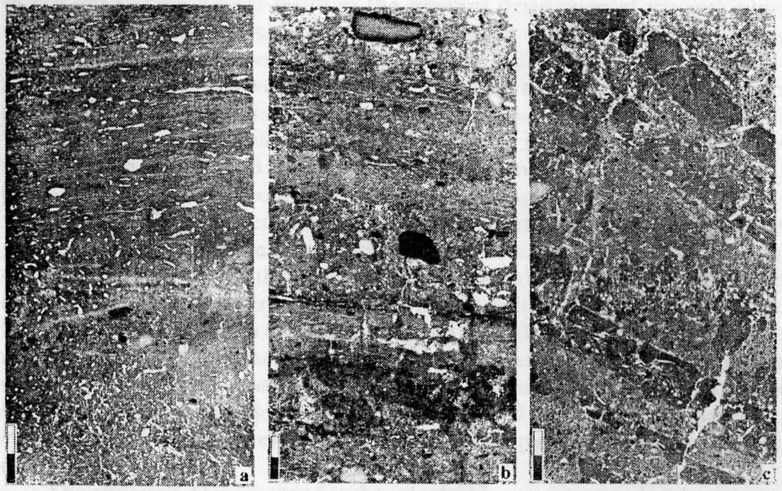

Figure 8.8. Microstratified facies in occupation sequences of urban and proto-urban sites, PPL. (a) Typical anthropogenic microstratified facies resulting from careful maintenance (constant cleaning and seasonal replastering) from a room adjacent to the late 3rd millennium temple at Tell Leilan, Syria. (b) Stratified succession of anthropogenic microstratified facies from a moderately well-maintained room made of light construction materials (thatched roof, thin daub walls); the succession here results from the combined effects of human activity (plastering, domestic debris accumulation and trampling), decay of the walls and roof, and seasonal dripping of water. (c). Stratified succession in a room comprised of anthropogenic massive facies (plastered mud floor) and compound weakly ordered facies that illustrate alternation of seasonal occupation in a well-maintained space and the effects of natural processes (desegregation and insect activity) during phases of nonoccupation. (b) & (c): Pre-pottery Neolithic site of Tell Dja'dé (Middle Euphrates, Syria), see Fig. 8.2. Scale bars equal 1 cm.

sedimentation, where short-term cycles of erosion/sedimentation can maintain instability over long periods. Therefore, the soil surface is permanently refreshed and cannot be morphologically confused with a human-created soil interface. In rare cases, natural conditions can produce a soil interface morphology that can be confused with a human one. For example, an abrupt event (e.g., a wildfire) instantaneously destroying the natural vegetation and accompanied by a heavy rain spell can bring about soil compaction (Weiss et al., 1993). In turn, this compaction can produce a sharp discontinuity, which when buried (Fig. 8.9a) can resemble a human–soil interface (Courty et al., 1998).

4.3. From the Soil Interface to the Archaeological Layer

Archaeological settings display a large range of temporal sequences that document transformations of the initial soil surface into an archaeological layer.

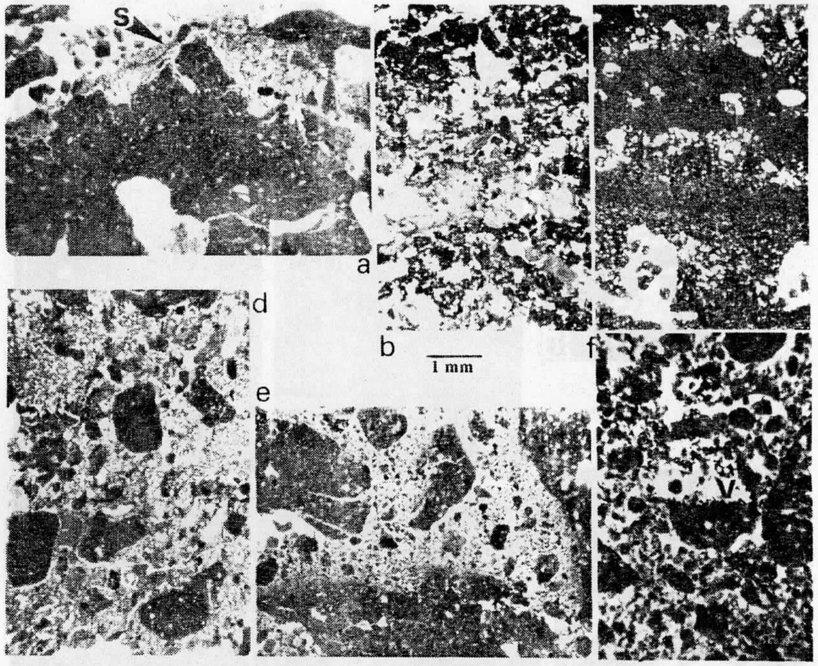

Figure 8.9. (a) View under the microscope (PPL) of a natural soil surface (S) resembling a human soil interface that results from a wildfire contemporaneous with fallout of exogenous dust and strong physical disturbance of the underlying subsoil (Tell Leilan region, NE Syria, burnt surface dated at 3980 yr BP); its wide regional occurrence attests to its nonanthropogenic character. (b) A regularly microstratified pedogenic sequence in the Middle Palaeolithic layer of the cave of Vaufrey (Dordogne, France) resulting from episodic colonization of the cave surface by cryptogamic vegetation and strong weathering of the sparse limestone debris by organic acids; interference with human activity is here marked by repeated burning. PPL. (c) Homogenous massive strata (randomized sedimentary facies) of the middle Paleolithic Cave of Lazaret (Alpes-Maritimes, France): local preservation of this type of clayey silt microlayered accumulation demonstrates slow deposition and weak pedogenic disturbances. PPL. (d), (e), & (f): View in thin section (PPL) of an exceptional event traced over NE Syria that relates to the burnt surface shown in (a); incorporation of exogenous particles (i.e., V in photo f: black vesicular glass) and physical disturbances (here sudden fragmentation of the brick constructions) similar to the ones identified in natural contexts are here identified in occupation sequences and discriminated from anthropogenic processes; (d): Tell Brak, (e): Tell Leilan, (f): Tell Beydar.

Different scenarios are possible depending on the balance between three main dynamics: (1) additions as the result of natural sedimentation and/or anthropogenic inputs; (2) losses as the result of erosion and/or anthropogenic removal; and (3) *in situ* transformation as the result of pedogenesis and/or anthropogenic modification.

Schematically, additions can be understood as exhaustion of the soil interface at different accumulation rates, with differing consequences on the morphology of the soil surface. Losses result in the physical destruction of the soil interface that is, in most cases, instantaneous and generally varies with the microtopography. *In situ* transformations, in theory, leave the soil surface in a stable condition, although its properties may undergo significant changes. The most important modifications involve the layers situated below the supposed stable interface. These changes are governed by two counteracting processes: progressive downward horizonation caused by vertical exchanges between the solid liquid and gas phases and progressive homogenization due to biogenic mixing.

Regularity of the processes involved in the formation of stratified sequences generally allows the estimation of rates of deposition, the duration of exposure of the soil interface, and the environmental conditions associated with individual cycle. Archaeological layers with microstratified sedimentary sequences generally have formed in proximity to water bodies, such as lakes or large meanders, where seasonal flooding has gently refreshed the soil interface, thus preventing vertical disturbance by soil fauna and root growth. In the most regular sequences, occurrences of archaeological strata sandwiched between two depositional episodes provide clear evidence for short occupation of seasonal duration (Fig. 8.10).

The common occurrence of archaeological layers associated with microstratified pedogenetic sequences (although exceptional for natural soils; Soil Survey Staff, 1975) demonstrates the importance of human-induced modifications in the soil microenvironment: reduced seedling and root growth, and preferential colonization of the soil surface by cryptogamic vegetation (mosses and algae), particularly in cave settings (Fig. 8.9b). Microstratified pedogenetic sequences with diffuse horizon boundaries have also developed during the last glacial cycle (and also in postglacial soils) under periglacial conditions as the result of regular aeolian additions, stabilization of the soil surface by a short grass cover, and reduced physical disturbances that are generally restricted to well-drained conditions. Study of the morphology and thickness of microhorizons allows us to evaluate the environmental significance and duration of each pedogenic phase, whereas evaluation of the degree of soil surface alteration by human activities provides indications of the length of occupation.

Anthropogenic microstratified sequences are assumed to occur in well-preserved habitation areas, such as proto-urban and urban sites (Brown and Harris, 1993; Matthews et al., 1997). Microfacies analysis reveals that typical anthropogenic microstratified strata are, in fact, exceptional and restricted to well-maintained habitation areas (Fig. 8.8a). Finely stratified sequences—commonly produced by natural processes such as lacustrine deposition—embody interactions of natural and human processes of similar tempos that are particularly regulated by seasonality (examples in Fig. 8.8b & Fig. 8.10). Cyclical natural sedimentation or surface pedogenic alteration can even be the predominant process involved in the formation of regularly micro stratified sequences of habitation areas (e.g., courtyards and streets) largely open to atmospheric agents (Fig. 8.8c). These sequences offer a unique, high-resolution record to monitor the evolution and environmental conditions with the successive occupation phases (Fig. 8.11). Low-energy deposition and weak pedogenesis that are common to all

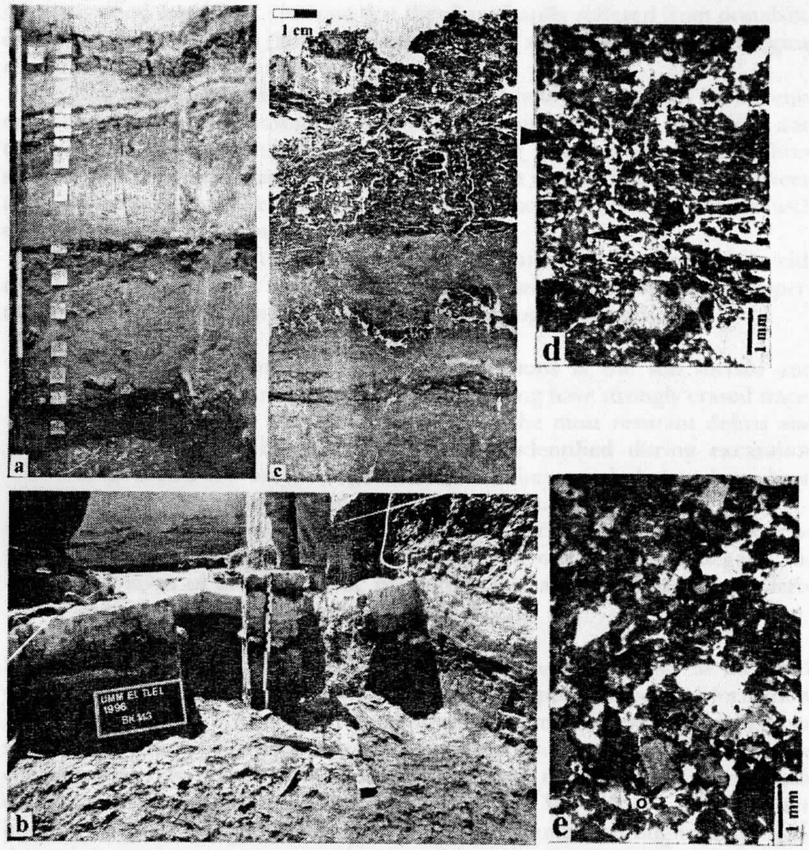

Figure 8.10. The Middle Paleolithic sequence of Umm el Tlel (El Kowm basin, Syria) showing a contrasted succession of well-stratified sedimentary deposits interlayered with a series of short occupation phases. (a) Field view of the stratigraphic section from layers V to VI; rectangles indicate location of samples seen in (b). (b) Detailed field view of the extremely rich V2 Mousterian complex (ca. 42,000 BP) showing the well-preserved V2πa occupation surface and extraction of an undisturbed large-size block during the excavation. (c) Microscopic view (PPL) at low magnification of layer V2β (short Mousterian occupation) showing progressive transition from a regularly microstratified biogenic lacustrine deposit (seasonally wetted pond) to a dark organic-rich facies (swamps episodically affected by wildfires). (d) PPL view at high magnification of the upper part of (b) showing millimeter thick archaeological strata (arrows) sandwiched within the sedimentary sequence. (e) Contrasted view of a disorganized archaeological strata from the coarsely stratified Mousterian VI4a layer (bottom of the sequence shown in photo (a)); reduced vertical dispersion of microartifacts indicates that reworking occurred just after the occupation due to rapid flooding. PPL. (Photos (a) and (b) Courtesy of Eric Boëda)

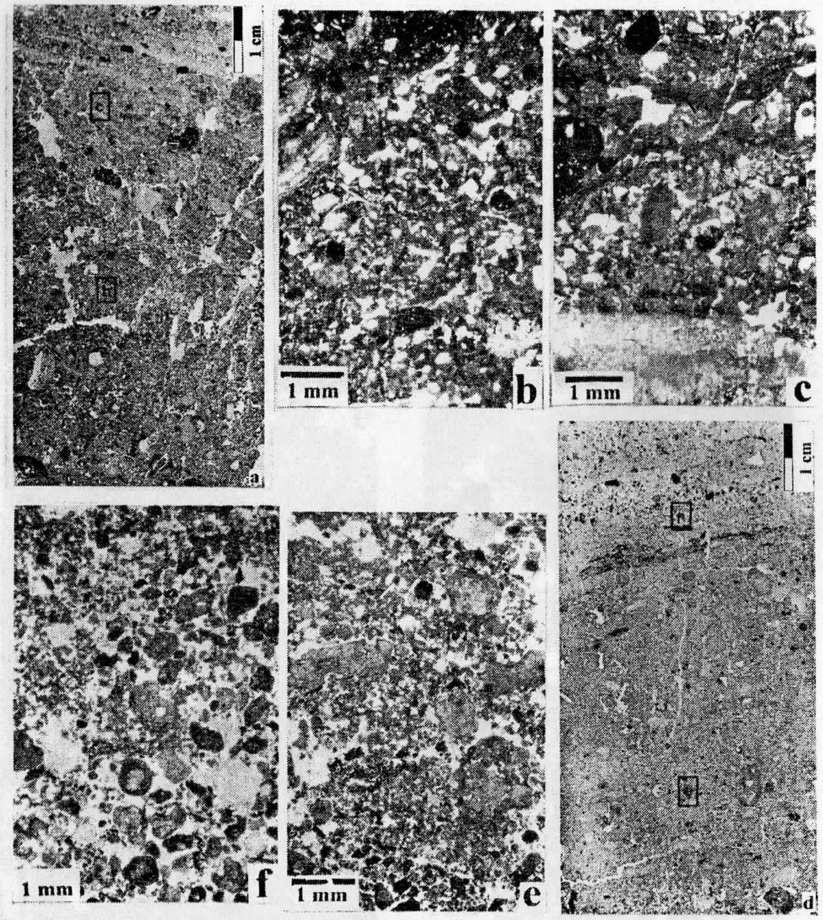

Figure 8.11. Environmental change from wet to dry conditions evidenced from a street sequence, site of Tell Arqa (Northern Lebanon), PPL. (a) Low-magnification view from the bottom part of the street (ca. 2300–2250 B.C.) showing succession of regularly ordered microstratified loose anthropogenic facies. (b) High-magnification view of rectangle 1 from (a): the accumulation here results from slow desegregation of the plastered mud walls adjacent to the street and trampling in well-drained conditions as shown by the lack of compaction. (c) High-magnification view of rectangle 2 from (a): the coarse-textured, loosely packed facies indicates episodic torrential runoff along the street, and an overall maintenance of dry conditions. (d) Low-magnification view from the upper part of the street (ca. 2200–2150 B.C.) showing succession of regularly ordered microstratified dense anthropogenic facies. (e) Massive facies (rectangle 1 from (d)) indicating rapid brick collapse of the adjacent walls and compaction under wet conditions. (f) Microstratified facies formed by the combined action of wall desegregation, human trampling in wet conditions, and surface slaking by mud flow.

microstratified sequences, illustrate that they have hardly suffered from postabandonment transformations (Phase 2), and thus offer a high-quality archaeological record as deduced from excavations.

Weakly ordered strata generally appear in the field as essentially homogeneous deposits with wide variations in properties, such as color, cohesion, and texture, that often give the impression of having gradual boundaries. Three subgroups can be recognized (Table 8.1) that exhibit distinct interactions between anthropogenic and contemporaneous natural processes (Phase 1), each with different archaeological implications.

For subgroup II.1, the environmental conditions contemporaneous with discontinuous deposition, as reconstructed from their pedosedimentary properties, permits identification of two types of archaeological records:

1. In this case, chemically aggressive conditions at the soil surface and intense biological mixing or repeated flooding have strongly erased traces of anthropogenic influence, leaving only the most resistant debris and occasionally weakly preserved structures identified during excavation (Fig. 8.12); the archaeological record is thus concluded to have been strongly altered but stratigraphically coherent.
2. This case is a nonaggressive environment characterized by moderate biological mixing and lack of resistant microdebris, which negates the alteration of anthropogenic properties that are concluded to not have existed, suggesting weak human influence.

Strata from sub-groups II.2 and II.3, although generally similar in the field, present subtle structural differences that reflect on specific modes of formation. For example, the structural logic of aggregation permits differentiation between slow desegregation by natural processes (e.g., insect burrowing and dripping), by contemporaneous human activities, and by rapid destruction of earth-made constructions (see examples in Fig. 8.8c, Fig. 8.9d, e & f, & 8.11). For the latter, however, similarity of physical actions exerted by humans through dumping or through instantaneous natural collapse explains that the distinction between the two scenarios cannot be solely deduced from microscopic observations but requires consideration of the overall excavation context.

The randomized group corresponds to archaeological strata that in the field show an overall homogeneity, with gradual boundaries or sharp erosional contacts, and that are interpreted either as occasional occupations or reworked sites, depending on artifact patterns. At microscopic scales the observed homogeneity appears to relate to postoccupation events (Phase 2), such as rapid sedimentation (III.1), long pedogenic development (III.2) or a combination of both (III.3). Randomized strata have, therefore, lost the memory of their early stages (Phases 0 and 1) and microfacies analysis is unable to restore a reliable image of the original context. The pedosedimentary properties are, however, sufficiently informative to allow recognition the mode of deposition and the nature of pedogenic alterations and their environmental significance. Thus it is possible to evaluate the impact of these transformations on the original configuration of the artifact assemblage. Compound randomized strata (III.4) form a

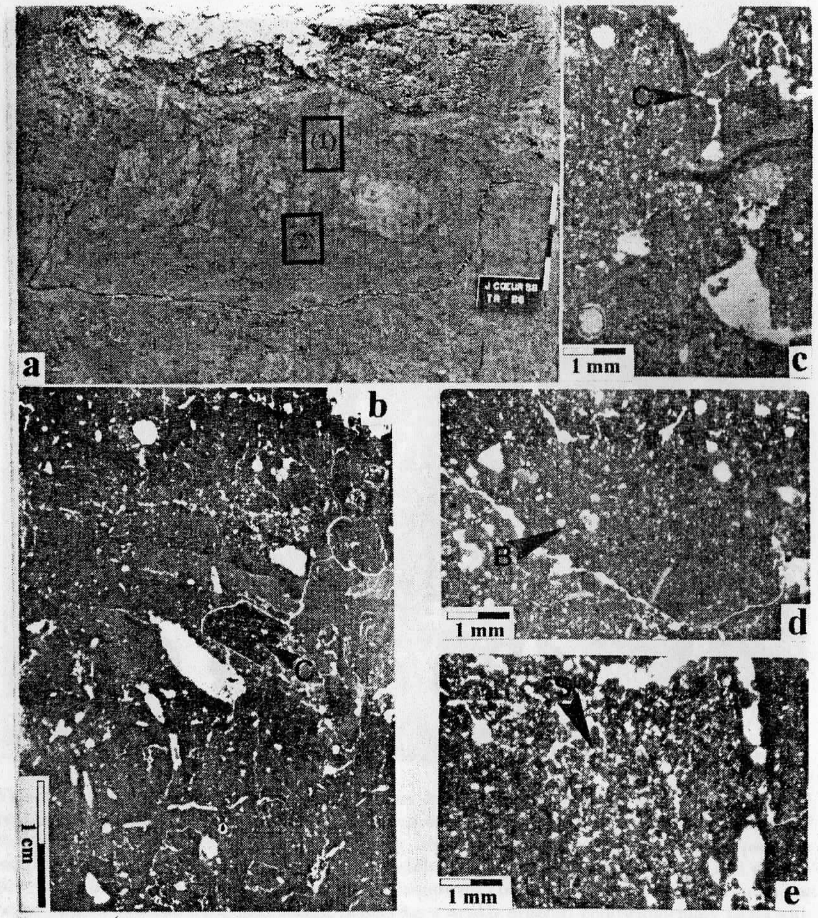

Figure 8.12. Chassean (Middle Neolithic) site of Port-Marianne, Lez flood plain (Hérault, France). (a) Anthropogenic structure with rare sherds recognized during test trenching, interpreted as a foundation pit. (b) View at low magnification of thin section from sample (2) (see location in photo (a)) showing a typical, weakly ordered pedosedimentary facies with massive calcareous loam strongly reworked by biological activity and ceramic fragment (c). Evidence at high magnification of fragmented slaking crusts (S) as shown in photo (c), dense subangular millimetric aggregates identified as brick fragments (B) as shown in photo (d) and concentrations of loamy sand (S) in the packing porosity of aggregates as shown in photo (e) helps to demonstrate that the pedosedimentary facies corresponds to collapse of mud–brick constructions and their strong reworking by biological activity and flooding. PPL. The severe alteration of anthropogenic facies explains the difficulty to identify geometry and function of the archaeological structures suspected in the field. (Photo (a) courtesy of Luc Jalot)

separate subgroup in terms of genetic significance, although they also present an overall homogeneity at microscopic scales and a lack of an anthropogenic signal. In most cases, their anthropogenic origin can be established by excavation. However, human intervention, restricted to transportation, has not significantly modified the original properties of the soil materials quarried for various purposes, such as construction of an earth platform.

4.4. Stratigraphic Relationships and Three-Dimensional Reconstruction

The earth sciences attempt to reconstruct former landscapes, and similarly the ultimate goal of archaeological facies analysis is to restore the three-dimensional image of a human-related space at a given time and to describe its evolution. The precision of this three-dimensional reconstruction is strongly constrained by the quality of the stratigraphic record. Theoretically, the finest reconstruction can be achieved for the sites dominated by regularly ordered sequences, particularly the ones offering well preserved microstratified anthropogenic strata (I.2). In some exceptional situations, sites predominantly made of weakly ordered anthropogenic strata (II.2) offer a record sufficiently coherent to achieve a detailed reconstruction of the geometry of the site and its evolution since its abandonment (Fig. 8.13).

Restoring the configuration of the site contemporaneous with the microstratified signal depends on the ability to accurately control in the field the lateral facies variability for each individual laminae as recognized under the microscope. Reasonably, the sampling interval cannot be smaller than 50 cm in order to preserve the coherence of artifact assemblages and the spatial continuity of occupation surfaces needed for archaeological purposes. Archaeological and radiometric dating are not capable of improving the fine stratigraphic correlation provided by such a high-resolution signal. In some exceptional situations, distinct microstratigraphic markers that are spatially invariable can facilitate the correlation between contemporaneous individual microstrata of different facies (Fig. 8.8d, e, f). Practically, the most efficient method is to correlate segments of vertical sequences with occupation phases defined in the field as based on artifact assemblages, chronological indications, and general information on site configuration. Laminae with distinct properties, and those with more easily recognized with the naked eye, can be tentatively used as stratigraphic markers to match the vertical sequence seen under the microscope with field observation.

Changes in the quality of construction material through time are also helpful indicators for refining stratigraphic correlation between habitation areas. For each segment of a sequence, facies of the successive micro laminae are interpreted in terms of human activities, the nature of the habitation unit, and the local environmental conditions. Spatial variability of the vertical sequence from contemporaneous segments thus provide an evolution of the use of space and contemporaneous environmental conditions for the different sampled areas.

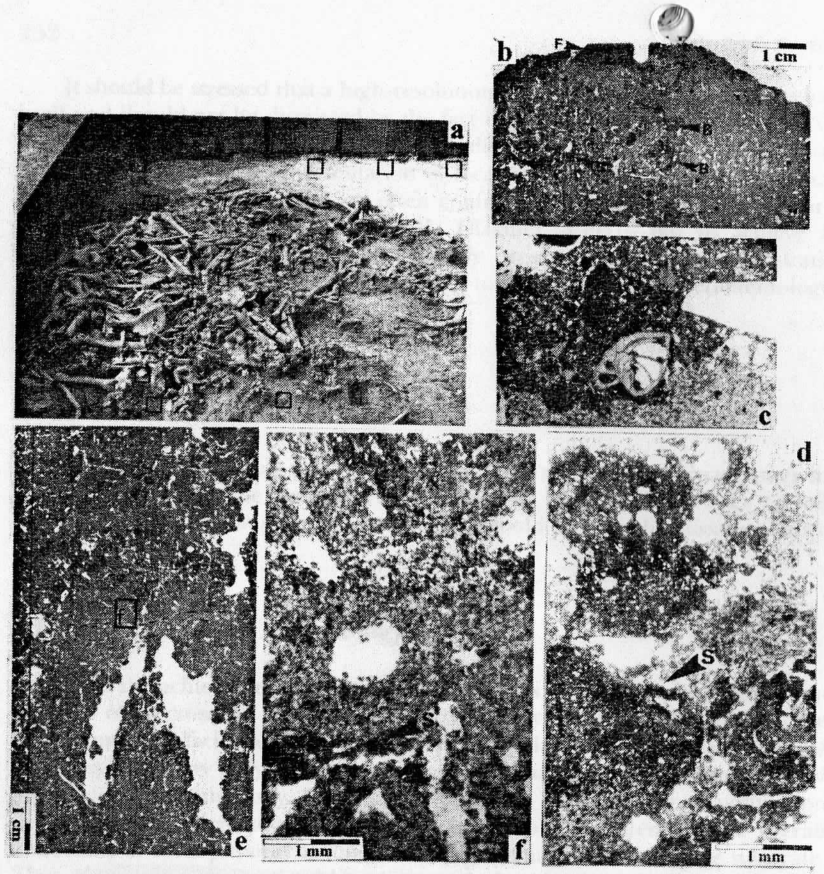

Figure 8.13. (a) Celtic sanctuary of Ribemont-sur-Ancre (Somme, France): rich accumulation of human bones (mostly articulated) that raised questions about preparation of the area and mode of deposition of the corpses; according to ancient texts and archaeological data, the corpses are supposed to have remained exposed for a time while hanging above a ritual platform and then to have fallen down (rectangles indicate sampling location). (b) Low-magnification view of the strata just below large articulated bone assemblage, displaying a weakly ordered pedosedimentary facies with evidence of intense bioturbation, dispersion of mortar (M) and mud–brick fragments (Br), and an upper compacted surface with ferruginous staining (F). (c) View at high magnification of mortar fragments showing the calcitic fine mass, chalk fragments and calcareous coarse grains; their sharp limit with the juxtaposed matrix indicates that the mortar did not suffer dissolution. (d) View at high magnification of the bottom part of the archaeological strata below the bones showing a partly desegregated soil interface (S) marked by ferruginous staining and organic impregnation. (e) Lateral variation of the archaeological strata down the southern slope where bone density rapidly decreases: view at low magnification showing an homogenous, weakly ordered pedosedimentary facies with two weakly distinct subunits (1 & 2). (f) View at high magnification of the contact between subunits 1 & 2 showing relicts of a soil interface (S) with slaking crust sealing a surface horizon that was not disturbed by human activities; also shown is the deposition by gentle runoff of the upper subunit, which is derived from reworking of the bone-rich archaeological strata. The funerary platform is thus concluded to have been carefully prepared with human-made mud brick and mortar constructions, and then covered with an impervious carpet. This remained exposed to atmospheric agents for a substantial period before the corpses fell on the floor; subsequent gentle runoff along the slope has significantly changed the original configuration as constructed by humans. (Photo (a) courtesy of Jean-Louis Brunaux)

Access to a large diversity of habitation units, (roofed rooms, open courtyards, alleys, streets) offers the possibility to control effects of local factors on the record of environmental conditions and therefore obtain a high-resolution record of short time climate shifts of regional significance (e.g., Fig. 8.11). The most regularly microstratified sequences often can be used to provide an annual record, assuming that seasonal variability constrains the rate of desegregation. An annual rhythm is, however, not always recognizable, particularly when low rates of accumulation and intense trampling obscure the distinction between individual laminae.

Only a partial three-dimensional reconstruction can be achieved for sites offering a juxtaposition between high resolution sequences (group I and II.2) and medium- to low-resolution ones (groups II.1, II.3, and III.1, 2, and 3). The differential preservation of the stratigraphic signal generally expresses the influence of the microtopography on the record of human-induced structural changes at the soil interface and their preservation during the subsequent fossilization (Fig. 8.12). These lateral discontinuities are generally well identified in the field, although they are often confusing due to the difficulty in distinguishing lateral changes related to different functional areas from those caused by subsequent natural variations. The three-dimensional reconstruction based on facies analysis helps to determine whether the natural variations originally present have only affected preservation of the stratigraphic signal after abandonment or whether they have also influenced the spatial patterns of the occupation units. Thus, the common match between subtle microtopographic situations that offer greater protection from natural hazards (e.g., runoff, erosion, flooding, water stagnation) and the mosaiclike distribution of high resolution stratigraphic signals suggests that humans might have preferentially settled at microlocations offering the most suitable living conditions, particularly for occupation on floodplains and universally unstable piedmonts.

For sites dominantly formed of randomized strata, the three-dimensional reconstruction cannot be expected to portray the spatial configuration of a site at the time of occupation due to the lack of high-quality signal related to anthropogenic events and contemporaneous natural incidents. However, an extensive microfacies study of an apparently homogeneous stratum very often draws attention to subtle spatial changes of certain pedosedimentary properties needed to decipher the paleogeography of the site at the time of occupation and subsequent transformations. This is well illustrated, for example, in the Middle Palaeolithic layers of Western European caves, which consist of massive and homogeneous strata traditionally interpreted to relate from episodic colluviation of *terra rossa* soils and/or *in situ* pedogenic weathering (Laville, 1975; Miskovsky, 1974). In thin section, the fine-scale lateral changes in carbonate content of the fine and coarse fraction, and their degree of dissolution, as well as the degree of cohesion of the fine mass help elucidate spatial variations in the configuration of the cave at the time of occupation. They attest to a slow rate of deposition and moderate pedogenic alteration (Fig. 8.9c). These subtle lateral changes, therefore, provide an independent line of evidence that reinforces the impression of good preservation of the archaeological record as deduced from the nature of the artifact assemblage.

It should be stressed that a high-resolution stratigraphic sequence speaks for itself and should not be dismissed by the fact that it is preserved only locally. As long demonstrated in paleogeographical studies (Rat, 1969), the question is not to debate the degree of representation of local observations—particularly ones obtained at microscopic scales, as often confused in archeology and in geoarchaeology (Barham, 1995, Canti, 1995; Glassner, 1994)—but to achieve a comprehensive understanding of the locally preserved high-resolution stratigraphic signals for extrapolating according to the principles of sedimentology and pedology.

5. Implications

Several general comments can be made that have relevance to broad issues in archaeology and in the earth sciences, from site formation processes to soil genesis and paleoclimatology. These remarks should provide direction for future studies.

5.1. Implications for Archaeology

Similar to the achievements in the various branches of petrography, the systematic use of microscope techniques in archaeology—particularly through the development of facies analysis—should help to elaborate a coherent body of stratigraphic theory fully adapted to describe and understand the originality of archaeological stratigraphy. The close similarity in the character of occupation deposits from a large diversity of sociocultural contexts attests to the overall uniformity of most physical actions exerted by humans on their living substrate. Thus, a research priority should be given in archaeology to improve the general classification of anthropogenic facies. Additionally, adoption of a standardized terminology would help unify the different perceptions of archaeological strata. This strategy would reinforce the cohesion of the scientific community involved in stratigraphic archaeology by providing all excavation participants with the possibility of becoming familiar with information obtained at microscopic scales.

The opportunity offered by the microscope to give access to the three-dimensional geometry of archaeological strata represents a unique occasion for refining our perception of archaeological contexts, from habitation areas to landscape units. This tactic requires that we rethink the way we try to control the spatial continuity of individual strata, particularly in cases where rapid lateral changes make excavation over large surface areas extremely difficult. A practical alternative would be to combine surface excavation with a series of small vertical sections, which would provide good stratigraphic control. Development of high-resolution three-dimensional modeling is crucial to a better understanding of the vast range of processes that can produce regular fine stratification with sub-horizontal accumulation of artifacts and can thus help us discriminate the soil surfaces that are truly well-preserved occupation floors.

The vital interest in archaeology to accurately estimate the duration of occupation will benefit from the ability of microscope studies to define high-resolution, relative chronologies of environmental changes that reflect rapid shifts at different levels, from local to regional and from seconds to millennia. This issue should stimulate soil micromorphology to better understand the tempos of natural processes for providing independent lines of evidence that can challenge interpretations traditionally based on the logic content of artifact assemblages. In addition, recognition of high-quality paleoenvironmental signals preserved in a large diversity of contexts invites archaeologists to better document the record of natural events at spatiotemporal scales significant to past humans. This course of action is needed in order to refresh engraved ideas on the linkages between natural forcing and sociocultural dynamics of the past.

5.2. Implications for Soil Science

The contribution of the microscope to explain the formation of archaeological layers as the temporal transformation of the soil interface provides an original view on soil dynamics. The great diversity of geomorphic contexts in which archaeological sites occur indicates that they are not present at exceptional locations. Moreover, the strong resemblance of any archaeological layer to a soil horizon, a sediment, or a pedosedimentary unit attests that they are not unique sedimentary bodies. However, the common occurrence of archaeological layers as full stratigraphic entities with original interfaces and pedosedimentary fabrics inherited from the time of deposition shows that a great number of them have escaped vertical soil differentiation and do not present the expected ABC horizonation that should theoretically be developed during slow burial. Only very few sites have benefited from instantaneous burial by rapid and nondestructive sedimentation or human accumulation, and this is clearly not the general explanation. As documented in this chapter, the decreasing gradient of preservation of ancient soil interfaces, from ordered archaeological strata to randomized ones, suggests that vertical soil development has been counteracted by regular to discontinuous surface accretion. The role of sedimentary input on soil genesis has long been recognized by soil scientists, giving rise to the concept of cumulic soils (Soil Survey Staff, 1975). However, the ability of sedimentation to compete with horizonation is assumed to be restricted to the geomorphic contexts influenced by seasonal flooding or endemic airborne dust input (Simonson, 1995). The soil-sedimentary record offered by archaeological sites illustrates the fact that surface accretion is a major component of soil dynamics that is operational in all kinds of geomorphic contexts and at various temporal scales, from seconds to millennia. In addition, the frequent coincidence of the pedogenic boundary with the limit between archaeological strata suggests that horizonation is not simply time transgressive but is strongly constrained by a lithological reality. Thus, the theory of soil genesis can no longer provide the simplified view of successive horizons developing gradually through time below an hypothetical stable soil surface. Instead it should better document the reality of soil surface dynamics.

The integrative use of soil micromorphology and physical measurements has recently enabled us to considerably improve the knowledge of short-term dynamics of the soil surface, particularly through intensive human exploitation (Casenave and Valentin, 1989; Perrier and Cambier, 1996). This research effort has not been extended to medium- and long-term perspectives, most probably because of inaccurate dating of the successive stages of soil development and the difficulty to experimentally control the complex processes involved in the aging of soil fabrics. The threat of global change expected to initiate threshold responses with considerable modifications of properties over short time spans (Stewart et al., 1990) urges the reinforcement of long-term studies of soil dynamics. This crucial issue for the future can greatly benefit from the lessons of the past, and with archaeological sites, soil science is offered a profusion of pedogeomorphic situations to study events that have punctuated the history of our planet's surface.

Differences in ancient site preservation, as illustrated by our classification of archaeological strata focuses future research on a better understanding of spatial soil heterogeneity that so far has been neglected due to the need for standard classification systems for agricultural purposes (Cady and Flach, 1997).

5.3. Implications for Paleoenvironmental Research and Paleoclimatology

Quaternary sequences of prehistoric sites—particularly caves and rock-shelters of southern France—have been the privileged stage since the 1970s to the development of multidisciplinary paleoenvironmental studies aimed toward deciphering the periodicity and nature of climate changes during the recurrent glacial-inter-glacial cycles (Bazile et al., 1986; Laville, 1975; Miskovsky, 1974). The flashy progress of paleoclimatology obtained from high-resolution, long-term sequences from peat, lake, ocean, and ice caps have rapidly obscured the ones from prehistoric sites (Dansgaard and Duplessy, 1981; Jouzel et al., 1987; Pons et al., 1989; Sancetta et al., 1973; Woillard, 1978). Prehistoric sites were relegated to particular sedimentary environments in which the paleoenvironmental record would have been strongly biased by local factors, and therefore would not be reliable for paleoclimatic reconstruction (Campy, 1990; Van Andel and Tzediakis, 1996). Results presented in this chapter encourage us to resuscitate the stratigraphic record of archaeological sites for paleoenvironmental research: these records provide a unique source of information for documenting the in-site and inter-regional complexity of past climate changes at fine temporal scales. The challenge is particularly crucial for the Holocene period, now demonstrated to have undergone a series of abrupt climatic fluctuations (Bond and Lotti, 1995; Gasse and van Campo, 1994; Kutzbach and Liu, 1997; Mayevski et al., 1994; Street-Perrot and Perrot, 1990). The presence of these fluctuations refutes the long-accepted notion of overall climate stability during the Holocene. Moreover, it questions the importance given to human landscape transformations with the emergence and prosperity of early agricultural societies, rather than to climate fluctuations (Bottema and Woldring, 1990; Vernet and Thiebault, 1987; Zangger, 1992). Paleoenvironmental research is now invited to better discriminate natural from anthropogenic forcing and revise the mythical view of a humanity portrayed as the main, largely destructive agent of landscape modification (Crowley and Kim, 1994; O'Brien et al., 1995). Microfacies study of archaeological sites and surrounding regions offer the possibility of obtaining a high-resolution sequence of events from which the effects of cultural factors can be disentangled from the ones of natural agents (Fedoroff and Courty, 1995; Hourani and Courty, 1998).

6. Conclusion

A few years ago, Renfrew (1992) declared that the potential impact of soil micromorphology on the practice of excavation was clearly considerable. At the same time we expected that increasing the number of practitioners and improving the dialogue with archaeologists would be sufficient to reinforce this research direction (Courty, 1992). Although both conditions have now been achieved, the full possibilities of the use of microscopic tools to better understand archaeological strata are still underutilized, if not simply ignored, misused, or even refuted.

Most difficulties now encountered should be viewed as indirect consequences of the general evolution of modern science. Following the technological revolution that gave a leading role to empirical sciences, good research in the modern sense is expected to deal with hard reliable data, with measurement of well-known processes, and with the production of simple models to simulate complex phenomena. For a professional scientist who is expected to be efficient, competitive, and rigorous there is no place for ignorance and no possibility to be wrong. At the same time, the developing complexity of techniques has forced the sciences to become segmented into highly specialized research areas, leaving no other alternatives for those dealing with broad aspects than to remain old-fashioned generalists.

The perception of the various applications of earth sciences to archaeology by the lay human scientist simply reflects this recent partition. Measurement and quantification as provided by the most advanced techniques are generally preferred because they upgrade environmental sciences to the rank of a true science according to modern standards. On the contrary, qualitative techniques, such as soil micromorphology, are accused of being obsolete and are urged to become more reliable and less speculative in order to obtain similar scientific recognition. Maintaining the pressure for more research on quantification might push practitioners of microscopic techniques—particularly those just starting out—into a dead end, simply because our understanding of basic processes is not mature enough to properly design meaningful measurement strategies. The future of soil micromorphology in archaeology, as attempted with this chapter on the study of microfacies, simply depends on our ability to no longer view microscopic tools as the specialized technique adapted to solve specific problems, but as the indispensable companion of archaeological stratigraphy that has been missing for too long.

One can only hope that the eve of the third millennium will mark the end of our naive fascination for high technology and for a science entirely directed to producing a verifiable and reproducible truth. Observing thin sections of sediments, soils, and even more archaeological materials have long taught us that the more we learn, the more we realize how little we know, and how much more we have to simply observe. Accepting our ignorance seems to be one of the most refreshing ideas for the science of the future, and we sincerely hope that many will join us "below the microscope" to enjoy a fascinating challenge that can transform our life into a permanently exciting one.

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