Geoarchaeology can be viewed as a methodological framework that uses an earth-science, or a geoscience, perspective to interpret the temporal and spatial contexts connected with artifacts. Some of the kinds of archaeological questions that are addressed using a geoarchaeological framework are presented in Table 25.1. The geoscience perspective is directly connected with the methodologies that can be applied while preparing for and conducting fieldwork and collecting field data, the choice and application of laboratory analytic techniques, as well as the overall goals of the study of the prehistory. In this sense the geoarchaeological approach unites the study of the archaeological record with the natural (physical and biological) sciences while preserving as its ultimate goal the understanding of the human past. Geoarchaeology also provides a means of organizing methodologies derived from the natural sciences within a framework that focuses on the linkages and relationships between human prehistory and changes in the physical and biotic environment. These connections can be chronological, spatial or a combination of both. From a conceptual view the techniques employed within a geoarchaeological framework emphasize a sense of time and a sense of place. Here, an effort is made to focus on two related topics. First, some of the conceptual connections and developments that have led to the geoarchaeological approach are examined. Second, some of the more critical ways by which different field-
Table 25.1. Earth-Science Methodologies to Address Archaeological Goals

<table>
<thead>
<tr>
<th>Archaeological Goals and Questions</th>
<th>Earth-Science and Geoscience Methods</th>
</tr>
</thead>
<tbody>
<tr>
<td>Determining past availability of natural resources and environmental settings potentially useful to humans or conducive to human presence on landscape; predicting the location of archaeological entities</td>
<td>Geologic, physiographic, topographic mapping; geomorphic or landscape evolution analysis; paleogeographic and paleobiotic reconstructions; remote sensing; geophysics; stratigraphic studies</td>
</tr>
<tr>
<td>Estimating age of artifacts, archaeological features, deposits containing artifacts, stratigraphic and landscape contexts related to archaeological record</td>
<td>Geologic or geomorphic mapping; relative dating using stratigraphy, succession, correlation, physical and biotic time markers; chronometric dating techniques</td>
</tr>
<tr>
<td>Identifying and describing archaeological site matrix (sedimentary deposits, soils) and composition of raw materials of artifacts</td>
<td>Sedimentology; pedology; petrography; geochemical and isotope analyses</td>
</tr>
<tr>
<td>Evaluating events of site formation and the proportion of the archaeological record under examination resulting from past human behavior and geologic restructuring</td>
<td>Sedimentologic, taphonomic and preservation-destruction studies</td>
</tr>
<tr>
<td>Examining linkages between past human populations and other components of the biosphere and geosphere</td>
<td>Application of geoecological concepts to the late Cenozoic prehistoric record; integration of geoscience and paleoenvironmental data sets with archaeological record</td>
</tr>
</tbody>
</table>

and laboratory-based methodologies can be integrated within the geoarchaeological approach are reviewed.

**Conceptual Links**

**Development of Concepts and Methodologies**

Like the archaeological record itself, the development of a geoarchaeological perspective is a product of the interplay
between people, place, and time. Although there are a variety of ideas concerning what, exactly, constitutes the realm of geoarchaeology, its development illustrates the long-term concern researchers have had in connecting the artifactual record with the surrounding world (Rapp and Hill 1998). Geoarchaeology has been distinguished in two general ways: as a set of techniques, or a set of goals. Thus it has been viewed as the geoscience tradition within archaeology or as the conduct of archaeological research using earth-science concepts and methods (Gladfelter 1981; Butzer 1982). The term geoarchaeology has been used both to characterize studies of the archaeological record that emphasize the application of geoscience methods and to characterize the purpose of the research.

The implicit application of geoscience methodologies has been part of archaeological research since the 1800s, but the movement toward a more explicit theoretical convergence is a product of conceptual developments initiated after about 1950. Use of the term geoarchaeology became more common from the late 1970s. Table 25.2 broadly outlines the history of interaction between the geoscience concepts and archaeology.

The foundation for a geoarchaeological framework, built during the 1800s, is exemplified by the writings of Lyell (1863) and Geikie (1877). Interdisciplinary research in the geosciences and archaeology was implicit and focused on the issue of human antiquity or human-earth interactions (Gifford and Rapp 1985; Russell 1997; Stein 2000). The issue of human antiquity placed an emphasis on geologic stratigraphy; applications of stratigraphic concepts became more refined in archaeology during the late 1800s and early 1900s.

By the beginning of the 1900s a phase of interaction perhaps characterized by more multidisciplinary cooperation or collaboration had developed (Rapp and Hill 1998). Specialists became an increasingly essential part of archaeological research, with especially expanded contributions by geologists, soil scientists, and paleontologists. Cooperation with the natural sciences often focused on environmental and paleoclimatic changes that could be related to archaeological studies. In field methodologies, there was a continued refinement of the application of stratigraphic concepts of sequence and association. Building on the
Table 25.2. Overview of Historical Interaction between the Geosciences and Archaeology

<table>
<thead>
<tr>
<th>Phase of Interaction</th>
<th>General Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-1900s, implicit</td>
<td>Focus on antiquity of humans, stratigraphic chronology</td>
</tr>
<tr>
<td></td>
<td>Preliminary interest in human-earth interactions</td>
</tr>
<tr>
<td>ca. 1900–1950, multidisciplinary collaboration</td>
<td>Increased interest in paleoenvironmental and paleoclimatic conditions</td>
</tr>
<tr>
<td></td>
<td>Refinement of application of stratigraphic principles to archaeological contexts</td>
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<tr>
<td></td>
<td>Growth in use of geoscience-derived laboratory analytical techniques</td>
</tr>
<tr>
<td>ca. 1950–present, convergence</td>
<td>Emphasis on empirical approaches to evaluating site context and formation trajectories, including site location and artifact taphonomy or processes leading to structural patterns in the archaeological record</td>
</tr>
<tr>
<td></td>
<td>Extensive interaction in paleoclimatic and environmental studies, stratigraphy, and analytic techniques, including chronometric, isotopic, and raw-material analyses</td>
</tr>
</tbody>
</table>

Earlier concern for stratigraphy reflected in the work by geoscientists such as Falconer and Pengelly at Brixham Cave, England, during the 1850s, there was an expanded emphasis on the role of stratigraphy and sequence. This is illustrated by the kinds of field methods used by Dorpfeld in Turkey, Petrie in Egypt, and Pitt-Rivers in England. Geologic principles of stratigraphy had also been applied in North America as early as the middle 1800s and continued to be refined in mound and early-man studies (Rapp and Hill 1998; Stein 2000).

The research of Antevs and Bryan illustrates some of the kinds of methodological contributions of geoscientists to archaeological questions during the first half of the 1900s (Haynes 1990). Both researchers utilized geologic methodologies to estimate the age of archaeological sites. Antevs pioneered the application of correlating varve sequences with paleoclimatic change across large geographic regions in an effort to estimate the age of geomorphic features and deposits that could be related to archaeological sites. Bryan and his students undertook stratigraphic
and geomorphic studies emphasizing the role that environmental and climate change played in their studies of the geologic context and age of archaeological sites. Examples illustrating the recognition of the potential value of taking into consideration geoscience concepts and methods during this time include de Terra (1934) and North (1938) and, slightly later, Wheeler (1954).

Major advances in analytic techniques as well as a new focus on addressing the conceptual framework of the study of the human past have characterized research since the 1950s. In terms of analytic techniques, these are illustrated by the advent and proliferation of chronometric techniques, by technical advances in compositional studies of artifactual raw materials, and in isotopic and other geochemical studies. There has also been an increase in the combined application of field and laboratory paleobiotic studies. Technical advances in remote sensing and in geophysical and geochemical prospecting have also expanded the application of earth-science techniques in the effort to discover archaeological sites and delimit their extent. The pervasive use of analytic techniques derived from the geosciences has served to deepen our understanding of the roles the physical and biotic contexts have had on past as well as present human populations.

The role that the geosciences could play in assisting archaeology beyond long-standing mutual concerns such as chronology, through advances in analytic methods such as geochronology, was recognized in a growing overlap between the long-term goals of geoscience disciplines and archaeology. The movement toward a conceptual convergence with the purpose of building an understanding of the interrelationships between landscapes (physical and biotic) and humans through time began to emerge in the 1950s and 1960s, a result of a growing interest by geoscientists as well as changes within archaeology (Clarke 1979; Clark 1993). This view of the importance of the earth sciences in archaeological interpretation is reflected in Cornwall's Soils for the Archaeologist (1958), considered to be the first systematic effort at geoarchaeology (Butzer 1982). The importance of this approach was reinforced by Butzer (1964, 1971, 1978, 1982) and Haynes (1964) and by the 1970s and 1980s began to obtain widespread support (Rapp 1975, 1987; Renfrew 1976; Davidson and Shackley
1976; Gladfelter 1977, 1981; Hassan 1978; Farrand 1985; Stein and Farrand 1985; Gifford and Rapp 1985). One measure of the importance of the geoscience approach to archaeology was its official recognition by academic and professional societies: the Archaeological Geology Division of the Geological Society of America was founded during the early 1970s and the Geoarchaeology Interest Group of the Society for American Archaeology in the late 1990s. Since the beginning of the 1990s several edited volumes or textbooks dealing exclusively with archaeology and the earth sciences have been published (Lasca and Donahue 1990; Waters 1992; Bettis 1995; Brown 1997; Herz and Garrison 1998; Rapp and Hill 1998; Mandel 2000; Goldberg et al. 2001; French 2003; Garrison 2003).

Given the strong development of interest in the study of earth-human interactions and the continued refinement and application of geoscience concepts and techniques in archaeology, it is not too surprising that there is a relatively diverse set of ideas concerning what geoarchaeology encompasses. Some have argued for essential equivalence with archaeological geology (see Albanese 2000) and archaeogeology. Others have suggested that whereas the methods and techniques are similar or the same, geoarchaeology and archaeological geology can be distinguished by different bottom-line disciplinary goals. Still others prefer the view that the archaeological record is essentially a special kind of geologic record and that archaeology is itself subsumed within the earth sciences (cf. West 1982; Farrand 1985). As another alternative, Ferring (1994) views geoarchaeology as an “empirical approach to archaeological problems” in response to theoretical and conceptual developments initiated in the 1960s. One broadly inclusive view might be an alternative where archaeology is seen as one of several disciplines dedicated to understanding the late Cenozoic prehistoric record (Rapp and Hill 1998). Both geoarchaeology and archaeological geology provide venues for focusing attention on the connections between human populations and the Quaternary geosciences (cf. Holliday 2001).

There are also alternative viewpoints on whether geoarchaeology is limited primarily to the application of stratigraphic, geomorphic, and site-formation studies or, more broadly, whether it also incorporates the analysis of archaeological raw materials,
and geomorphic studies emphasizing the role that environmental and climate change played in their studies of the geologic context and age of archaeological sites. Examples illustrating the recognition of the potential value of taking into consideration geoscience concepts and methods during this time include de Terra (1934) and North (1938) and, slightly later, Wheeler (1954).

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chronometric techniques, and analytic methods used to construct both the physical and biotic components of paleolandsneces (Gladfelter 1977, 1981; Thorson 1990; Waters 1992; Rapp and Hill 1998; French 2003). Besides different viewpoints on what constitutes the arena of geoarchaeology (Figure 25.1), there appears to be clear overlap between the goals and methods of geoarchaeology and other kinds of archaeology and related science disciplines (Bradley 1999; Evans and O'Connor 1999; Redman 1999; Dincauze 2000).

**Time**

Perhaps the most fundamental conceptual and methodological connection between the geoscience approach and the study of the human past is an appreciation of the relative vastness of time. The crucial element of long amounts of time and the ideas of chronology and sequence link the natural-science disciplines that study the record of physical change through strict geologic and geographic events and processes and those disciplines focused on paleobiology (such as paleontology and archaeology). The concern with time connects these historical sciences both conceptually and in the employment of certain field and laboratory techniques.

The fundamental nature of the importance of the concepts of time and chronology is expressed throughout the development of archaeology. During the 1800s this was expressed in a shared concern by archaeology and geology with the methodologies that could help determine the relative age and order of events preserved in the prehistoric record. Thus, there has been a long-term cross-disciplinary interest in the concepts and methods of stratigraphy, including superposition, succession, association, taphonomy, correlation, and markers of time or indicators of intervals of time. One illustration of this conceptual and methodological linkage between geology and archaeology from the 1800s is the question of the antiquity of humans (Rapp and Hill 1998; Stein 2000). The archaeological question of whether human prehistory extended to a time where humans coexisted with extinct animals and substantially different environmental conditions was answered by applying techniques derived from the
Figure 25.1. A variety of dimensions of space and time are used to evaluate archaeological interpretations from the perspective of different scales for geoenvironmental change.
geosciences. The fundamental concern over time as expressed in stratigraphy and the concepts of relative sequences, superposition, and time markers intimately connects the geosciences and archaeology.

**Interrelationships: Geoarchaeology as Paleoecology**

Although a concern for time and chronology is crucial, another fundamental aspect of the geoarchaeological perspective is that of studying the interrelationships between and within components of the biosphere and the physical environment (geosphere and atmosphere). In this sense geoarchaeology serves to emphasize concepts and analytic methodologies that are concerned with diachronic as well as synchronic contexts. Embedded within a geoarchaeological framework is a fundamental concern both for change through time and, just as importantly, for the contemporary interactions between people, plants, animals, and the physical world. In this emphasis on earth-human interactions over time, the goals and concepts of geoarchaeology overlap with other approaches to archaeology (see Figure 25.1) such as contextual archaeology (Butzer 1978) and environmental archaeology (Dincauze 2000), as well as related studies that integrate history and human ecology (Russell 1997). The geoarchaeological goal of understanding earth-human relationships reflects its status as a bridging, integrative discipline connecting the geosciences with human behavior (Leach 1992; Chastain 2000; Hooke 2000).

**Goals and Techniques: The Application of Geoarchaeology**

In a broad sense, geoarchaeology signifies the application of a geoenvironmental theoretical and philosophical approach combined with the use of techniques derived from the natural sciences to interpret the prehistoric record (see Table 25.1). From this point of view the artifactual record is considered part of a matrix of physical and biotic objects, features, and assemblages formed over time and reflecting a combination of possible
events. The goal of a geoarchaeological perspective is to utilize natural-science methodologies to evaluate the human component of the prehistoric record within the context of changes in or interactions between components of physical and biotic landscapes.

The strong connections and relationships between the earth’s geoenvironmental systems and people are visible at many scales of time and space (see Figure 25.1). The geoarchaeological perspective provides a framework for studying the archaeological record and understanding it as a product of any of these contexts combining chronology and place. Thus the dynamics of space and time provide many promising venues where geoscience techniques are of potential value when studying the archaeological record (see Table 25.1).

From a viewpoint of levels of organization, different geoscience-derived techniques and concepts can be applied to the examination of the archaeological record (Figure 25.2). On the simplest level of a single artifact, the kinds of geoscience techniques that may be applied include a wide range of laboratory analyses for determining the composition of artifacts and direct dating. Some geoscience analytic methods can, at a minimum, serve a primarily descriptive or classification purpose, starting with the basic procedures of mineral and rock identification and classification (Rapp and Hill 1998; Rapp 2002; Garrison 2003). These applications also use inherent connections between the study of the meaning of artifacts and their composition or their age. Petrographic or chemical fingerprinting techniques derived from geology may be employed to determine the composition of a stone artifact or a piece of pottery, information then used to help answer specifically archaeological questions. When it is possible to determine an artifact’s source rocks or sediments with a geoscience-derived laboratory technique—perhaps by petrographic analysis or some geochemical method—it becomes possible to explore the transportation of the materials through exchange between people or the movement of human groups.

Using geochronometric techniques directly to date individual artifacts or materials in immediate association with archaeological features plays an increasingly important role in archaeological interpretation. Direct chronometric dating essentially
eliminates the issue of coassociation, while also providing independent and complementary information for other geoscience methodologies, such as stratigraphic chronology or correlation. These kinds of applications are also good examples of how continued refinements in analytic techniques strengthen the connections between the geosciences and archaeological studies. Accelerator mass spectrometry (AMS) radiocarbon dating, with its need for only small samples, has provided new opportunities to directly date artifacts containing small amounts of carbon without destroying the object, and the same procedure applied to nonartifactual biotic materials assists in more reliable stratigraphic and environmental chronologies that can then be connected to the archaeological record.
Individual artifacts and paleobiotic materials combined in assemblages form another level of structural organization for the archaeological record that can be investigated using geoscience methods and concepts (see Figure 25.2). Broadly speaking, many of the interpretational issues associated with these sets of artifactual or ecofactual materials can be studied using principles of archaeological site formation, principles primarily derived from the methods of sedimentology and taphonomy. The incorporation of the basic concepts of sedimentology and how over time sediments influence the structure of artifact assemblages after they are removed from the sphere of human activity and behavior is crucial to evaluating the artifactual record and placing it in prehistoric context (Figure 25.3). In this geoarchaeological perspective, archaeological inference begins with some aspect of past human activity and culminates in the interpretation of that behavior based on whatever remnants of the activity can be recovered from the prehistoric record. This can entail applying concepts directly derived from the geosciences, especially those connected with processes of erosion, size sorting, transport or movement, and differential preservation, as well as weathering and physical or chemical alteration.

Thus a multitude of potential pathways start with the initial structuring of the artifactual record by prehistoric human behavior, continue with the transformations caused by physical and biotic processes, and eventually lead to the database available for study and interpretation by archaeologists (see Figure 25.3). This concern in archaeology for discerning the relative contribution of behavioral patterning (structure imposed by prehistoric humans) and patterns imposed by natural processes (chiefly geologic and pedogenic [soil forming] structuring) evolved as a result of the convergence of methodological and conceptual developments in archaeology, geology, and paleontology (Rapp and Hill 1998; a concise summary is provided in Stein 2001).

Within a geoarchaeological framework, the processes leading to the formation of the archaeological record begin with the initial landscape context, followed by the interactions between humans and the physical and biological components of these paleolandscapes (see Figure 25.3). At any particular locality, human
Figure 25.3. A simplified flow diagram shows some of the potential trajectories for archaeological site formation and interpretation.

activity can leave physical evidence of this interaction (as an example, by the extraction or use of some natural resource). The activity may produce an artifact assemblage consisting of a set of individual artifacts or features—hearths, say, or a quarried area, or some other physical structure. Once human activity ceases at the locality, a variety of modifications of the artifact assemblages or archaeological features may take place (see Figure 25.3). There are two main formational or taphonomic trajectories: the record of human activity can be left essentially intact (usually by sudden or low-energy burial) or the remnants of behavior can be modified by a variety of natural processes. Following the principles of sedimentology and taphonomy, parts of the record can be selectively destroyed by weathering or erosion, concentrated, or
dispersed. Artifact assemblages may be selectively sorted by size and weight and transported to different degrees, again modifying the initial behavioral structuring. Soil-forming processes may preferentially preserve some materials or lead to artifact movement after burial. Burrowing animals and plants may mix artifacts from different deposits. These types of processes all transform the initial behavioral patterns into the structure available for study.

Another level of organization within the archaeological record exists for sets of artifacts or archaeological features that are distinct because they are spatially separated but are part of the temporal landscape (see Figures 25.1 and 25.3). These relationships can vary in scale. They can be separate accumulations on a single landscape surface at a specific site, or they can be isolated sites spread over the larger landscape, even existing in different environmental settings. At this level of inquiry, ideas commonly used in the geosciences, such as the concept of facies or the principles of correlation or the application of landscape analysis, can often make useful contributions. Lateral facies consist of different depositional settings occurring as part of the same broader landscape. In this form, they are somewhat analogous to different functional or activity areas on a single living surface or contemporary archaeological landscape.

Stratified or sequential sets of artifacts or archaeological features also can be interpreted from the geoarchaeological perspective (see Figure 25.2). In the historical interaction between the geosciences and archaeology, stratigraphy—and its essential role as a reflection of relative time—provides a common fundamental link. Stratigraphy and sequence also are critical in the study of site formation (see Figure 25.3). At any particular archaeological site, the deposits containing or separating artifact assemblages and features provide the matrix, literally the organizing or contextual framework supporting the archaeological record. To be of significant interpretive value, either in site-formation studies or for higher-level studies of paleoenvironmental and paleoclimatic change, this matrix needs to be described by empirical methods, qualitatively or quantitatively. Here too, the application of geoscience methods and concepts has proven to be of value. At a minimum they serve as a standard
for classifying sediments and soils. Beyond the value of standardization in identification and description of stratigraphic deposits, these methodologies serve as the starting point for distinguishing vertical and lateral changes that can be informative at the level of evaluating site formation or inferring linkages with broader patterns of environmental change.

Although geoscience techniques can be usefully applied at the level of individual artifact, assemblage, site or across syn-chronic and diachronic landscapes, the broadest goals of geoarchaeology fall within the realm of linking the study of the human past with the dynamics of environmental change. This is not the exclusive domain of geoarchaeology. Even within archaeology there is a large degree of overlap on this level of study with the allied fields of contextual and environmental archaeology.

**Geoscience and the Human Past**

Geoarchaeology applies methods and concepts from the earth sciences to interpret the physical record of the human past (see Table 25.1 and Figure 25.2). From a geoarchaeological perspective the physical record of the human past is addressed both on the human-time scale (spanning at least the last 2.5 million years) and at any geographic location or set of locations where human activity has occurred (see Figure 25.1). For example, in the Old World the geoarchaeological approach has been applied to study hominin behavior associated with Paleolithic artifacts, archaeological sites from the world of classical antiquity, and present-day human-environment interactions. In a similar fashion, the archaeological record from the New World—extending from the last part of the Ice Age (the late Pleistocene) to more recent times where written records are available—has been studied using a geoarchaeological approach.

Old World Paleolithic sites contain the evidence for changes in human behavior and adaptation that can be linked to Pleistocene climates and environments. Some examples from the Paleolithic record of north Africa—in the Sahara and the Nile Valley—serve to illustrate some of the kinds of geoarchaeological approaches that can be used. For example, Paleolithic
(Acheulean and Middle Paleolithic, or Mousterian) occurrences from the eastern Sahara have been studied by applying geoarchaeological principles in an effort to provide information that can be used to evaluate landscape settings, site formation (taphonomic) processes, and paleoclimate chronologies associated with middle Pleistocene hominids (Hill 1993a, 1993b, 2001a). The sedimentologic and stratigraphic evidence appears to show changing landscape conditions in the Sahara during the middle Pleistocene, before about 130,000 years ago.

Studies of the sedimentologic contexts of archaeological sites in southern Egypt containing Acheulean hand axes, for instance, help to document the physical landscapes associated with the presence of hominids in this region (Hill 2001a). The sites with Acheulean hand axes consist of sediments composed of clastics (sands, silts, and clays) and carbonates. These deposits imply the episodic presence of ponds or small lakes in the region during wet (pluvial) climate intervals. Based on the particular geomorphic and depositional contexts associated with the Saharan Acheulean sites it is possible to develop inferences about the landscape setting and resources available to middle Pleistocene hominids and also the influence geologic processes had on transforming the surviving, observable record. For instance, some Acheulean sites—from the geoarchaeological perspectives of taphonomy and site integrity—do not appear to have been significantly affected by postdepositional processes. At other sites, however, geoarchaeological studies document modifications of the patterns originally produced by hominid activity. Vertical displacement of artifacts may be associated with trace fossil horizons indicative of bioturbation.

Alteration of the original Acheulean artifact assemblages at some sites is also implied by evidence for wind erosion—deflation can remove the sedimentary matrix and lead to dense concentrations of artifacts, and it can also lead to the destruction of smaller artifacts (such as debitage), thus changing the original character of the assemblage. Eolian processes have deflated sediments that once contained Lower Paleolithic artifacts dating to perhaps 600,000 to 500,000 years ago. The wind removed the sandy matrix and left the larger artifacts in lag position mantling the remnant of a fossil groundwater pond. Smaller artifacts seem
to have been destroyed by the deflation. The deposits not affected by deflation contained a much higher percentage of smaller artifacts relative to larger Acheulean artifacts (hand axes) when compared with the surface collection. In terms of archaeological interpretation, the presence of higher proportions of smaller artifacts in the undeflated deposits suggests that hand axes were being used and resharpened at the site. It also implies that the site artifacts are in primary context. The deposits with Acheulean artifacts are overlain by carbonates deposited in a groundwater-fed pond. The carbonate protected the underlying sediments from erosion, whereas on the margins of the basin, where there was no protective carbonate, wind could easily erode the sandy deposits (Hill 2001a).

Geoarchaeological studies that involve the spatial and size-fraction analyses of artifacts provide data useful in evaluating site-formation events associated with both hominid behavior and geoenvironmental processes that may have contributed to the archaeological record. A small typical Mousterian site at Bir Tarfawi, Egypt, provides an example of some of the ways geoarchaeological approaches can be used to more fully understand the archaeological record (Hill 1993a). The artifacts from this site were found on a surface composed of sandy mudstone plates, beneath sandy muds. The paleolandscape at the time the Mousterian artifacts were used and deposited by hominids was likely the surface of a pan, or seasonally dry lake, that existed before 100,000 years ago. The cemented plates probably formed as the surface of the basin dried.

Besides information on the landscape, geoarchaeological studies provided two alternative site-formation interpretations for the spatial distribution of the Mousterian artifacts. Some clustering of the artifacts may have been caused by a short, intense episode of flooding at the end of a dry season. Another possibility is that the spatial distribution of artifacts directly reflects hominid behavior. In this case, the different concentrations of artifacts would primarily reflect direct evidence of hominid activities in the basin without extensive postdepositional modifications. The size fractions of the sediments (medium and fine sands and muds) indicate a medium-to-low-energy environment for transportation and deposition that could be connected with local rainfall or fluctuating groundwa-
ter levels. As with the Acheulean localities, the stratigraphy and geochronology of the Bir Tafawi Mousterian site indicate the presence of pluvial conditions in the Sahara during the Pleistocene.

At a nearby Middle Paleolithic site in southern Egypt, the assemblage consisted of more than 50,000 stone artifacts embedded in sandy deposits, which were interpreted as the beach and shore zone of a shallow lake that existed around 100,000 years ago (Hill 1993b). The assemblage contained three size groups of artifacts. Cores were the largest artifacts, tools were intermediate in size, and the smallest artifacts consisted of debitage. The spatial distributions of the sets of artifacts were compared with their relationship with the margins and central part of the ancient lake that had been in existence at the time of the Middle Paleolithic presence. The size-distribution patterns showed that the larger, heavier artifacts were in a different location than the smaller, lighter artifacts. The arrangement of artifacts was what might be expected if they were deposited by hominid behavior along the edge of a lake and then subjected to wave action. The spatial pattern appeared to indicate some size sorting; the heavier artifacts did not seem to have been moved very far from their point of initial deposition, whereas the smaller artifacts appeared to have been eroded and redeposited closer to the center of the basin.

The Nile Valley also contains a record of prehistoric behavior associated with Paleolithic artifacts that has been studied using geoarchaeological methods (Hill 1989). In this case, petrographic properties from Wadi Kubbaniya—located northwest of Aswan—were used to document and compare sediments associated with Acheulean, Middle Paleolithic, and Late Paleolithic artifacts in the Nile Valley. The presence of Acheulean and Middle Paleolithic artifacts in the Nile Valley deposits are used to infer that these deposits date to the middle or early-late Pleistocene. Sedimentary deposits with Middle Paleolithic artifacts in the Wadi Kubbaniya region are older than about 40,000 B.P. whereas younger Pleistocene deposits are associated with Late Paleolithic artifacts. Detailed petrographic studies of the Wadi Kubbaniya sediments illustrate two of the most common applications of geoarchaeological methods: description of lithostratigraphic units and interpretation of paleoenvironments associated with prehistoric human groups.
The textural and compositional characteristics used to study the Nile Valley sediments included particle size, clay mineralogy, organic content, and carbonate content. On the basis of grain-size fractions (granulometry) the deposits from Wadi Kubbaniya could be separated into two groups. The first group, dominated by coarser (larger-size) particles, appears to be the product of wadi wash, sand sheet, and dune contexts. The second group, dominated by silts and clays (muds), appears to be the result of Nilotic (fluvial) and lacustrine (lake) depositional environments. Clay mineralogy—which is dependent on both original lithology and secondary weathering—provided clues to environmental change. For instance, vertisols at Wadi Kubbaniya contain higher amounts of secondary chlorite. The relative amounts of organics and carbonates also proved useful for evaluating environmental conditions associated with the Paleolithic in the Nile Valley. For example, sediments associated with floodplain environments have higher carbonate values, as can pond and lacustrine deposits. Sand-dominated units generally do not have high organic or carbonate values. The petrographic descriptions of sediments from the Wadi Kubbaniya illustrate some of the geoarchaeological methods that have been used to evaluate paleoenvironmental conditions associated with the archaeological record.

Another Old World example of the application of geoarchaeological methods demonstrates the application of geoarchaeological methods to Holocene-age archaeological sites. In this case, the relative frequencies of specific sediment size fractions were used to characterize and distinguish archaeological strata associated with Bronze Age, Iron Age, and younger archaeological periods (e.g., Persian, Hellenistic, Roman). For example, the textures of deposits at the site of Tel Michal, situated along the eastern Mediterranean coastal plain, were examined in terms of the relative percentages of three sand-size fractions (Gifford et al. 1989). The Hadera dune sands and Dor kurkur sediments were mostly composed of coarser sands. In contrast, Ramat Gan and Nasholim sediments had higher frequencies of smaller-size sand grains. These types of difference in the textures of the natural sediments in the vicinity of the site could be compared with the materials used for construction purposes at the site, or ar-
chaeosediments. The Netanya hamra and Tel Aviv kurkur were used in the construction of leveling platforms during the Middle Bronze Age. Walls composed of hamra or Ramat Gan kurkur were used to build walls on these platform fills. The Tel Aviv kurkur used during the Middle Bronze Age was replaced by the Late Bronze Age with Hadera sediments. Mud brick from the Persian period strata correlate with samples of Netanya hamra. In this instance geoarchaeological methods were used to document and interpret the Holocene physical environment and track the use of these geologic resources by people.

In the New World, geoarchaeology has also been used to address a diverse array of archaeological issues ranging from predicting the location of archaeological sites to documenting landscape evolution and past physical environments, evaluating site formation and taphonomic contexts, and analyzing artifactual raw materials. For example, studies focused on discovering and evaluating the earliest (late Pleistocene) human presence in the Americas have relied on the application of geoarchaeological approaches. In other instances, geoarchaeology has been applied to study the landscape contexts associated with historic human events and (written) documentation.

One example of the application of the geoarchaeological approach to study the landscapes and environmental contexts associated with late Pleistocene human populations in North America has focused on the region from the western Great Lakes to the Rocky Mountains (cf. Hill 1994, 1995, 2001b, 2003; Huber and Hill 2003). This region contains geomorphic contexts directly affected by continental and mountain glaciation and other types of terrain adjacent to the areas that were glaciated. Geoarchaeological studies have helped to document the timing and extent of glaciation, the landscape response to environmental change during the late Pleistocene and early Holocene, as well as assist in the prediction of the location of archaeological sites (see Table 25.1).

In the Great Lakes region, for example, late Pleistocene landscape habitats of the Lake Superior area are directly connected to evolving glacial conditions. The glacial time framework can serve as the basis for an integrated understanding of the ways landscape change affected late Pleistocene biotic populations,
including prehistoric human groups, entering ice-margin and recently deglaciated landscapes stretching from glacial Lake Agassiz in the west to the Superior basin in the east. The present-day physiography, along with the stratigraphic relationships of the deposits that form this landscape, provides a means to evaluate the physical context for the late Glacial and earliest post-Glacial paleobiotic communities of the region. The geomorphic processes occurring during the Late Quaternary affected the age, distribution, and visibility of paleontological and archaeological sites.

The remains of extinct mammals (such as mammoth and mastodon fossils) and the presence of fluted and basally thinned (Paleoamerican) artifacts appear to support the contention for the existence of late Pleistocene habitats that could sustain biotic communities associated with the end of the Rancholabrean land mammal age in the Great Lakes region. Geologic contexts associated with deglaciated landscapes contain the potential for the discovery of associations between extinct Rancholabrean fauna and late Pleistocene humans. For instance, intriguing discoveries of mastodon and mammoth remains possibly connected with late Pleistocene humans have been reported for the Great Lakes area and—although rare—Clovis artifacts or other fluted points are known from the western Lake Superior region. If these fluted points can be considered as indicators of the time of prehistoric human presence, they imply inhabitable landscapes starting at least by the Pleistocene-Holocene boundary, marked by the end of the Younger Dryas chronozone. In this instance, a geoarchaeological perspective can help to evaluate (1) the chronological relationship between deglaciation dynamics and age-diagnostic artifact forms and (2) landscape habitats available to late Glacial Rancholabrean fauna and human groups. Geomorphic and stratigraphic relationships of Quaternary deposits can be used to construct interpretations of the physical settings available to late Rancholabrean-age faunal communities and human populations. To the east, in the Superior basin, lakes fluctuated in elevation and extent. Ancient abandoned (high) shorelines could have been occupied by human populations using either fluted or lanceolate artifact forms. Artifacts deposited on some abandoned shorelines may have been buried or reworked as a result of a lake transgression associated with the Marquette-interval ice
advance that started around 10,000 B.P. and lasted until about 9500 B.P. Artifacts associated with any human presence before or during this interval may be associated with higher lake levels. After about 9500 B.P. occupations would have been associated with shoreline features of lower lake levels. Continued lowering of the lake formed recessional beaches that would contain occupations dating to about 8000 B.P.

The Rainy lobe of the Laurentide ice sheet melted away, leaving a deglaciated terrain in some parts of this region, while glacial activity persisted to the east in the Superior basin and to the west in the Agassiz basin. A deglaciated and ice-free region extended north to the Vermilion moraine by about 12,000 B.P. By about 11,000 B.P. the ice margin of the Rainy lobe was in southern Canada, leaving the central portion of northeastern Minnesota available for Rancholabrean faunal communities and human populations associated with Clovis artifacts as well as other fluted and unfluted late Pleistocene artifact forms. The landscapes left unglaciated after the melting of the Rainy lobe to the Vermilion moraine area are partly contemporary with ice-margin habitats elsewhere in the Great Lakes that contain radiocarbon-dated Rancholabrean fauna, sometimes apparently in association with non-age-diagnostic artifacts.

The temporal interval from the beginning of the melting of the Saint Louis sublobe of the Laurentide ice sheet—starting before 11,000 B.P. until about 9000 B.P.—contained landscapes connected with changing configurations of the lake shorelines within the Upham and Aitkin basins. These landscape features could contain the suite of fluted to Plano-type artifact forms. In the Lake Agassiz basin, Paleoamerican artifacts may be associated with higher lake levels associated with the Lockhart phase dating to around 11,000 B.P. Recessional beaches of the Agassiz low-water Moorhead stage might be associated with later fluted and unfluted artifact forms. Artifacts at these sites would have been buried or possibly eroded and redeposited when Lake Agassiz returned to higher levels during the Emerson stage. Early Plano-type artifacts might be expected on these higher beaches as well as later recessional beaches.

The western Lake Superior–Agassiz basin region provides a record of landscape evolution connected with deglaciation
dynamics extending from the last Glacial maximum to the Pre-boreal chronozone (Hill 1994, 1995). This time interval includes the Pleistocene-Holocene boundary and was also associated with the extinction of Rancholabrean megafauna and the presence of time-diagnostic fluted and unfluted points. Remains of extinct late Rancholabrean mammals, including _Mammuthus_, have been recovered from the west of the Lake Superior basin (in the Agassiz basin—Herman beach—the upper Mississippi drainage, and the inland drainage of the Superior basin within the Cloquet River drainage). Clovis, Folsom, Holcombe, Agate Basin, and Hell Gap artifact forms, elsewhere dated to the late Glacial interval, have been found within the region, and landscapes were available that could contain older nondiagnostic artifact forms associated with Rancholabrean fauna.

Geomorphic and stratigraphic relationships of Quaternary deposits in the western Lake Superior region can be used to construct interpretations of the physical settings available to late Rancholabrean-age faunal communities and Paleoamerican populations. Between about 20,000 and 14,000 B.P. the Rainy lobe of the Laurentide ice sheet melted away from the region between the Agassiz and Superior basins. By perhaps 12,500 B.P. an ice-free region extended to about the location of the Vermilion moraine and by 11,000 B.P. the ice margin was in southern Canada. This left the area immediately west of the Superior basin available for Rancholabrean faunal communities and late Glacial human populations using fluted and unfluted points. Isolated ice-margin lakes may have been present within the Superior basin as a result of the Marquette advance, which also resulted in the Emerson transgression of Lake Agassiz. This is an example of the way geoarchaeological models can be used to integrate interpretations of the spatial and temporal landscapes and assessments of the temporal range of archaeological evidence to study late Pleistocene human adaptations in North America.

Another example of the application of geoarchaeological methods is the development of a landscape model associated with Quaternary environmental change on the northern Great Plains, within the lower Yellowstone River basin (Hill 2003; Huber and Hill 2003). The uplands within the lower Yellowstone
drainage contain stratigraphic sequences associated with the last glacial-interglacial transition. These sedimentary contexts indicate that late Glacial environments were associated with intervals of eolian deposition interrupted by periods of increased landscape stability and soil formation. Some pedogenic features consist of secondary carbonates possibly associated with arid climates, whereas other buried soils are characterized by well-developed A-horizons that could be the result of wetter or cooler climates. Two stratigraphic sequences illustrate this pattern. The South Fork of Deer Creek flows into the Yellowstone Valley from the north. Upland silts overlie bedrock and contain buried A-horizons and secondary carbonates. The silts contain the remains of a mammoth (*Mammuthus columbi*). Radiocarbon ages from this mammoth indicate the silts were deposited around 12,330 to 11,500 B.P., followed by the soil-forming episodes. Thus the deposits contain clues to the landscapes that were contemporary with human groups using Clovis (Paleoamerican) artifacts in the western interior of North America. Stratigraphic sequences south of the Yellowstone River also contain eolian silts and buried soils. For example, buried A-horizons developed within eolian silts present at Oscar T. Lewis Ridge, south of Glendive, Montana, have radiocarbon ages of 11,415 to 9330 B.P. These upland lithostratigraphic sequences can be correlated with the Aggie Brown Member of the Oahe Formation and other regional late Pleistocene–early Holocene deposits that are contemporary with Clovis and Folsom artifacts.

Geoarchaeology has also been used to help predict the location and evaluate the landscape contexts associated with archaeological sites even where there are other sources of information available, such as historical documentation. One example is the application of geoarchaeology to study the landscapes associated with the Lewis and Clark expedition (Hill and Karsmizki 2003, 2004a, 2004b). The Lewis and Clark expedition traveled west toward the Rocky Mountains in 1804 and 1805. The journals of several members of the expedition and in particular the notes and field maps of William Clark document the landscapes along their journey from Saint Louis, Missouri, to the Pacific Ocean near the mouth of the Columbia River. Geoarchaeological studies have been conducted at two locations along the Missouri
River. Geoarchaeological studies focused on the landscapes associated with Fort Mandan, North Dakota, and around the Great Falls, Montana, provide an opportunity to compare the records of Lewis and Clark with the geomorphic and stratigraphic contexts along the Missouri River. Fort Mandan was the 1805 winter camp of the expedition. It was situated on a low fluvial terrace on the north side of the Missouri, several miles downstream from the confluence of the Missouri and Knife rivers. Clark’s maps document the location of the Missouri River and its tributaries, other physiographic features like river bluffs, and the location of Mandan and Hidatsa villages. In this region the higher terraces and upland areas contain Pleistocene and Holocene glacial, lake, river, and eolian deposits as well as buried soils (paleosols) within some of these deposits. Comparison of the location of the Missouri River as documented by Clark with its present-day location appears to show that the river has been meandering through the valley in the Fort Mandan vicinity. In some places the river has eroded the landscape features present at the time of Lewis and Clark, whereas in other places deposition has prevailed. On the low terrace in the vicinity of Fort Mandan, for example, the stratigraphic sequence consists of three texturally distinct sets of deposits. The cross-bedded lower sands appear to reflect higher-energy fluvial environments compared with the overlying set of silt beds. The silt beds reflect a lower-energy depositional environment and are overlaid by more sandy sediments. The silts contain buried soils, burned areas with charcoal, and fragments of bone. Some of the charcoal has a radiocarbon age within the time range of Lewis and Clark (Hill and Karsmizki 2004b). Thus the geoarchaeological investigations in the Fort Mandan region appear to indicate that erosional and depositional processes have influenced the evolution of the landscape in this region over the last 200 years; in some places sediments have been removed, whereas in other places there has been episodic aggradation (deposition) since about the time of the Lewis and Clark expedition.

In contrast to the Fort Mandan area, the area around the Great Falls of the Missouri River in present-day Montana appears to have been the scene of much less movement of the river channel and also less aggradation. Many of the physiographic
features documented by William Clark can be observed today, including the locations of the Missouri River, Belt (Portage) Creek, a spring, the bluffs, rapids, and the falls. All these provide connections between the historical landscape associated with the expedition and the present-day physiography of the area. In addition, stratigraphic studies reveal the evolution of the landscape. Fluvial gravels are overlain by glacial deposits and tills associated with the late Pleistocene advance of the Laurentide ice sheet. The ca. 6800 B.P. Mazama tephra is interbedded within alluvial and colluvial deposits. Radiocarbon ages on bone collagen, wood, charcoal and charred material, and soil-bulk organics or organics recovered from the alluvial deposits indicate slow deposition over the last 3,000 years (Hill and Karsmizki 2004b). In this case the use of geomorphic, stratigraphic, and geochronological evidence appears to demonstrate that little change has occurred in the landscape context of the Great Falls locality during the late Holocene.

Conclusion

What kind of archaeological questions can be addressed from a geoarchaeological framework? Table 25.1 shows some ways that geoscience methods and concepts can be applied to address archaeological issues. A geoarchaeological approach helps determine the natural resources available for use by humans; assists in predicting site location; helps estimate the age of archaeological contexts; identifies, describes, and classifies soils, sediments, and artifactual raw materials; and helps examine synchronic and diachronic links between humans and the earth. Geoscience methods can be applied to help answer questions ranging from the characterization of the materials that constitute artifacts to the understanding of archaeological features and the sediments and soils that form part of the archaeological record. Or they can be used to evaluate the reasons for the presence of an object at a particular place or context, as part of evaluating the processes of archaeological site formation and preservation. From this perspective, geoarchaeology provides a methodological structure to organize the use of geoscience methods with the goal of
interpreting the prehistoric record and understanding the human past, especially the connections between people and physical and biotic landscapes through time. Thus geoarchaeology can be regarded as a framework for implementing various overlapping aspects of other natural sciences with environmental, contextual, and processual archaeology. The questions that can be addressed include why a particular fragment of the landscape contains archaeological materials, what resources led to the use of a particular location, and what conditions prevailed to preserve the artifactual record.

From a methodological perspective geoarchaeology represents the application of techniques derived from the earth sciences to interpret the human past. Geoarchaeology can also be perceived as a conceptual framework for using natural-science techniques with the goal of more fully developing an understanding of the past and present relationships between people, other organisms, and the physical environment.

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