

Geoarchaeology

The Earth-Science Approach to
Archaeological Interpretation

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Raw Materials and Resources

The excavation of an archaeological site usually brings to light only a small portion of the material culture of a society. Because artifacts of rocks and minerals as well as the debris produced during their manufacture are stable in the earth-surface environment, they make up a large part of what is recovered. Most inorganic remains are derived from geologic raw materials. From early Paleolithic tools through building materials and ceramics to sophisticated metal alloys, the source materials are rocks and minerals. By the end of predynastic times the following had been used for stone vessels in Egypt: alabaster, basalt, diorite, granite, gypsum, limestone, marble, schist, serpentine, and steatite. By Neolithic times stone was being used for construction in Cyprus and the Near East. At Tell es-Sultan, near Jericho in Palestine, stone was being used for house walls by about 6000 B.C.

Let us begin with some basic definitions. A rock is a specific aggregate of one or more minerals that occurs commonly enough to be given a name (granite, limestone). A mineral is a naturally occurring inorganic element or compound having a specific crystal structure and a characteristic chemical composition (quartz, mica). Obsidian is a volcanic glass that has not yet crystallized but in all other respects is a rock. Our section below on rocks describes the three genetic types of rocks recognized by the geologic sciences and provides a basic nomenclature. The word *stone* has many meanings. Within a geosarchaeological context the usage should be restricted to building stone and gemstone.

Archaeologists use the word *lithic* (from the Greek *lithos*, meaning "stone" or "rock") for materials and artifacts made from rocks or minerals.

Geologic nomenclature also makes extensive use of this Greek root: *lithification* (the compaction and cementation of an unconsolidated sediment into a coherent, solid rock), *lithology* (the description of the characteristics of a rock, such as color, mineralogy, and grain size), and *lithosphere* (the solid portion of the earth, as contrasted with atmosphere and hydrosphere).

Lithic resources have been used since our hominid ancestors first threw stones and made stone tools. The ancient Greeks and Romans had specific names for a large number of common rocks and minerals. The Greek natural scientist Theophrastus published his *On Stones* in the fourth century B.C., and the last five books of Pliny's *Natural History* (first century A.D.) are devoted chiefly to the consideration of lithic materials. Pliny discusses approximately 150 separate rock and mineral species and indicates that there are many more that he does not discuss. Many names of common rocks and minerals come down to us from these early times. From Theophrastus, we have derived *alabaster*, *agate*, *amethyst*, *azurite*, *crystal* (quartz), *lapis lazuli*, *malachite*, and *obsidian*.¹ There is a vast array of archaeological lithic materials. Here, we have concentrated on those rocks and minerals that geoarchaeologists are likely to encounter in Old World and New World contexts.

Minerals

Chert and Chalcedony

There are more than 3,000 mineral species. The chemical and structural makeup of the various species gives each a distinct set of physical prop-

erties, such as color, hardness, cohesiveness, and characteristic fracture. Chemical composition is the key characteristic in determining how certain minerals—like the ore minerals, which provide metals—were used in the past.

Long before the development of writing, humans recognized such distinct mineral properties as hardness, cohesiveness, and color. They used hard, cohesive jade for adzes and formed tools and weapons from fine-grained varieties of quartz. Red hematite and black manganese oxide minerals were used in cave paintings. Brightly colored minerals provided ornaments. Technological development led to the mining and smelting of ore minerals to produce copper, lead, silver, and iron.

The hardness of a mineral is defined as its resistance to scratching. Hardness was quantified by the Austrian mineralogist Friedrich Mohs, who proposed the following scale of relative hardness in 1922: 1) Talc, 2) Gypsum, 3) Calcite, 4) Fluorite, 5) Apatite, 6) Orthoclase, 7) Quartz, 8) Topaz, 9) Corundum, 10) Diamond. Each of the minerals lower in the scale can be scratched by those higher in the scale. The scale is not linear; in absolute hardness diamond is three orders of magnitude harder than talc.

Hardness is an important diagnostic property in the field identification of minerals. In addition to the minerals in the scale, the following materials serve as handy references for hardness (on the Mohs scale): fingernail: 2 to 2.5; copper coin: approximately 3; pocket knife: 5 to 5.5; window glass: 5.5; steel file: 6.5.

Rocks, per se, as assemblages of minerals do not have Mohs hardnesses, although some monomineralic rocks like quartzite and marble will exhibit the hardness of their constituent mineral. A rock like granite, composed of orthoclase and quartz, would exhibit a Mohs hardness of between 6 and 7. However, the importance of granite for building stone lies not in its hardness but in its cohesiveness and its mechanical strength. Granite was used for hammer stone as much as for its cohesiveness and lack of tendency to fracture as for its hardness.

Rocks and minerals composed chiefly of quartz make up a large percentage of lithic artifacts. Quartz is the most stable of all minerals under

sedimentary conditions and in the earth's surface environment. Few areas of lithic nomenclature are as confusing as that of fine-grained varieties of quartz (SiO_2), and *chert* has been used as a general term for any fine-grained siliceous rock of chemical, biochemical, or biogenic origin. Chert is usually a very hard compact material that fractures conchoidally when struck. (Quartz has a Mohs hardness of 7, and chert can be between 75 and 99 percent quartz.)

In a comprehensive monograph on chert and flint, archaeologist B. E. Luedtke opts for using *chert* as the general term for all rocks composed primarily of microcrystalline quartz.² Our approach differs only slightly. For example, we distinguish chalcedony from chert because it has a different structure (fibrous) that is easy to recognize under the petrographic microscope.

Chert occurs as bedded deposits, discontinuous lenses, and nodules that are usually interstratified with chalk, limestone, or dolomite. Chert is microcrystalline quartz composed of interlocking, often roughly equigranular, grains. It can be almost any color and accommodate a wide variety of impurities which affect its workability in lithic manufacture. Grain size also has a significant effect on fracture properties.

The chief varieties of chert of interest in archaeology are flint, jasper, and novaculite. The term *flint* should be used primarily for the gray-to-black nodular chert found in chalk and marly limestone. It is very fine-grained and tough, and it often has directional properties that are of value in flint knapping. Impurities are usually less than 1 percent and consist chiefly of sponge spicules and calcite. The best flints of Europe occur in chalk beds.

Jasper is a common, widespread red chert. It is usually fine-grained and dense, with up to 20 percent iron oxide. Jasper from the eastern desert has been used in Egypt since predynastic times for beads, amulets, and scarabs.

Novaculite is a white, unlaminated microgranular quartz of uniform grain size. It is not common and so is of special archaeological importance when it is found as an artifact.

Chalcedony is also microcrystalline quartz, but texturally it is composed of radiating fibers in bundles. (The texture can be established by

microscope examination.) This texture is more porous than that of chert, and in addition, chalcedony has a more greasy luster than chert. Chalcedony has no significant impurities and so tends to be whitish, although many chalcedonies turn red with heating. The name comes from Chalcedon, an ancient maritime city on the Sea of Marmara in Turkey.

Semiprecious Stones

Semiprecious stones are gemstones of lesser value than precious stones like diamond and emerald. They usually have a hardness of 7 or less on the Mohs scale. The most common semiprecious stones used by ancient craftsmen are varieties of quartz. We shall list here only the most important varieties of macroscopic quartz crystals for archaeology.

Amethyst, which is of bluish, reddish, or purplish violet color, can occur in large crystals (15 cm long). It was used in Hellenistic and Roman times for engraved seal stones. The name comes from the ancient Greek word for "not drunken": an amethyst amulet was supposed to protect from intoxication. Amethyst was also one of the twelve gemstones worn by ancient Israelite high priests to represent the twelve tribes of Israel, and amethyst mines in Egypt are known from Old Kingdom times. As early as the First Dynasty (2920–2770 B.C.) in Egypt, amethyst was used for beads (in bracelets and necklaces), amulets, and scarabs. The Romans exploited amethyst from the eastern desert, where it occurs in cavities in a reddish granite.

Rock Crystal is clear quartz in large crystals, used extensively in ancient times for everything from small seals to large vases. Diverse ancient societies (Greek, Roman, Chinese, Japanese) thought of these clear crystals in the same way; each group referred to them as "permanent ice." Predynastic Egyptians mined rock crystal north of Aswan. Ancient Egyptians coveted rock crystal for beads, vases, and filling in the corneas of eyes in statues and coffins.

By the eighth century, the rock crystal deposits of Mutsu Province, Japan, were developed on a commercial scale. Because quartz crystals break with a sharp conchoidal fracture, they were used

in North America for projectile points. Some archaeologists have used the term *rock crystal* for the quartz of these points.

Varieties of fine-grained crystalline quartz were also used for seal stones, jewelry, amulets, and related objects. Many of the names date from antiquity. The most important varieties were agate, carnelian, and sard.

Agate is a varicolored quartz; the colors often occur in irregular or concentric bands. Sometimes agate contains mossy or dendritic inclusions that give the impression of landscapes or vegetation. Known from ancient times—its name comes from the Achates River in Sicily—agate has been used for projectile points and mortars, as well as for cups, bowls, and bottles. The Sumerians used agate in ceremonial ax heads. Engraved agates were highly esteemed by the ancient Romans. One Roman two-handled wine cup made of agate had a capacity of more than 550 ml and an exterior carved with Bacchanalian themes. The prophet Muhammad wore a signet of Yemen agate.

Carnelian is a red (sometimes deep blood red) variety of quartz that may be transparent or translucent. Carnelian is found abundantly as pebbles in the eastern desert of Egypt. It was used in Egypt from predynastic times on for beads, amulets, and inlay in jewelry, furniture, and coffins. In the classical world carnelian was used for sealing rings and seal stones. *Sard* is similar to carnelian but more brown and opaque in appearance. It is the *sardion* of Theophrastus, named from Sardis, the capital of ancient Lydia in Anatolia.

Onyx and *sardonyx* are banded forms of silica. In onyx and sardonyx the bands are usually straight and comparatively regular; in onyx, milk-white bands alternate with blackish bands, while in sardonyx, white bands alternate with reddish brown or red, as the name implies (onyx alternating with sard).

A related mineral, *opal* ($\text{SiO}_2 \cdot \text{H}_2\text{O}$), occurs in many colors and has been popular since antiquity. The name is believed to derive from the Sanskrit word meaning "precious stone." The use of opal as a gemstone in antiquity dates back to the fifth century B.C., when it was mined in Slovakia. Its use was prevalent in ancient India, and it was a favorite gem of the Romans, who mined

it in Hungary. Opal and onyx were mentioned in the first book of the Bible. In the Americas, gem opal is found in a belt of scattered deposits that stretches from the northwestern United States through Central America to Brazil. Some Mexican opal was taken back to Europe by explorers as early as 1520. It has also found favor as a material for projectile points. Opal cannot long survive exposure to the effects of surface weathering. It tends to lose water and become cracked and opaque. Opal from quarry discard piles becomes chalk white and crazed.

The nonquartz semiprecious stones most commonly found in archaeological sites are lapis lazuli, jade, and turquoise. *Lapis lazuli* is a mixture of complex silicates that exhibits a range of colors from deep blue to azure blue and from greenish blue to violet blue. It has a hardness of 5-6, depending on impurities. It has been used for at least 7,000 years; in predynastic Egypt, it was a favorite material for cylindrical and flat seals, scarabs, beads, pendants, and amulets. Lapis lazuli was also used as a pigment. The most important source was at Badkshan, Afghanistan, a mining area that Marco Polo visited and described in 1271. There it occurs in large blocks and crystals in a white calcite matrix. Although it was popular in antiquity in China, India, Sumer, Israel, Egypt, Greece, and Rome, the modern name dates only from the Middle Ages and derives from the Latin word for stone (*lapis*) and the Persian word for blue (*lazward*). The Romans and Israelites called it *saphiris*.

Jade can be one of two minerals: jadeite (a pyroxene with a hardness of 6.5-7) or nephrite (an amphibole with a hardness of 6-6.5). Jadeite is somewhat more vitreous, nephrite more oily in appearance. Nephrite is generally more cohesive because of its texture of interlocking fibers. The coloring of jadeite comes from minor chromium; it can be a rich emerald green. Jade can also be bluish, purplish, or even reddish. The Chinese have made extensive use of jade since the beginning of the Neolithic; they acquired their nephrite pebbles from Burma (where it occurs in serpentine in boulders that can weigh up to several tons) and from Chinese Turkestan.² Burmese jade occurs in a wide range of colors. The Aztecs and

Mayans also used jade extensively,⁴ although it has been found less commonly in archaeological contexts in other parts of North and South America. Throughout history many names have been used for jade, and many materials have been called jade, so considerable uncertainty exists about early references to it. The name in English dates only to 1727 and comes from the Spanish term *pietra de yjada*, meaning "stone of the side"—an allusion to its supposed powers to cure side pains.⁵

Turquoise is a blue or bluish-green mineral with a hardness of 5-6. It is a secondary mineral usually found in small veins in weathered volcanic rocks in arid regions. Some turquoise will change color as a result of dehydration shortly after mining. Turquoise was highly prized by, among others, Pre-Columbian societies of the American southwest, the ancient Egyptians (as early as the Neolithic), and many other groups throughout the ancient Near East. The famous Persian mines were found near Nishapur in the province of Khorasan. The name *turquoise* is French, meaning Turkish, the original stones having come into Europe through Turkey from Persia.

In the southwestern United States—principally New Mexico—turquoise deposits were mined in prehistoric times. In some ancient quarries, stone mauls, pecks, and chisels have been recovered. There is evidence that the common technique of heating and quenching the bedrock was used to free the turquoise. In southern North America (Mesoamerica) turquoise was in common use. Aztec ruins contain many human skulls that were completely covered with turquoise.

The *feldspars* are a group of silicates that are the most common minerals in the earth's crust. They are major constituents of most igneous rocks. Feldspars are generally dull, cloudy, and fairly opaque, so they have not been sought after as ornamental "stones." They have, however, been found in archaeological contexts and as important constituents of igneous rocks. The common feldspars are orthoclase, plagioclase, and microcline. Semiprecious stone varieties of feldspar include sunstone, moonstone, and amazonstone. Indigenous Americans used all three as gems: moonstone by various groups in Mexico, sunstone by the Apaches in Arizona, and amazonstone by the

Aztecs, Mayans, and Indians of Venezuela, Brazil, Trinidad, Wisconsin, and California.

Other Archaeologically Important Minerals

In addition to semiprecious stones of considerable hardness a number of softer minerals were widely used in similar fashion. *Alabaster*, a fine-grained, cohesive variety of the mineral gypsum, usually has a whitish to pinkish color. It is quite soft: its Mohs hardness of 2 is less than that of a fingernail. Alabaster was employed in ancient Egypt from early dynastic times as a subsidiary building material to line passages and rooms. It was also popular for funerary vessels that contained the viscera of mummies. Some Egyptian material called alabaster is actually fine-grained calcite, which has a hardness of 3. Most New Kingdom stone vessels were alabaster (both true alabaster and calcite). The name comes from the Greek word *alabastrus*; the Greeks used it to make ointment vases, and the Etruscans for vases, urns, and ornaments.

Malachite is a dark-green copper-carbonate hydrate with a hardness of 3.5–4.5. It was most likely the first mineral ever smelted (see the discussion of ores, below), but it has also been used since the Neolithic for beads and other ornaments. It occurs in the oxidized portions of copper ore deposits, especially in regions where limestone is present. Along with many other green minerals, malachite was much in favor with the ancient Egyptians for ornaments. Malachite was used as an eye-paint as far back as 5000 B.C. in Egypt. The name comes from the Greek *mallos* (resembling the color of the leaf of the mallow), in allusion to its green color.

Although it is not strictly a mineral, *amber* has been used as a precious stone since the Neolithic. Amber is fossilized tree resin from evergreens and lacks crystalline structure. Amber is brittle and breaks with a conchoidal fracture. It is soft enough to be cut easily by any metallic knife. Easy to shape, amber was used for a wide variety of ornaments and amulets. The Greeks and Romans so revered amber that it was reserved for the nobility.

Amber is found in many parts of the world, but the principal supply for Europe and the Near East has been the Baltic region, where it has even been

collected from the Baltic Sea because it is buoyant enough to float on salt water. Baltic amber has been found in archaeological contexts as disparate as central Russia, Etruscan Italy, Mycenaean Greece, Pharaonic Egypt, and early first millennium Mesopotamia.

The world's oldest amber comes from the Appalachian region of the United States. Other sources in the Americas are Manitoba, Alaska, the Atlantic seaboard, Mexico, Ecuador, and Colombia. A primary source is the Dominican Republic, where it is found in the north, the east, and the center of the country, near the village of Cotui. It was the first American gemstone recognized by Columbus (a necklace of amber was presented to him by the indigenous peoples of the Dominican Republic as a welcoming gift). Amber earplugs and beads were found in Tomb 7 near Monte Alban, Mexico, dating from around 1100. The Aztecs controlled the amber trade from their capital, Tenochtitlan. This trade network went through Chiapas, an outpost of the Aztec Empire. The *Codex Mendoza* mentions amber as part of the tribute materials paid to Montezuma by certain districts in Mexico. Amber was also in common use by the Eskimo.⁴ In southeast Asia the major source of amber was Burma. Burmese amber has been imported into China since the Han Dynasty.

Often mistakenly called "black amber," *jet* is a compact and dense form of fossil coal. Geologists think that jet derives from water-logged pieces of driftwood. High-quality jet has a conchoidal fracture and no foreign matter like pyrite (common in most coal). Because it takes a high polish and is a deep, pure, velvety black, jet has often been used for ornaments. Its Mohs hardness varies between 3 and 4. The jet of Whitby, England, appears to have been used in Britain since pre-Roman times. In North America high-quality jet has been found in southern Colorado and Pictou, Nova Scotia.

The name *mica* derives from the Latin word meaning "to shine." Mica is not one mineral but a group of related sheet silicates, the most important of which is muscovite. Muscovite is colorless and transparent; with one perfect cleavage, it can occur in sheets called *books* that are as large as a meter across. It was therefore used for mirrors

in ancient Nubia. Prehistoric societies throughout the Americas used muscovite. It was mined from many deposits in the Appalachian region and Alabama and traded as far west as the Mississippi River. From a single mound of the Mound Builders, more than 250 mica objects were recovered. Its name derives from its use as a substitute for glass in Old Russia (*Muscovy*).

Many of the large sheets of mica found in Hopewellian ceremonial contexts in eastern North America apparently came from the southern Appalachian region. Mica outcrops in western North Carolina were mined extensively in prehistoric times.⁷

A hydrous calcium sulfate, *gypsum* is a soft mineral that has many uses. It is a common mineral, widely distributed in sedimentary rocks, often as thick beds. The colorless, transparent variety called selenite can be found in large-cleavage sheets that have been used as windows since Roman times. Alabaster is another variety of gypsum. Gypsum has also been used widely as a plaster (its name comes from the Greek word for plaster), and it is the raw material for plaster of Paris. The Minoans used large gypsum blocks as building stone.

Common table salt, the mineral *halite* (NaCl) has been the source of salt for human nutritional needs from the beginning of human evolution. It has also served as a preservative, a medium of exchange, and a source of tax revenue. Salt oases lay on the caravan route through the Libyan Desert in the time of Herodotus. The salt mines of ancient India were the center of widespread trade. The salt of its harbor Ostia supplied some of Rome's needs. Those of Caesar's soldiers who were "worth their salt" received part of the pay (their *salarium*) in the form of salt. Throughout the world, salt takes little energy to exploit, and it has always been easily transported. It can be recovered by boiling sea water or merely by allowing the water to evaporate. Large-scale boiling of brine to recover salt dates back to the Iron Age in Europe.

Halite also occurs in major beds in many Triassic sedimentary rocks in central Europe and England. Halite deposits form when arms of the sea are cut off from a supply of water and dry up.

Sea water is about 2.5 percent NaCl . In coastal estuaries evaporation can increase this percentage to about 8 percent. Pliny identified and described the three different raw materials for salt production: rock-salt beds from evaporite deposits, brine, and sea water. In prehistoric Europe the rock-salt mines of the eastern Alps were a major source: the mines at Salzburg, Hallstatt, and Hallein were worked on a scale far exceeding local needs. Miners dug as far as 350 meters into the salt beds of the mountain sides.

In Mesoamerica, Yucatan was the greatest producer of salt. Salt beds extended along the coasts, where the salt was collected at the end of the dry season. Underwater excavations off the coast of Belize have uncovered a site where the Mayans produced salt from sea water more than 1,000 years ago. The salt trade was important in the development of Classic Mayan civilization. Plants have a very low sodium content, so inland agricultural societies need mineral salt. People in the tropics have high salt requirements because they sweat so much. They therefore were forced to import their salt. Salt was also recovered from Guatemalan wells.

Salt deposits can form from the hot brines of hot springs. Since around the year 1000, humans have excavated salt from brines and brine deposits originating in the Rift system in East Africa. Of special note are the deposits at Bunyoro on the eastern shore of Lake Albert.

In the Krakow region of Poland, the earliest salt-making sites date to the Middle Neolithic. Ditches, storage tanks, hearths, pits, and ceramics have all been recovered in association with salt making from brine springs. The brine was channeled through clay-lined ditches to prevent seepage into the sandy soil, into storage tanks, and into ceramic vessels used for heating and evaporation. The Krakow region also has salt mines that have been worked for more than 1,000 years from a layer of salt nearly 400 meters thick lying far beneath the surface. In Romania, many saltwater springs provided salt from the Neolithic through the Middle Ages.

In Japan the environment for salt production is poor. Although surrounded by salt water, the islands of Japan lack coastal flats for evaporation

fields; in addition, they have too little sun. As a result, at least for the past 1,400 years, the Japanese have relied on a two-step process for concentration and evaporation. Seaweed soaked in seawater was dried, and the salt that precipitated was rinsed off into more seawater, which produced a more concentrated brine that was evaporated by being heated in clay pots.

It should be noted that the evaporation of sea water will yield not only halite but also the other salts that are dissolved in the sea. The salts produced by evaporation in natural salt pans occur in the following order: calcium carbonate (calcite), calcium sulfate (gypsum), sodium chloride (halite), and potassium magnesium chloride (carnallite), with halite occurring in the greatest quantity. The composition of natural brines varies widely. Many are unsuitable for salt production.

Natron is a naturally occurring mixture of sodium carbonate and sodium bicarbonate. It occurs abundantly at Wadi Natrun (a depression in the Libyan Desert 60 kilometers northwest of Cairo). Each Nile flood vastly increases the supply of water entering the wadi and its string of small lakes. During the dry season evaporation from the lakes causes deposition at the bottom of the lakes and as an incrustation on the ground adjoining them. In Ancient Egypt, as Pliny notes, natron was also prepared artificially, in much the same manner as table salt, except that Nile water rather than sea water was used. The Egyptians used natron in mummification, for purifying the mouth, for making glass and glaze, for bleaching linen, and in cooking and medicine.

Metals and Ores

Of the approximately seventy metallic chemical elements, eight (gold, copper, lead, iron, silver, tin, arsenic, and mercury) were recognized and used in their metallic state before the eighteenth century. Only gold and copper were sufficiently available in their native (metallic) state to be of importance to early societies. In the Old World, metallurgy had its beginnings in the Near East more than 7,000 years ago with copper and gold.

The first uncontested use of metallic copper dates to the late eighth millennium B.C. at an aceramic Neolithic site in southeastern Turkey. Here archaeologists found beads made of native copper. In the New World, Andean metallurgists developed sophisticated technologies that later moved north and flourished from Panama to Mexico. The Andes Mountains contain some of the richest gold, copper, tin, and silver mines in the world. Unlike the Old World focus on copper, metallurgy in Andean societies focused on gold from the middle of the second millennium B.C.

The word *ore* is derived from an Anglo-Saxon word meaning a lump of metal. It is applied to an aggregate of minerals from which one or more metals can be extracted *at a profit*. Therefore, what may be an ore under one set of economic conditions may not be an ore under other economic circumstances, for example, when it is possible to import a metal more cheaply than to extract it from a local deposit. In recent years there has been a tendency to drop the requirement that the desired substance be metallic. The worthless material from an ore deposit is called *gangue*.

Copper and *gold* (Au) were the first metals to be used by humans, primarily because they occur in the native, uncombined state in nature. The ancient Egyptians particularly prized gold for its eternal sheen, and they had a nearby source, the extensive deposits in Nubia. There is also a gold-bearing region between the Nile and the Red Sea. In the ancient world gold was exploited for purely decorative purposes. Deposits in the Taurus Mountains of Anatolia were extensively mined in the Early Bronze Age, and deposits in Greece were worked throughout the Bronze Age. In the New World, the use of gold came much later but reached great volume and artistic heights south of the Rio Grande, in Central America, and in northern South America. Indeed, stories of the abundance of gold objects were the driving force behind the Spanish conquest.

Gold is widely distributed in small amounts. It usually occurs in high silica (SiO_2) igneous rocks and quartz veins. Its exceptionally high density (19.3 g/cm^3 ; more than six times the density of the average rock) causes it to concentrate in what are called placer deposits (see below). Its melt-

ing point of $1,063^{\circ}\text{C}$ means that it can be melted and cast, and its chemical status as a noble metal means that it is free of unsightly corrosion.

Silver (Ag) does occur in the native state, but in ancient times most of it came as a byproduct from the smelting of lead ores. Silver was used in Egypt before 3000 B.C. but was comparatively rare until the Eighteenth Dynasty. In North America, native silver has been found in some Mound Builder (Hopewell) sites. *Electrum* is an alloy of gold and silver. The earliest electrum used was probably natural, although by Greek and Roman times artificial electrum was also used.

Over a considerable span of time, ancient metalsmiths discovered the rewards of applying pyrotechnology to metalliferous rocks. The smelting of copper (Cu) ores goes back six millennia in the Old World. Our knowledge of the origins of copper alloy metallurgy is primarily indirect, derived from analyses and interpretations of the composition and structure of artifacts, slags, and ores. Because archaeology (particularly Old World archaeology) has focused on the excavation of temples, graves, and habitation sites, relatively few examples of Chalcolithic or Early Bronze Age metallurgical or mining sites are known. Most of these have provided scant evidence of ores or technology. Only since the time of the English chemist and physicist John Dalton (1766-1844), who made significant contributions to our understanding of what a chemical element is, has the concept of chemical elements been used in a scientific or technical sense. The development of alloy metallurgy, therefore, must have come about without the artisans having any clear notion of elements and compounds. Ancient metalsmiths must have been aware of the results of smelting a mix of different "ores," but they must have marveled at the outcome of the results of smelting both metallic-looking and nonmetallic-looking stones.

A variety of scenarios may be proposed to account for the initial discovery that copper can be separated from such nonmetallic looking minerals as malachite and azurite. Bright green malachite or bright blue azurite may have been applied as decoration on the surface of pottery by Chalcolithic artisans. If the pottery were then fired in a

reducing atmosphere, copper beads would have formed. Malachite and azurite begin to decompose below 400°C . It is likely that the earliest copper smelting was done well below the melting temperature of copper ($1,083^{\circ}\text{C}$). When ancient metallurgists learned how to smelt the more difficult copper sulfide ores, perhaps about 2000 B.C. in the eastern Mediterranean, they turned to the much more abundant copper iron sulfide, chalcopyrite (see below), for their ore.

North of the Rio Grande prehistoric people did not smelt, melt, cast, or alloy metals, relying instead on the relative abundance of native copper. Copper use began in the Lake Superior region about 5,500 years ago. The native copper occurrences in the Lake Superior region are by far the most extensive in the world. Native copper is found in lode (original) deposits; in river, shoreline, and lag deposits of rounded nuggets; and in nuggets from glacial till. Subject only to surface alteration, native copper is nearly indestructible in the surface geologic environment. Most of the sources of native copper are associated with mafic volcanic rocks (e.g., those in the Lake Superior region, in the Copper River in Alaska, on the Coppermine River in the Northwest Territories, and at Cap d'Or, Nova Scotia) and are found in the oxidized zone of copper sulfide deposits (e.g., in southwestern United States and in the Near East, where metallurgy began).

Unlike gold, silver, and copper, lead (Pb) does not occur in the native state but must be smelted from its ores, especially lead sulfide (galena), lead carbonate (cerussite), and lead sulfate (anglesite). Lead becomes molten at 327°C , so it is easily cast. It may have been smelted as early as copper: it is known from the Old World as long ago as the sixth millennium B.P. Lead mining at Rio Tinto, Spain, goes back to about 900 B.C., and at Lavrion, Greece, mining extends at least back to the late prehistoric times. Lead-tin pewter has been used since Roman times.

The Romans used lead for many purposes: storage vats, water pipes, pewter. It was also used as a preservative in wines. This toxic element then found its way into their bodies, causing severe medical disorders and leaving its archaeological trace in their bones.⁸ Litharge (PbO), called red

lead, has been widely used since ancient times as a red pigment. It too is quite toxic. Natural litharge forms in the oxidized zone of lead ore deposits. By Roman times red lead was also being manufactured from other lead minerals such as cerussite (lead carbonate).

Cinnabar is a blood-red mineral, mercury sulfide. The Mayans prized it highly as a pigment, probably because its color could symbolize blood and blood sacrifice. Most of the cinnabar probably came from the Mayan highlands. Excavation of a Mayan site in Belize dating to the late ninth or early tenth century uncovered an offering vessel containing more than 100 grams of hematite, 19 grams of cinnabar, and other objects floating in a pool of 132 grams of mercury. Two possible sources for the Belize mercury are the Todos los Santos Formation of Guatemala or the Matapan Formation of western Honduras. This suggests that the mercury was acquired locally and not through trade.⁸ Native mercury is rare in geologic deposits, and it is not known whether the Mayans mined liquid mercury or smelted it from cinnabar.

Cinnabar was used for the coloring on the famous oracle bones of ancient China. But all the ancient artisans had great difficulty differentiating among the various red pigments. Pliny's account of red mineral pigments is quite garbled.

A deep blue complex copper hydroxycarbonate related to malachite, but less abundant, *azurite* is an easily smelted ore of copper that was used both for its copper content and as a blue pigment, probably as early as the seventh millennium B.C. It forms in the upper oxidized zone of copper sulfide deposits, along with the more common malachite.

As a tin oxide, *cassiterite* is the only ore of tin. (Tin becomes molten at 232° C and was occasionally used in its metallic form in the ancient Old World.) Because of its specific gravity of 7 g/cm³, cassiterite is found in placer deposits, often along with gold. Cassiterite is widely distributed in small amounts, but cassiterite deposits of ore grade are rare. Perhaps the greatest unsolved problem in Old World Bronze Age metallurgy is where the tin came from. The plentiful placer cassiterite from Cornwall was certainly mined for British Isles Bronze Age metallurgy, but we do not know how widely that ore was

traded (see Chapter 7). By Roman times cassiterite from Iberia and Cornwall was available throughout the Mediterranean. The name cassiterite comes from the ancient Greek word for tin.

Galena is lead sulfide. It is recognizable from its perfect cubic cleavage, high density, and silvery metallic color. It is a common metallic sulfide frequently associated with silver minerals. Since Greek and Roman times a large part of the supply of lead has come as a byproduct of ores mined for their silver content. The Romans gave the name galena to this lead-ore mineral.

In North America where in antiquity no smelting occurred to recover metals, the brilliant silvery luster of galena nevertheless attracted the indigenous peoples, and it was used extensively in burial practices and for ornaments. Geologic sources of galena are numerous in the region from the southern Appalachians to the western Great Lakes area, and from Virginia to northeastern Oklahoma.

Galena has been reported from more than two hundred prehistoric sites in eastern North America. The earliest known use was during the Early Archaic. Of the 232 sites reported by Walthall, 60 percent were mortuary sites in which galena was used in a burial association.¹⁰

Galena rarely occurs in sites earlier than the Late Archaic. During the Late Archaic and Early Woodland periods galena is found in the Great Lakes and Mississippi Valley regions. During the Middle Woodland, a large quantity of galena was moved through regional and long-distance exchange systems. More than sixty Mississippian sites from Illinois to the southern Appalachians contained galena. These artifacts often exhibited ground, rather than natural, facets.

A red iron oxide, *hematite* (hardness 5–6.5) derives its name from the Greek for "blood red." But although the streak (the color of the finely powdered mineral, so called because of the diagnostic test used by geologists of drawing a mineral across a piece of unglazed porcelain and noting the streak) of hematite is red, the color of the mineral itself can be black or, in the case of specular hematite, a silvery metallic color. Hematite is widely distributed in rocks of all ages and is the most abundant and important ore of iron. En-

graved cylinder seals of hematite were found in the ruins of Babylon, and it was used extensively by the ancient Egyptians. Red ocher is hematite and has been commonly used as a pigment throughout history. The ancient Egyptians had plentiful supplies of red ocher near Aswan and in the oases of the western Desert.

Most hematite can be ground into a red ocher powder. In North America red ocher, either in the form of lumps or ground into a pigment, accompanied the dead in their burials. In central and eastern North America (the area roughly bounded by Minnesota, Ontario, North Carolina, and Alabama), hematite was used in prehistoric times to make pendants, axes, celts, and edged tools. Celts are the most common and widespread hematite implements in this region. Hematite was recovered from both glacial till and bedrock quarries.

Red ocher has been used for decoration at least since Mousterian times. The pigments for the cave paintings in France contained red ocher. It was used in the Upper Paleolithic in cave painting and since the Neolithic for painted pottery.

Limonite is a field-geology term referring to hydrous iron oxides of uncertain identity. *Goethite* is hydrous iron oxide and a major iron ore. When it is yellow in color, goethite is called yellow ocher. Goethite is one of the commonest and most widespread of minerals and forms the *gossan* or "iron hat" that caps oxidized sulfide deposits. Goethite is common in near-surface sediments and soils as a secondary or concretionary material precipitated from circulating ground water. Our lack of archaeological knowledge concerning iron ore mines of the European Iron Age probably stems from the wide occurrence of small, shallow deposits of limonitic and hematitic iron ores. The exploitation of such ores would have had little lasting effect on the landscape.

At the Nichoria excavation in southwestern Greece, goethite was found in the shape of small rods in Bronze Age contexts. This created quite a stir, because it was conjectured that these might have been pre-Iron Age oxidized iron nails. However, Rapp demonstrated that the rods had a radial cross-sectional structure similar to other known goethite nodules rather than the concen-

tric or structureless cross-section that would have been consistent with a rusted metallic iron nail. Goethite was named in honor of the poet Johann Wolfgang von Goethe.

Magnetite is a magnetic iron oxide; it is iron black with a metallic luster and a black streak. A natural magnet, magnetite is known as lodestone. It is common in small amounts in most igneous rocks. Occasionally there are concentrations large enough to be classed as an ore deposit.

Although most *meteorites* are stony in composition, many are composed of an iron-nickel alloy that is nearly rustproof and easily recognizable as a metal. Meteoric iron is malleable and easily worked. It can be distinguished from smelted iron by its high nickel content, 5–26 percent. Metallic meteorites were picked up and used by humans long before the Iron Age in the Old World and were prized in prehistoric America. Ancient Sumerian texts mentioned meteoric iron, calling it "fire from heaven." Artifacts of meteoric iron are known from the end of the third millennium B.C. in Egypt and the Near East. The Aztecs made knives from iron meteorites.

A copper iron sulfide, *chalcopyrite* is the most widely occurring ore of copper. It is easily recognized by its brass-yellow color. The development of copper sulfide metallurgy—which is more complex than copper oxide metallurgy—allowed the continued expansion of bronze-making in the ancient world. The sulfide ores in copper deposits lie below the oxidized ores, so ancient metallurgists may have been forced into sulfide smelting when the oxide ores were depleted.

The most common and widespread of all sulfide minerals, *pyrite* frequently occurs as crystals and has long been called "fools' gold" for its color, although it is not as golden as chalcopyrite. An iron sulfide, it is easily distinguished from gold by its brittleness and hardness (6–6.5 on the Mohs scale) and from chalcopyrite by its paler color and greater hardness. It is ubiquitous in copper deposits and contributes to the formation of *gossan*, which marks most sulfide deposits. Pyrite has been found in many archaeological contexts. The Mayans used it to make mirrors, while the Aztecs used it for inlays in mosaics and eyes in statues. The Inuit and others employed it as a firestone be-

Table 5.1 Igneous Rocks

	Lighter colored	Darker colored	
	<i>High SiO₂ (silica)</i>	<i>Intermediate SiO₂</i>	<i>Low SiO₂ (silica)</i>
Coarse grained	granite, syenite	diorite	gabbro
Fine grained	rhyolite, felsite	andesite	basalt

cause of its ability to give off sparks when struck. It was also used to make amulets.

Rocks

Just as the silica minerals have always been preferred for tools and weapons, the common durable rocks were the material of monuments, statuary, burial chambers, and buildings.

The major classifications of rocks are *igneous* (from the Latin for fire): rocks formed from molten magma; *sedimentary*: rocks formed from the consolidation of deposited clastic particles or by precipitation from solution; and *metamorphic* (from the Greek for undergoing a change of form): rocks formed by a major alteration of preexisting rocks owing to high temperature and pressure.

Geology has hundreds of names for variations in igneous rocks, but the names in table 5.1, with the addition of obsidian, should suffice for most archaeological work. The difference between granite and syenite lies in the percentage of quartz, with syenite having little or none. Rhyolite is the fine-grained mineralogic equivalent of granite. Felsite is a general term for any light-colored, fine-grained igneous rock, with or without phenocrysts, that is composed chiefly of quartz and feldspar. Basalt is sometimes called trap or trap rock. The wide range of igneous rocks used for hammer-stones, axes, and other pounding instruments is too extensive to be discussed here.

There are also hundreds of names for the varieties of the common sedimentary rocks (table 5.2). For example, a sandstone that has feldspar as a major constituent of the clastic particles is

called a greywacke. The pebbles or boulders in conglomerate are often very hard chert or quartz; the ability of prehistoric societies to dress blocks of conglomerate cutting neatly across tough chert boulders (for example, at the Lion Gate at Mycenae in southwestern Greece) is extraordinary. On the other end of the hardness scale, shale was used for beads because it was easy to shape and drill.

And there are many names in the geologic literature to account for mineralogic or textural variation within the major metamorphic rock types (table 5.3). It should be noted that not all quartzites are of metamorphic origin. A quartz sandstone completely cemented with silica can fracture through (rather than around) the grains, thus emulating metamorphic quartzites.

Individual rock types of special interest in geoarchaeology include:

Andesite A widespread fine-grained volcanic rock, named after the Andes Mountains, it is hard and cohesive. Vesicular andesite has been used extensively throughout the world for grinding stones for such grains as wheat and corn.

Basalt Fine-grained and often extremely tough and cohesive, basalt has found widespread favor for lithic tools, querns, and, in Egypt, statues. The earliest stone vessels made in Egypt were Neolithic basalt vases. Basalt is widely distributed in Egypt and was used as early as the Old Kingdom as a material for pavements in the necropolis stretching from Giza to Saqqara. Its source apparently was the Fayum, where one can still see the ancient quarry. During Pharaonic times, basalt was used in statues and sarcophagi.

Felsite Felsite is a general term for any fine-grained, light-colored igneous rock composed chiefly of quartz and feldspar. Felsite can be very hard and cohesive. Like chert, it breaks with a

Table 5.2 Major Sedimentary Rocks

Shale	The most common sedimentary rock. Shales are composed of clay and silt and often exhibit a finely laminated structure that resembles bedding.
Sandstone	Rounded or angular particles of sand size cemented together by silica, iron oxide, or calcium carbonate. Sandstones are often quartz and may be well cemented and therefore cohesive or poorly cemented and therefore friable.
Conglomerate	Coarse-grained elastic rocks composed of large rounded pebbles, cobbles, or boulders set in a fine-grained matrix of sand or silt cemented by silica, iron oxide, calcium carbonate, or hardened clay.
Limestone	Calcium carbonate in the form of calcite, formed by either detrital, biologic, or chemical processes. Many are highly fossiliferous and represent ancient shell banks or coral reefs. Chalk and travertine are also limestones.

sharp conchoidal fracture, which makes it valuable as a lithic material.

Rhyolite Almost the same as felsite, rhyolite is the fine-grained mineralogic equivalent of granite. Thus it contains quartz as an essential constituent.

Granite and Diorite Fairly abundant, often mechanically tough and free of cracks, aesthetically pleasing, and capable of taking a high polish, these igneous rocks have been widely used in the construction of large monuments. As early as predynastic times in Egypt they were also used for bowls and vases, and later for statues, obelisks, and stelae. The Pharaonic Egyptians carved single large obelisks from Aswan granite and used diorite for large statues. Diorite has been used in Egypt since Neolithic times for axes, palettes, and mace heads. Not all coarse-grained igneous rocks used in Egyptian statuary that are called diorite by archaeologists are actually diorites—granodiorite, granite, and other rock types have been mistakenly identified as diorite. Granite and diorite vary considerably in composition, texture, color, and durability, however.

Scoria In regions where there has been extensive metallurgical activity, scoria has been mistaken by archaeologists for slag. Scoria is the name applied to very dark, highly vesicular, sometimes glassy rock of basaltic composition. Coal clinker has the same appearance and is sometimes also called scoria. In the eastern Mediterranean

region a blackish residue from the melting of kiln walls under reducing conditions has also been mistaken for slag. This latter material, however, has very low density.

Obsidian The name obsidian goes back as far as Pliny, who described obsidian from Ethiopia. It is a volcanic glass, usually black but sometimes of other colors or even variegated. High-silica volcanic rocks are typically fine-grained or glassy. The molten material from which these rocks formed is so viscous that crystal growth is impeded and noncrystallized rocks often form during rapid cooling. Obsidians contain less than 1 percent H_2O by weight because magma at high temperature that is extruded onto the earth's surface, or intruded at very shallow depth, cannot retain much water in solution. However, obsidian can become hydrated (up to nearly 10 percent) by later absorption of groundwater (see Chapter 6 for a discussion of obsidian provenance studies and Chapter 7 for obsidian hydration dating). As a glass, obsidian breaks with a conchoidal fracture. Because it is easily worked into sharp projectile points and other implements, it has had wide use since prehistoric times.

Obsidian was in use as far back as Upper Paleolithic times. It was found in level C of Shanidar Cave in Iraq and dated to approximately 30,000 B.P. Obsidian has been recovered from almost every Neolithic site in the eastern Mediterranean area. It was equally important in New

Table 5.3 Metamorphic Rocks

Transformation of sedimentary rocks
through high temperature (→) and
high pressure (→)

Limestone → Marble

Sandstone → Quartzite

Shale → Slate → Phyllite → Schist → Gneiss

World contexts. Indigenous miners in central America pursued high-quality obsidian at depth, developing underground mines. The Aztecs made extensive use of obsidian for projectile points, knives, razors, swords, mirrors, and ornaments. There are numerous high-grade obsidian deposits in western North America, such as Obsidian Cliff in Yellowstone National Park and in the volcanic regions of Central America.

Pumice and Ash Pumice is a light-colored, vesicular, glassy, pyroclastic rock that is commonly composed of rhyolite. It is often porous enough to float and has been widely used as an abrasive. Pyroclastic rocks are volcanic rocks that form as particle deposition from explosive eruptions. When particles are smaller than 2 mm in size, they are called ash. Pumice from archaeological excavations can now almost routinely be traced to the volcano of origin and often dated to a particular eruption.

Quartzite Composed chiefly of quartz sandstone with silica cement, this rock fractures conchoidally, which allows it to be worked into sharp tools, just as chert and obsidian are. Quartzite was used in Pharaonic Egypt for statues and sarcophagi. Nubian sandstone, a quartzite, was used by Paleolithic people in the Sahara.

Marble Marble was the preferred statuary and monumental stone of the classical world. In Egypt it was also used for vases. Marble can be found in thick deposits of wide areal extent that are relatively free of cracks and easy to quarry. It takes a high polish. Its chief drawback is its high susceptibility to disintegration under the action of acid rain (modern pollution aside, rain is acid because

CO₂ dissolves in atmospheric water to create a never-ending supply of carbonic acid in rain). Marble is plentiful in western Anatolia, Italy, Greece, and elsewhere in the Mediterranean area, where it was widely used.

Serpentine A rock composed chiefly of the green minerals of the serpentine group (hardness 2.5–3.5), it occurs widely as the alteration product of mafic igneous rocks. It has been used since antiquity in the Old World for stone bowls, vases, carved figures, and occasionally molds. It was popular throughout North America because it was easily worked.

Siliceous Shale/Slate As with quartzite, this low-grade metamorphic rock fractures conchoidally. Because it is composed chiefly of silica, it has a hardness approaching 7 on the Mohs scale. It was widely used in North America, especially in northern Minnesota, for projectile points and other sharp tools.

Steatite (Soapstone) A fine-grained, compact rock consisting chiefly of the mineral talc (hardness 1) but usually containing many other constituents. It has been favored since antiquity for ornaments and molds because of its softness and cohesion. Nearly all of the North and Central American prehistoric peoples used steatite for pots, bowls, and pipes. The Inuit and others used steatite for lamps. Steatite outcrops are common in many locations throughout the Appalachian Mountains.

Catlinite A red, siliceous, indurated clay that is often called pipestone because of its extensive use in North America since at least the late sixteenth century a.c. for making tobacco pipes. Catlinite is named after George Catlin (1796–1872), well-known painter of Native Americans. Although the best-known quarry is in southwest Minnesota, there are also deposits in Wisconsin, Ohio, and Arizona. The trade in catlinite was countrywide and extended into Canada.

Shells

Along the Atlantic seacoast in North America shells were made into wampum beads that in the Colonial Period were the Native American's form

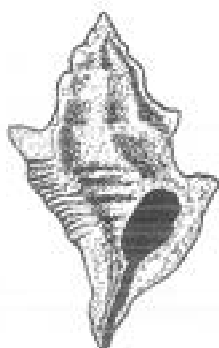


Figure 5.1 Murex Shell

of money. Crinoid stems were drilled and worn as beads. Water-tumbled stones of glacial till containing shell fossils were used for such everyday objects as hearth and boiling stones, hammers, anvils, and mullers. Some projectile points from the eastern United States have shell fossils located centrally in the artifact, suggesting its intentional placement as an ornament. Shell fossils and concretions, some stained with hematite, have been found associated with burials and grave goods.¹¹

In the eastern Mediterranean region, shells from certain species of the marine gastropod genus *Murex* yielded the royal purple dye of the ancients, especially favored by the Romans. (A substance secreted by murex turns purple when put into heated seawater.) The use of murex purple dye goes back to 1500 B.C. at Ugarit on the Levant coast. Murex shells were found associated with Middle Minoan pottery on the small island of Korephronisi just off Crete, and Cretan use of the purple dye was mentioned by Herodotus. Murex may have been bred in tanks along the ancient south coast of Turkey. Pliny gave fairly good descriptions of the gastropods and their dye. Murex shells are highly ornamented and easily identifiable (figure 5.1).

Clays

The primary raw materials for archaeological ceramics were local clay-rich sediments and soils that were used for the paste and coarse sedi-

mentary particles that were used for the temper. Clay deposits are of two general types: 1) primary deposits formed in situ by the weathering of bedrock like granite or shale, and 2) secondary deposits formed by river (fluvial) or lake (lacustrine) deposition. The secondary deposits are often referred to as transported clays. In soils, clay minerals form as part of the natural chemical weathering of the parent bedrock. Clay minerals are low-temperature hydrous minerals that are stable in the earth-surface environment. They form in soils from the breakdown of minerals that were created in high-temperature anhydrous environments. These primary minerals are not stable at the earth's surface. Plant nutrients become available during this chemical weathering. The supply of potassium (K) in a soil correlates well with the rate of clay formation.

It must be noted that the word *clay* has two meanings: it is both a particle size (smaller than two microns) and the name of a group of silicate minerals that have a sheetlike structure. Because of their small size and sheet structure, clays become plastic when mixed with water. This plasticity allows the mixture to be shaped and to retain the new shape. Whether a clayey raw material will make good pottery—one of the primary uses of clay—depends on which clay mineral predominates, the shape and size distribution of the nonclay minerals, the organic content, the exchangeable ions present, and the size distribution in the whole mass. Good pottery clays also contain fine-grained quartz, which provides the refractory backbone during firing.

Crude pottery is relatively simple to make. Many clayey soils and sediments can be fired to form simple, thick-walled vessels that can withstand moderate thermal and physical stress. Fired clay objects are known from the Upper Paleolithic of central Europe. The earliest known ceramics from North America come from Florida and date to about 1700 B.C.

The major clay minerals and their important properties for pottery making are:

Kaolinite, $(\text{OH})_2\text{Al}_2\text{Si}_2\text{O}_{10}$ Kaolinite is the most refractory of the clays and has excellent firing properties. Not only does it have the best high-temperature stability, it can also be heated

rapidly, and it has low shrinkage. Because of its restricted chemical composition, kaolinite maintains its white color. It is the clay of fine china. Its particle size and shape—it forms as small hexagonal plates—give it good plasticity. Kaolinite is the only clay that works well alone in pottery manufacture. It is a common and widespread product of the weathering of feldspars in igneous and metamorphic rocks. It can also be found as a secondary clay.

Halloysite, $(\text{OH})_6\text{Al}_4\text{Si}_4\text{O}_{10}$. Although similar to kaolinite in composition, halloysite has thin platelets that curl up, leading to poor workability (for example, it can crack during forming and drying). Halloysite must be heated slowly to prevent fracture during firing. It is a common product of the alteration of feldspars and often occurs with kaolinite.

Montmorillonite/Smectite, $(\text{OH})_2(\text{Al,Mg,Na})_2\text{Si}_4\text{O}_{10}$ (composition variable). The smectites are the expanding (swelling) clays that can absorb large amounts of water between the sheets in their structure. Their ceramic properties include high plasticity and moderate refractoriness but also high shrinkage. These clays are widespread alteration products of the weathering of volcanic ash and of many high magnesium igneous and metamorphic rocks. They also form as soil clays.

Illite, $(\text{OH})\text{K}_4\text{Al}_4(\text{Si,Al})_8\text{O}_{20}$ (composition variable, usually containing iron and magnesium). Illite has good plasticity, variable shrinkage, and low refractoriness. It is good for slips. Illites are the dominant clay minerals in shales and mudstones. They also form commonly in soils from the alteration of micas and other clay minerals and from colloidal silica. Illite is the only clay mineral containing significant potassium.

Other sheet silicates are found mixed with these clay minerals in many deposits, but they all reduce the plasticity. The addition of fine-grained organic material and many varieties of plastic and aplastic tempers can improve plasticity, strength, and firing properties.

To reduce shrinkage and/or improve workability, temper is added to the clayey material before it is formed. Coarse sediments for temper are normally available in nearby streams. Fossil shells also make good temper because calcium carbon-

ate has the same thermal expansion as the average pottery clay. The same is true for marble (also calcium carbonate). Chips of broken pottery, called *grog*, were also used as temper.

The glaze is a thin layer of material applied to ceramics before firing that becomes a glassy coating at high temperatures. Low-melting materials are necessary for glazes. Sodium and lead are the most common elements used to lower the melting point of the silicates in ceramic glazes. Lead glazes can cause lead toxicity if used for drinking or eating ware. Soluble salts or saline water can be the source of sodium. High-fired glazes usually contain feldspars, calcite, dolomite, or wood ash. Low-fired glazes are usually alkaline (containing sodium or potassium).

Building Materials

The nature of the building materials employed by a society depends primarily on the kind of material available. It was no accident that the great tells of the Middle East resulted from the disintegration of mud-brick buildings. For hundreds of kilometers around, there were neither hard-rock outcrops nor trees available for building. At Çatal Hüyük in Anatolia, walls and even built-in furniture were made of clay earth by 6800 B.C. In more northern regions, also lacking sufficient timber and where mud-brick walls would not survive, stone construction was a necessity. Except for timber, almost all building materials reflect the exploitation of minerals and lithic resources. Early in human cultural evolution, we turned to rocks for building, first to improve a cave or rock shelter, later to construct dwellings. In the Near East, rock walls for houses and towns go back more than 7,000 years. In areas where rock masses were scarce, earth plaster and mud bricks were used.

Ancient Egypt, Greece, and Rome were responsible for great advances in the use of quarried and dressed stone for building. By 3000 B.C., the Egyptians had learned to shape their comparatively soft Tertiary limestones into rectangular blocks. Before 2000 B.C., they had learned how shape the more difficult granite and diorite.

By the time of the Third Dynasty in Egypt

(2649–2575 B.C.) there was a marked increase in the use of stone for buildings. Limestone was the primary building material, but large blocks of granite were used in an unfinished pyramid located between Giza and Abusir and in the step pyramid of Djoser at Saqqara. By the Eighteenth Dynasty (1550–1307 B.C.), limestone had largely given way to the more durable sandstone and granite. The great sandstone quarries along the Nile about 60 kilometers north of Aswan bear inscriptions dating from the Eighteenth Dynasty down to Greek and Roman times. The Egyptians removed the surface layers of granite outcrops by burning papyrus on them and then drenching them with cold water, which caused the granite to spall and disintegrate. If no natural crack or joint could be exploited in quarrying the granite, a trench was made around the desired block by pounding it with balls of dolerite, a fine-grained basaltic rock. Wooden wedges were inserted in cracks or trenches, driven tight when dry, then wetted.

The Greeks and the Romans developed masonry building in shaped (ashlar) blocks to a fine art. During the Late Bronze Age the Mycenaeans in Greece constructed "Cyclopean" walls by fitting angular blocks neatly together. Sometimes mortar was used in masonry: the Egyptians favored gypsum while the Greeks and Romans used burnt lime (calcium oxide) and clay. Lime plaster was formed by heating limestone (calcium carbonate) at temperatures higher than 900° C to drive off the carbon dioxide. This left calcium oxide. Calcium oxide reacts rapidly with water to form calcium hydroxide. When exposed to the atmosphere, the calcium hydroxide takes up carbon dioxide again, becoming a stable calcium carbonate—hard and cementlike.

The Greeks and the Romans also discovered that certain volcanic ash produced a hydraulic cement when mixed with slaked lime and water. The Greeks used the volcanic tuffs from Thera (Santorini), while the Romans discovered around 100 B.C. that the volcanic ash from the village of Pozzuoli on the slopes of Mount Vesuvius was suited for this purpose. Not all volcanic ash has this property; the Roman recipes call the cements made with volcanic ash Pozzolanian ce-

ments. These cements can set under water; they were used as early as 144 B.C. to line water channels.

In the early nineteenth century, portland cement was invented in Britain (named after the Isle of Portland in Dorsetshire). The basic materials of portland cement are clay and limestone. Some iron is needed, but this is usually supplied by iron minerals in the clay. The most stringent requirement of the limestone is that it not contain more than about 5 percent magnesium carbonate. Portland cement is hydraulic—water is involved in the basic chemical reactions of manufacture. The first portland cement produced in the United States was in the Lehigh Valley of Pennsylvania in 1875.

Building Stone

A large number of distinct hard rock types (including limestone, sandstone, granite, and gneiss) make good building stone. The necessary characteristics are: 1) structural strength (ability to carry a load without failure), 2) durability (resistance to weathering), 3) ease of quarrying and dressing, and 4) availability (the energy cost of transportation).

By the time very hard rocks like granite, diorite, quartzite, and conglomerate came into use for building stone, the use of abrasives must have become commonplace. The Aztecs worked granite with copper implements with quartz sand as an abrasive. Emery, a grayish-black mixture of magnetite and corundum (which is second only to diamond in hardness), and pumice must have been used as abrasives from early on in those areas where they were available. Emery is abundant in the Near East and some of the Aegean Islands.

On the low end of the structural-strength scale are clays and muds. Yet these were important building materials (with only minor processing) in antiquity. As a geologic term, *mud* is a mixture of silt and clay-sized particles. (The word in common usage describes essentially the same material.) Many natural muds also contain some sand-sized grains. As noted earlier, *clay* has more than one meaning, but the thing to keep in mind is that most clay-sized material is composed of clay minerals.

The optimal sand-silt-clay ratios vary for dif-

ferent types of structures. For rammed earth walls, there should be about 50–75 percent sand in the mixture to prevent excessive shrinking of the plastic components. The size range of the sand and coarse particles is of little importance. In rammed earth walls only a small amount of clay is desirable: more than 30 percent clay results in rapid erosion. The pre-Spanish inhabitants of the American southwest used the *pisé* technique to build layered walls in three-foot (vertical) units of adobe-type mud, rather than making mud bricks.

To make satisfactory adobe bricks, a lithology lying outside the range used for rammed earth walls is needed. Adobe bricks must have a higher percentage of clay and contain straw for binder. Good sun-dried adobe bricks can be made from earth containing 9–28 percent clay. (The Uniform Building Code in the United States requires that the clay content of adobe bricks be greater than 25 percent and less than 45 percent.) Too much clay causes the brick to develop cracks as it dries; too little makes the brick too weak, so that it crumbles easily. Individual clay minerals have different bonding properties, and the lime content as well as the organic content will affect the physical properties. Sand-silt-clay ratios cannot tell the whole story. Compositions suitable for adobe or sun-dried mud brick can be attained by mixing a range of materials, but it is likely that in prehistoric times raw materials for mud brick were primarily clay and organic binders such as straw. In present-day mud-brick making in Egypt and Turkey, bricks are carved out of the soil directly, without going through a molding step. Enough plant material may exist in the soil there to take the place of added binder.

Burnt Brick

For thousands of years stone, clay, or clay plus timber were the dominant construction materials. The use of timber is recorded in archaeology by the abundance of debris in "destruction levels" that result when towns and villages are burnt down. London was destroyed by the Great Fire of 1666 because it was built chiefly of timber and mud. It was rebuilt with brick produced from the abundant high-quality clays available in southeast Britain. The art of baking clay to pro-

duce bricks dates from the second millennium a.c. in Mesopotamia, India, and Egypt. It was the Romans, however, who developed the technology of making burnt brick of high quality by carefully choosing and fine-grinding raw materials, then subjecting them to controlled firing. Since the twelfth century brick making has become ubiquitous; clayey sediments and weathering products are widely distributed. Although all clay minerals begin to recrystallize above 1,200° C, the mineralogy of the clay is almost as critical in brick making as in pottery manufacture. The compositions of brick raw materials can vary widely throughout the world. In Georgia in the United States, brick is made from pure kaolinite, some feldspar, fire clay, and bentonite (a rock composed chiefly of montmorillonite). In Great Britain red marls, deltaic muds, and illitic sediments of Jurassic age have all provided raw materials for brick. Throughout the world the most common raw material used for bricks is recent alluvium from the great floodplains of the Yellow, Ganges, Nile, Mekong, and Indus rivers. These alluvial deposits, however, are often high in silt and low in clay, leading to a weak and porous brick—best suited for single-story houses.

Mortar

Ancient mortar, before the advent of cement, usually consisted of clay, gypsum, or lime. Both gypsum and lime mortar required preparation in high-temperature kilns. The ancient Greeks and Romans used lime, whereas Pharaonic Egyptians used gypsum because in a land where wood was scarce, the firing of gypsum plaster was accomplished at lower, fuel-saving temperatures.

Clay mortar was used primarily with mud bricks. Clay, lime, and gypsum all served a dual purpose as mortars and as plaster. The ancient Egyptians mixed clay and gypsum and also clay and fine limestone for wall plaster.

Other Materials

When considering the geologic raw materials that may be found in an archaeological context, it also pays to become acquainted with objects that can

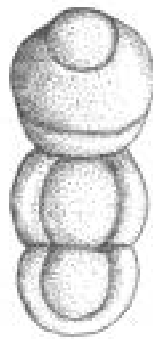


Figure 5.2 Concretions

resemble natural materials in shape or some other aspect but that have a different origin. Chief among these are concretions and dendrites.

Concretions are hard, compact segregations of mineral matter found in sedimentary rocks, particularly shales and sandstones, as well as in soils. They are formed by precipitation from aqueous solution, growing outward from a nucleus, and usually are of a composition somewhat different from the host rock. Concretions represent a concentration of a cementing material, such as iron oxide, calcite, silica, or gypsum. Most concretions are spheroidal, ellipsoidal, or discoidal, although many attain odd or fantastic shapes, sometimes mimicking turtle shells, bones, leaves, or other fossil material. These concretions are often *septarian*. Figure 5.2 shows one concretionary shape. Many concretions have an internal structure similar to that of concentric shells. Chert nodules have similar shapes (figure 5.3).

In soils, concretions cemented by iron oxide are found in better-drained soils but require some moisture to form, whereas calcareous concretions form in dry soils, particularly under alkaline conditions. Concretions range in size from a few millimeters to up to 3 meters. Concretions have been found in many ancient refuse pits and as grave goods on pre-European North American archaeological sites.

Dendrites are near-surface deposits of manganese oxide that have crystallized in a branching pattern along fractures in rocks. They are often

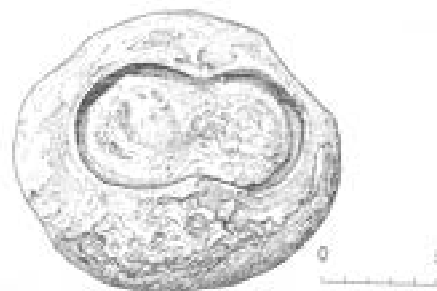


Figure 5.3 Chert Nodules

These nodules form in carbonate rocks that weather away, leaving the nodules lying loose on the surface. This nodule was collected in the Valley of Kings near Luxor, Egypt, by Rapp. The scale is in centimeters.

mistaken for fossils. Figure 5.4 shows a common dendrite.

Nearly all the rocks and minerals that hold their color when ground to a powder (most silicates turn white) have been used as pigments. There are too many of these for detailed consideration here. Among the most common are hematite (red ocher), goethite (yellow ocher), malachite, azurite, selenite (gypsum), cinnabar, varieties of coal, calcite, huntite (a rare white calcium-magnesium carbonate), magnesite (a white magnesium chloride), and manganese oxides and graphite.

Maya blue, used since the beginning of the Mayan Late Classic Period, is a mixture of minerals and indigo—a blue dye obtained from various plants. The mineral constituents are palygorskite (formerly called attapulgite), a white clay mineral, and sepiolite (also called meerschaum—from which smoking pipes are made). Both minerals occur as alteration products of serpentine. The dye becomes affixed to the absorbent white minerals after heating. This pigment was unknown in other parts of the ancient world. It continued to be used in central America in mural paintings into the nineteenth century.

Rock and Mineral Recovery

Geologists use the term *outcrop* for rock bodies that jut up at the surface of the earth. It seems a safe assumption that most rock and mineral prod-

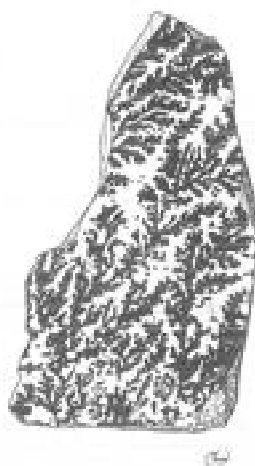


Figure 5.4 Dendrites

These near-surface deposits of manganese oxide that have crystallized along fractures in the rocks are frequently mistaken for fossils. (Drawing by Elaine Nissen)

ucts used by prehistoric cultures were gathered from outcrops. When a particularly high-quality stone or ore deposit was discovered, early humans developed mining and quarrying techniques to maximize its exploitation. The miners often made use of natural vertical joints in the rock in quarrying.

At Rudna Glava in Serbia people of the Vinca culture mined copper 4,500 years ago from 15-meter vertical shafts. The mining of copper ores and minerals in the Egyptian Sinai date to the Old Kingdom. Underground flint mines that operated in England more than 5,000 years ago during the Neolithic had shafts of more than 4 meters deep.

In prospecting for ancient mines the geoarchaeologist should look for evidence of waste dumps. The surrounding (waste) rock in metal mining is called country rock or gangue. This material was routinely discarded at the mining site so the miners would not have to transport it to smelting or other metal-processing sites.

A troubling problem in Old World prehistoric metallurgy has been the dearth of copper slag dumps from the Bronze Age. Copper smelting generates large quantities of slag—a waste product. Scientists speculate that later societies resmelted or comminuted (pulverized) some of the

earlier slags that retained recoverable copper. Or perhaps archaeological surveys have been insufficiently intensive to locate these mounds.

Throughout human prehistory people have prospected stream gravels for lithic raw materials, recognizing that the boulders that could survive the rough-and-tumble ride down water courses would not shatter easily. In most parts of the world these boulders were composed largely of chert and related quartzose rocks and minerals.

Most of the debris from weathering is moved away from its point of origin by running water. What size, shape, and density particles can be transported depends of the velocity of the water. Larger and denser particles tend to lag behind and accumulate in low spots in the channel, where the water velocity is lower. When there is a sharp change in water velocity—for example, where a river emerges from a mountainous area onto a plain—the larger and denser particles are deposited immediately. These concentrations of heavier particles are called *placers*. The earliest gold and cassiterite deposits used by humans were undoubtedly placers. The California Gold Rush of 1849 was based on placer deposits formed by the active erosion of lode deposits and gravels higher up in the Sierra Nevada Mountains. Placer mining has led to extensive excavations of alluvial valleys.

Large blocks of building stone were secured through quarrying. Quarries are not easily eroded or removed from the landscape, except when they are replaced by even larger quarries, so many landscapes contain ancient quarries. The quarrying of large blocks of rock for building stone was not possible until the advent of copper and bronze tools for working the softer rocks like limestone. Blocks of rock were quarried by isolating a block on four sides by means of trenches cut in the rock and then detaching it from below by means of wooden wedges wetted with water. In Egypt quarrying probably had its beginnings in the cutting away of limestone to make tombs.

Artifacts recovered from nearly 12,000 years of occupation of the Cebolleta Mesa region in New Mexico illustrate the broad range of mineral resources exploited for human needs.¹² Most of the materials came from the immediate area or

adjacent regions. Use was made of sandstone for masonry blocks and paint mortars; adobe from alluvial soils for building; basalt for tools, mauls, and bowls; clay from clay sediments for pottery; quartzite, chert, chalcedony, obsidian and pitchstone, pipestone, calcite and travertine, limestone, hematite and limonite for pigments; jet and turquoise for ornaments; halite for food; and felsite and metamorphic rock (other than quartzite) for implements. Also recovered were feldspar, quartz crystals, malachite, azurite, galena, and pyrite.

Ball has published an extensive treatise on the mining of gems and ornamental stones by Native Americans before they came into contact with Europeans.¹³ He noted that while mineral products were essential to both Indian and European ways of life, the Indians used coal mainly as an ornament and petroleum as a liniment. Ball reports on 84 different geologic materials used for gems and ornamental stones. Similarly, Heizer and Treganza have located and plotted 142 mine or quarry sites where California Indians exploited rock and mineral resources.¹⁴

The use of petroleum by Native Americans is well documented from archaeological sites. Asphalt was used as a mastic in the Ohio Valley and elsewhere. Many fossil hydrocarbon deposits (oil shale, tar sands, tar springs) were used as fuels in pre-European North America. Fossils, fossiliferous rocks, quartz crystals, galena cleavages, and sheet mica all have been found as grave goods.

The most necessary lithic material in Precolumbian North America was quartzose material, which was used for projectile points. The continent contains innumerable lithics that are good to excellent for this purpose, and large quarries were operated in what are now Ohio and New York for chert, Pennsylvania and New Jersey for jasper and rhyolite, New York for quartzite, and Minnesota for a slightly metamorphosed high-silica siltstone.

Water

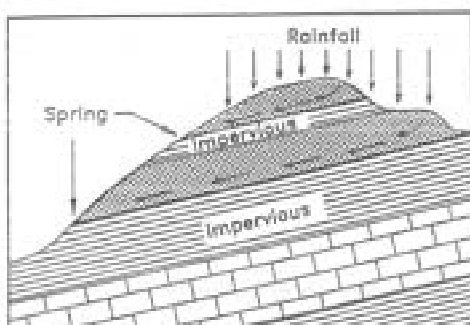
For geoarchaeologists, water is perhaps the most important and the least understood compound. It

is key not only to keeping organisms alive but to climate, weathering, agriculture, and transportation. Habitation sites have always depended on a supply of potable water.

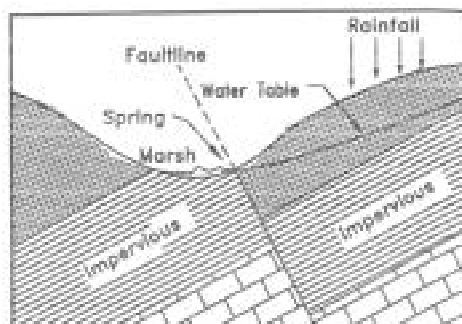
The appearance of natural water reveals only part of its total composition and potability. Suspended and dissolved matter imparts color to water: turbidity from abundant suspended clay particles imparts a yellowish color, abundant phytoplankton will generate a deep green, iron oxide a rusty red. The dark colors of swamps and bogs are due to suspended humic material and tannic acid. All surface and near-surface waters contain bacteria in concentrations of up to hundreds of thousands per cubic centimeter. Even unpolluted water contains large quantities of dissolved matter and dissolved gases, particularly O_2 and CO_2 , that have been picked up from the atmosphere. Most natural rainwater—unaffected by acid pollution—is acid because the carbon dioxide it picks up in the atmosphere forms carbonic acid. This phenomenon has major archaeological consequences including the dissolution of buried bone, the corrosion of monuments (especially marble and limestone) and metal artifacts, the decay of organic matter, and the formation of caves and rock shelters.

Rainfall that does not run off or evaporate seeps into the ground, where it has an important effect on human economy. It provides the medium for chemical and biochemical soil development, chemical and physical transport in soils, and nutrients for plant growth. Water not removed by plants returns to the surface by capillary rise, where it evaporates, returns to rivers or the sea by lateral flow, or, emerging as springs, is retained as groundwater. The top of the zone where the groundwater saturates the earth is called the water table. Because of modern-day drainage of low-lying areas for land use and the heavy pumping of groundwater for agricultural and other uses, contemporary water tables are much lower than in prehistoric or early historic times.

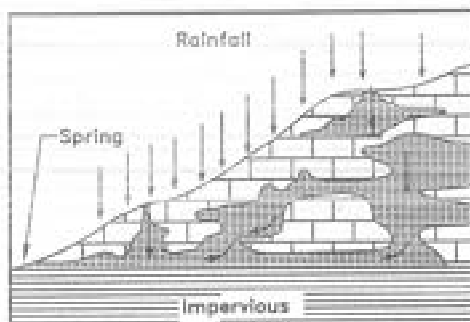
The quality of the groundwater is of critical importance for domestic uses. Usually, groundwater that is not near urban areas is free from bacteria because it is naturally filtered as it flows through near-surface strata and soils. Pure water



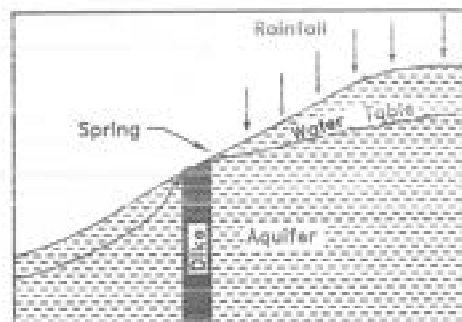
1. Charged aquifer above or between dipping impervious strata results in springs where lower edge of aquifer breaks surface.



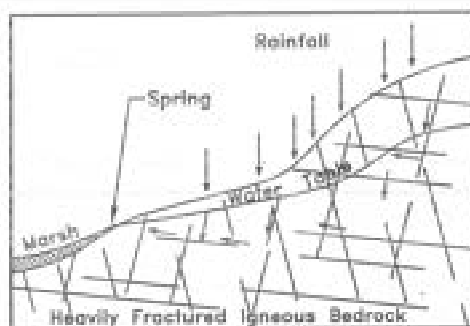
2. Downfaulting of tilting impervious strata results in subsurface impoundment of trapped groundwater with overflow breaking surface as spring.



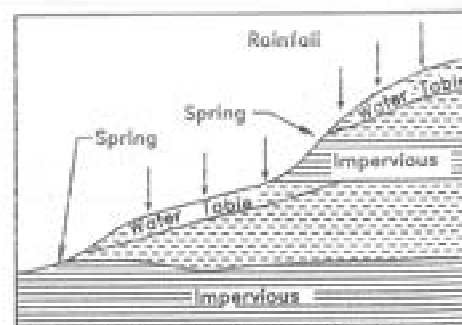
3. Percolating groundwater in karst areas is trapped above impervious strata and forms springs where impervious strata break surface. Common near the floor of river valleys.



4. Igneous dike acts as dam to prevent migration of groundwater with resultant spring on uphill side of dike. Waterholes which result are common in arid areas.



5. Groundwater migrates along fractures in bedrock breaking ground as spring where surface dips below water table.



6. Groundwater trapped above or between level impervious strata results in seeping springs where top edge of strata meet sloping surface.

Figure 5.5 Geologic Formations That Can Result in the Creation of Springs

will dissolve only 20 parts per million (ppm) of calcium carbonate and 28 ppm of magnesium carbonate. However, as noted above, water entering the groundwater system as rainfall will be acidic. Such water can dissolve hundreds of parts per million of sodium, calcium, magnesium, and iron minerals.

One of the main criteria for the acceptability of drinking water is its salinity. Below about 400 ppm sodium chloride imparts no taste to water. By about 500 ppm the water begins to taste brackish and by 4,000 ppm, water is undrinkable. The salinity of groundwater depends on the composition of the local rock formations, the depth from which the water is drawn, and the climate. Water also plays a primary role in chemical weathering and alteration by dissolution phenomena and frost action.

The accessibility of groundwater is critical if it is to be exploited economically. The structure, porosity, and permeability of the near-surface rock strata in large part govern the accessibility. Most important is how the pervious and impervious beds alternate. If impervious strata lie at the surface, no water will penetrate to the groundwater system. If an impervious layer lies somewhat beneath the surface, it will be a barrier to vertical flow. When pervious and impervious strata lie at an angle to the surface, springs may develop as groundwater moves down because of the pull of gravity. Because both geologic and climatic conditions remain stable for long periods, most springs have a continuous flow. Figure 5.5 illustrates the geologic conditions that lead to the formation of springs. For a comprehensive discussion of springs, see Chapter 9.