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MICROSCOPY. The light microscope, invented in about 1600, became a useful analytical tool in the nineteenth century. Microscopy is a "mature" technique that is invaluable for studying archaeological artifacts. It is usually the first physical technique employed in investigating material culture. A binocular microscope with a magnification of up to 20 × has a depth of focus large enough to provide three-dimensional vision useful for studying surface details or selecting certain mineral grains from a powder.

Higher magnifications require a special sample preparation that depends on the type of material being studied. Transparent materials are usually examined as thin sections of about 0.03 mm thickness in transmitted light, which may be polarized. To prepare a thin section for petrographic analysis, the sample is mounted on a standard-size glass slide (50 × 25 mm) so that a relatively large area can be studied. Mineral grains are identified by their shape (or cleavage pattern), color, and pleochroism (the differential absorption of polarized light in different directions). Rocks are composed of minerals, whose morphologies, relative abundances, and intergrowth may be characteristic of a specific occurrence of a certain rock type. It is therefore possible to relate the raw material of stone artifacts or of rock fragments in coarse-grained pottery to their original source, providing evidence for the transport of raw materials, be it by trade, human

migration, or natural events. A classic example is the petrographic study of the bluestones erected at Stonehenge that derive from Pembrokeshire, some 150 miles away. Major applications of this method, often in combination with chemical analyses, have been reported on the provenance of the limestones of Egyptian monuments and on millstones from the eastern Mediterranean. The diorite statues of Manishtushu and of Gudea, the ruler of Lagash, are said to originate in Oman. In pottery, the mineral assemblage can also provide information about firing temperature. [*See* X-ray Diffraction Analysis.]

Organic materials are also regularly studied with this technique. Various sorts of wood differ in their microscopic structure and can therefore be identified from small samples of about 1 mm in diameter. Similarly, textile fibers can be unequivocally identified.

Opaque materials, such as metals, are examined in reflected light. For sample preparation a piece is cut from a metal artifact, embedded in a resin, and polished. The sample can be small (less than 1 cu mm), but larger samples (ideally a thin slice providing a cross-section through the artifact) are easier to work with and yield more information. Often, the polished surface is etched with suitable reagents to enhance the internal structure. Because thermal and/or mechanical treatment like cold-working, annealing, or hot-working results in different microstructures, considerable information on the techniques employed in the fabrication of nonferrous metal artifacts can thus be obtained. Identifying the various phases in iron-carbon alloys sheds light on the processes used in the manufacture of iron and steel artifacts (e.g., carburization, quenching, and tempering) and the progressive evolution of iron metallurgy. Because many ore minerals are also opaque, ores and slags are also often examined using this technique.

As a result of diffraction effects, the limit of resolution of light microscopy is in the order of 1 μm (i.e., 0.001 mm), corresponding to magnifications of about 500 times. Still higher magnifications are obtained in electron microscopes with a resolution of less than one manometer (i.e., 0.000001 mm), which approaches the size of single atoms. For archaeological material, the most useful and widely employed form of electron microscopy is the so-called scanning electron microscope (SEM). A beam of high-energy electrons (up to 100 keV) is focused by a series of magnetic lenses so that the illuminated area of the specimen is about 0.02 μm in diameter—which is also the typical resolution obtainable with this instrument. Additional magnetic coils allow the beam to be deflected so that it scans, in a regular manner, over the surface of the specimen. The primary electron beam stimulates, among other effects, the emission of secondary electrons from the surface of the specimen. These are collected and converted into an electric signal. Because the number of secondary electrons ejected on each spot depends largely on the tilt angle, a grazing beam produces more secondary electrons and, hence, a greater signal than a beam at right angles. The detector is used to modulate the brightness of a display cathode ray (television) tube that has its line scan driven in synchronism with the probe beam in the microscope column. There is a one-to-one correspondence between the brightness of each point on the display tube and the number of secondary electrons emitted from any spot on the surface of the specimen. In this way, a map of a large number of single points (between 50,000 and 100,000) of different brightness is built up that yields a picture of the surface topography of the specimen with a large depth of focus.

The electron beam has to be operated in a vacuum because electrons cannot travel any appreciable distance in air. Therefore, the sample must not contain any substances that are not stable in a vacuum. Otherwise, the requirements for specimen preparation are minimal. Most SEMs have relatively large sample chambers, so that even bulky samples can be accommodated. It is desirable that the specimen be rendered electrically conducting. This is usually achieved by evaporating a thin (10–20 nm) layer of metal or elementary carbon onto the specimen in the vacuum.

Another important feature of the interaction of the electron beam with the sample is the excitation of X-rays characteristic of the chemical composition at the illuminated spot. Hence, it is possible to obtain information on the distribution of certain elements on the sample surface in addition to the topographical picture. However, such analyses can only be considered semiquantitative because of the variable self-absorption of the X-rays in the sample as a result of surface roughness. For quantitative analyses, the electron probe microanalyzer is used. [*See* Analytical Techniques.] The SEM has frequently been used to study the surface microtopography of archaeological materials, especially in investigating ceramic and metal technology and identifying pigments and lime plaster.

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