

## Glossary (revised 22 Feb 2010)

This glossary contains brief and relatively nontechnical definitions of words used in this book. The definitions focus on ancient metalworking, not modern industrial processes. For instance, beneficiation today can be carried out by drying, flotation, or magnetic separation. In antiquity, only roasting and hand-picking were used, so the definition mentions only those processes.

Greek letters:

$\alpha$ : alpha

$\beta$ : beta

$\gamma$ : gamma

$\delta$ : delta

**AAS** (atomic absorption spectroscopy): a quantitative spectrographic technique for elemental analysis. If an intense beam of light containing the characteristic wavelengths of a specific element, for example aluminum (Al), is directed through an excited gas sample which contains Al atoms, then the Al wavelengths in the beam can be absorbed by the gas and the reduction in intensity detected. This reduction in intensity for these characteristic wavelengths is proportional to the concentration of the specific unknown element being analyzed.

**Acicular**: needle-like.

**Adit**: a horizontal or nearly horizontal passage driven into a mine from the side of a hill in order to reach the ore or to drain water.

**Adorno**: a decorative addition applied to or hung from a bangle. It would not include decoration intrinsic to the bangle form, such as scalloping or slashes, but would include applied elements such as bosses or elements that are slid on, such as looped bells.

**Adzes/tillers**: implements with cutting edges usually on a splayed flat head with a blade transverse to and in alignment with the axis of the hafting element. All examples found at the four sites are socketed, with both winged and plain symmetrically splayed blades.

**Alloy**: a metallic substance that is composed of at least two separate metals, such as copper and tin. In this publication, each metallic constituent must make up at least 2% by weight of the substance. This 2% figure, while arbitrary, was picked in order to separate accidental metallic admixtures from deliberately produced alloys. Adding even a small percentage of another metal can significantly alter the properties of a metal; for example, adding arsenic or tin to copper lowers the melting point and greatly increases the hardenability of the metal.

Steel and cast iron (iron and carbon) are frequently described as alloys, but strictly speaking, this is not true, because carbon is not a metal.

**$\alpha$  +  $\delta$  eutectoid**: the hard two-phase ( $\alpha$  and  $\delta$ ) constituent of a tin bronze that appears between grains of  $\alpha$  bronze when cooled. Under equilibrium conditions, copper will dissolve up to

approximately 14% tin at room temperature before the eutectoid reaction occurs, but under non-equilibrium conditions  $\alpha + \delta$  eutectoid can appear in the microstructure in an alloy with as little as 5% tin. Also, see eutectoid.

**Alteration (of metal):** the corrosion or oxidation of metal.

**Amorphous:** as used in this volume, amorphous artifacts are irregular lumps of metal. Some may once have been part of an object, but most were probably casting splashes or debris resulting from metal smelting or melting; i.e., most amorphous were not deliberately shaped.

**Annealing:** heating a metal or alloy to homogenize or soften it for further shaping.

**Annealing twin:** When face-centered cubic metals or alloys are worked and annealed, often a plane in the atomic lattice in some of the crystals forms a mirror image of the undeformed lattice next to it. After etching, the crystal appears to have two parallel straight lines across the grain.

**Archaeometallurgy:** the study of metals found in archaeological contexts. The study is carried out in the field, through excavation of mines and metal-extraction and working sites, and also in the laboratory, where a variety of techniques are used to examine metal artifacts, ores, crucibles, slag, and the remains of furnaces and other processing debris.

**Arsenical copper (arsenical bronze):** Copper containing over 2% weight of arsenic.

**As-cast:** a microstructure of a cast artifact that has received no further treatment such as annealing or hammering.

**Austenite:** a face-centered cubic crystalline form of iron that exists at high temperatures. Austenite can dissolve more carbon than can body-centered cubic ferrite, the low-temperature crystalline form of iron. If an austenitic steel is quenched rapidly, the austenite may be transformed to a very hard martensite.

**Back-scattered electrons:** in scanning electron microscopy, images are generated by electrons that have been aimed at a sample and are reflected back because they encountered the nuclei of atoms. The number of backscattered particles is a function of the atomic number of the elements on the surface of the sample; the elements with the higher atomic numbers will backscatter more electrons.

**Bainite:** the phase produced when an austenitic steel is quenched and held at temperatures between 550°C and 250°C and then allowed to cool to room temperature. Bainite is an aggregate of ferrite and carbide. It appears feathery if formed at the higher end of the temperature range, somewhat acicular if formed at the lower end. The term is most often used to refer to the decomposition of martensite in steel when the quenched martensite is tempered at about 200-350 °C.

**Bangle:** curved lengths of variable cross-section with intact examples comprising a closed or nearly closed ring. The curvature and scale are such that the object could have fit around a human body part. Fragmentary examples are arcs of the original circles. This class includes bracelets, anklets, necklaces, and finger rings.

**Bells:** small round rattle-type bells (clapper is loose within a globe), often with a small loop for attachment and a slit in the body.

**Beneficiation:** the process of crushing ore with hammers and picking out and discarding the pieces of gangue. The ore could also be roasted to increase the friability of the ore, reduce the water content, and drive off sulfur. Also called ore dressing.

**$\beta$ -tin martensite:** a high-temperature phase in high-tin bronze that may transform into martensite when quenched.

**Bimetallic:** an artifact composed of two metals, such as a spear point with a bronze hilt cast onto an iron blade.

**Bivalve mold:** a two piece reusable casting mold. Pulling the two pieces apart allows the artifact to be removed easily.

**Blades:** implements whose primary working areas are cutting edges along a longitudinal side parallel to the axis of the hafting element, if present. Cutting edges can be either straight or curved. **Hafting elements** include sockets and tangs but some blades lacking these elements may have been hafted to wood or bamboo along the longitudinal side opposite the working edge.

**Blast furnace:** a shaft furnace fitted with an air blower and used to smelt metals; especially, a furnace that is hot enough to produce liquid cast iron.

**Block-twisting:** a method of making wire. A slender rod of square or rectangular cross section is twisted tightly around its long axis and then rolled between two flat plates. The distinguishing marks of this method are an even shaft diameter, a round cross section, a smooth surface, and two spiral grooves on the surface.

**Bloom:** the crude, solid, spongy mass of iron and slag produced in a bloomery furnace. To produce usable iron, the slag must be squeezed out of the bloom by many cycles of heating and forging.

**Bloomery furnace:** a smelting furnace whose end product is a solid bloom of iron and slag. The bloom contains varying but often low percentages of carbon.

**Body-centered cubic:** see *Crystalline solid*.

**Brass:** an alloy of copper and zinc. In antiquity the zinc content was never higher than 28%.

**Breccia:** “a coarse-grained elastic rock composed of angular broken rock fragments held together by a mineral cement or in a fine-grained matrix; it differs from conglomerate in that the fragments have sharp edges and unworn corners. Breccia may originate as a result of talus accumulation, explosive igneous processes, collapse of rock material, or faulting” (U.S. Bureau of Mines 1996).

**Bronze:** in antiquity, the alloy of copper and tin. In modern times a term used for other copper alloys as well.

**Bronze disease:** spongy, flaky bronze corrosion

**Carburization:** the process of heating iron in the presence of a carbon-containing material so that the carbon will be absorbed into the surface of the iron and, by diffusion, form a layer of steel with a concentration gradient of carbon.

**Cassiterite:**  $\text{SnO}_2$ , the most important ore of tin.

**Cast iron:** A mixture of iron and 2%-4% carbon, frequently accompanied by 1-3% silicon. Without further treatment it is very hard and brittle. It is relatively easy to cast because the large amount of carbon lowers the melting temperature considerably below the melting point of pure iron and steel.

**Castability:** the ability of a metal to be cast easily. Good castability means that the metal is fluid enough to fill well and take fine impressions in a mold. Adding lead to bronze greatly increases the castability of the alloy.

**Casting:** The process of pouring molten metal into a mold and allowing it to cool until solid; also, the object resulting from a casting operation.

**Casting debris or casting splashes:** The spillage, splashes, and other accidental remains of a casting operation.

**Casting flash:** the small ridge of metal left on a cast artifact where the two pieces of a bivalve mold met.

**Cementite:** a hard, brittle compound of iron and carbon called iron carbide ( $\text{Fe}_3\text{C}$ ) found in steel or cast iron. Pearlite is a eutectoid composed of ferrite and cementite.

**Cenotaph:** a burial with grave goods or markers but no body.

**Charcoal:** a light black substance that is the result of the incomplete combustion of wood. It was the preferred fuel in bloomery furnaces both because it burns hotter and cleaner than wood and because burning charcoal produces the carbon monoxide essential to the reduction of the ore.

*Cire perdue:* see *lost wax casting*.

**Co-smelting:** the accidental or deliberate smelting together of a mixture of oxide/carbonate copper ores and copper sulfide ores, resulting in the direct one-step production of copper. In Thailand evidence suggests this was frequently performed in a crucible.

**Coke:** the substance left after the incomplete combustion of coal. Used as fuel in blast furnaces.

**Cold working:** the plastic deformation of a metal at a temperature lower than its recrystallization temperature, usually at room temperature. In most metals and alloys, cold work, often by hammering, causes an increase in hardness and tensile strength and a decrease in ductility, because the deformation causes dislocations in the atomic planes to accumulate at the edges of the crystals.

**Contact metasomatism:** “A deposit formed by high-temperature magmatic emanations along an igneous contact. Contact metasomatism is a mass change in the composition of rocks in contact with an invading magma, from which fluid constituents are carried out to combine with some of the country-rock constituents to form a new suite of minerals” (U.S. Bureau of Mines 1996).

**Compositional analysis:** elemental analysis.

**Corrosion:** the deterioration of a metal as a result of chemical attack.

**Coring:** the segregation or separation of components of an alloy as it solidifies.

**Crucible:** the heat-resistant (refractory) ceramic vessel, either open or closed, in which metal is heated until molten in order to cast it. In Thailand as well as other parts of the world smelting was frequently carried out in crucibles rather than in furnaces.

**Crystalline solid:** a solid substance composed of atoms or molecules arranged in a pattern that is repeated in three dimensions. Metals are crystalline; face-centered cubic and body-centered cubic are two crystalline structures common among metals. Substances can change their crystal structure when heated or cooled, even if they remain solid.

**Decarburization:** the loss of carbon on the surface of iron or steel when the metal is exposed while hot to an oxygen-rich atmosphere.

**Dendrites:** the multi-branching treelike or fernlike microstructure of an as-cast alloy or impure metal, produced by the solidification or freezing of one of the constituent metals while the other, with a lower freezing temperature, is slower to solidify. For example, as a molten bronze alloy cools, the copper will solidify before the tin and the first part of the dendritic arms to become solid will be richer in copper. The outer portion of the arms, the last to cool, will be richer in tin. This phenomenon is called *coring*. Extremely slow cooling allows the constituent elements to diffuse evenly and eliminates the segregation that produces the dendrites, but under normal cooling conditions the dendrites freeze in place before homogenization can occur. Annealing after casting can partially or fully eliminate the dendrites and allow the metal or alloy to take on a structure of equiaxed grains.

**Detection limit:** the quantity of atoms below which a particular technique of elemental analysis will not detect the presence of an element.

**Diffusion:** the temperature-dependent spreading out of the segregated atoms or molecules of a particular constituent of a substance, resulting in the composition of the substance becoming uniform. An example is the diffusion of carbon into iron.

**Disseminated:** an ore deposit in which the metallic minerals occur as scattered particles in the rock, but in sufficient quantity to make the deposit worth exploiting. Some disseminated deposits are very large.

**Drawing:** the process of pulling a wire through successively smaller holes in a plate (die) of hard material, with the objective of making the wire smaller and smaller in diameter. This technique of wire production has not been documented thus far in prehistoric Southeast Asia.

**Dross:** the mineral layer that forms on the surface of a molten metal. It can result both from oxidation of the molten surface and from the rising of impurities to the surface.

**Ductility:** the ability of a metal or other substance to deform plastically without cracking or breaking. This property can be quantified by bend tests and other measures of elongation, reduction of area, and torsion.

**EDS:** see *energy-dispersive spectrometry*

**Elemental analysis:** see *compositional analysis*

**Energy-dispersive spectrometry (EDS):** a form of X-ray fluorescence that produces qualitative and quantitative elemental analyses quickly and nondestructively. The sample is bombarded with X-rays, and the secondary X-rays produced from the sample are separated by their energy levels and displayed in spectra. All elements are detected at the same time.

**Equiaxed grains or crystals:** hexagonal grains or crystals that have approximately the same dimensions in all directions.

**Etchants:** chemical or electrolytic reagents which, when applied to a polished metal sample, will reveal details of the microstructure, including grain shape, size, and orientation.

**Etching:** subjecting a polished metal sample to various chemicals in order to reveal its structure.

**Eutectoid:** A eutectoid structure is the result of the transformation, upon cooling, of one homogeneous solid phase into two completely different, intimately mixed, and finely dispersed solid phases.

**Fabric:** the matter of a fired ceramic, including the clay and inclusions. Also called paste.

**Face-centered cubic:** see Crystalline solid.

**Ferrite:** the low temperature, body-centered cubic form of nearly pure crystalline iron, with less than 0.02% carbon.

**Fines:** very finely crushed ore and host rock.

**Flux:** a material such as limestone or hematite added to a smelt or refining operation to remove impurities while lowering the melting point of the slag and making it more free-flowing.

**Forging:** to shape a piece of metal, especially iron, by heating and hammering.

**Furnace:** the structure, in antiquity often constructed of clay, in which metal is smelted from the ore.

**$\gamma$  (gamma):** a high-temperature phase that is retained when a high tin bronze is quenched at around 550°C.

**Gangue:** the portion of an ore that is non-metallic mineral and without value. The gangue is discarded during beneficiation and before smelting.

**Ghost dendrites:** the faint trace of dendritic structures seen microscopically in an incompletely annealed metal sample.

**Gossan:** An iron-bearing weathered product which caps a copper sulfide deposit. Through exposure to air and water, the sulfide ores are oxidized into oxide and carbonate ores and the sulfur and most metals leach out and are redeposited in deeper zones, leaving behind hydrated iron oxides. The hydrated iron oxides are most often a distinctive red or brown.

**Grain:** an individual crystal in a metal or alloy. Grains are visible because they have distinct boundaries and different orientations from one another. Grains may be twinned or deformed by working.

**Grog:** crushed or ground potsherds added to clay as a tempering material.

**Haft:** the handle of an implement.

**Hammerscale:** the thin layer of oxidized iron that forms on the surface of a piece of iron while it is being heated in a smithing hearth. The layer is knocked off every time the piece is hammered, so that the iron mass of the piece is lessened slightly with every cycle of heating and forging. Hammerscale is deposited around the hearth, providing archaeologists with an important marker of blacksmithing.

**Hammerstones or mauls:** stones used in antiquity to pound ore from mine walls and to crush ores during beneficiation. They have battered ends and in many parts of the world have distinctive hafting grooves or pecking.

**Host rock:** a body of rock containing other rocks or mineral deposits.

**Hot working:** the working of a metal or alloy when the metal is above the temperature of recrystallization. Unlike cold working, hot working does not cause hardening.

**ICP-ES:** see *inductively-coupled plasma emission spectroscopy*.

**Inclusions:** nonmetallic particles of slag or mineral in the body of a metal.

**Inductively-coupled plasma emission spectroscopy:** a method of elemental analysis. The sample is vaporized in a flame at 8000°C. This temperature is high enough to excite even the most refractory elements and allows the components to be measured at a lower concentration than with AAS. Twenty or more elements can be analyzed simultaneously.

**Ingot:** metal cast into standardized shapes for easy handling, transport, and processing.

**Intergranular corrosion:** corrosion that proceeds preferentially along grain boundaries.

**H<sub>v</sub>:** Vickers test hardness number.

**Lagging:** a layer of quartz rich silt that has been mixed with a binder and smeared on the inside of a crucible before use. This lagging layer enhances the refractory qualities of the crucible and permits re-use.

**Laterite:** a reddish-brown residual soil that develops in humid, subtropical, and tropical areas with good drainage. Lateritic soil is leached of silica by rainfall and contains concentrations of iron oxides and hydroxides, along with aluminum hydroxides. The concentrations of iron, aluminum, manganese, or nickel are sometimes high enough for the soil to serve as an ore of these metals.

**Lathe:** a machine for shaping a piece of wood or metal by means of a spindle that turns the piece against a variety of tools.

**Lead-isotope analysis:** Lead exists in four different isotopic forms, and different lead and lead-containing ore sources have different ratios of the four isotopes. Lead-isotope analysis attempts to connect the lead in a metal, glass, or glazed artifact to a particular ore source.

**Leaded antimonial copper:** a copper that contains over 2% by weight of both lead and antimony.

**Leaded bronze:** an alloy of copper, tin, and over 2% lead. The addition of lead improves the castability of the metal but decreases the hardness.

**Lost wax casting:** the process of casting using a wax model. The wax is shaped in the form of the final object and encased in clay. The clay is then heated, allowing the wax to melt and run out, leaving an empty space that is then filled with molten metal.

**Malleable:** not cracking when hammered.

**Marshall's reagent:** an etchant used to reveal the structure of iron and steel. The reagent is composed of a half and half mixture of  $\text{H}_2\text{O}_2$  (hydrogen peroxide) and a solution made up of 5 ml  $\text{H}_2\text{SO}_4$ , 8 g oxalic acid, and 100 ml water.

**Martensite:** A high-temperature phase that is retained when steel or a high-tin bronze is quenched above a certain temperature. It appears needle-like under the microscope. Martensitic steel is very hard and brittle; martensitic high tin bronze is more ductile than unquenched high-tin bronze.

**Matrix** (in a metal): the principal phase or medium in which another phase is dispersed. (In a ceramic): the main clay body of a pot or ceramic.

**Matte smelting:** a complex reduction and concentration process for smelting low-grade copper sulfide ores. The ores are roasted to drive off sulfur. The ore is then smelted in an oxidizing atmosphere along with a quartz flux to produce slag. The result is a matte, or solid mixture of copper sulfides and iron sulfides. This matte is broken up and roasted to convert the sulfides to oxides, and smelted again to produce an impure copper.



**Meteoritic iron:** iron that came to the Earth as part of meteorites, as opposed to terrestrial iron. In many places meteoritic iron was the first iron to be used. Meteoritic iron is almost always high in nickel.

**Midrib:** a raised central spine of metal that runs the length of a dagger, sword, or spear point.

**Munsell Color Charts:** a set of charts used to standardize color descriptions.

**Non-slagging:** a copper smelting process that produces little or no slag.

**Optical metallography:** the examination of mounted, ground, polished, and etched metal samples under a metallurgical microscope.

**Ore:** a naturally occurring deposit of metal-bearing minerals.

**Ore dressing,** see Beneficiation.

**Oxidation:** the process of bringing a material in contact with oxygen, usually oxygen in the air. Also, the process that produces a coating of tarnish or rust on a metal, as the metal combines with oxygen and returns to a lower-energy state.

**Pearlite:** a fine-layered, platelike (lamellar) mixture of ferrite and cementite occurring in steel and cast iron.

**Phase:** a homogeneous region of a material that differs in structure or composition from another region. Frequently a metal goes through changes in phase as it is heated or cooled.

**Phase diagram:** a diagram that presents the different phases that an alloy will undergo with changes in temperature and composition.

**PIXE:** Proton-induced X-ray Emission Spectroscopy, a method of compositional analysis.

**Planishing:** the act of finishing the production of a decorative metal artifact such as a bowl by hammering it all over with a light hammer. This hardens the metal and leaves small overlapping facets that reflect light when polished.

**Points:** small points, spear points, and other small and long straight points that have a tapered end coming to a point extending from and in alignment with the hafting element. The shape implies that they were used to pierce an object. The cross section of the point can be flattened or round. The hafting elements on complete examples are either sockets or tangs.

**Porphyry:** an igneous rock of any composition that contains conspicuous large mineral crystals in a fine-grained groundmass.

**Ppm:** parts per million

**Prill:** small droplets of metal found trapped in slag or crucible linings after use.

**Quenching:** plunging a red or white hot metal into cold water or oil to cool it quickly. This frequently has the effect of preserving at room temperature phase structures that would normally exist only at high temperatures. The most common examples of this are martensite in high-tin bronzes and steel.

**Recrystallization:** By heating a metal or alloy above a certain temperature, a new, strain-free crystal structure is formed after the grains of a metal have been distorted by cold working. The precise recrystallization temperature will vary with the composition and purity of the metal, the length of the heating process, and the amount of prior cold work.

**Redeposited copper:** copper that has been removed from a tin bronze during corrosion and redeposited in pure form inside already existing gas or shrinkage voids.

**Reducing atmosphere:** an atmosphere low in oxygen and high in carbon monoxide. A reducing atmosphere is necessary for smelting.

**Refractory:** ceramic materials that can tolerate high temperatures without melting, usually because they are high in silica and alumina.

**Rhyolites:** a group of extrusive porphyritic igneous rocks, usually appearing flowed.

**Scanning electron microscope (SEM):** SEM shoots a beam of electrons across the surface of a sample to produce an image of a compositionally heterogeneous or irregularly surfaced material. Energy-dispersive spectrometers or wavelength-dispersive spectrometers can be attached to produce qualitative or quantitative compositional analyses on particular phases or inclusions.

**Secondary electrons:** electrons near the surface of a sample that have been knocked out of their orbits by a primary beam of electrons.

**Segregation:** where one constituent of an alloy, usually the component with the lowest melting point, is concentrated in the center of the casting. In inverse segregation, the constituent with the lowest melting point is concentrated near and on the surface of the casting. Tin and arsenic are prone to inverse segregation.

**SEM:** see *scanning electron microscope*

**SEM/EDS:** a scanning electron microscope with an energy-dispersive spectrometer attached.

**Shrinkage voids:** voids in a cast metal object resulting from the shrinkage produced when a metal solidifies.

**Skarn:** rock made up primarily of lime-bearing silicates. It originates when nearby intrusives have injected large quantities of silica, aluminum, iron, and magnesium into nearly pure limestones or dolomites.

**Slag:** a dense, glassy, or rock-like waste material produced during a smelt. Slag is composed of ore minerals, metal oxides, and remains of fluxes and furnace linings.

**Slag stringers:** slag inclusions in an iron or steel that have been flattened by forging. While metal will recrystallize upon heating, slag and other minerals will not, hence they will always retain their worked, linear shape.

**Smelting:** the extraction of a metal or alloy from its ore in a furnace or crucible by means of a high temperature chemical reaction under reducing conditions.

**Smithing hearth bottom:** a plano-convex cake of vesicular slag that forms from the agglomeration of charcoal, hammerscale, and slag droplets at the bottom of a smithing hearth. Also known as a PCB or plano-convex bun.

**Socket:** a hollow cylinder attached to an axe, adze, blade, or point that is intended for the insertion of a shaft or handle, usually of wood.

**Solder:** an alloy with a low melting temperature used to join two metallic surfaces together.

**Spheroidization:** the process of holding steel at a high temperature for several hours, which produces a spherical form of carbide in steel. This process softens the metal.

**Spectroscopy:** a form of elemental analysis undertaken by a number of different methods, all of which measure the absorption or emission of radiant energy on the surface of a sample.

**Sprue hole:** the small funnel in a mold that allows molten metal to enter the mold.

**Sprue:** the cone-shaped plug of excess metal that fills the sprue hole after the metal has cooled.

**Steel:** a malleable mixture of iron and 0.1-1.9% carbon.

**Stockwork:** a mineral deposit consisting of a three-dimensional network of veins spaced closely enough so that the entire body can be mined.

**Strain lines** or **slip lines:** microscopic lines caused by the movement of one part of a metallic crystal lattice relative to another part. Produced by working or other form of stress.

**Subgrain:** an area of a grain or crystal that has an orientation slightly different from that of the surrounding areas.

**Swaging:** a method of making wire. A strip of metal is hammered between two hard blocks which have had a groove or hollow cut into them. As the hammering proceeds, the metal is forced into the shape of the groove.

**Tailings:** the gangue and other refuse material resulting from the beneficiation of ground ore.

**Tang:** the metal projection of a blade or point that extends into the handle.

**Temper** (in a ceramic): material such as grog, straw, sand, or chaff added to the clay in a ceramic to improve its properties.

**Tempering:** removing some of the hardness and brittleness from a quenched martensitic steel by heating it to between 450-650°C.

**Tuyère:** a nozzle of ceramic or metal inserted through a furnace wall through which air is forced from a bellows into the fire.

**Vesicular:** characterized by the presence of small cavities caused by gas bubbles.

**Vickers microhardness test:** one of several kinds of microhardness tests. The Vickers test involves pressing a diamond pyramid indenter into a metal for a fixed length of time and at a fixed pressure. The dimensions of the depression produced are then measured; the larger the depression, the softer the material. The various microhardness tests use different scales, so that a given number in the Vickers scale will not mean the same thing on a Rockwell scale.

**Vitrification:** the process of becoming glass-like. As a result of exposure to high temperatures, the particles within a ceramic or slag fuse and form a homogeneous body.

**Wavelength-dispersive spectrometry (WDS):** a form of X-ray fluorescence that uses crystals to cause secondary X-rays to be diffracted at a particular angle, the angle being characteristic of the element. This extra dispersion allows for greater separation of the X-ray peaks and thus greater sensitivity than found in energy dispersive spectroscopy, WDS, however, is slower than EDS and requires destruction of the sample.

**WDS:** see *wavelength-dispersive spectrometry*.

**Widmanstätten structure:** a structure in many metals, but most commonly discussed in relation to iron, which results when a single phase at a high temperature decomposes into two solid phases at a lower temperature. Frequently it appears as a pattern of regularly oriented plates or laths that have been precipitated out along the crystallographic planes of the original grains. They usually result from a relatively quick but unquenched cooling of the molten metal.

**Wires/rods:** a length of metal, more or less straight or slightly curved, of consistent width or slightly tapered, commonly with either a round or a square cross section. According to the typology used in this volume, wires range from 1–4 mm in thickness and rods are thicker than 4 mm. Context shows that some of the wires were parts of jewelry, but the function of the other examples, both wire and rods, is unclear. Some may have been parts of tools.

**Work hardening:** the hardening effect on many metals of being hammered at room temperature. Working at high temperatures (for iron, above 600°C) does not harden.

**Working:** shaping an artifact by hammering. In iron, working is called forging.

**Wrought iron:** low carbon iron heated and hammered from a bloom and containing small slag inclusions; this iron can be wrought or forged readily. Wrought metal of any kind is metal that has been shaped by hammering or forging rather than casting.

**X-ray fluorescence (XRF):** probably the most widely used form of compositional analysis in museums. X-ray fluorescence analyzes a surface by directing a beam of X-rays at the object.

After striking the sample, the X-rays are either scattered or absorbed, generating secondary X-rays with energies characteristic of all the elements that have been struck. These secondary X-rays hit a detector, which turns the rays into electrical pulses. The intensity of the pulses varies with the amount of the X-rays of each element, so the analysis can be quantitative.