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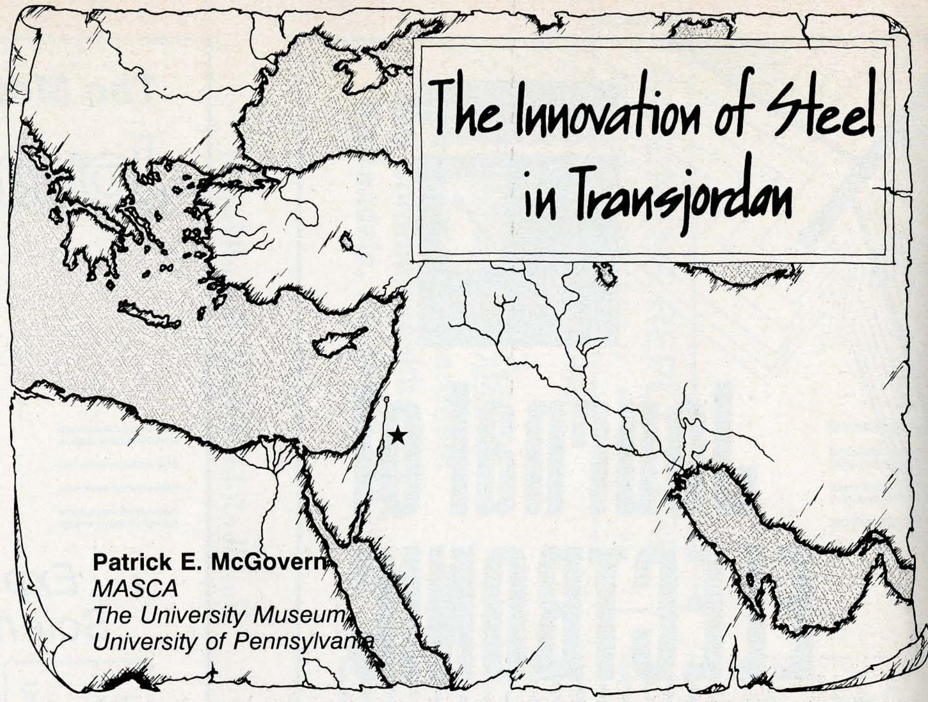
Over the last twenty years, there has been a discernable increase in the number of scholars who have focused their research on metal production, working and use in antiquity, a field of study which has come to be known as ARCHAEOMETALLURGY. *Materials scientists and conservators have worked primarily in the laboratory while archaeologists have conducted fieldwork geared to the study of metal technology in a cultural context with laboratory analysis as one portion of the interpretive program.*

The Innovation of Steel in Transjordan



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Editor's Note: This discussion is based on chapter 8 of the Baq`ah Valley monograph (Reference 2). For the initial study, see V.C. Pigott, P.E. McGovern and M.R. Notis, "The Earliest Steel from Transjordan," *MASCA Journal*, 2 (1982), pp. 35-39.

INTRODUCTION

In this modern "Age of Steel," we are apt to overlook the fact that steel was first made more than 3,000 years ago in areas bordering the eastern Mediterranean Sea. Dating to the transitional period between the Late Bronze Age and the Iron Age (ca. 1300-1100 B.C.), iron/steel artifacts, including jewelry, weapons and tools, have been excavated at sites in present-day Cyprus, Greece, Turkey, Syria, Egypt, Iran, Israel and Jordan.[1] Thus far, the largest discoveries have been made in Cyprus, Israel and Jordan. Because of the vagaries of archaeological reconnaissance and since many artifacts currently lie buried and unstudied in museum storerooms, the relative quantities of iron artifacts from various countries can easily change.

INNOVATION OR ACCIDENT?

Definitive evidence for solid-state carburization of steel would be the presence of a carbon gradient at or near the surface of an artifact (i.e., a pattern of carbon diffusion into the iron that would have proceeded from the exterior surface inward). The metallography of the Baq`ah artifacts, however, revealed no surface gradients of this type in the cross-sections studied, in part because the microstructure of the metal is so uniform and much of the surface region is oxidized. Thus, it is not possible to state definitely that surface carburization occurred. Apparent diffusion gradients, however, were observed in 10th century B.C. steel artifacts from Taanach, a site approximately 40 km (25 miles) northwest of the Baq`ah.[3]

An alternative possibility may be put forth that would account for the microstructures of the Baq`ah steel artifacts. In the microstructures, the carbon is either at or near the eutectoid composition, and regions of "primary" nodular cementite are indicative of local melting. Further, in another specimen, the cementite regions were too large to have originated from surface carburization. These features can be explained if the iron being reduced had reached a semi-molten (slushy) or locally melted state in the smelting furnace. Although the temperatures required to achieve this state, 1,400 to 1,475°C (2,552-2,687°F), are well above the normal range thought to have been routinely used in antiquity, they are not actually beyond the capacity of a bellows-blown furnace. Localized regions of the bloom or even the entire bloom itself could, therefore, have been made molten,[4] yielding appropriately high diffusion rates and high solubility of carbon (and nitrogen) in the liquid iron.[5]

In fact, smelting simulation experiments have been described by Pleiner[6] in which steel blooms were obtained featuring structures which ranged from mostly eutectoid to local regions of hypereutectoid composition, and with a cementite network. Regions protected from the direct oxidizing blast of the mouth of the tuyere (i.e., in a reducing environment), either because of furnace chamber design (about which little is known) or the protection afforded by a nontapped slag, tended to possess increased carbon contents sufficient to allow them to be characterized as true steel. Only regions of the bloom which were directed toward the mouth of the tuyere (an oxidizing environment) were ferritic or ferritic-pearlitic, effectively yielding a low-carbon wrought iron. The furnace temperatures for this experiment and others described by Pleiner ranged between 1,300 and 1,460°C (2,372-2,660°F), which accords with the temperatures hypothesized for the Baq`ah steel artifacts. Although the artifacts show no indication of having been subjected to any heat treatment, such as quenching or tempering, this metal would have had mechanical properties (e.g., strength) that would have made it equal, if not superior to the tin-bronzes found in the same burial cave.

However one interprets the metallographic evidence, the prevalence of steel during the period points to intentionality, if only at the empirical level. If so, the question may be raised as to whether the initial impetus for the innovation of steel at this time necessarily involved the mechanical properties of the metal. If one follows the traditional view that the Philistines, one of the "Sea Peoples," introduced ironworking into Palestine near the beginning of the Iron Age,[7] then it is a short step to proposing that iron/steel was of particular importance in conquering the native peoples and environment (i.e., as weapons in war and as axes and ploughs to clear forests and till the fields for agriculture).

METALLOGRAPHIC EVIDENCE

Iron artifacts from Jordan, particularly from the plateau region near Amman, are especially interesting and raise a host of questions about the origins of steelmaking technology. During an excavation which the author directed, a group of eleven complete jewelry pieces, along with forty odd fragments, were recovered and analyzed from a burial cave dating to the early Iron Age (ca. 1200-1050 B.C.). In the Baq`ah Valley (Figure 1), about 15-20 km (9-12 miles) northwest of Amman.[2] These artifacts more than tripled the number of iron artifacts from Jordan and Israel which have been cataloged in Waldbaum's compendium.[1] In the cave which measured only 5 × 7 m, 227 individuals of all ages and both sexes had been crammed, body upon body. The iron artifacts were confined to a select few who wore rings and one or a pair of anklets and/or bracelets (Figure 2).

Remarkably, some of these artifacts had only a thin surface layer of oxidation, making them ideal for detailed metallographic study and chemical analysis. Several of the artifacts with well-preserved cross-sections were subsequently shown to be composed of a mild steel (Figure 3), with the amount of carbon near or slightly less than the eutectoid composition (0.8%).

The over-all morphology of one anklet/bracelet (Figures 3-4) was typical of a cast or seriously overheated steel. The presence of "primary" nodular cementite attested to the probable local melting of small regions within the bloom during the smelting process. SEM analysis of the fayalite (Fe_2SiO_4) slag matrix of particles entrapped in the metal indicated that they contained a relatively high level of potassium, which would point to a charcoal-fueled process. A small volume fraction of wüstite (FeO) attested to the high efficiency and skill of the smelting process.

It appears that, during cooling from the austenitic region, the metal, which had a heterogeneous carbon content, underwent a Widmanstätten transformation under relatively great undercooling conditions [i.e., at about 200°C (392°F)]. The ferrite that formed, both as proeutectoid and within the pearlite structure (Figure 4), was therefore supersaturated with carbon. Following the Widmanstätten transformation, the "tertiary" carbide precipitation process intervened not only in the Widmanstätten ferrite but also in the ferrite portion of the pearlitic structure.

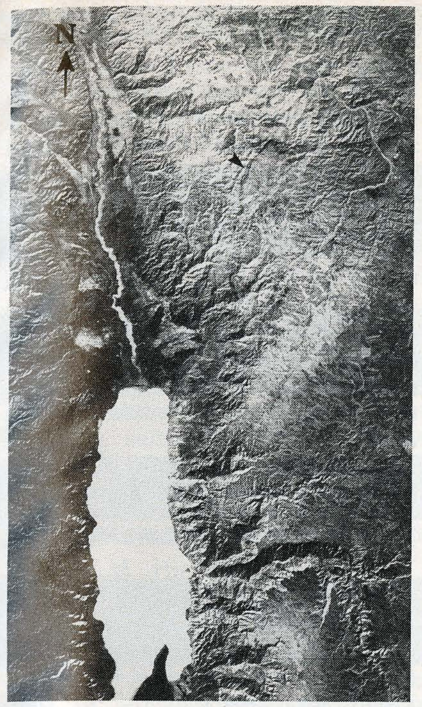

Figure 1. LANDSAT view (Photo No. 8114407430500, EROS Data-Center, Sioux Falls, South Dakota) of central and southern Transjordan from an altitude of 912 km (563 miles). The Baq`ah Valley stands out clearly as a flat, elliptical plain (marked with a black arrow) in the middle of the bend in the Wadi Zarqa, which meets the Jordan River at about 1,000 ft. (328 m) below sea level. The Dead Sea is visible at the lower left.

CULTURAL AND TECHNOLOGICAL CHANGE

There is no doubt that Transjordan underwent a major cultural transformation about this time, with the collapse of its city-state system and the emergence of a dispersed network of small villages with, as compared with the preceding Late Bronze Age, a much lower standard of living and fewer foreign contacts. But none of the iron/steel artifacts from the Baq`ah are weapons or tools—they are exclusively jewelry items. Their ornamental nature thus suggests that the hardness of the metal was less important to the smith than its aesthetic qualities: color, sheen or the jingling sound of a pair of anklets or bracelets worn together.

Where were the iron/steel artifacts made that have been excavated in central Transjordan? There is no compelling reason for arguing that the artifacts from the Baq`ah burial cave had to be imported. The pottery was locally made, and other artifacts, apart from marine shells, are of types common enough at other early Iron-Age sites on the plateau and elsewhere in Palestine.

It has been argued that the adoption of iron/steel technology in its early stages throughout the eastern Mediterranean area was encouraged by a reduced or inconsistent availability of copper and/or tin.[8] As a result of the socio-political upheavals that characterized the last two centuries of the second millennium B.C., trade routes would have been cut off, and craftsmen would have turned to alternative metal ores. The consistently high-tin bronzes of the artifacts in the Baq`ah burial cave (averaging 10.6% tin) contrast with the lower tin bronzes (averaging 7.8% tin) of the area's Late Bronze Period (ca. 1550 to 1200 B.C.) and suggest that the model does not apply to the Transjordanian plateau. Unless they had a means of enriching the tin contents of recycled older bronzes, the local metalsmiths must still have had a source of tin.

Another scenario may be proposed for the innovation of steel. In the wake of economic and social dislocations at the end of Late Bronze Age, the urban population apparently dispersed into hinterland areas where alternative subsistence strategies were required. Under these circumstances, iron ores may have been experimented with and a new technology of ironworking may have been developed, including the steeling of the metal.[cf.3] Although the initial impetus for this innovation may have come from the outside, the available archaeological evidence from the Baq`ah suggests that this was a native industry, established near the end of the Late Bronze Age.

LOCAL IRON ORE RESOURCES

Iron ore deposits of limonite and hematite exist nearby in the Wadi Zarqa and Ajlun areas.[9] Limited archaeological investigation in the Ajlun at the site of Mugharat el Wardeh by Coughenour[10] has thus far only uncov-

Figure 2. Baq`ah burial cave: anklet in-situ, next to a chalice and lamp.

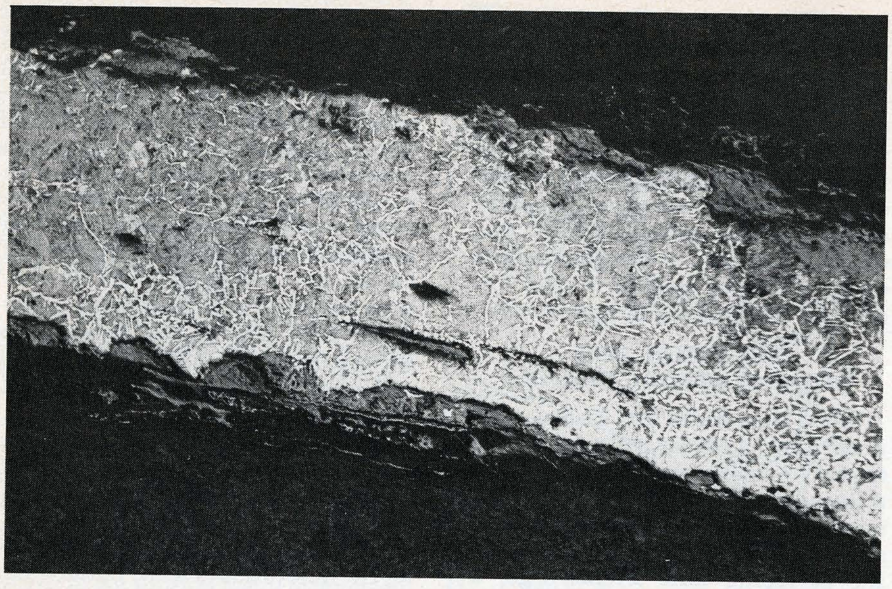

Figure 3. Cross-section of anklet/bracelet from Baq`ah burial cave, showing extensive inhomogeneous carburization with Widmanstätten patterning.

ered medieval Islamic smelting operations, but preliminary surveys at a site only 10 km (6 miles) north of the Baq`ah, Dhahrat Abu Thawab, have yielded early Iron-Age sherds. The chemical composition of one well-fused piece of slag from the latter site, as determined by proton-induced x-ray emission spectroscopy, is close to that of one of the Baq`ah iron/steel artifacts, particularly in its elevated cobalt content. This is even more noteworthy because a few red glass beads, found in association with the iron/steel artifacts in the Baq`ah burial cave, also show elevated cobalt. Since the glass has a very high iron-oxide content (48%), it is quite possibly a reworked slag, perhaps a spin-off product of the primary metals industry.[11]

Dhahrat Abu Thawab is in the midst of a fertile area at a higher elevation than the Baq`ah along the watershed, and probably received more rainfall in antiquity than it does today. In a period of climatic deterioration such as the late Late Bronze and early Iron Ages are projected to have been, it would have been a preferred direction of migration. The area also includes extensive tracts of oak foresting, which could have met building and, especially, fuel needs.

It may be suggested that native metalsmiths only began to exploit an ore deposit in the Abu Thawab area on a large scale when the Late Bronze culture began to disintegrate and decentralize. It is also possible that metalsmiths from farther south, who were associated with the copper industry in the Wadi Arabah, may have contributed to the development of the new technology (the prevalence of Red Sea molluscs in the Baq`ah burial cave is evidence of such contact).

SOME REMAINING CONSIDERATIONS

Until the Abu Thawab smelting site is excavated, we cannot be certain whether this was a source of the Baq`ah steel or was even in operation during the Late Bronze-early Iron Age transitional period. As a final note of Transjordan's crucial place in understanding the origins of iron ore smelting and metalworking in the ancient Near East, mention should be made of the recent discovery (1987) of another large group of iron artifacts from an early Iron-Age burial cave with over a hundred individuals, at Pella in the northern Jordan Valley.[12] The vast majority of the iron artifacts from the Pella tomb were anklets/bracelets and rings of the same types as those from the Baq`ah tomb.

The Pella discovery is intriguing in view of a single piece of steel from the same site, reported to be of Middle Bronze-Age date,[13] over 500 years earlier than the early Iron Age group. Unless the time gap can be explained, it is likely that the earlier Pella piece is a later intrusion.[12] From the burial cave evidence at Pella, a picture of early ironworking very similar to that in the Baq`ah is emerging (viz., limited amounts of iron are found toward the end of the Late Bronze Age and then much larger quantities during the early Iron Age). As yet, detailed metallographic study of the Late Bronze/early Iron Pella artifacts has not been carried out, but their contemporaneity and stylistic similarities with the Baq`ah artifacts strongly imply that they could also be made of steel.

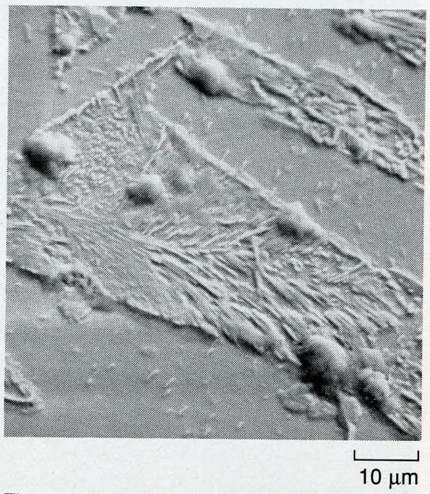

Figure 4. Scanning electron micrograph, nital etch, of anklet/bracelet used in Figure 3. Nodular carbides are visible at the interface between pearlite and ferrite regions.

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