The Origins of Ceramic Technology at Dolni Věstonice, Czechoslovakia

PAMELA B. VANDIVER, OLGA SOFFER, BOHUSLAV KLIMA, JIŘI SVOBODA

A typology was established for more than 5000 ceramic artifacts at Dolni Věstonice, Czechoslovakia. Conjectured methods of manufacture were confirmed by radiography. The compositions and mineralogy of the artifacts were identical to those of the local soil, loess. A firing temperature range of 500° to 800°C was measured and compared with those of hearths and kilns. The mechanism of sintering was impurity-initiated, liquid-phase sintering. Many fracture sections show evidence of thermal shock, although thermal expansion of the loess is low. The making, firing, and sometimes exploding of the figurines may have been the prime function of the ceramics at this site rather than being manufactured as permanent, portable objects.

ALTHOUGH THE ORIGINS OF CERAMIC TECHNOLOGY HAVE long been identified with ceramic figurines from Dolni Věstonice that have been dated at 26,000 years before present (B.P.) and some 14,000 years before the earliest pottery vessels, the technology of these ceramics has received sparse research attention. Production of utilitarian pottery dates from 12,500 years B.P. in Japan and later in Southwest Asia (8,400 years B.P.) and northern China (12,000 years B.P.) (*1*). Although about six Upper Paleolithic examples of hand-modeled and possibly fire-hardened earth or clay have been reported across Eurasia, at Mas d'Azil and La Bouiche in the Pyrenées, at Kostienki in the U.S.S.R., at Maina in the Yenisei basin of Siberia, and at Zazaragi in Japan (*2*), the Moravian sites of Dolni Věstonice I and II, Pavlov I and II, Předmosti, and Petřkovice in Czechoslovakia (Fig. 1a) have yielded the largest ceramic inventories, more than 10,000 fragments (*3*). The remains of two walled structures used as kilns were also preserved at Dolni Věstonice I. This ceramic assemblage provides the most abundant evidence for an Upper Paleolithic fire-using technology, one that produced ceramics without developing pottery.

Although often treated as individual sites, Dolni Věstonice I, Pavlov, and Předmosti are actually site clusters (Fig. 1b). All six of the Moravian sites contained exclusively Paleolithic cultural layers, and, with the possible exception of Předmosti, all had single cultural layers at the base of the youngest Pleistocene loess, from 3 to 5 m below the present-day surface. The lithic and bone inventories of these sites are assigned to the Pavlov culture, a local variant of the wider spread Eastern Gravettian technocomplex, and stratigraphic and radiocarbon data indicate that all these sites were occupied between 28,000 and 24,000 years B.P. Dates from the other Eurasian sites of Kostienki, Maina, Zazaragi, and Mas d'Azil are millennia later, 22,000, 15,000, 18,000, and 14,000 years B.P., respectively.

Only a few ceramics were found at Předmosti, excavated largely at the turn of the century, and at Petřkovice; most ceramic fragments were excavated at Dolni Věstonice and Pavlov, both open-air sites located in the Moravian lowlands about 35 km south of Brno and about 300 m from each other on the lower slopes of the Pavlov Hills, a rocky outcrop of Jurassic limestone that rises about 500 m above the surrounding plain at the confluence of the Dyje and Svratka rivers (Fig. 1c). Dolni Věstonice occupation was concentrated at two site clusters. The first, Dolni Věstonice I, contained as many as five diachronically occupied sites and was excavated by Absolon and Klima continuously from 1924 to 1979. Dolni Věstonice II was uncovered by commercial quarrying in 1985, and salvage excavation was undertaken through 1987. Pavlov was excavated during the hiatus by Klima, and Milovice, about 3 km south of Dolni Věstonice, is currently being excavated by the Antropos Institute, Moravske Museum.

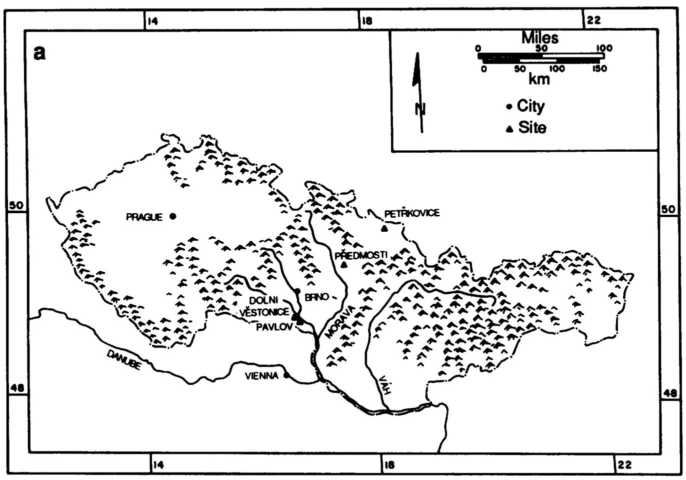
The Ceramic Inventory

The ceramic inventory (Fig. 2) amounts to more than 10,000 fired fragments: more than 6,750 from Dolni Věstonice I (Table 1), about 3,500 from Pavlov, and fewer than ten pieces from Předmosti and Petřkovice. The ceramics from Dolni Věstonice I include primarily two classes of objects: (i) over 3,700 broken fragments of figurines (Fig. 2, b and c) with one worked or smoothed surface of compound curvature and (ii) over 2,000 small (4 to 10 mm) gray pellets of irregular shape, most of which are almost whole and quite hard; human figurines (Fig. 2a), flattened slablike objects, and nearly spherical balls are rare (Table 1). About 90% of the fragments at Dolni Věstonice I are gray to black in color and matte in texture, indicating firing at low temperatures in a reducing atmosphere. The remainder are yellow, red, or brown, unlike the orangish-yellow soil common at the site. Most have a splotchy layer of black siliceous ash on their surfaces, even most of those that did not come from a hearth or kiln context, which probably means that a pristine surface was not required.

On the basis of a wet chemical analysis of the well-known Dolni Věstonice Venus (Fig. 2a) made by M. F. Kelauner in the 1920s,

P. B. Vandiver is senior research scientist in ceramics at the Conservation Analytical Laboratory, Smithsonian Institution, Washington, DC 20560. O. Soffer is professor of archeology at the University of Illinois, Urbana, IL 60801. B. Klima and J. Svoboda are researchers at the Archeologicky Ustav, Brno, Czechoslovakia.

Absolon proposed that the figurine was made of mammoth fat and bone mixed with bone ash and local loess and that Upper Paleolithic technologies included ceramics. The qualitative analysis interpreted as indicating the presence of carbonized bone or ivory consisted of identification of CO_3, SiO_2, PO_4, Ca, Fe, and Mg. No alumina or potassia was found; thus clay initially was excluded as a raw material. Our microscopic examination of the fracture in the hip of the Venus, from which Kelauner's sample was taken, failed to show bone or other organic inclusions, and no such inclusions were found in other fragments. We were unable, by using the techniques of x-ray diffraction, radiography, amino acid determination, and liquid chromatography, to detect the presence of bone or other organic remains. Only trace (0.01 to 0.1%) amounts of fatty acids and ammonia were present in the surface layer and interior of the Věstonice samples, the same as found in loess taken from occupation levels at the site. Because both ammonia and fatty acids are breakdown products of surface plant remains, their presence shows that the porous ceramic samples are in equilibrium with the surrounding soil; however, no bone or organic material is present in the Dolni Věstonice figurines.



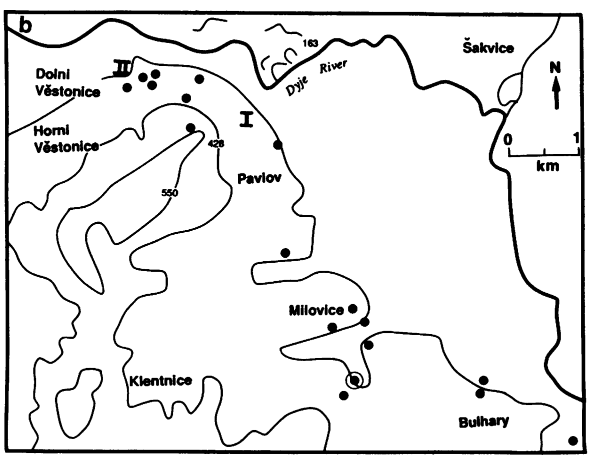


Fig. 1. (**a**) Map of Czechoslovakia showing Dolni Věstonice and Pavlov, which are located in the Moravian basin south of Brno. Předmosti and Petřkovice are located to the northeast of Brno. (**b**) Relief map showing Upper Paleolithic sites along the northeast side of the Pavlov Hills. Dark lines are waterways. (**c**) The Pavlov Hills are a prominent feature in the Moravian basin. The aeolian loess deposits are primarily on the northeast slopes next to the Dyje River, as shown in this view to the southeast. They provide an excellent confluence of resources to support human occupation.

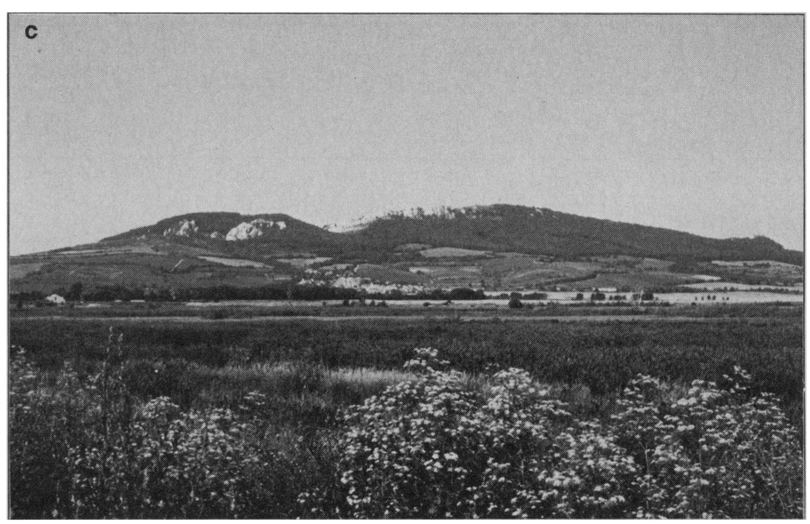
Table 1. Typology of Dolni Věstonice I ceramics.

Type	Nearly whole	Broken	Total
Figurines			
Animal	77	630	707
Human	1	13	14
Fragments, probably from figurines because of compound curvature of unbroken surface		>3000	>3000
Slablike objects, 6 to 8 cm in maximum length	20		20
Nearly spherical balls 1 to 2 cm in diameter	20		20
Small pellets with irregular surfaces, less than 1 cm in diameter	>2000		>2000
Total			>5761

Loess, the Raw Material

In 1954, Klima, on the basis of a quantitative chemical analysis by V. Šiške that demonstrated the presence of alumina, stated that the figurines of animals were made of fired clay, sometimes using the term "terracotta," meaning "fired earth" (Table 2, column 2). We expanded this single analysis to 20 samples and established local loess as the raw material by using three lines of evidence: similarity of composition, microstructural characteristics, and phase identification. X-ray diffraction of three loess samples and ten figurine fragments showed that quartz, muscovite, biotite, and minor illite, chlorite, dolomite, and anorthite, occurred in similar proportions in the two sets of samples, with the exception of calcite, of which there was more in the loess samples. Apatite, indicative of bone, was sought but not found.

We determined the bulk chemical composition by electron beam microprobe analysis of 20 samples, using two techniques: (i) energy-dispersive analyses of 0.5-mm^2 areas of polished sections and comparison with geological standards with the use of χ^2 corrections and (ii) wavelength-dispersive analysis of 200-mg samples ground and fused to glass in a carbon arc and corrected with a ZAF program (Z, atomic number; A, absorption; F, fluorescence). The compositions range from 60 to 75% (by weight) SiO_2, 10 to 21% Al_2O_3, 1.3 to 4.1% CaO, 1.6 to 2.7% MgO, 0 to 2.7% TiO_2, 0 to 0.8% P_2O_5, 4.5 to 7.4% FeO, 1.0 to 3.3 Na_2O, and 1.2 to 3.2 K_2O (Table 2). The P_2O_5 content (mean, 0.6%) is high for clayey soils



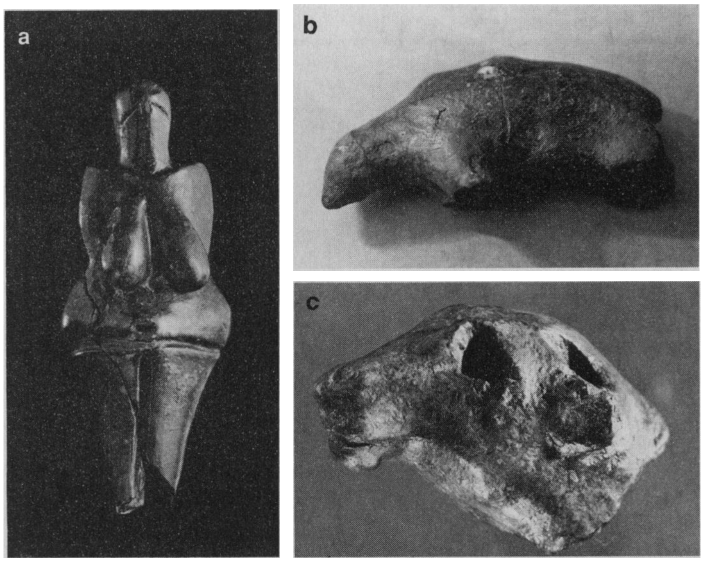


Fig. 2. (**a**) Fragmentary Dolni Věstonice Venus figurine (height, 11.2 cm), collection of the Moravske Museum. [Photo courtesy of Ira Block] (**b**) Bear figurine; prefabricated legs were attached to the previously joined head and body (length, 7.6 cm). (**c**) Lioness figurine head from Dolni Věstonice I (length, 4.5 cm). [Photo courtesy of Alexander Marshack]

but is consistent in both the ancient fragments and loess. This high P_2O_5 content may have led Kelauner to conclude that bone was present. The loess has the same ratio of alumina to silica and iron to alkalies as the ancient fragments. The CaO and MgO values are about twice those of the ancient samples, which is consistent with observations at the site of weathering of limestone outcrops.

The same bimodal distribution of particle sizes is present in both the ancient figurines and loess (Fig. 3, a and b). Quartz, mica, and other gritty particles measure about 5 to 150 μm in maximum diameter (mean, ~50 μm), and the smaller platey particles of illite, mica, and chlorite range from 0.5 to 5.0 μm in maximum diameter (mean, 2 to 3 μm). Point counting yielded volume fractions of 80% (by volume) coarse and 20% platey fine particles. Thus, the Dolni Věstonice "clay" body is made of local, coarse-particled loess with only minor clay present.

Methods and Sequence of Fabrication

Microscopic analysis indicates that the porosity of the loess (50 to 60% by volume) is about twice that of the figurine fragments (20 to 40%). This difference is important in understanding the process of forming the figurines, because loess could not have been selected in bulk form and carved to shape; rather the figurines were formed plastically with wetted loess, which allowed the particles to cohere. Test firing of wetted loess resulted in a hard, durable ceramic, whereas firing unwetted loess resulted in a friable, nondurable mass.

Further evidence of hand modeling, such as finger impressions and scraping marks, have been adduced to describe the methods of manufacture; however, earlier descriptions did not specify whether a primarily additive or a primarily subtractive process was used to form the figurines. Radiography and low power microscopy indicate that kneaded, semiplastic masses of loess were modeled into the bodies and that legs, feet, tails, heads, and ears were shaped separately as prefabricated parts and then joined to the body. Considerable variability in the amount of kneading and water content is shown by the presence of irregularly shaped pores; some of the bodies were only partially wetted and have triangular-shaped pores. Surfaces were scarcely reworked once parts were pushed together; evidence of smoothing, wiping, or scraping on convex surfaces is rare. However, microscopy of surface impressions and details of eyes, ears, and concave surfaces showed that in order to incise or impress such details, these surfaces were well worked with fingernails, pointed tools, and microliths. The teeth marks of bladelets are present in short strokes 5 to 10 mm in length in many indentations. There is no evidence of burnishing or pigmented decoration.

Sintering Mechanism and Range of Firing Temperature

Differential thermal analysis (DTA) aided by x-ray diffraction, scanning electron microscopy (SEM), and simple hardness and durability tests were used to confirm that the Dolni Věstonice ceramics had been fired and to determine the range of temperatures used in firing. The hardness of 30 figurine fragments ranged from 4 to 5 on the Mohs scale with three outliers at 3, the same range as

Table 2. Compositions (mean and range) of Dolni Věstonice I figurine fragments compared with those of loess excavated from the basal level at Dolni Věstonice II; 50 analyses of each of these samples were conducted. The results of Šiške's 1954 wet chemical analysis of the Venus figurine are also given; results of two analyses are listed. LOI, loss on ignition; EDS, energy-dispersive spectroscopy.

Component	Šiške's analysis of figurine		Modern loess	Soft gray ceramic, sample 2	Black ceramic, sample 3	Gray ceramic, sample 4	Gray ceramic, sample 5
	Reported values (normalized values)						
SiO_2	61.75 (68.04)	62.35 (71.44)	61.1 (56.7–69.2)	64.4 (62.5–66.2)	67.6 (65.8–70.5)	68.0 (62.5–76.9)	66.3 (60.8–70.0)
Al_2O_3	13.73 (15.13)	13.48 (15.44)	18.0 (15.6–19.7)	17.8 (16.9–18.7)	17.0 (15.7–18.2)	16.1 (10.9–18.5)	17.5 (15.4–21.0)
CaO	6.33 (6.97)	5.57 (6.38)	7.4 (4.8–9.5)	2.2 (1.9–2.6)	2.2 (1.3–2.7)	2.2 (1.6–2.5)	3.4 (2.7–4.1)
MgO	5.57 (6.14)	2.54 (2.91)	3.3 (2.3–4.0)	2.6 (2.0–3.0)	2.3 (2.1–2.7)	2.1 (1.6–2.5)	2.1 (1.3–2.6)
TiO_2			0.5 (0–0.9)	1.5 (0.5–2.7)	0.9 (0.6–1.1)	0.8 (0.4–1.1)	0.9 (0.7–1.2)
P_2O_5			0.7 (0.4–1.1)	0.5 (0.4–0.7)	0.4 (0.0–0.6)	0.6 (0.3–0.8)	0.4 (0.0–0.7)
FeO	3.38 (3.72)	3.34 (3.83)	3.8 (2.9–4.8)	6.0 (4.9–6.7)	5.4 (4.5–6.0)	5.6 (4.0–7.4)	5.1 (4.4–5.7)
Na_2O			2.8 (2.6–3.1)	2.3 (1.4–3.3)	1.7 (1.3–2.2)	2.4 (1.9–2.6)	2.1 (1.0–3.1)
K_2O			2.4 (1.6–3.1)	2.7 (2.4–2.9)	2.6 (2.1–3.2)	2.1 (1.2–3.1)	2.3 (1.8–2.9)
LOI	10.27	10.24					
Total	101.03 (100.0)	90.76 (100.0)	100.0	100.0	100.1	99.9	100.1
Trace Impurity (%)			Sulfur (less than 1%, found by EDS scan)		None 30	Sulfur 30–40	Sulfur 30–40
Porosity (%)			50–60	25–40			

earthenware ceramics. Millimeter-sized pieces from ten fragments were set in boiling water for 6 hours, then soaked for 18 hours. All survived intact, as is typical of stable and durable ceramics.

Replica figurine fragments made of loess excavated from the basal level of Dolni Věstonice II were fired in increments of 100°C from 400° to 1000°C, and two figurine samples were refired in 100°C increments to serve as standards in the determination of the range of firing temperature. Each sample was examined at each increment for evidence of microstructural changes that correlated with increasing temperature, such as glass formation at contact points between particles and rounding of the edges of clay and other fine particles. These changes occurred between 700° and 800°C in both the replicas and the refired figurines, although a small amount of a glassy phase was formed at and above 500°C (changes in hardness were observed) (Fig. 4).

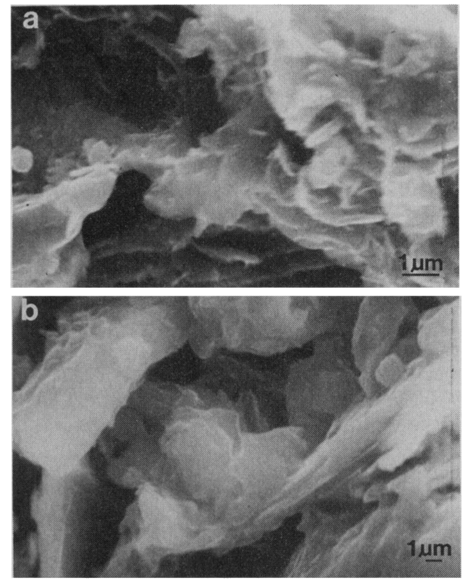


Fig. 4. Fracture section of Dolni Věstonice I sample 4 fired to (**a**) 700°C and (**b**) 800°C; secondary SEM micrographs show the changes that occurred during firing.

Each fired sample of loess and figurine fragment was heated in a DTA apparatus from 50° to 1100°C at 10° per minute and compared with pure mineral standards of the phases identified as present in the figurines by x-ray diffraction. Decomposition endotherms occurred in the clay and mica dehydroxylation range. X-ray diffraction of the loess and Věstonice sample standards were made below and above the endotherm to identify that these species decomposed. The temperature of the α to β inversion in quartz was used to monitor instrument drift, although a range in this inversion temperature of 2.5°C, due to solid substitution effects, has been reported in 250 quartz samples (*4*). Results showed that as the firing temperature increased, the decomposition endotherms of illite and mica shift to lower temperatures and the peak heights and areas decrease (Fig. 5, a and b). Prior heating had initiated partial dehydroxylation of the clay and fine mica constituents. The firing temperatures of other figurine fragments were compared with these standards: one was in the range from 700° to 800°C, three to about 700°C, and six to between 500° and 600°C (Fig. 5c).

The phase diagram for SiO_2, K_2O, Al_2O_3, where the compositions lie, shows that the first liquid should form at 695°C (Fig. 6). One can lower the fusion temperature of a glass by using mixtures of alkalies such as are found in the figurine fragments from Dolni Věstonice II. The presence of 0.6% (by weight) P_2O_5, 1.5% Na_2O, 3% K_2O, 5% FeO, 2% CaO, and 2% MgO produces such a mixed alkali effect. Firing these fluxes in the proportions shown in a loess crucible at 500°C for 45 min produced a durable, sintered mass. When each flux was fired separately under the same conditions in a fusion button test, only the P_2O_5 and calcium sesquiphosphate produced nonfriable, hard masses. The loess was soaked and washed to remove the soluble salts and phosphates for 1 week, and after firing at 500°C the loess did not sinter but remained a friable, powdery mass. Adding 0.5% P_2O_5 to the salt-free, washed loess and firing at 500°C for 45 min resulted in a nonfriable, sintered ceramic. We suggest therefore that phosphate in the loess soil acted as a flux that initiated the glass-forming reactions in the Dolni Věstonice ceramics, and, even though phosphate glasses are not durable, the other fluxes joined the melt to form a durable, glassy bonding phase. Further evidence is found in microprobe analyses of glassy contact points in Věstonice fragments, which contained more P_2O_5, K_2O, FeO, and CaO by a factor of 2 or 3; however, mixed in with this glassy phase are fine particles of illite, chlorite, and mica, from which a minor amount of potassium may have diffused into the glass. Thus, impurity-initiated, liquid-phase sintering is the mechanism of forming durable ceramics that was used at Dolni Věstonice.

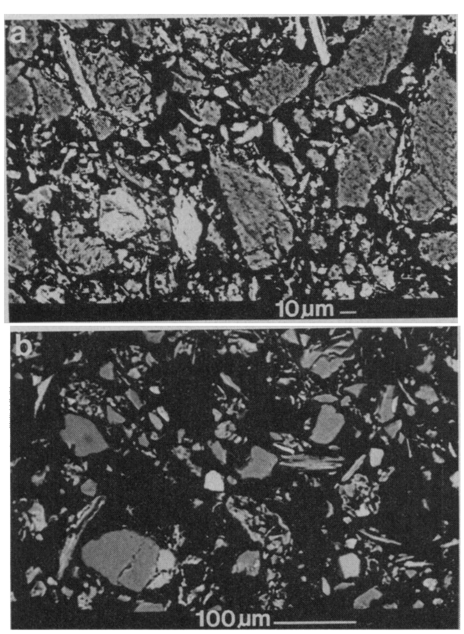


Fig. 3. (**a**) Backscattered SEM micrographs of polished sections of Dolni Věstonice I sample 4 showing quartz (gray), mica (white), and porosity (black) (×430); (**b**) backscattered SEM micrograph of fired loess from Dolni Věstonice I, showing greater porosity (×180).

Hearths and Kilns

Two structures, identified as kilns on the basis of the abundance of ceramics present, were excavated at Dolni Věstonice I (Fig. 7). One, containing over 2300 ceramic fragments, was found inside a circular hut some 80 m upslope from the dwelling area and consisted of an oval depression, measuring 130 cm by 40 cm and 40 cm deep, domed on the northeastern to northwestern sides. A second kiln, excavated in 1979 some 40 m west of the first one, measured about 1 m in outside diameter and 60 cm deep. Around nearly three-quarters of its perimeter was a horseshoe-shaped loess wall, and figurine fragments were found inside the basal ash lens. Microexcavation and testing of the friable samples from this structure, which had been recovered "in block," showed that the red interior layer had been fired to above 700°C, the gray interior wall had been fired to about 600°C, and a sample from the tan base had been fired to about 500°C (Fig. 5d), that is, in the same range as the figurine fragments.

During the summer of 1987 a modern kiln was constructed of loess by the excavation crew working at Milovice, about 3 km south of Dolni Věstonice; this modern kiln was fired only once. The pottery and figurines were fired to about 650° to 1000°C, but the wall of the kiln was fired to only about 500°C as determined by DTA. Comparison with the evidence from the ancient kiln suggests that the ancient kiln was fired several times or for a longer period of time.

It is difficult to distinguish a hearth from a kiln when the structure is not well developed as at Dolni Věstonice. A kiln must meet three requirements to reach the temperatures required for ceramic production: (i) control of draft, the path of air and combustion gases through the kiln, to optimize spread of heat away from the fuel source; (ii) support for the ware; and (iii) a surrounding refractory structure to insulate the ware and allow even heating and control of the draft (*5*). Although the structures designated kilns meet these requirements, the hearths at Dolni Věstonice have very little or no surviving structure and appear as lenses of friable red, brown, gray, and black earth in the tan loess soil. Sometimes these lenses are superimposed or staggered in section, indicating multiple use as opposed to a single use or period of use indicated by one lens. We microexcavated six hearths at Dolni Věstonice II in 1987; none contained figurine fragments. Hearths D, I (DV87 II/3) and II (DV87 V/9), were fired highest, to about 700° to 800°C in the red and yellow layers and hearth IV (DV 86) somewhat less (Fig. 5d). Hearths III (DV87 X/10) and V (DV87 IV/16) were fired to about 600°C. Thus the range of firing temperature does not distinguish hearths from kilns. The orange and red samples tended to have the highest firing temperatures, about 700° to 800°C, whereas the gray and black ones tended to have lower firing temperatures of about 500° to 600°C.

An alternate means of determining firing temperature was found in hearth D, a multilayer lens, radiocarbon-dated to 26,390 ± 270 years (ISGS 1744) and found next to hominid DV XVI (*6*). The fire-cracked limestone blocks on the hearth were coated on one face with a white millimeter layer of lime plaster consisting of micrometer-sized rounded particles of calcium carbonate. Such plasters were naturally produced as surface layers on the fired limestone blocks and required exposure to temperatures of 820° to 840°C (*7*). Such coatings may well have served as models for the later development of man-made lime plasters.

Fractography and Thermal Shock

Out of more than 10,000 Moravian ceramic fragments, only some small pellets and one figurine, a wolverine from Předmosti measuring 3.4 mm long, are unbroken. Of 887 fragments from the domed kiln area of Dolni Věstonice I, 461 (52%) were observed to have rough, branching, and stepped surfaces when studied with optical light microscopy, and 426 (48%) fragments have smooth, nonbranching fractures. In the mid-slope dwelling area (site M), 169 (89%) fragments have smooth, nonbranching fractures and 21 (11%) have rough, stepped fractures. These rough, branching fractures are not the result of local heterogeneities in composition or particle size. Many internal cracks in the rough fracture surfaces end at right angles to the surfaces, and many have opened such that the parts no longer fit together, indicative of drying or firing cracks.

Potential causes of such fracture surfaces and cracks are weathering, trampling, or mechanical breakage and thermal shock. The drying shrinkage of a body with such large particles is very low and was measured as less than 2%. Mechanical fracture of ancient fragments and replicas by percussion and pressure flaking produced mostly smooth fracture surfaces with intergranular fractures. In a simulated weathering experiment, in which we used a rapid freeze-thaw cycle for 360 days on samples fired to 500° and 750°C, intergranular, smooth fracture surfaces were produced on the fragments. The major result of weathering on the samples fired to lower temperatures was the development of a fine network of intergranular cracks, and eventually the density of particle packing

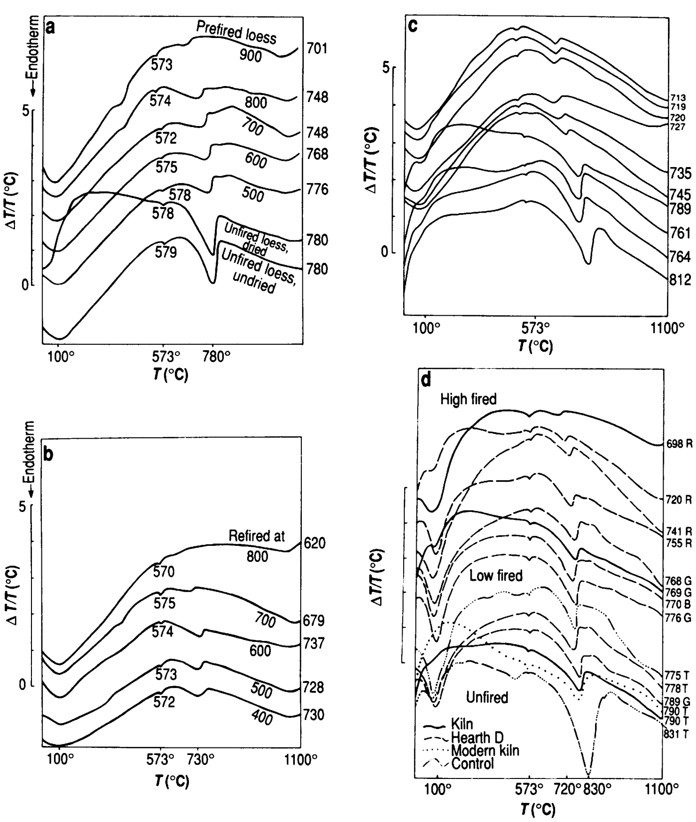


Fig. 5. DTA curves for (**a**) loess standard, (**b**) refired figurine fragment standard (note the decrease in peak size when the original firing temperature has been exceeded at 700°C), (**c**) Dolni Věstonice I figurine fragments, and (**d**) kilns, hearths, and control samples; T_{min} of the endotherm (in degrees Celsius) is given to the right; R, red; G, gray; B, black; T, tan.

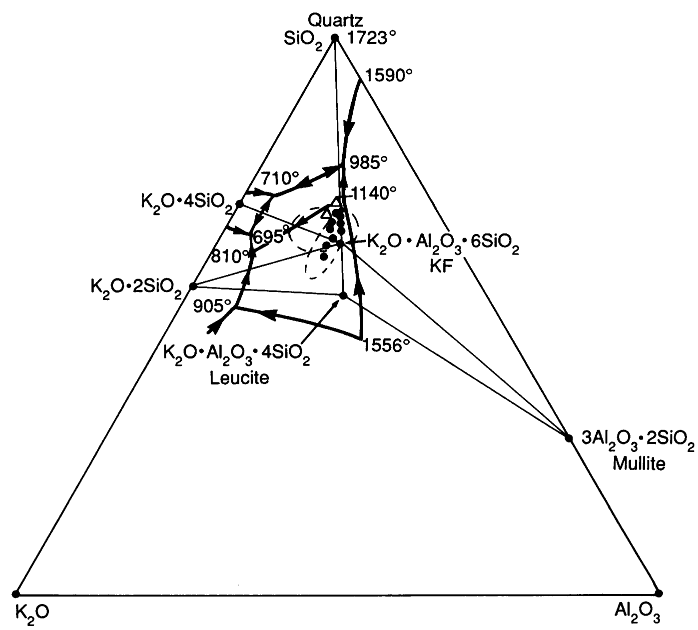


Fig. 6. Ternary plot of Dolni Věstonice I compositions given as mean and range (dotted line) in the SiO_2-Al_2O_3-K_2O equilibrium phase diagram; KF, potassium feldspar.

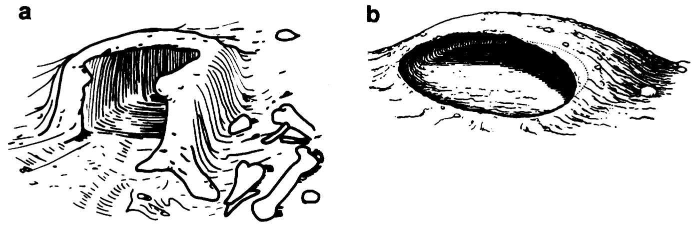


Fig. 7. Kilns from Dolni Věstonice I: (**a**) horseshoe-shaped kiln found in a hut upslope (excavated 1951–1952); (**b**) domed and banked kiln with 2300 ceramic fragments (1979).

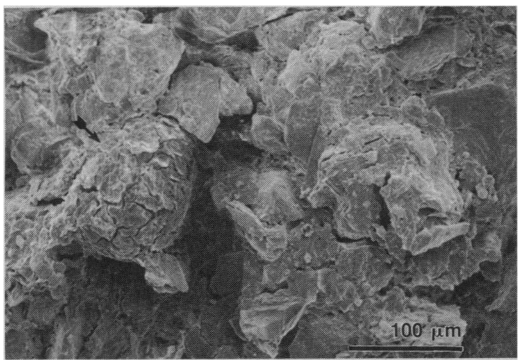


Fig. 8. Fracture section of Dolni Věstonice I sample 6 showing thermally shocked particles (arrow) and transgranular, stepped, and branching fracture surface (secondary SEM, ×450).

was reduced, such that a porous microstructure similar to that of unfired loess was found. Samples fired to 750°C were durable. Trampling produced some stepped fractures, but these rounded with continued trampling, and this rounding was accompanied by the production of a residue of crushed powder from the ceramic. The rough, stepped, and branching fractures observed in the ancient ceramics probably could not have been caused by mechanical fracture, drying, trampling, or weathering.

We suggest that the rough, branching, and stepped fractures, especially those in which the loess pulled away from the crack, were caused by high-energy fracture processes that occurred during brittle fracture by thermal shock during firing. The first criterion of thermal shock is the presence of stepped and branching fractures, which are simulated only by thermal shock as studied with light microscopy. The second criterion of thermal shock is the presence of occasional thermally shocked rock fragments (Fig. 8). Inasmuch as weathering and mechanical fracture commonly occurred, it is surprising that any of the Dolni Věstonice fragments have retained evidence of thermal shock. The numbers presented must be considered, therefore, minimum numbers of artifacts.

Intentionality

Such properties of the Dolni Věstonice loess as the near-zero drying and firing shrinkage, low thermal expansion, and relatively high porosity make thermal shock an improbable event during firing. Successful replication of thermal shock required firing of pieces larger than 1 cm that were so wet they would barely hold their shape and rapid placement in the hottest part of the fire. Thermal shock did not occur accidentally but required intentional effort and practice. We found, for instance, that slabs, 15 by 5 by 1 cm, that were formed and then placed without any drying time directly into a bonfire and a 700°C kiln exhibited no cracking and no thermal shock spalling, a test repeated 20 times for each condition. If the object was too wet, it would deform in gross shape, sometimes flattening, and the resulting microstructure would contain large pockets where steam had concentrated, a microstructure unlike that of any of the ancient fragments we tested. Internal water transforms to steam in Dolni Věstonice ceramics without the possibility of easy internal entrapment in pores, whereas clay-based ceramics, which are dry, will blow up if they are heated rapidly through 100°C.

We measured success in replicating thermal shock by the production of high-energy, branching fractures; however, the other measure of success, and the one most immediately sensed as the figurines were put in the fire, was the evolution of steam, often with a sizzle. Then the figurine would shatter with a pop, sometimes sending pieces flying through the air. In view of the physical properties of the loess that constrain its behavior and these experimental observations, we believe that intentional effort was required to produce the thermally shocked microstructures found in Dolni Věstonice ceramics.

Ceramic Technology as Behavior

Because most of the Dolni Věstonice figurines were broken, this loss rate means either that their makers were "awfully bad potters" by modern standards or that they may not have been trying to produce durable images in clay. The difficulty of mastering a new technology is certainly one possible explanation of such a high loss rate. However, the low expansion, high porosity, and other properties of loess and our replications showed that the raw material was particularly resistant to thermal shock. It is also possible that we have found just kiln wasters, production rejects that were left near or in hearths and kilns while unbroken ceramic objects were taken elsewhere. However, were this the case, a larger collection of unbroken objects should have been found at other Pavlovian sites. We must entertain the possibility that these workers were not trying to produce durable ceramic images and that the earliest use of ceramics may have been for their special and unique fire-related properties rather than for a function based on their visual appearances. If both water content and drying were controlled or if pieces were occasionally placed in a cooler part of the fire, then only designated samples would have blown up, and the whole process could have served some sociorituai, perhaps divinational, purpose. The practice of thermal shock may account for the existence of walls observed in the kilns; these walls may have served to protect the people from flying fragments and to control the thermal shock process. We suggest that the pellets placed in a kiln would have steamed and sizzled but, because of their small size, would not have blown up, whereas the figurines either would or would not have broken depending on the control exercised by the performer of the firing.

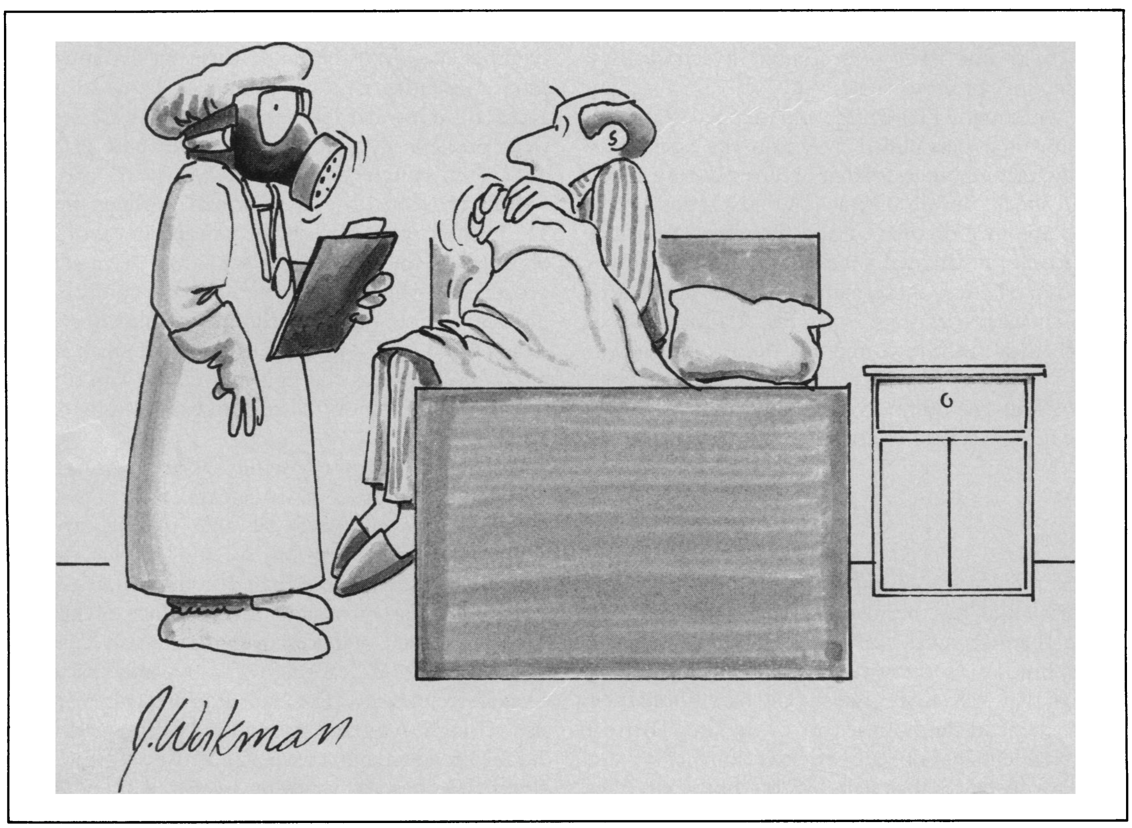
Did their makers purposefully fabricate the figurines as permanent portable goods or as active agents in an activity of performance? Although we will never be able to unequivocally demonstrate intentionality and function, we suggest that the sheer size of the ceramic inventory, more than 10,000 artifacts, their presence at so many Moravian sites, and the existence of kilns argues that the relevant cultural practices over time involved repetition and both transmission and learning of a specific, patterned behavior of ceramic technology. The high fracture rate encountered, however, also strongly suggests that what was important was not the final durable product but rather the process of making and firing the objects. Because it was this relatively brief production and use process that may have been of prime importance, we also suspect that its behavioral context may not have been a utilitarian one. The differential distribution of thermally shocked figurative artifacts from the unshocked pellets and the predominance of both in just some kilns and ash lenses, located a considerable distance upslope from the settlement area, suggests that activities involving figurines were carried out by only a small number of people. The separation of the locus of this behavior, away from yet near the settlement, may imply the special and nonutilitarian nature of this behavior as well as the control of this behavior by just some individuals in the community.

The special composition of the Dolni Věstonice ceramics, which are particularly durable, may imply that ceramic technology was actually more widespread than shown in the archeological record. Figurines made in other areas may not have been preserved because of problems of durability in objects fired at low temperatures with an unstable glassy bonding composition. The potential finds of Moravian figurines that have weathered to their original condition as soil would increase the uncertainty of the conclusions but would not alter them. With respect to the DTA measurement of firing temperatures, weathering of the artifacts would mean that a lower firing temperature was measured than had originally been used. However, higher ranges of firing temperature would not alter the conclusions presented. The results of this study show that control of materials technology was as crucially important in the Upper Paleolithic period as it is today. This ceramic production remains a precocious Upper Paleolithic soft stone technology, which, because of the social context of this technology, could not have led to pottery production.

REFERENCES AND NOTES

1. T. Akazawa, in *Hunters in Transition*, M. Zvelebil, Ed. (Cambridge Univ. Press, Cambridge, 1986), p. 151; F. Ikawa-Smith, *Am. Sci.* **68** (no. 2), 134 (1978); K.-C. Chang, *The Archaeology of Ancient China* (Yale Univ. Press, New Haven, CT, 1986), p. 107; P. B. Vandiver, *Paleorient* **13** (no. 2), 9 (1987); *Archeomaterials* **2** (no. 2), 139 (1988).
2. P. G. Bahn, *Antropos (Athens)* **5**, 98 (1978); A. Leroi-Gourhan *et al.*, *L'Art des Cavernes* (Ministere de la Culture, Paris, 1984); A. D. Stolyar, *Proishozhdeniie Izograzitel'nogo Iskusstva* (Iskisstvo, Moscow, 1985), pp. 211–226; R. S. Vasil'evskii and N. M. Ermolova, in *Paleolit Sibiri*, R. S. Vasil'evskii, Ed. (Nauka, Novosibirsk, U.S.S.R., 1983), p. 65; Z. A. Abramova *et al.*, in *Arkheologischeskie Otkrytia 1973 goda*, B. A. Rybakov, Ed. (Nauka, Moscow, 1974), pp. 38–40; Colloquium for Lithic Cultures, *Excavation Report of Zazaragi Site 1* (Tohoku, Sendai, Japan, 1978).
3. K. Absolon, *Rev. Anthropol.* **37** (nos. 1–3), 75 (1927); *C. Palaeoethnol.* **5** (no. 7), 1 (1938); *ibid.* 7 (no. 15), 1 (1942–44, 1945); ——— and B. Klima, *Fontes Archaeol. Moravicae* **8**, 1 (1977); B. Klima, *Antiquity* **28** (no. 109), 4 (1954); *ibid.* **30** (no. 118), 98 (1956); *ibid.* **32** (no. 126), 8 (1958); *Archaeol. Rozhledy* 11 (no. 1), 3 (1959); *Dolni Věstonice, Monumenta Archaeologica 11* (Ceskoslovenske Akademia, Praha, CSSR, 1963); in *Courses Toward Urban Life*, R. J. Braidwood and G. R. Willey, Eds. (Wenner-Gren Foundation, New York, 1962), p. 193; *Pamatky Archeol.* **64**, 1 (1973); *ibid.* **55**, 229 (1973); *ibid.* **65**, 229 (1974); *Acta Sci. Natur. (Brno)* **10** (no. 4), 51 (1976).
4. W. W. Wendlandt, *Thermal Analysis* (Wiley, New York, 1986), p. 373; M. L. Keith and O. F. Tuttle, *Am. J. Sci.* (part II of the Bowen volume), **252**, 203 (1952).
5. F. H. Norton, *Elements of Ceramics* (Addison-Wesley, Reading, MA, 1952), p. 136.
6. J. Svoboda, *J. Hum. Evol.* **16** (nos. 7/8), 827 (1987).
7. W. D. Kingery *et al.*, *J. Field Archeol.* **15** (no. 2), 219 (1988).

8. We thank L. Seitl and M. Oliva of the Antropos Institute, Moravske Muzeum, Brno, in addition to Y.-M. Chiang, M. Goodway, E. V. Sayre, D. Stanford, N. Tuross, D. von Endt, E. Jarosewich, D. Lange, H. Wesley, S. Johannessen, B. Godwin, W. Williams, R. Edging, and M. Conkey. Funding was provided by the Fulbright Scholar Research Award, the Smithsonian Institution, the National Geographic Society, and the Center for Advanced Studies of the University of Illinois.



"I realize you're only here for a check up, sir. It's just hospital policy."