Prehistoric Domestication of Animals: Effects on Bone Structure

Abstract. *Analytical techniques more usually applied in mineralogy have revealed consistent structural differences between the bones of wild and domestic animals from archeological deposits.*

For many years some zoologists and archeologists have suggested that there is a qualitative difference between the bones of wild and domestic animals. These suggestions have been regarded with scorn by many other archeologists and zoologists, probably because the differences tended to be described in highly subjective terms (*1*). Such words as "heavy," "greasy," "porous," and so forth are difficult to translate into objective comparative criteria, and most efforts to do so bogged down into a sort of tacit agreement that wild and domestic animal bones had a different "feel." Not unnaturally, there was widespread suspicion that all this was not really scientific.

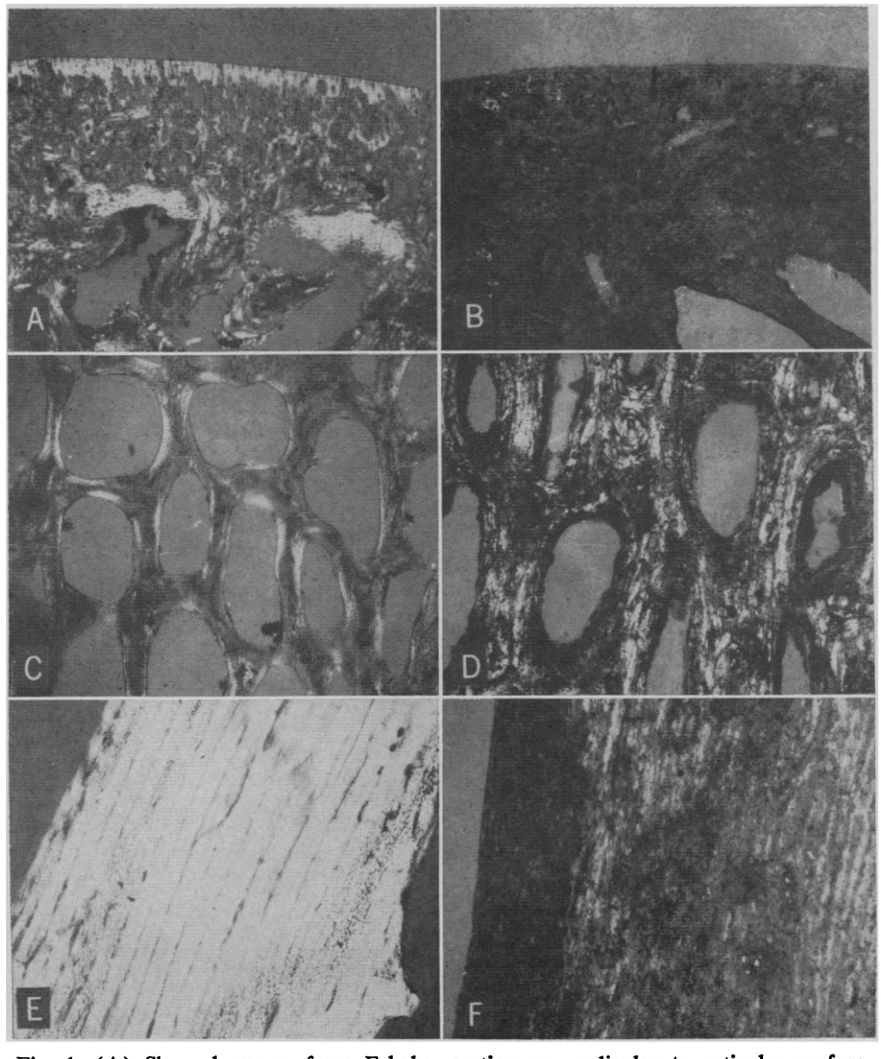

Fig. 1. (A) Sheep humerus from Erbaba, section perpendicular to articular surface. The rim of oriented crystallites is characteristic of all bones of mature animals from this site. (B) Sheep humerus from Suberde, section perpendicular to articular surface. No rim was observed in bones from mature animals; some immature animals exhibited a poorly defined rim. (C) Sheep astragulus from Erbaba, internal structure. The lacunae are large and tend to be rectangular. The trabeculae of bones from Erbaba averaged 0.1 to 0.2 mm in thickness. Strong yellow interference colors are associated with the thinner walls. (D) Sheep astragulus from Suberde, internal structure. The lacunae are typical of bones from Suberde; the trabeculae averaged 0.2 to 0.4 mm in thickness. The thinner walls show blue interference colors. (E) Shaft of sheep metapodial from Erbaba showing characteristic striations of alternating blue and yellow interference colors parallel to the length of the shaft. (F) Shaft of sheep metapodial from Suberde. Striations are not so strongly marked and the interference colors are the magenta-red of the background and blue (× 32).

However, there are some important structural differences between the bones of domestic animals and those of their wild counterparts, and these differences may be demonstrated objectively with the help of techniques rarely utilized in archeology. Examination of the bones in standard petrographic thin-section and x-ray diffractometer studies indicate that there are well-defined characteristics that distinguish specimens of wild animal bone from those of domestic animals. Clearly this is of vital importance in determining the cultural status of food animal remains, particularly in the Near East, where wild ancestral forms and domestic animals of the same species could have coexisted. Prior to this study, when the gross morphological changes common in the later stages of domestication are absent, it has been easier to identify an entire population of animals' remains as either wild or domestic than to determine the cultural status of either a single specimen or a small number of specimens.

In attempting to determine and describe differences between wild and domestic animal bones, we would have preferred to compare samples from known wild and domestic animals of the same species, from the same site. No such collection was available, but we did have material from two sites on the Anatolian Plateau in Turkey, excavated by J. Bordaz (University of Montreal). The two sites, Erbaba and Suberde (*2*), are about 50 km apart, and have been dated by carbon-14 to 5780 and 6570 B.C., respectively. Their settings are very similar at present, and analysis of the soils indicates that the mineralogical character of both sites is so similar that observed differences in specimens from the two collections are unlikely to be the result of the postmortem environment (*3*). These sites both contained substantially the same important food animals, with the crucial difference that the species exhibited quite different cultural status. On the basis of our initial analysis, we are certain that the animals eaten at Suberde were wild, whereas the animals eaten at Erbaba were domestic. Suberde and Erbaba were identified as hunting and husbanding groups, respectively, on the basis of (i) the age-grade composition of the food animals' population, (ii) the character of the pattern of the re-

mains, indicating where, in relation to the settlement, the animals were killed, and (iii) the average size of the individuals of each species.

Seventeen specimens of bone from Suberde and 19 from Erbaba were selected for detailed study, representing three genera (*Bos, Ovis,* and *Capra*), and three bones from each (distal metapodial and distal humerus of mature animals, distal epiphysis of immature metapodial and immature humerus, and astragalus). The specimens were sectioned perpendicular to the distal articular surface of the metapodia and humeri, more or less bisecting their shafts. The metapodia were sectioned in a transverse plane, the humeri parallel to the sagittal plane. The astragali were sectioned in a vertical transverse plane. Standard petrographic thin sections were prepared from each specimen (*4*), and portions of the remainder were reserved for x-ray diffractometer and emission spectrographic analysis. In addition we also examined, with the same techniques, single specimens of *Ovis* and *Capra* from Zawi Chemi Shanidar, a site in northern Iraq. This site is of particular interest to this study, since the earliest reported domestic sheep (indeed, the earliest known domestic animals) were found there. The diagnosis of domestication was based on a statistical analysis similar to that used at Suberde and Erbaba, since the sheep were morphologically identical to the wild form (*5*). The site is quite different geologically (*3*) and ecologically from the Anatolian sites, which enabled us to test our hypothesis that differences between wild and domestic animals are functional and not a product of the postmortem environment. There had been some infiltration by calcite and iron oxides from the ground water, but no replacement of the integral structure of the bone in any specimen we examined.

The calcium phosphate content of bone is essentially a cryptocrystalline hydroxyapatite (*6*). We thought that useful information might be obtained by treating the bones as if they were fine-grained rocks. Examination of the thin sections between crossed polarizers with a standard gypsum plate inserted in the light path enabled us to find three consistent ways in which the bones of the domestic animals from Erbaba differed from those of the wild animals from Suberde (Fig. 1).

The gypsum plate in the light path produces a magenta-red interference color. Random orientation of the submicroscopic crystallites of the bone mineral does not alter this basic color; however when the prismatic apatite crystals are aligned with their *c* optic axis (the vertical axis of the hexagonal prism) parallel to the slow ray of the gypsum plate, the background red is changed to blue. When the *c* axis is perpendicular to the slow ray, the red is changed to yellow. Thus, the interference colors produced are precise indicators of the orientation of the apatite crystals in the bone structure. The bones from Suberde, which are from wild animals, produced little color change, which indicated that the crystallites are randomly oriented throughout most of the bone, although there is indication that the apatite prisms in certain layers tend to be oriented parallel to the long axis of the long bone shafts (Fig. 1). The bones from Erbaba, on the other hand, showed strong blue interference colors on all articular surfaces, which indicated that in these areas the crystals are almost all aligned with their long axes perpendicular to the areas of bone-to-bone contact. In the long bone shafts of the Erbaba specimens, there were alternating bands of yellow and blue; unlike the Suberde specimens, the apatite prisms here appear to be aligned in more or less concentric layers in which the apatite prisms are arranged radially as well as parallel to the long axis of the bone shaft. The *Capra* metapodial bone from Zawi Chemi Shanidar was similar to the Suberde specimens, whereas the *Ovis* metapodial and astragalus appeared to be identical with the Erbaba specimens, showing strong alignment of prisms at the articular surfaces.

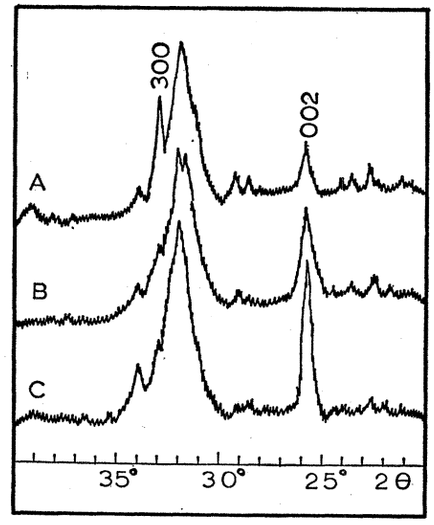

Fig. 2. The x-ray diffractometer patterns of bone samples. The mineral constituent is hydroxyapatite. (A) In unoriented powder samples, the 002 reflection from the basal planes (normal to the *c* crystallographic axis) is about two-thirds as intense as the 300 reflection from the prism faces ($I_{002}/I_{300} = 0.66$ to 0.72 for all bones from both Suberde and Erbaba). Articulation surfaces of wild animal bones give similar x-ray diffractometer patterns ($I_{002}/I_{300} = 0.7$ to 0.8). (B) Articulation surface of humerus from domesticated sheep. The intensity of the 002 reflection is nearly double that of the 300 reflection ($I_{002}/I_{300} = 1.6$ to 1.9), which indicates preferred alignment of hydroxyapatite prisms at right angles to the articulation surface. Sections cut at right angles to the length of the shafts of domestic animal bones give similar diffractometer patterns ($I_{002}/I_{300} = 1.4$ to 1.7). (C) The 002 reflection is three times as intense as the 300 reflection ($I_{002}/I_{300} = 2.8$ to 3.3) in sections cut perpendicular to the length of the shaft of bones from wild animals. In these bones the intensity ratio is not reduced by layers of crystallites oriented radially. As would be expected from the optical evidence, sections cut parallel to the length of the shafts showed a greater proportion of prism faces in the bones of the domestic animals ($I_{002}/I_{300} = 0.35$ to 0.41) as compared with those of wild animals ($I_{002}/I_{300} = 0.53$ to 0.57).

The x-ray diffractometer studies confirmed the microscopic observations. Samples of powdered bone from both sites were compared with slices of bone taken from the articular surfaces and long-bone shafts (Fig. 2). The powder samples were essentially identical for all species from both Erbaba and Suberde, which indicated that there are no important mineralogical differences between wild and domestic bone. The slices (*7*), in which the bone structure was preserved, showed definite structural differences in the orientation of their component crystals. Changes in the x-ray diffractometer patterns of the articular surfaces of the bones from Erbaba, and in the bone shafts from both sites confirm that the hydroxyapatite crystallites have a much greater tendency to become aligned in bone from domestic animals.

A third basis for differentiating wild from domestic bone is revealed by their internal structure. When magnified between five and ten times the pattern of the structure of wild and domestic bones is quite evident. There is no overlap in the average size of the lacunae in the two groups, nor in the average thickness of the trabeculae (Fig. 1, C and D). The lacunae in bones of wild animals are rounded, whereas those in the bones of domestic animals are more

rectangular. The transition between compacta and spongiosa is sharply marked in the domestic animals; wild specimens show less abrupt transition.

At present, we feel that we must limit ourselves to describing the differences we have observed, since we do not feel that sufficient research has been done to suggest that the underlying causes can be more than tentatively explained. However, it seems obvious that this approach is of value to the study of prehistory. Our results suggest that there are fundamental differences in the microstructure of bone of wild and domestic animals and that these differences are evident at the earliest stages of animal husbandry.

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References and Notes

1. See, for example, C. A. Reed, in *Studies in Ancient Oriental Civilization No. 31*, R. J. Braidwood and B. Howell, Eds. (Univ. of Chicago Press, Chicago, 1960), p. 124.
2. J. Bordaz, *Turk Arkeol. Derqisi*, in press.
3. The soils from Suberde and Erbaba consist of calcite, quartz, kaolinite, and montmorillonite, in approximate order of decreasing abundance. Soil from Erbaba is somewhat higher in calcite and lower in clay minerals than soil from Suberde. Both soils test alkaline, with a *p*H of about 8. Soil from Zawi Chemi Shanidar contains quartz, illite-montmorillonite interlayered clay and magnesian calcite; the *p*H is about 7. Analyses by emission spectroscopy of bones from the three sites, without attempting to remove the nonintegral mineral concretions observed microscopically, yielded the following averages: copper, 0.0001 percent for Erbaba and Suberde, 0.02 percent for Zawi Chemi Shanidar; iron, 0.08 and 0.06 percent, respectively, for Erbaba and Suberde, in excess of 0.5 percent for Zawi Chemi Shanidar; magnesium, 0.1 and 0.05 percent, respectively, for Erbaba and Suberde, in excess of 1 percent for Zawi Chemi Shanidar; manganese, 0.02 and 0.01 percent for Erbaba and Suberde, 0.5 percent for Zawi Chemi Shanidar; sodium, 0.1 percent for both Erbaba and Suberde, 0.05 percent for Zawi Chemi Shanidar; silicon, 0.2 and 0.3 percent for Erbaba and Suberde, in excess of 1 percent for Zawi Chemi Shanidar. [These elements are among those listed as biologically important in *Trace Mineral Studies with Isotopes in Domestic Animals* (International Atomic Energy Agency, Vienna, 1969), p. 147.]
4. The slices of friable bone were first impregnated with plastic under vacuum. M. Rev, who made all the thin sections for this study, reported that the bones from Suberde, in contrast to those from Erbaba, were particularly resistant to penetration of the plastic.
5. For a description of the site see R. L. Solecki, *Rep. IV Int. Quatenary Congr. Warsaw 1961* **5**, 405 (1964). For a description of the fauna, see D. Perkins, Jr., *Science* **144**, 3626 (1964).
6. The most important references are collected in W. Deer, R. Howie, J. Zussman, *Rock Forming Minerals*, vol. 5, *Non-Silicates* (Wiley, New York, 1962), pp. 323–338.
7. H. Klug and L. Alexander, *X-Ray Diffraction Procedures* (Wiley, New York, 1954), pp. 194–195.
8. We thank R. S. Solecki (Columbia University) for initiating these investigations and for continued interest. Partially supported by the Sackler Fund, and by NSF grant GS 2828. J. Curtis and M. Friedman assisted with the spectrographic analyses. B. C. Hesse assisted with the initial study of the fauna of Suberde and Erbaba.

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Potassium-Uranium Systematics of Apollo 11 and Apollo 12 Samples: Implications for Lunar Material History

Abstract. *Apollo 11 and Apollo 12 lunar rock suites differ in their potassium-uranium abundance systematics. This difference indicates that relatively little exchange of regolith material has occurred between Mare Tranquillitatis and Oceanus Procellarum. The two suites appear to have been derived from materials of identical potassium and uranium content. It appears unlikely that bulk lunar material has the ratio of potassium to uranium found in chondrites. However, systematic differences in the potassium-uranium ratio between Apollo samples and crustal rocks of the earth do not preclude a common potassium-uranium ratio for bulk earth and lunar material.*

Extensive studies (*1, 2*) have shown that the K/U ratios of most igneous rocks on the earth are within 50 percent of 1.0×10^4, despite the fact that differentiation has produced rocks with a range of K and U concentrations that covers 3½ orders of magnitude (*3*). The Apollo 11 samples exhibit K/U ratios that are systematically lower than those of earth rocks (*4*) and, on the average, the K/U ratios obtained for Apollo 12 samples are lower than those for the Apollo 11 samples (*5*).

In Fig. 1 we have plotted K content versus U content for earth rocks (*1, 2, 6, 7*), and for *all* the Apollo 11 and Apollo 12 moon samples as reported by the Lunar Sample Preliminary Examination Teams (*4, 5*). For comparison, we have also plotted averages of values reported by several investigators for chondrites and achondrites [see (*3*)] and for tektites (*8*).

Within each Apollo suite, the samples appear to be members of a single family defining their own trend line, which represents the correlation between their K and U contents. The two suites exhibit different K-U correlation trends, although membership of individual samples in one suite or the other cannot be established by their K or U contents alone. Potassium and uranium enrichment in the Apollo samples must be regarded as the result of magmatic differentiation. Many lunar samples are as high in U as average earth basalt, and at least 50 times as high as chondrites (normally regarded as possessing approximately primordial solar-system relative abundances of nonvolatile elements). We conclude that rock suites from the Mare Tranquillitatis (Apollo 11) and Oceanus Procellarum (Apollo 12) sites represent two distinct populations with respect to their igneous derivation.

The fact that breccias and fines appear to be members of the corresponding K-U trend lines defined by local igneous rocks is in agreement with other evidence (*9*) for local derivation of the regolith. "Bracketing" of these fragmental materials (in Fig. 1) by igneous members of each suite may be fortuitous, however, in view of the small number of samples and the subjective factors involved in sample selection. We conclude that the K-U systematics of Apollo samples argues against moonwide transport and exchange of regolith materials subsequent to the formation of Oceanus Procellarum.

The two trend lines in the Apollo data appear to diverge from a common cluster of points on Fig. 1, which suggests that the two suites represent two separate differentiation sequences originating from materials of identical K and U content. According to material balance requirements, if the two suites exhibit different enrichment trends, complimentary portions of the suites must exist which exhibit different depletion trends. This might cause the two trend lines to appear to cross at a point corresponding to the U and K contents of the starting material. But within the severe limitations of the sampling represented by the two Apollo suites, no such crossover is obvious. Thus, it appears likely that large masses of depleted phases may be "hidden" at great depth or elsewhere on the lunar surface. For example, if the highlands are indeed anorthositic, as suggested by Olsen (*10*) and Wood *et al.* (*11*), measurement of the K/U ratio of "anorthositic" fragments, identified by Wood *et al.* in returned mare breccia, might be infor-