Reports

Strontium in Fossil Bones and the Reconstruction of Food Chains

Abstract. *The strontium content of bone is a function of the strontium content of the ingested food. Under favorable conditions of fossilization it can be used for the determination of feeding habits of extinct terrestrial vertebrates. Homogeneous samples of fossil biotic communities are a prerequisite for significant results.*

Odum (*1*) has shown that in terrestrial organisms the ratio of strontium to calcium is controlled both by the Sr/Ca ratio in the soil and by biotic factors. In plants the biotic factors may include selective uptake or preferential exclusion of Sr. In terrestrial vertebrates preferential exclusion of Sr by a practically constant factor during formation of the skeleton seems to be the usual case. The Sr/Ca ratio in the bone of fossil vertebrates can thus be expected to be determined, in herbivores, by the Sr content of the particular plants which formed the food of the species; in carnivores, it is determined by their position in the food chain.

These relationships can be used for paleoecological reconstructions if two conditions are met. The biotic factor being the variable to be determined, the other variable (that is, abundance in the inorganic source) must be kept constant. This can be achieved if comparisons are based on material coming from a single fossil quarry. The other requirement is that the Sr content shall have been unaffected by significant postmortal changes or that these changes shall have produced uniform results in the whole sample. Whether this condition is met by a particular quarry sample can be determined by a study of the sample itself.

Fossil bones are essentially monomineralic, consisting of apatite. Their Ca content can be assumed to vary only slightly. Therefore, it cannot be expected to seriously affect the Sr/Ca ratio, and knowledge of Sr concentrations alone is sufficient for drawing paleoecological inferences.

We determined the weight proportion of Sr by x-ray emission spectrography on a G.E. XRD-5 unit. All bones were carefully cleaned of matrix and finely ground in an agate mortar. Samples were packed by hand in a plastic holder. Determinations of the Sr content were based on 100-second counts of the $K\alpha$ peak. An analytical curve obtained from known standards was used to convert counts into parts per million (by weight).

Replicate analyses showed that the standard deviation of the method was 9.0 ± 2.5 ppm with 95-percent confidence. Systematic error is possible but does not affect the results.

The first quarry sample analyzed is from the Lower Pliocene of Knox County, Nebraska. We tested the possibility of a difference in Sr content between different age groups and/or different skeletal elements within a species. The results (Table 1) show that in neither case is the difference significant at the .6 level. These data also demonstrate the very low variability in the Sr content of bones of a single species and suggest that postmortal changes have not critically affected the Sr concentrations.

Bones of different types of animals were then compared. The results are shown in Table 1. From dental morphology, and partly by comparison with their closest living relatives, the antilocaprid *Merycodus* and the horse *Pliohippus* are judged to have been grazing forms. *Hypohippus*, a horse with low-crowned teeth (*2*), and the tortoise *Testudo* (*3*) are, by contrast, considered to be browsing animals which ate primarily succulent vegetation. The carnivore sample includes members of both the cat and dog families.

The mean Sr content is lowest for the carnivores. The mean Sr content of the carnivore bones is significantly different from that of each of the herbivorous animals at the .001 level. The difference in mean amounts of Sr between *Merycodus* and the browsing horse *Hypohippus* is also significant at the .001 level. The same holds true for a comparison between *Merycodus* and *Testudo* and between *Pliohippus* and *Hypohippus*. A much less significant difference (.05 level) was found between the Sr concentrations of *Merycodus* and *Pliohippus*. *Testudo* and *Hypohippus* were not significantly different (.9 level).

The differing Sr concentrations in the bones of these five fossil animals

Table 1. Concentration of strontium in bones of various Pliocene vertebrates (ppm).

Bone source	Number of specimens	Mean conc.	Standard deviation	Coefficient of variation
Carnivores	4	477	15	3.1
Merycodus				
Mandibles	10	523	27	5.1
Mature metacarpals	10	526	34	6.5
Immature metacarpals	10	529	28	5.3
Total	30	526	29	5.5
Pliohippus	10	552	35	6.4
Hypohippus	10	630	37	5.8
Testudo	10	636	24	3.7

thus confirm the feeding habits deduced from their dental morphology. We suggest that the observed differences among the herbivorous animals are due to different Sr concentrations in their preferred foods, specifically to the concentrations of Sr in succulent herbaceous vegetation, higher than in grasses (*4*). *Hypohippus* and *Testudo*, both adapted to eating leafy vegetation, have the highest values. *Merycodus*, a form with very high-crowned teeth, is considerably lower in Sr than the browsers, a fact which reflects its probable diet of harsh grasses. *Pliohippus* is fairly low in Sr but higher than *Merycodus*. The *Pliohippus* at this locality has relatively shorter-crowned teeth than *Merycodus* and is also primitive in retaining side toes, suggesting that it was less exclusively a grazing animal than *Merycodus*. Carnivores are the lowest of all in Sr content. This agrees with the postulated progressive exclusion of Sr in the food chain.

Favorable conditions of fossilization appear to be prerequisite for obtaining ecologically meaningful information from the Sr content of fossil bones. Ten crocodile scutes from an Eocene locality in Carbon County, Wyoming, were analyzed for their Sr content. Bones at this locality show considerable enrichment of iron, manganese, and barium. The amounts of Sr found in the crocodile scutes were much more variable than for any of the Pliocene genera studied (coefficient of variation is 24 for the crocodiles, 3.1 to 6.4 for the various mammals and reptiles of the Pliocene fauna). It is doubtful whether statistically significant differences can be obtained from available samples under such conditions of high variability. The cause of variability probably lies in distortion of the original composition of the bone by intense postmortal chemical change.

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References and Notes

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"Lunar Calendar" from the Hungarian Upper Paleolithic

Abstract. *A carved limestone object found in the East Gravettian site at Bodrogkeresztur, Hungary, has been identified as a uterus symbol. It may also be a lunar calendar. Prehistorians should reexamine similar objects for similar evidence.*

Marshack's interpretation (*1*) of certain objects from the Upper Paleolithic as lunar calendars was most interesting. Although such interpretations of Paleolithic paintings, engravings, and sculptures are seldom verifiable, one fact is clear: man of the glacial period led a complex spiritual-cultic life, and he can be compared in this respect with the people of today's (or yesterday's) "asymmetrical" cultures.

In 1963, loess excavated near Bodrogkeresztur in northern Hungary uncovered the remains of an occupied site belonging to the older level of the East Gravettian group (*2*). Among the finds was an object, carved from limestone, that was shaped like a halfmoon or horseshoe; it measured 56 by 56 by 17 mm. If the object, as it appears in Fig. 1*A*, were oriented, the top is "north" left is "west," and right is "east"; the base of the halfmoon is "south." Near the center of the northern edge are two near-vertical carved lines, 6 to 7 mm long, that slightly converge to the north. Eastward and westward from the lines, the sharp edges of the object are notched almost symmetrically. There are 11 notches on the eastern side and 12 on the western; all notches extend to the reverse side (Fig. 1*C*). Parallel with and near the southern edge is a carved line 12 mm long.

I do not propose to list all possible interpretations (*3*) of the object. Because of its positive-negative conformity with other objects that were found at Kostienki I (*4*), I chose to regard the Bodrogkeresztur object as a uterus symbol, although its lunar or solar shape was noted. However, on the basis of Marshack's paper (*1*) I have considered the following possible interpretation.

The western of the pair of converging lines (northern edge) may be regarded as the symbol of the new moon.

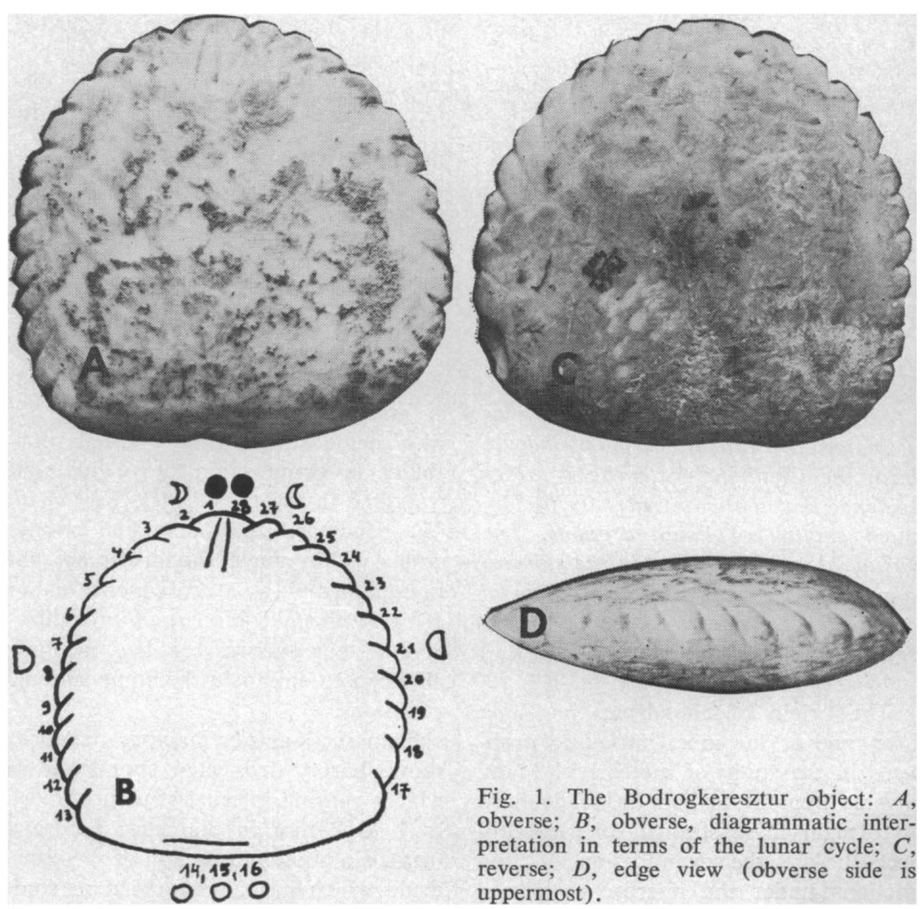

Fig. 1. The Bodrogkeresztur object: *A*, obverse; *B*, obverse, diagrammatic interpretation in terms of the lunar cycle; *C*, reverse; *D*, edge view (obverse side is uppermost).