Reports

Spongy Bones in Prehistoric America

Abstract. *A well-preserved mummified child from about A.D. 1200 was recovered from Canyon de Chelly in northeastern Arizona in 1971. Striking skull changes were found and microscopic, ultrastructural, and cytochemical studies confirm the diagnosis of porotic hyperostosis that resulted in spongy bone appearance. We suggest that a possible cause for this condition could be iron deficiency of a severity seldom found in modern societies.*

During the 1971 summer excavation of the Antelope House in the Canyon de Chelly area, Arizona (Fig. 1), Don P. Morris of the National Park Service recovered a well-preserved mummified child. This mummy is of interest because part of the skull has an unusually spongy appearance caused by surface defects that have been described as spongy hyperostosis (*1*), cribra cranii (*2*), symmetrical osteoporosis (*3*), and cribra orbitalia (*4*). However, the term porotic hyperostosis (*5*) seems more descriptive, since these lesions consist of conglomerates of irregular openings or pores connecting the underlying thickened layers of the bone surface.

The pottery in the intrusive trash, the vessels associated with the burial, and the construction dates for the rooms north of the burial site suggest a date of around A.D. 1200 (*6*).

Radiographic analysis of carpal ossification indicates the child was approximately 12 to 18 months old at the time of death. The presence of the first and the partial crown formation of the second permanent molars, however, suggests that the child may have reached the age of 5 to 6 years. Thus we may assume a severe case of skeletal retardation. The central upper milk incisors display evidence of developmental enamel hypoplasia. No other pathologies or anomalies appear to be present in the skeleton.

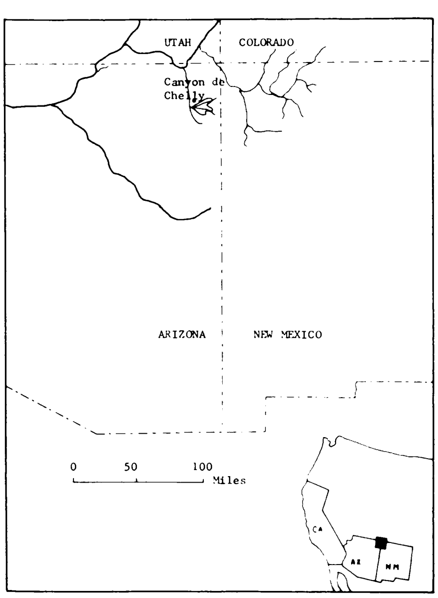

Fig. 1. Geographic location of Canyon de Chelly.

In the postcranial skeleton, four to six growth arrest lines (Harris lines) were observed on x-ray films in both right and left tibiae and femora. These lines persist for varying lengths of time in individuals undergoing stress sufficient to interrupt growth. Such stress may consist of episodes of reduced food intake, disease, or both (*7*).

Representative samples of the sternum, right clavicle, fifth right metatarsal bone, and midportion of the left parietal bone were examined in histological, cytochemical, and ultrastructural studies. Histological evaluation was carried out in specimens after rehydration in 4°C isotonic salt solution for 10 to 15 days, followed by fixation in buffered aldehydes, decalcification, and embedding. Specimens for ultrastructural studies were processed under vacuum conditions and coated with gold and palladium for scanning electron microscopy.

The most striking histological findings consisted of irregular knobs and ridges of bony tissue in the calvarium, with destruction of a portion of the outer table. The bone masses were extremely dense with presence of pores of cancellous bone extending from the diploe. While ghost figures of cellular structures in the diploe were noted, no periosteal tissue remained (Fig. 2). The inner table was grossly normal and showed no evidence of microscopic changes. Scanning electron microscopy confirmed that the irregular lesions found in the skull sample were a result of defects of the outer table connecting with the diploe but did not involve the inner table, which showed a normal surface (Fig. 3). The metatarsal bone that was studied showed evidence of chondrodysplasia with absence of regular alignment of cellular spaces. No gross or histological evidence of rickets or osteomalacia was found.

Severe cases of chronic iron deficiency anemia in infants and children, seldom found in contemporary societies, may occasionally induce skull changes similar to those found in congenital hemolytic anemias as a result of erythroid hyperplasia. The cranial bones show widening of the diploe spaces and displacement of the external table with thinning and eventual atrophy. Because the diploe trabeculae are eventually pushed outward, perpendicular to the inner table, radiological changes described by Moseley as having a "hair-on-end" appearance are produced (*8*).

In the case we studied, the severe porotic hyperostosis found in the orbital roof and the cranial vault suggest that the child's death may have been related to anemia. The condition closely resembles the autopsy and roentgenologic findings of hemolytic anemias associated with bone marrow hyperplasia (Figs. 4 and 5). In this mummy, the orbits and all bones of the cranial vault show a very prominent, well-marked spongy formation that is similar in appearance to a coral, with sieve-like porosity. In the parietal bones, these porous openings average about 16 per square centimeter. The thickness in the cranial vault is three to four times greater than that of normal bone. There is no evidence of facial bone swelling resulting from pneumatization of the maxillary sinuses as is usually found in Old World cases of Cooley's anemia (thalassemia major) or in hemolytic crisis after ingestion of fava beans or other hemolytic agents (*8*). Therefore, chronic dietary

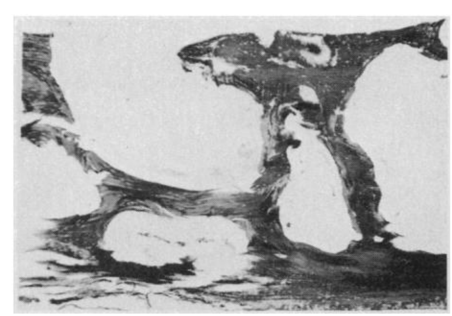

Fig. 2. Section of decalcified left parietal bone showing thickened diploe with large defects communicating with the outer table (top) (Masson's trichome staining; ×40).

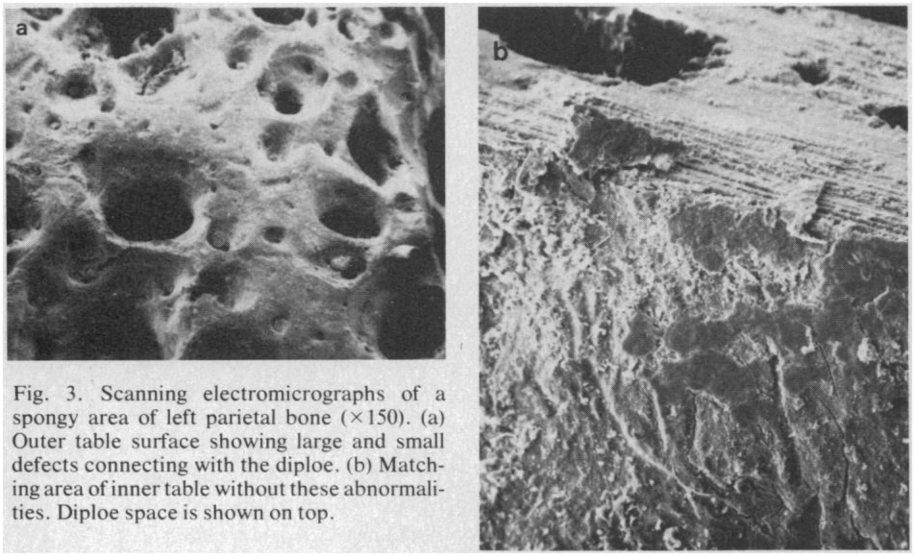

Fig. 3. Scanning electromicrographs of a spongy area of left parietal bone (×150). (a) Outer table surface showing large and small defects connecting with the diploe. (b) Matching area of inner table without these abnormalities. Diploe space is shown on top.

iron deficiency is a likely alternative. Because of the low iron content of the bone samples obtained, chemical analysis did not provide further evidence of chronic iron deficiency anemia in the formation of the hyperostotic lesions. Studies on better-preserved remains of the same period may reveal further information.

Evidence of dietary iron deficiency as a possible cause of skull changes resembling those found in this Pueblo Indian mummy have recently been reported in present-day African natives (*9*). Jelliffe and Blackman (*9*) studied the Hamitic Bahima people of Uganda, who exhibit similar radiological changes, including "hair-on-end" appearance, as a result of marrow hyperplasia. Severe iron deficiency anemia occurs in these children because they are fed an exclusive milk diet during their development. Recent ethnographic and clinical studies among modern Southwestern Pueblo Indians who breast-feed their children and use cow's milk as a supplement for 2 to 3 years after birth show an unusually high incidence of iron deficiency anemia that reaches 100 percent in some groups (*10, 11*).

In the Old World, the distribution of porotic hyperostosis fits well with the occurrence of the thalassemias and sicklemia (*12*). However, neither human malaria nor hemoglobin variants associated with hemolytic anemias are known to have existed in the pre-Columbian New World (*13*) and therefore cannot explain the occurrence of porotic hyperostosis among New World natives. Furthermore, of the 1000 southwestern Indian children examined by Caffey (*14*), none show evidence of abnormal hemoglobin variants.

For the prehistoric inhabitants of Canyon de Chelly, where this mummy was found, the diet consisted primarily of maize (*Zea mays*) (*15*). It is important to point out that this type of maize is a nonhybrid variety and contains a very low iron content (*10*). At Canyon de Chelly, in a manner common to most prehistoric southwestern Indians, the usual method of maize preparation was grinding the kernels on a metate and then placing the dough to bake in hot ashes or on hot rocks. Alkali was obtained from wood ashes and lime (*16*). Losses of significant quantities of thiamin, riboflavin, niacin, nitrogen, fat, and crude fiber, as a result

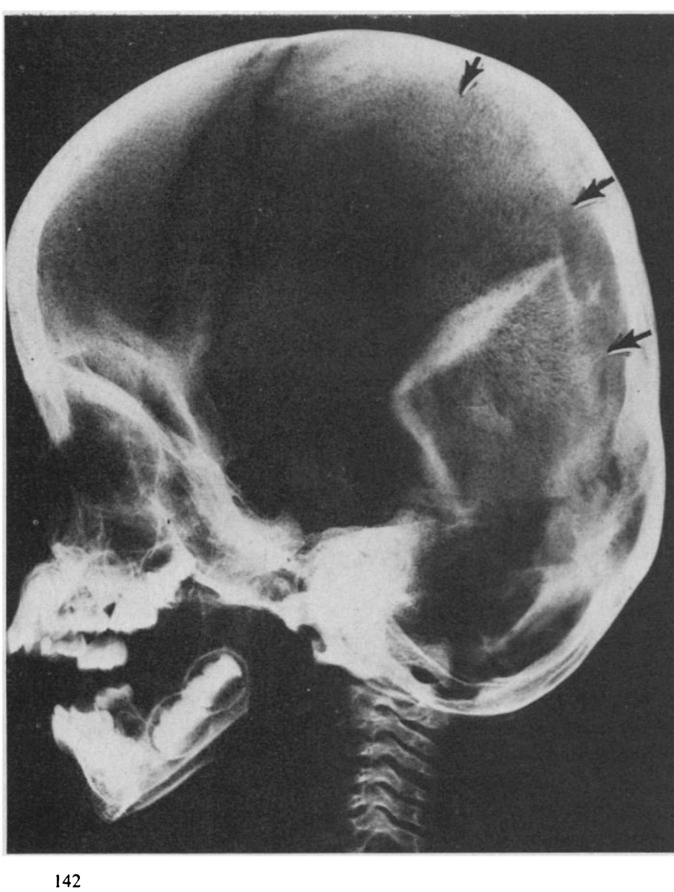

Fig. 4 (left). Roentgenological lateral view of the mummy's skull showing typical "hair-on-end" appearance on parietal and occipital areas (arrows). Fig. 5 (right). Porous openings on the right parietal and occipital bones give a spongy appearance to a large area of the skull.

of alkaline treatment, have been shown (*17*). Maize is also deficient in the essential amino acids lysine and tryptophan (*16*).

The iron content of maize is relatively low and less than 5 percent of this iron is absorbed by the human body (*18*). The availability of iron in foods taken with maize is also decreased (*19*). In addition, maize contains large quantities of phytic acid in the outer covering of the grain (*20*). Experimental evidence shows that phytic acid, an iron chelating agent, adversely affects the absorption of iron by making it unavailable for metabolism (*21*). Thus populations subsisting on a maize diet with little or no animal protein are in a critical position with regard to meeting their iron needs. Young children, because of their rapid growth, are particularly susceptible to adverse effects.

Among inhabitants of environments similar to that of Canyon de Chelly, where maize constituted over 75 percent of the diet, porotic hyperostosis reaches a high incidence of 83 percent (*15*). A high incidence of porotic hyperostosis (74 percent) is also found among Peruvian Indians with a similar diet (*10*). Comparisons of the incidence of porotic hyperostosis between canyon bottom inhabitants and other southwestern Indian groups living in sage plain areas where iron and animal protein were plentiful show the differences to be highly significant (*15*). Ten fish species, 41 mammal species, 52 bird species, and 77 plant species have been reported to exist in the sage plain areas (*22*). Children from canyon areas have an incidence of porotic hyperostosis ranging from 64 percent at Inscription House, Arizona, to 88 percent at Canyon de Chelly, Arizona. The incidence ranges from 15 to 18 percent among the sage plain groups at Navajo Reservoir and Gran Quivira, New Mexico.

The porotic hyperostosis found in ancient skulls of Peru and Yucatan has been described by Moseley (*3*) as the result of iron deficiency anemia. It is of interest that in this kind of bony change, iron therapy produces very slow results, if any. There is a documented case where treatment with iron produced no noticeable evidence of healing; the bony changes remained unaffected (*23*).

Of particular interest is the fact that the child under study was on a cradleboard. If the association is interpreted correctly, the child may have been crippled, mentally retarded, and, perhaps, unable to participate in normal infant behavior. Because of the unusually high incidence of porotic hyperostosis among these prehistoric American natives, we suggest that such findings merit further interdisciplinary investigation.

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Microfossils in *Conophyton* from the Soviet Union and Their Bearing on Precambrian Biostratigraphy

Abstract. *Silicified specimens of the Vendian (late Precambrian) "index fossil"* Conophyton gaubitza *from South Kazakstan contain a diverse assemblage of well-preserved cyanophytic and apparently eukaryotic algae, the first stromatolitic microbiota to be reported from the Soviet Union. Unlike the stromatolites in which they occur, the microorganisms that apparently built this form of* Conophyton *did not become extinct at the end of the Precambrian.*

Conically laminated stromatolites of the group *Conophyton* Maslov are among the most distinctive and widespread of biogenic structures occurring in Precambrian strata. Although they are especially abundant in the Early and Middle Riphean (between about 1700 ± 50 and 950 ± 50 million years ago), the range zone of fossil members of the group extends from the pre-Riphean into the Vendian, terminating near the close of the Precambrian (*1*). Indeed, and although living examples of *Conophyton* are known from modern hot spring environments (*2*), the apparent absence of such stromatolites from Phanerozoic rocks—coupled with their abundance in Precambrian sediments and their readily identifiable morphology—has led several workers to regard fossil *Conophyton* as a Precambrian "index fossil" (*1, 3, 4*) with the top of its range zone being one of two features suggested as defining the Precambrian-Paleozoic boundary (*5*, p. 37). The reliability of stromatolites as time-stratigraphic indicators, however, seems open to question; stromatolite form can be influenced markedly by physical aspects of the environment (*4*), factors that are neither time-restricted nor subject to unidirectional change. Moreover, limited data are available regarding the composition and evolution of microbial communities involved in formation of fossil stromatolites (*6*). Thus, it remains to be established whether differing types of coeval stromatolites were formed by differing microbiotas, or whether a singular community might have produced different stromatolites in different environments. Similarly, although "uncommon filaments" exhibiting "generally poor preservation" have been detected in a *Conophyton* of Early Riphean age (*7*), diverse, well-preserved microfossils have not previously been reported from such stromatolites. Thus, there has been little evidence to suggest whether fossil *Conophyton* was produced by the same mechanisms as its modern analog (*2*) or to indicate whether the occurrence of such fossil forms might reflect the presence of an atypical, and possibly Precambrian-restricted, biologic group. The