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Discovery of Osteocytes in Adult and Juvenile Bones of Duck-billed Dinosaurs

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Abstract Scanning electron microscopy (SEM) observations of osteocytes found in two Cretaceous ornithischian dinosaurs, an adult of a hadrosaurid species and a juvenile specimen of *Maiasaura peeblesorum*, are described. In the juvenile specimen of *M. peeblesorum*, the osteocyte casts, exposed by etching, in the bone lacunae were 15–20 μm in long diameter and 5–7 μm in short diameter on average. This is comparatively smaller than those of the adult hadrosaurid species. It is suggested that the main function of osteocytes in the juvenile specimen may have differed from that of the adult. Furthermore, the osteocyte precesses were obscure in the former. We consider that the minute osteocyte precesses, corresponding to canaliculi, were not preserved in the bone matrix because of retardation of bone calcification in the juvenile of *M. peeblesorum*. The presence of smaller osteocytes in the juvenile than those in the adult is probably due to the importance of bone growth, rather than bone hardness, at the young stage.

Key words: *Maiasaura peeblesorum*, hadrosaurid species, osteocytes, Upper Cretaceous, N. America.

Microscopic histological structures found in dinosaur bones have been described in several pubications based on the results of current research (e.g. Ricqles, 1980). A comparative embryological study by means of histology was carried out on some young legbones of two Cretaceous ornithischian dinosaurs, *Orodromeus makelai* and *Maiasaura peeblesorum* from the Two Medicine Formation, western Montana (Horner and Weishampel, 1988). As a result, some details of bone growth and the ecology of young herbivorous dinosaurs have been clarified. However, there is no information on osteocytes in dinosaur bone tissues.

The first purpose of this study was to characterize dinosaur osteocytes and describe their form. The second purpose was to examine preliminarily the function of the osteocytes based on morphological differences at different growth stages.

Materials and methods

Comparative scanning electron microscopy (SEM) observations were made on osteocytes of two Cretaceous ornithischian dinosaurs: Hadrosauridae gen. et sp. indet. and *Maiasaura peeblesorum*. Although it would have been better to compare the same bones and the same areas of the bones from adult and juvenile specimens of the same species, an upper part of the left femoral bone and a piece of compact bone from the central mandible of an adult hadrosaurid from the Judith River Formation distributed near Brooks, Alberta, were examined, together with a piece of compact bone from the upper articular face of a hind limb, probably the tibial bone, of a juvenile specimen of *Maiasaura peeblesorum* from the Two Medicine Formation, distributed near Choteau, Montana.

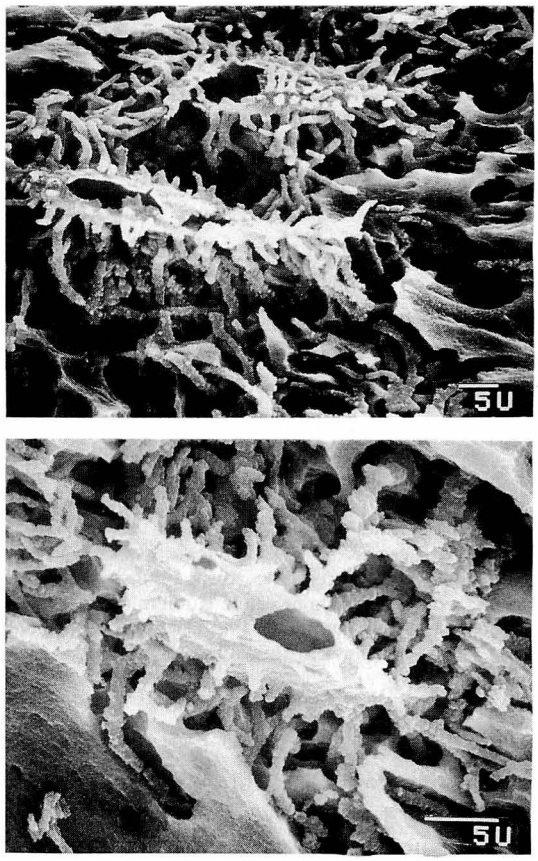
Small parts of these bones were prepared for SEM observation by sectioning with a diamond cutter to a size of 1 cm^3. Subsequently, the sectioned surface was etched with 4% hydrochloric acid for 5 min., and the decalcified surface was washed with pure water several times and coated with gold or carbon. The microstructure was observed by SEM using the gold-coated specimen, whereas the semiquantitative ultimate composition of the microstructure was analyed using the

carbon-coated specimen with an energy-dispersive X-ray microanalyzer attached to the SEM.

Observations and discussion

In the compact bone of the adult hadrosaurid, the Haversian canals were densely distributed, in accord with that of the bone tissues of an adult hadrosaurid, *Anatosaurus*, reported by Reid (1985). Concentric bonelamellae are well developed around these canals. Some fusiform osteocytes, 30–35μm in long diameter and 5–7μm in short diameter, were evident in the inner parts of bone lacunae arranged along the bone lamellae (Figs. 1–2). The elemental composition of the osteocytes included Fe, in striking contrast to the bone matrix around them, which consisted mainly of Ca and P. This was thought to be due to penetration of water containing Fe into the bones buried in mudstone for a long period of time, and subsequent Fe accumulation in the inner parts of bone lacunae where the cell material had already disappeared, forming an elaborate natural cast of the osteocytes. The interior part of the cast was always empty, probably due to gradual deposition of Fe like plastering work on a wall. The wall of each cast was about 0.2μm thick.

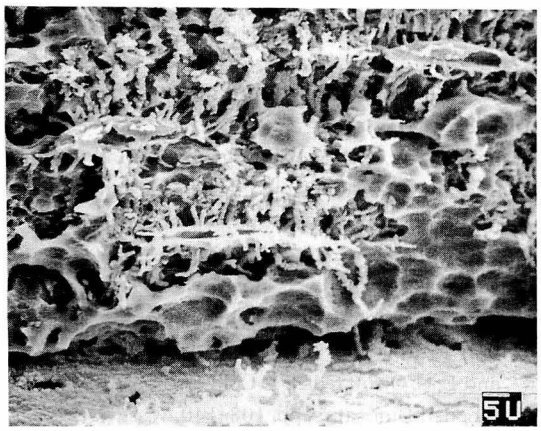
From the outer surface of the fusiform osteocyte wall, one hundred or more slender processes extended outward to those of the adjoining osteocytes. This situation was the same as that for osteocytes in the mandible (Figs. 3–4). The morphological features of osteocytes of the hadrosaurian dinosaur correspond to those of Recent mammals at the mature growth stage (Schulz *et al.*, 1974): the size and the number of osteocyte processes are very similar to those described for some Recent mammals (Wasserman and Yeager, 1965; Jande and Belanger, 1971). The fairly large size of the osteocytes and the large number of processes in the adult hadrosaurid suggest that Ca and P were taken up from the blood by the osteocytes, and that the rate of subsequent metabolic secretion of Ca and P into the bone matrix was as high as that in Recent mammals (Jowsey *et al.*, 1964; Vitalli, 1968; Remagen *et al.*, 1969).

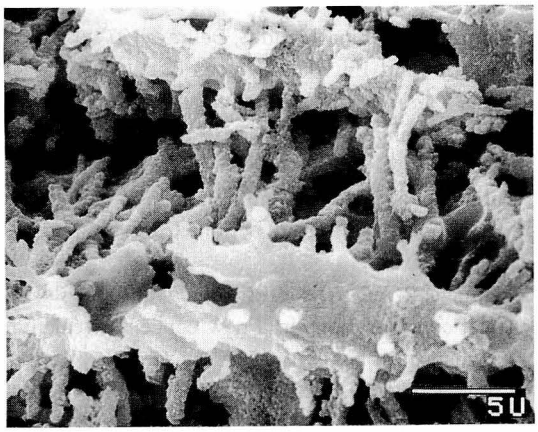


Figs. 1 (upper)–2 (lower). Scanning electron micrographs showing osteocytes of an adult specimen of a Campanian hadrosaurian ornithopod. U represents μm. Fusiform osteocyte casts discovered from the compact bone on the upper part of left femoral bone.

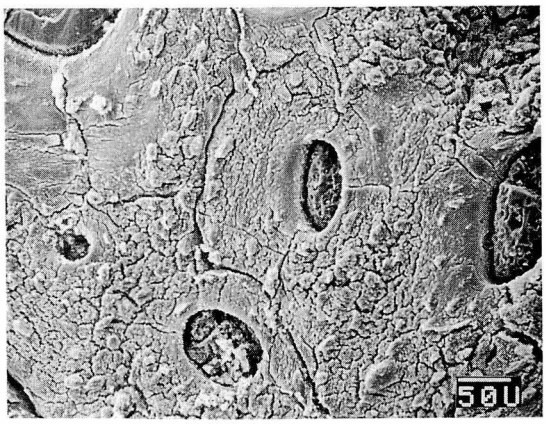
Therefore, it can be inferred that large amounts of inorganic substances such as Ca, P were stored in the bone tissue by osteocytes under the control of parathyroid hormone in the adult body. Thus, osteocytes contributed greatly to the maintenance of bone hardness and the regulation of inorganic elements in the blood (Talmage, 1969). It can be reasonably suggested that the parathyroid gland of some dinosaurs, as represented by the hadrosaurids, was fairly large and functional.

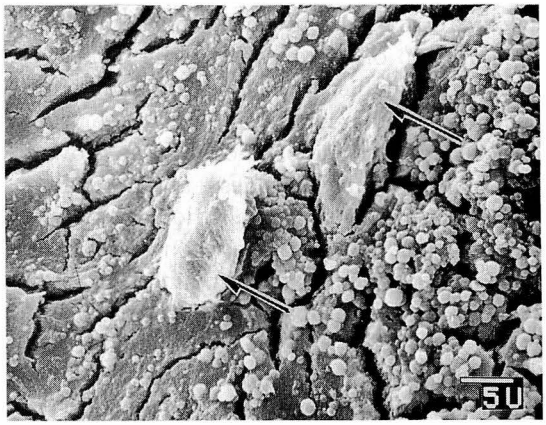
In the juvenile specimen of *Maiasaura peeblesorum*, the density of Haversian canals was low, and the bone lamellae were less well developed than those of the adult (Fig. 5). The osteocyte casts, exposed by etching, in





Figs. 3 (upper)–4 (lower). Scanning electron micrographs showing osteocytes of an adult specimen of a Campanian hadrosaurian ornithopod. U represents μm. Fusiform osteocyte casts discovered from the compact bone on the central part of mandible, being nearly similar form as those of left femoral bone.





Figs. 5–6. Scanning electron micrographs showing osteocytes in a juvenile specimen of Campanian *Maiasaura peeblesorum*, a hadrosaurian ornithopod. U represents μm. **Fig. 5 (upper).** Low magnified cross-section of the compact bone on the upper articular face of hind limb. **Fig. 6 (lower).** Fusiform osteocyte casts (arrow) discovered from the compact bone on the upper articular face of hind limb.

the bone lacunae were about 15μm in long diameter and 5–7μm in short diameter (Fig. 6), being about half the size of those in the adult. Furthermore, the osteocyte processes were obscure and not fully replaced by Fe. We consider that the minute osteocyte processes, corresponding to canaliculi, were not preserved in the bone matrix because of retardation of bone calcification in the juvenile *Maiasaura peeblesorum* (Horner and Weishampel, 1988), and because of the breaking up of part of the organic bone tissue after the death of the individual in taphonomy. The presence of smaller osteocytes in the juvenile specimen than in the adult probably reflects the importance of bone growth at the young statge, rather than bone hardness (Jande, 1971).

Conclusion

We were able to recognize fairly large-sized osteocytes and numerous processes in the adult specimen of a Campanian hadrosaurid from the Judith River Formation, Brooks, Alberta. Such morphologic features of the osteocytes appeared to be almost uniform for the thigh bone and mandible, and similar to those of some Recent mammals. It is suggested that the rate of Ca and P metabolism in the osteocytes was high. Thus it can be inferred that large amounts of inorganic sub-

stances such as Ca and P were stored in the bone tissue in adults, and that osteocytes contributed greatly to maintenance of bone hardness and regulation of inorganic elements in the blood.

The osteocytes in the juvenile specimen of Campanian *Maiasaura peeblesorum*, from the Two Medicine Formation, Choteau, Montana, are comparatively smaller than those in the hadrosaurid species. Furthermore, the osteocyte processes were obscure. The minute osteocyte processes were not preserved in the bone matrix because of retardation of bone calcification in the juvenile, and because of breaking up of the organic tissue in taphonomy. The smaller osteocytes in the juvenile specimen compared with the adult one probably reflects the importance of bone growth rather than bone hardness at the young stage. The elemental composition of osteocytes includes Fe, in striking contrast to the bone matrix, which consists mainly of Ca and P. This is due probably to penetration of water containing Fe into the bone buried in mudstone for a long period of time, and subsequent accumulation of Fe in the inner parts of bone lacunae, forming empty natural casts of osteocytes.

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カモノハシ竜の成体および幼体の化石骨から見いだされた骨細胞について

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北米産の白亜紀後期の鳥盤類ハドロサウルス科に属する化石骨を走査電子顕微鏡で観察し，明瞭な骨細胞の印象化石を捕えることに成功した．X線分析の結果，それらの骨細胞化石は骨小腔内に鉄分が浸込むことによって形成された，骨細胞の精巧な鋳型であることがわかった．その骨細胞を写真で示し，さらに *Maiasaura peeblesorum* の幼体のものと比較し，その機能について検討を加えた．