OSTEOHISTOLOGY OF THE HADROSAUROID (DINOSAURIA: ORNITHOPODA) FROM LABIRINTA CAVE, BULGARIA: AN EXAMPLE OF INSULAR DWARFISM OR SIMPLY YOUNG GIANT?ⁱ

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INTRODUCTION

The fossils of non-avian dinosaurs in Bulgaria are rare. Most of them come from two fossiliferous locations inside the Labirinta cave (Vratza district, Northwestern Bulgaria), which is formed in the upper Maastrichtian limestones of the Kajlâka Formation. Labirinta's dinosaur material is described as pertaining to hadrosauroid ornithopod (Godefroit and Motchurova-Dekova, 2010). Interesting characteristic of the hadrosauroid bones is their small size, but, as noted by Godefroit and Motchurova-Dekova (2010), without osteohistological data it is not possible to affirm whether they belong to young individual/s or to small-sized adult animal/s. This problem is of interest due to the presence of ornithopods on the islands of the latest Cretaceous European archipelago which are thought to be an example for insular dwarfism. Herein I present information about the long bone histology of the Bulgarian hadrosauroid and test the hypothesis that this ornithopod is an island dwarf.

MATERIAL AND METHODS

One partial diaphysis and six bone fragments found in association with the fossil material described by Godefroit and Motchurova-Dekova (2010) were transversely sectioned (Fig. 1). Thin-sections were then prepared following standard paleohistological methods (Chinsamy and Raath, 1992; Wilson, 1994), with some changes in the methodology due to limitations imposed by available tools and material (Fig. 2). The application of the less destructive Histological Coring Method (Stein and Sander, 2009) was not viable option because of the extremely fragmentary nature of the studied material.

ⁱ The following content (text and figures) represents slightly modified version (featuring minor alterations which aim to improve the grammar and readability, but with no changes to the general structure of the original text) of a poster presentation which was featured in the program of the 3rd International Symposium on Paleohistology, held in Bonn, Germany, in 2015. The original citation of this work is as follows: Nikolov, V. 2015. Osteohistology of the hadrosauroid (Dinosauria: Ornithopoda) from Labirinta cave, Bulgaria: An example of insular dwarfism or simply young giant? 3rd International Symposium on Paleohistology, Program and Abstracts: p. 97. All of the interpretations presented herein are based on raw data and are yet to be subjected to peer-review.

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Figure 1. Studied hadrosauroid fossil bone fragments from Labirinta cave (Vratza district, NW Bulgaria). (A) Fragmentary diaphysis NMNHS F31442. (B) Bone fragment NMNHS Mos19-1. (C) Bone fragment NMNHS Mos19-2. (D) Bone fragment NMNHS Mos19-3. (E) Bone fragment NMNHS Mos19-4. (F) Bone fragment NMNHS Mos19-5. (G) Bone fragment NMNHS Mos19-6. Scale bar: 3 cm.

Jessica Mitchell and Martin P. Sander (both from IPB) kindly provided high-resolution scanned images of thin-sections from 3 femora, 2 tibiae and 3 humeri of the basal hadrosaur *Telmatosaurus*, and 4 femora and 3 humeri of the rhabdodontid *Zalmoxes*. These images were used as comparative material.

Figure 2. Transverse thin-sections of the hadrosauroid fossil bone fragments from Labirinta cave (Vratza district, NW Bulgaria). (A) NMNHS F31442. (B) NMNHS Mos19-1 (numbers mark zones with distinct vascularization patterns). (C) NMNHS Mos19-2. (D) NMNHS Mos19-3. (E) NMNHS Mos19-4. (F) NMNHS Mos19-5. (G) NMNHS Mos19-6. cb – cancellous bone, ccb – compacted cancellous bone, Hb – Haversian bone, mc – medullary cavity, pb – periosteal bone. 1 – first zone with laminar bone, 2 – zone with mostly reticular bone, 3 – second zone with laminar bone, 4 – zone with reticular bone. Scale bar: (A-D, F) 1 cm, (E, G) 5 mm.

Information about the studied specimens is provided in Table 1. The osteohistology of the Bulgarian hadrosauroid was observed and studied with Leica DM2500 microscope under plane-polarized and cross-polarized light.

Specimen	Taxon	Skeletal element	Length	Locality
NMNHS F31442	?Hadrosauroidea	fragmentary diaphysis	9.8 cm (incomplete)	Labirinta cave, Bulgaria
NMNHS Mos19-1	?Hadrosauroidea	bone fragment	-	Labirinta cave, Bulgaria
NMNHS Mos19-2	?Hadrosauroidea	bone fragment	-	Labirinta cave, Bulgaria
NMNHS Mos19-3	?Hadrosauroidea	bone fragment	-	Labirinta cave, Bulgaria
NMNHS Mos19-4	?Hadrosauroidea	bone fragment	-	Labirinta cave, Bulgaria
NMNHS Mos19-5	?Hadrosauroidea	bone fragment	-	Labirinta cave, Bulgaria
NMNHS Mos19-6	?Hadrosauroidea	bone fragment	-	Labirinta cave, Bulgaria
MAFI OB3130	<i>Telmatosaurus</i>	femur, right	46.6 cm (est.)	Valiora, Romania
FGGUB R1832	<i>Telmatosaurus</i>	femur, left	25 cm	Simpetru, Romania
FGGUB R1981	<i>Telmatosaurus</i>	femur, left	hatchling	-
MAFI OB3129	<i>Telmatosaurus</i>	tibia	26.5 cm (incomplete)	-
FGGUB R7	<i>Telmatosaurus</i>	tibia, left	45 cm (est.)	Duparau, Romania
FGGUB R1850	<i>Telmatosaurus</i>	humerus, right	hatchling	-
MAFI OB3126	<i>Telmatosaurus</i>	humerus, left	32.5 cm (est.)	Valiora, Romania
FGGUB R1985	<i>Telmatosaurus</i>	humerus, right	14 cm (35 cm - est.)	Gropa, Romania
FGGUB R1382	<i>Zalmoxes robustus</i>	femur, left	28 cm (est.)	Carare, Romania
FGGUB R1002	<i>Zalmoxes robustus</i>	femur	32 cm (est.)	Simpetru, Romania
FGGUB R1088	<i>Zalmoxes shqiperorum</i>	femur, left	16.4 cm (est.)	Valiora, Romania
FGGUB R1608	<i>Zalmoxes shqiperorum</i>	femur, left	33.3 cm	Turka, Romania
FGGUB R6	<i>Zalmoxes robustus</i>	humerus, right	18 cm (est.)	Duparau, Romania
FGGUB R1392	<i>Zalmoxes robustus</i>	humerus, right	9.3 cm (20.1 cm - est.)	Carare, Romania
FGGUB OB3077	<i>Zalmoxes</i> sp.	humerus, left	25.5 cm	Valiora, Romania

Table 1. List with the studied fossil specimens and information about their taxonomy, size, and locality.

RESULTS

Thin-sections reveal that the cortex of all 7 specimens is built of highly vascularized tissues of the woven-parallel complex. Vascularization patterns differ in different areas of the

cortex but the predominating model is of laminary organized primary osteons. Where present the laminar bone tissue is more than 5 mm in thickness (in specimens which preserve sufficient part of the cortex, it may have thickness of about 1 cm, or more). In NMNHS Mos19-5 and in the deep cortex of NMNHS Mos19-1 the laminar organization of the vascular system is result of circumferential rows of longitudinal primary osteons (Fig. 3).

Figure 3. Primary bone tissues in the cortex of the studied bone fragments of the Bulgarian hadrosauroid in cross-polarized light. (A) Woven-parallel bone tissue in the outer cortex of NMNHS F31442. (B) Woven-parallel laminar bone tissue in the deep cortex of NMNHS Mos19-1. (C) Woven-parallel bone tissue in the middle cortex of NMNHS Mos19-1, at the boundary between zone 1 and zone 2. (D) Woven-parallel reticular bone tissue in the middle cortex of NMNHS Mos19-1. (E) Woven-parallel laminar bone tissue in the outer cortex of NMNHS Mos19-1. (F) Woven-parallel laminar bone tissue in the outer cortex of NMNHS Mos19-2. (G) Woven-parallel laminar bone tissue in the outer cortex of NMNHS Mos19-2. (H) Woven-parallel laminar

bone tissue in the middle cortex of NMNHS Mos19-3. (I) Woven-parallel laminar bone tissue in the middle cortex of NMNHS Mos19-3. (J) Woven-parallel laminar bone tissue in the deep cortex of NMNHS Mos19-4. (K) Radially vascularized parallel-fibered bone in the outermost cortex of NMNHS Mos19-5. (L) Woven-parallel laminar bone tissue in the outermost cortex of NMNHS Mos19-6. Scale bar: (A) 1 mm, (B, C, I) 200 μm , (D-H, J-L) 500 μm .

The bone matrix consists almost entirely of parallel-fibered or lamellar bone tissue. Woven component is usually in higher quantity around longitudinal primary osteons, especially in the deep cortex (Fig. 3).

The cortical tissues of all studied specimens are affected by processes of resorption and/or secondary remodeling in various degrees. Locally dense Haversian bone is present up to the subperiosteal cortex (Fig. 4). The number of generations of secondary osteons is typically up to 3, but it could reach 5.

Figure 4. Secondary bone tissues in the cortex of the studied bone fragments of the Bulgarian hadrosauroid in cross-polarized light. (A) Dense Haversian bone in the middle and outer cortex of NMNHS F31442. (B) Secondary osteons locally developed in zone 2 of the cortex of NMNHS Mos19-1. (C) Dense Haversian bone in the cortex of NMNHS Mos19-3. Note the difference in histological and cellular characteristics of the secondary osteons from different generations. Nicols are crossed at angle allowing maximum visibility of tissue characteristics. (D) Dense Haversian bone in the cortex of NMNHS Mos19-4. Note the difference in histological and cellular characteristics of the secondary osteons from different generations. Nicols are crossed at angle allowing maximum visibility of tissue characteristics. (E) Haversian bone in the outermost cortex of NMNHS Mos19-5. (F) Two generations of endosteal bone in NMNHS Mos19-4. Arrow heads mark the reversal lines. Scale bar: (A) 1 mm, (B, E, F) 500 μm , (C, D) 200 μm .

Two generations of endosteal bone are locally developed in NMNHS Mos19-4 (Fig. 4F). With the exception of a possible line of arrested growth in the anterior cortex of NMNHS F31442 and an example of (irregular) modulation in NMNHS Mos19-1, no growth lines are observed in any of the specimens. Similarly, external fundamental system is not observed, but the bone periphery of some specimens seems to be partially eroded or is strongly affected by early diagenetic alteration.

DISCUSSION

Bone tissue vascularization of the Bulgarian hadrosauroid is very similar to that of *Telmatosaurus*, and differs from that of *Zalmoxes* and other small-sized non-hadrosauroid ornithopods. Unlike in large hadrosaurs, the laminar structure of the studied hadrosauroid remains is characterized by larger number of longitudinal primary osteons and shorter circumferential osteons. The bone matrix shows high spatial organization, a condition observed and described in *Telmatosaurus* and some sauropods (Benton et al, 2010; Klein et al, 2012). Presence of high amounts of parallel-fibered and lamellar bone in the woven-parallel complex is indicative of greatly reduced growth rates in the hadrosauroid from Labirinta cave compared to other hadrosaurs. While bones of *Telmatosaurus* show growth lines, sometimes in large number, these histological structures appear to be absent, or at least very rare, in the bones of the Bulgarian hadrosauroid, a feature which seems to be genuine and may be related to the ecology of this animal.

The transition from bone tissues with predominantly longitudinally oriented osteons to true laminar bone, the thickness of the latter, the extensive secondary bone remodeling and Haversian tissue with at least 3 generations of secondary osteons, as well as the presence of endosteal bone in one of studied specimens all suggest that the material pertains to animal/s at a late sub-adult ontogenetic stage. Although external fundamental system is not observed, based on the degree and characteristics of secondary remodeling it may be suggested that NMNHS F31442 pertains to an adult individual.

CONCLUSIONS

Bone histology suggested ontogenetic stage for the studied fossil material, and the presence of osteohistological features indicative for lowered growth rates and sometimes connected with marked decrease in body size reveal yet another dwarfed ornithopod that lived on the islands of the latest Cretaceous European archipelago, and present further example for insular dwarfism in non-avian dinosaurs.

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