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Late Cretaceous Plesiosaur Teeth from Axel Heiberg Island, Nunavut, Canada

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ABSTRACT. We report the discovery of Late Cretaceous plesiosaur teeth from non-marine strata on Axel Heiberg Island in the Canadian High Arctic. In comparison to other plesiosaur teeth, these specimens are most similar to the teeth of elasmosaurs: they have a smooth outer surface and crenulated inner surface, with crenulations that extend nearly to the tip of the tooth. Comparisons with elasmosaurid fossils elsewhere indicate that the Axel Heiberg teeth are from juveniles. The presence of a plesiosaur in non-marine strata on Axel Heiberg Island supports the suggestion that juvenile elasmosaurs frequently inhabited freshwater environments. The temporal distribution of the Axel Heiberg specimens and other occurrences from the High Arctic suggests that elasmosaurids may have expanded their range during a time of extreme climatic warmth.

Key words: Late Cretaceous, Axel Heiberg Island, elasmosaurids, paleoclimate, paleoenvironment

RÉSUMÉ. On signale la découverte de dents de plésiosaure du Crétacé supérieur d'une strate non marine à l'île Axel Heiberg, dans l'Extrême-Arctique canadien. Comparativement aux autres dents de plésiosaures, ces spécimens ressemblent beaucoup aux dents d'elasmosaures : leur surface extérieure est lisse et leur surface intérieure est crénelée, les crénulations s'étendant presque jusqu'à la pointe de la dent. Après avoir comparé ces spécimens aux fossiles d'elasmosaures trouvés ailleurs, on a remarqué que les dents trouvées à Axel Heiberg sont les dents de juvéniles. La présence d'un plésiosaure dans une strate non marine de l'île Axel Heiberg vient étayer la suggestion selon laquelle des elasmosaures juvéniles évoluaient souvent dans les milieux dulçaquicoles. La répartition temporelle des spécimens d'Axel Heiberg et d'autres occurrences de l'Extrême-Arctique laissent suggérer que les elasmosaures auraient pu étendre leur parcours au cours d'une période d'extrême chaleur climatique.

Mots clés : Crétacé supérieur, île Axel Heiberg, elasmosaures, paléoclimat, paléoenvironnement

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Vertebrate fossils collected from sedimentary strata on Axel Heiberg Island in the Canadian High Arctic suggest a mean annual temperature greater than 14°C during the Late Cretaceous (Turonian-Coniacian) in the Arctic region (Tarduno et al., 1998). Oxygen isotope data from lower-latitude deep-sea sites have indicated a similar period of warmth (Huber et al., 2002; Wilson et al., 2002). Because of its high latitude location during the Late Cretaceous (approximately 71°N, Tarduno et al., 2002), the Axel Heiberg locality can provide special insight into how latitudinal temperature gradients of the warm Late Cretaceous Earth are reflected in the vertebrate fossil record. Here we report the discovery of two well-preserved plesiosaur teeth found in the uppermost part of the thin (3.0 m) sequence of shale and siltstone from which vertebrate fossils have been recovered. These fossils add further to our understanding of the ecology of the Axel Heiberg assemblage and the environment of deposition.

The Late Cretaceous Axel Heiberg vertebrate locality is near Expedition Fiord (present-day location: 79°23.5′ N, 92°10.9′ W). The fossil-bearing sediments were deposited atop the subaerial basalts of the Strand Fiord Formation and are overlain by marine shales of the Kanguk Formation. The fossils define a diverse freshwater assemblage of turtles, fishes, and champsosaurs (Tarduno et al., 1998). The ichthyofauna consists of lepisosteids, amiids, and teleosts (Friedman et al., 2003). With the exception of a few jaw elements, the fossil fish elements are disarticulated and therefore could have undergone transport. The presence of articulated champsosaur fossils in the sediments, however, suggests that transport was minor (Tarduno et al., 1998).

The teeth recovered from the Axel Heiberg Island locality closely resemble those of elasmosaurid plesiosaurs (Plesiosauroidea). The teeth are gently curved and culminate in a sharp apex (Fig. 1). The teeth are broken off from the root. The crowns, which are fully covered by enamel, measure 18.34 mm and 12.45 mm long, with maximum diameters of 3.61 mm and 3.12 mm, respectively. In both specimens, the crown has been beautifully preserved, displaying fine longitudinal striations that are most prominent on the lingual side. Fine longitudinal striations and slender shape are characteristic of elasmosaurid teeth; in contrast, absence or reduction of striations on the labial

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FIG. 1. Two plesiosaurid teeth from Axel Heiberg Island, Canadian High Arctic. a: Labial view (UR 00.210; b: Axial view (UR 00.210); c: Labial view (UR 00.211); d: Axial view (UR 00.211). Scale bar represents 20 mm.

surface is a feature present in a range of plesiosaur taxa (e.g., Brown, 1981). The teeth are more slender than is usually the case in elasmosaurid plesiosaurs, but this could be a feature associated with their small size. Alternatively, they could be posterior teeth from a polycotylid plesiosaur. Slender recurved teeth are present in the Late Cretaceous genus *Dolichorhynchops*. In that genus, however, striations are confined to the lower two-thirds of the teeth (Carpenter, 1996), whereas in the Axel Heiberg specimens the striations extend nearly to the tip. Slender recurved teeth are also present in ornithocheirid pterosaurs, but in that group, the enamel surface is smooth, restricted to the apex of the tooth, and asymmetrically distributed (Averianov et al., 2003, 2005). Thus, on the basis of the general shape of the teeth, the extensive covering of enamel, and the distribution of striations on the enamel, we identify these teeth as Elasmosauridae gen. et sp. indet.

Two fossil adult elasmosaurs (NZGS CD425 and NZGS CD442) from New Zealand have been described as having teeth 35–40 mm long above the alveoli (Wiffen and Moisley, 1986). An adult elasmosaur from Cretaceous beds of Texas, measuring just under 6 m in total length, contained teeth with crowns up to 50.8 mm long and 9.5 mm in diameter (Schuler, 1950). The teeth collected from Axel Heiberg are noticeably smaller. A relatively complete juvenile elasmosaurid (MMM J. T. 86-100) from France contained teeth that are at maximum 54 mm long, including the root. The crown is described as comprising one-third of the total length (Bardet et al., 1999), indicating a crown length of 18 mm, which is comparable to the longer tooth from the Axel Heiberg vertebrate assemblage. Size estimates based on isolated teeth are inherently uncertain, but this comparison suggests the teeth recovered from Axel Heiberg Island were from a juvenile elasmosaurid no more that 3.9 m in total length.

While the majority of plesiosaur material is associated with marine shelf deposits, some specimens have been found associated with lagoonal (Forrest and Oliver, 2003), estuarine, or delta-margin environments (Cruickshank and Fordyce, 2002) and freshwater environments (Sato et al., 2005). Sedimentological evidence for the environment of deposition of the Axel Heiberg locality indicates that it was deposited in a lagoon or bay, but the evidence is equivocal as to the salinity of the water during deposition. While the occurrence of the plesiosaur suggests marine or brackish-water conditions, the associated fauna suggests a non-marine environment. Taxa found in association with plesiosaurs recovered from marine and near-shore lagoonal environments typically include a diverse assemblage of marine vertebrates. Mosasaurs (Kear, 2003) are typically found in association with plesiosaurs in Late Cretaceous vertebrate assemblages. Other marine vertebrates typically found in association with plesiosaurs include marine turtles (Whetstone, 1977; Kear, 2003) and various fishes, such as *Enchodus*, *Coelodus*, *Oseroides*, and *Hoplopteryx* (Ekrt et al., 2001). However, such taxa are absent in the Axel Heiberg assemblage. At this locality, the vertebrates found in association with the plesiosaur remains are all taxa that are typical of non-marine vertebrate assemblages. Thus the faunal evidence suggests that these teeth represent an additional non-marine occurrence of plesiosaurs.

Plesiosaur occurrences in non-marine settings are typically dominated by small individuals. In the Late Campanian Dinosaur Park Formation of Alberta, all the plesiosaur remains recovered are from individuals of small size, and one-third of the specimens show features indicative of juvenile individuals (Sato et al., 2005). The small size of the plesiosaur from the Axel Heiberg assemblage is consistent with the dominance of juveniles in non-marine environments.

The Cretaceous saw an explosion of plesiosaurian diversity, and distributions extended to above the Arctic Circle. In the Southern Hemisphere, high-latitude occurrences of Cretaceous plesiosaurs have been reported from Seymour Island of the Antarctica Peninsula (Fostowicz-Frelik and Gazdzicki, 2000), New Zealand (Wiffen and Moisley, 1986; Cruickshank and Fordyce, 2002), Argentina (Gasparini et al., 2003), and Australia (Kear, 2003). In addition to the new Axel Heiberg occurrence, high-latitude occurrences of plesiosaurs in the Cretaceous of the Northern Hemisphere include reports of plesiosaurs from the Kanguk Formation of Ellesmere Island (Fig. 43.4 of Ricketts and McIntyre, 1986) and from Upper Cretaceous

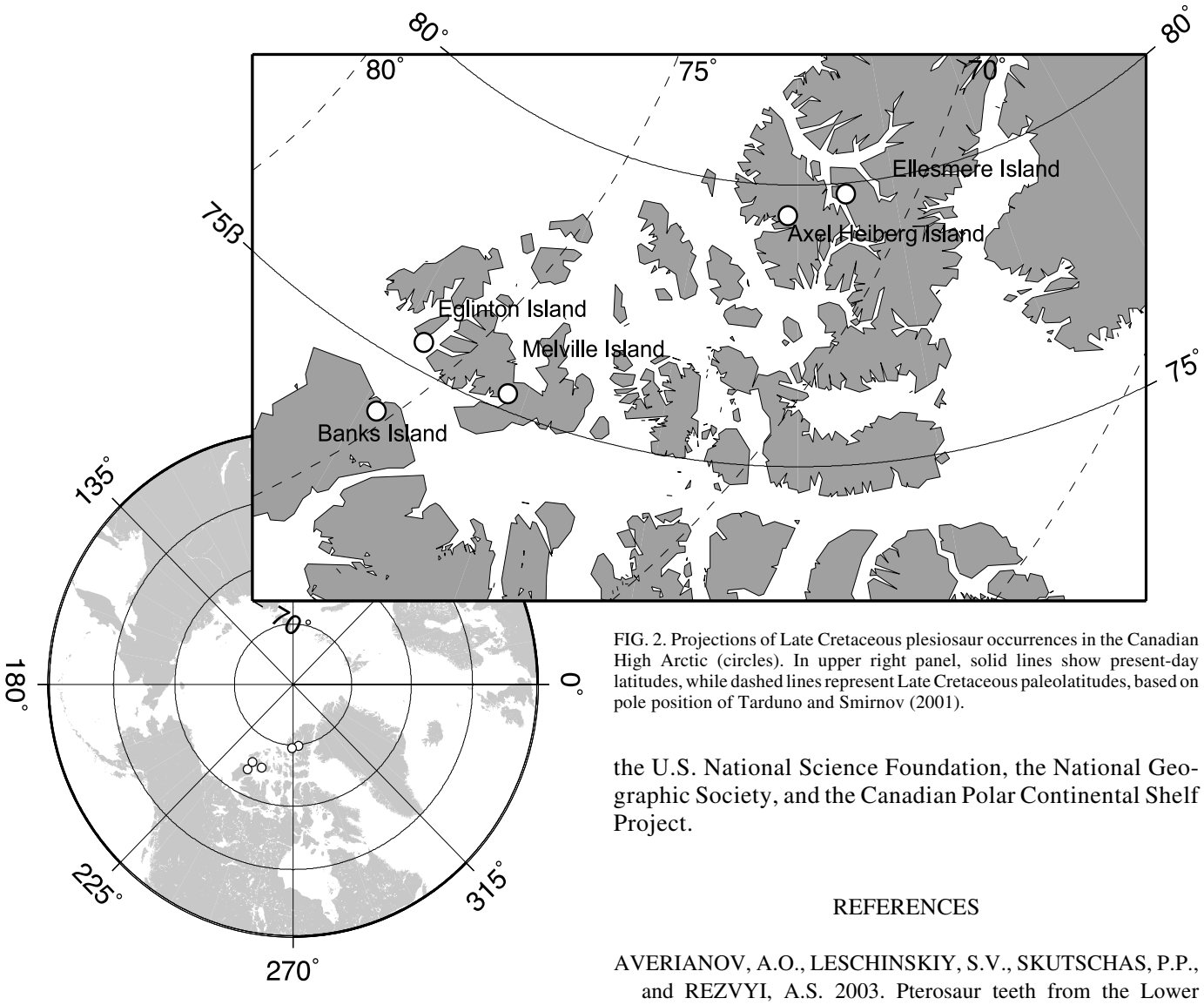

FIG. 2. Projections of Late Cretaceous plesiosaur occurrences in the Canadian High Arctic (circles). In upper right panel, solid lines show present-day latitudes, while dashed lines represent Late Cretaceous paleolatitudes, based on pole position of Tarduno and Smirnov (2001).

sediments on Banks Island (Jutard and Plauchut, 1973), Eglinton Island (Russell, 1988), and Melville Island (Tozer and Thorsteinsson, 1964) in the western Canadian Arctic (Fig. 2). The ages of some of the western Arctic occurrences are not yet well constrained, but it is possible that they are from sedimentary correlates of the Kanguk Formation (e.g., Jutard and Plauchut, 1973).

Seasonal migration of vertebrates has been discussed for some Cretaceous Arctic vertebrates (Russell, 1987). But the high-latitude distribution of plesiosaurs may also be a further reflection of the extreme Turonian-Coniacian climatic warmth, which is apparent from other vertebrates found in the Axel Heiberg assemblage (Freidman et al., 2003).

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