

# BIRD OR MANIRAPTORAN DINOSAUR? A FEMUR FROM THE ALBIAN STRATA OF SPITSBERGEN

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The first known fossil vertebrate found in the Lower Cretaceous of Spitsbergen (Svalbard, Arctic Norway) is presented and described. The specimen, a femur, was collected from the Zillerberget member of the Carolinefjellet Formation at Schönrockfjellet in 1962 and was recently re-discovered. The bone is referred to ?Avialae based on a combination of characters, including extreme thinness of the cortex, a well-developed head, and the presence of a patellar sulcus. From biostratigraphic analysis, it is demonstrated that the bone comes from the lower part of the middle Albian. This find is important because the Early Cretaceous fossil record of Avialae remains poorly documented in most parts of the World and is non-existent in Arctic strata. A general overview of the geology and stratigraphy of the Lower Cretaceous in Spitsbergen is presented in order to provide context for the fossil occurrence, with a particular focus on the Aptian and Albian sedimentary system and with the first-ever report on the entire stratigraphy on the east face of Schönrockfjellet.

**Key words:** Avialae, Albian, Spitsbergen, Carolinefjellet Formation, Cretaceous, Svalbard, Arctic.

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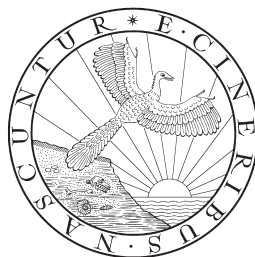
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## INTRODUCTION

Although tracks and footprints of medium- and large-sized ornithopod dinosaurs have been previously reported from the Lower Cretaceous in Svalbard (Lapparent 1962; Hurum *et al.* 2006, 2016; Midtkandal *et al.* 2007; Midtkandal and Nystuen 2009), no vertebrate fossils have hitherto been described. This paper reports the finding of the first known fossil vertebrate from the Lower Cretaceous in Svalbard. In order to provide a stratigraphic context, the paper also provides an overview of the Early Cretaceous palaeogeography, sedimentary environments and biostratigraphy of the Svalbard region. The specimen, an almost complete right femur, was originally found by Jenő Nagy in 1962 and was deposited in the Natural History Museum, Oslo, on a shelf of uncatalogued material. This dust-covered fossil was rediscovered by JHH in 2011. Nagy's detailed field notes made it possible to locate the fossil's exact stratigraphic position and locality (Fig. 1). In 2012, some of the authors (JHH, HAN, IM, and SO) revisited the Schönrockfjellet locality to see if any more vertebrate remains could be found. Although our team relocated Nagy's stratigraphic horizon, no additional bones were found on the hillside.

Although only a single element (Fig. 2), the first documented bone in the Lower Cretaceous of Svalbard is significant. At the time of deposition, the Svalbard Archipelago was situated between 63–66°N (Torsvik *et al.* 2012) and had a warm-temperate (mean annual temperature of 7–10°C) and humid climate supporting an ornithopod dinosaur population, deciduous conifers, ginkgo trees, and peat accumulations in the Barremian (Steel and Worsley 1984; Nemec 1992; Hurum *et al.* 2006, 2016; Harland *et al.* 2007). The sporadic occurrence of calcitic pseudomorphs (glendonites) and ice-rafted debris at several stratigraphic intervals within the Lower Cretaceous may suggest periods of cold (4–7°C) bottom-water conditions (De Lurio and Frakes 1999; Maher *et al.* 2004; Price and Nunn 2010; Price and Passey 2013).

Despite a great increase over the last 15 years in our knowledge of mid-Late Cretaceous non-avian and avialan theropods (including birds), the earliest stages of the Cretaceous still remain under-sampled (Brocklehurst *et al.* 2012; Mitchell and Makovicky 2014; Wang *et al.* 2015). However, recent fossil discoveries indicate that, by the Early Cretaceous, all of the currently recognised major lineages of birds had diversified (Wang *et al.* 2015). These lineages include the diverse enantiornithines, which did not survive after the end of the Cretaceous; and Ornithuromorpha, another widespread and phylogenetically diverse clade that includes the antecedents of all living birds (Wang *et al.* 2015). Any additions to the Early Cretaceous avialan fossil record are thus important, especially at extreme palaeolatitudes; with the exception of the famous Jehol Biota of western China, the bulk of the Early Cretaceous avialan fossil record is comprised of isolated and incomplete fossil remains (Brocklehurst *et al.* 2012).

This paper gives a detailed description and interpretation of the femur from Schönrockfjellet, and further argues for an avialan affinity of the fossil. The finding is also discussed in a broader context and is compared to global and other Arctic bird fossil discoveries. The fossil was collected from the Zillerberget member (Carolinefjellet Formation), which has only been briefly described and dated until this paper.

**Institutional abbreviation.** — PMO, Natural History Museum (formerly Paleontologisk Museum), University of Oslo, Oslo, Norway.

**Acknowledgements.** — In this volume dedicated to our late friend, colleague, role model and scientific co-operator, Zofia Kielan-Jaworowska, the first author (JHH) wishes to acknowledge the enormous impact she has had on his career. She was a highly inspiring supervisor for his MSc and Ph.D. during her tenure as Professor at the Natural History Museum in Oslo, Norway (1987–1995), with an enduring friendship and scientific cooperation until her last years. Her support, wide experience and sometimes radical thinking moulded a young scientist's mind. Her leadership of the Polish-Mongolian expeditions was a direct inspiration for more than ten Spitsbergen expeditions led by JHH and HAN, and some of the results from this field-work are included in this paper. Another Svalbard connection was her charismatic late husband, Zbigniew Jaworowski, who featured prominently in the expedition group spending their first ever winter season at the Polish Polar Station in Hornsund, Spitsbergen, in 1957–1958.

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Fig 1. Map of Svalbard emended from original by Winfried Dallmann (unpublished), Norwegian Polar Institute.

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## GEOLOGICAL SETTING

The bulk of Mesozoic strata on Spitsbergen are exposed along the margins of the SSE–NNW trending Central Palaeogene Basin. In western Spitsbergen, the Mesozoic strata are tectonically steeply dipped, while in eastern Spitsbergen they are gently inclined ( $< 3^\circ$ ; Steel *et al.* 1985; Midtkandal and Nystuen 2009).

During the Early Cretaceous, Svalbard was a part of the epicontinental Boreal Basin, which has since been fragmented as a result of the opening of the Atlantic (Steel and Worsley 1984). Tectonics related to igneous activity and opening of the Canada Basin during the Hauterivian to Aptian (Grantz *et al.* 2011) caused regional thermo-tectonic uplift of the northern margin of the Barents Sea Shelf, including the Svalbard

Archipelago (Maher *et al.* 2004; Corfu *et al.* 2013; Polteau *et al.* 2016). The tilting and resultant subsequent erosion of the northern shelf displaced the shoreline southeastward during the Barremian (Steel and Worsley 1984; Gjølberg and Steel 1995; Maher 2001; Midtkandal and Nystuen 2009).

Svalbard's Lower Cretaceous strata and the coeval intrusive and extrusive Diabasodden Suite are exposed on Spitsbergen and Kong Karls Land (Fig. 3). Sediments consist mainly of mudstone, siltstone and sandstone with subordinate amounts of coal and conglomerates, forming a > 1500 m thick succession, mapped as the Upper Jurassic to Lower Cretaceous Adventdalen Group (Parker 1967; Mørk *et al.* 1999). In Spitsbergen, the Cretaceous part of the Adventdalen Group comprises, in ascending stratigraphic order, the Rurikfjellet, Helvetiafjellet and Carolinefjellet formations (Parker 1967; Nagy 1970; Dypvik *et al.* 1991). The fossil specimen described here belongs in the Carolinefjellet Formation.

**Carolinefjellet Formation.** — The study area is confined to Schönrockfjellet in Heer Land on the east coast of Spitsbergen, the largest island of the Svalbard Archipelago, Arctic Norway (Fig. 1), where the specimen, PMO 228.582, was found. The locality is on the east side of Schönrockfjellet about 500 m from the coastline (*i.e.*, Schönrockfjellet Profile 4 in Nagy 1970, pl. 12; *ca.* 5 m above a sand layer; *Hoplites/Grycia* horizon, level 23; 116 m above mean sea level).

The Carolinefjellet Formation was first investigated by Nathorst (1910) and Stolley (1912), who both focused primarily on marine fossils and provided only brief stratigraphic descriptions. More detailed stratigraphic work was conducted by Hagerman (1925), Różycki (1959), and later by Parker (1967), who suggested the formal and present unit name.

The Carolinefjellet Formation is up to 1000 m thick and records an open-marine, storm-dominated shelf succession. It comprises five members that are alternately sandstone-rich or shale-dominated: Dalkjegla, Innkjegla, Langstakken, Zillerberget, and Schönrockfjellet members (the latter two have informal member status) (Parker 1967; Nagy 1970). The shale-dominated units represent outer shelf environments, and the local occurrences of sideritic mudstone horizons, strata-bound concretions and micritic hardgrounds within these units indicate periods of sediment starvation. The sandstone-rich units form southward- to southeastward-thinning wedges that contain abundant hummocky cross-stratification and scattered coquinas representing storm-dominated, inner shelf conditions (Nagy 1970; Nøttvedt and Kreisa 1987). Low relief, coastal barrier/lagoon systems have also been suggested by Mutrux *et al.* (2008). A high abundance of volcanic detritus and plagioclase in the sandstones indicates that some material was derived from a volcanic terrain that formed in association with the High Arctic Large Igneous Province north and east of Svalbard (Maher 2001; Maher *et al.* 2004; Senger *et al.* 2014; Polteau *et al.* 2016).

An angular Palaeocene unconformity truncates the Carolinefjellet Formation, leaving no Upper Cretaceous strata preserved in Svalbard. The relief of this unconformity increases to the northwest due to northern uplift (Parker 1967; Nagy 1970; Major and Nagy 1972). Therefore, all five members of the Carolinefjellet Formation are completely preserved in the southeastern parts of Spitsbergen (Fig. 3). This contrasts with central Spitsbergen, where only the two lower members are preserved (Nagy 1970; Major and Nagy 1972).

The fossil was collected from within the second youngest unit, the Zillerberget member, which has only been briefly described to date. Uncertainties remain as to the extent and distribution of the uppermost two members of the Carolinefjellet Formation in eastern and southern Spitsbergen, hence their informal status. However, there is a general consensus that the Zillerberget member formed as outer shelf deposits, while the succeeding Schönrockfjellet member represents a lower shoreface environment (Nagy 1970; Grundvåg *et al.* 2015). Storm surges on the continental shelf seems the most likely process to have been the agent of placement of the bone and its juxtaposition along with the pelecypods in the Zillerberget member.

## MATERIAL AND METHODS

Specimen PMO 228.582 was scanned using  $\mu$ -Computer tomography ( $\mu$ -CT) with a Nikon XT H 225 ST. Visualisation and digital modelling processing was completed utilising 3D Analysis Software, Avizo version 8.1 at the Natural History Museum, University of Oslo. Avizo allows for the exclusion of material in different densities, permitting the visualisation of PMO 228.582 in all dimensions, including the side imbedded in matrix, thus yielding important anatomical information otherwise unavailable.

Based on the stratigraphic sections published by Nagy (1970) and Århus (1991), and more recent field-



work conducted in 2014 (by SAG), a composite stratigraphic description was constructed (Fig. 3). The log covers all the stratigraphic units present on Schönrockfjellet (*i.e.*, the Zillerbeget and Schönrockfjellet members). The log was measured bed-by-bed, and includes descriptions of rock type, grain size, sorting, sedimentary structures, body and trace fossils, and palaeocurrent directions (no data presented here).

Five samples were collected for palynological analysis during fieldwork in the summer of 2014. All samples were prepared at the Geological Survey of Denmark and Greenland by conventional techniques used for palynological preparation. Slides were prepared from both oxidized and unoxidized residues, and each has been scanned in order to identify key species for the Lower Cretaceous dinocyst zonation of Nøhr-Hansen (1993). Note that age estimates are based on preliminary analysis, where only presence/absence data have been collected; the results of a more detailed analysis will be published elsewhere.

## RESULTS

### BIOSTRATIGRAPHIC DATING OF PMO 228.582

**Ammonite zonation.** — Ammonites and dinoflagellate cysts are the two main age-diagnostic fossil groups in the Carolinefjellet Formation. In the lower part of this formation, which is not exposed in the studied section, ammonites indicate an early-to-late Aptian age for the Dalkjegla Member (Nagy 1970), whereas late Aptian ammonites (*e.g.*, *Tropaeum arcticum*) are present in the Innkjegla Member (Stolley 1912; Frebold and Stoll 1937; Owen 1988). Nagy (1970) produced a comprehensive study of the ammonites in the upper part of the Carolinefjellet Formation in southeastern Spitsbergen. According to this study, the uppermost part of the Innkjegla Member and the entire Langstakken Member are early Albian in age because of the presence of a fauna attributable to the *Otohoplites* Ammonite Zone, the later part of the *Douvilleiceras mammillatum* Superzone (*e.g.*, Owen 1996). Nagy (1970) also suggested that the youngest units of the formation, the Zillerbeget and Schönrockfjellet members, are of middle Albian age based on an ammonite fauna dominated by *Hoplites* and *Grycia*, and attributable to the *Hoplites dentatus* Ammonite Zone (*e.g.*, Owen 1996, 1999). In addition, Nagy (1970) reported on the sporadic occurrences of *Euhoplites*, *Dimorpholites* and *Gastrolites* in loose scree. These ammonites possibly belong to the *Euhoplites lautus* Ammonite Zone and suggest that some parts of the succession may also be of late middle Albian age (Owen 1999). Nagy (1970) did not report any age-diagnostic ammonites from the Schönrockfjellet member; a middle Albian age for this unit is based solely on the lack of late Albian ammonites.

**Dinocyst zonation.** — Using dinoflagellate cysts, Århus (1991) suggested a middle Albian age for both the Zillerbeget and Schönrockfjellet members. This suggestion was based mainly on the recognition of *Litosphaeridium arundum*, *Pseudoceratium expositum* and *Odontochitina singhii*. Although Århus (1991) did not establish any formal dinocyst zonation, he noted similarities with other taxa described from northern Europe and East Greenland. As a part of the present study, correlation between the taxa reported by Århus (1991) and the Lower Cretaceous dinocyst zonation from North-Eastern Greenland suggested by Nøhr-Hansen (1993) has been conducted. New supplementary evidence includes five samples analysed from the uppermost part of the Schönrockfjellet member, an interval which was not covered by Århus (1991). By putting together the data from Århus (1991; nine samples marked as red triangles in Fig. 3) with our new samples (five samples, marked as black triangles in Fig. 3), we are able to report coverage for the entire stratigraphic section exposed on the east face of Schönrockfjellet. Our preliminary results show that most of the studied section is of middle Albian age and belong to the *Rhombodella paucispina* Zone (IV) of Nøhr-Hansen (1993).

Århus' (1991) samples show a low abundance of dinoflagellate cysts in general and a low number of age-diagnostic dinoflagellate cysts in particular. The lowest sample (SCH 660 of Århus 1991) yielded no age-indicative taxa. The two higher samples (SCH 700 and 735 of Århus 1991) contained *Pseudoceratium polymorphum* (referred to as *Aptea polymorpha*/*Cyclonephelium compactum* Group by Århus 1991), which belongs to the Zone III Subzone 4 or possibly the lower part of Zone IV of Nøhr-Hansen (1993). This indicates a latest early to middle Albian age. The higher-located samples (SCH 795, 825, 935, 965, 995 of Århus 1991) contain *Chichaouadinium vestitum*, *P. polymorphum* (referred to as *A. polymorpha*/*C. compactum* Group by Århus 1991), *Litosphaeridium arundum* and *Odontochitina singhii*, and are attributed to the Zone IV of Nøhr-Hansen (1993), thus indicating a middle Albian age. Some samples (SCH 700, 855 and 895 of

Århus 1991) were more problematic to analyse and date because the dinocyst fauna was insufficiently diverse (Århus 1991, p. 211) and not many age-markers were observed or preserved.

In five new samples from the Schönrockfjellet member, the co-occurrence of *Chichaouadinium vestitum* and *Rhombodella paucispina* narrows the age to middle Albian (and Zone IV of Nøhr-Hansen 1993). The lower part of the member (sample position: two lower black triangles in Fig. 3) most probably represents the *Litosphaeridium arundum* Subzone 1. The common presence of *C. vestitum* in the uppermost part of the member (sample position: three upper black triangles in Fig. 3) suggests that this interval belongs to the *Chichaouadinium vestitum* Subzone 2.

**Other age-diagnostic fossils.** — The large pelecypod shell that protected PMO 228.582 is a pectinid, and probably belongs to the (sub) genus *Maclearnia* (Crickmay 1930; synonym = *Boreionectes* Zakharov 1965). The specimen is preserved as an internal mold and, as such, the shell which is necessary for species identification is missing. However, additional specimens, some preserved as external molds, were collected during field work in 2012 by some of the authors (JHH, HAN, SO, IM) from the same level. These are rather smooth and display growth lines. *Maclearnia* is common in the Tithonian to Aptian (Kelly 1984; Fürsich and Thomsen 2005); the reported stratigraphic ranges for this genus are in the Early Cretaceous of Europe and Canada, and in the Pliensbachian and Valanginian of Russia (Crickmay 1930; Zakharov 1965). The present findings at the Schönrockfjellet locality expand this genus' range up into the Albian; the youngest occurrences thus far reported.

Non-age diagnostic bivalves (including pectinids) and *Ditrupa* worm tubes are very common, whereas belemnites, gastropods, crinoid fragments and echinoderms (asteroids and ophiuroids) occur more rarely (e.g., Nagy 1963, 1970; Grundvåg 2015).

In sum, the available biostratigraphic data indicate that the femur PMO 228.582 is of early–middle Albian age.

#### PALEONTOLOGICAL DESCRIPTION OF THE FEMUR

PMO 228.582 is a well-preserved but fragile femur, preserved in three dimensions in the proximal and partly in distal views (Fig. 2). The excellent preservation of this element is due to its placement under a large shell of a pelecypod (*Maclearnia* sp.); during compaction, this shell protected the fragile bone in a pressure shadow. The bone is 35 mm long and the cortex is 0.2 mm thick at midshaft, and even thinner in the femoral head. The fossil is preserved in a lens of ironstone containing a coquina of pelecypod bivalves and, close to the bone, a serpulid (*Ditrupa* sp.) and small gastropods can also be seen.

PMO 228.582 is preserved embedded in matrix, such that only the cranial aspect is visible (Fig. 2). The bone is gracile compared to small theropods (e.g., Hwang *et al.* 2002), not markedly pinched in its midshaft, and is slightly arched craniocaudally. The shaft is partially collapsed and some parts of the cortex are missing, making it possible to observe the trabeculae, especially on the proximal end. The cortex is thin: the bone wall thickness (cortex) / diameter of midshaft ratio is  $0.2/2.8 = 0.07$ . The missing parts of the cortex mean that intermuscular lines cannot be seen on the cranial surface (Fig. 2).

The femoral head of PMO 228.582 is well-defined and spherical. It faces medially and is separated from the trochanter by a slender neck (Fig. 2). The capital region is not preserved. The femoral trochanter is low; a trochanteric shelf is present and this region does not project proximally above the femoral head. An expanded iliotrochanteric muscle attachment is present just distal to the missing cortex of the trochanter (Fig. 2).

The distal end of PMO 228.582 is well-preserved and a distinct patellar groove separates the lateral and medial condyles joining the intercondylar sulcus distally (without forming a distinct ridge) (Fig. 2). The medial condyle is larger than its lateral counterpart while the latter is more distally projected (Fig. 2) and the entire distal end is turned medially (Fig. 2). There are no lateral or medial epicondyles. On the lateral condyle a fossa for the *musculus tibialis cranialis* is seen; proximal to this condyle there is an impression for the *musculus iliofibularis* (Fig. 2).

A high-resolution CT analysis was conducted in order to visualise the caudal surface of PMO 228.582 embedded in matrix (Fig. 2). However, contrast between the bone and the matrix is poor; in micro-CT images the mid shaft is undetectable but the proximal and distal ends of this bone can clearly be seen. On the proximal end, the spherical femoral head and trochanters are visible (Fig. 2) along with a distinct groove separating the greater and posterior trochanters. The posterior trochanter is about one third the size of the greater trochanter and does not project as high.

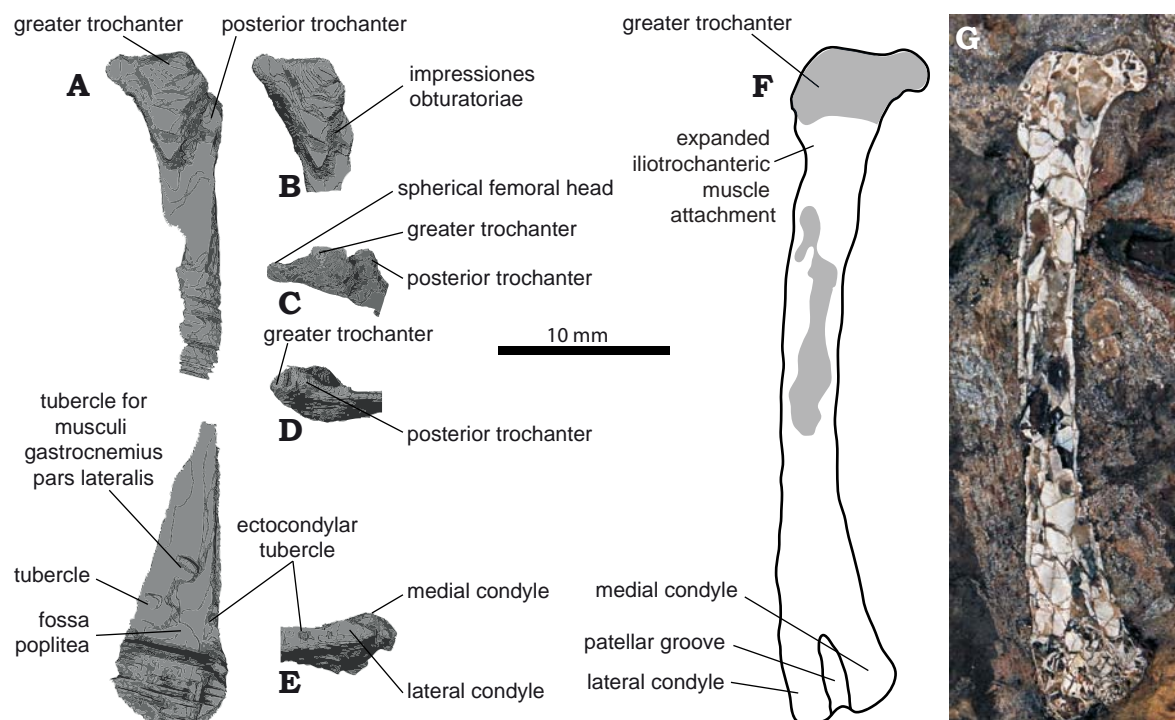


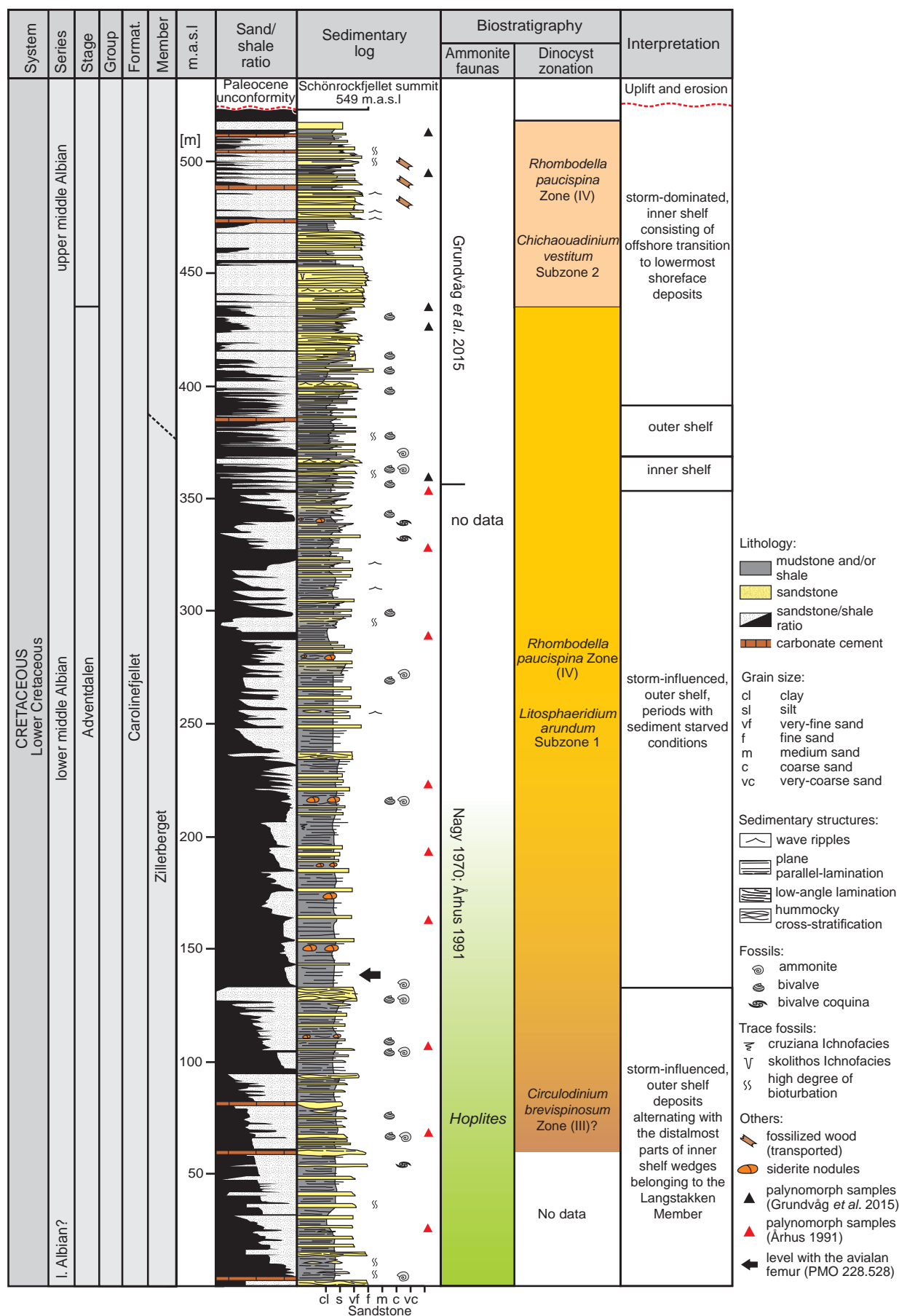
Fig. 2. Femur PMO 228.582 from Zillerberget member of the Carolinefjell Formation, Schönrockfjellet, Spitsbergen. **A.** Complete bone in caudal view, reconstructed from micro CT. **B.** femoral head in a slightly caudomedial view. **C.** Femoral head in proximal view. **D.** Femoral head in lateral view. **E.** Condyles in lateral view. **F.** Interpretive drawing of cranial aspect. Grey shading delineates where the cortex is missing. **G.** Cranial aspect of bone in matrix.

The two distal condyles of PMO 228.582 are partly crushed; the medial condyle is somewhat larger than the lateral (Fig. 2). Proximal to the condyles there are three tubercles; one is present on the medial side of the popliteal fossa; the second, on the lateral margin, is interpreted as the ectocondylar tubercle. A third, larger tubercle is placed more proximally to the latter and may be interpreted as the tubercle for the *musculus gastrocnemius pars lateralis*.

## DISCUSSION

Limited taxonomically useful characters are preserved in the specimen described here, owing to the fact that recent phylogenetic studies of basal birds do not rely heavily on femora as sources for informative characters (e.g., Wang *et al.* 2015) and these elements tend to preserve a mixture of basal and derived features. For example, the femoral popliteal fossa is not distally bounded by a complete transverse ridge and the ectocondylar tubercle and lateral condyle are separated by a deep notch (primitive characters). The femoral posterior trochanter is separated from the greater trochanter, as seen in some euenantiornithurine femora (Chiappe and Walker 2002), several theropods, *Archaeopteryx* Meyer, 1861 and Confuciusornithidae (Hutchinson 2001).

We tentatively place the femur in ?Avialae based on a combination of three of the characters described above: the presence of extremely thin-walled cortex, a well-developed femoral head, and a patellar sulcus. These three characters suggest that the femur belongs to an avialan but they are not autapomorphies exclusive to Avialae. Thin-walled bone occurs in pterosaurs, certain derived theropod dinosaurs and some mammals. Comparative data published by Currey and Alexander (1985) and Hutchinson (2001) show that the ratio of cortical thickness to mid-shaft diameter is generally around 0.2 in non-avian theropods; pterosaurs down to half of that (0.1); in more basal archosaurs about 0.3 and in most birds less than 0.2. The described femur has a ratio of 0.07 which is low even for a bird, and somewhat lower than pterosaur long bones (Fastnacht 2005; Elgin and Hone 2013). *Confuciusornis* Hou *et al.*, 1995 is comparable, with a ratio of 0.09 (Hutchinson 2001, table 3).





A well-developed femoral head and a patellar sulcus occur in mammals and some non-avian theropod dinosaurs. Even so, a patellar sulcus is suggested as an autapomorphy of Aves by Regnault *et al.* (2014) and further used as such by Wang *et al.* (2015). A well-developed femoral head projecting in an acute angle to the shaft is not present in pterosaurs (see *e.g.*, Witton 2013).

The condition of the trochanters is similar to that present in non-avian theropods, but also various birds. The inflated trochanteric area that extends lateral to the femoral shaft in cranial view is a character that is not present in most non-avian outgroups. In derived maniraptorans, the trochanteric crest is generally in line with the femoral shaft (Hutchinson 2001, figs. 3, 6, 8).

The bone is gracile and slightly arched craniocaudally, differing from hesperornithiforms (see *e.g.*, Zinoviev 2011, fig. 3) and pterosaurs (Witton 2013), in which the femur is straight; additionally, this element is more compact in hesperornithiforms. Hesperornithiforms represent the only avialan clade known from the Cretaceous of the Arctic at present and, excluding trace fossils, no prior occurrences antedate the Campanian (Rees and Lindgren 2005; Wilson *et al.* 2011). In basal avialans like *Confuciusornis sanctus* (see Martin *et al.* 1998, fig 2G) and *Sapeornis chaoyangensis* Zhou *et al.* 2002 (see Zhou and Zhang 2003, fig. 9) the craniocaudal arch is more prominent than seen in PMO 228.582. In comparison to PMO 228.582, the small and similarly-aged theropod *Microraptor zhaoianus* Xu *et al.*, 2000 (Dromaeosauridae) has a femur twice the length (74 mm) and is a considerably more robust bone, with minimum midshaft diameter of 4–5 mm (Hwang *et al.* 2002, fig. 27), as does the femur of *Confuciusornis* (Martin *et al.* 1998, fig 2G).

The taxonomic position of PMO 228.582 is unclear, as few diagnostic characters are available. However, this specimen represents the first Cretaceous vertebrate fossil from Svalbard, demonstrating the possibility of future discoveries in the region. More avialan or theropod material from Svalbard is needed to fully resolve the phylogenetic position of PMO 228.582.

## CONCLUSIONS

The ?avialan femur described herein is the only vertebrate fossil recovered to date from Cretaceous strata on Svalbard. It is also the oldest ?avialan found in the Arctic. While several ornithopod footprints have been described, PMO 228.582 is exceptional in its status as a fossil bone. This paper adds an important data point to the ongoing discussion regarding the true age of the Cretaceous strata on Svalbard and their corresponding units in the Barents Sea. It also highlights the potential for fragile non-marine vertebrate fossils to be discovered in a marine setting. The accompanying new biostratigraphic interpretation and the resolution it provides place important new constraints on the older Cretaceous strata in the region.

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- ← Fig. 3. Composite sedimentary log from Schönrockfjellet. Black arrow indicates the level where the fossil bird bone was found. Red (from Århus 1991) and black (from Grundvåg *et al.* 2015) triangles indicate stratigraphic positions of the shale samples used for biostratigraphic dating. Ammonites are sparse and belong to the *Hoplites* Ammonite Zone (Nagy 1970). The ammonite fauna and the dinoflagellate cysts together indicate that the investigated bone was deposited during the early middle Albian. Note that the lower part of the log (0–355 m) is based on data from Nagy (1970) and Århus (1991), whereas the upper part (355–520 m) is based on data from Grundvåg *et al.* (2015).

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