

Supplementary Information

**A Large Ornithurine Bird (*Tingmiatornis arctica*) from the
Turonian High Arctic: Climatic and Evolutionary
Implications**

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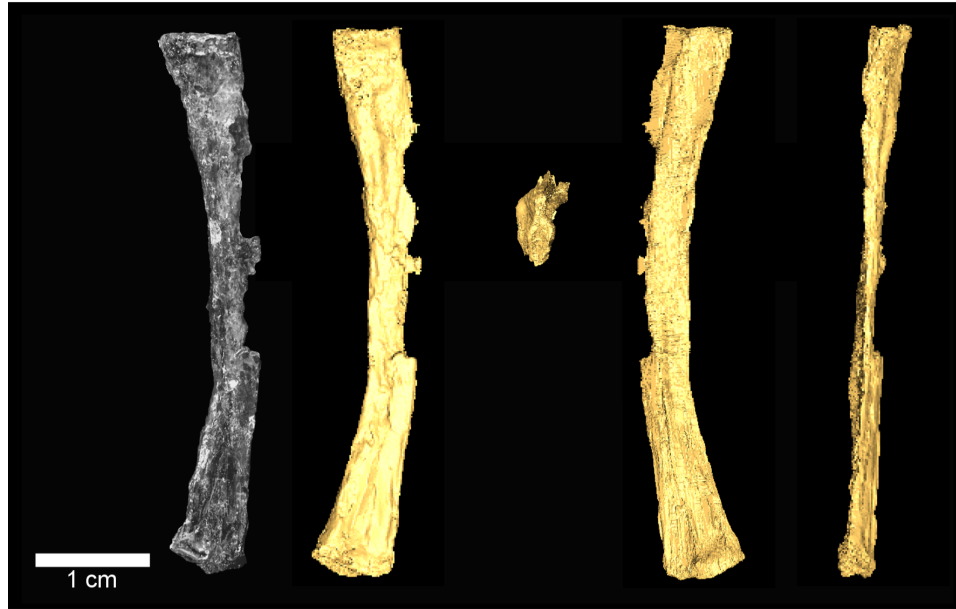
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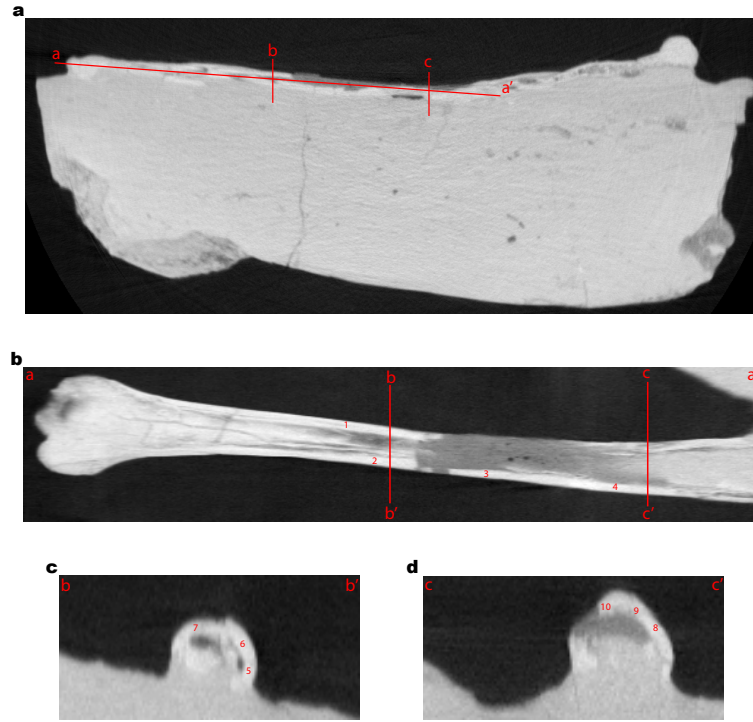
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Supplementary material for “A Large Ornithurine Bird
(*Tingmiatornis arctica*) from the Turonian High Arctic:
Climatic and Evolutionary Implications”

Supplementary Figures



Supplementary Figure S1: Unidentified bird element, *Tingmiatornis arctica*, NUFV number 1781 (specimen number 06-042). Far left: grayscale photograph of posterior and computerized tomography (CT) scans (shown left to right): caudal, dorsal, cranial, and medial views.



Supplementary Figure S2: Cortical thickness of *T. arctica* humerus (NUFV 1960). a) Reference CT image. Cross-sectional view a-a', and locations for cross-sectional views b and c, marked in red. b) Cranial view of humerus interior along a-a', cross-sectional views b-b' and c-c' marked in red. c) Cross-sectional view of humeral shaft, b-b' (red). d) Cross-sectional view of humeral shaft, c-c' (red). Red numbers in parts b, c and d mark locations for humeral cortical thickness measurements (Supplementary Table S3).

Supplementary Table S1: Late Cretaceous Northern Hemisphere Bird Localities.

Entry	Locality	Taxon	Class.*	Long.°, Lat.°	Stage	Age (Ma)	Notes
1.	Vermillion River Fm. (Manitoba, Canada)	<i>Hesperornis regalis</i> ^[1]	H	-98.1, 49.2	Early Campanian ^[2]	83.6-~81.5 ^[3]	Pembina Member now correlated to Pierre Shale ^[2]
2.	Niobrara Fm. (Kansas)	<i>Parahesperornis</i> sp. ^[4]	H	-101.1, 38.9	Early Campanian	83.6-~82.5 ^[3]	Smoky Hill Member, <i>Sca. hippocrepis</i> zone
3.	Barun Goyot Fm. (Mongolia)	<i>Hollanda luceria</i> ^[5]	O†	99.8, 43.3	Late Campanian (?)	~76.5-72.1 ^[3]	Formation age uncertain
4.	Hell Creek Fm. (Montana)	<i>Avisaurus archibaldi</i> ^[6]	E	-107.0, 47.3	Maastrichtian	72.1-66.0 ^[3]	
5.	Igneok Fm. (Alaska)	<i>Hesperornis</i> sp. ^[7]	H	-148.3, 69.4	Coniacian - Campanian	89.8-72.1 ^[3]	
6.	Marnes de la Maurine Fm. (France)	<i>Gargantuavis philoinos</i> ^[8]	O	2.2, 42.9	Late Campanian - early Maastrichtian	~76.5-~69.5 ^[3]	
7.	Tangshan Group (Zhejiang Prov.)	<i>Yandangornis longicaudus</i> ^[9]	O†	121.4, 28.4	early Late Cretaceous	~81.5-92.9 ^[10]	Xiaoxiong Basin; Tangshan Gp. is now called Xiaoxiong Group ^[10]
8.	Mesaverde Fm. (Wyoming)	<i>Hesperornis</i> sp. ^[11]	H	-107.5, 43.0	Late Campanian	~76.5-72.1 ^[3]	
9.	No Fm. reported (Lebanon)	<i>Enantiophoenix electrophyla</i> ^[12]	E	36.1, 34.3	late Middle Cenomanian	~97 ^[3]	
10.	Djadokhta Fm. (Mongolia)	<i>Gobipteryx minuta</i> ^[13]	E	99.6, 43.5	Campanian	83.6- 72.1 ^[3]	
11.	Barun Goyot Fm. (Mongolia)	<i>Gobipteryx minuta</i> ^[13]	E	99.8, 43.3	Campanian	83.6- 72.1 ^[3]	

Entry	Locality	Taxon	Class.*	Long. [°] , Lat. [°]	Stage	Age (Ma)	Notes
12.	Mooreville Chalk Fm. (Alabama)	<i>Halimornis thompsoni</i> ^[14]	E	-88.0, 32.9	Early-Middle Campanian	83.6-~76.5 ^[3]	
13.	Niobrara Fm. (Kansas)	<i>Apatornis celer</i> , <i>Iaceornis marshi</i> ^[15]	O	-101.1, 38.9	early Campanian	83.6-~82.5 ^[3]	Smoky Hill Chalk Member, assigned age data from entry #2
14.	Austin Chalk Fm. (Texas)	<i>Austinornis lentus</i> ^[15]	O	-96.6, 33.2	Coniacian - early Campanian ^[16]	89.8-~81.5 ^[3]	Location in north-east Texas, age based on foraminifera ^[16]
15.	Na.	<i>Guildavis tener</i> ^[15]	O [†]	-101.8, 38.9	Cretaceous		No formation or locality information is reported.
16.	Ozan Fm. (Arkansas)	<i>Hesperornis</i> sp. ^[17]	H	-93.6, 33.8	Campanian	83.6-72.1 ^[3]	
17.	Csehbanya Fm. (Iharkut, Hungary)	<i>Bauxitornis mind-szentyae</i> ^[18]	E	17.4, 47.1	Santonian	86.3-83.6 ^[3]	
18.	Zhuravlovskaya Svita (Kazakhstan)	<i>Asiahesperornis bazhanovi</i> ^[19]	H	64.4, 52.3	Maastrichtian	72.1-66.0 ^[3]	
19.	Dinosaur Park Fm (Alberta, Canada)	<i>Baptornis</i> ^[20] sp.	H	-110.5, 49.1	Late Campanian	~76.5-72.1 ^[3]	tentative taxonomic assignment
20.	Lance Fm. (Wyoming)	<i>Potamornis skutchi</i> ^[21]	H	-104.2, 43.1	Late Maastrichtian	~69.5-66 ^[3]	

Entry	Locality	Taxon	Class.*	Long. [°] , Lat. [°]	Stage	Age (Ma)	Notes
21.	Barun Goyot Fm. (Mongolia)	<i>Gobipteryx minuta</i> ^[22]	E	101.5, 43.3	Campanian	83.6-72.1 ^[3]	
22.	Greenhorn Limestone Fm.(Kansas)	Baptornithidae (family) ^[23]	H	-99.0, 39.0	upper Middle Cenomanian	~95.5 ^[24]	Lincoln Member, age based on Ar-Ar data ^[24]
23.	Foremost Fm.(Alberta, Canada)	<i>Hesperornis</i> cf. <i>regalis</i> ^[25]	H	-105.1, 53.3	Middle Campanian	~79.9-~76.5 ^[3,26]	Now Foremost Member of Judith River Fm within C33 ^[26]
24.	Kaskapau Fm. (Alberta, Canada)	<i>Ichthyornis</i> ^[27] sp.	O	-117.6, 55.7	Latest Cenomanian-Early Turonian	94.3-~93.0 ^[3,28]	Vimy Member; U-Pb age ^[28]
25.	Niobrara Fm. (Kansas)	<i>Hesperornis regalis</i> ^[29]	H [†]	-101.0, 39.0	Coniacian-Maastrichtian ^[30,31]	89.77-81.28 ^[3]	<i>S. preventricosus</i> to <i>S. hippocrepis III</i> of ref. [30, 31]
26.	Kanguk Fm. (Ellesmere Island, Canada)	<i>Hesperornis</i> sp. ^[32]	H	85.4, 79.5	Early to Middle Campanian	83.6-~76.5 ^[3]	
27.	No Fm. reported (Bylot Island, Canada)	<i>Canadaga arctica</i> ^[33]	H	-78.5, 73.3	middle Maastrichtian	~69.0 ^[3]	
28.	No Fm. reported (Russia)	<i>Hesperornis rossicus</i> ^[34]	H	42.8, 47.8	Early Campanian	83.6-~81.5 ^[3]	
29.	Bissekty Svita Fm. (Uzbekistan)	<i>Incolornis martini</i> ^[34,35] , <i>Explorornis Walkeri</i> ^[34]	E	65.2, 40.0	Coniacian	89.8-86.3 ^[3]	<i>I. martini</i> reclassified in ref. [35]
30.	Melovatskaya Fm. (Russia)	<i>Cerebavis cenomanica</i> ^[36]	E	44.4, 50.5	Middle Cenomanian	~96.5-~95.5 ^[3]	
31.	Nemegt Fm. (Mongolia)	<i>Teviornis gobiensis</i> ^[36]	O	100.5, 43.6	Early Maastrichtian ^[37]	72.1-~69.5 ^[3]	
32.	Mancos Shale Fm. (New Mexico)	<i>Ichthyornis</i> sp. ^[38]	O	-107.9, 35.0	Late Turonian	90.65-90.24 ^[3]	<i>Sca. whitfieldi</i> zone

Entry	Locality	Taxon	Class.*	Long. [°] , Lat. [°]	Stage	Age (Ma)	Notes
33.	Niobrara Fm. (Kansas)	<i>Hesperornis crassipes</i> , <i>Parahesperornis gracilis</i> , <i>Ichthyornis dispar</i> ^[39,40]	H, O	-99.3, 39.4	Early Campanian	83.6-~81.5 ^[3]	Pteranodon beds ^[41] , equivalent of Smoky Hill Chalk ^[42] , age from entry #2; reclassifications in ref. [40]
34.	Niobrara Fm. (Kansas)	<i>Baptornis advenus</i> ^[43]	H	-101.2, 38.9	Early Campanian	83.6-~81.5 ^[3]	Pteranodon beds ^[41] , equivalent of Smoky Hill Chalk ^[42] , age from entry #2
35.	Judith River Fm. (Montana)	<i>Hesperornis altus</i> ^[40,41]	H	-109.2, 47.3	Campanian	~78 ^[44]	Fm. uncertain; age from Ar-Ar analyses in ref. [44]; reclassifications in ref. [40]
36.	Sharon Springs Fm. (South Dakota)	<i>Brodavis varneri</i> ^[45]	H	-103.5, 43.3	Middle Campanian	~81.5-~76.5 ^[3]	Pierre Shale Group
37.	Sharon Springs Fm. (South Dakota)	<i>Hesperornis chowi</i> , <i>Hesperornis bairdi</i> ^[46]	H	-102.8, 44.0	Middle Campanian	~81.5-~76.5 ^[3]	Pierre Shale Group
38.	Sharon Springs Fm. (South Dakota)	<i>Hesperornis macdonaldi</i> ^[46]	H	-103.3, 43.5	Middle Campanian	~81.5-~76.5 ^[3]	Pierre Shale Group
39.	Sharon Springs Fm. (Manitoba Prov., Canada)	<i>Hesperornis mengeli</i> ^[46]	H	-98.1, 49.2	Campanian	83.6-72.1	Pierre Shale Group
40.	Pierre Shale Fm. (Nebraska)	<i>Hesperornis</i> sp. ^[47]	H	-104.0, 43.0	Campanian - Maastrichtian ^[48]	79.9-69.27 ^[3,48]	Age by correlation with Pierre Shale of Wyoming (C33N-C31N) and hence uncertain; tentative taxonomic assignment
41.	Upper Niobrara Fm. (South Dakota)	<i>Hesperornis regalis</i> ^[49]	H	-103.3, 43.5	Campanian	83.6-72.1 ^[3]	
42.	Niobrara Fm. (Kansas)	<i>Parahesperornis alexi</i> ^[40]	H	-99.9, 39.4	Early Campanian	83.6-~81.5 ^[3]	Smoky Hill Chalk Member
43.	Niobrara Fm. (Kansas)	<i>Baptornis advenus</i> ^[50]	H	-101.8, 38.9	Early Campanian	83.6-~81.5 ^[3]	Smoky Hill Chalk Member
44.	Frenchman Fm. (Saskatchewan, Canada)	<i>Brodavis americanus</i> ^[51]	H	-107.3, 49.1	Latest Maastrichtian	68.5-66.0 ^[3,52]	Age assigned from ref. [52] and [3] spans chron 33N/29R
45.	Hell Creek Fm. (South Dakota)	<i>Brodavis baileyi</i> ^[51]	H	-103.7, 45.4	Maastrichtian	72.1-66.0 ^[3]	

Entry	Locality	Taxon	Class.*	Long.°, Lat.°	Stage	Age (Ma)	Notes
46.	Nemegt Fm. (Mongolia)	<i>Brodavis mongoliensis</i> ^[51]	H	99.6, 43.5	Maastrichtian	72.1-66.0 ^[3]	
47.	Zhuravlevskaya Fm. (Kazakstan)	<i>Asiahesperornis bazhanovi</i> ^[53]	H [†]	64.6, 52.5	Senonian (Coniacian - Maastrichtian)	89.8-66.0 ^[3]	Age (stage) information from the Paleobiology Database download, March 2015
48.	No Fm. reported (Ukhaa Tolgod, Mongolia)	<i>Apsaravis ukhaana</i> ^[54]	E [†]	99.6, 43.5	Campanian (?)	83.6-72.1 ^[3]	
49.	Rybushka Fm. (Russia)	<i>Hesperornis rossicus</i> ^[55]	H	42.9, 48.0	Early Campanian	83.6~81.5 ^[3]	
50.	Pflugerville Fm. (Texas)	<i>Ichthyornis dispar</i> ^[56]	O	97.8, 30.3	Campanian	83.6-72.1 ^[3]	
51.	Gober Chalk Fm. (Texas)	<i>Ichthyornis dispar</i> ^[56]	O	96.1, 33.5	Campanian	83.6-72.1 ^[3]	
52.	Ector Chalk Fm. (Texas)	<i>Ichthyornis dispar</i> ^[56]	O	96.4, 33.6	Coniacian	89.8-86.3 ^[3]	
53.	Hell Creek Fm. (North Dakota)	Hesperornithiformes (<i>Potamor-nis</i>) ^[57]	H [†]	-103.7, 46.1	Maastrichtian	72.1-66.0 ^[3]	tentative taxonomic assignment
54.	No Fm. reported (Ivö Klack, Sweden)	<i>Hesperornis</i> sp., <i>Baptornis</i> sp., <i>Hesperornis rossicus</i> ^[58]	H	14.4, 56.1	latest Early Campanian	83.6-81.5 ^[3]	No attempt made to subdivide E. Campanian
55.	Anderson River beds (Mackenzie, NWT, Canada)	<i>Hesperornis regalis</i> ^[59]	H	-129.1, 69.7	Early Campanian	83.6~81.5 ^[3]	Age assignment based on correlation with Niobrara fauna
56.	Cambridge Greensand Fm. (England)	<i>Enaliornis barretti</i> , <i>Enaliornis sedgwicki</i> ^[60]	H	0.1, 52.2	Late Albian	~107.5-100.5 ^[3]	Age (stage) information from the Paleobiology Database download, March 2015
57.	Claggett Fm. (Montana)	<i>Hesperornis montana</i> ^[61]	H	-109.6, 47.7	latest lower to earliest upper Campanian ^[62]	83.6-72.1 ^[3]	No attempt to divide Campanian
58.	Judith River Fm. (Saskatchewan, Canada)	<i>Baptornis</i> sp. ^[63]	H	-107.8, 50.5	Campanian	83.6-72.1 ^[3]	

Entry	Locality	Taxon	Class.*	Long. [°] , Lat. [°]	Stage	Age (Ma)	Notes
59.	Frenchman Fm. (Saskatchewan, Canada)	<i>Cimolopteryx</i> sp. ^[64]	O	-108.4, 49.7	Latest Maastrichtian	68.5-66.0 ^[3,52]	
60.	Pierre Shale Fm. (Saskatchewan, Canada)	<i>Hesperornis</i> sp. ^[65]	H	-103.7, 53.1	Early Campanian ^[65]	83.6-~81.5 ^[3]	
61.	Bell Fourche Fm. (Saskatchewan, Canada)	<i>Pasquiaornis</i> <i>hardiei</i> , <i>Pasquiaornis</i> <i>tankei</i> , <i>Ichthyornis</i> (Species A and B), Enantiornithes ^[66]	E, H, O	-103.6, 53.3	Middle-Late Cenomanian ^[67]	96.5-~95.2 ^[3,67]	young-age con- straint based on data quoted in ref. [67]
62.	Woodbine Fm., (Texas)	<i>Flexomornis</i> <i>howei</i> ^[68]	E	-97.3, 32.6	early-Middle Cenomanian	~96.5-~95.5 ^[3]	No attempt to divide Mid- Cenomanian
63.	Two Medicine Fm. (Montana)	<i>Avisaurus</i> <i>gloriae</i> ^[69]	E	-113.0, 48.7	Campanian	83.6-72.1 ^[3]	
64.	Two Medicine Fm. (Montana)	<i>Piksi</i> <i>barbanula</i> ^[70]	O	-113.0, 48.7	Campanian	83.6-72.1 ^[3]	
65.	no Fm. reported (Masecaps, France)	<i>Martinavis</i> <i>cruzyensis</i> ^[71]	E	2.9, 43.4	Late Campanian-Early Maastrichtian	~76.5-~70.0 ^[3]	
66.	Jiangdihe Fm. (Yunnan Province, China)	<i>Parvavis chux-</i> <i>iongensis</i> ^[72]	E	101.5, 25.0	Turonian- Santonian	93.9-83.6 ^[3]	
67.	Kanguk Fm. (Nunavut, Canada)	<i>Canadaga</i> <i>arctica</i> ^[73]	H	-87.1, 75.1	Campanian	83.6-72.1 ^[3]	

*Classification of entry for Figure 2: E, Enantiornithes; H, Hesperornithiformes; O, non-Hesperornithiform ornithurines. †Tentative taxonomic assignment.

Supplementary Table S2: Comparison between *Tingmiatornis arctica* and *Pasquiaornis humerii*

Humerus	<i>Tingmiatornis</i> *	<i>Pasquiaornis</i> [†] (min.-max.)	<i>Pasquiaornis</i> [†] (average $\pm$ s.d.)
Length	118.7	102.8	
Deltapectoral crest extension	37.0		
Proximal end breadth	21.0	6.9-19.8	15.4 $\pm$ 3.8
Distal end breadth	13.4, 16.4	5.5-13.7	10.7 $\pm$ 2.6
Mid-shaft diameter	8.5	3.0-7.4	5.2 $\pm$ 1.1

*Measurements for *Tingmiatornis arctica* from this study. [†]Measurements for *Pasquiaornis* from Sanchez (2010). Reported above are *Pasquiaornis* minimum and maximum ranges, and average size with one standard deviation for each measurement. All measurements in mm.

Supplementary Table S3: Cortical thickness measurements for *T. arctica* humerus (NUFV 1960)

Spot	Thickness (mm)
1	1.64
2	1.43
3	1.33
4	1.23
5	1.12
6	1.10
7	1.10
8	1.04
9	1.27
10	1.15
Average $\pm$ s.d.	1.24 $\pm$ 0.19

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