

# Biostratigraphy and avian origins in northeastern China

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## *Abstract*

The Late Jurassic age frequently attributed to fossils from the Yixian Formation (Liaoning and Hebei provinces, People's Republic of China), including theropod dinosaurs with feathers or integumentary structures (for example, *Beipiaosaurus*, *Caudipteryx*, *Protarchaeopteryx*, *Sinornithosaurus* and *Sinosauropteryx*) and the primitive bird *Confuciusornis*, is based heavily on biostratigraphic arguments. However, most Yixian taxa are endemic, known only from singular localities and few specimens. Accurate biostratigraphic correlation requires geographically widespread taxa represented by many specimens and restricted stratigraphic ranges. Other support for a Late Jurassic age based on fauna-level differences from well-constrained Early Cretaceous faunas and assumed "stage of evolution" comparisons are dubious when taphonomic and paleoecological factors are taken into account. Precise dating of the beds is important because, if these are truly Late Jurassic, then the hypotheses advocating a maniraptoriform theropod ancestry of birds are complicated. Radiometric dates obtained from interbedded volcanics in the Yixian Formation yield Early Cretaceous ages, which contrast sharply with many of the biostratigraphic data, implying that the primitive Yixian taxa may be relicts. Given the problems with Yixian biostratigraphy, the radiometric data, which indicate Cretaceous ages between 120 and 25 my, must be viewed as the best evidence for the age of the Yixian Formation.

## *Keywords*

Sihetun, geochronology, Liaoning, birds, feathered dinosaurs, Yixian.

## Appendix: Biota of the Yixian Formation and the endemicity of its taxa

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## Appendix: Biota of the Yixian Formation and the endemism of its taxa

Abbreviations and symbols used in the table are as follows: **N**, endemic; **G**, both genus and species endemic to Yixian Formation; **S**, species (only) endemic to Yixian Formation; **J**, Jiufotang Formation; **H**, Shanhai Formation; **F**, Fuxin Formation; **O**, older; **C**, coeval; **Y**, younger; **E**, Early; **M**, Middle; **L**, Late; **Ord**, Ordovician; **Carb**, Carboniferous; **P**, Permian; **Tr**, Triassic; **Jr**, Jurassic; **K**, Cretaceous; **Pal**, Paleocene; **Eoc**, Eocene; **Olig**, Oligocene; **Mio**, Miocene; **Plio**, Pliocene; **Plei**, Pleiocene; **Holo**, Holocene; **Plg**, Paleogene; **Neog**, Neogene; **X**, reference in the last column mentions species without reference or notes further references that either were not cited or could not be obtained for this analysis. A question mark (?) indicates unknown or uncertain; an asterisk (\*) indicates the species is identical between Yixian and other formation (absence of an asterisk indicates only the genus is shared); minus (-) indicates "no," plus (+) indicates "yes," but more specific information is unavailable. Citation numbers refer to numbered references in the Literature Cited. Footnotes are listed at the end of the table.

	Principal citations for Yixian Fm	Taxon occurs			Chronological Range		Citations (for earliest occurrences of	
		Higher within Jethol	Elsewhere in East	Elsewhere				
<b>Palynomorph</b>								
<i>Abietinaepollenites</i> sp.	168	?	?	O, C, Y	O, C, Y	L Tr?-Quat	?	259, 301/186, 115
<i>Aequitriradites spinulosus</i>	148, 221	—	J*, H*, F*	C*?, Y*	O*, C*, Y*	L Jr-Mio	L Jr -Mio	331 <sup>†</sup> , 323/132
<i>A. verrucosus</i>	221	—	J*, H*, F*	C*?, Y*	O*, C*, Y*	L Jr-Mio	L Jr- Eoc	331 <sup>†</sup> /93 <sup>†</sup>
<i>Bayanhuaspora setacea</i>	221	—	J*, F*	C*?	—	E K?	E K?	348 <sup>†</sup>
<i>Cicatricosisporites australiensis</i>	148, 221	—	J*, H*, F*	C*?, Y*	O*, C*, Y*	L Tr?-Neog	L Tr-Neog	64 <sup>†</sup> , 129, 16/113
<i>C. curvatus</i>	148, 221	—	H*	—	—	L Tr?-Neog	E K	221 <sup>†</sup>
<i>C. dorogensis</i>	221	—	—	C*?, Y*	O*, C*, Y*	L Tr?-Neog	E Jr-Neog	332 <sup>†</sup> /57 <sup>†</sup>
<i>C. liaoningensis</i>	221	S	—	—	—	L Tr?-Neog	S	221 <sup>†</sup>
<i>C. ludbrookii</i>	148, 221	—	J*, H*, F*	O*, C*?, Y*	O*, C*, Y*	L Tr?-Neog	L Jr-Pal	167 <sup>†</sup> /91 <sup>†</sup>
<i>C. minor</i>	148, 221	—	J*, H*, F*	C*?, Y*	O*, C*, Y*	L Tr?-Neog	L Jr-Pal	244 <sup>†</sup> /281 <sup>†</sup>
<i>C. minutaestriatus</i>	148, 221	—	J*, H*, F*	C*?, Y*	O*, C*, Y*	L Tr?-Neog	E Jr-Olig	300 <sup>†</sup> /133 <sup>†</sup>
<i>C. sibiricus</i>	148, 221	—	—	Y*	O*, C*, Y*	L Tr?-Neog	E K	6 <sup>†</sup> , 53 <sup>†</sup>
<i>C. spiralis</i>	148, 221	—	J*	C*?, Y*	C*, Y*	L Tr?-Neog	E K-L K	176 <sup>†</sup> , 70 <sup>†</sup> , 299 <sup>†</sup> /216 <sup>†</sup> , 270 <sup>†</sup> , 271 <sup>†</sup> , 272 <sup>†</sup>
<i>C. suibinensis</i>	221, 274	S	—	—	—	L Tr?-Neog	S	221 <sup>†</sup> , 274 <sup>†</sup>
<i>Classopollis annulatus</i>	221	—	J*, H*, F*	O*, C*?, Y*	—	L Tr-Pal	L Tr-Pal	28 <sup>†</sup> /222 <sup>†</sup>
<i>Concavissimisporites minor</i>	147, 221	—	J*, H*, F*	O*, C*?, Y*	O*, C*, Y*	M Jr-L K	M Jr-E K	245, 223 <sup>†</sup> , 19 <sup>†</sup> /202, 216 <sup>†</sup> , 334
<i>C. punctatus</i>	221	—	J*, H*, F*	C*?, Y*	O*, C*, Y*	M Jr-L K	M Jr-L K	223 <sup>†</sup> , 19 <sup>†</sup>
<i>C. variverrucatus</i>	221	—	J*, H*, F*	C*?, Y*	O*, C*, Y*	M Jr-L K	M Jr-L K	223 <sup>†</sup> , 19 <sup>†</sup>
<i>Coptospora granulata</i>	221	—	F*	C*?	—	E K	E K	335 <sup>†</sup>
<i>Couperisporites complexus</i>	148, 221	—	J*	C*?, Y*	O*, C*, Y*	L Jr-E K	L Jr-E K	1 <sup>†</sup> /216 <sup>†</sup>
<i>Cyathidites australis</i>	221	—	J*, H*, F*	O*, C*?, Y*	O*, C*, Y*	M Tr-Neog	L Tr-Mio	71 <sup>†</sup> , 254 <sup>†</sup> , 129/132 <sup>†</sup> , 250
<i>C. minor</i>	221	—	J*, H*, F*	O*, C*?, Y*	O*, C*, Y*	M Tr-Neog	L Tr-Mio	71 <sup>†</sup> , 254 <sup>†</sup> /132 <sup>†</sup>
<i>Cycadopites nitidus</i>	221	—	J*, H*, F*	O*, C*?, Y*	O*, C*, Y*	L P-Olig	L P-Olig	49 <sup>†</sup> , 205 <sup>†</sup> /4 <sup>†</sup>
<i>Densosporites microrugulatus</i>	221	—	J*, H*	O*, C*?, Y*	O*, C*, Y*	L Tr-L K	L Tr-L K?	254 <sup>†</sup> , 89, 94 <sup>†</sup> /141, 10 <sup>†</sup> , 134
<i>D. perinatus</i>	168, 221	—	J*, H*, F*	O*, C*?, Y*	O*, C*, Y*	L Tr-L K	L Tr-L K	254 <sup>†</sup> , 94 <sup>†</sup> /135 <sup>†</sup> , 134 <sup>†</sup>
<i>D. velatus</i>	221	—	J*, H*, F*	C*?, Y*	O*, C*, Y*	L Tr-L K	L Tr-L K	254 <sup>†</sup> , 94 <sup>†</sup> /135 <sup>†</sup> , 134 <sup>†</sup>
<i>Fixisporites tortus</i>	148, 221	—	J*, H*, F*	O*, C*?, Y*	—	E K	E K	348 <sup>†</sup>

Continued.

## Appendix, continued.

Type	Taxon	Taxon occurs					Chronological Range		Citations (for earliest occurrences of genus/species) <sup>a, g</sup>
		Principal citations for Yixian Fm occurrence <sup>a</sup>	N <sup>b</sup>	Higher within Jethol Group <sup>c</sup>	Elsewhere in East Asia <sup>d</sup>	Elsewhere globally <sup>e</sup>	Genus <sup>f</sup>	Species <sup>f</sup>	
	<i>Foraminisporites</i> sp. <sup>h</sup>	168	?	?	?	?	?	?	?
	<i>Heliosporites</i> sp.	221	?	J	?	?	?	?	?
	<i>Hsuisporites jiufoatangensis</i>	221	—	J*, H*	?	—	E K-Eoc	E K	310/146, 221 <sup>†</sup>
	<i>H. multiradiatus</i>	221	—	J*, H*, F*	O*?, C*?	—	E K-Eoc	E K-L K	334 <sup>†</sup> /347 <sup>†</sup>
	<i>H. rugatus</i>	221	—	H*, F*	O*?, C*?	—	E K-Eoc	E K-Pal	333 <sup>†</sup> /305
	<i>Impardecispora apiverrucata</i>	148, 221	—	J*, H*, F*	C*?, Y*	O*, C*, Y*	M Jr-L K	M Jr-L K	47 <sup>†</sup> , 43 <sup>†</sup> /303 <sup>†</sup> , 169 <sup>†</sup>
	<i>Inaperturopollenites</i> spp.	221	?	J, H, F	O, C?, Y	O, C, Y	L Carb-Plei	?	198/211, 18
	<i>Klukisporites pseudoreticulatus</i>	221	—	J*, H*, F*	O*, C*?, Y*	O*, C*, Y*	L Tr-Plg	L Tr-Mio	301 <sup>†</sup> /132 <sup>†</sup>
	<i>K. variegatus</i>	221	—	J*, H*, F*	O*, C*?, Y*	O*, C*, Y*	L Tr-Plg	E Jr-M Eoc	130 <sup>†</sup> /181 <sup>†</sup>
	<i>Leptolepidites verrucatus</i>	221	—	J*, H*, F*	C*?, Y*	O*, C*, Y*	L Tr-Plio?	L Tr-Plio?	265 <sup>†</sup> /187 <sup>†</sup> , 166 <sup>†</sup>
	<i>Lycopodiacidites cerniidites</i>	221	—	J*	C*?, Y*	O*, C*, Y*	E Jr-L K	E Jr-L K	43 <sup>†</sup> /12 <sup>†</sup>
	<i>Lycopodiumsporites austroclavatidites</i>	221	—	J*, H*, F*	O*, C*?	O*, C*, Y*	L Tr-Mio	L Tr-Mio	228 <sup>†</sup> /13 <sup>†</sup>
	<i>L. reticulumsporites</i>	221	—	J*	O*, C*?	O*, C*, Y*	L Tr-Mio	M Tr-L K	50 <sup>†</sup> /158 <sup>†</sup>
	<i>Lygodiumsporites subsimplex</i>	221	—	J*, H*, F*	C*?, Y*	O*, C*, Y*	M Jr-L K	M Jr-L K	2 <sup>†</sup> /182 <sup>†</sup>
	<i>Osmundacidites speciosus</i>	221	—	J*, H*, F*	C*?, Y*	—	L Tr-Mio	E K	349 <sup>†</sup>
	<i>O. wellmanii</i>	221	—	J*, H*, F*	?	O*, C*, Y*	L Tr-Mio	L Tr-Mio	48 <sup>†</sup> /287 <sup>†</sup>
	<i>Piceapollenites</i> spp.	221	?	J, H, F	O, C?, Y	O, C, Y	L Carb-Plei	?	296, 88/269, 177
	<i>Pinuspollenites</i> spp.	221	?	J, H, F	O, C?, Y	O, C, Y	L P-Plei	?	351/252
	<i>Podocarpidites</i> spp.	221	?	J, H, F	O, C?, Y	O, C, Y	E P-Plei	?	220/115
	<i>Rusatisporis kazouensis</i>	221	S	—	?	—	E K	E K	221 <sup>†</sup>
	<i>Schizaeoisporites certus</i>	221	—	J*, H*, F*	C*?, Y	—	L Jr-Plg	L Jr-Plg	249 <sup>†</sup> /133 <sup>†</sup>
	<i>Toroisporis yixianensis</i>	221	S	F	O, C?, Y	O, C, Y	L P-L Mio	S	214, 215/204, 62
	<i>Triporetetes reticulatus</i>	148, 221	—	J*, H*, F*	C*?, Y*	O*, C*, Y*	L Jr?-L K?	L Jr?-L K?	245 <sup>†</sup> /23 <sup>†</sup> , 137 <sup>†</sup>
<b>Sphenophyta</b>									
	<i>Equisittites</i> sp.	24, 352	?	J, H, F	O, C?	O, C, Y	Carb?-Holo?	?	291, 292
<b>Pteridophyta</b>									
	<i>Cladophlebis</i> spp.	54	?	J, H, F	O, Y	O, C?, Y	L Tr-L K	?	8/297
	<i>Coniopteris</i> sp.	24	?	H, F	O	C?, Y	M Jr-L K	?	291/297
	<i>Onychiopsis psilotoides</i> (= <i>O. elongata</i> )	152, 297	—	J*, H*, F*	Y?	O	L Jr-L K	E K	297 <sup>†</sup> , 278 <sup>†</sup>
	? <i>Ruffordia</i> sp.	24	?	F	Y	O, C?, Y	E K-L K	?	291/297
<b>Ginkgophyta</b>									
	<i>Baiera</i> cf. <i>gracilis</i>	152	—	J*, F*	O*	O, C, Y	E Jr-L K	L Jr-L K	188 <sup>†</sup> , 291, 297 <sup>†</sup>
	<i>B. orientalis</i>	152	S	J, F	O	O, C, Y	E Jr-L K	S	X
	<i>Czekanowskia rigida</i>	152	—	J*, H*	O*, C?	O, C	E Jr-L K	E Jr-E K	297 <sup>†</sup> , 278, 352 <sup>†</sup>
	<i>Ginkgoites sibiricus</i>	152	—	J*, F*	O?, C*?	O, C, Y?	L Tr-Holo?	M Jr-E K	8, 320, 352/291, 297
	<i>Leptostrobus</i> sp.	24	?	—	O, C?,	O,	E Jr-E K	?	291, 297
	<i>Nageiopsis?</i> sp.	34	?	?	?	Y	?-L K	?	297
	<i>Phoenicopsis</i> cf. <i>augustifolia</i>	24, 352	—	J*, H, F	O*?	O, C?, Y	L Tr-L K	E Jr-E K	8, 352 <sup>†</sup> /297 <sup>†</sup>
	<i>Solenites</i> sp.	24, 352	?	J, H	O	—	L Jr-E K	?	352/278
	<i>Sphenobaiera longifolia</i>	54	—	F*	O*, C?, Y	O	L Tr-L K	M Jr-E K	188 <sup>†</sup> , 8/297 <sup>†</sup>

Continued.

## Appendix, continued.

Type	Taxon	Taxon occurs				Chronological Range			Citations (for earliest occurrences of genus/species) <sup>a, g</sup>
		Principal citations for Yixian Fm occurrence <sup>a</sup>	N <sup>b</sup>	Higher within Jethol Group <sup>c</sup>	Elsewhere in East Asia <sup>d</sup>	Elsewhere globally <sup>e</sup>	Genus <sup>f</sup>	Species <sup>f</sup>	
<b>Cycadophyta</b>									
	<i>Tyrmiia</i> sp.	24	?	J, H	O	—	E Jr-E K	?	320/297
<b>Coniferophyta</b>									
	<i>Elatocladus manchurica</i>	54	—	J*, H*, F*	O*, C?, Y	O, C?, Y	L Tr-L K	?	9/297 <sup>†</sup>
	<i>Pityolepis</i> sp.	24	?	J	O, C?	C?	E Jr-E K	?	352/297
	<i>Pityophyllum</i> cf. <i>lindstroemi</i>	152	S	H, F	O*	O, C, Y	E Jr-L K	S	297
	<i>Podozamites lanceolatus</i>	152	—	J, H, F*	O*, C, Y	O, C, Y	M Tr-L K	E Jr-E K	116/297
	<i>Schizolepis jeholensis</i>	152	—	J*, H	C?	O, C?	L Tr-E K	S	8/139, 152 <sup>†</sup>
	<i>Sequoia? jeholensis</i>	152	—	J*	?	Y	L Jr-Holo	E K	294/297
	<i>Yanliaolia sinensis</i>	54	—	?	O*, C*?	—	M Jr?-E K?	M Jr?-E K?	X, 320 <sup>†</sup> , 346 <sup>†</sup>
<b>Gnetales<sup>1</sup></b>									
	<i>Chaoyangicarpus liangi</i> <sup>j</sup>	55	G	G	G	G	G	G	G
	<i>Eragrosites changii</i>	24	G	G	G	G	G	G	G
<b>Angiospermae</b>									
	<i>Archaeofructus liaoningensis</i>	279	G	G	G	G	G	G	G
	<i>Davallia? niehhtzuensis</i>	152	G	G	G	G	G	G	G
	<i>Liaoxia chenii</i>	24	G	G	G	G	G	G	G
	<i>Potamogeton?</i> (= <i>Ranunculus</i> ) <i>jeholensis</i>	24, 152	—	?	C*?	Y	E K-Mio	?	320 <sup>†</sup> , 139/291
<b>Bivalvia</b>									
	<i>Ferganoconcha</i> cf. <i>burejensis</i>	340	—	J, H*, F*	O*, C*?, Y*?	—	M Jr-E K	E K?	44/188, 340 <sup>†</sup> , 261 <sup>†</sup> , 313 <sup>†</sup> , 336
	<i>F. curta</i>	340	—	J, H*, F*	O*, C*, Y*?	—	M Jr-E K	E K?	340 <sup>†</sup> , 261 <sup>†</sup> , 313 <sup>†</sup>
	<i>F. estheriaeformis</i>	338	—	J, H, F	O*, C, Y	—	M Jr-E K	E K?	340 <sup>†</sup> , 261 <sup>†</sup> , 313 <sup>†</sup>
	<i>F. hebeiensis</i>	338	S	J, H, F	O, C, Y	—	M Jr-E K	S	S
	<i>F. jorekensis</i>	340	—	J*, H*, F*	O*, C?, Y?	—	M Jr-E K	E K?	340 <sup>†</sup> , 261 <sup>†</sup> , 313 <sup>†</sup>
	<i>F. jurassica</i>	338	S	J, H, F	O, C*?, Y	—	M Jr-E K	S	S
	<i>F. lingyuanensis</i>	338, 340	—	J, H*, F*	O, C*?, Y*	—	M Jr-E K	E K?	340 <sup>†</sup> , 261 <sup>†</sup> , 313 <sup>†</sup> , 356 <sup>†</sup>
	<i>F. pingquanensis</i>	338	S	J, H, F	O, C, Y	—	M Jr-E K	S	S
	<i>F. quadrata</i>	338, 340	—	J, F*	O, C*?, Y*	—	M Jr-E K	E K?	340 <sup>†</sup> , 261 <sup>†</sup> , 313 <sup>†</sup> , 356 <sup>†</sup>
	<i>F. sibirica</i>	308	—	J*, H*, F*	O*, C*?, Y*	—	M Jr-E K	M Jr-E K?	340 <sup>†</sup> , 261 <sup>†</sup> , 313 <sup>†</sup> , 356 <sup>†</sup>
	<i>F. subcentralis</i>	338, 340	—	J*, H*, F*	O*, C*?, Y*	—	M Jr-E K	M Jr-E K?	340 <sup>†</sup> , 261 <sup>†</sup> , 313 <sup>†</sup> , 356 <sup>†</sup>
	<i>F. tomiensis</i>	338	—	J, H, F	O, C*, Y*	—	M Jr-E K	E K?	338 <sup>†</sup> , 356 <sup>†</sup>
	<i>F. cf. yanshanensis</i>	338	—	J, H, F	O, C*?, Y	—	M Jr-E K	E K?	338 <sup>†</sup> , 356 <sup>†</sup>
	<i>Margaritifera</i> (?= <i>Mengyinaia</i> ) sp.	35	?	J, H, F	O, C?	Y	L K-Holo	?	44
	<i>Myrene</i> (=? <i>Corbicula</i> ) ( <i>Mesocorbicula</i> ) <i>tetoriensis</i>	35	—	—	O, C*?	C?	M Jr-E K	M Jr-E K	178 <sup>†</sup> , 179 <sup>†</sup> , 44
	<i>Neomiodon hebeiensis</i>	338	S	J	C?	O, C?	M Jr-E K	S	44/338, 355 <sup>†</sup>
	<i>Sibireconcha? dageensis</i>	338	S	—	O	—	L Tr-M Jr	S	45/188, 261, 338 <sup>†</sup>

Continued.

## Appendix, continued.

Type	Taxon	Taxon occurs					Chronological Range		
		Principal citations for Yixian Fm occurrence <sup>a</sup>	N <sup>b</sup>	Higher within Jethol Group <sup>c</sup>	Elsewhere in East Asia <sup>d</sup>	Elsewhere globally <sup>e</sup>	Genus <sup>f</sup>	Species <sup>f</sup>	Citations (for earliest occurrences of genus/species) <sup>a, g</sup>
	<i>S. fengningensis</i>	338	S	—	O	—	L Tr-M Jr	S	338 <sup>†</sup>
	<i>S. sichuanensis</i>	338	—	—	O	—	L Tr-M Jr	?	X
	<i>Sphaerium</i> cf. <i>anderssoni</i>	313	—	J*, H*, F*	C*?, Y?	C?, Y	L Jr-Holo	?	44, 261 <sup>†</sup> , 313 <sup>†</sup> , 336 <sup>†</sup> , 338 <sup>†</sup> , 354 <sup>†</sup> , 356 <sup>†</sup>
	<i>S. jeholense</i>	35	—	J*, H*, F*	C*?, Y*?	C?, Y	L Jr-Holo	?	188 <sup>†</sup> , 261 <sup>†</sup> , 336 <sup>†</sup> , 338 <sup>†</sup> , 354 <sup>†</sup> , 356 <sup>†</sup>
	<i>S.</i> cf. <i>orientalis</i>	338	S	J, H, F	C?, Y?	C?, Y	L Jr-Holo	S	338 <sup>†</sup>
	<i>S. pinguanense</i>	338	S	J, H, F	C?, Y?	C?, Y	L Jr-Holo	S	338 <sup>†</sup>
	<i>S. pujiangense</i>	338	—	J*, H*, F*	C*?, Y*?	C?, Y	L Jr-Holo	?	X, 188 <sup>†</sup>
	<i>S.</i> aff. <i>rectiglobosum</i>	338	—	J, H, F	C?, Y?	C?, Y	L Jr-Holo	?	X
	<i>S. rotundum</i>	338	—	J*, H, F	C*?, Y?	C?, Y	L Jr-Holo	?	313 <sup>†</sup> ; 356 <sup>†</sup>
	<i>S. simplex</i>	338	S	J, H, F	C?, Y?	C?, Y	L Jr-Holo	S	338 <sup>†</sup>
	<i>S. subplanum</i>	340	—	J*, H*, F*	C*?, Y*?	C?, Y	L Jr-Holo	?	188 <sup>†</sup> , 354 <sup>†</sup> , 356 <sup>†</sup>
	<i>S. selenginense</i>	340	—	J*, H*, F	C*?, Y?	C?, Y	L Jr-Holo	?	X, 188 <sup>†</sup> , 354 <sup>†</sup> , 356 <sup>†</sup>
	<i>S.</i> aff. <i>yanbianense</i>	338	—	J, H, F	C*?, Y*?	C?, Y	L Jr-Holo	?	X
	<i>S. elliptiformis</i>	338	S	J	—	—	E K?	S	338 <sup>†</sup>
	<i>S. luanpingensis</i>	338	S	J	—	—	E K?	S	338 <sup>†</sup>
	<i>S. sinensis</i>	338	S	J	—	—	E K?	S	338 <sup>†</sup>
	<i>S. subcentralis</i>	338	—	J*	—	—	E K?	E K?	338
	<i>S. triangulates</i>	338	S	J	—	—	E K?	S	338 <sup>†</sup>
	<i>Tetoria?</i> sp.	338	?	J	C?	—	M Jr-E K	?	178
	<i>?Tutuella rotunda</i>	338	—	—	O*, C*?	—	E Jr-E K?	?	44, 188 <sup>†</sup> , 261 <sup>†</sup> , 338
	<i>Weichangella angularia</i>	338	—	—	C?	—	E K	E K	337
	<i>W. antiqua</i>	338	—	—	C*?	—	E K	E K	337 <sup>†</sup>
	<i>W. caelata</i>	338	—	—	C*?	—	E K	E K	337 <sup>†</sup>
	<i>W. oblonga</i>	338	—	—	C?	—	E K	E K	X
	<i>W. qingquanensis</i>	338	—	—	C?	—	E K	E K	X
	<i>W. shalingouensis</i>	338	—	—	C*?	—	E K	E K	337 <sup>†</sup>
	<i>W. trapezoidalis</i>	338	S	—	C?	—	E K	S	S
	<i>Xishanoconcha</i> sp.	338	?	?	Y?	—	E K?	?	338 <sup>†</sup>

## Gastropoda

	<i>Amnicola chaoyangensis</i>	339	—	J*, H*, F	O, Y?	Y	M Jr?-Holo	E K?	206, 339 <sup>†</sup> /46, 342
	<i>Bithymia haizhouensis</i>	308, 339	—	J*, H*, F*	O, C?	Y	M Jr?-Holo	E K?	206, 339 <sup>†</sup> /46, 342
	<i>Campeloma clavilithiformis</i>	79	S	J, H, F	Y?	Y	?-Plio	S	79/46
	<i>C. fengtienensis</i>	79	S	J, H, F	Y?	Y	?-Plio	S	S
	<i>C. tani</i>	79	—	J*, H*, F*	Y?	Y	?-Plio	E K?	79, 339 <sup>†</sup> /46
	<i>C. yihsiensis</i>	79	S	J, H, F	Y?	Y	?-Plio	S	S
	<i>Galba minuta</i>	339	S	H, F	O, Y?	Y	M Jr?-Holo	S	206/339, 342
	<i>G.</i> cf. <i>obrutschevi</i>	339	—	H*, F*	O, C*?, Y*	Y	M Jr?-Holo	E K-L K?	206, 339 <sup>†</sup> , 342
	<i>G. pseudopalustris</i>	339	—	H*, F	O C*?	Y	M Jr?-Holo	E K?	X, 339 <sup>†</sup>
	<i>Probaicalia gerassimovi</i>	339	—	J*, H*, F*	C*?, Y*	—	E K?	E K-L K?	313 <sup>†</sup> , 356 <sup>†</sup>
	<i>P. vitimensis</i>	308, 339	—	J*, H*, F*	C*?, Y*	—	E K?	E K-L K?	356 <sup>†</sup>
	<i>Reesidella robusta</i>	304	—	H	C*?	C?	?	?	313
	<i>Viviparus?</i> <i>matumotoi</i>	313	—	J*, H*, F*	C?, Y	Y	?-Holo	?	46, 339 <sup>†</sup> , 342
	<i>V. onogoensis</i>	33	—	H*?, F*?	C?, Y*?	Y	?	?	339 <sup>†</sup> , 356 <sup>†</sup>

Continued.

## Appendix, continued.

Type	Taxon	Taxon occurs				Chronological Range			Citations (for earliest occurrences of genus/species) <sup>a, g</sup>
		Principal citations for Yixian Fm occurrence <sup>a</sup>	N <sup>b</sup>	Higher within Jethol Group <sup>c</sup>	Elsewhere in East Asia <sup>d</sup>	Elsewhere globally <sup>e</sup>	Genus <sup>f</sup>	Species <sup>f</sup>	
	<i>Zaptychius</i> ( <i>Omozaptychius</i> ) <i>angulatus</i>	339	—	H*, F*	Y	?	EK-LK	EK?	339 <sup>†</sup> , 355
<b>Conchostraca</b>									
	<i>Chaoyangestheria diformis</i>	301	G	G	G	G	G	G	G
	<i>C. xiasanjiaziensis</i>	301	G	G	G	G	G	G	G
	<i>C. yanjiagouensis</i>	301	G	G	G	G	G	G	G
	<i>Clithrograpta gujialingensis</i>	301	G	G	G	G	G	G	G
	<i>C. lingyuanensis</i>	301, 313	G	G	G	G	G	G	G
	<i>C. ovata</i>	301	G	G	G	G	G	G	G
	<i>C.? polyreticulate</i>	301	G	G	G	G	G	G	G
	<i>C. xiaodonggouensis</i>	301	G	G	G	G	G	G	G
	<i>Diestheria abnormis</i>	301	S	H	C?	—	EK	S	27, 29, 37, 188, 260, 309
	<i>D. dadianzensis</i>	309	S	H	C?	—	EK	S	S
	<i>D. dahuchangensis</i>	309	S	H	C?	—	EK	S	S
	<i>D. gigantea</i>	309	S	H	C?	—	EK	S	S
	<i>D.? heichengziensis</i>	27	S	H	C?	—	EK	S	S
	<i>D. hejiaxinensis</i>	301	S	H	C?	—	EK	S	S
	<i>D. jeholensis</i>	27, 301	S	H	C?	—	EK	S	S
	<i>D. lijiaogouensis</i>	301	S	H	C?	—	EK	S	S
	<i>D. longinqua</i>	27, 309	S	H	C?	—	EK	S	S
	<i>D. ovata</i>	309	S	H	C?	—	EK	S	S
	<i>D. shangyuanensis</i>	27, 301	S	H	C?	—	EK	S	S
	<i>D. suboblona</i>	27, 301	—	H	C*?	—	EK	EK	37 <sup>†</sup> , 188 <sup>†</sup>
	<i>D. yixianensis</i>	27, 301	S	H	C?	—	EK	S	S
	<i>Diformograpta gongyingziensis</i>	301	—	J*	C?	—	EK	EK	311, 312 <sup>†</sup>
	<i>D. cf. middendorfi</i>	301	—	J*	C?	—	EK	EK	301 <sup>†</sup>
	<i>D. opipera</i>	301	—	J*	C?	—	EK	EK	301 <sup>†</sup>
	<i>D. persculpta</i>	301	?	J	C?	—	EK	EK	X
	<i>D. cf. pudica</i>	301	S	J	C?	—	EK	S	S
	<i>D. triformis</i>	301	?	J	C?	—	EK	EK	X
	<i>D. vera</i>	301	—	J*	C?	—	EK	EK	301 <sup>†</sup>
	<i>Dongbeiestheria fuxingtunensis</i>	301	S	J	C?	—	EK	S	S
	<i>D. tereovata</i>	301	S	J	C?	—	EK	S	S
	<i>D. yushugouensis</i>	301	S	J	C?	—	EK	S	S
	<i>Eosestheria bella</i>	309	S	J, H	C?	—	EK	S	27, 29, 37, 188, 260, 309
	<i>E. brevis</i>	56	S	J, H	C?	—	EK	S	S
	<i>E. changshanziensis</i>	301	—	J*, H	C?	—	EK	EK	27, 29, 37, 188, 260, 309, 301 <sup>†</sup>
	<i>E. cf. chii</i>	195, 309	?	J, H	C?	—	EK	EK	X
	<i>E. donggouensis</i>	309	S	J, H	C?	—	EK	S	S
	<i>E.? elliptica</i>	27, 301	S	J, H	C?	—	EK	S	S
	<i>E. cf. elongata</i>	309	?	J, H	C?	—	EK	EK	X
	<i>E. erisopsiformis</i>	309	S	J, H	C?	—	EK	S	S
	<i>E. fengningensis</i>	309	S	J, H	C?	—	EK	S	S

Continued.

## Appendix, continued.

Type	Taxon	Taxon occurs					Chronological Range		Citations (for earliest occurrences of genus/species) <sup>a, g</sup>
		Principal citations for Yixian Fm occurrence <sup>a</sup>	N <sup>b</sup>	Higher within Jethol Group <sup>c</sup>	Elsewhere in East Asia <sup>d</sup>	Elsewhere globally <sup>e</sup>	Genus <sup>f</sup>	Species <sup>f</sup>	
	<i>E. fengshanensis</i>	309	S	J, H	C?	—	EK	S	S
	<i>E. gibba</i>	309	S	J, H	C?	—	EK	S	S
	<i>E. heshangouensis</i>	195, 309	S	J, H	C?	—	EK	S	S
	<i>E. fangangshanensis</i>	27, 301	S	J, H	C?	—	EK	S	S
	<i>E. lahaigouensis</i>	309	S	J, H	C?	—	EK	S	S
	<i>E. lingyuanensis</i>	27, 309	S	J, H	C?	—	EK	S	S
	<i>E. linjiangensis</i>	309	S	J, H	C?	—	EK	S	S
	<i>E. longiquadrata</i>	309	S	J, H	C?	—	EK	S	S
	<i>E. middendorfi</i>	27, 31	—	J, H	C?	—	EK	EK	29 <sup>†</sup> , 37 <sup>†</sup> , 188 <sup>†</sup> , 260 <sup>†</sup>
	<i>E. minor</i>	195, 309	S	J, H	C?	—	EK	EK	S
	<i>E. ovaliformis</i>	27, 301	S	J, H	C?	—	EK	EK	S
	<i>E. persculpta</i>	27, 309	S	J, H	C?	—	EK	EK	S
	<i>E. quinquanensis</i>	309	S	J, H	C?	—	EK	S	S
	<i>E. radiata</i>	309	S	J, H	C?	—	EK	S	S
	<i>E. ramulosa</i>	309	S	J, H	C?	—	EK	S	S
	<i>E. reticulata</i>	309	S	J, H	C?	—	EK	S	S
	<i>E. shangshixiaensis</i>	309	S	J, H	C?	—	EK	S	S
	<i>E. songyingensis</i>	309	S	J, H	C?	—	EK	S	S
	<i>E. takechenensis</i>	195, 309	?	J, H	C?	—	EK	EK	X
	<i>E. triformis</i>	27, 31	S	J, H	C?	—	EK	S	S
	<i>E. weichangensis</i>	309	S	J, H	C?	—	EK	S	S
	<i>E. (Isoestheria) qingquanensis</i>	309	S(G)	G	G	G	S(G)	S(G)	S(G)
	<i>E. (I.) yanbizigouensis</i>	309	S(G)	G	G	G	S(G)	S(G)	S(G)
	<i>Fengninggrapta huajiyensis</i>	309	—	—	—	—	EK?	EK?	X
	<i>Filigrapta corpulepta</i>	301	?	J	—	—	EK?	EK?	X
	<i>F. equilateralis</i>	313	?	J	—	—	EK?	EK?	X
	<i>F. jianshangouensis</i>	301	—	J*	—	—	EK?	EK?	313 <sup>†</sup>
	<i>F. phalosana</i>	301	S	J	—	—	EK?	S	S
	<i>F. producta</i>	301	?	J	—	—	EK?	EK?	X
	<i>F. taipingouensis</i>	301	S	J	—	—	EK?	S	S
	<i>F. zhuanchenziensis</i>	301	?	J	—	—	EK?	EK?	X
	<i>Liaoningestheria ovata</i>	27, 34	S	J, H	—	—	EK?	S	27, 34
	<i>L. cf. shangyuanensis</i>	34	S	J, H	—	—	EK?	S	S
	<i>Oncabrestheria elliptica</i>	195	G	G	G	G	G	G	G
	<i>O. inflata</i>	195	G	G	G	G	G	G	G
	<i>O. latiovata</i>	195	G	G	G	G	G	G	G
	<i>O. orbiculata</i>	195	G	G	G	G	G	G	G
	<i>O. ovata</i>	195	G	G	G	G	G	G	G
	<i>O. subquadrata</i>	195	G	G	G	G	G	G	G
	<i>O. subtriangularis</i>	195	G	G	G	G	G	G	G
	<i>O. tuberculata</i>	195	G	G	G	G	G	G	G
	<i>Taeniestheria ovata</i>	194	G	G	G	G	G	G	G
	<i>T. qingquanensis</i>	194	G	G	G	G	G	G	G
	<i>T. reticulata</i>	194	G	G	G	G	G	G	G
	<i>T. suboblonga</i>	194	G	G	G	G	G	G	G
	<i>T. subquadrata</i>	194	G	G	G	G	G	G	G

Continued.

## Appendix, continued.

Type	Taxon	Taxon occurs				Chronological Range			Citations (for earliest occurrences of genus/species) <sup>a, g</sup>
		Principal citations for Yixian Fm occurrence <sup>a</sup>	N <sup>b</sup>	Higher within Jethol Group <sup>c</sup>	Elsewhere in East Asia <sup>d</sup>	Elsewhere globally <sup>e</sup>	Genus <sup>f</sup>	Species <sup>f</sup>	
	<i>Yanjiestheria</i> (= <i>Yanshanina</i> ) <i>dabeigouensis</i>	27, 308	S	H	C?	—	EK?	S	27, 260, 306, 309
	<i>Y.</i> (= <i>Y.</i> ) <i>fengningensis</i>	309	S	H	C?	—	EK?	S	S
	<i>Y.</i> (= <i>Y.</i> ) <i>subquadrata</i>	27, 308	S	H	C?	—	EK?	S	S

## Ostracoda

<i>cf. Clinocypris scolia</i>	345	—	J*	C*?, Y*?	O, C	E Tr?-E K	?	17, 208 <sup>†</sup> , 344 <sup>†</sup>
<i>Cypridea</i> aff. <i>sainschandaensis</i>	313, 345	?	J, H, F	Y?	O, C, Y	L Jr-E Eoc	?	253, 282, 322/87, X
<i>C. altidorsangulate</i>	210	?	J, H, F	Y?	O, C, Y	L Jr-E Eoc	?	X
<i>C. sulcata</i>	151	?				L Jr-E Eoc	?	X
<i>C. xitaiyanpoensis</i>	210	?	J, H, F	Y?	O, C, Y	L Jr-E Eoc	?	X
<i>C. (Cypridea) deflecta</i>	313, 345	S	J, H, F	Y	O, C, Y	L Jr-E Eoc	S	S
<i>C. (C.) dorsobispina</i>	313, 345	—	J*, H, F	Y	O, C, Y	L Jr-E Eoc	E K	345 <sup>†</sup>
<i>C. (C.) ganzhaensis</i>	313, 345	S	J, H, F	Y	O, C, Y	L Jr-E Eoc	S	S
<i>C. (C.) fangangshenensis</i>	313, 345	S	J, H, F	Y	O, C, Y	L Jr-E Eoc	S	S
<i>C. (C.) liaoningensis</i>	313, 345	S	J, H, F	Y	O, C, Y	L Jr-E Eoc	S	S
<i>C. (C.) placida</i>	313, 345	S	J, H, F	Y	O, C, Y	L Jr-E Eoc	S	S
<i>C. (C.) prognata</i>	313, 345	?	J, H, F	Y	O, C, Y*?	L Jr-E Eoc	?	344 <sup>†</sup>
<i>C. (C.) ex. gr. sinensis</i>	345	?	J, H, F	Y	O, C, Y	L Jr-E Eoc	?	X
<i>C. (C.) spatiosa</i>	313, 345	S	J, H, F	Y	O, C, Y	L Jr-E Eoc	S	S
<i>C. (C.) suborthocera</i>	313, 345	S	J, H, F	Y	O, C, Y	L Jr-E Eoc	S	S
<i>C. (C.) tubercularis</i>	313, 345	?	J, H, F	Y	O, C, Y	L Jr-E Eoc	?	X
<i>C. (C.) venustata</i>	313, 345	S	J, H, F	Y	O, C, Y	L Jr-E Eoc	S	S
<i>C. (C.) veridica</i>	313, 345	—	J*, H, F	Y	O, C, Y	L Jr-E Eoc	E K	345 <sup>†</sup>
<i>C. (C.) zaocishanensis</i>	313, 345	S	J, H, F	Y	O, C, Y	L Jr-E Eoc	S	S
<i>C. (Urwella) muriculata</i>	313, 345	S	J, H	Y?	O, C, Y	L Jr-E Eoc	S	S
<i>C. (U.) semiovata</i>	345	S	J, H	Y?	O, C, Y	L Jr-E Eoc	S	S
<i>C. (Yumenia) sp.</i>	345	?	J	Y?	O, C, Y	L Jr-E Eoc	?	345
<i>Damonella circulata</i>	345	—	J*, H*, F*	O?, C?	O, C?	L Jr-E E K?	?	209, 345 <sup>†</sup>
<i>D. extenda</i>	313, 345	?	J, H, F	O?, C?	O, C?	L Jr-E E K?	?	X
<i>D. subsymmetrical</i>	313, 345	S	J, H, F	O?, C?	O, C?	L Jr-E E K?	S	S
<i>Darwinula contracta</i>	345	—	J*, H*, F*	O, C*?, Y*	O, C, Y	Ord?-Holo	?	17, 208 <sup>†</sup> , 344 <sup>†</sup>
<i>D. oblonga</i>	345	—	F	C*?,	O, C, Y	Ord?-Holo	?	17
<i>Djungarica camarata</i>	313, 345	—	J*	C?, Y	—	L Jr-E E K	?	209, 345
<i>D. procurva</i>	313, 345	S	J	C?, Y	—	L Jr-E E K	S	S
<i>Lycoprocypris debilis</i>	345	—	J*, H*, F*	C*?, Y*	O, C*?, Y	E K-Pal	E K	189, 190, 344 <sup>†</sup> /285
<i>L. infantilis</i>	345	—	J*, H*, F*	C*?, Y*	O, C, Y	E K-Pal	E K	344 <sup>†</sup> 345 <sup>†</sup>
<i>Mongolianella subtrapezoidea</i>	345	?	J	C?, Y	C, Y	E K-L K	?	286, X
<i>Rhinocypris dadingziensis</i>	210	?	J, H	C?, Y?	?	L Jr-E E K	E K?	17
<i>R. echinata</i>	210, 345	—	J*, H	C*?, Y*?	C?	L Jr-E E K	E K?	208 <sup>†</sup> , 344 <sup>†</sup> 345 <sup>†</sup>
<i>R. foveata</i>	210	—	J, H	C*?, Y*?	C?	L Jr-E E K	E K?	208 <sup>†</sup>
<i>R. subechinata</i>	210	?	J, H	C?, Y?	C?	L Jr-E E K	E K?	X
<i>Timirisevia jianshangouensis</i>	313, 345	S	J, H	C?, Y	O, C	M Jr-Pal	S	17/285
<i>T. opinabilis</i>	210	?	J, H, F	C?, Y	O, C	M Jr-Pal	?	X
<i>T. pusilla</i>	345	—	J*, H*, F*	C*?, Y*?	O, C	M Jr-Pal	?	344 <sup>†</sup> 345 <sup>†</sup>
<i>Yanshanina dabeigouensis</i>	210	?	—	C?, Y	—	E K	E K	X, 210 <sup>†</sup> , 209 <sup>†</sup>
<i>Y. elongata</i>	210	?	—	C?, Y	—	E K	E K	X

Continued.



## Appendix, continued.

Type	Taxon	Taxon occurs					Chronological Range		
		Principal citations for Yixian Fm occurrence <sup>a</sup>	N <sup>b</sup>	Higher within Jethol Group <sup>c</sup>	Elsewhere in East Asia <sup>d</sup>	Elsewhere globally <sup>e</sup>	Genus <sup>f</sup>	Species <sup>f</sup>	Citations (for earliest occurrences of genus/species) <sup>a, g</sup>
	<i>Y. postitruncata</i>	210	?	—	C?, Y	—	EK	EK	X
	<i>Y. subovata</i>	210	—	—	C?, Y*	—	EK	EK	209 <sup>†</sup>
	<i>Ziziphocypris linchengensis</i>	345	—	I, H, F	C?, Y*?	C, Y	EK-LK	EK	179/286, 344 <sup>†</sup> , X
<b>Insecta</b>									
	<i>Aeschnidium densum</i>	343	—	J*	+*	O*, C, Y	LJr-EK	LJr-EK	15, 90, 155/343 <sup>†</sup>
	<i>A. heishankowense</i> (= <i>Sinaeschnidia</i> ) <i>heishankowensis</i> , <i>Pseudosamarura largina</i> , <i>Archaeogomphus labius</i> , <i>Yixiangomphus labius</i> )	343	—	J*?	?C*	O, C, Y	LJr-EK	EK	343 <sup>†</sup>
	<i>Aeschnidiella kabanovi</i>	34, 313	S	—	C?	—	EK	S	341
	<i>Aethephasma megista</i>	234	G	G	G	G	G	G	G
	<i>Alleremonomus liaoningensis</i>	237	G	G	G	G	G	G	G
	<i>A. xingi</i>	237	G	G	G	G	G	G	G
	<i>Allogaster ovata</i>	240	G	G	G	G	G	G	G
	<i>Allomyia ruderalis</i>	236	G	G	G	G	G	G	G
	<i>Alloraphidia anomala</i>	232	S	—	—	C?	EK	S	25
	<i>A. longistigma</i>	230	S	—	—	C?	EK	S	S
	<i>A. obliquivenatica</i>	230	S	—	—	C?	EK	S	S
	<i>Alloxylula lingyuanensis</i>	240	G	G	G	G	G	G	G
	<i>Atalosciophila yanensis</i>	240	G	G	G	G	G	G	G
	<i>Baissodes grabaui</i>	240	S	—	C?	C?	EK	S	225, 227
	<i>Baissoptera euneura</i>	232	S	—	—	O?	LJr-EK	S	175
	<i>B. grandis</i>	240	S	—	—	O?	LJr-EK	S	S
	<i>Basilorhagio venustus</i>	240	G	G	G	G	G	G	G
	<i>Bibitica hebeiensis</i>	98	G	G	G	G	G	G	G
	<i>Blattula delicatula</i>	240	S	—	+	O	EJr-EK	S	90, 298
	<i>B. exetenuata</i>	240	S	—	+	O	EJr-EK	S	S
	<i>B. platypa</i>	240	S	—	+	O	EJr-EK	S	S
	<i>Caloraphidia glossophylla</i>	232	G	G	G	G	G	G	G
	<i>Cephenopsis mirabilis</i>	98	G	G	G	G	G	G	G
	<i>Chengdeserphus petiolatus</i>	240	G	G	G	G	G	G	G
	<i>Chironomaptera</i> (= <i>Mesotendipes</i> ) <i>gregaria</i>	154, 213	—	J*	C*?	—	EK	EK	155 <sup>†</sup> , 98 <sup>†</sup>
	<i>Chironomopsis gracilis</i>	213	—	?	C*?	O	LJr-EK	EK	90/100 <sup>†</sup> , 188 <sup>†</sup>
	<i>Choromyrmeleon othneius</i>	238	G	G	G	G	G	G	G
	<i>Chrysogomphus beipiaoensis</i>	231	G	G	G	G	G	G	G
	<i>Clypostemma xyphidie</i>	98, 308	—	?	C*?	C?	EK-LK	EK	155 <sup>†</sup> /156
	<i>Coptoclava longipoda</i>	154, 213	—	J*	C*?	—	EK	EK	155 <sup>†</sup> , 98 <sup>†</sup> , 188 <sup>†</sup>
	<i>Eopangonius pletus</i>	236	G	G	G	G	G	G	G
	<i>Ephemeropsis trisetalis</i>	154, 213	—	J*	C*?	—	EK?	EK?	155 <sup>†</sup> , 98 <sup>†</sup> , 188 <sup>†</sup>
	<i>Euryxylea longhuaensis</i>	98	G	G	G	G	G	G	G
	<i>Florinmestrius pulcherrimus</i>	235, 236	G	G	G	G	G	G	G
	<i>Geotrupoides songyingziense</i>	98	S	—	C?	O	LJr-EK	S	90/98 <sup>†</sup> , 99
	" <i>Glypta</i> " <i>qingshilaensis</i> <sup>k</sup>	240	—	—	Y*?	—	EK	EK	98
	<i>Habrohagla curtivenata</i>	240	G	G	G	G	G	G	G

Continued.

## Appendix, continued.

Type	Taxon	Taxon occurs				Chronological Range		Citations (for earliest occurrences of genus/species) <sup>a, g</sup>	
		Principal citations for Yixian Fm occurrence <sup>a</sup>	N <sup>b</sup>	Higher within Jethol Group <sup>c</sup>	Elsewhere in East Asia <sup>d</sup>	Elsewhere globally <sup>e</sup>	Genus <sup>f</sup>		Species <sup>f</sup>
	<i>Hagiphasma paradoxa</i>	234	G	G	G	G	G	G	G
	<i>Hebeiaeschnidia fengningensis</i>	98	?	?	?	—	EK?	EK?	X
	<i>Hebeihagla songyingziensis</i>	98	—	?	C*?	—	EK?	EK?	97
	<i>Helempis eucalla</i>	236	G	G	G	G	G	G	G
	<i>H. yixianensis</i>	236	G	G	G	G	G	G	G
	<i>Jeholoropronia pingi</i>	240	G	G	G	G	G	G	G
	<i>Jibeicossus qingshilaense</i>	98	G	G	G	G	G	G	G
	<i>Kalligramma liaoningensis</i>	238	S	—	—	O	MJr-EK	S	207/171
	<i>Karataviella pontoforma</i>	154	S	—	O, C?	O	MJr-EK	S	155
	<i>Karatavoblatta formosa</i>	240	S	—	—	O	MJr?-EK	S	298
	<i>Lasiomylus newi</i>	238	G	G	G	G	G	G	G
	<i>Lembochrysa miniscula</i>	238	G	G	G	G	G	G	G
	<i>L. polymeura</i>	238	G	G	G	G	G	G	G
	<i>Leptemochaetus lithoecius</i>	236	G	G	G	G	G	G	G
	<i>Leptoplectia zhangshanyingensis</i>	98	S	?	?	—	EK?	S	X
	<i>Liadoxyela chengdeensis</i>	240	S	—	—	O	EJr?-E K	S	26
	<i>Liaotoma linearis</i>	240	G	G	G	G	G	G	G
	<i>Lichnoplecia kovalevi</i>	240	G	G	G	G	G	G	G
	<i>Liogomphus yixianensis</i>	239	G	G	G	G	G	G	G
	<i>Longhuaia rara</i>	98	G	G	G	G	G	G	G
	<i>Longipedia pingquanensis</i>	98	G	G	G	G	G	G	G
	<i>Luanpingia senjituensis</i>	98	S	?	C?	V	EK?	S	X, 224
	<i>Manlaya flexosus</i>	240	S	—	C?	—	EK	S	226
	<i>Megabittacus beipiaoensis</i>	233	G	G	G	G	G	G	G
	<i>M. colosseus</i>	233	G	G	G	G	G	G	G
	<i>Mesascalaphus yangi</i>	240	G	G	G	G	G	G	G
	<i>Mesaulacinus rasnitsyni</i>	240	S	?	—	C?	MJr?-E K	S	174
	<i>Mesoblattina sinica</i>	213	S	?	C?	O, C?	LJr?-E K	S	20, 96
	<i>Mesocordulia boreala</i>	239	G	G	G	G	G	G	G
	<i>Mesohemerobius jeholensis</i>	213	G	G	G	G	G	G	G
	<i>Mesoleuctra peipiaoensis</i>	213	S	—	C?	—	LJr?-E K?	S	20
	<i>Mesoraphidia amoena</i>	232	S	—	+	C?	MJr?-E K	S	172, 173
	<i>M. heteroneura</i>	232	S	—	+	C?	MJr?-E K	S	S
	<i>M. sinica</i>	232	S	—	+	C?	MJr?-E K	S	S
	<i>Mesosirex volantis</i>	98	G	G	G	G	G	G	G
	<i>Mioraphidia</i> ( <i>Mesoraphidia</i> ) <i>furcivenata</i>	232	G	G	G	G	G	G	G
	<i>Multimodus dissitus</i>	240	S	—	C?	—	EK	S	275
	<i>M.? elongatus</i>	240	S	—	C?	—	EK	S	S
	<i>M. stigmaeus</i>	240	S	—	C?	—	EK	S	S
	<i>Necrotaulius qingshilaense</i>	98	S	—	C?	O	EJr-E K	S	90/98
	<i>Nipponoblatta acerba</i>	240	S	—	O	—	EJr-E K	S	74
	<i>Oiobrachyceron limnogenus</i>	236	G	G	G	G	G	G	G
	<i>Oloberotha sinica</i>	238	G	G	G	G	G	G	G
	<i>Opiparifungivora aliena</i>	240	G	G	G	G	G	G	G
	<i>Orephasma eumorpha</i>	234	G	G	G	G	G	G	G
	<i>Osobrachyceron chinensis</i>	236	G	G	G	G	G	G	G

Continued.

## Appendix, continued.

Type	Taxon	Taxon occurs				Chronological Range		Citations (for earliest occurrences of genus/species) <sup>a, g</sup>	
		Principal citations for Yixian Fm occurrence <sup>a</sup>	N <sup>b</sup>	Higher within Jethol Group <sup>c</sup>	Elsewhere in East Asia <sup>d</sup>	Elsewhere globally <sup>e</sup>	Genus <sup>f</sup>		Species <sup>f</sup>
	<i>Orthophlebia liaoningensis</i>	233	S	—	C?	O	E Jr-EK	S	90
	<i>Palaepangonius eupterus</i>	235, 236	G	G	G	G	G	G	G
	<i>Parachorista miris</i>	154	G	G	G	G	G	G	G
	<i>Parorysus suspectus</i>	154	S	—	—	O	M Jr-EK	S	174, 224
	<i>Paurolacus sinicus</i>	213	G	G	G	G	G	G	G
	<i>Pauromyia oresbia</i>	236	G	G	G	G	G	G	G
	<i>Perlariopsis peipiaoensis</i>	213	G	G	G	G	G	G	G
	<i>Phiradia myrioneura</i>	232	S	—	—	O	L Jr-EK	S	324
	<i>Probelus sinicus</i>	98	S	—	—	O	M Jr-EK	S	7
	<i>Protapiocera ischyra</i>	236	G	G	G	G	G	G	G
	<i>P. megista</i>	236	G	G	G	G	G	G	G
	<i>Protempis minuta</i>	236	S	—	—	O	M Jr-EK	S	295
	<i>Protonemestrius beipiaoensis</i>	236	S	—	—	O	M Jr-EK?	S	243
	<i>P. jurassicus</i>	235	S	—	—	O	M Jr-EK?	S	243
	<i>Pseudohalga pospelovi</i>	313	—	?	O*	—	M Jr?EK?	?	X
	<i>Rudialeschna limnobia</i>	239	G	G	G	G	G	G	G
	<i>Rudiraphidia</i> ( <i>Baissoptera</i> ) <i>liaoningensis</i>	232	G	G	G	G	G	G	G
	<i>Sibirobittacus atalus</i>	233	S	—	C?	—	EK	S	276
	<i>Siboptera</i> ( <i>Liaoraphidia</i> ) <i>forcinata</i>	232	S	—	C?	—	EK	S	219
	<i>Sinoelaterium melancolor</i>	213	G	G	G	G	G	G	G
	<i>Sinogomphus taushanensis</i>	98	?	?	?	—	EK?	EK?	X
	<i>Sinohagla pleioneura</i>	240	S	—	O, C?	—	E Jr-EK?	S	97, 153
	<i>Sinonemoura grabau</i>	213	G	G	G	G	G	G	G
	<i>Sinoperla abdominalis</i>	213	G	G	G	G	G	G	G
	<i>Sinosepulca gigathoracalis</i>	240	G	G	G	G	G	G	G
	<i>Sinoviparosiphum lini</i>	240	G	G	G	G	G	G	G
	<i>Solichneumon</i> ( <i>Yanichneumon</i> ) <i>rectivenius</i>	240	G	G	G	G	G	G	G
	<i>Sophogramma eucalla</i>	238	G	G	G	G	G	G	G
	<i>S. papilionacea</i>	238	G	G	G	G	G	G	G
	<i>S. plecophlebia</i>	238	G	G	G	G	G	G	G
	<i>Tétraphalerus laetus</i>	154	S	—	—	Y	M Jr-Holo	S	217, 218/26
	<i>T. lentus</i>	240	S	—	—	Y	M Jr-Holo	S	217, 218/26
	<i>Xynoraphidia polyphlebia</i>	232	G	G	G	G	G	G	G
	<i>X. (Archeraphidia)</i> <i>shangyuanensis</i>	232	G	G	G	G	G	G	G
	<i>Yanocleistogaster canaliculata</i>	240	G	G	G	G	G	G	G
	<i>Yanocossus guoi</i>	240	G	G	G	G	G	G	G
	<i>Yanoraphidia gaoi</i>	240	G	G	G	G	G	G	G
	<i>Yanorthophlebia hebeiensis</i>	240	G	G	G	G	G	G	G
	<i>Yanosmylus rarivenatus</i>	240	G	G	G	G	G	G	G
	<i>Yenshania hopeiensis</i>	98	?	?	?	—	E K?	E K?	X

## Decapoda

<i>Cricoidoscelosus aethus</i>	290	G	G	G	G	G	G	G	G
<i>Palaeocambarus licenti</i>	290	G	G	G	G	G	G	G	G

Continued.

## Appendix, continued.

Type	Taxon	Taxon occurs					Chronological Range		Citations (for earliest occurrences of genus/species) <sup>a, g</sup>
		Principal citations for Yixian Fm occurrence <sup>a</sup>	N <sup>b</sup>	Higher within Jethol Group <sup>c</sup>	Elsewhere in East Asia <sup>d</sup>	Elsewhere globally <sup>e</sup>	Genus <sup>f</sup>	Species <sup>f</sup>	
<b>Osteichthyes</b>									
	<i>Jinanichthys longicephalus</i> (= <i>Changichthys dalinghensis</i> and <i>Liaoxiichthys longicephalus</i> )	68	—	J*, H*	C*?	—	EK	EK	165 <sup>†</sup> , 68 <sup>†</sup>
	<i>Lycoptera davidi</i> (= <i>L. middendorffi</i> and <i>L. tokunagai</i> )	68, 164	—	J*	C*?	—	EK	EK	11 <sup>†</sup> , 58 <sup>†</sup> , 288 <sup>†</sup> , 192 <sup>†</sup>
	<i>L. muroii</i>	68	—	J*, H	—	—	EK	EK	11 <sup>†</sup>
	<i>L. (Asiatolepis) sinensis</i>	68	S	J, H	C*?	—	EK	S	288 <sup>†</sup> , 188
	<i>Peipiaosteus fengningensis</i>	159	S	—	—	—	EK	S	159
	<i>P. pani</i>	68	—	J*	—	—	EK	EK	11 <sup>†</sup> , 68 <sup>†</sup>
	<i>Protosephurus liui</i>	68, 159	—	J*	—	—	EK	EK	68 <sup>†</sup>
	<i>Sinamia</i> sp.	314	?	Y	C?	—	EK	EK	188, 273, 330
	<i>Yanosteus longidorsalis</i>	67, 68	G	G	G	G	G	G	G
<b>Anura</b>									
	<i>Callobatrachus sanyanensis</i>	316	G	G	G	G	G	G	G
	<i>Liaobatrachus grabaui</i>	314	G	G	G	G	G	G	G
<b>Chelonia</b>									
	<i>Manchurochelys liaoxiensis</i>	123	G	G	G	G	G	G	G
	<i>M. manchoukuoensis</i>	60	G	G	G	G	G	G	G
<b>Diapsida incertae sedis</b>									
	<i>Hyphalosaur</i> (= <i>Sinohydrosaurus</i> ) <i>lingyuanensis</i> <sup>1</sup>	77, 145	G	G	G	G	G	G	G
<b>Sphenodontia</b>									
	<i>Monjurosuchus splendens</i> (= " <i>Rhynchosaurus</i> " <i>orientalis</i> )	314	G	G	G	G	G	G	G
<b>Lacertilia</b>									
	<i>Dalinghosaurus longidigitus</i>	314	G	G	G	G	G	G	G
	<i>Yabeinosaurus tenuis</i>	314	G	G	G	G	G	G	G
<b>Pterosauria</b>									
	<i>Dendrorhynchoides</i> <i>curvidentatus</i> <sup>m</sup>	126, 128	G	G	G	G	G	G	G
	<i>Eosipterus yangi</i>	125, 128	G	G	G	G	G	G	G
<b>Ceratopsia</b>									
	<i>Pittacosaurus</i> sp. (= <i>P. meileyingensis</i> or <i>P. mongoliensis</i> ) <sup>n</sup>	127, 327	?	J, H	C?, Y?	—	EK	EK	52, 161

Continued.

## Appendix, continued.

Type	Taxon	Taxon occurs				Chronological Range		Citations (for earliest occurrences of genus/species) <sup>a, g</sup>
		Principal citations for Yixian Fm occurrence <sup>a</sup>	N <sup>b</sup>	Higher within Jethol Group <sup>c</sup>	Elsewhere in East Asia <sup>d</sup>	Elsewhere globally <sup>e</sup>	Genus <sup>f</sup>	
<b>Theropoda</b>								
	<i>Beipiaosaurus inexpectus</i>	328	G	G	G	G	G	G
	<i>Caudipteryx zoui</i>	121	G	G	G	G	G	G
	<i>Protarchaopteryx robusta</i>	118, 121	G	G	G	G	G	G
	<i>Sinornithosaurus millenii</i>	329	G	G	G	G	G	G
	<i>Sinosauropteryx prima</i>	39, 117	G	G	G	G	G	G
<b>Aves</b>								
	<i>Changchengornis hengdaoziensis</i>	119	G	G	G	G	G	G
	<i>Confuciusornis dui</i> <sup>o</sup>	110	G	G	G	G	G	G
	<i>C. sanctus</i> (= <i>C. chuonzhous</i> , <i>C. suniae</i> ) <sup>o</sup>	103, 105, 106, 110	G	G	G	G	G	G
	<i>Eoenantiornis buhleri</i>	109, 314	G	G	G	G	G	G
	" <i>Jibeinia luanhera</i> " <sup>p</sup>	103	G	G	G	G	G	G
	<i>Liaoningornis longidigitris</i>	102, 108, 314	G	G	G	G	G	G
	<i>Liaoxiornis delicatae</i>	104	G	G	G	G	G	G
<b>Mammalia</b>								
	<i>Jeholodens jenkinsi</i>	120	G	G	G	G	G	G
	<i>Zhangtheotherium quinquecupiden</i>	112, 314	G	G	G	G	G	G

<sup>a</sup> Numbers in these columns refer to numbered references in the bibliography.

<sup>b</sup> "Endemic" refers to the Yixian Formation specifically, where only the species is endemic; information in following columns refers to other occurrences of the genus. A question mark (?) indicates that, since no species has been specified, endemism cannot be assessed.

<sup>c</sup> "Higher within the Jehol Group" includes the Jiufotang, Shaihai and Fuxin Formations, but does not include the Mongolian and Transbaikali deposits.

<sup>d</sup> "Elsewhere within East Asia" includes other formations in China, Mongolia, eastern Russia, Japan, Thailand and Korea. Because many of the formations in which the taxa co-occur suffer from the same types of dating problems as the Yixian Formation (e.g., the Mongolian and Transbaikali taxa; see text), whether or not the occurrences outside the Jehol Group are coeval is not assessed here.

<sup>e</sup> Age comparisons use the Barremian–Aptian age of the Yixian Formation supported in this paper.

<sup>f</sup> Where a genus or species is limited to the Yixian and possibly coeval formations within China or East Asia that have been considered Late Jurassic, we denote them here as Early Cretaceous based on our conclusions of the age of the Yixian Formation; any other formations are not necessarily Early Cretaceous and may represent earlier occurrences of the genus or species. Occurrences in other formations include cf. and aff. attributions.

<sup>g</sup> A dagger (†) indicates that the reference pertains to the species (absence of a dagger indicates that the reference is only for the genus). References for genus are given only with first occurrence of the genus on the list.

<sup>h</sup> No further reference could be found for the genus *Foraminisporites*; it may be a misspelling of *Foraminisporis*, or it may be a wholly endemic taxon.

<sup>i</sup> *Chaoyangicarpus* and *Eragrostites* were initially described as angiosperms, but are considered gnetalean by Sun et al. (1998).

<sup>j</sup> The generic name *Chaoyangia* Duan 1998 is not to be confused with the ornithurine bird *Chaoyangia* Hou 1993 from the Jiufotang Formation, though both names are valid because they belong to different Linnean kingdoms.

<sup>k</sup> The generic name "*Glypta*" was given to a coleopteran by Hong (1984), but the name appears to be preoccupied by *Glypta* Gravenhorst 1829, a hymenopteran, per Carpenter (1992). If the coleopteran discussed by Hong (1984) is a valid taxon, it requires a new name.

<sup>l</sup> Gao et al. (1999) and Li et al. (1999) separately named and described part and counterpart of the same specimen; *Hyphalosaurus* is considered here to have priority over *Sinohydrosaurus*.

<sup>m</sup> *Dendrorhynchoides* has been identified as a composite of a pterodactyloid pterosaur onto which a dromaeosaurid theropod tail has been grafted, and does not constitute a rhamphorhynchoid pterosaur occurrence in the Yixian Formation. See the text for further discussion.

<sup>n</sup> The Yixian Formation specimen of *Psittacosaurus* was not placed into a known species by Xu and Wang (1998) but was differentiated from others and described as "more primitive" than known species. Numerous specimens and species of *Psittacosaurus* are known from many formations in Asia; see Lucas and Estep (1998) for details.

<sup>o</sup> *C. chuonzhous* and *C. suniae* were shown to be synonyms of *C. sanctus* by Chiappe et al. (1999); they also suspected *C. dui* to be a synonym, although we provisionally retain its species distinction here.

<sup>p</sup> Hou (1997b) used the name "*Jibeinia luanhera*" in the figure caption of a photograph of a fossil bird from the Yixian Formation in Hebei Province, but did not provide a formal description of the bird, so the name is presently a nomen nudum.

