

Classification of the Asian non-marine Cretaceous System

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The Asian non-marine Cretaceous System may be divided into two geographical provinces: a southern one, dominated by clastic red salt-bearing formations, and a northern one, dominated by clastic grey, yellowish green and black formations containing coal (kukersit). Vertically, on the basis of three trigoniodacean assemblages (bivalves), the System may be subdivided into Lower, Middle and Upper Cretaceous, three provincial series exhibiting this tripartite character. 4 zones and 6 subzones of the known trigoniodaceans are tentatively presented.

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The Asian non-marine Cretaceous is extensively distributed in China, Japan, Korea, Laos, Thailand, Singapore, Mongolia and the Asian part of the Soviet Union. It exhibits remarkable provincial characteristics that have allowed renewed investigation on the basis of the endemic trigoniodacean faunae. The sequence consists mainly of a suite of non-marine clastic rocks reaching the considerable thickness of 2.000-12.000 m and containing abundant volcanics in the peri-Pacific areas. It is generally difficult to determine the precise age of any particular formation within the Asian non-marine Cretaceous in terms of the international scale, owing to scarcity of true marine intercalary beds. In order to correlate with marine series, it is necessary first to study its present stratigraphic status.

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Subdivision of the Asian non-marine Cretaceous provinces

On the basis of lithological characteristics controlled by palaeoclimatic factors, the Asian non-marine Cretaceous may be tentatively divided into two provinces, a southern and a northern, by the line running from the south part of the Ural

Mountains via Tianshan-Qilianshan to Qinling Mountains (Text-figure 1). There is some transitional development locally near the provincial boundary.

The Southern Province

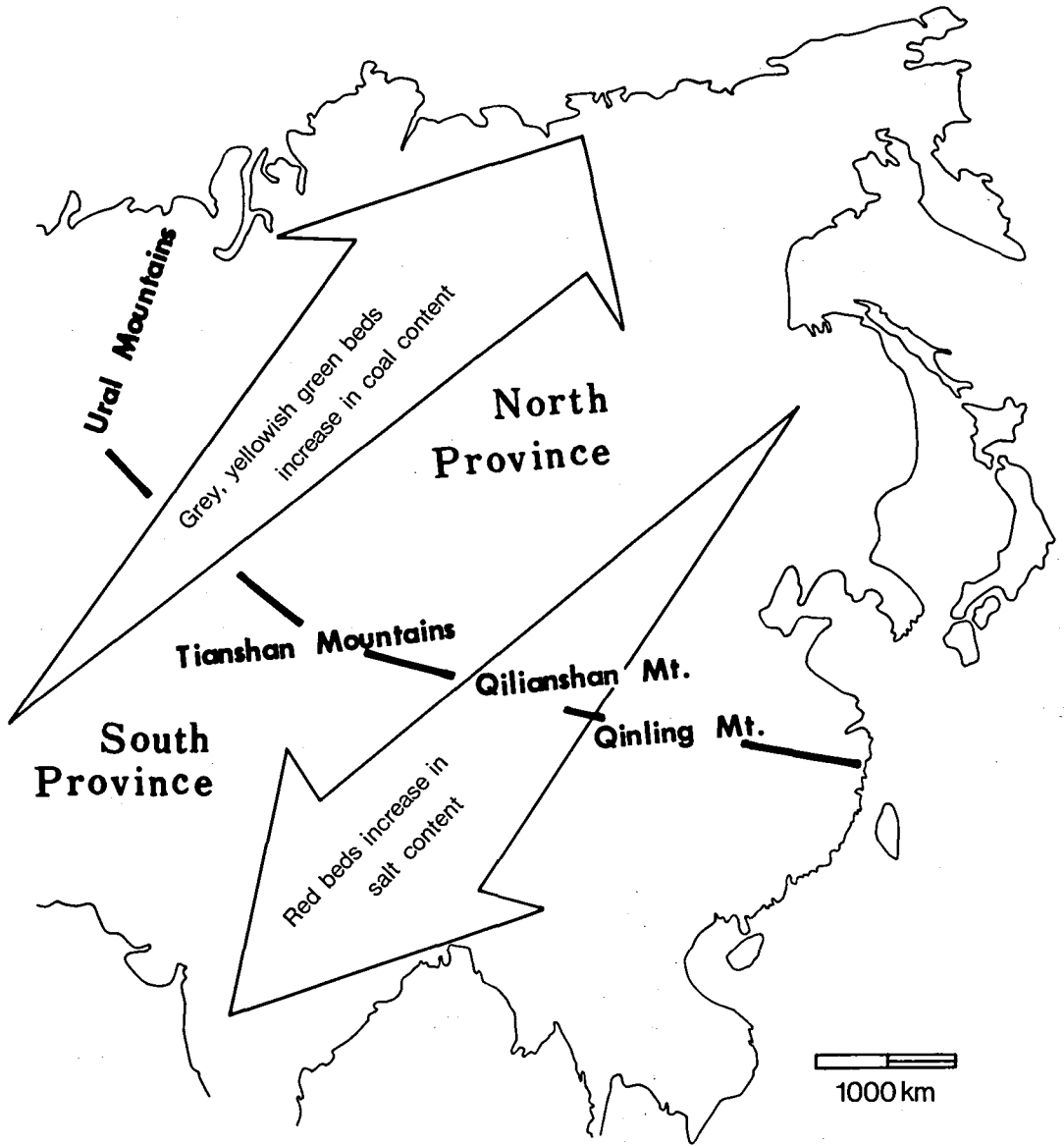
In this province the non-marine Cretaceous System is dominated by clastic red salt-bearing rocks. The sequence of West Yunnan, which shows general features of the province, may be summarized as follows, in descending order:

Overlying strata: Paleocene: Mengyejing Formation. Brick-red sandstones, siltstones and mudstones intercalated with mud-conglomerates bearing gypsum-salts.

Conformity or Disconformity

Upper Cretaceous:

Mankuanhe Formation. Purplish red with more or less variegated mudstones and siltstones, salt-bearing, yielding ostracods: *Cypridea* (*Cypridea*) *cavernosa* Galeeva, *Cypridea* (*Cypridea*) *zhengdongensis* Ye et Chao, *Talicypridea shixuangbannaensis* (Ye), *Cypris* (*Cristocypris*) *zhengdongensis* (Ye), *Sinocypris jinghongensis* Gou, *Sinocypris zhengdongensis* Gou, *Ziziphocypris simokovi* (Mandelstam); charophytes: *Porochara*



**Text-figure 1 DIVISION OF THE ASIAN
NON-MARINE CRETACEOUS PROVINCES**

anluensis Z. Wang, *Porochara spherica* Z. Wang, *Porochara oblonga* Z. Wang, Huang et S. Wang, *Peckichara dangyangensis* Z. Wang, *Charites tenuisa* Z. Wang, etc.

1,000–2,000 m

Disconformity?

Middle Cretaceous:

Bashahe Formation. Grey, greyish green sandstones

50–200 m

Conformity

Mangang Formation. Purplish red sandstones, containing bivalves: *Trigonioides sinensis* Gu et Ma, *Nippononaia* (*Nippononaia*) *carinata* Kobayashi; ostracods: *Monosulcocypris mirabilis* Hou, Ye et Cao, *Monosulcocypris yunnanensis* Hou, Ye et Cao, *Cypridea* (*Cypridea*) *subquadrata* Cao et Yang, *Cypridea* (*Pseudocypridina*) *ovata* Cao et Yang; charophytes: *Atopochara trivolvris* Peck, etc.

500–3,000 m

Conformity

Lower Cretaceous:

Jingxing Formation

Upper Member. Purplish red mudstones and siltstones, with bivalves: *Koreanaia yunnanensis* Guo, *Nippononaia* (*Eonippononaia*) *diana* Guo, *Sinonaia chuxiongensis* (Gu et Ma), *Plicatounio* (*Plicatounio*) *rostratus* Guo et Zhang, *Peregrinoconcha nuanliensis* Guo; ostracods: *Damonella ovata* Gou, *Jingguella extensa* Gou, *Darwinula paracrassa* Ye, etc.

100–1,300 m

Lower Member. Greyish green, purple sandstones intercalated with purplish red mudstones and siltstones, yielding bivalves: *Nippononaia* (*Eonippononaia*) *diana* Guo, *Cyotrigonioides* sp., etc.

200–1,400 m

Conformity or Disconformity

Underlying strata: Upper Jurassic Bazhulu Formation. Purplish red, greyish purple sandstones and siltstones.

The Napai and Bali Formation of Guangxi, China, and the corresponding horizon of the Khorat Group of Laos, which are equivalent to the upper Mangang Formation, contain bivalves: *Hoffetrigonia* (*Hoffetrigonia*) *trigona* (Hoffet), *Hoffetrigonia* (*Hoffetrigonia*) *laotiae* (Hoffet), *Diversitrigonioides diversicostatus* (Hoffet), etc. In Fergana basin of the Soviet Union the horizon equivalent to the Mankuanhe Formation yields bivalves: *Pseudohyria* (*Pseudohyria*) *aralica* (Martinson), *Plicatotrionioides simakovi* (Martinson), *Plicatotrionioides kuramensis* Martinson, *Neotrigonioides gigantus* (Martinson), etc.

The Northern Province

The non-marine Cretaceous System of this province is marked by clastic grey, yellowish green and black formations, bearing coal-kukersit, locally, with more or less purplish red beds. The Cretaceous sequences of West Liaoning-North Hebei and the Songliao basin show some general features of this province. In West Liaoning and North Hebei there are the following rock formations of Rehe Group in descending order.

Overlying strata: Middle Cretaceous. Sunjiawan Formation. Purplish red, greyish white, greyish green conglomeratic sandstones intercalated with mudstones, yielding bivalves: *Nippononaia* (*Nippononaia*) cf. *yanjiensis* Gu.

Unconformity

Lower Cretaceous Rehe Group:

Fuxin Formation. Grey, greyish black coal-bearing sandstones and mudstones, with bivalves: *Nippononaia* (*Eonippononaia*) *sinensis* Nie, *Ferganoconcha subcentris* Chernyshev; ostracods: *Cypridea vitimensis* Mandelstam; plants: *Ruffordia goepperti* (Dunker) Seward, *Onychiopsis elongata* (Eeer) Vassilevskaja.

500–1,400 m

Conformity

Jiufotang Formation. Greyish green, yellowish green sandstones and mudstones intercalated with kukersit, yielding bivalves: *Nippononaia* (*Eonippononaia*) *sinensis* Nie, *Nakamuraia*

chingshanensis (Grabau), *Nakamuranaia elongata* Gu et Ma, ?*Ferganoconcha sibirica* Chernyshev, *Myrene* (*Mesocorbicula*) *tetoriensis* (Kobayashi et Suzuki), *Sphaerium jeholensis* (Grabau); ostracods: *Cypridea sinensis* Hou; conchostracans: *Eosetheria middendorffii* (Jones), *Dietheria yangliutunensis* Chen; insects: *Ephemeropsis trisetalis* Eichward; fishes: *Lycoptera davidi* (Sauvage), *Lycoptera tokunagai* Saito; reptiles: *Psittacosaurus chaoyangi* Chao et Cheng.

400–2,000 m

Disconformity

Jianchang Formation. Greyish purple, greyish green andesites intercalated with agglomerates and volcanic breccias.

3,500 m

Disconformity

Jingangshan Formation. Tuffaceous grey, greyish green, greyish white mudstones and sandstones, with bivalves: *Nakamuranaia chingshanensis* (Grabau), ?*Ferganoconcha triangularis* (Ragozin), *Sphaerium jeholensis* (Grabau); ostracods: *Cypridea sulcata* Mandelstam, *Lycoperocypris infantilis* Lubimova; conchostracans: *Eosetheria middendorffii* (Jones), *Eosetheria jingangshanensis* Chen; insects: *Ephemeropsis trisetalis* Eichwald; fishes: *Lycoptera muroii* (Takai).

400–2,000 m

Disconformity

Yixian Formation. Greyish purple andesites, greyish black basalts, intercalated with agglomerates and tuffaceous sandstones and mudstones, containing conchostracans: *Nestoria* aff. *prissovi* Krasinetz; insects: *Ephemeropsis trisetalis* Eichwald.

2,500 m

Unconformity

Underlying strata: Upper Jurassic. Tuchengzi Formation. Greyish purple andesites.

In Songliao basin, where the Cretaceous is well developed, there is the following sequence, which shows general features of the Middle and

Upper Cretaceous, summarized as follows, in descending order.

Overlying strata: Eocene. Yian Formation. Fine-grained greish white sandstones.

Unconformity

Upper Cretaceous:

Mingshui Formation. Greyish green sandstones and black mudstones, becoming brownish red towards the top, intercalated with conglomerates, containing bivalves: *Pseudohyria* (*Pseudohyria*) *aralica* (Martinson), *Protelliptio* (*Plesielliptio*) *songhuaensis* Gu et Yu, also ostracods: *Cypridea tera* Su, etc.

300–600 m

Conformity

Sifangtai Formation. Brownish red mudstones intercalated with grey, greyish green, light greyish yellow, greyish white mudstones and sandstones, with bivalves: *Pseudohyria* (*Pseudohyria*) *obliqua* Gu et Ma, *Pseudohyria* (*Pseudohyria*) *songhuaensis* Gu et Yu, *Protelliptio* (*Plesielliptio*) *songhuaensis* Gu et Yu; ostracods: *Talicypridea amoena* (Liu); conchostracans: *Daxingstheris distincta* (Chang et Chen).

200–400 m

Disconformity or Unconformity

Nenjiang Formation. Black, greyish green mudstones intercalated with kukersit, yielding bivalves: *Pseudohyria* sp., *Plicatounio* (*Plicatounio*) *latiplicatus* Gu et Yu; ostracods: *Cypridea gungulinesis* Su; conchostracans: *Mesolimnadiopsis anguagensis* Chang et Chen.

500–1,000 m

Part of the Nenjiang Formation probably belongs to the Middle Cretaceous.

Conformity

Middle Cretaceous:

Yaojia Formation. Brownish red mudstones intercalated with greyish green, greyish black mudstones, containing bivalves: *Plicatounio* (*Plicatounio*) *latiplicatus* Gu et Yu; ostracods: *Cypridea favosa* Ye, *Ziziphocypris coneta* Cea;

Assemblage	Ornamentation			Hinge teeth	
	Radial	V-shape ribs		Crenulations on sides	Subumbonal teeth
Upper	Radial ribs or also with postero-dorsal oblique ribs	Angles	Model	Strong	Absent
		Absent			
Middle	Multiplicatus	Small 7°-27°	Para-	Universalized basically	Present
Lower	Rariplicatus	Large 30°-130°	Eu-	Absent in majority	Absent

Table 1. Major morphological characteristics of the three trigonoidacean assemblages.

conchostracans: *Dictyestheria elongata* Zhang et Chen.

70-200 m

Conformity or Disconformity

Qingshankou Formation. Black, greyish green mudstones and siltstones intercalated with kukersit, yielding bivalves: *Nippononaia (Nippononaia) jilinensis* Gu et Yu, *Plicatounio (Plicatounio) subrhombicus* Gu et Yu, *Plicatounio (Plicatounio) equiplicatus* Gu et Yu; ostracods: *Cypridea dekhoinensis* Sou; conchostracans: *Nemestheria qingshankouensis* Chang et Chen.

200-600 m

Conformity

Quantou Formation. Purplish grey, greyish white, greyish green sandstones and dark purple, brownish red mudstones in alternation, intercalated with greyish black mudstones, containing bivalves: *Nippononaia (Nippononaia) jilinensis* Gu et Yu; ostracods: *Cypridea vetusta* Ye.

500-1,500 m

Conformity or Disconformity

Underlying strata: Lower Cretaceous. Dengloulou Formation. Dark brownish red, greyish green, greyish black mudstones and greyish green, greyish white siltstones, sandstones and conglomerates.

Comparison of the two provinces reveals generally changing trends of rock character: (1) red salt-bearing beds increase from the north to the south, and (2) grey, yellowish green beds containing coal-kukersit increase from the south to the north. Thus, coal measures, for example, occur in Lena coal basin of the Soviet Union, whereas saline formations, for instance, occur in the southeast Asia and Yunnan of China, these locations being close to the south and north ends of the two provinces.

Assemblage	Zone		China		Korea	Japan		International Scale	
	Zone	Subzone	West Yunnan	Songliao Basin		Inner Zone of S. W. Japan	Central Kyushu		
Upper	4	4b	Mankuanhe F.	Mingshui F.	Bulgusa G.	Nohi F.	Tenkadaiyama F.	U. Cretaceous	
		4a	Bashahe F.	Nenjiang F.		Asuwa F.	Abu F.		
	3	2b	Mangang F.	Yaojia F.	Sinla Subg.	Shunan F.	Mifune G.		Himenoura G.
				Qingshankou F.	Nagdong Subg.	Shimonoseki Subg.			
Middle	2	2a	Quanton F.		Akaiwa Subg.	Wakino Subg.			
		1b	Jingxing F.	Rehe G.	Myogog F.	Itoshiro Subg.	Toyonishi G.		
Lower	1	1a	Lower Member					L. Cretaceous	
			Upper Member						M. Cretaceous
								U. Cretaceous	
								Upper Cretaceous	
								Lower Cretaceous	
								Maast.	
								Camp.	
								Sant.	
								Conic.	
								Tur.	
								Cen.	
								Alb.	
								Apt.	
								Barr.	
								Haut.	
								Valang.	
								Ber.	

Table 2. Tentative zonation of the Asian non-marine Cretaceous on the basis of trigonioidaceans.

Three major divisions and trigonioidacean zonation of the Asian Cretaceous

The Asian non-marine Cretaceous System contains bivalves, gastropods, ostracodes, conchostracans, insects, fishes, reptiles, charophytes, plants, spore-pollens, etc., among which trigonioidacean bivalves appear to be of exceptional importance for the subdivision of the succession. The trigonioidaceans exhibit relatively swift evolution together with variation of conspicuous morphological characteristics, making their appearance in the Early Cretaceous, reaching a climax in the Middle Cretaceous, and declining in the Late Cretaceous. They become extinct before the Paleocene. Although the trigonioidaceans are fewer in number than microfossils, they may be used to define several distinct limits by means of their obvious morphological characteristics, and thus they play a significant role in the classifica-

tion of the Asian non-marine Cretaceous System.

On the basis of the three evolutionary stages and the morphological features of every phylogenetic stage of these bivalves (Table 1) (Guo, 1981), the trigonioidaceans can be arranged in three assemblages as follows, in ascending order:

A lower, also named *KEP* or primitive *TNP* assemblage, characterized by *Koreanaia-Eonippononaia-rariplicatus Plicatounio-Sinonaia-Peregrinoconcha*;

A middle, known as *TNP* assemblage, characterized by *Trigonioides-Nippononaia s.s. - multiplicatus Plicatounio-Wakinoa-Hoffetrigonia s.s. - Kumamotoa*;

An upper, designated *PP* assemblage, represented by *Pseudohyria s.s. - Plicatotrighonioides-Neotrighonioides*.

The Asian non-marine Cretaceous may be subdivided by the three assemblages into Lower, Middle and Upper Cretaceous, the three provincial series revealing this tripartite character

(Guo, 1982) (Table 2). The ages of volcanic rocks, determined by radiometric isotopic dating, are respectively 105–108 m.y. and 85–88 m.y. between the three provincial series (Hu et al., 1982).

Naming of the three provincial series awaits further discussion, as does also the selection of stratotypes in cooperation with colleagues when certain conditions mature.

Furthermore, on the basis of the sequence of occurrence of their species, their morphological characteristics and phylogeny, 4 zones and 6 subzones of trigonioidaceans can tentatively be distinguished as follows, in ascending order:

Zone 1: Zone of *Koreanaia cheongi* Yang – *Peregrinoconcha nuanliensis* Guo – *Koreanaia antiqua* (Gu et Ma), may be divided into two subzones.

Subzone 1a: Subzone of *Koreanaia antiqua* (Gu et Ma), represented by the Gaofengsi Formation of Central Yunnan, China.

Subzone 1b: Subzone of *Koreanaia cheongi* Yang – *Nippononaia (Eonippononaia) tetoriensis* Maeda – *Sinonaia chuxiongensis* (Gu et Ma) – *Peregrinoconcha nuanliensis* Guo, can be found in the Itoshiro Subgroup of Japan, the Myogog Formation of Korea, the Puchang Formation and the upper member of the Jingxing Formation of Yunnan, China, and elsewhere.

The age of the Itoshiro Subgroup containing *Nippononaia (Eonippononaia) tetoriensis* Maeda, an important representative of zone 1, is thought to be Neocomian (Kimura, 1975; Guo, 1982).

Zone 2: Zone of *Trigonioides kodairai* Kobayashi and Suzuki – *Wakinoa wakinoensis* (Ohta) – *Nippononaia (Nippononaia) ryosekiana* Suzuki, could be subdivided into two subzones in some localities.

Subzone 2a: Subzone of *Wakinoa wakinoensis* (Ohta) – *Nippononaia (Nippononaia) ryosekiana* Suzuki, represented by the Lower Wakino Subgroup of Japan and the Lower Nagdong Subgroup of Korea.

Subzone 2b: Subzone of *Trigonioides kodairai* Kobayashi and Suzuki – *Trigonioides sinensis* Gu et Ma – *Trigonioides tetoriensis* Maeda, represented by the Upper Wakino Subgroup and the Akaiwa Subgroup of Japan, the Middle Upper Nagdong of Korea, the Middle Mangang Formation from Yunnan and the Guantou Formation

from Zhejiang, China, the Kokhyar Formation (Кокъярская свита) of Fergana, U.S.S.R.

Nippononaia (Nippononaia) ryosekiana Suzuki, one of the important representatives of zone 2, is confined to the Aptian-Albian age according to ammonites and other marine fossils occurring in marine beds of the underlying and overlying strata (Hayami et Ichikawa, 1965; Matsukawa, 1977).

Zone 3: Zone of *Hoffetrigonia (Kumamotoa) mifunensis* (Tamura) – *Hoffetrigonia (Kumamotoa) paucisulcata* (Suzuki) – *Hoffetrigonia (Hoffetrigonia) kobayashii* (Hoffet), represented by the Goshonoura and Mifune Groups of Japan, the Sinla Subgroup of Korea, the Upper Matoushan Formation from Central Yunnan and the Bali Formation from Guangxi, China, and so on.

According to marine fossils occurring in marine intercalations, the Goshonoura and Mifune Groups, containing important representatives of zone 3, *Hoffetrigonia (Kumamotoa) matsumotoi* (Kobayashi et Suzuki), *Hoffetrigonia (Kumamotoa) mifunensis* (Tamura), have been thought to be Cenomanian-Turonian, Cenomanian or Upper Albian-Turonian by Matsumoto (1938, p. 24–27; 1977, p. 68, 69), Ohta (1975, p. 86, 95), Tamura (1975, p. 55; 1979; 1980, p. 225–235) and others.

Zone 4: Zone of *Pseudohyria (Pseudohyria) gobiensis* MacNeil – *Pseudohyria (Pseudohyria) songhuaensis* Gu et Yu – *Plicatotrigonioides kuramensis* Martinson, represented by the Nenjiang Formation, the Sifangtai Formation, the Wangsi Group, the Erlian Formation from China, and the Tokubay Formation (Токубайская свита), the Yalovatchy Formation (Яловачская свита) of Fergana, U.S.S.R. Zone 4 could be divided into two subzones in part of the region.

Subzone 4a: Subzone of *Pseudohyria (Pseudohyria) gobiensis* MacNeil, represented by the Erlian Formation of Inner Mongolia and the Nenjiang Formation of Heilongjiang, China.

Subzone 4b: Subzone of *Pseudohyria (Pseudohyria) songhuaensis* Gu et Yu, Sifangtai Formation of Heilongjiang, China.

According to Martinson (1965), some important faunal elements of zone 4, such as *Plicatotrigonioides kuramensis* Martinson, *Neotrigonioides gigantus* Martinson, etc., belong to late Turonian-Santonian.

Dansk sammendrag

Kridtsystemet i Asien er hovedsagelig ikke-marint. Det kan deles i to provinser: en nordlig, domineret af kulførende, klastiske grå-gullige formationer, og en sydlig, domineret af saltførende, klastiske røde facies.

Trigonioidacea (muslinger) i marine indslag bruges til at dele sekvensen i nedre, mellem og øvre kridt; fire zoner og seks underzoner er foreslået.

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