

The *Psittacosaurus* biochron, Early Cretaceous of Asia

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Abstract

Fossils of the primitive ceratopsian dinosaur *Psittacosaurus* are widely distributed in Asia in Russia (western Siberia), Mongolia, China (Liaoning, Nei Monggol, Gansu, Ningxia, Xinjiang, Shandong, and Hebei provinces), Thailand, and possibly Japan. All *Psittacosaurus* records are of Early Cretaceous age, and a *Psittacosaurus* biochron can be recognized equivalent to the Tsagantsabian and Khukhtekian land-vertebrate faunachrons (LVF). The Tsagantsabian LVF is defined as the time interval between the first appearance datum (FAD) of *Psittacosaurus*, and the FAD of the turtle *Peishanemys*. The Khukhtekian LVF is the time between the FAD of *Peishanemys* and the FAD of the ceratopsian dinosaur *Microceratops* (=beginning of the Baynshirenian LVF). Cross correlation to the standard global chronostratigraphic scale, mostly by radioisotopic dates and palynology, indicates the Tsagantsabian is Barremian-early Aptian, and the Khukhtekian is late Aptian-Albian. The duration of the *Psittacosaurus* biochron thus is about 20 myr of Barremian-Albian time.

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1. Introduction

Fossils of *Psittacosaurus* (Fig. 1), long considered the oldest and most primitive ceratopsian dinosaur, have a broad geographic distribution in Asia. Equally old and older ceratopsians are now known from Asia (Early Cretaceous *Liaoceratops* and *Archaeoceratops*, and Late Jurassic *Chaoyangosaurus*, Dong and Azuma, 1997; Zhao et al., 1999; Xu et al., 2002; You and Dodson, 2003), but *Psittacosaurus* remains the most abundant and widely distributed ceratopsian in the Asian Lower Cretaceous.

The concept of an Early Cretaceous psittacosaur-pterosaur fauna or ornithopod-*Psittacosaurus* faunal complex is well entrenched in the literature (e.g., Dong, 1973, 1979, 1992, 1993, 1995; Zhen et al., 1985), and the idea that *Psittacosaurus* occurrences are Early Cretaceous is as old as the original discovery of the dinosaur (Osborn, 1923, 1924; Berkey and Morris, 1927; Morris, 1936). These fossils thus have been used to

define a *Psittacosaurus* biochron, which is an interval of Early Cretaceous time (Lucas and Estep, 1998; Lucas, 2001).

However, the duration of this biochron is not agreed on. Some authors suggest that *Psittacosaurus* had a very narrow temporal distribution around the Aptian-Albian boundary (e.g., Sereno, 1990a,b; Buffetaut and Suteethorn, 1992), whereas others have argued it had a much longer temporal range from the Valanginian through the Albian (e.g., Russell and Zhao, 1996). Xu and Zhao (1999), advocating a long temporal duration of *Psittacosaurus*, have even suggested there are two temporally distinct assemblages with *Psittacosaurus*, an earlier one with primitive psittacosaur, basal therizinosaur and dromaeosaur, and primitive pterosaur, and a later one with derived psittacosaur and dromaeosaur comparable to Late Cretaceous forms. Still others have suggested that *Psittacosaurus* had a diachronous distribution and cannot be used as an index fossil (Manabe and Hasegawa, 1991; Matsukawa and Obata, 1994). Here, I review the distribution and age relationships of *Psittacosaurus* fossils and further develop the vertebrate biochronology of the Asian Early Cretaceous.

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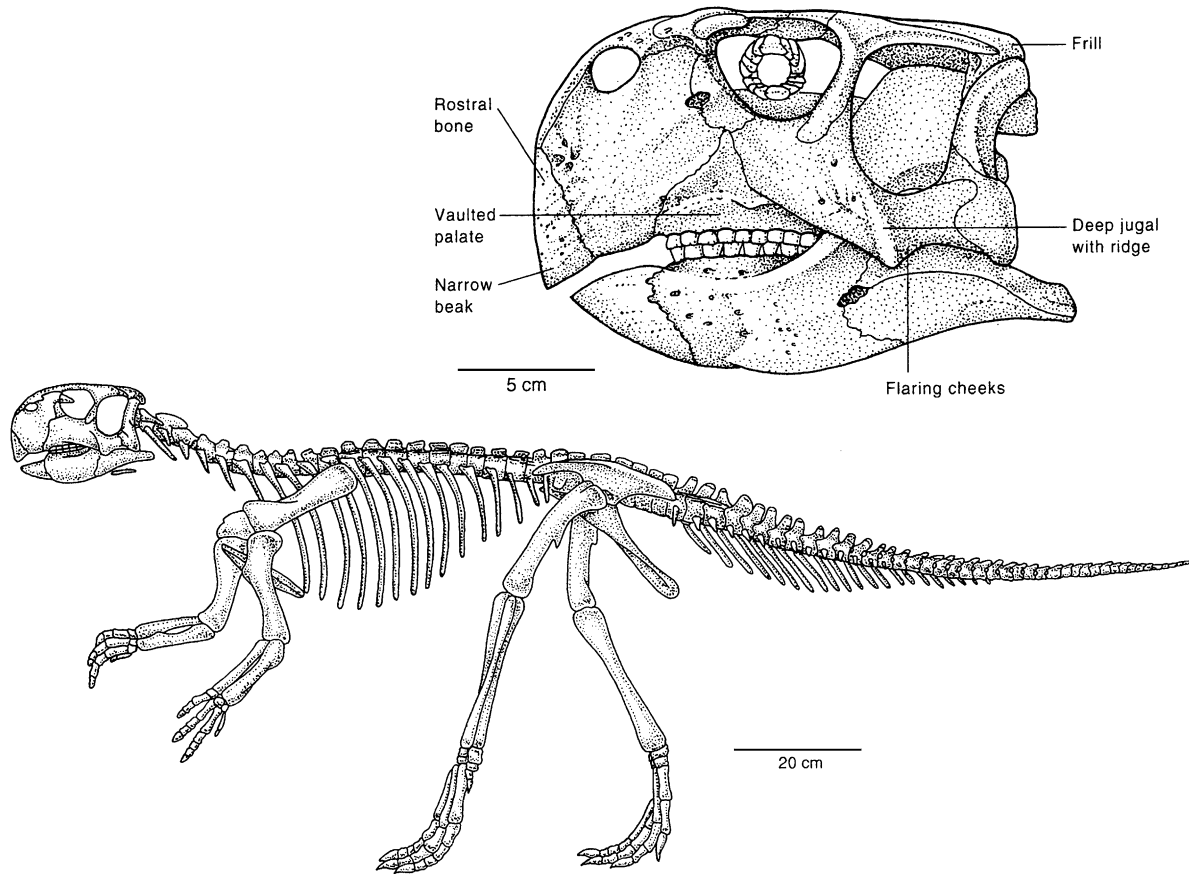


Fig. 1. Skeleton and skull of *Psittacosaurus mongoliensis* with key ceratopsian features of the skull indicated (after Lucas, 2004).

2. *Psittacosaurus*: the dinosaur and its taxonomy

Psittacosaurus (Fig. 1) has long been considered the archetypal ceratopsian. It possesses the key evolutionary novelties of the Ceratopsia, even though it has only the most rudimentary of frills (the posterior end of the skull roof just barely overhangs the back end of the skull). The short snout, high position of the nostrils, tall rostrum that superficially resembled a parrot's beak, and reduction of the functional digits of the hand to three are among the diagnostic features of *Psittacosaurus* among ceratopsians. As many as 14 species of *Psittacosaurus* have been named from the Lower Cretaceous of Asia, and their remains include many complete skulls and skeletons.

No detailed taxonomic revision of *Psittacosaurus* has been undertaken. However, Sereno (1990a,b) did briefly review the species-level taxonomy of the genus to conclude that there are only two well-established species, *P. mongoliensis* Osborn (the type species) and *P. sinensis* Young. Thus, Sereno (1990a,b) regarded *Protiguanodon mongoliense* Osborn, *Psittacosaurus osborni* Young, *P. tingi* Young, and *P. guyangensis* Cheng as junior subjective synonyms of *P. mongoliensis* (as did Xu and Zhao, 1999). Sereno also regarded *P. youngi* Chao as a junior subjective synonym of *P. sinensis*, as did Xu and Zhao. However, several relatively recently named species of *Psittacosaurus*, *P. meileyingensis* Sereno, Chao, Cheng and Rao, *P. xinjiangensis* Sereno and Chao, *P. neimongolensis* Russell and Zhao, *P. ordosensis* Russell and Zhao, *P. mazongshanensis*

Xu, *P. sibiricus* Voronkevich and Averianov, and *P. sattayarakii* Buffetaut and Suteethorn, should be taxonomically re-evaluated. They are mostly based on single specimens and are purportedly distinguished from each other by minor cranial features.

As is the case in most studies of Mesozoic vertebrate biochronology, I use the genus as the operational taxonomic unit. Thus, my interest is primarily in the temporal distribution of the genus *Psittacosaurus*, not in its nominative species. Indeed, as is made clear below, the individual species of *Psittacosaurus* appear to be of no precise biochronological value at present.

3. Asian land-vertebrate faunachrons

For most of the last century, correlation of Asian Cretaceous land-vertebrate assemblages was made by reference to marine stage-ages. This practice continues, despite the problems inherent to correlating nonmarine fossils from Asia to marine stages defined in southern Europe. However, Jerzykiewicz and Russell (1991) proposed a succession of "Mongolian land-vertebrate ages" (MOLVAs) for Late Jurassic-Late Cretaceous time based on formations and vertebrate fossil assemblages from Mongolia, thus providing a vertebrate biochronological framework with which to correlate (Fig. 2). Despite the caveats noted by Lucas and Estep (1998) and Lucas (2001), several of the MOLVAs named by Jerzykiewicz

Series	land-vertebrate faunachron
Late Cretaceous	Nemegtian
	Barungoyotian
	Baynshirenian
Early Cretaceous	Khukhtekian
	Tsagantsabian
	Ningjagouan

Fig. 2. Land-vertebrate faunachrons of the Cretaceous of Asia (after Lucas and Estep, 1998).

and Russell (1991) can be recognized as land-vertebrate faunachrons (LVFs) (sensu Lucas, 1998, 2001). They are time intervals recognized by vertebrate faunas, and thus are biochronological units best termed faunachrons, not “ages”, which have a different formal meaning in stratigraphy. Five of these “MOLVAs” can be identified by Chinese Cretaceous vertebrate fossil assemblages (Lucas and Estep, 1998), and two are relevant to the temporal distribution of *Psittacosaurus*: Tsagantsabian and Khukhtekian. In the Appendix to this paper, I formally define the Tsagantsabian and Khukhtekian LVFs.

The vertebrate fossil assemblages of the Gurvan Eran, Tevsh, Undurukhin, and Tsagantsab formations of Mongolia formed the basis of the Tsagantsabian LVF (Jerzykiewicz and Russell, 1991, p. 363). Jerzykiewicz and Russell (1991) provided no formal definition of the Tsagantsabian, but taxa characteristic of Tsagantsabian time include the theropod *Prodeinodon*, the sauropod *Asiatosaurus* (both form genera based on teeth), the stegosaur *Wuerhosaurus*, the ceratopsian *Psittacosaurus*, and the pterosaur *Dsungaripterus* (Lucas and Estep, 1998). The lycopterid fish *Lycoptera* also is present. It obviously has a long temporal range that spans the Jurassic-Cretaceous boundary, but its last appearance datum (LAD) is in the Tsagantsabian (Jerzykiewicz and Russell, 1991; Chang and Jin, 1996; Lucas, 1996).

Like Lucas and Estep (1998), I do not recognize the Shinkhudukian “MOLVA” of Jerzykiewicz and Russell (1991), which was supposed to be the time interval between the Tsagantsabian and Khukhtekian. This is because the characteristic assemblage of the Shinkhudukian encompasses only a few taxa (*Lycoptera*, the turtle *Hangaiemys*, *Psittacosaurus* and the single record of the bird *Ambiortus*) that do not distinguish it from the older Tsagantsabian. I thus abandon the Shinkhudukian and consider its time interval to be the later part of the Tsagantsabian (Fig. 2).

The vertebrate fossil assemblages of the Dzun Bayan, Dushilin, and Khulsyngol formations of Mongolia were the basis of (characterized) the Khukhtekian vertebrate faunachron (Jerzykiewicz and Russell, 1991, pp. 364–365). Jerzykiewicz and Russell (1991) provided no formal definition of the Khukhtekian, but taxa characteristic of Khukhtekian time include the turtle *Peishanemys*, the theropod family Harpimymidae, the ceratopsian *Psittacosaurus*, the ornithopods *Proactrosaurus* and “*Iguanodon*”, the ankylosaur *Shamosaurus*, and the amphilestid mammal *Gobiconodon* (Lucas and Estep, 1998).

4. Distribution and age of *Psittacosaurus* localities

4.1. Russia

In Russia, *P. mongoliensis* and the recently named *P. sibiricus* are present in the Ilek Formation in the Gorno-Altay Autonomous Region of western Siberia (Fig. 3) (Rozhdestvensky, 1955, 1960, 1973; Voronkevich, 1998). They co-occur with a diverse tetrapod assemblage of turtles, lizards, crocodylians, theropod and sauropod dinosaurs, a tritylodontid, and the amphilestid mammal *Gobiconodon* (Maschenko and Lopatin, 1998). This assemblage has been assigned a Khukhtekian age (Averianov and Skutschas, 2000; Averianov et al., 2002), and the presence of *Gobiconodon* supports this assignment.

4.2. Mongolia

In Mongolia, fossils of *Psittacosaurus* occur in strata that Jerzykiewicz and Russell (1991) assigned Tsagantsabian and Khukhtekian ages (Fig. 3). Tsagantsabian records of *P. mongoliensis* include the Tsagantsab Formation at Khovd and Nayanchongor (e.g., Kalandadze and Kurzanov, 1974; Shuvalov, 1974; Matsukawa et al., 1997).

Khukhtekian records are more extensive. The Khukhtek Formation at Ovorkhangai, which encompasses the Ondai Sar and Oshih formations of Berkey and Morris (1927), contains the type locality of *Psittacosaurus mongoliensis* (Osborn, 1923; Coombs, 1980, 1982). Other *Psittacosaurus* localities of Khukhtekian age in Mongolia include Dundgo, Dornogov, Khamryn-Uus (=Gashuny-Khuduk), Khobur, Anda-Khuduk, Oiwi-Nuru, Khuren-Dkh, Gashuny-Khudukh, Tsakhurt, and Ulan-Osh (Kalandadze and Kurzanov, 1974; Suslov, 1983). Other vertebrate taxa from these localities, and thus co-occurring with *Psittacosaurus* (mostly *P. mongoliensis*, and records identified only as *P. sp.*), include the ornithopod “*Iguanodon*”, the ankylosaur *Shamosaurus*, and the mammal *Gobiconodon* (Osborn, 1923, 1924; Rozhdestvensky, 1952; Martinsson and Shuvalov, 1973; Shuvalov, 1974; Barsbold and Perle, 1983; Suslov, 1983; Tumanova, 1987).

Jerzykiewicz and Russell (1991) mostly used Krassilov’s (1982) correlations of plant megafossil assemblages to correlate the Mongolian Tsagantsabian and Khukhtekian vertebrate assemblages to the marine stages of the Early Cretaceous. Thus, they correlated the Tsagantsabian to the Valanginian-Barremian, the “Shinkhudukian” to the Aptian and the

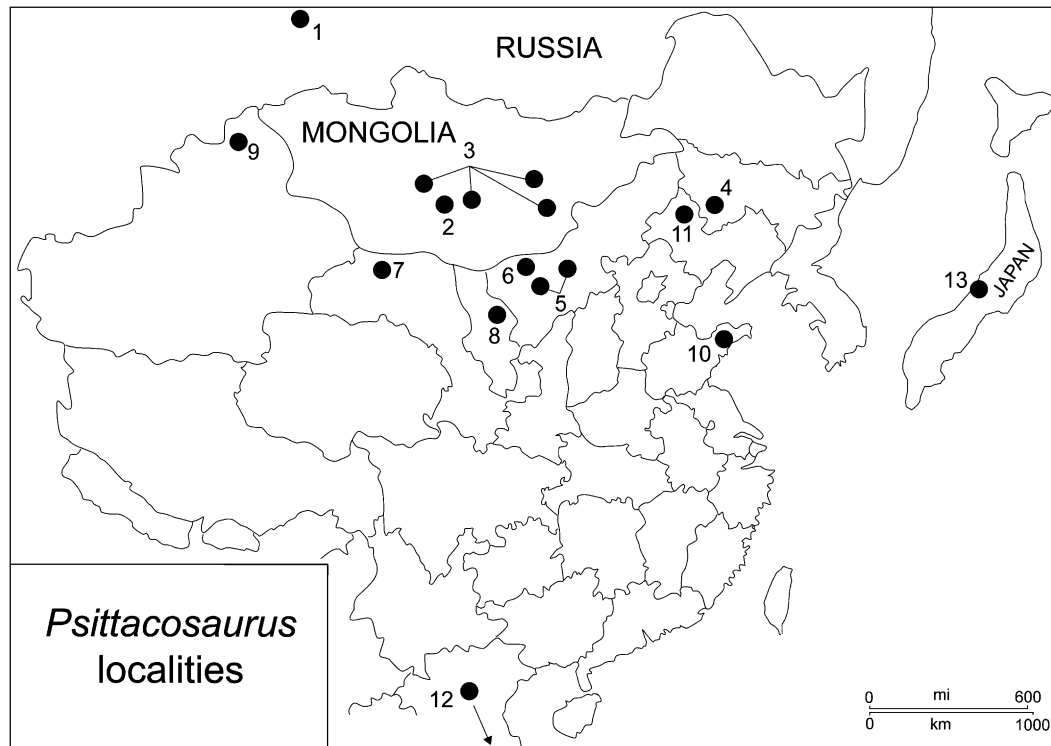


Fig. 3. *Psittacosaurus* localities in eastern Asia. Localities are: 1, Ilek Formation, western Siberia, Russia; 2, Tsagantsab Formation, Mongolia; 3, various Khukhtekian localities, Mongolia (see Kalandadze and Kurzanov, 1974 for more details); 4, Jehol Group, western Liaoning, China; 5, Ejinhor Formation and other localities in Nei Monggol, China (see Russell and Zhao, 1996 for more details); 6, Tebch, Nei Monggol, China; 7, Mazongshan, western Gansu, China; 8, unspecified locality in eastern Ningxia, China (Dong, 1987); 9, Tugulu Group, Urho area, Xinjiang, China; 10, Qingshan Group, Laiyang area, Shandong, China; 11, Tujingzi Formation, northern Hebei, China; 12, Kok Khruat Formation, Ban Dong Bang Noi, Thailand (just off of map); and 13, Kuwajima Formation (and equivalents), Tetori Group, southwestern Japan.

Khukhtekian to the late Aptian-Albian. They also noted the presence of late Aptian selachians in Khukhtekian-equivalent strata in Kyrgyzstan (Nessov and Fedorov, 1989) and stated that trionychid turtles (there are none in Khukhtekian-age vertebrate assemblages) do not appear in Asia until the late Albian (Nessov, 1984).

Jerzykiewicz and Russell (1991) also noted that Tsagantsabian basalts in Mongolia yield K/Ar ages of about 130 Ma (Samoilov et al., 1988), arguing that they are consistent with ostracods, molluscs, conchostracans, and fossil plants that suggest a late Neocomian age. However, a more recent compilation of basalt ages indicates a range of dates of 119 to 141 Ma for the Tsagantsabian and 108 to 113 Ma for the Khukhtekian (Shuvalov and Nikolaeva, 1998).

A close reading of Krassilov (1982) and of Vakhrameev (1988), however, indicates that paleobotanical support for an age older than Barremian for the Tsagantsabian is questionable. Thus, Krassilov (1982, p. 2) stated that “on the evidence of invertebrates and fishes, the Tsagantsab level is assigned to the Neocomian, Shin-Khuduk [late Tsagantsabian]—to the late Neocomian-Aptian and the Khulsyngol [Khukhtekian]—to the Aptian-Albian”. No further explanation of these age assignments was provided, though Krassilov (1982, p. 4) did recognize and correlate four “phytostratigraphic units”. The oldest of these, at the Tsagantsab level, he termed a “*Baiera manchurica* zone” and correlated it to the Urgal Formation in the Bureya basin of Siberia, to which

he assigned a Valanginian age. Krassilov (1982, p. 4) stated that in the overlying “*Otozamites-Pseudolarix erensis* zone”, also Tsagantsabian, “the flora is of generalized Wealden aspect and does not seem younger than Neocomian”. Krassilov (1982) considered the next floral zone, of late Tsagantsabian (“Shinkhudukhian”) age, the “*Baierella hostata* zone”, to be Aptian based on similarities to “Aptian” floras of the Bureya basin, Primorye, and Yakhtutia regions of Siberia. This, of course, implies a substantial hiatus between the Tsagantsabian and “Shinkhudukhian” intervals. The youngest flora, the “*Limnothetis-Limnoniobe* zone” from the Khukhtekian Khulsyngol Formation, was also thought by Krassilov (1982) to be Aptian because of its similarity to the underlying floral zone.

Vakhrameev (1988), however, interpreted the age of the Tsagantsabian floras differently. He noted the presence of angiosperms in the Tsagantsabian flora documented by Krassilov (his oldest zone) from the Undurkhan “svita” at Manlay, and questioned a Neocomian age assignment for these records. Instead, he concluded that they are much more likely to be Barremian-Aptian based on the oldest ages assigned to similar angiosperms in Siberia (also see Vakhrameev and Kotova, 1977). Vakhrameev (1988) also argued that the pollen complex of the Anda-Khuduk svita (“Shinkhudukhian”) contains *Asteropollis* and is most likely of Barremian-Aptian age. Vakhrameev (1988) thus provided strong arguments against an age older than Barremian for the Tsagantsabian.

Paleomagnetic analysis indicates that the Khukhtekian strata at Khuren Dukh (strata previously mapped as Shinekhu-dag Formation; now the Khuren Dukh Formation: see Ito et al., 2006) are in the early part of Chron 34n, and the palynomorph assemblage from these strata (especially the presence of reticulate tricolpate forms and of *Asteropollis asteroides* Hedlund and Norris) suggests an Albian age (Hicks et al., 1999). Indeed, the palynomorphs, if coeval with North American assemblages, cannot be older than middle Albian according to Hicks et al. (1999). This suggests a somewhat younger age for at least part of the Khukhtekian than do the other data.

My reading of these data is that a late Aptian-Albian age for the Khukhtekian has good support. How much older the Tsagantsabian is within the Early Cretaceous is less clear based on the data from Mongolia, but a Neocomian age seems unlikely.

4.3. Liaoning, China

In western Liaoning (Fig. 3), *Psittacosaurus mongoliensis* occurs near the base of the Binggou Formation, as does *P. meileyingensis* Sereno, Chao, Chang and Rao, 1988. Numerous records of *Psittacosaurus* sp. have been reported from the Yixian Formation, and the overlying Jiufotang Formation yields specimens assigned to *P. mongoliensis* (e.g., Xu and Wang, 1998; Wang et al., 1999, 2000; Smith et al., 2001; Zhou et al., 2003).

These strata have long been included in the Jehol Group and the fossils considered part of the “Jehol biota”, stratigraphic and biotic concepts that date back to Grabau (1923, 1928). The age of the Jehol Group was originally, and for many years, considered to be Cretaceous (e.g., Morris, 1936), but in recent years some have concluded it is Jurassic (e.g., Gu, 1992).

Fossils from the Jehol Group are of palynomorphs, mega-fossil plants, conchostracans, insects, ostracods, gastropods, bivalves, and vertebrates (including dinosaur footprints). Each one of these groups is of potential biochronological significance, but the overwhelming majority of the taxa known from these strata are endemics and thus of no real significance to correlation (Smith et al., 2001). One of the few exceptions is *Psittacosaurus*, which is known elsewhere only from Early Cretaceous localities, so it indicates an Early Cretaceous age for its records in Liaoning.

The principal reason some Chinese geologists and paleontologists considered the Jehol Group to be Jurassic is its correlation with marine strata to the east, in Helongjiang, that supposedly yielded Jurassic bivalves and ammonites (see Gu, 1992, for an excellent summary of this point of view). However, recent restudy of these marine fossils, which are from the Longzhaogou and Jixi groups, indicates that they were misidentified and actually are Early Cretaceous (Barremian-early Albian) in age (e.g., Sha et al., 1994, 2002; Futakami et al., 1995). Furthermore, radioisotopic ages from the upper Jehol Group volcanic ashes are in the 121–125 Ma range (though see Lo et al., 1999 for different ages),

and thus indicate an Early Cretaceous age (Smith et al., 1995, 2001; Swisher et al., 1999, 2002; Wang et al., 2000).

Psittacosaurus occurs at various stratigraphic levels in the Yixian and Jiufotang formations (e.g., Wang et al., 2000). The stratigraphically lowest level in the Yixian Formation is above radioisotopic ages of ca. 125 Ma, and other ages from the Yixian Formation of 121–123 Ma are intercalated with *Psittacosaurus* localities. The overlying Jiufotang *Psittacosaurus* are probably close in age to the Yixian records, and the Binggou Formation *Psittacosaurus* records must be slightly younger. The radioisotopic ages thus are consistent with correlation to Lower Cretaceous marine strata in establishing an Early Cretaceous (Barremian-Aptian) age for the *Psittacosaurus*-bearing strata in Liaoning.

4.4. Nei Monggol, China

There are more published records of *Psittacosaurus* from Nei Monggol than from any other Chinese province, and most occurrences appear to be of Tsagantsabian age (Fig. 3). *P. guyangensis* Cheng, 1983 is from the Lisangou Formation in central Nei Monggol, as are *P. osborni* and *P. tingi* (Young, 1931), all considered synonyms of *P. mongoliensis*. *P. osborni* Young is also known from the slightly younger Xinpongnaobao Formation (Young, 1931).

P. sinensis is also reported from the Laohuandong Formation in Nei Monggol, which also produced the fish “*Sinamia*”, the turtle *Ordosemys leios*, the champsosaur *Ikechosauros*, the crocodylians *Eotomistoma* and *Shantungosuchus*, stegosaurs, sauropods, ornithopods, a pterosaur, and a mammal. I consider this a Tsagantsabian record (Lucas and Estep, 1998).

P. neimongoliensis Russell and Zhao and *P. ordosenis* Russell and Zhao are from the Ejinhor Formation of Nei Monggol, where they co-occur with *Wuerhosaurus*, *Saurornithoides*, and cf. *Chiayusaurus* (Russell and Zhao, 1996). The presence of *Wuerhosaurus* suggests a Tsagantsabian age. *Psittacosaurus* sp. is from red beds at Muhaxiao in Nei Monggol that also yielded the troodontid dinosaur *Saurornithoides youngi* Russell and Dong. In the Alxa Desert of Nei Monggol, the type locality of the theropod *Alxasaurus elesitaiensis* Russell and Dong yields *Psittacosaurus* sp. Other occurrences in Nei Monggol are Alouchaideng (Ejinhor Formation), Ulan Obo (Ejinhor Formation?), Hangginqi (Ejinhor Formation?), Laolonghuozi (Luohandang Formation), Elesitai (Bayin Gobi Formation), and at Hulanhusu (Dong, 1993; Russell and Zhao, 1996). Russell and Zhao (1996) report that Albian palynomorphs are associated with the Elesitai occurrence.

An $^{40}\text{Ar}/^{39}\text{Ar}$ age from the Tebch basalts at Tebch, Nei Monggol is 110 ± 0.52 Ma. This is above the *P. mongoliensis* occurrence there, which is associated with *Prodeinodon?* and the ankylosaur *Sauropites* (Bohlin, 1953; Weishampel, 1990; Eberth et al., 1993). The probable presence of *Prodeinodon* suggests a Tsagantsabian age. Palynomorphs from the *Psittacosaurus*-bearing strata were assigned a Barremian or early Aptian age based on the absence of tricolpate pollen

and the presence of *Asteropollis* cf. *A. trichotomosulcatus* (Eberth et al., 1993).

4.5. Gansu, China

Psittacosaurus mazongshanensis is from the lower red beds of the Xinminbao Group in the Mazongshan area (“Gongposhuan basin”) of western Gansu (Fig. 3) (Xu, 1997; Dong, 1997; Tang et al., 2001). This species is part of a tetrapod assemblage that includes the iguanodontid *Probaetosaurosaurus*, the theropod *Saurornithoides*, the sauropod tooth genus *Chiayusaurus* and a new gobiconodontid. I correlate this assemblage to the Khukhtekian Dashigou (Tashikou) Formation of Nei Monggol, which also includes *Probaetosaurosaurus* (Rozhdestvensky, 1966; Lucas and Estep, 1998). Tang et al. (2001) consider this occurrence Albian based largely on palynomorphs.

4.6. Ningxia, China

Dong (1987, p. 53) illustrated an *incomplete* skull of *Psittacosaurus* from eastern Ningxia (Fig. 3) but provided no stratigraphic information or precise geographic provenance.

4.7. Xinjiang, China

Psittacosaurus xinjiangensis Sereno and Chao, 1988 (also see Brinkman et al., 2001) is from the Lianmuqin Formation (upper Tugulu Group) of the Junggur basin, Xinjiang (Fig. 3). It is part of a tetrapod assemblage (Shen and Mateer, 1992) that includes the sauropod *Asiatosaurus*, the stegosaur *Wuerhosaurus*, and the pterosaur *Dsungaripterus*, and thus is of Tsagantsabian age (Lucas and Estep, 1998).

4.8. Shandong, China

Psittacosaurus sinensis Young (= *P. youngi* Chao) from the Doushan Formation of the Qingshan Group near Laiyang in Shandong (Fig. 3) is part of an assemblage that includes indeterminate sauropods and pterosaurs and the turtle *Peishanemys* (Chow, 1954; Young, 1958; Chao, 1962). This is a Khukhtekian record (Lucas and Estep, 1998). *Psittacosaurus* sp. also is reported from the Zhujiazhuang Formation (lowest unit of the Qingshan Group) (Cheng et al., 1995). Volcanic rocks of the Shiumoutou Formation, which is between the Zhujiazhuang and the Doushan formations, yielded a K/Ar age of 122.6 Ma according to Cheng et al. (1995).

4.9. Hebei, China

Dong (1987, p. 54) reported “psittacosaur specimens” from the Tujingzi Formation in northern Hebei (Fig. 3) but provided no further documentation. Palynomorphs suggest an early Albian age for this unit (Gan and Zhang, 1985).

4.10. Thailand

At Ban Dong Bang Noi in northeastern Thailand (Fig. 3), *Psittacosaurus sattayaraki* is from the Khok Khruat Formation (Buffetaut and Suteethorn, 1992). Known only from a dentary and maxillary fragment, this *Psittacosaurus* co-occurs with the hybodont shark *Thaiodus ruchae*. The same shark taxon has been reported from Tibet in deltaic sediments assigned an Aptian-Albian age based on orbitolinid foraminiferan biostratigraphy (Cappetta et al., 1990), so Buffetaut and Suteethorn (1992) suggested an Aptian-Albian age for *P. sattayaraki*.

4.11. Japan

The Tetori Group consists of siliciclastic strata in Japan (Fig. 3) that yielded femur and tibia fragments identified as “Psittacosauridae” (Dong et al., 1990; Manabe and Hasegawa, 1991). These fossils were reported from the “Kitadani Formation”, which has also produced turtle, crocodile, and other dinosaur fossils, most notably the theropod *Fukuiraptor* (e.g., Azuma and Tomida, 1995; Azuma and Currie, 2000; Azuma, 2003). The “Kitadani Formation” has been assigned an Aptian age based on its stratigraphic relationship to marine, ammonite-bearing strata (Matsukawa and Obata, 1992, 1994) or a Barremian age based on its bivalve faunas (Fujita, 2003). However, the most recent stratigraphic analysis of the Tetori Group indicates that the vertebrate fossils are actually from the Kuwajima, Okurodani, and Izuki formations, lateral facies equivalents that range in age from Valanginian to Barremian (Matsukawa et al., 2006).

Dong et al. (1990, p. 30) illustrated the “psittacosaurid” fossils from the Kitadani Formation, two femoral fragments and an incomplete tibia. They are certainly not diagnostic of the genus *Psittacosaurus*, though they appear to be from a small ceratopsian. The presence of a psittacosaurid in Japan thus must be considered tentative.

5. The *Psittacosaurus* biochron

Outside Liaoning, China, no record of *Psittacosaurus* has ever been assigned a Jurassic age, and, indeed, none of the occurrences of the genus is demonstrably Jurassic in age. No occurrence of *Psittacosaurus* has ever been assigned a Late Cretaceous age, and no evidence supports such an assignment. All *Psittacosaurus* records are of Early Cretaceous age, and all are of Tsagantsabian and Khukhtekian age as those land-vertebrate faunachrons are defined here. These occurrences define a *Psittacosaurus* biochron that is a recognizable time interval of the Early Cretaceous across eastern Asia.

P. mongoliensis and *P. sinensis* are present in both Tsagantsabian and Khukhtekian horizons, but the other species of *Psittacosaurus* are single occurrences of either Tsagantsabian (*P. neimongolensis*, *P. ordosensis*, *P. xinjiangensis*) or Khukhtekian (*P. meileiyungensis*, *P. mazhongensis*, *P. sattayaraki*, *P. sibiricus*) age. The species of *Psittacosaurus* thus do not provide a sound basis for subdivision of the *Psittacosaurus* biochron. Furthermore, the *Psittacosaurus*

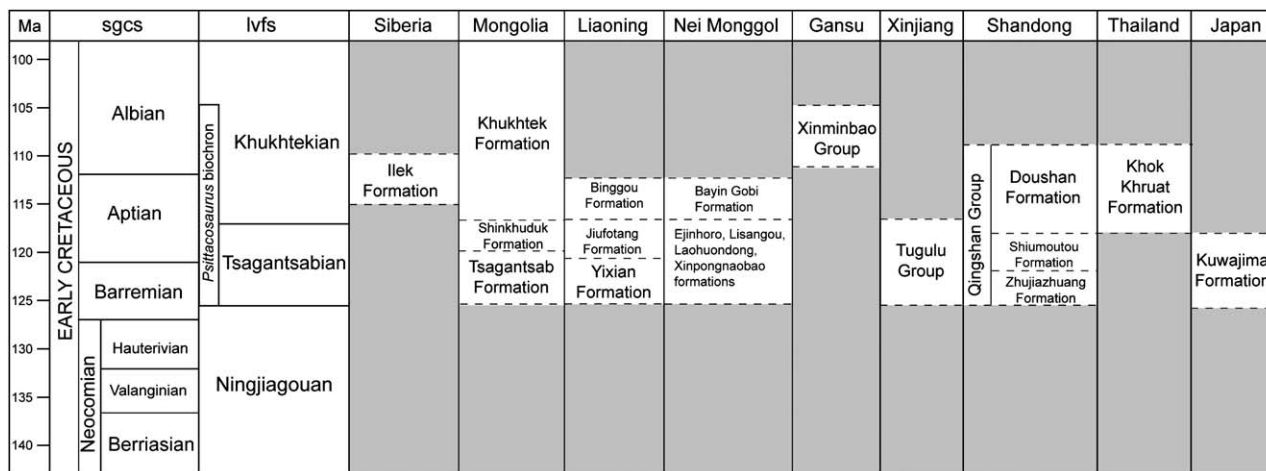


Fig. 4. Correlation chart of *Psittacosaurus*-bearing stratigraphic units in Asia. The numerical age calibration is from the most recent IUGS timescale. All age boundaries of the *Psittacosaurus*-bearing stratigraphic units (shown as dashed lines) should be considered provisional, but correlation of units to the Tsagantsabian and Khukhtekian LVBs is more definite.

biochron is relatively long (about 20 myr, see below) and encompasses all of the Tsagantsabian and part of the Khukhtekian. Thus, the *Psittacosaurus* biochron does not provide a very precise basis for correlation.

The preceding text reviewed data from radioisotopic ages, palynology, megafossil plants, vertebrate paleontology and regional stratigraphy that have been used to cross correlate the Tsagantsabian and Khukhtekian LVBs to the marine stages of the standard global chronostratigraphic scale (SGCS). The oldest age of the Tsagantsabian on the SGCS is Barremian. Vakhrameev's (1988) revision of Krassilov's (1982) megafossil-plant correlations supports this. The oldest reliable radioisotopic ages below *Psittacosaurus* fossils are from the base of the Yixian Formation in Liaoning, China and are ca. 125 Ma, which is early Barremian (Fig. 4). Palynology indicates an age no older than Barremian for the Tsagantsabian record of *Psittacosaurus* at Tebsch, Nei Monggol. All reliable lines of evidence suggest the beginning of the Tsagantsabian is no older than Barremian.

Correlation of the Khukhtekian to the SGCS is more strongly supported. Thus, Khukhtekian strata in Mongolia contain the shark *Asiodontus*, also found in marine upper Aptian strata of Kyrgyzstan (Nessov, 1997; Averianov and Skutschas, 2000). In North America, the Khukhtekian index taxon *Gobiconodon* occurs in the Cashenranchian LVB of Lucas (1993), which is of late Aptian-early Albian age. Magnetostratigraphy and palynology indicate an Albian age for some Khukhtekian strata. Indeed, by the definition presented here (see Appendix), the end of the Khukhtekian is defined by the beginning of the Baynshirenian LVB, which appears to be a Cenomanian datum (Jerzykiewicz and Russell, 1991). The Khukhtekian thus appears to correlate to the late Aptian and all of the Albian.

The youngest known fossil of *Psittacosaurus*, however, may only be in the middle part of Khukhtekian time, in strata of early or middle Albian age (Fig. 4). Thus, the entire duration of the *Psittacosaurus* biochron is about 20 myr (ca.

105–125 Ma), which is part of Barremian, all of Aptian and part of Albian time (Fig. 4).

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Appendix

Definition of the Tsagantsabian and Khukhtekian LVFs

Here I precisely define two biochronological units, the Tsagantsabian and Khukhtekian LVFs. The format used is that of recent definition of Triassic and Cretaceous LVFs (Lucas, 1998; Sullivan and Lucas, 2003).

Tsagantsabian

Definition. The Tsagantsabian LVF is the interval of time between the Ningjiagouan (Lucas, 1996) and the Khukhtekian LVFs. The beginning of the Tsagantsabian (=end of the Ningjiagouan) is the first appearance of the ceratopsian dinosaur *Psittacosaurus*. The end of the Tsagantsabian (=beginning of the Khukhtekian) is the FAD of the turtle *Peishanemys*.

Characteristic assemblage. As indicated by Jerzykiewicz and Russell (1991), the characteristic vertebrate fossil assemblage of the Tsagantsabian LVF is from the Gurvan Eran, Tevsh, Undurukhin and Tsagantsab formations of Mongolia.

Principal correlatives. The most extensive vertebrate assemblage of Tsagantsabian age is from the Liamuqin Formation of the Tugulu Group in Xinjiang, China. Other Tsagantsabian assemblages are from the Ejinhoro Formation of Nei Monggol, China, the Napai Formation in Guangxi, China and possibly the Tetori Group in Japan.

Index fossils. *Prodeinodon*, *Asiatosaurus*, *Wuerhosaurus*, *Dsungaripterus*.

First appearance. *Hangaiemys*, *Prodeinodon*, *Asiatosaurus*, *Wuerhosaurus*, *Psittacosaurus*, *Dsungaripterus*.

Last appearance. *Lycoptera*, *Sinemys*, *Prodeinodon*, *Asiatosaurus*, *Wuerhosaurus*, *Dsungaripterus*.

Khukhtekian LVF

Definition. The Khukhtekian LVF is the interval of time between the Tsagantsabian and the Baynshirenian LVFs. The beginning of the Khukhtekian (=end of the Tsagantsabian) is the first appearance of the turtle *Peishanemys*. The end of the Khukhtekian (=beginning of the Baynshirenian) is the FAD of the ceratopsian dinosaur *Microceratops*.

Characteristic assemblage. As indicated by Jerzykiewicz and Russell (1991), the characteristic vertebrate fossil assemblage of the Khukhtekian LVF is from the Dzun Bayan, Dushilin and the Khulsyngol formations of Mongolia.

Principal correlatives. Vertebrate fossil assemblages from the Ilek Formation, Siberia, Dashigou Formation, Nei Monggol, China, lower red beds of the Xinminbao Group, Gansu, China and the Doushan Formation of the Qingshan Group, Shandong, China.

Indexfossils. *Peishanemys*, *Harpimymidae*, *Probactrosaurus*, “*Iguanodon*”, *Shamosaurus* and *Gobiconodon*.

First appearance. *Peishanemys*, *Harpimymidae*, *Probactrosaurus*, “*Iguanodon*”, *Shamosaurus* and *Gobiconodon*.

Last appearance. *Peishanemys*, *Hangaiemys*, *Harpimymidae*, *Probactrosaurus*, “*Iguanodon*”, *Shamosaurus*, *Psittacosaurus* and *Gobiconodon*.