

Late Cretaceous biota and the Cretaceous-Paleogene (K-Pg) Boundary in Jiayin of Heilongjiang, China

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Abstract: An international cooperative study of the Late Cretaceous biota and non-marine strata including the Cretaceous-Paleogene (K-Pg) boundary in Jiayin near the Heilongjiang River, China during 2002-2010, is summarized in this paper. The strata includes the Upper Cretaceous Yong'ancun-, Taipinglinchang-, Yuliangzi-, and Furao formations, and the Paleocene Wuyun Formation consisting of Baoshantou Member and a Coal-bearing Member. Seven palynological assemblages from Santonian to Paleocene are recognized, which is used for definition of the K-Pg boundary. Through the palynological analysis of three drilled boreholes (XHY-2005, 2006, 2008) in Xiaoheyuan of western Jiayin, the K-Pg boundary is defined within 22.00-22.05 m in the borehole XHY-2006 (as a standard boundary) which is just between the top of Furao Formation (late Maasterichtian) and the base of Baishantou Member (early Danian). These new research results are supported by paleomagnetic, geochemical and other analyses, also. On the other hand, the presence of eight taxa of Maasterichtian dinosaurs (mostly hadrosaurids) have been recognized by the authors; and two mega-plant assemblages from the Yong'ancun Fm (Santonian) to Taipinglinchang Fm (Campanian) are confirmed. These research a-

chievements indicate that the Upper Cretaceous- Paleocene in Jiayin can be well correlated to the strata in the neighboring Zeya-Bureja basin, Russia. The K-Pg boundary defined in Jiayin is the first well documented non-marine K-Pg boundary in China. Also the related paleoclimate, paleoenvironment and the mass extinctions in this area during the Cretaceous-Paleocene transition are also discussed.

Key words: Biota; Late Cretaceous; Paleogene; K-Pg boundary; Heilongjiang River, Jiayin

1 Introduction

The Late Cretaceous (99.6-65.5 Ma) is an important period in evolutionary history of the Earth and its organisms. The Late Cretaceous-Paleogene (K-Pg) boundary has recorded the geo-/bio- events during the critical transitional time at about 65.5 Ma ago, particularly recorded the mass extinctions in the world, including the dinosaurs, ammonites, and more than 70% of the organisms of the world, particularly in the northeastern Asian region. In the Late Cretaceous, the terrestrial plants were thriving, the herbivorous hadrosaurid dinosaurs began to occur on the Earth, and the carnivorous dinosaurs such as *Tyrannosaurus* had governed the creature world. Along with the sea level reached the climax of Mesozoic era in Turonian (Haq *et al.*, 1987), the southern Atlantic Ocean opened, and volcanoes became more active, and large-scale regression happened in Maastrichtian, the land and continental shelf even oceans, with the paleoclimate and all organisms, had changed much during the end of Late Cretaceous.

Since Alvarez *et al.* (1980) first reported the high anomaly of Iridium at the Cretaceous-Paleogene (K-Pg) boundary strata in Europe, and later many scientists found the high anomaly of Iridium in non-marine deposits of the Gulf of Mexico also (Orth *et al.*, 1981; were), most of people have believed the mass extinctions are directly linked to impact of an extraterrestrial body on the Earth, though the cause of the K-Pg extinctions has been argued in paleontology for more than 30 years (Nichols & Kirk, 2008). Since geoscientists in Northeast Asia have never seen similar case of impact of extraterrestrial body in the K-Pg boundary strata in this region, the study of the inextricable subject on the K-Pg boundary and in

searching of the mass extinction reasons, appear to be more interesting. On the other hand, besides the hypothesis of impact of extraterrestrial body, some other hypotheses are proposed also, including the perturbation in the global carbon cycle by Deccan Traps volcanism (McLean, 1985), a global fall in sea level at the end of the Cretaceous (Haq *et al.*, 1987), etc. Although there are no records on the impact of an extraterrestrial body in China, or even in northeastern Asia, during the K-Pg boundary interval, it is certain that the large scale mass extinctions might exist in these areas at the K-Pg boundary time. The unexpected faunal extinction marked by sudden disappearance of dinosaurs and ammonites, and the extensive biotic recoveries represented by the emergence of a great number of new taxa of organisms after the K-Pg boundary time, suggest the existence of the global event in this region. The study of the Late Cretaceous biota and the K-Pg boundary would be more beneficial for better understanding what happened on the Earth during the critical transitional time around 65.5 Ma ago, how about the paleoenvironment so strongly influenced the kingdom of organisms facing the disasters on the Earth. Meanwhile the study would help us to find some regulations on the organism evolution of the past world, including of the Northeast Asian region where the Late Cretaceous biota was prosperous and formed oil, coal and other significant mineral resources, particularly in the Song-Liao basin of China and its neighboring Zeya-Bureja basin in Russia.

Jiayin is located in the northeastern Heilongjiang Province of Northeast China, along the Heilongjiang (Amur) River in right bank (ca. 48°52'N and 130°23'E), nearby the Zeya-Bureya basin of Russia (Fig. 1). The Jiayin is a comparatively ideal area for study of the non-marine K/Pg boundary. In 1902, the first

skeleton of dinosaur fossil *Mandschurisaurus amurensis* Riabinin was found in this area (Riabinin, 1925, 1930). Later, particularly for the recent decades, a lot of dinosaur and plant fossils found in this areas, mainly in the Yuliangzi Formation which age has been considered the Maastrichtian (Markevich, 2004, 2006; Godefroit, 2001, 2004). Since the coal-bearing Wuyun Formation overlying the Furao Formation (overlying the Yuliangzi Fm in conformity), yields abundant Paleocene flora (Zhang, 1983; Tao, 2000; Xiong, 1986; Manchester *et al.*, 1999; Feng *et al.*, 2000, 2002), it has been interested in searching of the K-Pg boundary between the Wuyun Formation and Furao Formation. On the other hand, in the Zea-Bureya Basin of Russian opposite the Jiayin of China by the Heilongjiang (Amur) River, particularly in "Belaya Gora"-Akhara area, there are several sites preserved continuous K-Pg boundary strata yielding Maastrichtian and Danian floras, respectively associated with the Maastrichtian dinosaurs represented by *Amurosaurus riabinini* Bol. et Kurz and *Olorotitan arharensis* Goldefroit *et al.* (Bolosky *et al.*, 2004; Godefroit *et al.*, 2003), the K-Pg boundary stratatype in the Zea-Bureya Basin has been a good referring for correlation in the K-Pg boundary study (Akhmetiev, 1973, 2004; Markevich, 2001).

Although Jiayin is a smaller and remote town, the huge dinosaur *Mandschurosaurus* was found in 1902 (Riabinin, 1930; Godefroit *et al.*, 2011), which was the first discovery of dinosaurs in China (Dong *et al.*, 2003) (Fig. 2). Up to now, there have been more than eight taxa of hadrosaurid dinosaurs unearthed, showing the dinosaur diversity in this area during the Late Cretaceous, particularly in Maastrichtian (Godefroit *et al.*, 2003, 2009, 2011; Dong *et al.*, 2003; Yu. Bolotsky *et al.*, 2004). Besides the dinosaurs, there are abundant Late Cretaceous and Paleocene plants and invertebrates found in Jiayin area also, and the fossil-bearing strata well exposed along the Heilongjiang River on the right bank (China side). The fossils include abundant mega-plants in the Upper Cretaceous Yong'ancun- and Taipinglin-



Fig. 1 Sketch geographic map of Jiayin and its neighboring Russian areas showing the sites of Cretaceous-Paleocene fossils and K-Pg boundary in Xiaoheyuan of Jiayin, China

chang Formations (Zhang, 1983; Tao, 2000; Sun *et al.*, 2007; Golovneva *et al.*, 2008; Quan *et al.*, 2008, 2009; Kodrul, 2004); and the conostracha and other animal fossils have also been found, with a particularly significant finding in the Taipinglinchang Formation (Li *et al.*, 2004). Besides the Late Cretaceous biota, the Paleocene plants are also abundant in the coal-bearing Wuyun Formation in the Wuyun Coal-Mine of northwestern Jiayin (Xiong, 1986; Tao, 2000; Manchester *et al.*, 1999; Feng *et al.*, 2000, 2002; Sun *et al.*, 2002); and the rich spores and pollen from the Upper Cretaceous to Paleocene have played very important roles in the study of biostratigraphic divisions and correlation (Liu, 1990; Markevich *et al.*, 2004, 2006, 2009; Kezina, 2005). In addition, during the last ten years, many geologists come here, the studies of sedimentology, geochemistry, paleomagnetism and stratigraphy in the Upper Cretaceous and Paleocene of Jiayin have been in more progress, too (Okada, 2004; Suzuki *et al.*, 2004, 2011; Akhmetiev, 2004; Sun *et al.*, 2003, 2005). All the achievements mentioned above favor the present synthetic study on the Late Cretaceous biota and strata including the K-Pg boundary in this area.



Fig. 2 The first skeleton of *Mandschurosaurus* found in Longgushan of Jiayin, housed in the All-Russian Geological Museum (photo by Sun G.)

In September 2002, with the financial support of the Natural Science Foundation of China (NSFC), the authors were invited by Prof. Sun G. to gether in Changchun, China (Jilin University) and took field trip to Jiayin for the first investigation in the Heilongjiang River area. During 2003-2005, with the NSFC's support, the authors had carried out the cooperative project (NSFC-30220130698) titled "Late Cretaceous biota and the K-T boundary in Heilongjiang River area" with the leadship of Sun G. After that, we received the support from the Bureau of Land & Resources of Heilongjiang, China (2006-2007) and the NSFC (Project 40842002 in 2008) again. We successfully organized drilling work with three boreholes (XHY-2005, 2006, 2008) in Xiaohayan villege nearby Wuyun, and the cooperative research work on the Late Cretaceous biota and the K-Pg boundary has been in more and more progress. In 2009-2011, the authors have been engaged in the analyses and synthetic research for the project, particularly in the palynological analyses which were mainly

done in the IBSS (Vladivostok, Russia; headed by Markevich V.) and the University of Tuebingen (Germany; headed by Ashraf A. R.). Meanwhile, the radiometric dating work (mainly in Okayama University, headed by Suzuki S.); the geochemical analysis (mainly in Jilin University, headed by Ge W. C.), and the paleomagnetic analysis (in Jilin University, headed by Yang H. X.) have gained more good results.

On the other hand, during the last ten years (2002-2011) the authors have organized several symposia or workshops held in China and Russia, which provided favourable opportunities for discussions on the project work, exchanging scientific ideas, and making one and another co-working plans (Fig. 3). It is worthy to mention that the Jiayin was honorably selected as one of the global non-marine K-Pg boundary candidate points (site No. 95, Fig. 4) (Nichols & Kirk, 2008), and the research project on the K-T (K-Pg) boundary in Jiayin was officially agreed as one of the the NSFE(China)-NSF(USA) three key-cooperative projects on paleontology (in Denver, 2007). In sum, the achievement on the present research work have been concentrated on the wisdom and sweat of all the members of the international cooperative research team for the project on the Late Cretaceous biota and the K-Pg boundary in Jiayin.

This paper is focusing on the summary of the cooperative and synthetic studies on the Late Cretaceous biota and the K-Pg boundary in Jiayin of the Heilongjiang (Amur) River area, which includes the palynology, paleobotany, paleozoology, sedimentology, geochemistry, paleomagnetism and isotopic dating work; and first reveal the newest result on the K-Pg boundary research in Jiayin. According to the palynological and paleomagnetic analyses made by the authors, the K-Pg (K-T) boundary in the non-marine deposits of Jiayin area is defined at about 22.00-22.05 cm in the borehole XHY-2006, which is the first well documented non-marine K-Pg boundary in China, evidenced by the synthetic studying results. Meanwhile, the authors have proposed that in the



Fig. 3 The 2nd Int'l Symposium on Cretaceous Biota and K-T Boundary in Heilongjiang (Amur) River Area held in Blagoveshensk in Aug. ,2003 (photo by Li C T)

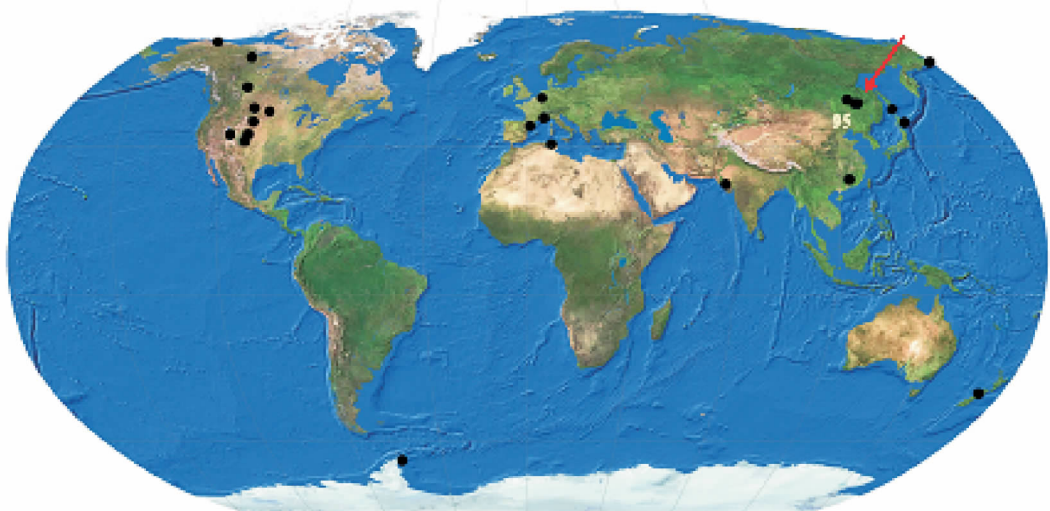


Fig. 4 Map showing the localities of the K-T boundary sections in nonmarine rocks (the arrow pointing the Jiayin of China as the site of No. 95) (after Nichols & Johnson, 2008)

Northeast Asia, including the Heilongjiang (Amur) areas, the dinosaur extinction was probably causally linked to the volcanic movement, see level down, and cooling climate coming in the end of the Cretaceous time, which is different from those caused by the catastrophic meteorite impact as shown in the North America, Europe and other related places in the world. The fact demonstrates that the great mass extinction event and the Cretaceous-Paleogene boundary have still been a complicate subject for the geoscience research. Many new findings will still challenge to search of the mysteries in evolution of the Earth and organisms through the Mesozoic era.

2 Biostratigraphy

The geological investigation of the Heilongjiang (Amur) area can be traced to about 150 years ago, when Schmidt (1861) found fossil plants in the Belaya Gora of Zeya-Bureja basin, nearby the Heilongjiang River in left side. The fossil plants were determined as Miocene age by Heer (Heer, 1878). Javorsky (1911) first used the term 'Tzagayan strata' in Russia which include the coal-bearing deposits exposed in Raichikha-Arkharo River area. Kryshtofovich studied the Tzagayan flora mainly from the Belaya Gora, and considered its age as Danian (Kryshtofovich & Baikovskaya, 1966). Krassilov carried out a revised and systematic study on the flora, and proposed the Tzagayan flora aged in the youngest Late Cretaceous to Danian (Krassilov, 1976). The new cycle of stratigraphical and paleontological investigations on the Tzagayan Group began in early 1990s, and has achieved particularly in the dinosaurs, paleobotany and palynology: Yu Bolotsky studied the dinosaurs mainly from Kundur (Bolotsky, 2004); Akhmetiev M, Markevich V, Bugdaeva E, Kodrul T, Golovneva L, and Kezina T and others have studied the strata, mega-flora and palynoflora mainly from the Pioneer and Progress sections and coal field of Raichikhian and Arkharo-Bouguchan since 2000 (IBP *et al.* , 2001).

On right side of Heilongjiang (Amur) mainly in

Jiayin, Chinese geologists have studied the Upper Cretaceous and Paleocene for many years also since 1980s (Luo,1983); Luo *et al.* subdivided the Cretaceous Jiayin Group into Yong'ancun-, Taipilingchang- and Yulangzi Formations; Zhang Z. C. has studied the Late Cretaceous plants (Zhang, 1983), Tao and Xiong studied the Paleocene Wuyun flora, and Liu (1990) studied the pollen and spores from Furao Formation and considered this beds as the Cretaceous-Tertiary transition deposit, and believed the palynological date from the Furao Formation with Maasterichtian-Danian characters (Liu, 1990). The new cycle of stratigraphical and paleontological study on the Upper Cretaceous and Paleocene in Jiayin area has been done since 2002, headed by Sun G. and joined mainly by Dong Z M (IVPP), Sun C L, Sun Y. W, Quan C, Chen Y J (Jilin Univ.), Luo K. L. (IG CAS) and Hai S L, Cui B. (Heilongjiang Geol Mus), etc. More than 15 colleagues from Russia, Germany, USA, Japan, Belgium, UK, Brazil and France, had also joined in this study. The members of the project team include Akhmetiev M, Markevich V, Bugdaeva E, Golovneva L, Kodrul T, Kezina T and Yu Bolotsky (Russia), Ashraf A R (Germany), Nichols D, Johnson K, Dilcher D(USA), Okada H, Nishida H, Terada K and Suzuki S (Japan), Godefroit (Belgium), Harding I(UK) and others, who have made contributions to this study in China. The main achievements include: (1) established a new subformation unit "Baishantou Member" from the Wuyun Formation which is divided to two members (Sun *et al.* , 2002, 2005; Akhmetiev, 2004); (2) established seven palynological assemblages from Santonian to Danian in Jiayin for detailed stratigraphic divisions and correlation (Markevich *et al.* , 2006, 2011); (3) first making a detailed stratigraphic correlation chart for the Upper Cretaceous to Paleocene of Jiayin (China) to of the Zeya-Bureja basin (Russia); and (4) first recognized eight hadrosaurid dinosaurs in Jiayin and its neighboring area along the Heilongjiang (Amur) River. It is worthy to mention that the new cycle research work has basically solved some problems on

the correlation of the Tsagayan Group in Zeya-Bureya basin in Russia with its equivalent in Jiayin of China, in which the Lower Tsagayan Formation is correlated to the Yulangzi Formation (both the dinosaur main horizon); the Middle Tsagayan Formation to the Furao Formation in Upper Cretaceous part; while the Upper

Tsagayan Formation equals to the Wuyun Formation in which the Sandstone SubFm (Kivda Bed) correlated to the Baishantou Member, and the Coal-bearing Sub-Fm equals to the Coal-bearing Member of the Wuyun Formation (Table 1; Fig. 5).

Table 1 Correlation of Upper Cretaceous of Jiayin of Heilongjiang (China) to Zeya-Bureya Basin (Russia)

Formation & Group Chron. Stratigr.		Region		Zeya-Bureya Basin Russia		Jiayin of Heilongjiang China		
Paleocene	Danian	U	Tsagayan Group	U	Coal-bearing Sub-Fm	Wuyun Fm.	Coal-bearing Mem.	
		L		Sandstone Sub-Fm.	Baishantou Mem.			
Upper Cretaceous	Maastrichtian	U	M	Bureya Fm.		Furao Fm.		
		M	L	Udurchukan Fm. (Main dinosaur horizon)		Yuliangzi Fm. (Main dinosaur horizon)		
		L						
	Campanian		Kundur Fm.		Upper Zavitin Fm.	Taipinglinchang Fm.		
	Santonian					Yong'ancun Fm.		
	Coniacian		Boguchang Fm.					
	Turonian						?	
Cenomanian		Lower Zavitin Fm.						



Fig. 5 Upper Cretaceous-Paleocene strata in both banks of Heilongjiang (Amur)

River left: Belaya Gora (K2-E1); right: Baishantou Member of Wuyun Fm (E1) (Photos by Li C T)

2.1 Yong'ancun Formation

The typical section of the Yong'anchun Formation is situated in east of the Jiayin Town about 15 km, along the Heilongjiang River on right side (Fig. 4). According to the report of the Regional Geological Survey No. 1 of Heilongjiang (BGMRH, 1993), the

formation is composed of grey, greyish green and greyish yellow siltstone and mudstone intercalated with sandstone, conglomerate, shale, few coal-seams, and tuffaceous fine-grained stone beds, mainly showing a lacustrine-alluvial facies, and more than 158 m in thickness. In this formation abundant fossil plants,

pollen-spores, ostracodes, conchastraca, fish, dinosaur foot print, *Jiayinosauropsis johnsoni* Dong *et al.* (Dong *et al.* , 2003) , have been found (Fig. 6).

In the Yong'ancun Formation, there are two shale-siltstone beds yielding fossil plants found by the authors, including the Site YN-1 (48°50'56.8"N, 139°31'510"E) near the formation base of observable interval, and the Site YN 2 (48°50'59.3"N, 130°31'30.7"E) , about 115 m above the base. In the Site YN-1, about 90% of the fossil plants are represented by aquatic angiosperms *Quereuxia angulata* (Lesq.) Krysht. , and associated with *Taxodium* sp. , *Cupressinocladus* sp. , *Ginkgo* sp. , *Trochodendroides* sp. , *Platanus* sp. , *Nyssidium* sp. , etc. In the Site YN-2, the authors found more diverse plant composition predominated by *Asplenium dicksonianum* Heer, *Sequoia* sp. , *Trochodendroides lanceolata* Golovn. , etc.

The plant assemblage of this formation was summarized as *Parataxodium-Quereuxia* Assemblage (Sun *et al.* , 2007) (Fig. 7). According to the mega-plant comparisons and the palynological data (*Kuprianipolis santaloides-Duplosporis borealis* Assemblage) , the

Yong'ancun Formation is considered as the Santonian in age (Markevich *et al.* , 2004, 2006).

2.2 Taipinglinchang Formation

The Upper Cretaceous Taipinglinchang Formation is lacustrine or lacustrine-alluvial in deposit facies. Its typical section is located in the right bank of the Heilongjiang (Amur) River, nearby the Taipinglinchang villege about 10 km from the Jiayin Town to southwest. This formation is overlying the Yong'ancun Formation perhaps in conformity, which is well exposed in the top of the Yong'ancun section. The basal bed, about 5 m thick, are composed by the blackish grey shales and siltstone, in which the typical index conchostraca *Halystheria yui* (Chang) was found, which documented this bed being correlated the basal bad of Nenjiang Formation of Song-Liao basin (Li *et al.* , 2004). The Nenjiang Formation in the Song-Liao basin was dated 77.4 Ma (K-Ar method) and 81 Ma (Rb-Sr method) by Wang P. J. *et al.* (1996) , which is clearly indicating the Nenjiang Formation as the Campanian age.



after Sun *et al.*, 2002

Fig. 6 The section of Yong'ancun Fm in Heilongjiang right bank nearrby Yong'ancun (left) and the dinisaur footprint *Jiayinosauropsis* Dong *et al.* , 2003 (right)

The Taipinglinchang Formation is mainly composed of fine-grained deposits, including mudstone, shale and siltstone intercalated with fine-grained sandstone and a few coal seams, more than 632.0 m

thick. In the section of eastern Longushan cliffs facing the Heilongjiang River, the siltstones and shales are dominant in rock types (Fig. 8). The formation is overlain by basal conglomerates of the Yuliangzi Forma-



1,2: *Asplenium dicksonianum* Heer; 3: *Cladophlebis* sp.; 4: *Carpolithes* sp.; 5,6: *Cupressinocladus vshnikovae* Ablajev; 7-10: *Metasequoia disticha* (Heer) Miki; 11: *Parataxodium* sp.; 12: *Ginkgo adiantoides* (Ung.) Heer; 13-15: *Trochodendroides arctica* (Heer) Berry; 16-19: *Quereuxia angulata* (Newb.) Krysh. Bars = 5 mm. All the fossils are housed in the Research Center of Paleontology (RCPS), Jilin Univ, China.

Fig. 7 Megafloora from Yong'ancun Formation of Jiayin.

tion, perhaps in parallel unconformity. In this formation, a lot of fossil plants were found, including *Talites* sp., *Equisetum* sp., "*Asplenium*" *dicksonianum* Heer, *Ginkgo* sp., *Larix* sp., *Pityophyllum* sp., *Pityospermum* sp., *Pityolepis* sp., *Sequoia* sp., *Metasequoia* sp., *Glyptosrtobus* sp., *Taxodium* sp., *Cupressinocladus* sp., *Elatocladus* spp., *Trochodendroides arctica* (Heer) Berry, *T. taipinglinchanica* Golovn *et al.*, *T. lanceolata* Golovn. *et al.*, *Arthollia tchernyschewii*, *Celastrinites Kundurensis* Golovn. *et al.*, *Quereuxia angulata* (Lesq.) Krysh., *Cobbania corrugata* (Lesq.) Stockey, etc. The formation is similar to the middle-upper part of the Kundur Forma-

tion of Zeya-Bureja basin in the Russia side, both in sedimentary and fossil characters. Most of the plants from the two formations are nearly the same in taxa, such as *Equisetum*, *Ginkgo*, *Sequoia*, *Metasequoia*, *Glyptostrobus*, *Taxodium*, *Cupressinocladus*, *Trochodendroides*, *Celastrinites*, and *Quereuxia*. The plant assemblage is summarized as *Metasequoia-Ginkgo-Cobbania* Assemblage (Sun *et al.*, 2007) (Fig. 9). According to the mega-plant comparisons and the palynological data (*Aquilapollenites conatus-Podocarpidites multesimus* Assemblage), this plants of the Taipinglinchang Formation is considered the Campanian in age (Markevich *et al.*, 2004, 2006).



Fig. 8 Section of Taipinglinchang Formation in right bank of Heilongjiang (Amur) River in Jiayin



1: *Equisetum* sp. ; 2: *Asplenium dicksonianum* Heer ; 3: *Larix* sp. ; 4: *Sequoia* sp. ; 5: *Metasequoia disticha* (Heer) Miki ; 6: *Parataxodium* sp. ; 7: *Cupressinocladus* sp. ; 8,22: *Glyptostrobus* sp. ; 9: *Pityospermum minutum* Samyl. ; 10,11: *Ginkgo adiantoides* (Ung.) Heer ; 12: *Trochodendroides taipinglinchanica* Golovn. *et al.* ; 13: *Trochodendroides microdentata* Golovn. *et al.* ; 14-16: *Celastrinites kundurensis* Golovn. *et al.* ; 17: *Arthollia* sp. ; 18-20: *Quereuxia angulata* (Newb.) Krysh. ; 21: *Cobbania corrugate* (Lesq.) Stockey *et al.* Bars = 5 mm. All the fossils are housed in the RCPS, Jilin Univ, China.

Fig. 9 Megaflores from Taipinglinchang Formation of Jiayin.

Paleoecologically, these mega-plants characterized by the mixture of the abundant broad-leaved deciduous angiospermous taxa (*Platanus*, *Trochodendroides*, etc.) and the rich thermophilous and hydrophilous gymnospermous taxa (*Metasequoia*, *Glyptostrobus*, *Ginkgo*, etc.), which appears to imply a warm temperate climate in this area during the Santonian-Campanian period. The existence of a lot of aquatic angiosperms (*Quereuxia* and *Cobbania*) demonstrates that these plants were probably growing surround (or in) a lacustrine circumstance in this area (Sun *et al.*, 2007).

2.3 Yuliangzi Formation

Overlying the Taipinglinchang Formation, in probable conformity, the Yuliangzi Formation (>278.5 m thick) is a major source of dinosaur fossils in this area (Godefroit *et al.*, 2001, 2004; Sun *et al.*, 2002). The formation with a delta fluvial-littoral lacustrine facies, consists of coarse deposits including grey-green or grey sandy conglomerate, pebbled sandstone, coarse sandstone-siltstone that contains fossil wood (Terada & Nishida, 2004). Palynological work indicated the formations as early-middle Maastrichtian age (Markevich *et al.*, 2004). The uppermost deposits are the Furao Formation mainly with lacustrine facies, consisting of dark grey and black mudstone, siltstone, intercalated with a few thin coal-seams.

The Yuliangzi Formation is composed of coarse-grained delta-alluvial sedimentary deposits, and usually with cross-bedded structure. The formation is mainly composed of grey and greyish green conglomerate, sandstone and siltstone, with about 287m in thickness (BGMRH, 1993). The typical section of this formation is exposed in the Longushan coastal cliffs at the right side along the Heilongjiang River (Fig. 9). The basal conglomerates of the formation (about 2 m thick) discordantly overlap the Taipinglinchang Formation. The top of the Yuliangzi Formation is unexposed, and overlain by Quaternary deposits. The formation yields wood remains (Riabinin, 1930; Terada *et al.*, 2011). These interlayers are probably concurrent to liparite tuffs of the Mt. Sagi-

bovskii Boguchan, because the latter also contain wood remains and vertebrate bones. Dinosaur bones predominant by hadrosaurid, are confined to three or four levels almost equally spaced in the section. The first (in 1902) skeleton of dinosaur *Mandschurosaurus amurensis* described by A. N. Riabinin was perhaps found here (Godefroit *et al.*, 2011). In the recent years, Godefroit *et al.* found a new taxon *Charonosaurus jiayinensis* in this site (Godefroit *et al.*, 2001), some new taxa such as *Wulagasaurus dongi* and *Sahaliyana elunchunorum* have been found in the same formation in Wulaga about 70 km to Jiayin (Godefroit *et al.*, 2009, 2011). In Wulaga, the authors found a huge fragmented skeletons of hadrosaurid dinosaur buried together as a "Dinosaur Tom" (Sun G *et al.*, 2004). On the left side of the Heilongjiang (Amur) River, the Yuliangzi Formation's equivalent (i. e. the Udurchukan Formation = Lower Tsagayan Formation) yields also abundant dinosaurs dominated by hadrosaurid in Blagoveshchensk and Kundur, such as *Amurozaurus riabinini*, *Keberosaurus manakini*, and *Olorotitan arharensis*, etc. (Bolotsky and Kirsanov, 1991; Godefroit *et al.*, 2011). Thus, to the present, there are nine taxa of Late Cretaceous dinosaurs, at least, including *Tynnanosaurus* with the teeth fossils, in the Heilongjiang (Amur) River area (Fig. 10).

Riabinin (1930) studied Krystofovich's and Renggarten's dinosaur bone collections from Longgushan, named new taxon of herbivorous dinosaur as *Mandschurosaurus amurensis* (Hadrosaurinae) and fragmentary turtle bones (*Aspederetes planicostatus*).

Chinese specialists have studied this locality more systematically since 1975, and discovered many bones of hadrosaurs and carnosaurs, including *Mandschurosaurus*. Through several years there was described "*Mandschurosaurus magnus*" (Xing *et al.*, 1994). Godefroit (Godefroit *et al.*, 2000, 2001) revised material from Jiayin and attributed it to a new taxon of hollow-crested hadrosaurid, *Charonosaurus jiayensis*, which was 14 m in length and probably a sister-taxon of *Parasaurolophus* from the late Campanian of North America. In Russia, a new dinosaur lo-



Fig. 10 Yuliangzi Fm in Longgushan of Jiayin, yielding dinosaurs fossils

The section (left) ; A new excavation in Longgushan river bank (right) (photo by JDM, 2010)

cality was discovered near Blagoveshchensk, Bolotsky and Kurzanov (1991) discovered a new lambeosaurine dinosaur there-*Amurosaurus riabinini*; later in 2004, *Kerberosaurus manakinii* Bolotsky et Godefroit (2004) were also discovered at Blagoveshchensk. The third main dinosaur locality was discovered near Kundur village along the Moscow-Vladivostok highway, Godefroit, Bolotsky and Alifanov described a nearly complete skeleton of a new lambeosaurine hadrosaurid dinosaur, *Olorotitan arhatensis* (Fig. 11). In all cases we have the same picture that the dinosaur skeletons and bones were concentrating into proluvial lenses in alluvial deposits of the Yuliangzi Formation and the Lower Tsagayan Formation in the Heilongjiang (Amur) River area.

According to the palynological study, the Yuliangzi Formation contain two palynological assemblages: *Aquilapollenites amygdaloides* - *Gnetaceaepollenites evidens* (Ass. III, lower Maastrichtian), and *Aquilapollenites amygdaloides* - *Gnetaceaepollenites evidens* (Ass. IV, middle Maastrichtian). Thus, the geological age of the Yuliangzi Formation is considered as the early-middle Maastrichtian (Markevich *et al.*, 2006).

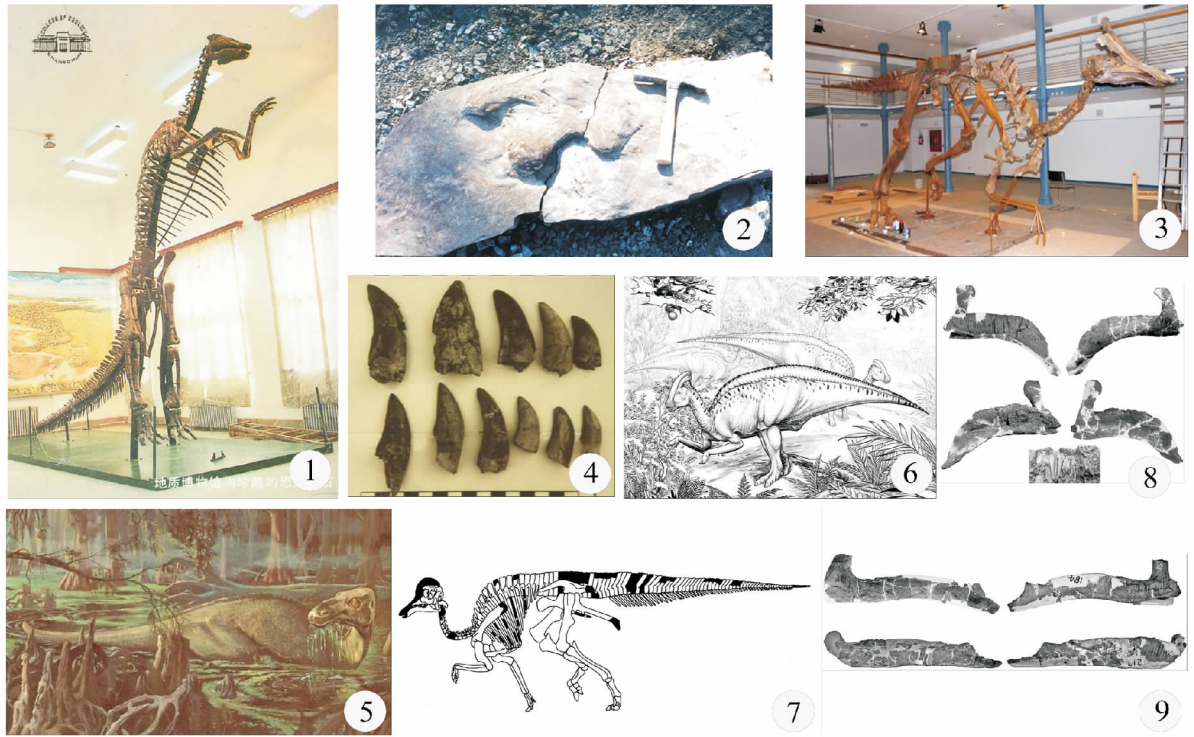
2.4 Furao Formation

Furao Formation is the uppermost formation of the Upper Cretaceous deposits in Jiayin area, composed of grey and greenish grey sandstone, siltstone and mudstone, intercalated with some thin tuff or tuf-

ficeous beds, more than 110 m in thickness.

In 2002-2004, taking the field work in the geological section of the Baishantou near the Wuyun Town about 3 km, on the right bank of the Heilongjiang River (Fig. 12), the authors found abundant fossil plants in the section, including important taxon *Tiliaephyllum tsagajanicum* (Krysht. et Baik.) Krasnikov, which is one of the key-fossils of the lower upper Tsagajan Group in the Zeya-Bureja basin, associated with *Ginkgo adiantoides* (Ung.) Heer, *Taxodium obrikii* (Heer) Brown, *Trochodendroides arctica* (Heer) Berry, *Nyssa* sp., *Platanus raynoldsii* Newb., *Archaeampelos acerifolia* (Newb.) Berry, etc., which showed the Paleocene age. Palynological work was supporting the Danian age for this fossil bearing beds also (Markevich *et al.*, 2004) (Fig. 12).

Since these beds in the Baishantou were included in the upper part of the Furao Formation and the age was previously considered as Late Cretaceous (BGM-RH, 1993) or Late Cretaceous-Danian (Liu, 1990) before, we have to change the definition of the former "Furao Formation" and divided it into two parts: the upper part named as the Baishantou Member belonging to the Wuyun Formation aged Danian, while the lower part assigned to the Furao Formation (Sun *et al.*, 2002, 2005). The new subdivision was supported by the isotopic dating work on the tuff layer of the lower part in the Baishantou section, about 0.9 m



1. *Mandschurosaurus amurensis*; 2. *Jiayinosauropsis johnsoni*; 3. Teeth of Tynnrosaurid; 4. *Olorotitan arharensis*, 5. *Keberosaurus manakini*, 6. *Charonosaurus jiayinensis*; 7. *Wulagasaurus dongi*; 8. *Amurozaurus riabinini*, 9. *Sahaliyania elunchunorum*;

Fig. 11 Nine taxa of Late Cretaceous dinosaurs in Heilongjiang (Amur) River area



Fig. 12 Drilling samples of Furao Formation in XHY-2006 (left); and working in Baoshantou section (2002)

in thick, made by Suzuki *et al.*, and the age is 64.1 ± 0.7 Ma (U-Pb) and 61.7 ± 1.8 Ma (fission-track dating) (Suzuki, 2004, Suzuki *et al.*, 2011- in press). Meanwhile, the palynological study indicated the Baishantou Member is the Danian age, too

(Markevich *et al.*, 2006).

During 2005-2008, taking the drilling work in the new term, the Furao Formation in Xiaoheyuan (XHY-2005, 2006, 2008) nearby Wuyun Town, the palynological and other study were successful by

Markevich *et al.* (Markevich *et al.* , 2006 , 2011) and others of the authors. The pollen and spores in the Furao Formation over 49 species of 29 genera, have been found, in which the taxa only occurred in Maastrichtian, including *Aquilapollenites funkhouseri*, *A. reductus*, *Pseudoaquilapollenites striatus*, *Pseudointegricorpus clariretuculatus*, *Marsypiletes cretacea*, *Zlvisporites novomexicanus*, *Rugulatisporites quintus*, *Wodehoseia stanley*, etc. , characterized by abundant *Aquilapollenites*, and some taxa, have the last occurrence in the late Maastrichtian only, such as *Aquilapollenites reductus*, *Marsypiletes cretacea*, etc. (Markevich *et al.* , 2006). Markevich *et al.* , (2006) named this palynological assemblage as *Aquilapollenites conatus-Pseudoaquilapollenites striatus* ssemblage (i. e. the Ass. V). This assemblage is similar to those from the lower part of Tsagayan stratotype section nearby the Belaya Gora on left bank of Heilongjiang (Amur) River, and other contemporaneous formations in eastern Siberia, Far East of Russia, Japan and even the North America. Thus, the geological age of the Furao Formation is considered the late Maastrichtian (Markevich *et al.* , 2006 , 2011).

Since the Furao Formation is the late Maastrichtian in age, and overlain by the early Danian Baishantou Member of Wuyun Formation in conformity, the condition has provided a favour for studying of the K-Pg (K-T) boundary in the Baishantou-Wuyun area of Jiayin.

Above the Furao Formation is the Baishantou Member of Wuyun Formation aged in Paleocene. The section in Baishantou comprises conglomerate, sandstone, mudstone, coal and rhyolitic tuff deposited in a fluvial environment (Sun *et al.* , 2002 , Suzuki *et al.* 2010). The succession of the section is subdivided into 10 beds from No. 1 to 10 based on their lithofacies (Sun *et al.* , 2002). The Danian plants characterized by *Tiliaephyllum tsagajanicum* were collected from the Bed 7. The palynological samples were collected from the beds 1, 3 and 4, indicating the Danian age. Insect fossils are obtained from the Bed 4. The dating sample was collected from the rhyolitic tuff

Bed of 2 which is 90 cm thick.

Over the Baishantou Member, it is the upper Wuyun Formation (Coal-bearing Member of Wuyun Fm). In this Member we found the following taxa: *Metasequiota occidentalis* (Newb.) Chaney, *Trochodendroides arctica* (Heer) Berry, *Ulmus furcinervis* (Bors.) Ablajev, *Archaeampelos acerifolia* (Newb.) McIver et Basinger, *Averrhoites affinis* (Newb.) Hickey, *Glyptostrobus* sp. , *Taxodium* sp. , *Platanus raynoldsii* (Newb.) , *Ulmus furcinervis* (Bors.) Ablajev, *Avezoites affinis* (Newb.) Hickey, *Phylodendron jiayinense* sp. nov. (MS), *Zingiberopsis magnifolia* (Knowlton) Hickey, *Typha* sp. , *Platanus raynoldsii* Newb. , *Beringiaphyllum cupanioides* (Newb.) Manchester, Crane et Golovneva. , which showing the Paleocene age (Sun *et al.* , 2002 , 2005).

3 The Cretaceous-Paleogene (K-Pg) boundary in Jiayin area

3.1 On the K-Pg boundary

The Cretaceous-Paleogene (K-Pg, formerly as K-T) boundary has been one of the major subjects in global geological study since Alvarez *et al.* published a paper in American journal *Science* in 1980 (Alvarez *et al.* 1980) which looked to revolutionize the science of geology. Alvarez *et al.* suggested that the Earth was struck by a large extraterrestrial object about 65 million years ago, and that moment marked the boundary between the Mesozoic and Cenozoic eras. Alvarez *et al.* also proposed that this extraterrestrial impact had been responsible for one of the greatest extinction in Earth history, which eradicated 70% or more of species on land and in the sea, ended that Mesozoic Era (Nichols & Johnson, 2008). The time line between the Cretaceous and Paleogene period was widely known as the K-T boundary and internationally accepted. However, since the International Commission of Stratigraphic (ICS) issued the official note on the ' Tertiary ' replaced by ' Paleogene ' , the present authors would change the ' K-T ' to ' K-Pg ' , or with special note for the change, in this paper.

Since the asteroid impact hypothesis can not ex-

plain the geological events everywhere in the vast world-land, particularly in the Northeastern Asia where recorded the geo-/bio- evolutionary history well during the Late Mesozoic concerned the extinctions of dinosaurs, the hypothesis has been controversial in paleontology and geology for about 30 years. Thus, the question has attracted and challenged us to search of the answer on the K-Pg boundary and the great mass extinctions.

Although there has been no find on the Maastichtian and Danian marine deposits in Northeast China, the Upper Cretaceous and Paleocene non-marine strata with abundant fossils are well exposed, particularly in the Heilongjiang (Amur) area. On the other hand, in the Russian side, many geologists (including some of the present authors) have been engaged in the study of the K-Pg boundary for a long time (Akhmetiev, 1973; Akhmetiev *et al.*, 1976; Markevich, 1994, 1995). In spite of the absence of fossil marine invertebrates may not accurately link the time of formation of terrestrial deposits with the geologic time scale, some of the authors have used the palynological analysis, which allowed correlating of marine-, brackish- to the continental deposits. In Russian Far East regions, the interrelation of the Cretaceous and Paleogene in marine deposits has been applied, such as in the Sakhalin Island, the Kuril Islands, and the Koryak Uplands, etc. Some of the authors have studied sedimentary sequences with the marine fauna occurred in the Naiba and Snezhinka rivers Basin (Sinegorsk horizon), the Yury Island (Yury and Zelyony units) and the Ugolnaya Bay (Koryak and Chukotka formations). These outcrops were palynologically sampled with good studied results. Also, during more than 50 years, the palynofloras and non-marine deposits from the Upper Cretaceous to Paleocene of the Russian Far East have been investigated (Markevich, 1994, 1995, 2001, 2008; Akhmetiev *et al.*, 1976; Akhmetiev, 2004). In addition, the famous Tsagayan flora and strata of the Zeya-Bureya Basin where is connected with the Jiayin area of China have been studied in detail for more than a century

(Heer, 1878; Konstantov, 1913, 1914; Finko, Zaklinskaya, 1958; Kryshstofovich & Baikovskaya, 1966; Krassilov, 1976; Kamaeva, 1990, Markevich, 1995; IBP *et al.*, 2001). All the research bases are favorable for the K-Pg boundary study in the Jiayin area.

According to the experiences made by the experts in the world, the general marks for definition of the K-Pg boundary should be including the following key-results: (1) Magnetostratigraphical data (i. e with the magnetochron 29r); (2) isotopic date (K-Pg boundary age at ca. 65 Ma); (3) pollen-and spores data; (4) comparison biotic and abiotic events reflected on sediments of the World; (5) ocean and continents and different types characteristics (climatic, geochemical, volcanic, eustatic, planetary, impact and others); and (6) beginning of erosional activity on contents, like result of reflection on Ocean level fall (Nichols, 2008 in workshop lecture in China).

3.2 Palynological evidence in Jiayin

Since 2002, the international cooperative project "Late Cretaceous Biota and the K-T boundary in the Heilongjiang River area", headed by Sun Ge (Jilin University, China) has been carried out, with the financial support of NSFC, China and the Bureau of Land & Resources, Heilongjiang Province. The authors had done the field investigations in all necessary sections of Upper Cretaceous and Paleocene along the Heilongjiang River's right bank, including the sample collecting, made in the three drillings at the Xiaohey-an village nearby Wuyun Town of western Jiayin. We have done a lot of laboratory and analysis work both in China and in the authors' own country, and finally received the fruitful research results. The main achievements including the following aspects.

Although the authors found the Paleocene (Danian) mege- and micro floras in the Baishantou section with the key-taxon *Tiliaephyllun tsagajanicum* and the palynological evidence showing the Danian age, and believed the K-Pg boundary underlying the Baishantou Member of the Wuyun Formation in the section (Sun *et al.*, 2002, 2003; Markevich *et al.*, 2004), the fact was that the outcrops of the uppermost Creta-

ceous which concerned the K–Pg boundary, is under the Heilongjiang River water with no outcrop. For searching of the Furao Formation/Baishantou Member continuous sequences and their boundary, the authors made drillings in the site nearby Xiaoheyuan where there is a tuff bed appearing to be coincident to the tuff bed (Bed 2, Sun *et al.* , 2002) of the Baishantou Member in the Baishantou section, with no far distance (less than 1 000 m) between the two sites. Headed by Sun G. in designment on the drilling site

(49°14'53"N , 129°35'14"E) , the Geological Surveying Institution No. 6 of Heilongjiang had carried out the drilling work for three years (XHY-2005, 2006, 2008) which was successful (Fig. 13).

In the three drilling boreholes (XHY2005, 2006, 2008) (Fig. 14) , the palynological studies mainly fulfilled by Markevich V. , Ashraf R. and Nichols D. , with main assistance of Bugdaeva E, etc, have been fruitful scientifically.

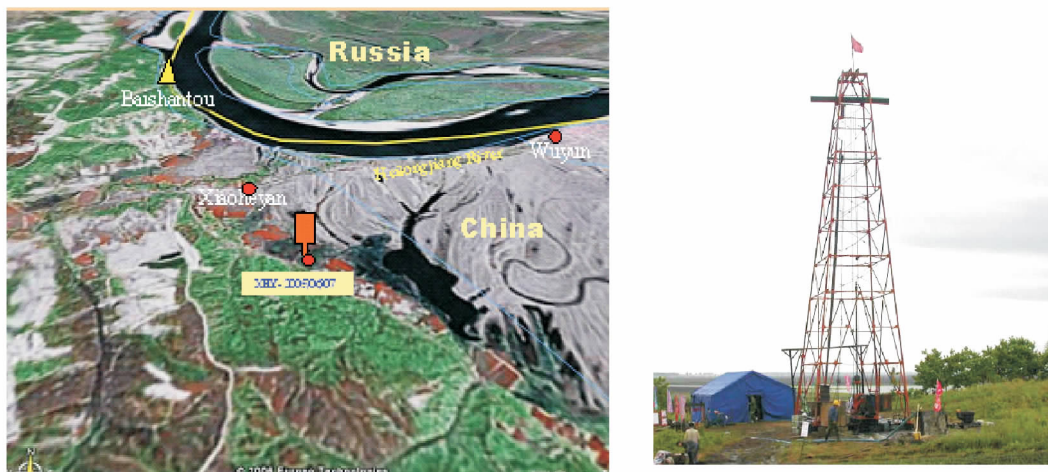


Fig. 13 Drilling site in Xiaoheyuan of Wuyun, Jiayin (2005-2008)

It should be mentioned that Markevich *et al.* (2004) proposed the seven assemblages from the Santonian to Danian in this area which was very useful for the study of the K–Pg boundary in the Xiaoheyuan boreholes. The seven assemblages are:

VII *Triatriopollenites plicatus Taxodiaceapollenites* assemblage (late Danian)

VI *Triatriopollenites confusus Aquilapollenites spinulosus* assemblage (early Danian)

V *Aquilapollenites conatus Pseudoaquilapollenites striatus* assemblage (late Maastrichtian).

IV *Wodehouseia aspera Parviprojectus amurensis* assemblage (middle Maastrichtian).

III *Aquilapollenites amygdaloides Gnetaceapollenites evidens* assemblage (early Maastrichtian).

II *Aquilapollenites conatus Podocarpidites multesimus* assemblage (Campanian).

I *Kuprianipollis santaloides Duplosporites borealis* assemblage (Santonian.)

In the Furao Formation, the sporopollen are dominated by Taxodiaceae (up to 50%) and Ulmaceae (up to 25%). The spores are predominated by the monolet *Laevigatosporites*; and the angiospermous pollen are rather diverse. The diversity of "unica"-type pollen increases, indicated by various *Aquilapollenites*, such as *A. attenuatus* Funkh. , *A. rigidus* Nort. , *A. spinulosus* Funkh. , *A. stelkii* Sriv. , *A. catenireticulatus* Sriv. , *A. striatus* Funkh. , *A. conatus* Nort. , *A. insignis* N. Mtch. , *A. subtilis* N. Mtch. , *A. reductus* Nort. , *A. procerus* Samoil. , *A. amurensis* (Bratz.) , *A. quadricretaceus* N. Mtch. , and *A. rombicus* (Samoil.) Stanl. The other taxa include *Intergricorpus bertillonites* N. Mtch. , *I. bellum* N. Mtch. , *Pseudointegricorpus clarireticulatus* (Sam-

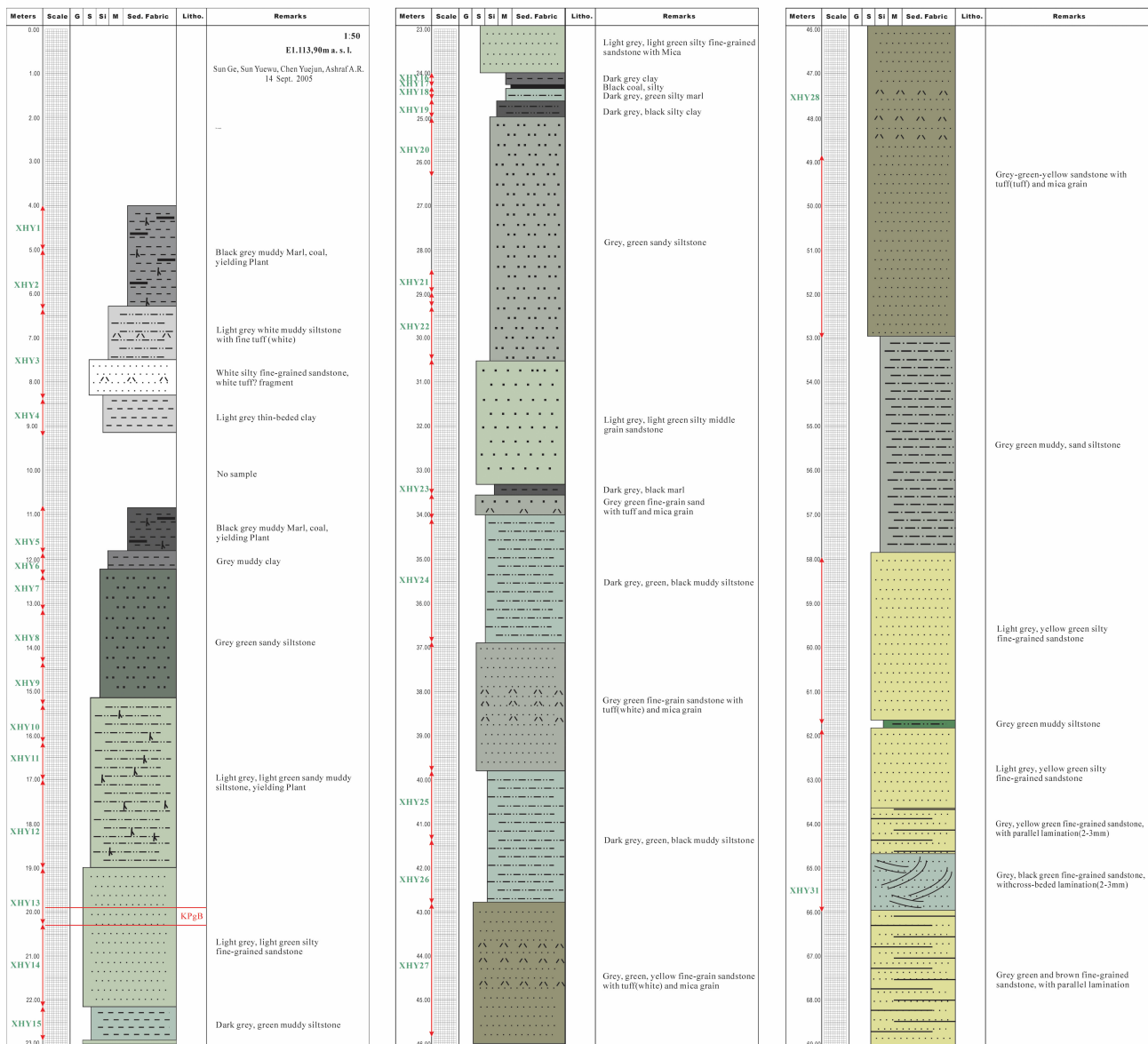


Fig. 14 Profile of the corehole of XHY-2005 (by Ashraf et al., 2002-2011)

oil.) Takah., *Triprojectus amoenus* (Liu) Zhao. The most typical taxa are *Marsypites cretacea*, *Tricolpites variexinus*, *Aquilapollenites stelkii*, *A. proceros*, *A. striatus*, *A. rigidus*, *Integricorpus bellum*, *Pseudointegricorpus clarireticulatus*, which are markable in the assemblage *Aquilapollenites stelkii*-*Pseudointegricorpus clarireticulatus* (Ass. V, Markevich et al., 2011). According to the comparisons of this assemblage to those of the equivalents from the upper part of the Middle Tsagayan Subformation in Zeya-Bureya basin,

the upper part of Krasnoyarka Formation (Sakhalin Island, dated by marine fossils), the upper Maastrichtian of the Yury Island (Krassilov et al., 1988), the middle part of the Koryak Formation of the Koryak Highlands characterized by the dominance of the fern spores *Laevigatosporites*, etc. Thus, the palynological assemblage from the Furo Formation is considered as the late Maastrichtian in age (Markevich et al., 2004, 2011).

The palynological assemblage from lower part of

Wuyun Formation (i. e. the Baishantou Member) is dominated by ferns and gymnosperms, in which the ferns' composition is up to 53% and represented mainly by *Laevigatosporites* and smooth trilete spores. The angiosperms are locally abundant (in some spectra reaching 42%), characterized by *Triatriopollenites confusus* Zakl., *T. plicoides* Zakl., *Tripopollenites plicatus* Krutz., *Juglanspollenites* sp., *Caryapollenites* sp., *Carya gracilis* Mart., *Pterocaryapollenites* sp., and predominated by of Fagaceae. The "unica"-and

"oculata"-type pollen suffer a sharp decrease in amount, *Aquilapollenites* with a few species, and *Wodehouseia* is rare. The assemblage is the assemblage of *Triatriopollenites confusus* – *Aquilapollenites spinulosus* indicating the early Danian age (Markevich et al., 2006). This assemblage is represented by *Triatriopollenites confusus*, *Momipites tenuipolus* Anders, *Rhoipites pissinus* Stanl., *Anacolosidites subtrudens* Sakl., *Aquilapollenites spinulosus*, and *A. proceros* (Markevich et al., 2011).

Chronological Stratigr.		Palyn. Ass.		Foramtion (Fm)& Group					
				Zeya-Bureya basin		Jiayin area			
Paleocene	Danian	U	VII	U	Carmakan Fm	Coal-bearing Mem.	Wuyun Fm	Wuyun Fm	Baishantou Mem.
		L	VI			Sandstone Sub-Fm	Coal-bearing Mem.		
Upper Cretaceous	Maastrichtian	U	V	M	Bureya Fm	Furao Fm	Furao Fm	Furao Fm	Furao Fm
		M	IV						
	Campanian	U	II ₂	L	Kundur Fm	Kundur Fm	Taipinglinchang Fm	Taipinglinchang Fm	Taipinglinchang Fm
		L	II ₁						
Santonian	U	I ₂							
	L	I ₁							

Species	Stratigraphic Range
<i>Diplosporites borealis</i>	Udurchukan Fm (main dinosaur hori.)
<i>Tricolpites gracilis</i>	Wuyun Fm
<i>Aquilapollenites rombicus</i>	Wuyun Fm
<i>A. amplius</i>	Wuyun Fm
<i>Tri. reticulatus conatus</i>	Wuyun Fm
<i>A. reticulatus</i>	Wuyun Fm
<i>Wodehouseia spinata</i>	Wuyun Fm
<i>A. stelkii</i>	Wuyun Fm
<i>A. striatus</i>	Wuyun Fm
<i>A. rigidus</i>	Wuyun Fm
<i>Parviprojectus amurensis</i>	Wuyun Fm
<i>P. dolium</i>	Wuyun Fm
<i>Protacidites mollis</i>	Wuyun Fm
<i>W. aspera</i>	Wuyun Fm
<i>W. gracilis</i>	Wuyun Fm
<i>Pseudointegricarpus clarireticulatus</i>	Wuyun Fm
<i>Integricarpus bellum</i>	Wuyun Fm
<i>I. bertillonites</i>	Wuyun Fm
<i>Rhoipites pissinus</i>	Wuyun Fm
<i>Anacolosidites subtrudens</i>	Wuyun Fm
<i>Triatriopollenites plicoides</i>	Wuyun Fm
<i>Comptonia sibirica</i>	Wuyun Fm
<i>Kupriantipollis santaloides</i>	Wuyun Fm
<i>K. elegans</i>	Wuyun Fm
<i>A. quadrilobus</i>	Wuyun Fm
<i>A. insignis</i>	Wuyun Fm
<i>Cranwellia striata</i>	Wuyun Fm
<i>O. striatus</i>	Wuyun Fm
<i>Orbiculapollis globosus</i>	Wuyun Fm
<i>Kurczikella tricuspidatus</i>	Wuyun Fm
<i>A. Cantharellus</i>	Wuyun Fm
<i>Triatriopollenites confusus</i>	Wuyun Fm
<i>Momipites tenuipolus</i>	Wuyun Fm
<i>W. funibrata</i>	Wuyun Fm

Fig. 15 Vertical stratigraphic distributions of the sporopollen around the K-Pg boundary and their related strata

According to the palynological comparisons with those mainly from marine deposits of northeastern Russia, Sakhalin and Kuril Islands dated by marine invertebrate fossils, the geological ranges of the sporopollen fossils studied in the interval of the Upper Cretaceous-Paleocene strata of Jiayin area, have been made clear. Based on the studies of Markevich et al. (2001, 2004, 2006), the guide fossils *Marsypites cretacea*, *Tricolpites variexinus*, *Aquilapollenites conatus*, *A. stelkii*, *A. reticulatus*, *A. quadrilobus*, *A. striatus*, *Integricarpus bellum*, *Pseudointegricarpus clarireticulatus*, *Aquilapollenites rombicus*, *Tripoprojectus amoenus*, *Orbiculapollis lucidus*, *Wodehouseia aspera*,

and *Quercoidites minor* are recognized and have last occurrence in the late Maastrichtian. While the Danian palynofloras usually are dominated by *Triatriopollenites plicoides*, *T. confusus*, etc. The taxa *Anacolosidites subtrudens*, *Aquilapollenites proceros*, and *A. spinulosus* have last occurrence in the Danian (Markevich et al., 2011) (Fig. 15).

Through the palynological analysis of three drilled boreholes (XHY-2005, 2006, 2008) in Xiaohayan of Jiayin, the K-Pg boundary is defined by the authors within 22.00-22.05 m in the borehole XHY-2006. In borehole XHY-2005, the boundary is within 19.90 m and 20.30 m (the sample from 19.90 m

contains the Danian palynospectrum, while the sample from 20.30 m contains the late Maastrichtian one). In the borehole XHY 2008, the K-Pg boundary is defined between 23.05 and 23.25 m (Fig. 14). It would be worthy to mention that in the base of the Danian deposits of the borehole XHY-2005, the "fern

spike" is well expressed on the K-Pg boundary, which is similar to the case in the section of the Belaya Gora of the Zeya-Bureya Basin, Russia, and rather well for the definition of the K-Pg boundary palynologically. (Markevich *et al.*, 2011).

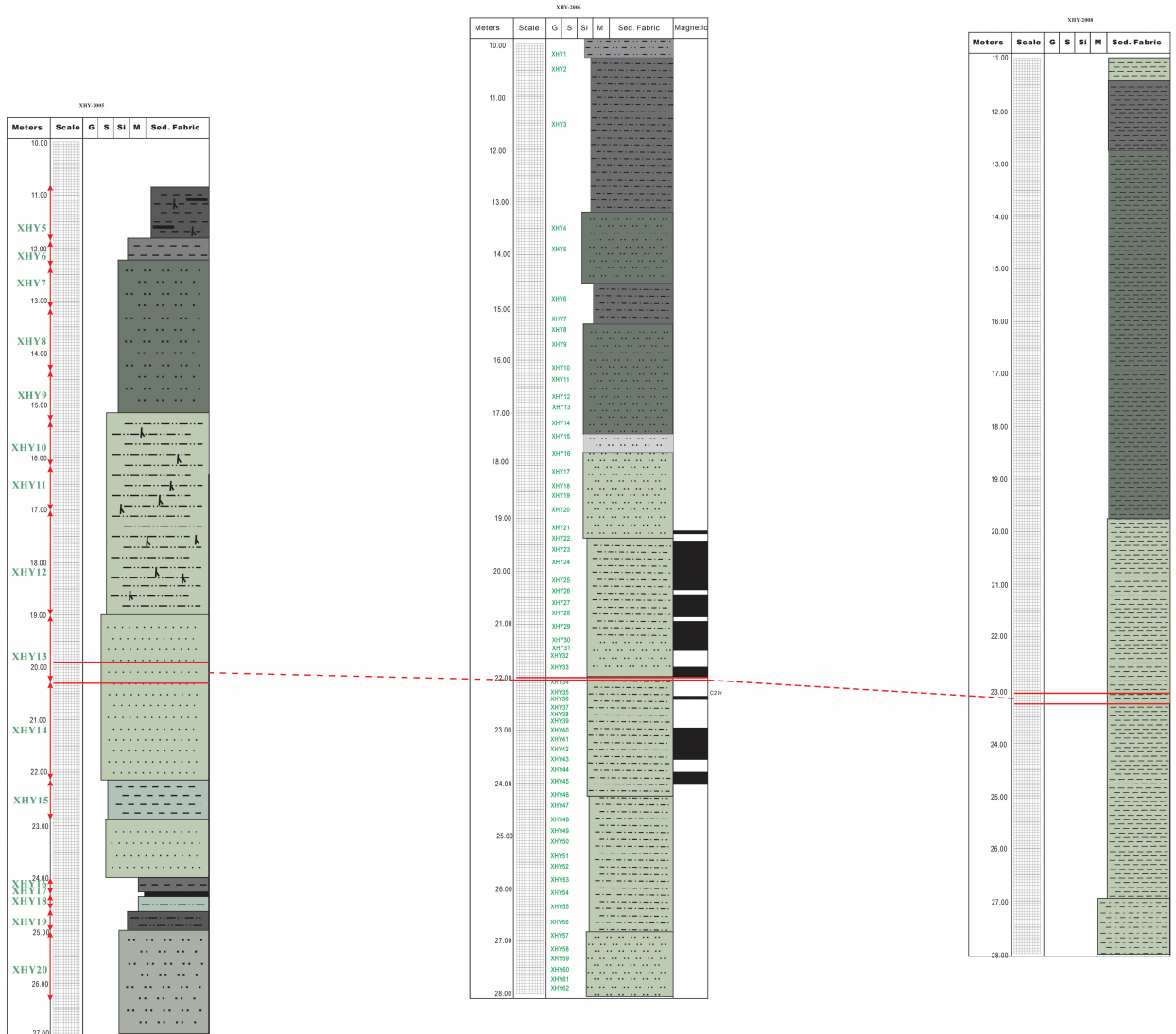


Fig. 16 Profiles of the three boreholes (XHY-2005, 2006, 2008) showing the K-Pg boundary in Xiaoheyuan, Jiayin (the red lines indicating the K-Pg boundary for each)

Over the K-Pg boundary, in the Baishantou Member of the Wuyun Formation, there are over 36 species of 27 genera found, in which the taxa only occurred in Danian stage including 7 taxa at least, e. g. *Triatriopollenites plicoides*, *Alnipollenites trina*, *Orbic-*

ulapollis lucidus, *Aquilapollenites spinulosus*, *Anacolisidites primigenius*, *Choshispora major*. Among these taxa, *Orbiculapollis lucidus* was reaching a peak in Danian, and disappeared after the Danian. Although some taxa, e. g. *Triatriopollenites confusus*, occurred

in the late Maastrichtian also, the time for its predominance is still Danian. (Markevich *et al.* , 2006).

3.3 Radiometric dating in Jiayin

Besides the palynological analysis, the definition of the K–Pg boundary in the Xiaoheyan area and the age of the Baishantou Member of Wuyun Formation were evidenced by the radiometric dating also which was mainly made by S. Suzuki, one of the present authors (Suzuki *et al.* , 2004 , 2011).

In 2002, the authors sampled from the rhyolite tuff in the lower part of the Baishantou Member in the Baishantou section (49°17.2'N, 129°32.7'E) nearby the bank of Heilongjiang Rive for the radiometric dating work. Suzuki selected hundreds of the zircon grains for this dating tested by the Kyoto Fission-Track Co. Ltd in Kyoto, Japan. The testing result shows the age as 61.7 ± 1.8 Ma (Fission-track method) (Suzuki *et al.* , 2004) .

In 2009, For checking the dating of the tuff of the Baishantou Member, some Suzuki *et al.* re-studied dating by U–Pb method. The result showed the tuff age as $64,1 \pm 0,7$ Ma (U–Pb zircon age) (Suzuki *et al.* , 2011). Although the two datings have some difference in age, both the two dating results have supported the Baishantou Member as the early Paleocene, and probably the Danian age. The results are basically agreed to those by paleontological studies

(Sun *et al.* , 2002 , 2003 , 2005 ; Akhmetiev , 2004 ; Markevich *et al.* , 2006).

However, in 2004, Chinese paleontologist Chen P. J (NIGPAS) and his geochemist partner Li X. H. (IGC CAS in Guangzhou) published papers and announced the age of the tuff from the Baishantou Member as 66 ± 1 Ma, by SHRIMP method) (Chen *et al.* , 2004). Using this data, they proposed the Baishantou Member of Wuyun Formation as the Late Cretaceous, not Paleocene. Later, ones of the authors (Sun *et al.* , 2005) published a refutable paper to point out that Chen *et al.* (2004)'s paper was more mistaken which was mainly caused by the incorrect identifications of the fossil pollen (e. g. of some *Aquilapollenites* pollen). The incorrect identifications might cause Chen *et al.*'s Cretaceous idea on the Baishantou Member, and their SHRIMP dating result was possibly influenced by the palynological work in their explanation of the isotopic dating results. It would be worthy to mention that if the SHRIMP dating result (66 ± 1 Ma) was correct, it could be reasonably explained the tuff samples from the Baishantou Member being still the Danian age. Because there were some examples occurred in the typical section of the K–Pg boundary in Denver basin of North America, which showed at least three datings as older than the 65.5 Ma above the boundary (Fig. 17r) , les along



The right photo showing the 3 dating results over 65.5 Ma in the K–T boundary typical section in Denver basin which are 66.8 ± 0.03 Ma; 66.03 ± 0.02 Ma and 65.97 ± 0.02 Ma) (courtesy by K. Johnson, 2007)

Fig. 17 Sampling in the tuff bed at the Baishantou of Jiayin along the Heilongjiang River (left; 2002)

the fossil mega-palnts and sporopollen both indicated the Danian age for the Baishantou Member (Sun *et al.*, 2002, 2005; Markevich *et al.*, 2006; Suzuki *et al.*, 2011; and communication with Nichols D., 2004). Anyway, the dating results of the Baishantou tuff made by Suzuki *et al.* (2011) as 64.1 ± 0.7 Ma and 61.7 ± 1.8 Ma both are important achievement for the study of the K-Pg boundary strata in the Jiayin area.

3.4 Paleomagnetic evidence in Jiayin

For getting more evidence for study of the the K-Pg (K/T) boundary in the Xiaoheyuan (Baishantou) area, following the drilling work of the boreholes XHY-2006 and XHY-2008 started in the Xiaoheyuan site nearby the Wuyun of Jiayin, the authors began to the paleomagnetic research work, headed by Yang H. X., one of the authors, and the analysis work was done in his Paleomagnetic Lab in Jilin University, in Changchun.

To document and check the position of K-Pg (K/T) boundary in the Xiaoheyuan defined mainly by the palynological study, an extensive program of paleomagnetic sampling was carried out in the drilling boreholes in Xiaoheyuan of Jiayin during 2006-2008.

The samples for paleomagnetic tests were collected from the core rocks of the XHY-2006 and XHY-2008 which are spanning the Maastrichtian and Paleocene intervals. The sampling was made in 2-5 cm for each length, and denser to the position of the possible boundary. The measurement of samples was used the DSM-2 Digital Spinner Magnetometer hosted in Jilin University (China), and every sample was demagnetized for 2mT. Based on the testing results, the histograms of XHY-2006 and XHY-2008 show the paleomagnetic declination and polarity (Fig. 18A). In correlation with the international Geomagnetic Polarity Time Scale (GPTS; Harland, 1982), the age for the K-Pg boundary is about 65.5 ± 0.3 Ma, which is within a reversed interval with magnetochron C29r. The results of the paleomagnetic measurement showed that in the core of XHY-2006, the reversed interval C29r is probably within 20.0-20.35 m; while the in XHY-2008 the reversed interval C29r probably within 23.22-23.32 m. According to the palynological analysis, the K-Pg boundary in the interval 22.0-22.05 m (XHY-2006) and the interval 23.05-23.25 m (XHY-2008) (Markevich *et al.*, 2011), and compared with the polarity reversal histogram (Fig. 18B),

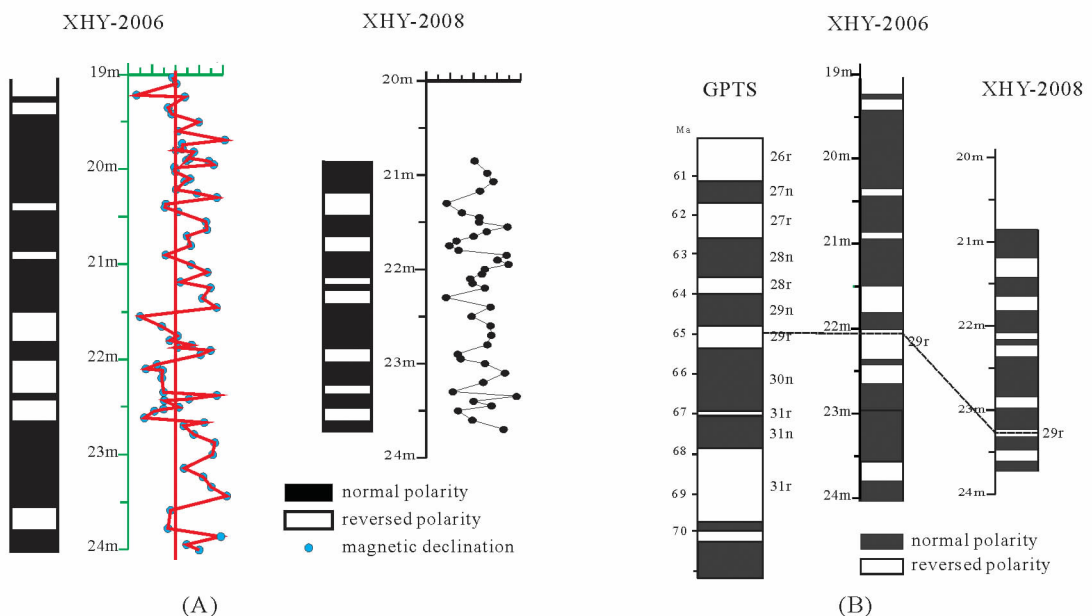


Fig. 18 Histogram of XHY-2006 and XHY-2008; B. Polarity reversal histogram (after Yang, 2011)

the magnetic samples were within the reversed intervals, in which the K–Pg boundary might be at ca. 22.05 m for the XHY-2006 and at ca. 23.25 m for the XHY-2008. Besides, other information about the polarity reversal can be determined from this histogram, such as the horizons corresponded to the magnetochrons C29n, C30n and so on.

Another work related to the present paleomagnetic tests was done by Hicks in 2003 (Hicks, 2004) who was joining the field investigative work with the authors in 2003. According to his paleomagnetic analysis, the upper part of the Kundur Formation in the Zeya-Bureja basin has the reversed magnetisation of 33r or 32r (indicating the upper Campanian) and probably the 31r, which might be remarkable for the lower Maastrichtian. The connective work on the paleomagnetic results from the Kundur Formation with the present paleomagnetic work would be further done in future.

3.5 Geochemic data in Jiayin

For analysis of the geochemical features of the interval K–Pg (K–T) transition strata in the Xiaoheyuan nearby the Bishantou of Jiayin, and checking the K–Pg boundary definition, the authors have analyzed the samples from the boreholes of XHY-2005, 2006 and 2008 for geochemical study which was headed by Ge W. C. (Jilin University) in China, and Akhmetiev M (IG RAS) in Moscow, Russia. During the geochemical work on all of the samples collected from the boreholes, we have not found any significant anomaly of Iridium (Ir).

In the borehole XHY-2006, at the interval of 15, 21 ± 16.46 m (Samples JY 001, 002) we found a little higher content of Ir (0.226 and 0.2425 ng/g) (Table 2) which was perhaps connected with the volcanic activity showing in the tuff bed of the Baishatou Member (Bed 2, Sun *et al.*, 2002), above K–Pg boundary, which is no special significance for the K–Pg boundary definition.

In the interval K–Pg transition strata in Xiaoheyuan with the XHY boreholes' samples, Ge (2010)^① found the major elements contents of the research

Table 2 PGE analysis results(ng/g) of mudstones in Jiayin area

	Ru	Rh	Pd	Ir	Pt	Au
JY001	0.116	0.017	0.3185	0.226	0.2215	0.8695
JY002	0.1045	0.013	0.2505	0.2425	0.1505	0.557
JY003	0.196	0.0285	0.6	0.0915	0.5575	2.009
JY004	0.0445	0.0135	0.2645	0.0245	0.183	0.756
JY005	0.057	0.017	0.392	0.0655	0.262	0.8895
JY006	0.038	0.02	0.372	0.032	0.2365	1.1815
JY007	0.0305	0.0125	0.27	0.0325	0.171	0.77
JY008	0.024	0.0135	0.2565	0.0175	0.1575	0.7705
JY009	0.0235	0.01	0.273	0.016	0.195	0.911
JY010	0.024	0.0095	0.2635	0.016	0.1915	0.906
JY011	0.0225	0.0105	0.328	0.012	0.2205	0.405
JY012	0.033	0.0095	0.3315	0.018	0.223	1.0235
JY013	0.025	0.0155	0.3655	0.0155	0.1905	1.293
JY014	0.038	0.016	0.656	0.0185	0.3125	2.402
JY015	0.0405	0.013	0.3485	0.0205	0.213	1.38
JY015	0.0605	0.016	0.3475	0.029	0.211	1.4165
JY016	0.023	0.013	0.2435	0.0255	0.1565	1.2065

samples composed of SiO₂ = 58.47% ~ 71.43%, Al₂O₃ = 15.50% ~ 22.65%, Na₂O = 0.16% ~ 1.22%, K₂O/Na₂O = 2.55 ~ 9.81, MgO = 0.45% ~ 0.90% (Table 3). The major elements content of different samples vary widely and Al₂O₃ content is high in partial samples because of being rich in feldspar and clay minerals. On the geochemical characteristics of REE and trace elements, the sedimentary rocks have a relative high content of ΣREE (59.8 × 10⁻⁶ ~ 624 × 10⁻⁶), with weak Eu negative and no Ce anomaly. The fraction of REE is relative obvious, the ratio of La/Yb is between 5.4 and 12.7. The fraction of LREE is moderate, and La/Sm is from 2.33 to 5.05. The fraction of HREE is relatively lower, and Gd/Yb is from 0.97 to 2.46. The normalized REE curve (Fig. 19) is right-deviation, LREE is relatively rich and HREE is relatively deficit, HREE

① Ge W. C. 2010. Geochemical report on the samples from Xiaoheyuan of Jiayin (MS)

curve is gently. Seen from the element data and normalized curve, every sample curve varies regularly. Ba and Sr that are large-ion lithophile elements are deficit, samples are rich in Rb and Th and HFS elements of La, Ce, Nd, Zr and Hf, which shows positive anomalies. The trace element web curves of samples in the Formation are basically similar (Fig. 20), showing a genetic relationship in source matter. Table 2 shows the content of PGE element. The abundance of Ru is from 0.0097 to 0.196 ng/g, Rh is from 0.0095 to 0.029 ng/g, Pd is from 0.2435 to 0.6 ng/g, Ir is from 0.012 to 0.066 ng/g. Seen from the abundance of PGE element (Table 3) and variation figure of plot of PGE element with depth (Fig. 20), it is suggested that the change of element abundance of the samples is little, and has no anomalies. Even Ir has no obvious change, and the sample JY006 which is located near the former tentative boundary line has no anomalies (Ge, 2010 MS).

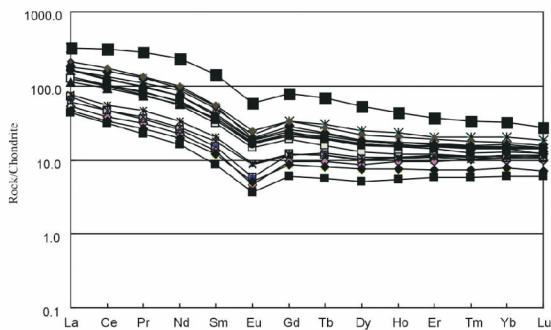


Fig. 19 REE distribution patterns

4 Discussion

4.1 On the definition of the K-Pg boundary in Jiayin

The definition of Cretaceous-Paleogene (K-Pg, K/T) boundary is the most important achievement made by the authors in cooperative study on the stratigraphy of the Jiayin area along the Heilongjiang (Amur) River, for the last ten years (2002-2011). Focusing on the palynological method, the authors applied the synthetic method to carry out this study, particularly with the paleomagnetic, geochemical and

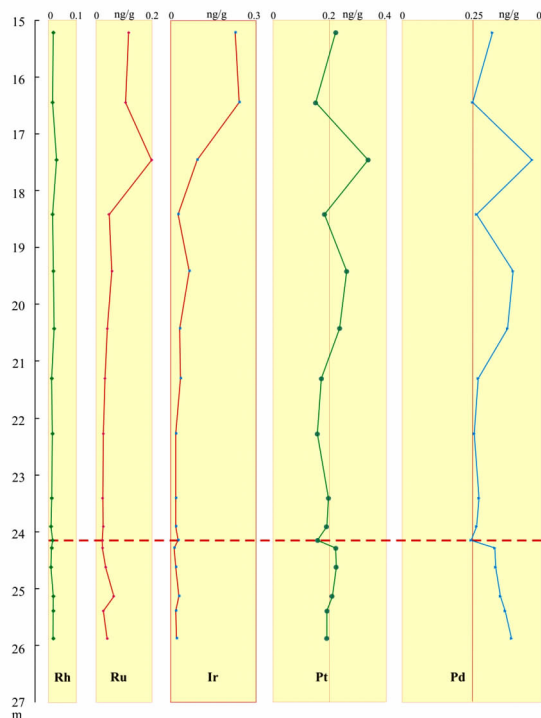


Fig. 20 variation relationship between PGE abundance and depth

other related studies as the important documentary data also (Fig. 21). In this study, the authors have made the definition on the K-Pg boundary in the Xiaohayang of Jiayin in the drilling boreholes, represented by the borehole XHY-2006, and within the interval of 22.00-22.05 m as the K-Pg boundary. This Jiayin K-Pg boundary is the most documented non-marine K-Pg boundary in China, and would be as one of the important K-Pg boundary points in the world. This new achievement would be promoting the further study on the K-Pg boundary in the Northeast Asia, even the world. Although we have gained such important and good results, it is still requested to do the more work for improving and supplementary of the K-Pg boundary in Jiayin.

Nichols D (2006)^① had proposed the criteria for evaluating the non-marine K-Pg boundary usually

① Nichols D., 2006. "Plants and the K-T Boundary: Palynology", Lecture in Jilin University, Changchun.

Table 3 Primary element and trace element analysis result of Jiayin section

	JY001	JY002	JY003	JY004	JY005	JY006	JY007	JY008	JY009	JY010	JY016	JY011	JY012	JY015	JY013	JY014
深度(m)	15.21	16.44	17.45	18.41	19.42	20.43	21.3	22.27	23.41	23.91	24.15	24.29	24.62	25.14	25.39	25.88
SiO ₂	58.47	64.09	57.66	59.24	61.83	65.40	66.68	68.87	69.65	67.04	71.43	61.34	62.47	61.62	60.71	61.08
TiO ₂	0.81	1.10	0.74	0.80	0.81	0.65	0.79	0.74	0.70	0.80	0.52	0.84	0.86	0.93	0.91	0.92
Al ₂ O ₃	22.65	19.50	23.11	19.91	19.30	19.85	17.71	16.94	16.27	17.31	15.50	19.96	19.55	20.26	20.49	19.97
Fe ₂ O ₃	5.58	4.97	6.08	8.40	6.73	3.60	4.37	3.53	3.50	4.35	2.93	5.51	5.41	5.45	5.91	5.91
MnO	0.03	0.02	0.03	0.04	0.03	0.02	0.03	0.02	0.02	0.03	0.02	0.04	0.04	0.04	0.04	0.04
MgO	0.59	0.45	0.70	0.76	0.70	0.79	0.71	0.56	0.52	0.64	0.46	0.90	0.84	0.81	0.83	0.86
CaO	1.21	0.95	1.25	1.23	1.01	0.64	0.85	0.74	0.72	0.80	0.71	1.08	1.00	1.06	1.11	1.03
Na ₂ O	0.25	0.16	0.16	0.16	0.26	0.58	0.74	1.12	1.22	0.94	0.95	0.30	0.32	0.24	0.24	0.26
K ₂ O	1.67	1.03	0.87	1.54	2.21	3.01	2.84	3.12	3.12	2.93	2.92	2.38	2.48	2.25	2.13	2.46
P ₂ O ₅	0.24	0.03	0.03	0.03	0.04	0.05	0.03	0.03	0.03	0.03	0.02	0.04	0.03	0.03	0.03	0.03
LOI	8.46	7.73	9.15	7.71	6.92	5.77	5.38	4.61	4.25	5.03	4.63	7.50	6.93	6.81	7.44	7.28
Total	99.95	100.03	99.78	99.82	99.83	100.36	100.14	100.27	100.01	99.88	100.10	99.89	99.93	99.52	99.84	99.85
Sc	17.95	12.14	20.41	14.25	13	13	11.8	9.854	9.548	11.9	7.525	14.76	14.87	15.48	16.09	15.77
V	89.87	77.52	109.9	87.76	79.42	75.95	73.54	64.79	62.12	71.91	51.4	93.11	97.09	102.2	100.8	98.46
Cr	88.57	73.05	85.5	66.05	63.05	45.48	57.67	53.96	55.04	61.2	36.87	72.26	71.45	78	82.45	79.26
Mn	214.8	186	282.7	298.9	247.3	195	234.8	198.1	200.2	241.3	204.5	315.9	304	310.6	306	302.8
Co	5.988	4.248	6.492	6.653	5.858	4.237	6.735	26.09	5.84	14.94	6.569	13.4	16.44	39.51	20.1	22.82
Ni	15.79	13.62	24.29	18.57	16.26	12.81	18.72	30.23	12.04	37.88	15.79	27.95	29.96	30.8	35.36	27.24
Cu	21.2	19.08	41.72	19.81	16.69	15.56	22.66	15.4	12.9	17.05	12.36	22.32	20.42	25.42	25.66	23.44
Zn	52.67	41.06	67.55	70.29	63.38	49.61	66.23	53.84	52.06	53.93	44.99	91.27	100.2	99.14	84.13	79.6
Ga	31.49	26.66	34.5	28.21	25.26	23.29	22.96	21.83	20.54	23.38	18.95	28.34	27.97	28.41	28.12	28.26
Ge	1.879	2.045	2.057	1.523	1.773	2.237	1.718	1.566	1.651	1.834	1.306	1.777	1.658	1.324	1.472	1.524
Rb	103	68.49	78.63	126.1	149.5	139.2	156	157.5	148.3	156.4	126.4	174.9	179.4	166.5	155.7	174.7
Sr	153	120	162.5	169.5	152.5	109.2	154.1	160.8	166.9	167.8	138.8	172.6	171.7	171.9	167.3	167.4
Y	26.57	20.87	15.47	11.77	29.61	68.05	42.43	28.64	33.12	30.89	21.61	37.94	28.54	31.9	20.71	18.72
Zr	235.9	347.9	204.6	203.6	215.9	223.5	278.7	314.5	353.9	292.9	174.8	218.8	241.6	236.7	209	227.5
Nb	20.01	26.73	20.28	19.57	18.33	14.12	17.9	16.2	15.99	17.05	11.53	19.18	20.16	20.87	20.86	21.05
Cs	8.615	9.37	10.59	11	13.11	11.69	11.38	9.687	8.729	11.09	7.986	12.92	13.64	14.23	13.76	15.76
Ba	554	377.1	374.6	363.7	631.5	538.9	635.4	726.8	763.6	739.6	720.5	620.2	654.5	624.7	602.8	653.7
La	22.42	16.41	14.58	13.64	55	101.8	50.32	50.83	50.5	41	38.76	64.86	38.94	35.37	18.94	23.35
Ce	37.1	30.77	26.84	25.14	127.3	256.1	106.7	100.1	98.48	82.3	80.3	138.4	81.55	73.82	37.87	44.75
Pr	4.411	3.831	3.222	2.708	15.74	35.31	13.42	11.88	12.13	10.17	9.17	16.5	10.04	9.084	4.608	5.701
Nd	15.56	13.54	11.73	9.623	55.61	138.6	52.05	43.83	44.11	36.43	32.49	59.85	36.9	34.41	16.66	19.73
Sm	2.901	2.555	2.307	1.699	10.25	27.45	9.566	7.745	8.117	6.675	6.025	10.63	6.737	7.192	3.437	3.923
Eu	0.425	0.335	0.368	0.27	1.461	4.244	1.599	1.335	1.411	1.204	1.081	1.831	1.207	1.262	0.629	0.648
Gd	3.09	2.476	2.204	1.552	7.313	20.66	8.534	6.113	6.696	5.725	4.957	8.758	5.496	5.881	3.036	3.088
Tb	0.546	0.452	0.382	0.263	1.108	3.313	1.43	0.932	1.055	0.896	0.751	1.316	0.9	1.004	0.58	0.556
Dy	3.295	2.731	2.398	1.649	5.918	16.85	8.068	5.284	5.915	5.201	4.116	7.037	5.06	5.724	3.553	3.172
Ho	0.775	0.68	0.543	0.396	1.171	3.114	1.675	1.068	1.218	1.126	0.874	1.457	1.091	1.239	0.786	0.747
Er	2.33	2.006	1.56	1.199	3.138	7.721	4.338	2.971	3.411	3.251	2.517	4.051	3.177	3.494	2.398	2.297
Tm	0.348	0.326	0.234	0.188	0.458	1.099	0.658	0.402	0.486	0.492	0.365	0.574	0.471	0.502	0.354	0.332
Yb	2.189	2.05	1.63	1.273	2.925	6.785	4.212	2.697	3.197	2.948	2.378	3.64	3.097	3.339	2.448	2.273
Lu	0.344	0.327	0.238	0.201	0.404	0.922	0.61	0.418	0.482	0.469	0.358	0.523	0.482	0.491	0.385	0.372
Hf	5.195	7.233	4.938	4.667	5.283	5.774	6.684	7.885	8.546	7.57	5.058	6.112	7.257	6.862	6.273	6.384
Ta	1.178	1.58	1.309	1.237	1.282	1.031	1.241	1.169	1.116	1.245	0.961	1.418	1.623	1.669	1.578	1.632
Pb	29.3	17.92	20.27	15.09	18.48	16.33	18.56	24.73	22.43	28.57	22.29	26.62	31.89	37.29	27.8	24.45
Th	19.02	18.65	21.57	17.9	20.2	15.9	19.11	17.15	16.27	18.83	13.73	21.35	22.63	23.88	23.27	22.73
U	11.26	4.278	6.333	3.679	4.639	5.443	4.592	3.731	4.867	4.599	3.174	5.517	6.428	9.018	4.501	5.185

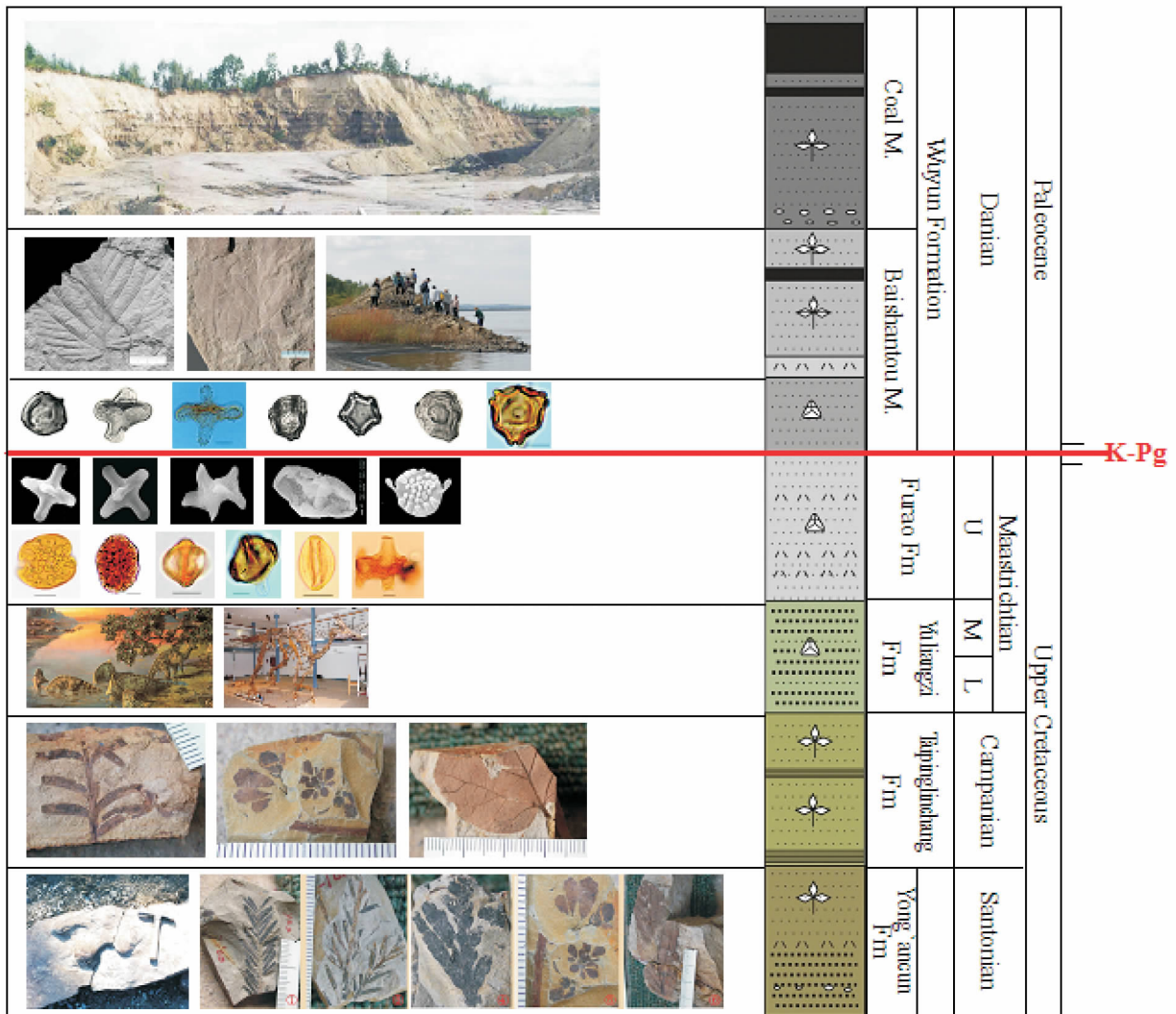


Fig. 21 A synthetic research achievement in the biostratigraphic study of Jiayin

with the following pre-conditions, which include (1) the ‘ferns-spike’ expressed, (2) the sample intervals as possible as less in thickness, (3) iridium (Ir) anomaly, and (4) the shock-metamorphosed minerals present, etc. However, the above-mentioned pre-conditions’ can usually be used for the extraterrestrial impact origin for the K-Pg boundary, which is not suitable for the normal non-marine conditions of the K-Pg boundary without the impact. Even though such idea was proposed by Nichols, the nonmarine K-Pg boundary in Jiayin has still indicated the characters of the ‘ferns-spike’ showed in the K-Pg interval in the borehole XHY-2005 of Jiayin (Markevich *et al.*,

2011). On the other hand, since the nonmarine K-T boundary in Jiayin has no impact evidence, the reasons for the K-Pg boundary events should be explained by other discussion, which would meet similar situations to those in the whole Northeastern Asian region.

4.2 On the dinosaur extinctions in Jiayin and on Iridium

The dinosaurs discovered in the Jiayin and in the Heilongjiang (Amur) River area are unique in abundance, diversity and excellent in preservation (Godefroit *et al.*, 2011). The hollow-crested lambeosaurine hadrosaurids are particularly well represented. Their

ancestors migrated from eastern Asia towards western North America might be before or at the beginning of the late Campanian, which was also before the dinosaur complete extinction at 65 Ma ago. The different kinds of dinosaur communities lived around the world by latest Cretaceous times, perhaps sudden (or periodically sudden) demise in the end of the Cretaceous period.

However, why did the dinosaurs extinct? Did the dinosaurs sudden demise or being gradually disappear? Did the impact happen in Chicxulub influence the whole world including the NE Asia at the end of Cretaceous? There are many questions for geoscientists to crack the mystery on the dinosaur mass extinctions.

Since Alverz *et al.* (1980) proposed the Earth was struck by a large extraterrestrial object at about 65 Ma ago, many people have believed the dinosaurs extinction was influenced by the impact of extraterrestrial body, and usually with the Iridium anomaly. However, according the authors' study, there was no impact and no special Iridium anomaly in the Northeast Asian land including the Heilongjiang (Amur) River area. According our study, the dinosaurs' extinctions were probably caused by the more strongly volcanic activities (eruptions), sea-level down, and the climate cooling during the latest Cretaceous, would be the main reasons for the dinosaur mass extinctions.

The volcanic activity and global regression during the K-Pg transition time, might be accompanied the cooling in climate change, and the sea-level down was not less than 100-130 m (Haq *et al.* , 1987). Increasing of the erosional activity, cooling, and the land arise up, caused the main food pastures stopped to supply for the dinosaurs living. The hiatus, rewashing of the late Late Cretaceous deposits near the K-Pg boundary transition, took place nearly all of the world, including the Siberia, Far East of Russia, Japan and China. The effect of cooling was increased the desiccation (drainage) in the middle and middle-high latitudinal land, which caused no food for the dinosaurs, and the volcanic activities increased may bring the unexpective disasters to the dinosaurs in ex-

inction.

The Upper Cretaceous in Jiayin and the lower-middle Tsagayan Group, we found a lot of volcanic materials. The volcanic contents increased in the samples of the intervals 34 m, 38m, 44m, and 48m in the borehole XHY 2005 (all before the K-Pg boundary) some documented the volcanic activitive in this area. These unexpected events caused the infulences (even disasters) to the dinosaurs, should be considered in study on the mass extinction. And, these facts should be considered in the study of the K-Pg boundary transition events took place in Jiayin and the Northeast Asia.

The Iridium anomaly has been a very common geological phenomenon which can be caused by many reasons, particularly as a result of volcanic movements, with no impact event took place. The Iridium contents in the Earth are usually as 1×10^{-7} or no more than 0.1 g/t. In dinosaurs bones (before K/T boundary) the contents of Iridium can be 60-90 times more than Clarke (Akhmetiev, 2004). The contents of Iridium in the Arkhara clays of the Zeya-Bureja basin can be up to-0.5% which are hundreds or thousands times more than the content of Iridium in the Earth, while which was no originated by impact. Therefore we must think the other reasons caused the Iridium contents, which is usually to be thought their volcanic nature on the Iridium.

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