to the lower part of the Yixian Formation) will be further supported, contrary to the Upper Jurassic[10] originally proposed. In the view of evolution of osteological characters, all the Chinese Mesozoic caudates (six species in five genera) have unicapitate ribs, a synapomorphy of living cryptobranchoids, indicating that they are of the same evolutionary stage, and might have similar geological age. Furthermore, these Chinese forms are all advanced over *Karaurus* (with heavy dermal sculpture and quadratojugals in the skull and double-headed ribs[1]) from the Late Jurassic of Kazakhstan. With the above discussions, the age of Daohugou fossil horizon is probably Early Cretaceous or Late Jurassic, and not as early as Middle Jurassic.

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SHRIMP U-Pb zircon dating of the uppermost Cretaceous Furao Formation near the Heilong River: An age closest to the K/T boundary

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Since Alvarez et al.[1] suggested that the presence of a large iridium concentration anomaly in sediments at the Cretaceous-Tertiary (K-T) boundary was evidence of a large bolide impact at this time that cause the K-T mass extinction, much attention has been paid to the precise age of this boundary with important geological event, mass extinction of organism and their mechanistic link. During the K-T boundary time, shocked quartz and microspherules were widely distributed in America, which were genetically related to the synchronous Chicxulub crater on the Yucatán Peninsula of Mexico[2,3]. These findings indicate that the K-T mass extinction was most likely caused by an extraterrestrial impact at about 65 or 66.5 Ma. On the other hand, large explosive gas release from cratonic lithosphere triggered by mantle plume activity is considered as the main reason of the major mass extinctions during Phanerozoic time including the K-T boundary[4,5]. In addition, the K-T mass extinction is also probably caused by multiple impacts of small planets with volcanic explosions[6].

In comparison with marine K-T Global Standard Section and Point (GSSP), investigations of non-marine K-T boundary strata are limited, and only a few boundary clay and iridium anomaly have been identified in North America[7,8]. Geologists, palaeontologists and geochemists are all along attempting to find the non-marine K-T boundary clay with iridium anomaly in Asia[9].

The upper Furao Formation at Baitoushan section near the Heilong (Amur) River in Jiayin County belongs to the Furaoan Stage that is the uppermost chronostratigraphic unit of non-marine Cretaceous in China. According to biostratigraphic analyses, it can be correlated with the Upper Maastrichtian Stage in Europe[10]. Overlying the Furao Formation is the Paleocene coal-bearing Wuyun Formation. In this region they are very similar to the K-T boundary strata of the Williston Basin in North America[8]. Consequently, it is hopeful to find the K-T boundary section with iridium anomaly in Furao and Wuyun districts.

Sample B_6, a rhyolitic crystal tuff, was collected for age determination from the uppermost Furao Formation at the Baitoushan Section[10]. Measurements of U, Th and Pb isotopes were conducted using the SHRIMP II ion microprobe at the Beijing SHRIMP Center using standard operating conditions[11,12]. Analytical results are listed in Table 1.

Zircons are mostly euhedral, transparent, and colourless to light brown, and show concentric zoning. There are two types of prismatic zircons in morphology. The elongate crystals have length to width ratios of 3:1 to 4:1 ranging up to 250—300 μm in length, whilst the stubby crystals have 150 μm in length with length to width ratios of 2:1 (Fig. 1). Twenty-one analyses of 21 zircons from this tuff sample were obtained, and the data are plotted in the U-Pb concordia diagram (Fig. 2). These zircon grains have moderately high and variable concentrations of U (118—931 μg/g) and Th (81—598 μg/g), and their Th/U ratios vary mostly between 0.5 and 1.0. Apart from analysis #4.1 showing clearly old $^{206}Pb/^{238}U$ age of 83.2±3.1 Ma due possibly to inherited radiogenic Pb, the remaining twenty analyses have indistinguishable $^{206}Pb/^{238}U$ ratios within analytical errors, which correspond to a single age population with a weighted mean $^{206}Pb/^{238}U$ age of 66.2±1.2 Ma (95% confidence level, MSWD = 1.4). We noticed that analyses# 1.1, 7.1 and 17.1 appear to have slightly older $^{206}Pb/^{238}U$ ages than others, although they all are generally overlapped within errors. It is not very clear whether such slightly older $^{206}Pb/^{238}U$ ages for these three zircons are caused by either presence of minor amount of inherited radiogenic Pb or statistic counting deviation, because their CL images are similar to others. If analyses# 1.1, 4.1, 7.1 and 17.1 are excluded, the remaining seventeen analyses give a weighted mean $^{206}Pb/^{238}U$ age of 65.5±1.0 Ma, identical to the grand mean age of 66.2±1.2 Ma within uncertainties. Thus, the best estimate of the formation age of sample B_6 is 66±1 Ma.

Outcrop of the Furaoan Stage in Baitoushan Section near the Heilong River is only 16.8 m in thickness. The overlying is gray-white massive sandstone of the Paleocene Wuyun Formation whose base is considered as the K-T boundary. Below the boundary, the Furaoan strata are rich in sporopollen fossils including about 10 species of Aquilapollens indicative of late Maastrichtian age[10]. In this section the isotopic dating sample (B_6) was collected from the 3rd bed of rhyolitic crystal tuff that is about 9.3 m below the K-T boundary. Our SHRIMP U-Pb zircon age of 66±1 Ma is only 0.5 to 1 Ma older than the recommended K-T boundary age in the International Stratigraphic Chart. It is so far the most reliable isotopic age near the top of the Upper Cretaceous in China, thus has significance to global correlation.

Table 1 SHRIMP U-Pb zircon data for a rhyolitic tuff sample B_6 from Furao Formation

Analysis	U /μg · g^{-1}	Th /μg · g^{-1}	Th/U	f_{206} (%)	$^{207}Pb^*/^{235}U$ (±1σ)		$^{206}Pb^*/^{238}U$ (±1σ)		$^{206}Pb^*/^{238}U$ age /Ma (±1σ)	
1.1	286	169	0.61	4.9	0.132	±0.010	0.0111	±0.0003	71.3	±2.7
2.1	584	437	0.77	2.9	0.071	±0.004	0.0099	±0.0003	63.4	±2.0
3.1	328	178	0.56	1.6	0.107	±0.006	0.0106	±0.0003	67.9	±2.2
4.1	214	110	0.53	9.7	0.106	±0.023	0.0130	±0.0004	83.2	±3.1
5.1	118	182	1.60	22.0	0.071	±0.010	0.0100	±0.0002	64.3	±4.0
6.1	512	307	0.62	6.4	0.060	±0.010	0.0098	±0.0001	63.0	±1.3
7.1	925	598	0.67	2.9	0.065	±0.004	0.0114	±0.0003	72.9	±2.3
8.1	176	101	0.59	8.9	0.055	±0.009	0.0103	±0.0003	66.1	±2.6
9.1	249	167	0.69	7.2	0.082	±0.008	0.0105	±0.0003	67.2	±2.6
10.1	414	300	0.75	4.4	0.069	±0.006	0.0102	±0.0003	65.7	±2.2
11.1	931	556	0.62	1.4	0.077	±0.004	0.0106	±0.0003	67.8	±1.9
12.1	188	81	0.44	5.8	0.071	±0.012	0.0104	±0.0003	66.7	±2.6
13.1	803	452	0.58	3.1	0.064	±0.004	0.0101	±0.0003	65.1	±1.9
14.1	379	394	1.08	5.7	0.078	±0.006	0.0102	±0.0003	65.1	±2.4
15.1	662	378	0.59	2.8	0.062	±0.005	0.0105	±0.0003	67.1	±2.0
16.1	272	199	0.76	7.6	0.070	±0.008	0.0101	±0.0003	65.0	±2.6
17.1	169	104	0.64	15.4	0.060	±0.029	0.0112	±0.0003	71.8	±3.9
18.1	322	205	0.66	9.2	0.057	±0.010	0.0103	±0.0003	66.0	±2.3
19.1	212	106	0.52	12.6	0.063	±0.017	0.0102	±0.0003	65.6	±2.7
20.1	408	236	0.60	5.2	0.078	±0.005	0.0104	±0.0003	66.8	±2.2
21.1	225	156	0.72	7.9	0.057	±0.012	0.0103	±0.0003	66.0	±2.4

f_{206} = percentage of common ^{206}Pb in total ^{206}Pb.

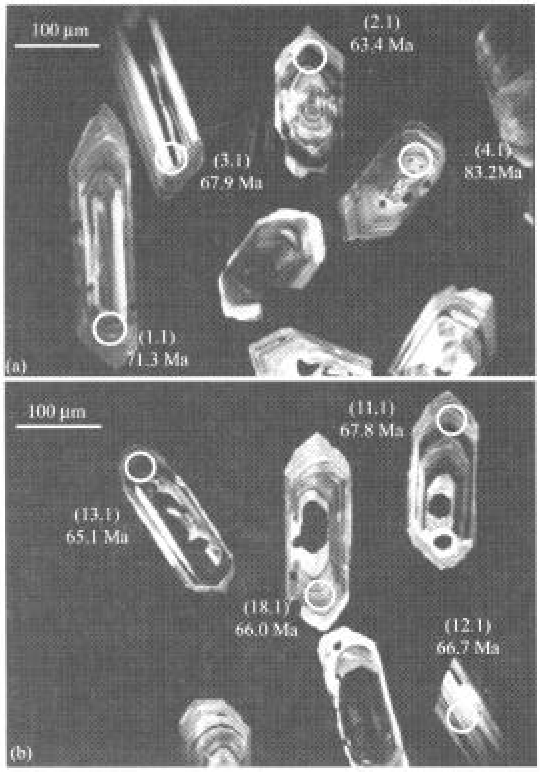

Fig. 1. Cathodoluminescence images of representative zircons from the Furao rhyolitic tuff. Rounded circles indicate the spots of SHRIMP analysis, with the ages and spot numbers being labeled nearby.

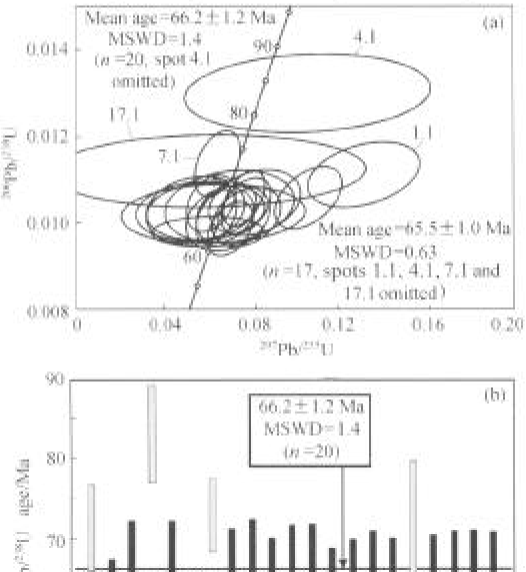

Fig. 2. (a) U-Pb zircon concodia plot, and (b) weight mean of $^{206}Pb/^{238}U$ zircon ages.

On the other hand, the lower part of Baitoushan section is frequently flooded by the Heilong River. It is difficult to find the lower boundary of the Furaoan Stage as stratotype section. Thus, a well boring and systematic sampling at the Wuyun Coal Mine near Baitoushan section are necessary to find the K-T boundary clay and possible iridium anomaly as well as other impact signatures. The sample of radiometric dating in this study is an acidic extrusive rock. Further investigations are needed to examine whether this volcanic eruption is related to the K-T mass extinction.

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