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The $^{40}Ar/^{39}Ar$ dating of the early Jehol Biota from Fengning, Hebei Province, northern China

H. Y. He
Laboratory of Paleomagnetism and Geochronology (SKL-LE), Institute of Geology and Geophysics, Chinese Academy of Sciences, Beijing 100029, China (huaiyuhe@mail.igcas.ac.cn)

X. L. Wang, F. Jin, and Z. H. Zhou
Institute of Vertebrate Paleontology and Paleoanthropology, Chinese Academy of Sciences, Beijing 100044, China

F. Wang and L. K. Yang
Laboratory of Paleomagnetism and Geochronology (SKL-LE), Institute of Geology and Geophysics, Chinese Academy of Sciences, Beijing 100029, China

X. Ding
Marine School, Chinese University of Geosciences, Beijing 100083, China

A. Boven
Graystreet 133, B-1050 Brussels, Belgium

R. X. Zhu
Laboratory of Paleomagnetism and Geochronology (SKL-LE), Institute of Geology and Geophysics, Chinese Academy of Sciences, Beijing 100029, China

[1] The bird fossil-bearing deposits at the Jiecaigou section, correlative to the Dabeigou Formation, in Fengning, Hebei Province, northern China, is well known for yielding a fossil assemblage representing the earliest evolutionary stage of the Jehol Biota. The precise age of the fossil-bearing deposits, however, is unknown. The $^{40}Ar/^{39}Ar$ age spectrum obtained on bulk K-feldspars from the tuff layer about 2 m below the bird fossil-bearing layer gave a plateau age of 129.0 ± 1.3 Ma (2σ, full external error) and an isochron age of 132.3 ± 4.5 Ma (2σ, full external error). Seventeen total-fusion $^{40}Ar/^{39}Ar$ ages on K-feldspars from the interbedded tuff about 6 m below the fossil-bearing layer resulted in a weighted mean of 130.7 ± 1.4 Ma (2σ, full external error). These dates suggest an age of $\sim$131 Ma for the early Jehol Biota and combined with previous dating indicate that this biota lasted at least from 131 Ma to 120 Ma (Late Hauterivian to Aptian). These dates also represent the earliest absolute age for known enantiornithine birds in the world.

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1. Introduction

[2] The Jehol Biota from East Asia includes representatives of almost all of the major clades of Lower Cretaceous terrestrial and freshwater vertebrates, a wide variety of invertebrates and a diverse flora. It provides arguably the best fossil evidence for the study of the early evolution of birds, angiosperms and mammals, and in particular, the recent discoveries of many feathered dinosaurs have drawn worldwide attention from both the academic community and the public [*Sereno and Rao*, 1992; *Hou et al.*, 1995, 1996; *Hu et al.*, 1997; *Chen et al.*, 1998; *Sun et al.*, 1998; *Zhou et al.*, 2003; *Zhou*, 2004]. The Jehol Group that produces the Jehol Biota was usually considered to comprise the Yixian Formation and overlying Jiufotang Formation [*Chang et al.*, 2003; *Zhou et al.*, 2003] and to be distributed mainly in western Liaoning Province and northern Hebei Province (Figure 1).

[3] Correlation between the Dabeigou Formation in northern Hebei and the Jehol Group in western Liaoning is controversial (Figure 2). Some workers correlated the Dabeigou Formation with the lower Yixian Formation [*Wang et al.*, 2000], while others insist that it should be lower than the Yixian Formation and represent the lowest horizon of the Jehol Group [*Chen*, 1999]. Recent research on vertebrates and geochronology [*Liu et al.*, 2003; *Tian et al.*, 2004; *Zhou*, 2006] prefer the proposal that the Jehol Biota experienced early, middle and late stages of evolution, corresponding to the fossil assemblages from the Dabeigou, Yixian and Jiufotang Formations respectively [*Chen*, 1999], although little is known about the precise age of the early stage of the biota (Figure 2).

[4] Studies on vertebrates indicate that the fossil assemblage of the Dabeigou Formation shows a relatively low biological diversity with animals of a more primitive appearance than those of the Yixian Formation. For instance, recent studies on vertebrates indicate that *Lycoptera*, a primitive teleost fish and the best-known fish in the Jehol Biota, does not occur in the Dabeigou Formation, and the only known bird from the Formation *Protopteryx* is more primitive than other enantiornithine birds from the Yixian Formation [*Zhang and Zhou*, 2000; *Zhou*, 2006].

[5] Recent dates based on the interbedded tuffs from the Yixian and Jiufotang Formations have provided direct ages for the middle and late stages of the Jehol Biota [*Swisher et al.*, 1999, 2002; *He et al.*, 2004], but little is known about the precise age of the Dabeigou Formation. *Liu et al.* [2003] have obtained a Sensitive High Resolution Ion Micro Probe mass spectrometer (SHRIMP) U-Pb zircon age of 135.4 ± 1.6 Ma for an ignimbrite, and *Chen and Zhang* [2004] obtained an ^{40}Ar/^{39}Ar age of 135.3 ± 1.4 Ma for rhyolite in the Zhangjiakou Formation, which is overlain by the Dabeigou Formation (Figure 2). These results are generally consistent with SHRIMP U-Pb dating of 135 ± 1 Ma, 135.8 ± 3.1 Ma and 136.3 ± 3.4 Ma from the volcanic rocks in the same area in the Luanping Basin in northern Hebei Province [*Niu et al.*, 2003; *Zhao et al.*, 2004] and have provided a maximum estimate of the oldest age for the Dabeigou Formation (Figure 2).

[6] *Liu et al.* [2003] provided the first direct age for the Dabeigou Formation in the northern Hebei Province by obtaining mean SHRIMP U-Pb ages of 133.9 ± 2.5 Ma and 130.1 ± 2.5 Ma from two tuffaceous sandstones in the Luanping area. However, all the analysis plots of tuffaceous sandstones are strongly discordant, due to either alteration of zircons or ^{204}Pb contamination of cracks [*Liu et al.*, 2003]. Moreover, it is difficult to correlate their dated tuffaceous sandstones with the fossil-bearing sediments. In this paper we provide the first ^{40}Ar/^{39}Ar dating on tuffs interbedded in the bird fossil-bearing sediments of the Dabeigou Formation at Jiecaigou in Fengning County, northern Hebei Province. Our study has provided a direct age for the fossil assemblage of the first evolutionary stage of the Jehol Biota, suggesting a more precise estimate of the duration of the Jehol Biota from 131 Ma to 120 Ma (Late Hauterivian - Aptian) during the Early Cretaceous [*He et al.*, 2004].

2. Geologic Setting and Sampling

[7] Since the Middle-Late Jurassic, structural lineaments in northern Hebei and western Liaoning appeared to have changed their strike orientations from an east-west to north-northeast trend presumably as a result of westward subduction of the Pacific plate [*Zhao et al.*, 2004]. Crustal extension then became prevalent in Late Jurassic and Early Cretaceous times [*Ren et al.*, 2002; *Meng*, 2003], as evidenced by occurrence of extensive volcanism [*Chen and Chen*, 1997] and development of rifted basins [*Davis et al.*, 1998; *Cope et al.*, 2001; *Meng et al.*, 2003]. In addition, the Cretaceous basin fills are rich in fossils, such as the well-known Jehol Biota [*Pan et al.*, 2001; *Wang and Zhang*, 2004].

[8] The Jiecaigou section (116.355°E, 41.639°N) lies in the north of Fengning County, Hebei Prov-

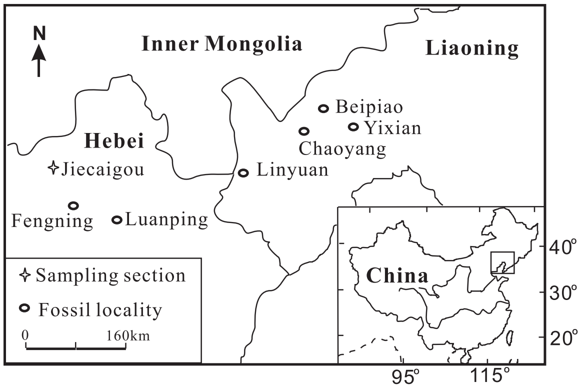

Figure 1. Sketch map showing the major vertebrate fossil localities of the Jehol Biota in northern Hebei and western Liaoning. Early Jehol Biota fossils were mainly preserved in the Dabeigou Formation in Fengning and Luanping; fossils of middle Jehol Biota were mainly preserved in the Yixian Formation in Lingyuan, Chaoyang, Yixian, and Beipiao. Late Jehol Biota fossils were mainly preserved in the Jiufotang Formation in Chaoyang and Yixian. Dated tuff samples in this study were collected at the Jiecaigou section in Fengning.

ince, northern China. Compared with other vertebrate fossil localities in western Liaoning, which mainly yield fossils of the middle and late Jehol Biota, the Dabeigou Formation at Jiecaigou is one of the major vertebrate fossil-bearing strata that yields the early Jehol Biota (Figures 1 and 2). Moreover, the correlation between the fossil-bearing beds and interbedded tuffs is clear, providing a chance to determine the age of the fossils precisely. Hundreds of fossils have been discovered in this section, including the bird *Protopteryx* [*Zhang and Zhou*, 2000], the fish *Yanosteus* [*Jin et al.*, 1995; *Jin*, 1999], and many insects [*Pang et al.*, 2002]. From top to bottom, the lacustrine sediments in the Jiecaigou section are mainly composed of fossil-bearing shales (about 2 meters thick), grayish tuffaceous sandstones and intercalated whitish tuffs (about 14 meters thick), and gray shales and mudstones (about 13 meters thick). Samples JCG-1 and JCG-5 were collected from the tuffs about 2 m and 6 m below the bird fossil-bearing layer, respectively (Figure 3).

[9] Thin section study shows that the tuffs JCG-1 and JCG-5 are mainly composed of fine volcanic ashes (80–90%), sanidine and orthoclase crystals

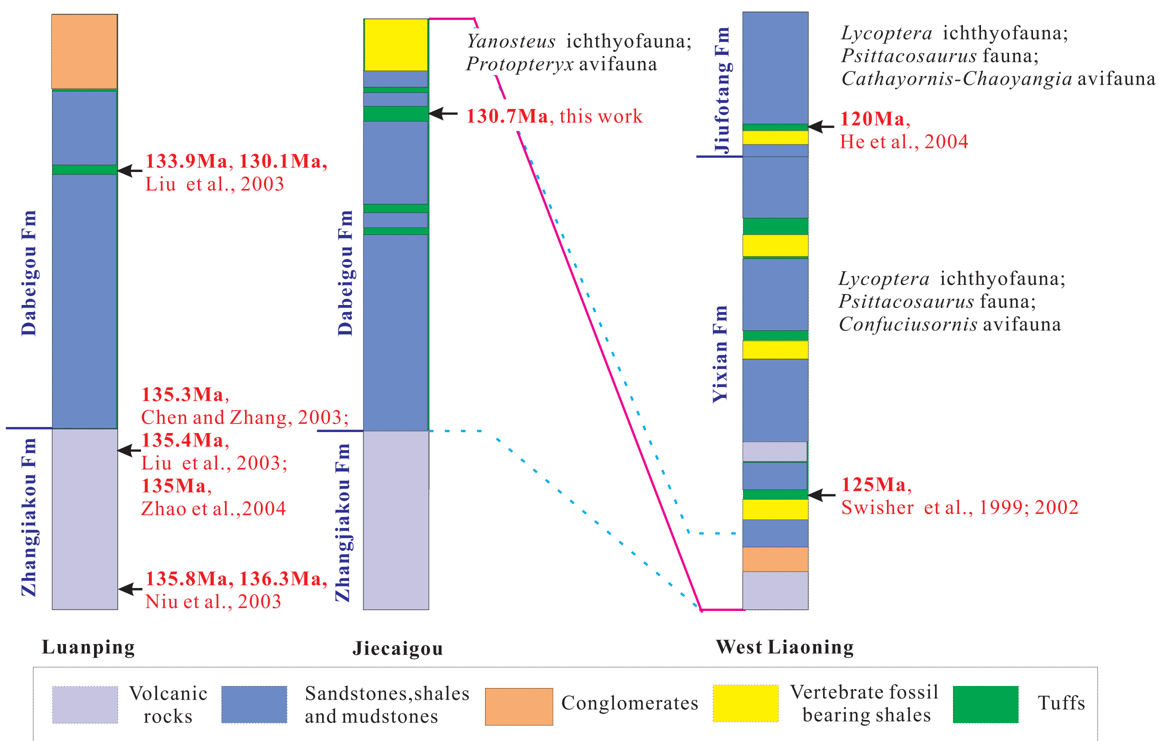

Figure 2. Sketch stratigraphic log of the Zhangjiakou, Dabeigou, Yixian, and Jiufotang Formations in Luanping, Jiecaigou, and west Liaoning, showing the radiometric dates and vertebrate faunas. *Wang et al.* [2000] correlated the Dabeigou Formation with the lower Yixian Formation (blue dashed lines). Most researchers now agree with the proposal that the Jehol Biota experienced early, middle, and late stages of evolution, corresponding to the fossil assemblages from the Dabeigou, Yixian, and Jiufotang Formations, respectively [*Liu et al.*, 2003; *Tian et al.*, 2004; *Zhou*, 2006] (pink line), a conclusion previously based mainly on fossil invertebrate evidence [*Chen*, 1999].

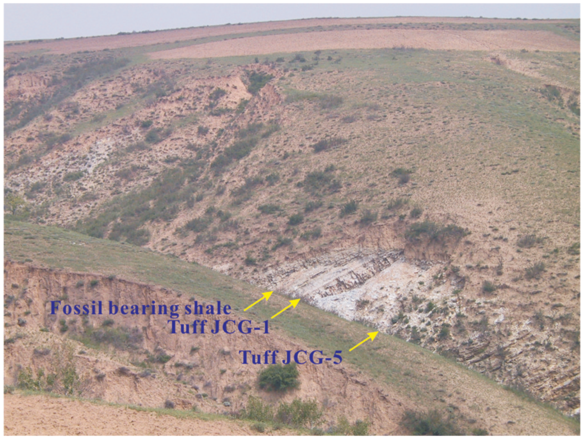

Figure 3. Field photo of the Jiecaigou section. The fossil-bearing shales that yield *Protopteryx* and *Yanosteus* are located about 2 m above the dated tuff layer JCG-1 and about 6 m above the dated tuff layer JCG-5.

(5–15%) and biotite crystals (5%). K-feldspar was chosen for laboratory analysis because it is less altered than biotite.

3. Analyses

[10] Tuff samples were crushed and sieved between 40–80 mesh (380–200 μm) fractions, and rinsed with distilled water. After heavy liquid separation the K-feldspars (sanidine and orthoclase) were obtained and washed with acetone in an ultra-sonic bath for 20 min. Cleaned K-feldspars were wrapped in Al foil and irradiated together with Ga1550-biotite standards, optical CaF_2 and K-glass monitors in position H8 of the 49-2 reactor, Beijing, China, for 45.7 hours with 0.5 mm cadmium foil shield. The reference age for GA-1550 biotite is 98.79 ± 0.96 Ma [*Renne et al.*, 1998]. Ca, K correction factors were calculated from the CaF_2 and K_2SO_4 monitors: $(^{40}Ar/^{39}Ar)_K = 8.8 \times 10^{-4}$, $(^{39}Ar/^{37}Ar)_{Ca} = 7.92 \times 10^{-4}$, $(^{36}Ar/^{37}Ar)_{Ca} = 2.21 \times 10^{-4}$.

[11] Although the $^{40}Ar/^{39}Ar$ correction factors of 49-2 nuclear center in Beijing, China were studied by Wang et al. in 1985, there is no report on horizontal and vertical neutron flux distribution. To optimize the $^{40}Ar/^{39}Ar$ dating, we studied the flux characteristics of the 49-2 reactor using data from 6 irradiations totaling 33 vials in the tunnel H8 (core). According to our data, the vertical flux gradients in the 49-2 reactor ranged from 1 to 8%/cm, and are related to the vertical position of the vials. Horizontal flux gradients are around 2%/cm. For multigrain step heating, horizontal gradients have little influence, but the single crystal fusion does illustrate a lateral variation. We are still trying to find a method to minimize the horizontal gradient. In this irradiation the horizontal flux gradient is about 1.4%/cm, and the grains are distributed in a 5 mm diameter disk; thus we add the horizontal J value errors (7E-5) to analytical errors of every laser fusion analysis to reflect this uncertainty. The uncertainties of the ages were reported as analytical error and full external error, where full external error combines the analytical error, the error on the J-value and the systematic error on the total decay constant λ.

[12] The $^{40}Ar/^{39}Ar$ analyses were performed at the Laboratory of Paleomagnetism and Geochronology (SKL-LE) at the Chinese Academy of Sciences, Beijing, on a MM5400 mass spectrometer operating in a static mode. The data were corrected for system blanks, mass discriminations, interfering Ca, K derived argon isotopes, and the decay of ^{37}Ar since the time of the irradiation. The decay constant used throughout the calculations is $\lambda = (5.543 \pm 0.010) \times 10^{-10}\ a^{-1}$, as recommended by *Steiger and Jäger* [1977]. Details of the step-heating analysis by furnace and data processing procedures were outlined by *He et al.* [2004].

[13] The $^{40}Ar/^{39}Ar$ dating of tuff is frequently hampered by excess argon or xenocrystic contamination [*Lo Bello et al.*, 1987]. In addition to $^{40}Ar/^{39}Ar$ step heating on K-feldspars from JCG-1 by furnace, the $^{40}Ar/^{39}Ar$ single crystal fusion of K-feldspars from JCG-5 by laser was also undertaken to address the possible xenocrystic contamination.

[14] The CO_2 laser extraction system comprises a CO_2 laser (New Wave™, 50W, wavelength of 10.6 μm), a sample chamber and the purification line. The view port of the sample chamber was designed by the Laboratory of Paleomagnetism and Geochronology ‘(SKL-LE). It consists of a ZnS window (made at the Research Institute of Synthetic Crystals in China), a U ring and a CF flange. The U ring was welded on the flange and the ZnS window was sealed on the U ring using a high temperature epoxy resin E505 (Epotecny™), as recommended by *Humbert et al.* [2000] as a low blank resin for N and Ar isotope study. Adding the U ring proves to be stress-resistant and makes the view port easier for baking and bolts tighten.

[15] Step heating analysis of JCG-1 by furnace indicate that the K-feldspars are altered, thus

Table 1. The $^{40}Ar/^{39}Ar$ Step Heating Data for K-Feldspar Separate From Tuff JCG-1[a]

Temp., °C	$^{39}Ar/^{40}Ar$ ± 1 s.d. (10^{-2})	$^{36}Ar/^{40}Ar$ ± 1 s.d. (10^{-4})	Ca/K	^{40}Ar (10^{-14} moles)	^{39}Ar Cum., %	$^{40}Ar^*$, %	$^{40}Ar^*/^{39}Ar$ ± 1 s.d.	Apparent Age ± 2 s.d., Ma
700	5.82 ± 0.01	15.25 ± 0.12	0.11	2.1	7.5	54.9	9.44 ± 0.07	148.83 ± 2.42
780	8.60 ± 0.02	7.50 ± 0.08	0.03	2.6	20.9	77.8	9.05 ± 0.03	142.86 ± 1.58
840	5.74 ± 0.01	16.80 ± 0.09	0.22	1.2	25.2	50.4	8.78 ± 0.05	138.84 ± 1.89
880	10.09 ± 0.02	5.18 ± 0.07	0.17	1.0	31.3	84.7	8.39 ± 0.03	132.88 ± 1.40
920	8.67 ± 0.01	9.72 ± 0.11	0.15	1.8	40.8	71.3	8.22 ± 0.04	130.34 ± 1.65
960	8.73 ± 0.02	9.76 ± 0.11	0.05	1.2	47.2	71.2	8.15 ± 0.04	129.15 ± 1.70
1000	8.15 ± 0.02	11.58 ± 0.13	0.00	1.0	52.2	65.8	8.07 ± 0.05	128.02 ± 1.95
1050	6.77 ± 0.01	15.68 ± 0.11	0.00	1.9	60.0	53.7	7.93 ± 0.05	125.77 ± 1.84
1100	5.89 ± 0.01	17.82 ± 0.09	0.04	2.5	68.9	47.4	8.04 ± 0.05	127.50 ± 1.92
1150	6.84 ± 0.01	14.98 ± 0.10	0.00	2.1	77.6	55.7	8.15 ± 0.04	129.21 ± 1.76
1200	7.41 ± 0.01	13.16 ± 0.12	0.00	1.1	82.8	61.1	8.24 ± 0.05	130.61 ± 1.95
1250	5.92 ± 0.01	17.61 ± 0.09	0.00	2.0	90.0	48.0	8.10 ± 0.05	128.48 ± 1.81
1300	6.45 ± 0.01	16.10 ± 0.12	0.00	1.8	97.1	52.4	8.13 ± 0.06	128.93 ± 2.07
1500	4.88 ± 0.01	20.32 ± 0.22	0.00	1.0	100.0	40.0	8.19 ± 0.13	129.87 ± 4.25

[a] Weight = 3.40 mg; J = 0.00911 ± 0.00005.

K-feldspars of JCG-5 for single crystal fusion were washed with 5% HF in an ultra-sonic bath for 10 min to remove alteration and expose fresh surfaces. Then the grains were rinsed with distilled water and dried, and loaded into ZnS sample chamber in an ultrahigh vacuum extraction line. The crystals were heated to fusion for 3 min using the CO_2 laser, and the beam size is 180 micrometers. Following three additional minutes of cleaning up on 2 SAES AP10 getters (operated at 350°C and 20°C, respectively), the gas was expanded into the MM5400 mass spectrometer. During the laser fusion, some grains were very close to each other and were sucked into the melting ball during the fusion, thus 6 analyses are fusions on multigrains. Other crystals are at least 1 mm away from each other, and the laser beam size is 180 micrometers; therefore 11 single crystal fusions were not affected by adjacent grains.

[16] Laser system blanks were measured between every three analyses. The total system blanks (6 min) were in the range of 3.6–4.0 × 10^{-16} moles for mass 40, 1.1–2.1 × 10^{-18} moles for mass 39, 2.3–3.6 × 10^{-19} moles for mass 38, 5.6–6.6 × 10^{-19} moles for mass 37, and 1.3–1.4 × 10^{-18} moles for mass 36. Blank corrections for all Ar isotopes were based on daily averages because the blanks were stable during analytical periods. Mass discrimination (1.0056–1.0080 per atomic mass unit) was monitored by everyday analysis of $^{40}Ar/^{36}Ar$ air pipette aliquots.

4. Results

[17] The results of the $^{40}Ar/^{39}Ar$ step heating analysis by furnace are shown in Table 1 and plotted as age spectrum and isotope correlation diagrams in Figure 4. The K-feldspar separated from tuff JCG-1 yields a disturbed age spectrum (Figure 4a), characterized by decreasing ages in the first 60% of the ^{39}Ar released, followed by a flat zone (six consequent steps, 40% of the total ^{39}Ar released), which defines a plateau age of 129.0 ± 0.8 Ma (2σ; ±1.3 Ma, full external error, MSWD = 1.15). All steps that formed the plateau give an inverse isochronal age of 132.3 ± 4.3 Ma (2σ; ±4.5 Ma, full external error, MSWD = 0.5) and $^{40}Ar/^{36}Ar$ intercept of 287 ± 8 (2σ), which is slightly lower than the air ratio (Figure 4c). The radiogenic ^{40}Ar of all the steps are lower than 85% (Table 1), considered here to be the combined effects of alteration of the K-feldspar and inadequate correction for furnace blanks. The disturbed age spectrum and low radiogenic ^{40}Ar content show that step heating analysis on K-feldspar separated from tuff JCG-1 are affected by alteration, and the age may not be precise. To get a better estimate of age, K-feldspars of JCG-5 were leached by HF to remove the altheration and fused by CO_2 laser.

[18] Seventeen total fusion ages obtained on tuff JCG-5 (Figure 5) gave a weighted mean age of 130.7 ± 0.4 Ma (2σ; ±1.4 Ma, full external error, MSWD = 0.97), an age indistinguishable from the isochron age of JCG-1. The ages scatter slightly as a result of the horizontal neutron flux gradient, and we add the horizontal J value errors (7E-5) to analytical errors of every laser fusion analyses to reflect this uncertainties. The radiogenic ^{40}Ar yields from all of the K-feldspars were greater than 99% (Table 2), and resulted in a small cluster of points when plotted on an inverse isochron, mak-

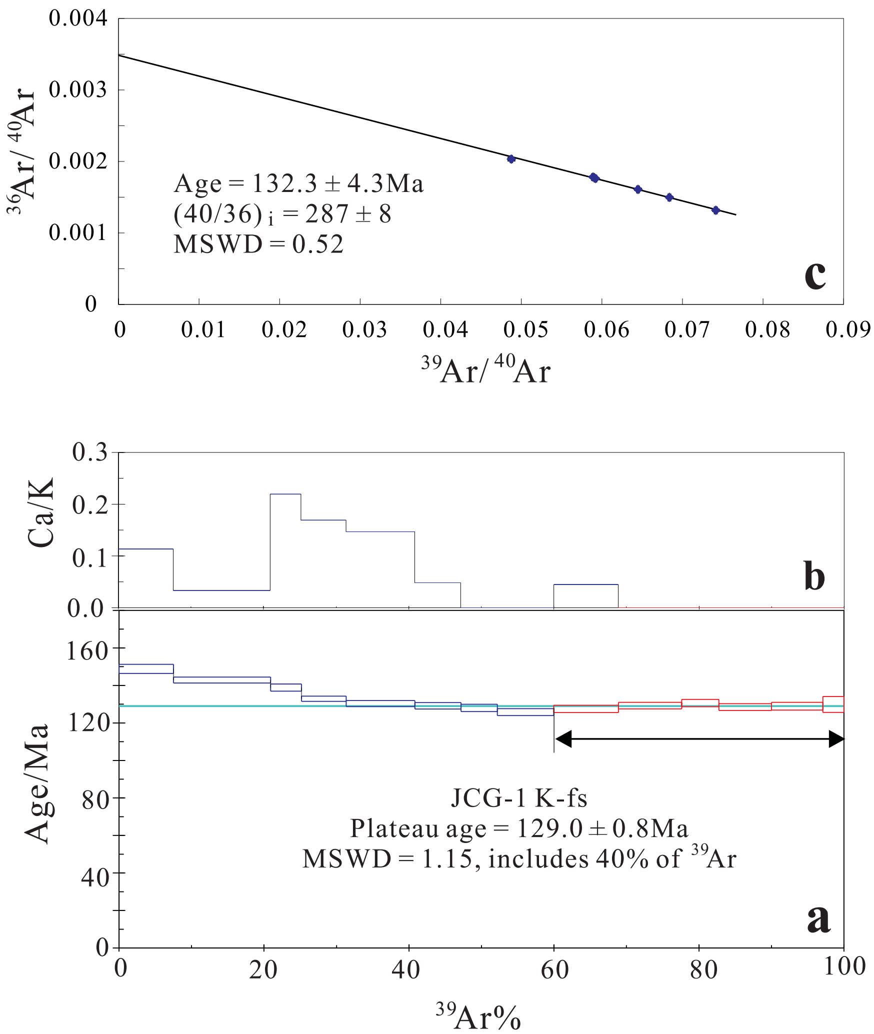

Figure 4. (a) Age spectrum of K-feldspar separate of tuff JCG-1. (b) Ca/K spectrum of K-feldspar separate of tuff JCG-1. (c) Inverse isochron plot of K-feldspar separate of tuff JCG-1.

ing any fit unreliable. No crystals of significantly older age were found that might suggest xenocrystic contamination in tuff JCG-5, and the uniformly high radiogenic ^{40}Ar of all 17 analyses indicates little alteration. Therefore we interpret the weighted mean age (130.7 ± 1.4 Ma; 2σ) as the most objective age estimate of the tuff JCG-5.

5. Discussion and Conclusions

[19] The $^{40}Ar/^{39}Ar$ step heating and single crystal fusion of the K-feldspar from tuffs interbedded in the shales of the Dabeigou Formation at Jiecaigou gave a weighted mean age of 130.7 ± 1.4 Ma, providing the first direct age for the primitive bird-bearing bed in Dabeigou Formation in Fengning, Hebei Province.

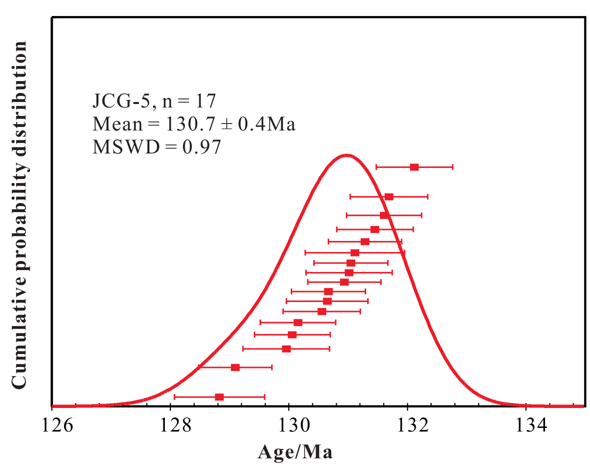

Figure 5. Age probability diagram for single K-feldspar crystal dates of tuff JCG-5.

Table 2. The ^{40}Ar/^{39}Ar Total Fusion Data for K-Feldspar Crystals of Tuff JCG-5[a]

^{39}Ar/^{40}Ar ± 1 s.d. (10^{-2})	^{36}Ar/^{40}Ar ± 1 s.d. (10^{-4})	Ca/K	^{40}Ar (10^{-14} moles)	Number of Grains	^{40}Ar*, %	^{40}Ar*/^{39}Ar ± 1 s.d.	Apparent Age ± 2 s.d.,[b] Ma
13.76 ± 0.04	0.28 ± 0.07	0.03	0.8	1 grain	99.2	7.21 ± 0.03	128.83 ± 1.93
13.52 ± 0.02	0.27 ± 0.09	0.03	0.6	1 grain	99.2	7.33 ± 0.02	131.03 ± 1.90
13.52 ± 0.01	0.11 ± 0.03	0.02	1.8	1 grain	99.7	7.37 ± 0.01	131.62 ± 1.76
13.81 ± 0.01	0.09 ± 0.02	0.04	1.9	1 grain	99.7	7.22 ± 0.01	129.10 ± 1.72
13.60 ± 0.02	0.35 ± 0.02	0.04	2.6	1 grain	99.0	7.28 ± 0.01	130.07 ± 1.76
13.44 ± 0.02	0.30 ± 0.04	0.03	1.0	1 grain	99.1	7.37 ± 0.01	131.70 ± 1.78
13.48 ± 0.02	0.09 ± 0.02	0.03	4.7	1 grain	99.7	7.40 ± 0.01	132.14 ± 1.78
13.58 ± 0.02	0.02 ± 0.01	0.04	10.0	3 grains	100.0	7.36 ± 0.01	131.47 ± 1.77
13.70 ± 0.04	0.11 ± 0.02	0.04	3.7	1 grain	99.7	7.27 ± 0.02	129.96 ± 1.90
13.59 ± 0.06	0.09 ± 0.03	0.03	3.3	1 grain	99.7	7.34 ± 0.03	131.13 ± 2.07
13.66 ± 0.01	0.04 ± 0.00	0.05	17.0	5 grains	99.9	7.31 ± 0.01	130.68 ± 1.74
13.71 ± 0.02	0.04 ± 0.01	0.04	9.6	1 grain	99.9	7.28 ± 0.01	130.16 ± 1.75
13.59 ± 0.01	0.04 ± 0.00	0.04	39.7	8 grains	99.9	7.35 ± 0.00	131.30 ± 1.73
13.63 ± 0.01	0.00 ± 0.00	0.05	17.1	3 grains	100.0	7.34 ± 0.01	131.06 ± 1.74
13.65 ± 0.02	0.09 ± 0.01	0.03	9.7	4 grains	99.7	7.31 ± 0.01	130.57 ± 1.78
13.64 ± 0.03	0.08 ± 0.02	0.02	5.3	1 grain	99.8	7.31 ± 0.02	130.66 ± 1.83
13.61 ± 0.01	0.07 ± 0.01	0.04	9.2	2 grains	99.8	7.33 ± 0.01	130.95 ± 1.73

[a] Seventeen analyses, 36 grains, J = 0.01027 (±0.00005, vertical error).
[b] Analytical error, including horizontal J value error 7E-5.

[20] The Dabeigou Formation is now generally accepted as the earliest horizon of the Jehol Group, and the fossil assemblage from the deposit was considered as representing the earliest stage of the evolution of the Jehol Biota. Therefore the result obtained in this paper, together with the datings of the Yixian and Jiufotang Formations [*Swisher et al.*, 1999, 2002; *He et al.*, 2004] that recorded the majority of evolution of the Jehol Biota, suggests that the Jehol Biota probably first appeared at about 131 Ma, which is late Hauterivian of the middle Early Cretaceous. Although the exact range of the temporal distribution of the Jehol Biota remains to be investigated, we have now at least obtained an approximate or minimum estimate of the duration of the Jehol Biota from late Hauterivian to Aptian or approximately 131–120 Ma in the middle and late Early Cretaceous, which can be regarded as a preliminary and reliable geochronologic framework for understanding the evolutionary radiation of the Jehol Biota.

[21] *Protopteryx* is probably the most important vertebrate fossil known from the Dabeigou Formation. It is generally held as the most primitive representative of the predominant Mesozoic avian group Enantiornithes [*Lacasa Ruiz*, 1989; *Zhang and Zhou*, 2000; *Zhou*, 2004]. The Enantiornithes became extinct by the end of the Late Cretaceous together with non-avain dinosaurs. The earliest age for other known enantiornithiens is 125 Ma from the lower Yixian Formation in western Liaoning Province; therefore the direct dating of the bird-bearing Dabeigou Formation at Jiecaigou has pushed back the history of the Enantiornithes for about 6 Ma.

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