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SIMS zircon U–Pb dating of the Late Cretaceous dinosaur egg-bearing red deposits in the Tiantai Basin, southeastern China

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ABSTRACT

Dinosaur eggs or fragments are abundant and extensively distributed in China. They can be very informative in biostratigraphic division and correlation of continental strata where other fossils are relatively lacking. Despite remarkable discoveries of vertebrate fossils, particularly dinosaur eggs and skeletons from the middle and Late Cretaceous of both northern and southern China, there is hardly any direct evidence for the ages of the vertebrate-bearing terrestrial deposits. To constrain their depositional ages, here we have obtained SIMS U–Pb zircon ages from the tuffs interbedded with dinosaur egg-bearing sediments from the Laijia and Chichengshan formations of the terrestrial red deposits of the Late Cretaceous in the Tiantai Basin, Zhejiang Province, southeastern China. The SIMS zircon U–Pb ages from the Laijia and Chichengshan formations are about 96–99 Ma (Cenomanian) and 91–94 Ma (Turonian), respectively, providing direct time constraints on the vertebrate and dinosaur egg evolution in the Late Cretaceous as well as a basis for correlation with terrestrial Cretaceous deposits in other regions of southern and northern China.

1. Introduction

The middle–Late Cretaceous is an important period in the Mesozoic for vertebrate evolution, particularly for understanding the impact of the greenhouse temperatures in the middle Cretaceous upon their taxonomic diversification, body size and diversity change. Middle and Late Cretaceous terrestrial deposits are well developed in both southern and northern China. Many important taxa of dinosaurs including both complete skeletons and eggs have been reported, some of which bear important paleogeographic and evolutionary significance (Zhao, 1994; Zhao et al., 2009; Li et al., 2009a,b; Xu et al., 2010; Wang et al., 2010b,c, 2012).

In the past years, we have made several excavations in a number of Cretaceous localities in the Tiantai Basin, eastern Zhejiang Province (Fig.1a and b), one of the typical regions of well developed terrestrial Cretaceous deposits in China. Recently, different dinosaur eggs have been reported and biostratigraphic division and correlation of continental strata have been discussed based on these eggs (Fang et al., 2000, 2003; Jin et al., 2007; Qian et al., 2008a,b; Wang et al., 2010b,c, 2011; Zhang, 2010). However, the lack of sufficient and reliable chronostratigraphic data for the Tiantai Group in the region that bears the dinosaur bones and eggs has become a growing predicament for precise correlation between vertebrates-bearing deposits in various basins in eastern Zhejiang as well as with Cretaceous deposits in other regions of China.

In this paper we report the SIMS U–Pb zircon dating results from tuffs interbedded in the fossil-bearing red deposits of the Laijia and Chichengshan formations in Tiantai County, Zhejiang, providing direct ages and a preliminary time frame for studying the vertebrate evolution in the region in the Late Cretaceous (approximately from 99 Ma to 91 Ma).

2. Geologic setting, dinosaur egg fauna and sampling

Zhejiang Province is located in southeast China (Fig. 1a). The region is well known for developing both the Early Cretaceous terrestrial deposits with abundant fossil fishes (Chang and Chow, 1977) and Late Cretaceous deposits that contain dinosaur bones and eggs. They are distributed in many pull-apart basins filled with fluvial

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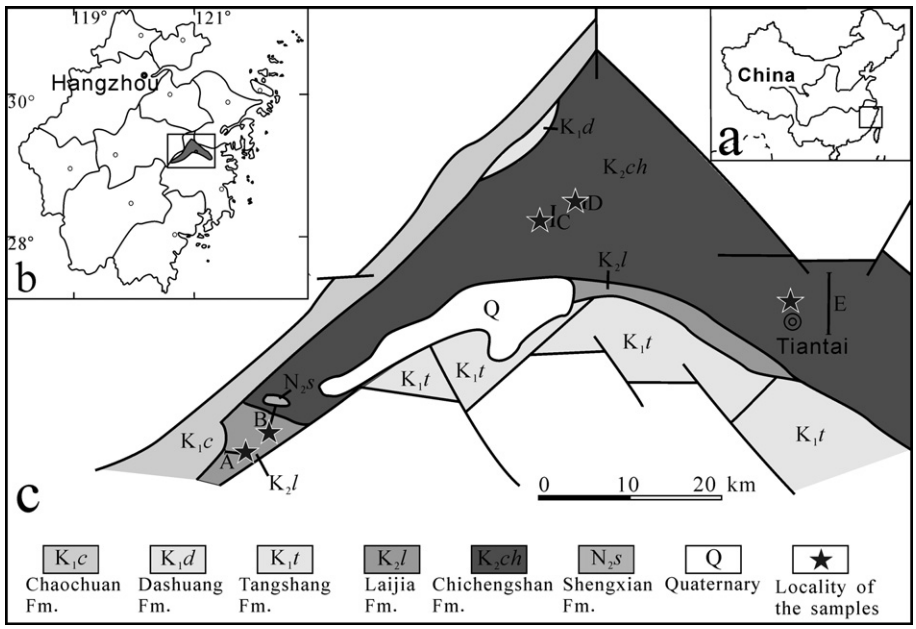

Fig. 1. (a) Sketch map showing the location of Zhejiang province. (b) Sketch map showing the location of Tiantai basin. (c) Mesozoic strata of the Tiantai basin and location of the studied sections (A–E). Modified from Wang et al. (2010c).

and lake sediments commonly with tuffs interbedded in some sections.

The late Mesozoic volcano-sedimentary rock series in eastern Zhejiang consists of the upper and the lower rock series, the former including the Upper Cretaceous Yongkang Group (Yongkang Basin, western Zhejiang), Qujiang Group (Quzhou-Jinhua areas, western Zhejiang) and Tiantai Group (Tiantai Basin, eastern Zhejiang), and the latter including the Lower Cretaceous Jiande Group (Jiande Basin, western Zhejiang) and Moshishan Group (Tiantai Basin, eastern Zhejiang). Previous studies, using K–Ar, Rb–Sr, U–Pb and Ar–Ar methods, of the volcanic rocks combined with biostratigraphic analysis have provided rough age estimates for those groups, e.g., 113–90 Ma for the Yongkang Group (see Luo and Yu, 2004 and references therein), 105–81 Ma for the Qujiang Group (see Yu et al., 2012 and references therein), and 109–94 Ma for the Tiantai Group (see Yu et al., 2010 and references therein). However, analytical procedures and detailed data are absent in the studies. It's thus hard to evaluate the quality of the dates. Recently, Wang et al. (2010a) have dated the feldspars from sediments of the Lower Cretaceous Moshishan Group in eastern Zhejiang Province by Ar–Ar method (single grain laser fusion) and estimated their temporal range to be 118–109 Ma.

The middle Cretaceous deposits in the Tiantai Basin (Fig. 1b and c) in eastern Zhejiang comprise the Tangshang Formation, Laijia Formation and Chichengshan formation from the bottom upwards (Fig. 2). The Laijia Formation comprises red fine sandstones and conglomerates. Most of the dinosaur eggs and bones have been found in the Laijia Formation and the bottom of the Chichengshan formation (Wang, 2010; Wang et al., 2011, 2012). Wang et al. (2010b,c) have recognized at least six layers of tuffs (from ten centimeters to more than 10 m thick, Fig. 2) interbedded within the sandstones. The Chichengshan formation also contains two layers of tuffs (Fig. 2). These tuff layers are conformably interbedded in the sandstones; both the lower and upper contacts of the tuff layers are sharp and planar. Hence, the dating of the tuffs provide a depositional age for the sedimentary layers that bracket the layer.

The dinosaur egg fauna of the Tiantai Basin represents one of the most important oofaunas in China with great diversity and abundance. It currently comprises seven oofamilies, 12 oogenera and 15 oospecies (Wang, 2010; Wang et al., 2010b,c, 2011, 2012; Zhang, 2010). Among them, faveoloolithids and dictyoolithids are most diverse and abundant, including three oofamily, five oogenus and seven oospecies, i.e., Faveoloolithidae (*Parafaveoloolithus*, *Hemifaveoloolithus*), Similifaveoloolithidae (*Similifaveoloolithus*) and Dictyoolithidae (*Dictyoolithus*, *Paradictyoolithus*). The Macroelongatoolithidae is found in the Tiantai Basin of Zhejiang Province and the Xixia Basin of Henan Province in central China, including two oogenus and two oospecies in the Tiantai Basin: *Macroelongatoolithus* and *Megafusoolithus*. In addition, some newly known ootaxa *Paraelongatoolithus* (Elongatoolithidae), *Prismatoolithus* (Prismatoolithidae), *Stalicoolithus* and *Coralloidoolithus* (Stalicoolithidae), and *Mosaioolithus* have also been found in the Tiantai Basin.

The dating samples in this study come from three stratigraphic sections of two formations in the Tiantai Basin, Zhejiang: samples T071201-01, T071201-04 and T071201-05 from the Laijia Formation; and samples T071202-01, T071202-02 and T071203-01 from the Chichengshan formation (Fig. 2). Thin section studies show that there are no significant compositional difference between these samples, and they are composed of slightly altered feldspar (30–40%), quartz (30–40%), altered biotite (10–15%), rock fragments (5–10%) and accessory minerals such as zircon and opaque minerals.

3. Analytical methods

Thin section studies showed that the feldspars in the tuff samples were slightly altered, and not suitable for $^{40}Ar/^{39}Ar$ dating. Thus we separated zircons for SIMS U–Pb dating. The samples were processed by conventional magnetic and density techniques to concentrate non-magnetic, heavy fractions. Zircon grains, together with zircon standard TEMORA 2 were mounted in epoxy which was then polished to section the crystals for analysis. All zircons were documented with transmitted and reflected light micrographs as well as cathodoluminescence (CL) images to reveal their internal structures, and the mount was vacuum-coated with high-purity gold.