



Stable isotopic evidence for climate and basin evolution of the Late Cretaceous Songliao basin, China



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ABSTRACT

Because of the need to understand the links and feedbacks of the carbon cycle during times of global greenhouse conditions numerous studies have focused on the Cretaceous climate. Much of what we know about this warm period in Earth's history comes from the study of ocean sediments recovered from both ocean drill cores and marine sediments exposed at the Earth's surface. In contrast, there are few studies of Cretaceous terrestrial sediments. The Songliao basin located in northeast China offers a unique opportunity to understand Cretaceous paleoclimate of terrestrial settings because it contains a nearly complete record of lacustrine sediments deposited throughout the Cretaceous and there is an active drilling program to recover core from this paleolake. We present carbon, oxygen and strontium isotopic data from ostracods collected from two drill cores (SK-1 (N) and SK-1 (S)) that cover a time interval that extends from the Turonian through the Maastrichtian. These data record robust isotopic trends with numerous carbon and oxygen isotope shifts that are both rapid and long-term. We tentatively interpret this record to reflect changes in both global climate and regional basin evolution. In the Turonian and Coniacian Qingshankou Formation we observe several carbon isotope shifts that appear to be correlative to marine isotopic records based upon timing and magnitude of the isotopic changes. We suggest that the carbon isotope record in the Songliao basin reflect the decrease in carbon isotope ratios following the strong positive excursion at the Cenomanian/Turonian boundary, a positive isotope excursion in the late Turonian, and the negative isotope shift that occurs at the Turonian/Coniacian boundary. Upward in the section, however, the marine and Songliao isotopic records diverge as sediment sources shift from the southwest, east and north to more northerly. Strontium isotopes record the change in source region as they increase markedly between the Coniacian/Santonian Yaojia and Santonian/Campanian Nenjiang Formations. As this is the first isotopic record of the Songliao basin we are cautious about many of our interpretations of these isotopic data. Yet it is clear that with tighter age constraints and focused sampling centered on many of the isotope excursions presented here will allow for a deeper understanding of the terrestrial response to changing climate and the hydrologic response to basin evolution.

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1. Introduction

Decades of ODP and IPOD coring have yielded a robust isotopic proxy record of inferred temperature change in the Cretaceous ocean (Douglas and Savin, 1975; Barrera and Savin, 1999; Fassell and Bralower, 1999; among many others). This record is especially significant because it include periods of extreme global greenhouse climate conditions (Huber et al., 2002), as well as several temporally

restricted times of widespread ocean anoxia (e.g. Arthur et al., 1985; 1987; 1988; Elrick et al., 2009). Cretaceous nonmarine stratigraphic sections are extensively exposed around the world and have yielded, for instance, abundant and excellent reptilian remains, yet there is currently no terrestrial isotopic proxy record even remotely similar in completeness to the Cretaceous marine record.

An ambitious effort is now underway to develop an oxygen and carbon isotopic record for a nearly complete Cretaceous nonmarine section in the Songliao basin of northeastern China (Fig. 1). This basin initiated as a rift basin in Late Jurassic time and persisted as a thermal-cooling sag depression throughout the Cretaceous (Feng et al., 2010) (Fig. 1). As such, it was a persistently subsiding topographic

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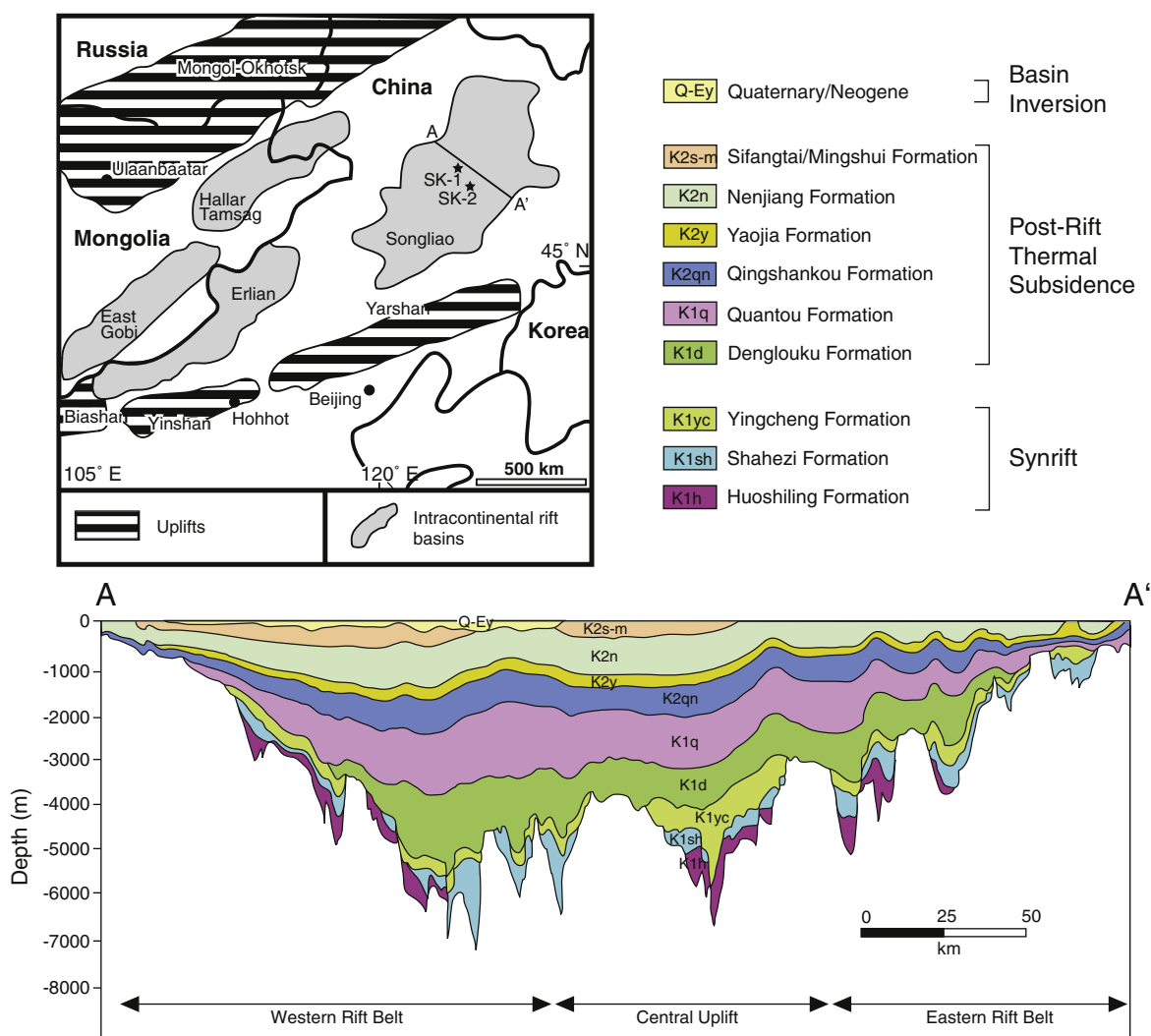


Fig. 1. Location map showing basins and major structures. Shown are the location of the two drill holes used in this study, SK-1 (N) and SK-1 (S). Stratigraphic column for A–A' is modified from Feng et al. (2010).

low spot in which lakes, sometimes quite deep, developed for most of the Cretaceous. Certain of the lacustrine deposits are especially rich in oil-prone organic matter, and as a result, the Songliao basin houses the Daqing oilfield, the largest oil field in China (Zhao et al., 2010). Given this basin history, and the intense drilling and seismic investigation of the basin by the Chinese petroleum industry, it is difficult to imagine a better location for a scientific coring program for a Cretaceous terrestrial climate record.

As a result, a coring program, the “Cretaceous Continental Scientific Drilling Program of China” (the SongKe, or simply SK drilling program), was initiated by the Ministry of Science and Technology of China and Daqing oilfield, which has to-date yielded nearly 2.5 km (2485.9 m) of continuous (>90% recovery) (96.46%) core of Upper Cretaceous nonmarine strata (Feng et al., 2010). The deposits largely reflect lacustrine and palustrine environments, and contain ostracods, which form the focus for our isotopic study.

In this paper, we provide the first reported isotopic results from this extraordinary stratigraphic section, and interpret them in terms of global climatic and regional hydrologic changes. We determined carbon and oxygen isotopes, elemental analyses, and strontium isotopes of ostracod shells from two coreholes. Our results show an incredibly textured and rich isotopic record, some of which can be related to global climate and other portions to basin evolution. Our interpretation of this record is provisional and awaits other geochemical proxies and better age control. Although the interpretations require further testing, in this

paper we show that the Songliao basin holds considerable promise as an archive of Cretaceous terrestrial climate. Specifically, we demonstrate that the carbon isotope records in Turonian and Coniacian sediments Songliao basin seemingly track the corresponding contemporaneous isotopic marine records, whereas the uppermost portion of this section appears to reflect the evolution of the basin itself.

2. Songliao basin

2.1. Geologic setting

At 26×10^4 km² preserved area, the Songliao basin is among the largest basins in China. Feng et al. (2010) recently published a thorough summary of the evolution of stratigraphic filling patterns and paleogeographic evolution of the basin, and we draw heavily on this excellent source for this discussion of the context for the cores we studied. The basin is especially well known, since it has been penetrated by 3000 petroleum exploration and exploitation boreholes and saturated by more than 10,000 km² of 3-D seismic reflection volumes and 130,000 km of 2-D seismic reflection profiles (Feng et al., 2010). Such exploratory efforts yielded the discovery of the super giant Daqing oilfield in 1959, which has already produced 2.1 billion tons of oil (Zhao et al., 2010).

The basin initiated with rifting and associated extensive volcanism in the Middle to Late Jurassic. Some geochemical studies tend to suggest

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