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Late Cretaceous climate changes recorded in Eastern Asian lacustrine deposits and North American Epieric sea strata

Chengshan Wang [a,f,*], Robert W. Scott [b,g,**], Xiaoqiao Wan [a,f], Stephan A. Graham [c], Yongjian Huang [a,f], Pujun Wang [d], Huaichun Wu [a,f], Walter E. Dean [e], Laiming Zhang [a,f]

[a] State Key Laboratory of Biogeology and Environmental Geology, China University of Geosciences, Beijing 100083, China
[b] Department of Geosciences, University of Tulsa, Tulsa, OK 74104, USA
[c] Department of Geological and Envrironmental Sciences, Stanford University, 397 Panama Mall, CA 94305, USA
[d] College of Earth Sciences, Jilin University, Changchun 130061,China
[e] U.S. Geological Survey, P.O. Box 25046, MS 980, Denver, CO 80225-0046, USA
[f] School of the Earth Science and Resources, China University of Geosciences, Beijing 100083, China
[g] Precision Stratigraphy Associates, Tulsa, OK 74104, USA

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A B S T R A C T

Cretaceous climate data of the long-lived Cretaceous Songliao Basin (SB) in eastern Asia is correlated and compared with the Western Interior Seaway (WIS) on the northern American plate, in order to understand better the dynamics of the Earth's past 'greenhouse' climates. Nearly continuous Late Cretaceous terrestrial deposition in the Songliao Basin is represented by two cores totaling 2431 m in length. The Turonian–Maastrichtian age of the section is based on integrated stratigraphy, and is comparable in age with Upper Cretaceous strata in the WIS. Being consistent with global trends, the dynamic Late Cretaceous climates of both the SB and WIS gradually cooled from the warmest Albian–Cenomanian time to the end of the Maastrichtian with several intervening warm periods as did the global climate. However regional differences existed, the Songliao Basin climate was humid to semi-humid, warm temperate–subtropical and the Western Interior Seaway was in the humid, warm temperate zone and experienced only moderate climatic changes. The shifts of oxygen isotope data in the Songliao Basin were frequent and abrupt, whereas WIS records more gradual change affected mainly by fresh-water runoff mixing with southern Tethyan and northern Arctic waters. Sedimentary cycles of eccentricity, obliquity and precession bands are recorded in both the SB and WIS basins. The sedimentary cycles in the WIS and SB are interpreted to be related to variations of the wet/dry runoff cycles, which indicate that orbital forcing played an important role in global climate change in Late Cretaceous. The most favorable condition for organic carbon burial in both the SB and WIS basin was bottom water anoxia regardless of the cause of the anoxia. But the organic carbon burial rate was usually much higher in the Songliao Lake than in the WI epeiric sea suggesting that giant lakes may serve as important sinks of atmospheric CO_2. In both basins organic-rich deposits formed during a rise in water level and incursion of saline waters. The integration of paleoclimate data from Cretaceous marine deposits and terrestrial sedimentary record will promote our understanding of the Cretaceous 'greenhouse' climate change and may provide insights for a future greenhouse world.

Contents

* Corresponding author. Tel.: +86 10 8232 1612; fax: +86 10 8232 2171.
** Corresponding author. Tel.: +1 918 243 5418; fax: +1 918 631 2091.
E-mail addresses: chshwang@cugb.edu.cn (C. Wang), rwscott@cimtel.net (R.W. Scott).

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1. Introduction

Throughout its long geological history, the Earth has had two fundamentally different climate states—a cool 'icehouse' state characterized by high latitude ice sheets and a 'greenhouse' state characterized by much warmer global temperatures and only small or no ice sheets. For most of the past 600 million years of geological time climate has fluctuated between a warmer greenhouse state and icehouse state (NRC, 2011). Intervals of warmer global temperatures are of great interest, as they may provide analogs for a future greenhouse world. Paleotemperature estimates (Huber et al., 1995; Barrera and Savin, 1999; Cramer et al., 2009; Friedrich et al., 2012) from a variety of geochemical proxies indicate that Cretaceous time was one of the classic "greenhouse states" of the Earth (Skelton et al., 2003). During this 80 myr interval atmospheric and oceanic temperatures varied over a wide range and carbon dioxide content changed drastically in both marine and atmospheric reservoirs. The N-S temperature gradient was lower than today and surface wind patterns and ocean circulation probably were quite different from the modern oceans (Hay, 2009; Trabucho Alexandre et al., 2010; Flögel et al., 2011a,b; Wagner et al., 2013). Cretaceous sea levels varied at amplitudes of tens of meters (Miller et al., 2005) and flooded about one-third of the continental areas creating extensive seaways (Ronov et al., 1989; Ronov, 1994).

Oxygen isotopes of marine fossils record the paleotemperature history of the ocean, indicating a cool greenhouse during the Early Cretaceous, warm greenhouse during the middle Cretaceous, and cold greenhouse during the Late Cretaceous (Huber et al., 1995; Barrera and Savin, 1999; Cramer et al., 2009; Friedrich et al., 2012). During the Early and Late Cretaceous the Polar Regions were cool temperate, whereas in the middle Cretaceous the North Polar Region was warm temperate. In contrast, brief glacial episodes have been proposed based on timing and range of sea-level fluctuations (Stoll and Schrag, 2000; Miller et al., 2010), although sedimentologic evidence is inconclusive (Ando et al., 2009). Late Cretaceous paleoclimate is mainly constrained by global-scale ocean current modeling and paleoclimate reconstruction (Pucéat et al., 2005; Haggart et al., 2006; Boucot et al., 2009), by global vegetation simulation (Otto-Bliesner and Upchurch, 1997; Upchurch et al., 1998; Donnadieu et al., 2009; Fricke et al., 2010). Much of our knowledge of the late Cretaceous paleotemperatures has come from marine records (Huber et al., 1995; Barrera and Savin, 1999; Cramer et al., 2009; Friedrich et al., 2012). The terrestrial paleoclimate records are few and the comparison and correlation between marine and terrestrial paleoclimate records are even fewer. A robust comparison among terrestrial and marine records may provide insight into possible similarities and differences in their paleoenvironment and paleoclimate, and help us test ocean-land climate interactions. Additional details on the spatial distribution of paleotemperatures will further resolve the late Cretaceous paleoclimate.

To understand the Cretaceous 'greenhouse' climate, data on magnitudes, rates, and impacts of hydrosphere/atmosphere records, and marine deposits must be integrated with terrestrial sedimentary rocks and fossils. Under the umbrella of International Geosciences Programme (IGCP) 555, the integration of Cretaceous climate data can be achieved by correlating and comparing the long-lived Cretaceous Songliao Basin (SB) in eastern Asia with the Western Interior Seaway (WIS) on the North American plate. The Western Interior Seaway spanned the North American continent dividing it into two landmasses and records Cenomanian to Maastrichtian marine deposition. The Songliao Basin is located on one of the largest landmasses of this period (Fig. 1). A unique, 2400 meter-long core taken by the SKI drilling program (Wang et al., 2008, 2013) recovered the Turonian to Maastrichtian terrestrial record in the SB; it forms the basis for this correlation. Both basins contain significant stratigraphic accumulations and were located within comparable latitudinal ranges (middle latitudes climate zone of the Northern Hemisphere) during the Cretaceous (Fig. 1). Paleomagnetic data show that they were located at middle latitudes similar to where they are now (see Section 2 of this paper). Consequently, correlation and comparison of the continental Songliao Basin with the marine Western Interior Seaway provide an excellent opportunity to study Late Cretaceous climate changes.

In this paper, we review and compare these two important Late Cretaceous basins of East Asia and western North America on opposite sides of the proto-Pacific Ocean and identify similarities and differences in paleoclimate and paleogeographic changes of both regions. This investigation advances understanding of climate change in the Cretaceous greenhouse world, and its relationship to geological events relevant to carbon cycles. It also addresses important problems, such as the identification and timing of important stratigraphic boundaries and the correlation of marine strata with terrestrial strata. Furthermore, this comparison may provide insights for future greenhouse worlds.

2. Late Cretaceous tectonic and paleogeographic settings

During the Late Cretaceous a significant part of the globe was occupied by the proto-Pacific Ocean, which was rimmed by active arc complexes much like today (Fig. 2a). The resultant topography influenced climate and paleoenvironments of adjacent landmasses. In the East Asian region extensive non-marine, rift and back-arc basins and overall low topographic relief were likely related to ongoing subduction to