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Discovery of Late Cretaceous foraminifera in the Songliao Basin: Evidence from SK-1 and implications for identifying seawater incursions

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The Songliao Basin is the largest oil-bearing basin in China. In the absence of sufficient evidence, the possibility of seawater incursion(s) into the Songliao Basin remains controversial. Recently, we discovered relatively abundant foraminifera fossils from units 1 and 2 of the Nenjiang Formation of borehole SK-1. Benthic foraminifera (*Gavlinella* sp., *Anomalinoides* sp., *Pullenia* sp., *Haplophragmoides* sp., *Karrorulina hokkaidoana*, *Clavulinoides* sp.), as well as planktonic foraminifera (*Archaeoglobigerina blowi*, *Archaeoglobigerina cretacea* and *Hedbergella flandrini*), were identified. These fossils were widely distributed in the marine Cretaceous. According to the global distribution of the above-mentioned planktonic foraminifera, the age of these fossil bearing strata appears to be Late Coniacian to Santonian. More importantly, these foraminifera provide direct evidence for marine water incursions into the Songliao Basin during deposition of the Lower Nenjiang Formation.

foraminifera, seawater incursion, Songliao Basin, SK-1, Nenjiang Formation, Cretaceous

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The Songliao Basin, in northeast China, is one of the largest Cretaceous continental rift basins in the world. Two lake transgressions occurred during sedimentation of the Lower Qingshankou and Lower Nenjiang formations, depositing a suite of dark mudstone, black shale and oil shale [1,2]. The possibility of seawater incursions into the Songliao Basin has been debated for more than thirty years [3–14]. Recently, based on bivalves fossils and other evidence, Sha [15] also concluded the possible existence of seawater incursion events in the Songliao Basin. Until now, fossil evidence supporting the hypothesis of seawater incursion has included brackish water fish, bivalves, dinoflagellates and calcareous nannofossils, which may have been associated with seawater, as well as a lack of typical marine fossils. In addition, it is difficult to use geochemical parameters to distinguish non-marine and marine environments. As a result, the presence of any marine water incursions was doubted [10,11]. Although microfossils in the Songliao Basin have been studied in detail [7,16,17], no foraminifera were discovered previously. Being the most important and widely distributed microfossils in the marine environment during and since the Late Cretaceous, foraminifera have become extremely useful in terms of biostratigraphy, paleoenvironmental reconstruction and in recognition of seawater incursion events.

This report presents the first record of foraminifera in Late Cretaceous age sediments of the Songliao Basin. This discovery will help us to better understand seawater incursion events, paleoenvironment and the formation of hydrocarbon source rocks in this basin. In this paper, we report a

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preliminary study of foraminifera, providing direct evidence for seawater incursion into the Songliao Basin.

1 Methods and materials

The China Cretaceous Continental Scientific Drilling Program-Songke 1 (south) borehole (SK-1(s)) is located in the central part of the Songliao Basin (Figure 1). The length of the core is 959.55 m, covering the strata of unit 3 of the Quantou Formation to unit 2 of the Nengjiang Formation [18]. Units 1 and 2 of the Nenjiang Formation (968.17 to 1128.17 m) consist mainly of dark mudstones, intercalated with thin carbonate layers, black shales and oil shales.

Samples for microfossil processing were collected at 1-m intervals, on average. Samples of 100 g dry weight sediments were dispersed in deionised water for several weeks prior to sieving through a 200 μm sieve. Foraminifera were picked from the samples under a low-powered binocular microscope, and subsequently stored in micro-paleontological specimen slides. Scanning Electron Microscope (SEM) images of foraminifera were taken at the China University of Geosciences (Beijing).

2 Composition and characteristics of foraminafera

Hundreds of foraminifera tests were picked from the samples, but only relatively well preserved fossils were identified in this study. The cored sediments contained 9 species in 8 genera. Benthic calcareous foraminifera (*Gavlinella* sp., *Anomalinoides* sp., *Pullenia* sp.), benthic agglutinated foraminifera (*Haplophragmoides* sp., *Karrorulina hokkaidoana*, *Clavulinoides* sp.), and planktonic foraminifera (*Archaeoglobigerina blowi*, *Archaeoglobigerina cretacea* and *Hedbergella flandrini*) were identified (Figure 2). The main characteristics of the foraminifera were (1) Foraminiferal tests were 0.2–0.5 mm in size, and a few agglutinated shells were up to 1 mm. Most of the foraminifera were calcareous, with only a small portion preserved as agglutinated tests. Furthermore, there were many planktonic foraminifera specimens. (2) Most of the foraminiferal tests were well preserved, with some pressed flat. In addition to agglutinated tests and a few calcareous tests, the other foraminifera were brownish in color. (3) Abundances of foraminifera were relatively high, with more than 100 tests/100 g in some samples. The diversity of foraminifera was moderate, including benthic calcareous foraminifera, agglutinated foraminifera and planktonic foraminifera. (4) Foraminiferal fauna in the Songliao Basin were similar to those of typical marine species. (5) The foraminifera fossils occurred separately in several layers of units 1 and 2 of the Nenjiang Formation.

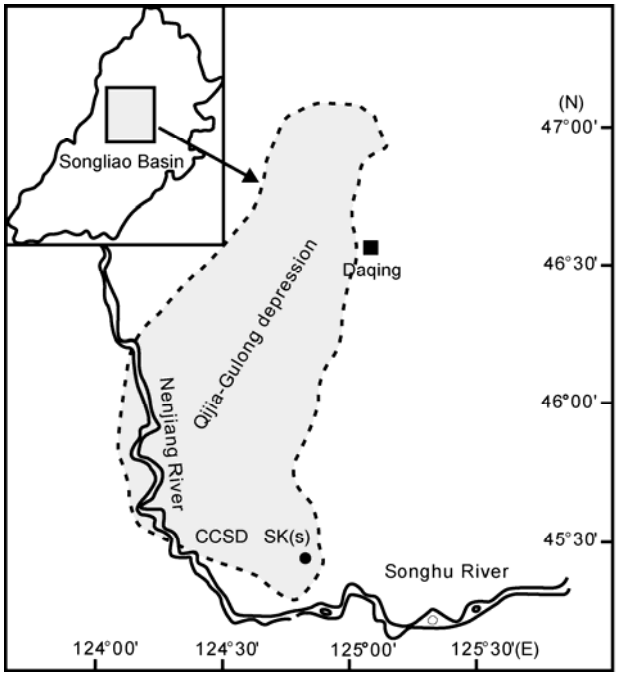

Figure 1 Sketch map showing the study area in the Songliao Basin.

3 Age of planktonic foraminifera

Planktonic foraminifera (*Archaeoglobigerina blow*, *Archaeoglobigerina cretacea* and *Hedbergella flandrini*) were discovered and constrain the age of lower unit 1 of the Nenjiang Formation. *Archaeoglobigerina blowi* ranges from the late Coniacian to Maastrichtian, *Archaeoglobigerina cretacea* from Coniacian to Maastrichtian, and *Hedbergella flandrini* from late Turonian to Santonian [19]. Benthic foraminifera found in the Songliao Basin were widely distributed regionally in Upper Cretaceous strata [20]. According to the global distribution of the above mentioned planktonic foraminifera, the lower unit 1 of the Nenjiang Formation appears to be late Coniacian to Santonian in age.

4 Paleoenvironmental significance

Foraminifera are marine organisms, although a few benthic foraminifera have been reported from brackish or saline lakes [21–26]. Brackish and saline lake settings normally have limited foraminiferal representatives, such as *Nonion*, and are characterized by lower specimen diversities, individuals with abnormal tests and absence of planktonic foraminifera [24]. Planktonic foraminifera are indicators of normal marine facies. Foraminifera in the Songliao basin represent various types, especially planktonic foraminifera. These species were distributed worldwide in marine Cretaceous sediments [19]. Almost all of the planktonic and benthic foraminifera are known from the northwest Pacific

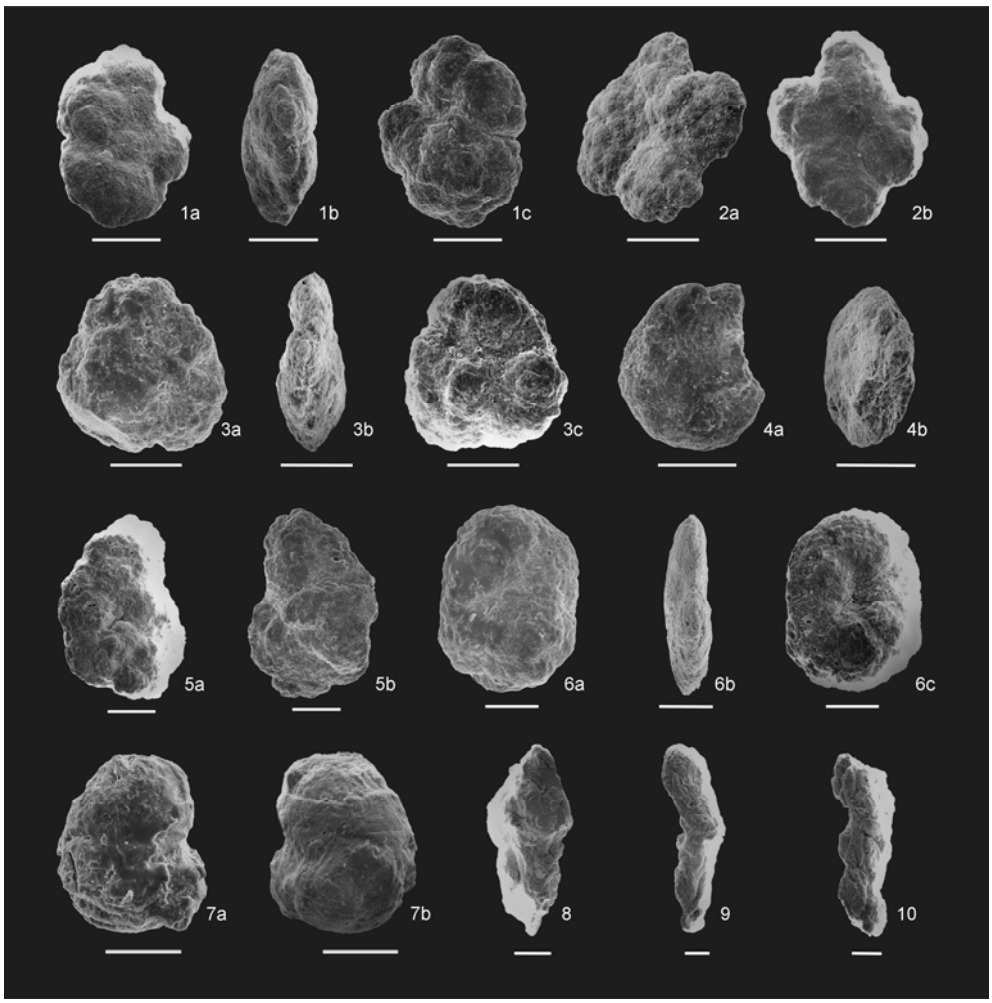

Figure 2 SEM photomicrographs of foraminifera from SK-1(s). The scale bar for all species is 200 μm. All species were deposited in the China University of Geosciences (Beijing). (1) *Archaeoglobigerina cretacea* d'Orbigny 1a, dorsal view; 1b, side view; 1c, ventral view. m222. (2) *Hedbergella flandrini* Porthault 2a, dorsal view; 2b, ventral view. m222. (3) *Archaeoglobigerina blowi* Pessagno 3a, dorsal view; 3b, side view; 3c, ventral view. m222. (4) *Gavlinella* sp. 4a, dorsal view; 4b, side view. m179. (5) *Anomalinoides* sp. 5a, dorsal view; 5b, side view. m169. (6) *Haplophragmoides* sp. 6a, dorsal view; 6b, side view; 6c, ventral view. m802. (7) *Pullenia* sp. 7a, ventral view; 7b, dorsal view. m810. (8) *Clavulinoides* sp. side view. m911. (9) *Karrorulina hokkaidoana* Takayanagi. side view. m913. (10) *Karrorulina hokkaidoana* Takayanagi. side view. m913.

[20,27]. Thus, the Songliao Basin was likely a near-shore continental basin with a relatively abundant and diverse foraminiferal fauna, but which were not continuous in their vertical distributions. This information supports the notion that these foraminifera came into the basin with marine water intrusions. Large lake transgressions occurred in the Songliao Basin during deposition of the Lower Nenjiang Formation. As a result, the lake level rose and its area enlarged [28]. At the same time, sea level also was higher. The ocean was not far away from the eastern margin of the Songliao Basin, and the paleo-Songliao lake was connected to the northwest Pacific periodically during phases of exceptionally high lake water and seawater levels.

The present work is a preliminary report on foraminifera in the Songliao Basin. An in-depth study of foraminifera containing other data will be presented in a future report along with a comprehensive explanation of seawater incursion events and paleoenvironmental change.

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