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Progress on Continental Scientific Drilling Project of Cretaceous Songliao Basin (SK-1 and SK-2)

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Scientific drilling is a significant exploration tool to better understand earth's environmental and biological evolution, physical composition and structure, and natural resources and geohazards, through directly sampling on subsurface rock, fluid, living organisms and long-term monitoring of on-going deep processes. It plays a critical role in deciphering earth system dynamics and in solving socio-economic problems currently facing by humans. Scientific drilling in modern earth science originated from Project Mohole, supported by National Science Foundation, USA in 1958, which was an ambitious attempt to retrieve material from the earth's mantle by drilling a hole through the earth's crust to the Mohorovicic Discontinuity. Although failed in its intended purpose, this project started a successful and fruitful series of oceanic scientific drillings, from Deep Sea Drilling Project (DSDP, 1966–1983), to Ocean Drilling Program (ODP, 1983–2003), and to the most recent Integrated Ocean Drilling Program or International Ocean Discovery Program (IODP, 2003 till now) [1].

Corresponding to the oceanic drillings, from 1970 to 1989 the Soviet Union conducted a deep scientific drilling project on land, namely the Kola Superdeep Borehole, located in the Pechengsky District on the Kola Peninsula, which holds the deepest record of scientific boreholes on Earth – 12,262 m. Following Kola borehole, the Federal Ministry of Research funded the German Continental Deep Drilling Program, which was carried out from 1987 to 1995 and reached a depth of 9,101 m. These drilling activities on land promoted the foundation of International Continental Scientific Drilling Program (ICDP), jointly set up by Germany, the USA and China in 1996 [2].

Since its foundation 22 years ago, ICDP has expanded to its current participation of over 30 member countries and organizations. More than 50 scientific drilling projects have been approved under three themes (climate and ecosystems, sustainable georesources, natural hazards) and seven topics (paleoclimate, deep life, impact structures, volcanoes, element cycles, plate margins, faults), among which half of the projects focus on paleoclimate studies (Fig. 1) [2].

Two ICDP scientific drilling projects have been completed in China's mainland: the Chinese Continental Scientific Drilling project in Donghai County, Jiangsu Province, and the Lake Qinghai Scientific Drilling Project [3,4].

The "Continental Scientific Drilling Project of Cretaceous Songliao Basin (SK): Continuous High-resolution Terrestrial Archives and Greenhouse Climate Change" is the third ICDP project in China's mainland, and the first to obtain a complete, continuous, terrestrial sedimentary record of the whole Cretaceous in the world [5,6]. This project has four basic scientific objectives: (1) to precisely define terrestrial stratigraphic boundaries (e.g., Jurassic-Cretaceous boundary, Cretaceous-Paleogene boundary) and make it possible to correlate the Cretaceous stratigraphy between marine and terrestrial sequences; (2) to study biotic response to terrestrial environmental change and the deep biosphere; (3) to understand terrestrial response to oceanic anoxic events and formation of massive terrestrial hydrocarbon source rocks; and (4) to decipher the geodynamics of deep earth during the Cretaceous Normal Superchron.

The SK project consists of two phases. Phase one, the SK-1 project, includes drilling and coring of early Paleogene to Late Cretaceous strata in two boreholes (north and south holes) that can be correlated through a regional marker bed of black shale (Fig. 2) [5]. Drilling depths of 1,811.18 and 1,915.00 m were achieved, rock cores of 2,485.89 m in total length were recovered and the recovery ratio reached 96.46%. A series of drilling and coring technologies including regular, confined, directional, and sealed coring, were utilized to ensure a high recovery ratio for the core, and specifically designed core handling procedures, e.g., splitting the core into 2/3 sampling part and 1/3 archive part and polishing, were utilized to make sure of long-term core preservation and research. Phase two, the SK-2 project, including drilling through the whole Cretaceous strata and coring of Early Cretaceous strata and early Mesozoic to Paleozoic basement of the Songliao Basin, started in 2014. This phase also consists of two boreholes, the east hole and the west hole (Fig. 2). In May of 2018, the SK-2 east hole completed drilling with a depth of 7018.00 m, a coring footage of 4,279.73 m, a total core length

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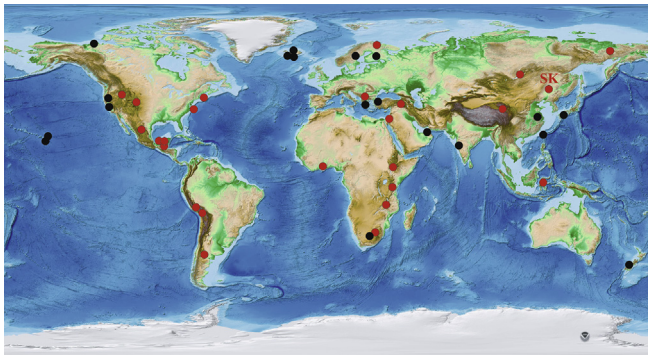

Fig. 1. Global distribution of completed and ongoing ICDP projects. Red dots represent scientific drilling projects under paleoclimate topic, whereas black dots represent projects under other topics. SK represents Continental Scientific Drilling Project of Cretaceous Songliao Basin (SK-1 and SK-2). Data source is from https://www.icdp-online.org/.

of 4,134.81 m, and a recovery ratio of 96.61% [7]. Multiple remarkable engineering records have been created, including the deepest borehole in ICDP history and in Asia (7,018 m), the longest continuous coring at φ311 mm in the world (1,651 m), the longest coring footage at φ216 mm in the world (41.69 m), and more than 30 m footage per roundtrip at φ311 mm, φ216 mm and φ152 mm, etc. [7]. Comprehensive geophysical logging was run throughout the SK-2 east hole, and the bottom hole temperature was measured as 241 °C, the highest temperature record of logging operations so far in China. Considering this high temperature, a formate-polymer water-based mud system was developed and applied in the SK-2 east hole, which is the first time that the water-based mud is operated at the working temperature higher than 240 °C in China [7]. Drilling and coring on SK-2 west hole is still in preparation. Overall, the SK project consists of two phases, four boreholes, and is expected to obtain more than 10,000 m long cores covering the whole Cretaceous period (Fig. 2).

After ten years' scientific research on SK cores, multidisciplinary research progress has been achieved based upon massive geological datasets. Chronological frameworks have been precisely established for SK-1 cores through integrated biostratigraphy, magnetostratigraphy, cyclostratigraphy and radiometric geochronology, whereas similar methods have been applied for SK-2 east hole studies. For SK-1, the age of terrestrial deposits is late Turonian to early Paleocene, spanning 27.4 Ma (missing 3.8 Ma), with a resolution better than 100 ka [8,9]. Current radiometric dating reveals a late Albian age for upper SK-2 east core and a middle Triassic age for volcanic-sedimentary strata in the basement of Songliao Basin, although geochronological efforts are still undergoing. Terrestrial climatic changes in Late Cretaceous at different time scales have been proved by multiple paleoclimatic proxies, which demonstrates that mid-latitude terrestrial climate is sensitive to global climate in a greenhouse world [10–12]. Sea water incursion events were identified when the paleo-Songliao lake expanded to maximum lake level and area [13,14]. Organic-rich deposits formed during rising lake levels and sea water incursion, which promoted bottom water anoxia as the most favorable condition for organic carbon burial [10].

Conflict of interest

The authors declare that they have no conflict of interest.

Acknowledgments

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.scib.2018.12.017.

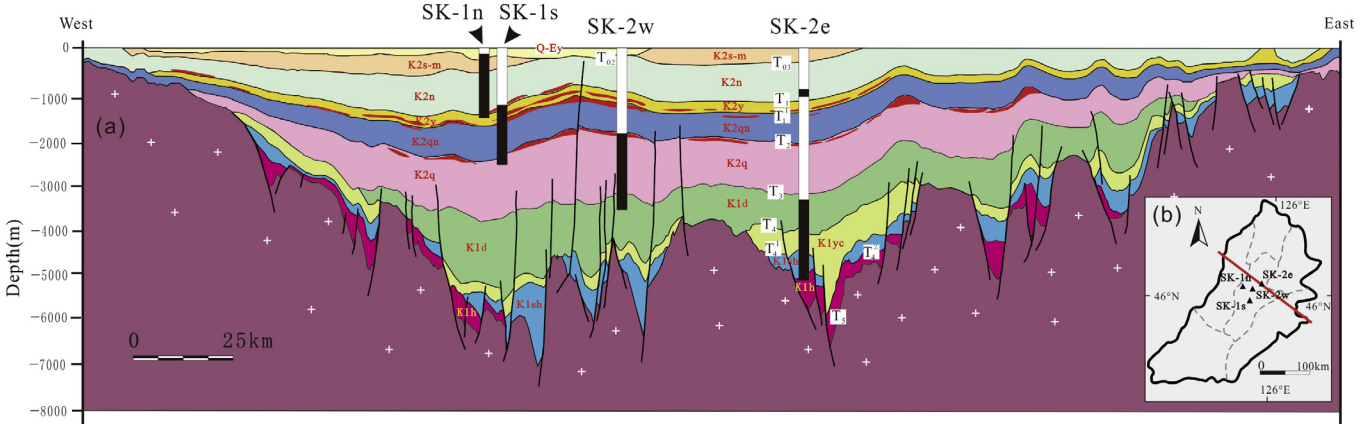


Fig. 2. Distribution of SK-1 and SK-2 scientific boreholes. (a) Structural cross section across the central part of the Songliao Basin and vertical projection of SK boreholes. Lithologies and formations derived from geophysical logs and cores tied to seismic sections. Q-Ey, Quaternary/Neogene; K2s-m, Sifangtai Formation and Mingshui Formation; K2n, Nenjiang Formation; K2y, Yaojia Formation; K2qn, Qingshankou Formation; K2q, Quantou Formation; K1d, Denglouku Formation; K1yc, Yingcheng Formation; K1sh, Shahezi Formation; K1h, Houshigou Formation. T03-5, seismic horizons. The red regions indicate oil reservoirs. SK-1n, SK-1 north borehole; SK-1s, SK-1 south borehole; SK-2w, SK-2 west borehole; SK-2e, SK-2 east borehole. The black bars in SK-1n, SK-1s, SK-2w and SK-2e are coring intervals and the white bars are un-cored intervals. (b) Outline of the Songliao Basin and drilling sites of SK boreholes. The red line indicates position of cross section in (a). Modified after Ref. [6].

References

[1] Bickle M, Arculus R, Barrett P, editors. Illuminating Earth's Past, Present, and Future – The Science Plan for International Ocean Discovery Program 2013–2023. The International Ocean Discovery Program; 2011.

[2] Horsfield B, Knebel C, Ludden J, editors. Unravelling the Workings of Planet Earth. Potsdam: International Continental Scientific Drilling Program; 2014. https://doi.org/10.2312/icdp.2014.001.

[3] Xu ZQ. The scientific goals and investigation progresses of the Chinese continental scientific drilling project. Acta Petrol Sin 2004;20:1–8.

[4] An ZS, Ai L, Song YG, et al. Lake Qinghai scientific drilling project. Sci Drill 2006;1:20–2.

[5] Feng Z, Wang C, Graham S, et al. Continental scientific drilling project of cretaceous Songliao basin: scientific objectives and drilling technology. Palaeogeogr Palaeoclimatol Palaeoecol 2013;385:6–16.

[6] Wang C, Feng Z, Wang P, et al. Initial report of continental scientific drilling project of the cretaceous Songliao Basin (SK1). Beijing: Science Press; 2016.

[7] Zhu YY, Wang WS, Wang XM, et al. Main technical innovations of Songke well No. 2 drilling project. China Geol 2018;1:187–201.

[8] Wan X, Zhao J, Scott RW, et al. Late cretaceous stratigraphy, Songliao basin, NE China: SK1 cores. Palaeogeogr Palaeoclimatol Palaeoecol 2013;385:31–43.

[9] Wang T, Ramezani J, Wang C, et al. High-precision U-Pb geochronologic constraints on the Late Cretaceous terrestrial cyclostratigraphy and geomagnetic polarity from the Songliao Basin Northeast China. Earth Planet Sci Lett 2016;446:37–44.

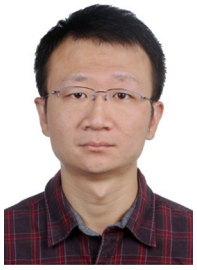
[10] Wang C, Scott RW, Wan X, et al. Late cretaceous climate changes recorded in Eastern Asian lacustrine deposits and North American epieric sea strata. Earth Sci Rev 2013;126:275–99.

[11] Gao Y, Ibarra DE, Wang C, et al. Mid-latitude terrestrial climate of East Asia linked to global climate in the Late Cretaceous. Geology 2015;43:287–90.

[12] Zhang L, Wang C, Wignall PB, et al. Deccan volcanism caused coupled pCO_2 and terrestrial temperature rises, and pre-impact extinctions in northern China. Geology 2018;46:271–4.

[13] Hu JF, Peng PA, Liu MY, et al. Seawater incursion events in a Cretaceous paleo-lake revealed by specific marine biological markers. Sci Rep 2015;5:9508.

[14] Xi D, Cao W, Huang Q, et al. Late Cretaceous marine fossils and seawater incursion events in the Songliao Basin NE China. Cretaceous Res 2016;62:172–82.



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