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Initial Report of Continental Scientific Drilling Project of the Cretaceous Songliao Basin (SK-1)

Wang Chengshan Feng Zhiqiang Wang Pujun Stephan A. Graham *et al.*

Science Press
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Foreword 1

The exploration of the universe, of the earth's interior and of the oceans are three great endeavors of humanity challenging nature in order to improve living conditions for humans. Scientific drilling is a significant exploration tools in current earth science research. We can directly observe the lithosphere which we know little about and obtain the rock record from its deeper parts through scientific drilling programs. Drilling provides important information about natural resources, disaster prediction and a variety of environmental problems currently facing by modern human society. Therefore, scientific drilling can be thought of as a telescope for us to look into the depths of the earth and far back into the past, in order to better understand earth evolution. Plate tectonics theory that developed in the middle of the 20th century is the result of a revolution in earth science based on ocean scientific drilling. Ocean scientific drilling currently has entered the third stage, Integrated Ocean Drilling Program (IODP), the previous stages being the Deep Sea Drilling Project (DSDP) and Ocean Drilling Program (ODP), with the former initiated in the early 1960s.

Humans aspire to better understand the evolution history of the earth's continents which have complex interactions with the oceans, climate and life on earth, by employing continental scientific drilling as one of the principal tools. To achieve such an objective, Germany, the United States and China set up jointly in February 1996 the International Continental Scientific Drilling Program (ICDP). Presently, about twenty states and member organizations participate in the ICDP. The Ministry of Science and Technology of China has sent delegates to represent the Chinese government as councilors of the Assembly of Governors (AOG) in the ICDP, to assist in policy formulation and important decision making.

Since the implementation of the ICDP, many continental scientific drilling projects have been completed. As a result, discoveries have been made in five key research themes: the physical and chemical processes responsible for earthquakes and volcanic eruptions; the manner in which the earth's climate has changed in the recent and deep past and the reasons for such changes; the effects of major impacts on climate and mass extinctions; how sedimentary basins and hydrocarbon resources originate and evolve; how ore deposits are formed in diverse geologic settings. Two ICDP scientific drilling projects have been completed in China, including the Chinese Continental Scientific Drilling (CCSD) project in Donghai County, Jiangsu Province, and the Lake Qinghai Scientific Drilling Project.

Another ambitious scientific drilling project currently in progress is the Continental Scientific Drilling Project of the Cretaceous Songliao Basin (SK-1) in the Daqing oil field, which represents

the largest known oil field in China. The SK-1 drilling process was completed in 2007. This project is supported by the National Basic Research Program of China (973 Program) "Integrated Study on the Cretaceous Major Geological Events and Greenhouse Climate Change", jointly sponsored by the National Ministry of Science and Technology of China and the Daqing Oilfield Company Ltd., and organized by China University of Geosciences, Beijing (CUGB), and the Daqing Oilfield Company Ltd. The Continental Scientific Drilling Project of the Cretaceous Songliao Basin has two major objectives: one is to correlate the oceanic and continental records and determine the principal drivers of climate change in order to assist in future climate change predictions and its influence on the earth's environment; the other is to further test the theory of terrestrial genesis of hydrocarbons, and to explore the formation of intra-continental sedimentary basins, as many are major hydrocarbon provinces. In addition, this project provides the scientific basis for exploration of the Daqing Oilfields, with a yearly production of forty million tons of oil.

In order to share the original data and preliminary scientific results of the SK-1 project with international geoscientists, similarly to the success of the ocean drilling programs, the SK-1 preliminary results are presented here in "Initial Reports of Continental Scientific Drilling Project of the Cretaceous Songliao Basin (SK-1)".

During the writing and publishing of this book, we were delighted to learn that the "Continental Scientific Drilling Project of the Cretaceous Songliao Basin: Continuous High-resolution Terrestrial Archive and Greenhouse Climate Change" was approved by the International Continental Scientific Drilling Program (ICDP) in September 2009. The project led by the CUGB and the Daqing Oilfield Company Ltd. includes scientists from more than ten countries including the United States and Austria, and is spearheaded by Chinese scientists. This project consists of two stages: the first stage named SK-1 which has been successfully completed, includes penetration of strata from the K/T boundary to Upper Cretaceous, and the second stage, named SK-2 which will begin soon, includes penetration of strata from the Lower Cretaceous to J/K boundary. The Ministry of Science and Technology of China will continue to support this important scientific endeavor that represents an important leap forward in Chinese earth sciences and welcomes international scientists to share and participate in the scientific research.

The world is entering a new exciting era to explore the earth in which scientific drilling will provide a quantum leap in our understanding of the deep earth and its deep history. It is expected that the publication of this book will play an important role in promoting scientific drilling and earth system science research. Meanwhile, the Ministry of Science and Technology of China will continuously support the Chinese earth science community to assume its important responsibilities and to play a greater role in this human endeavour.

Wan Gang

万钢

Minister of Science and Technology of China

January 8, 2010

Foreword 2

Sediment basins around the world host the most important resources for mankind: hydrocarbons and groundwater. Yet, the evolution of many of these basins over geological times is still often poorly studied despite the fact that the continuous deposition of sediments provides often very valuable records of the past.

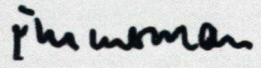
Depositional basins formed in continental environments are one of the least understood major sediment sinks. Their detailed stratigraphy and structure is the key to shed fresh light on orogenic and on sediment supply processes but especially the environmental and climate evolution encapsuled therein.

Therefore, the International Continental Scientific Drilling program, ICDP endorses continental basin research and is accordingly for example supporting recently two major study programs, namely in the Colorado Plateau in the southwestern United Sates and foremost in the Songliao Basin in northeastern China.

This volume summarizes in great detail the current status of knowledge derived from surface and borehole investigations at the Songliao Basin. Especially the two drilled core holes, SK-1 and SK-2 provide insight into the turbulent greenhouse climate world of the Cretaceous. Research highlights encompass the complex interplay of terrestrial and marine influences, the resulting biotic response and carbon cycling as well as the terrestrial reaction to major oceanic events; all of them studied with most modern methods and instruments.

The close cooperation of a Chinese-led international scientific team, national funding agencies and researchers and engineers of the hydrocarbon industry makes this project outstanding. The mutual benefit for science in getting deep access to a major continental basin and for industry in getting novel interpretations for sedimentary basin and hydrocarbon origins is obvious. In documenting such fruitful work, this volume is setting the stage for the even more pre-eminent deep drilling program that will be executed soon in the Songliao Basin.

Rolf Emmermann



Chair of the ICDP Executive Committee

October 25,2011

Preface

Scientific drilling began with the "Deep Sea Drilling Project" in 1960s and led early to a major scientific breakthrough and geosciences revolution which has changed our views of the Earth (Wang, 2007). With ocean studies currently highly advanced, there is a particular need for earth system studies to obtain relevant information from the continents. This prompted establishment of the International Continental Drilling Programe (ICDP) (Harms *et al.*, 2007).

Since foundation of the ICDP in 1996, initially launched by Germany, the US and China, interest in the program has expanded to its current participation of over twenty member countries. More than 100 continental scientific drilling boreholes of different depths have already been completed in more than 13 countries. The implementation of the continental scientific drilling has contributed to an increase in our understanding of continental plate motion, crustal stresses and earthquakes, volcanic processes, deep resources, the origin of life, earthquake hazards, global climate change, etc. (Truman, 2000; Detlev *et al.*, 2004). In the spring of 1999, under the direction of Chinese scientists, ODP Leg 184 has been implemented in the South China Sea and has obtained sedimentary records for the past 30 million years. This project not only resolved the history of the South China Sea's climate and environment change, but also elucidated the long-term ocean carbon pool (Wang, 2007). The Chinese Continental Scientific Drilling (CCSD) project in Donghai County, Jiangsu Province, completed in March 2005, was located south of the Sulu ultra-high pressure (UHP) metamorphic belt, which is one of the largest in the world. This was the first time that scientific drilling in an UHP metamorphic belt had been attempted and significant advances were made in the precise dating of deep subduction of voluminous continental material, UHP deep subduction metamorphism and exhumation, protolith formation, upper mantle rheology, discovery of new mantle minerals, subsurface fluid anomalies and subsurface microorganisms (Liu *et al.*, 2001; Hartmut, 2002; Xu *et al.*, 2005; Zhang *et al.*, 2005, 2006). Qinghai Lake is located at the northeastern margin of the Tibetan Plateau, boarding the Huangtu Plateau in the east, and represents the transition between the east-Asia monsoonal humid climate region and the inland arid region. The area is therefore very sensitive to climate and global environment change and was selected as the preferential location for environmental studies in western China, and for determining the role of global climatic change during uplift of the Tibetan Plateau uplift (An, 2006; Colman *et al.*, 2007). The Lake Qinghai Scientific Drilling Project began in July 2005 with a purpose of understanding east-Asia monsoon climate and inland arid climate change, evolution of Qinghai Lake basin structure and the history of Qinghai Lake surface fluctuation (An, 2006; Colman *et al.*, 2007).

In the past hundred years, the global climate has experienced a great change represented by significant warming. Human civilization is faced with an increasing urgency to understand global climate change and its potential effects on ecosystems, resources and habitability. This research has so far been focused on the modern and Quaternary climate record. The way to understanding the earth's climate system demands a fully integrated exploration of the earth and its geological history. Based on this premise, the "Deep Time" research project, which incorporates information of the earth's ancient climate change prior to the Quarternary, studies climate changes and main geological events using sedimentary records in pre-Quaternary rocks, in order to better predict future climate change (Sun and Wang, 2009). A new era in the Ocean Drilling Project (IODP) began in 2003 when it adopted "Environmental change, processes and effects" as one of the three most important scientific areas of ocean research. Over 30 International Continental Scientific Drilling Projects have been completed, which include climate change and global environment, impact structures, geobiosphere and early life, volcanic systems and thermal regimes, mantle plumes and rifting, active faulting, collision zones and convergent margins, natural resources, etc. Half of these projects were targeted to research related to "climate change and global environment". The ability to predict future global climate change has become an important objective for the scientific community with an indirect impact on the well being of the whole humanity.

Recent global climate is characterized by oscillating glacial-interglacial periods under "icehouse" conditions controlled by Milankovich cycles (Miller *et al.*, 1991; Wang, 2000). This is because since the Cenozoic the concentration of greenhouse gases in the atmosphere has been lower than the threshold amount (about 560 ppmV; DeConto and Pollard 2003). If the concentration of CO_2 in the atmosphere exceeds this critical concentration of about 560 ppmV, it will result in melting of the ice cover at the North and South poles, and it is widely held that the earth may be entering a greenhouse climate state with a global climate very different from the present. Asa result of human activity, the CO_2 content in the atmosphere is continuously increasing and it may exceed the critical concentration in the near future. Concentration levels of CO_2 may approach those modeled for the Cretaceous (Daniel *et al.*, 2001; Berner and Kothavala, 2001). Hence, it is particularly important to understand how and why the climate changed in the Cretaceous.

During the past forty years, oceanic scientific drilling projects have targeted the Cretaceous period and the climatic changes that occurred during that time. Research of the ocean response to Cretaceous climate changes is well advanced, but what is little known is the response of the continental environment, and no scientific drilling project has been done to obtain evidence from the Cretaceous terrestrial sedimentary record.

The reason for this is that the Cretaceous continental record is fragmentary and less extensive when compared to the oceanic basins. Sea level in the middle Cretaceous was the highest during the past 250 Ma (Haq *et al.*, 1987). At that time, the global continental areas shrank and the largest continent was that of the East-Asia area (inside cover). One of the areas with an extensive continental Cretaceous record is in China. Oil exploration in the Songliao Basin of northern China has demonstrated that this intercontinental basin, which was mostly a fresh water lake for the duration of the Cretaceous to Early Tertiary time, contains an almost continuous sedimentary

record. Thus, the Songliao Basin was selected by Chinese scientists to conduct research into Cretaceous continental climate. Further studies on marine-terrestrial correlation, paleoclimate and paleoenvironment reconstruction, terrestrial response to major geological events, large scale hydrocarbon formations, terrestrial biotic evolution and rapid climate changes under greenhouse climate conditions, will provide important information of the nature and mechanisms of Cretaceous climate change, allowing predictions of future climate change, and provide exploration targets in the Daqing Oilfield.

The "Continental Scientific Drilling Project of Cretaceous Songliao Basin: Continuous High-resolution Terrestrial Archives and Greenhouse Climate Change" is designed as a two stage drilling program. The first stage, SK-1, includes drillingof early Tertiary to Lower-Upper Cretaceous strata. This stage has been completed. The next stage, SK-2, will drill Middle and Lower Cretaceous to the Jurassic—Cretaceous boundary rocks and will begin soon. When completed, the entire Cretaceous continental sedimentary record will be available for paleoclimate studies for the first time globally. In order to share this unique primary data with the international scientific community, this book *Initial Report of Continental Scientific Drilling Project of the Cretaceous Songliao Basin* was compiled and published with Chinese and English language editions.

During drilling of SK-1, to ensure core recovery ratio, we integrated a series of drilling and coring techniques, invented long term preservation techniques, and established ten complete, continuous, high-resolution (centimeter) geological profiles. The Late Cretaceous chronological framework of Chinese terrestrial strata was revised according to the results of this drilling project. SK-1 is the first scientific drilling project to continuously core Cretaceous strata in China and obtained continuous, high-resolution, little disturbed, continental sedimentary records of Middle-Late Cretaceous age that may become a standard for global terrestrial Cretaceous research. SK-1 has made significant advances in areas such as drilling engineering, logging engineering, core repository, etc., and relevant technologies have been applied in these areas to yield important social and economic benefits.

The following researchers have contributed to SK-1 studies: Wang Chengshan (Co-Chief scientist), Feng Zhiqiang (Co-Chief scientist), Wang Pujun (Geological director), Feng Zihui (Geochemical research), Yang Gansheng (Drilling engineering director), Wu Heyong (Site selection), Wan Xiaoqiao (Palaeontology research), Ren Yanguang (Site selection), Huang Yongjian (Sedimentary geochemical research), Chi Yuanlin (Logging engineering), Li Yule (Drilling engineering of SK-1s), Zhu Yongyi (Drilling engineering of SK-1n), Wang Zhongxing (Core preservation), Deng Chenglong (Paleomagnetic research), He Mingyue (Core transportation and preservation).

This initial report is a crystallization of the collective wisdom and many institutes and scholars that have contributed to this book. The writers discussed the content and outline of this book in detail at meetings in Beijing, Changzhou and Guangzhou. Wang Chengshan and Feng Zhiqiang wrote the Preface, Wang Pujun and Wang Chengshan wrote Sections 1 and 2, Feng Zhiqiang, Yang Gansheng, Wang Pujun and Wu Xinsong wrote Section 3, Wang Chengshan, Feng Zhiqiang, Wang Pujun, Deng Chenglong, Wu Xinsong, Huang Yongjian, He Huaiyu, Dong Hailiang, Song Zhiguang,

Wan Xiaoqiao, Cheng Rihui and Wu Huaichun wrote Section 4, Wang Pujun wrotes Section 5, Wang Pujun, Wang Chengshan and Yang Gansheng wrote Appendix.

This book was compiled by Wang Chengshan, Feng Zhiqiang and Wang Pujun, assisted by Gao Youfeng and Gao Yuan. We also thank Dr. Lubomir Jansa, Canadian Geological Survey for his revision.

Special thanks to Professor Wan Gang, Minister of Science and Technology of China, and Dr. Rolf Emmermann, Chair of the ICDP Executive Committee, for contributing Forwords for this book.

Deep continental drilling which can be viewed as a telescope for humans to observe the deep earth and to increase our understanding of the earth evolution, has been carried out all over the world. From the Fennoscandian Arctic, Russia—Drilling Early Earth Project, to the Colorado Plateau Coring Project targeting Early Triassic—Early Jurassic strata in the USA, and to the the recent Lake El'gygytgyn drilling project in Siberia, these projects all prove that the global earth science community is entering a new stage of exploring the Earth's evolution. One consequence of this new exploration stage is the Continental Scientific Drilling Project of the Cretaceous Songliao Basin, the results of which are detailed in this Intial Report.

Wang Chengshan and Feng Zhiqiang

王成善　冯志强

May 2010

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Contents