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A TRIP TO DINOSAUR TIME

A project to drill a 10-kilometre-deep hole in China will provide the best view yet of the turbulent Cretaceous period. **Jane Qiu** reports.

The rock columns on the table are not much to look at. More than a metre long, 10 centimetres in diameter and mostly made up of oil shale and sandstone, they are a dull greyish green. But these, says Wang Chengshan, a geologist at the China University of Geosciences in Beijing, "are not ordinary rocks".

Taken from depths of more than 2 kilometres into the Songliao Basin in northeastern China (see map), the rocks may hold clues to one of the strangest and most dynamic ages of Earth's history: the Cretaceous period. Beginning about 145 million years ago, the Cretaceous was the heyday of the dinosaurs. It was a time of climatic extremes, when global temperatures exceeded even the most alarming forecasts for the greenhouse world of 2100, and sea levels were up to 250 metres higher than today, covering about one-third of the current landmass. It was also a period of great geological and biological unrest, associated with frequent volcanic eruptions, the formation of major mountain ranges and ocean oxygen depletion. And it ended in spectacular style, with the global catastrophe that saw off dinosaurs some 65 million years ago, an event known as the Cretaceous/Palaeogene (K/Pg) extinction.

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Earth scientists have pieced together their understanding of conditions in the Cretaceous mainly from sediment cores drilled from the bottom of the ocean. But the cores being drilled from an oilfield in the Songliao Basin — which could eventually extend 10 kilometres deep — promise the deepest and best record yet of what was happening on land, and a chance to understand what drove the extremes of the time. "They are the key to unlocking the secrets of that fascinating period of Earth's history," says Wang, who, as the lead principal investigator, chaired a workshop in Beijing in early July on the Songliao Scientific Drilling Project. The cores that the researchers have seen so far, from depths of up to 2.5 kilometres, have offered insight into the Cretaceous climate and its massive fluctuations in temperature, atmospheric carbon dioxide and lake levels. The team is now hoping to muster support for a push to the very bottom of the basin, a further 7.5 kilometres down, where the rocks should date from before the start of the Cretaceous.

Deep details

The peculiar geology of the basin allows researchers to look at the record in extraordinary detail. Ten kilometres deep and covering an area of 260,000 square kilometres, Songliao is a rift basin that was formed as Earth's crust was pulled apart by the same tectonic forces that transport continents over geological time. For nearly 100 million years, mostly during the Cretaceous, it was home to a series of gigantic lakes fed by vast rivers.

The lakes seem to have captured in their sediments an uninterrupted record of climate and environmental indicators. "Most lakes are rather ephemeral," says Judith Parrish, a palaeoclimatologist at the University of Idaho in Moscow. "It is extremely rare to find a palaeo-lake as large and long-lived as Songliao." This geological record is, in effect, "an encyclopaedia of the Cretaceous", says Stephan Graham, a sedimentary geologist at Stanford University in California, and one of the five principal investigators now involved in the project. "You just don't have something like this anywhere else on the planet."

The Songliao Basin is home to the Daqing oilfield, the largest oilfield in China. Chinese geologists had already drilled more than 50,000 wells across the basin and generated a comprehensive picture of the region. This type of drilling does not generally take cores, which is a much more costly enterprise — but it has helped researchers to select the best spot for the core drilling, where rock layers have not slid apart or folded together to complicate the geological record. The Daqing Oilfield Company

in Heilongjiang province contributed half of the 10-million-yuan (US$1.3-million) cost of drilling out the 2,500-metre core, which started in 2006, and China's science ministry and various research institutions have also contributed to the drilling and analyses. On the basis of the early results, the project won endorsement in 2009 from the International Continental Scientific Drilling Programme (ICDP), which is run by experts at research institutions and funding bodies worldwide. A one-third segment of the entire length of the core is now sealed in transparent bags to protect its original shape and structure from drying and disintegrating.

Time of great unrest

Preliminary analyses have offered a glimpse of terrestrial conditions in the Middle and Late Cretaceous, adding to what was known from marine cores. "It seems to be a time of great unrest with a lot of ups and downs," says Wang. The team analysed oxygen and carbon isotopes in fossil crustacean shells as a proxy for ancient temperature and carbon dioxide levels, finding that atmospheric CO_2 levels doubled and then halved over 3 million years in the Late Cretaceous. (The team is putting together its results for publication.) The same techniques showed that the temperature plunged by more than 7 °C during a 10-million-year period — possibly around the Cretaceous 'super greenhouse', when global temperatures were substantially higher than today.

The lake levels also seemed to have fluctuated greatly: the researchers discovered signs of surface soil in a few core segments, suggesting that the basin might have completely dried out a few times. If proved correct, this could help to build up a picture of the climate dynamics behind these dry periods, says Parrish.

The researchers hope to flesh out this picture, and pinpoint the causes of the climatic fluctuations with further analyses of the sediment compositions. They also want to examine the sources of the sediments and water that entered the lake by using isotopes of elements such as strontium. Deltas contained in the Songliao Basin are likely to be as large as the modern Nile Delta, so rivers that fed the lake may have flowed for hundreds or thousands of kilometres, leaving deposits that could provide insight into geological and ecological events in distant areas.

The Songliao core may also shed fresh light on a contentious scientific debate: whether a large ice cap, half the size of the modern Antarctic ice cap, existed during a period as hot as the Cretaceous super greenhouse[1]. A more detailed temperature record built from the core might, for example, show whether there were more short cooling periods, such as the 7 °C drop the team has already observed.

And the core could answer pressing questions about the K/Pg extinction, which many researchers believe was caused by an asteroid or comet strike at Chicxulub on Mexico's Yucatán Peninsula, and the climatic aftershock[2]. Most of the samples corroborating the theory have come from marine sediments. A terrestrial record at Songliao could reveal how the asteroid strike affected life on land, at a huge distance from the impact. "Sediment cores from Songliao will help to build a more complete picture of those extraordinary events," says Christian Koeberl, director of the Natural History Museum in Vienna and another principal investigator on the Songliao project.

Core segments are stored in a facility in Daqing, China.

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The key to answering all of these questions will be accurate dating of the core. This will help to correlate the Songliao records with their marine counterparts. "Without a precise timescale, the values of any other pieces of information that can be recovered from the core would be diminished tremendously," says Bradley Singer, a geochronologist at the University of Wisconsin–Madison.

To date the core, Deng Chenglong, a geophysicist at the Chinese Academy of Sciences' Institute of Geology and Geophysics in Beijing, and his colleagues took samples every half-metre along it and measured the orientation of magnetic mineral grains in nearly 4,400 samples. The iron-rich grains in every rock layer point in the direction of Earth's magnetic field at the time the rock was forming. That field flips its polarity every few hundred thousand years, and those reversals get imprinted in the rocks.

Magnetic calendar

Deng and his team established a rough magnetic calendar for the Songliao core, which they could then compare with the global geomagnetic record. But to make an accurate match, the researchers needed to scour the core for volcanic layers — enriched in isotopes of uranium and other elements — which can be dated using the known rates of radioactive decay. They identified a handful of centimetre-thick ash beds with enough material for such dating, and they hope to find more.

Other as-yet-unpublished results also point to a possible position for the K/Pg boundary. But it is about 100 metres below the depth determined by Wan Xiaoqiao, a palaeontologist at the Beijing-based China University of Geosciences who used fossils of spores, pollen, phytoplankton and ostracod to locate the boundary. The researchers are trying to determine why the estimates differ, and to nail the boundary down to 2–3 metres, so that detailed geochemical analyses can be performed to look for rare elements, such as iridium, that are common in meteorites and were spread around the globe by the cosmic impact.

The second phase of the drilling, an extra 7.5 kilometres, is contingent on further funding. The ICDP will provide $1.3 million, and Wang hopes to get another 200 million yuan for the drilling operation from the Chinese government. It is not yet clear whether the Daqing Oilfield Company will continue to offer substantial financial support. Feng Zhiqiang, a geologist and vice-president of the company, hopes that the drilling project will result in a better understanding of the geological composition and sedimentation processes of the basin. "The knowledge will ultimately help us to locate new resources more efficiently," he says.

Wang is more excited about the science. He picks up a rock segment, his eyes instantly lighting up, and weighs it in his hand. "This is not the end," he says. "It is just the beginning of an exciting scientific adventure." ■

Jane Qiu writes for *Nature* from Beijing.

1. Bornemann, A. *et al. Science* **319,** 189–192 (2008).
2. Schulte, P. *et al. Science* **327,** 1214–1218 (2010).