

An Overview: Special Issue on “Current Status of On-land Scientific Drilling in Japan and Its Prospects”

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Scientific drilling is an important means to collect samples and data that cannot be readily collected from surface outcrops. A series of ocean drilling projects, from the Deep Sea Drilling Project (DSDP; started in 1968) to the Integrated Ocean Drilling Program (IODP), has achieved significant results in earth science, which include verifying the theory of Plate Tectonics and settling the dispute on the mass extinction at the Cretaceous/Paleogene boundary. In 1996, about 30 years after the start of DSDP, the International Continental Scientific Drilling Program (ICDP), an international cooperation project for on-land drilling, was initiated. In Japan, the Unzen Drilling Project was first conducted with the help of funding from ICDP (see Nakada's paper in this issue). However, many fewer scientists are interested in ICDP than in IODP. A limited number of ICDP proposals have been submitted by Japanese scientists. To provide information on the scientific significance of ICDP and other on-land scientific drilling to the Japanese earth science community, the Japan Drilling Earth Science Consortium (J-DESC) Continental Drilling Section is publishing this special issue. We hope it will stimulate Japanese communities and increase their interest in on-land scientific drilling including ICDP.

This special issue comprises nine papers, the scientific contents of which will be very useful for on-land scientific drilling in Japan. The first paper, by Niitsuma (2013), looks at the history of continental scientific drilling projects in the latter part of the 20th century prior to the launching of

ICDP. Representative examples include super deep drilling projects conducted at the Kola Superdeep Well (Russia) and Kontinentales Tiefbohrprogramm (KTB) (Germany) sites. These projects developed technologies for preventing borehole break-outs and drilling under high-temperature conditions. However, the results obtained by the projects contradicted scientists' expectations and highlighted a lack of understanding of the Earth's interior. Scientific drilling projects were planned before ICDP started in Japan, but most have not yet been performed. All the proposed drill sites are introduced.

The second paper, by Urabe (2013), reviews the history and performance of ICDP, in particular focusing on those of Japanese scientists. ICDP was initiated to promote continental scientific drilling projects globally and enhance international cooperation. Although ICDP has a much smaller budget and organizational structure than ocean drilling projects such as IODP, its performance has been excellent. As he points out, a serious issue is that principal investigators (PIs) are required to fund large drilling costs if their proposals are accepted. In spite of such difficulties, continental drilling will become increasingly important when using scientific results to establish a sustainable future for human society.

Nakada (2013), a PI of the Unzen Drilling Project, reviews the scientific results of volcano drilling and its future prospects. Drilling into volcanoes is best suited for understanding subterranean three-dimensional geometrical and

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thermal structures, magmatic systems, and conditions at eruption sites, as well as eruption and development histories, which are useful to reveal magma processes in the upper crust, forecast future eruptions, and mitigate volcanic disasters. Such drilling projects have been conducted at many volcanoes including Mauna Kea (Hawaii) and Mount Fuji. Observation wells are available for *in-situ* monitoring of volcanic activity.

To understand paleo-climate change and tectonics, many on-land drilling projects have been conducted. Because lake sediments are excellent archives for reconstructing terrestrial paleo-environments and tectonic movements, they are one of principal targets of on-land scientific drilling. Kumon (2013) reviews scientific drilling projects targeting lake sediments in Japan. The first deep drilling projects were performed at Lake Biwa in 1971 and 1982–1983, which succeeded in delineating detailed climate changes and tectonic movements of the lake over the past 1.6 million years. Scientific results from drilling into lacustrine sediments at six lakes and adjacent onland sites and into lacustrine deposits exposed at two sites are reviewed. A research protocol that is suitable for core samples from lake sediments is also introduced.

In addition, on-land drilling around coastal plains has been conducted to understand geological, hydrological, and geotechnical features. Tanabe (2013) performs a sedimentary facies analysis and radiocarbon dating of three sediment cores from the upper Pleistocene to Holocene Shinano River incised-valley fill (alluvial deposits) in the Echigo Plain, Sea of Japan side of central Japan, showing 1000-year scale sediment stacking patterns taking into consideration the effects of seismic subsidence and meltwater pulse on stratum formation. He also suggests that seismic events strongly affect stratum formation in tectonically subsiding areas in Japan.

Following the 2011 Tohoku-Oki earthquake, it is urgently required to identify tsunami-related sediments from alluvial deposits forming coastal plains and to reveal histories of earthquakes and associated tsunamis over the last several thousand years. Fujiwara *et al.* (2013) report

the results of a case study on tsunami-related sediments in the Rokken-gawa lowland, located near Lake Hamana in central Japan, along the Nankai Trough. The criteria to identify tsunami sediments in their study may be commonly used in other areas with a similar sedimentological setting.

Several fault-drilling projects have been also conducted with the common aim of seeking direct access to zones of active faulting and understanding the fundamental processes governing earthquakes and fault behavior. Hirono *et al.* (2013) review recent scientific drilling projects related to the Nojima Fault, which slipped during the 1995 Hyogo-ken Nanbu Earthquake, the Chelungpu Fault, which slipped during the 1999 Taiwan, Chi-Chi earthquake, the San Andreas Fault Observatory at Depth, and also briefly introduce ongoing drilling research. One of the main outcomes of fault-drilling research is a better understanding of the physicochemical processes of a primary slip zone during an earthquake, which is closely related to the mechanism of dynamic fault weakening.

Because the Fukushima Dai-ichi Nuclear Power Plant was collapsed due to the 2011 Tohoku-Oki earthquake, new technologies/methods for power generation are urgently required to be developed in Japan. Promising technologies/methods include geothermal power generation. However, geothermal power generation currently has two problems: low recovery of injected water (< 50%) and increased fluid pressures in crustal rocks by injected water, causing induced earthquakes. Muraoka *et al.* (2013) propose geothermal power generation in ductile zones (below brittle zones). With this new method, an artificial brittle fracture reservoir system is surrounded completely by high-temperature ductile zones, enabling us to develop forms of geothermal power generation that are free from the above-mentioned problems.

In the past few decades, scientists have become more interested in the deep subsurface biosphere, which can be accessed only by terrestrial and seafloor drilling. Naganuma (2013) reviews the history of studies on the deep subsurface biosphere. He points out that the terrestrial deep subsurface bio-

sphere has been studied for human-related issues (e.g., sustainability, fuel and ore industries, waste storage) as well as for scientific interest, which contrasts with more science-oriented seafloor microbiology. It is also pointed out that, although preventing man-induced contamination of cored samples and pumped fluids is a major issue to be solved, anti-contamination protocols and facilities are better developed by and introduced to IODP expeditions than ICDP projects. Lessons from subterranean microbiology are expected to be applicable to some unsolved scientific problems such as the origin of life on Earth and extraterrestrial life.

We hope the articles in this special issue provide insights into some of the work that has been undertaken recently for ongoing and future on-land scientific drilling projects, and will stimulate further studies and collaboration among various workers.

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