# Conference on Continental Scientific Drilling: Defining Future Goals

by Ulrich Harms

A recent conference to discuss achievements and to guide future priorities in continental scientific drilling received overwhelming support by the scientific community. The meeting brought together a broad spectrum of researchers in the solid earth sciences through a common necessity for drilling as a tool to obtain otherwise inaccessible samples and critically needed data on active processes (Fig. 1).

More than 200 participants from twenty-four countries and from a very large variety of disciplines attended the meeting. The first day served to provide an overview and review of the past ten years of research conducted within the framework of the International Continental Scientific Drilling Program (ICDP). The second day of the meeting was used to develop visions for the future, to prioritize scientific questions, and to identify potential key locations. For this purpose, the conference split into eight breakout groups: climate dynamics and global environments, impact structures, geobiosphere and early life, volcanic systems and thermal regimes, hotspot volcanoes and large igneous provinces, active faulting and earthquake processes, convergent plate boundaries and collision zones, and natural resources. Results of the thematic working groups were presented on the third day in a plenary discussion to define the overarching goals and synergies.

Figure 1. Participants of the ICDP conference.

The working group on climate dynamics and global environments identified two grand challenges—to understand rapid changes during the late Quaternary at an unprecedented temporal resolution, and to gain a physical understanding of the reconstructed climate change by quantifying environmental change. For a mechanistic understanding of critical thresholds in the climate system, it is necessary to concentrate on natural experiments in the geological past that contain critical variations such as in greenhouse gas forcing. Laminated and high sedimentation-rate lake sediment sequences are instrumental for closing huge gaps in the knowledge of the impact of climate change on continental biota and ultimately the human environment. Specific research goals include a) understanding the variability of and the interplay among large-scale ocean–atmosphere oscillations, b) investigating the continental response of climate variability at centennial-to-millennial timescales, c) understanding potential shifts in climate zones of interannual to decadal climate variability during abrupt climate change, d) quantifying how interglacial modes of climate variability at centennial to millennial timescales modulate climate variations, and e) understanding the varying duration and amplitude of interglacial episodes during the late Quaternary. A full realization of such climate research goals requires the integration of terrestrial and marine archives and the application of improved analytical tools.

The formation of impact craters has changed the Earth dramatically through geological time and has been a key factor in the development of life on our planet. It is beyond any doubt that the study of impact craters on Earth is an absolute prerequisite for understanding some of the most fundamental problems of earth and planetary sciences, such as the variation of the morphology and structure of craters as a function of their size and of planetary gravity; the origin and evolution of early primitive life; the origin, constitution, and evolution of the Archean crust of the Earth; and the discontinuities in the evolution of later complex life (Phanerozoic mass extinctions). Also, a major topic of impact research is the effect on the global environment and possible relations to mass extinctions. At present, the Chicxulub impact structure, with an age close to the Cretaceous-Tertiary (K/T) boundary, is the only one for which a relation with a major mass extinction was established (at least with respect to the timing). To explore and demonstrate the potentially important role of a meteorite impact on biotic extinctions and subsequent evolution, it is important to find other examples of meteorite impacts that are related to mass extinctions. Scientific drilling should continue to focus on impact craters that are inherently world-class structures (e.g., Chicxulub), those that address world-class scientific issues, and those that are best addressed by available technology.

The still unexplored deep biosphere of Earth plays a fundamental role in global biogeochemical cycles over both

short and longer timescales. Estimates that the mass of the deep biosphere could be equal to that of the surface biosphere have been made by extrapolating from data collected from a very limited number of boreholes in marine and terrestrial environments. The lower depth limit of the biosphere has not been reached in any borehole studies that have included a microbiological component, and the factors that control the abundance and activities of microbes at depth and the lower depth limit of life are still poorly understood. While the Integrated Ocean Drilling Program (IODP) is now systematically probing the marine regions of the deep biosphere, the terrestrial deep biosphere is receiving somewhat less attention. This is where the continental drilling program must play the leading role. Another important target for future scientific drilling is to address the hallmark features of the Archean–Palaeoproterozoic transition when aerobic life began to shed light on the early biogeochemical evolution of the Earth.

The future exploration of volcanic systems and thermal regimes was discussed within three main topics. One fundamental scientific issue is that the origin and growth of the continents is governed by volcanic systems developing silicic plutons resisting subduction. Despite mankind's presence on the continents, however, the formation of oceanic crust is currently far better understood than that of continental crust. An issue of high societal relevance is the investigation of hazards caused by volcanic eruptions. Drilling provides a means to improve substantially our predictive capabilities about the onset, style, and cessation of eruptions, either at specific sites such as in the Tokyo area near Mount Fuji and the Naples area near Campi Flegrei and Vesuvius, or in general through improved understanding of relevant processes. The third issue discussed centered on the largely untapped renewable energy resource provided by continental thermal regimes, whose exploration and exploitation needs to be addressed using drilling as a tool.

In the last decade, continental scientific drilling allowed for unprecedented access to and novel observations in actively deforming zones. Although important knowledge thus has been gained on the strength of the upper crust and the global-scale tectonic stress fields, several long-standing fundamental questions on faulting processes are still not satisfactorily answered. Basic issues exist concerning the minimum stresses causing slip on a fault; the factors determining seismic, aseismic or weak behavior of fault zones; the controls of nucleation, propagation, arrest, and recurrence of earthquake rupture; and the role and origin of fluids in fault processes. The concepts and objectives for future drilling will be guided by contributions from three main sources: a) the cumulative experience from drilling active faults, such as the San Andreas Fault Observatory at Depth (SAFOD) or the IODP NanTroSEIZE project, revealing the capabilities and limitations of direct probing of faulting for the future, b) current geodynamic investigations, such as EarthScope, that generate new ideas and avenues for drilling linked to complementary field research, and c) an envisioned increase in the collaboration with industry and government agencies in the near future to the benefit of all sides.

Hot spot volcanoes and large iIgneous provinces (LIPs) originate most probably at the base of the mantle and therefore provide unique information about the deep Earth. Drilling through the horizontally layered flows and strata of such volcanoes allows for the collection of sample suites—

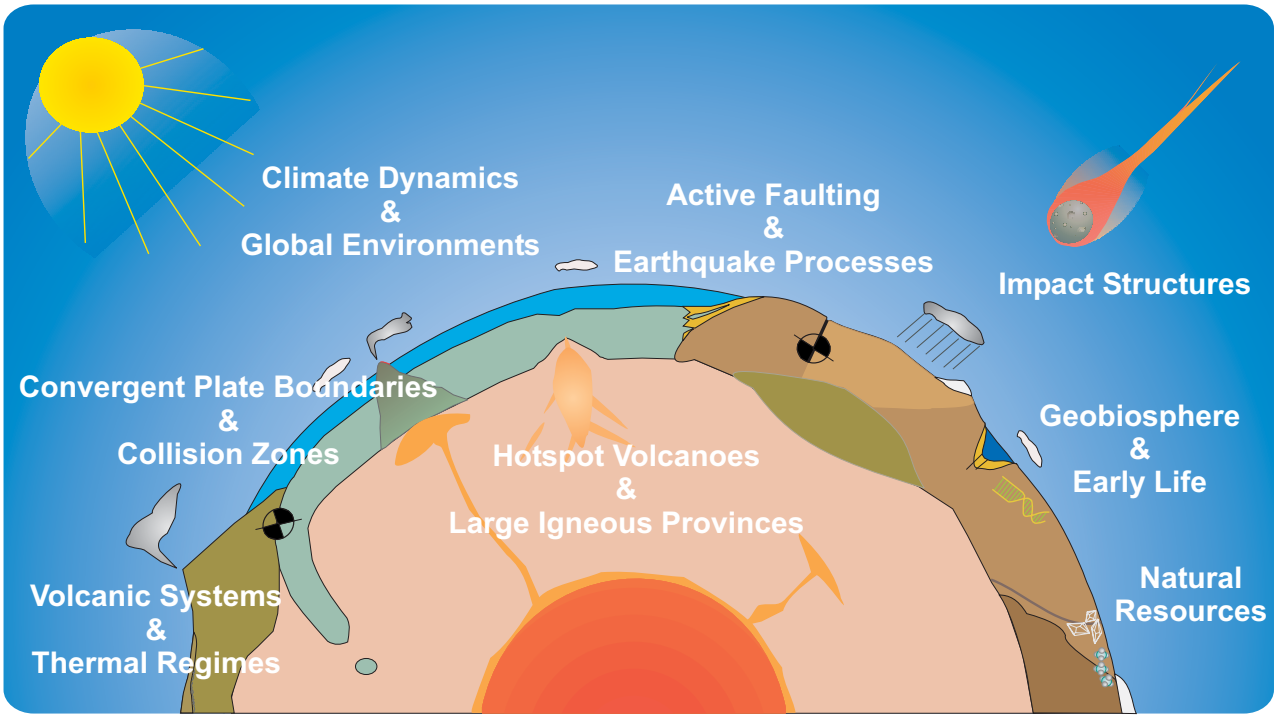


Figure 2. Sketch representing the major scientific themes of the ICDP.

from youngest to oldest—recording volcano build-up, plume structure, and melt extraction processes. The resulting geochemical and petrological datasets are critical for developing and testing a new generation of mantle magmatism models, and they provide input for new models of hotspot volcano growth and lithosphere deformation. Drilling also provides detailed tests of the relationship between LIPs and other global events as well as unique information on aquifers, temperature distributions, chemical alteration, and biological activity in the deep subsurface. Possible future targets for drilling that were discussed included oceanic island, the continental Snake River Plain to study plume lithosphere interaction, and the Kerguelen region and flood basalt provinces on land.

The majority of human population and industry is concentrated in the continental areas bordering convergent and collisional plate boundaries, where major natural disasters such as earthquakes, tsunamis, and volcanic eruptions threaten human life and economy. A strong need therefore exists for scientific and economic efforts to elucidate and understand the processes responsible for such geohazards as well as for mitigation strategies. Scientific drilling will play a vital role in such studies and is an integral part of this effort. The ICDP drilling in convergent and collisional plate margins faces unprecedented challenges regarding drilling technology, drilling depth, and requirements for long-term monitoring of Earth processes in downhole observatories. A comprehensive initiative to drill the continental crust bordering plate boundaries encompasses a wide range of topics: a) dynamics of active subduction and collision zones, with focus on the seismogenic zone at the plate interface, and the distribution of deformation and seismicity, b) the role of mantle plumes in orogeny, c) supra-subduction magmatism in arc systems, d) the geological manifestation of deep subduction and exhumation of the lithosphere, and e) aspects relating to the birth and growth of continental crust through the history of the Earth.

The natural resources working group recommended that this area should be recognized as a unique theme for scientific drilling within its broad scope because of the ever-growing societal relevance of environmentally sustainable natural resources. Limited funds for scientific drilling should not be used in ways that subsidize or compete with drilling that is more properly the domain of industrial and government entities concerned with the development of natural resources. Drilling projects involving the natural resources topic should strive to focus on leading-edge scientific questions of broad global significance and not on economic issues such as exploration or resource assessment. The ICDP should encourage novel drilling-related research with overarching research questions that are not routinely addressed by industry and with a potential for positive contributions to environmental problems.

At the same time as these thematic sessions, a workshop on drilling technology was held to highlight and summarize the existing and necessary technological needs of continental drilling. A second workshop on education and outreach addressed the use of scientific drilling results for training courses for graduate students and for undergraduate teaching, as well as for outreach to the general public.

Regarding the realization of the key scientific questions, all participants in their closing remarks expressed the need for internationally coordinated and community-steered continental scientific drilling in the future. Close cooperation with the IODP will play a major role, as the main scientific goals of the ICDP and the IODP overlap to a very high degree. Outstanding examples with a critical need of a joint approach are marine–continental transects across seismogenic zones as well as the integrated investigation of marine and continental climate archives.

The conveners of the thematic sessions have compiled the working results in a white paper, that will serve in the future as a Science Plan for the forthcoming activities of the ICDP. The white paper replaces the "Scientific Rationale for an International Continental Scientific Drilling Program" that served as a guideline for the ICDP from the start of supported activities in 1998. More information on the conference and the resulting white paper can be found at http://www.icdp-online.org.

The Conference on Continental Drilling was held at the GeoForschungsZentrum in Potsdam, Germany under the title "Continental Scientific Drilling 2005–A Decade of Progress and Challenges for the Future" from 30 March to 1 April 2005.

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