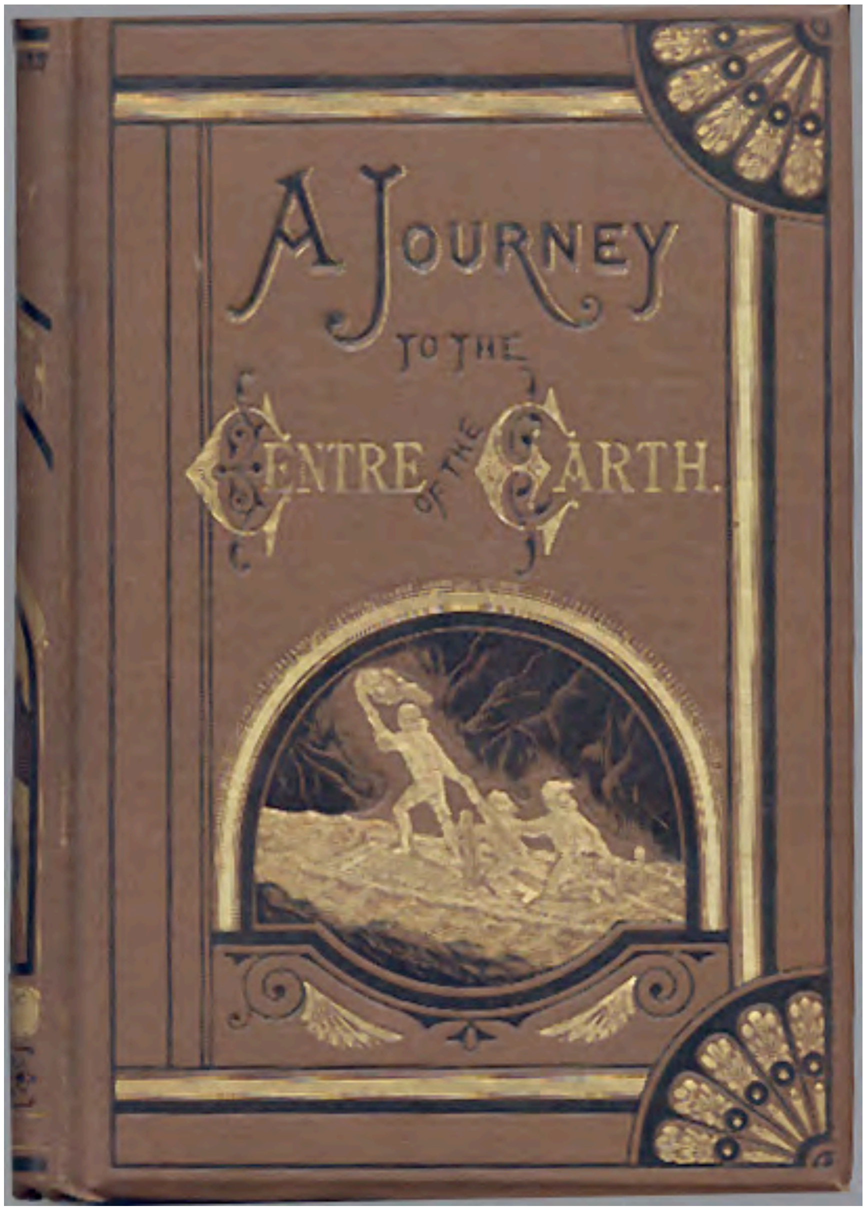
Attempts to Reach the Pristine Mantle

A source of information for personal use in preparation for the International Workshop on "Reaching the Mantle Frontier; Moho and Beyond" September 9-11, 2010.



Probing the Earth's interior

Indirect Methods	**Relevance to mantle**
Extra-terrestrial materials	Chondrites, Moon
Asteroids	Sample return mission (*Hayabusa*)
Exhumed samples	Ophiolites, Xenoliths, Kimberlites, Exposures
Laboratory experiments	Mantle condition reproduction
Computer simulations	Evolution, convection, plate tectonics, plumes
Remote sensing	
Seismic waves	Mohorovičić discontinuity, mantle structure
Geoid/Gravity	Density
Geoelectromagnetism	Origin of magnetic records, electrical conductivity
Heat flow	Temperature distribution
Muon/geoneutrino	

Direct *in situ* deep sampling attempts

Through ocean floor

1) The Mohole Project	1958-1966
2) DSDP-ODP (504B, 1256D +....)	1968-1983/1985-2003
3) IODP Riser Drilling	2003-2013

On land

4) Soviet Kola Peninsula Drilling Project	1970-1989
5) Siljan Ring Project	1986-1987
6) KTB Deep Drilling Project	1990-1994
7) ICDP	1996-

Ideas

8) Self-sinking capsule ideas

Records

Deepest drill hole: Kola SG-3 12,262 m (1970-1989)

Deepest scientific hole in ocean: 2,111 m Eastern equatorial Pacific (Legs 69, 70, 83, 111, 137, 140, 148 Hole 504B, DSDP/ODP, 1979-1993)

Deepest water depth drilled for science: 5,968.6 m Mariana Basin (Leg 129 Hole 802A, ODP, 1989-90)

Deepest oil well in ocean: 10,685 m (1,259 m water depth) Deepwater Horizon (BP)

Deepest water depth drilled for oil: 3,051 m Gulf of Mexico (Chevron)

Pre-Mohole to Mohole Phase 1

From Bascom (1961)

One of the earliest proposals for a purely geological hole was made in November 1902 by G. K. Gilbert, director of the Carnegie Institution of Washington, who suggested to the trustees that "an investigation of subterranean temperature be made by means of a deep boring into the plutonic rock."

T. A. Jaggar (founder and director of Hawaii Volcano Observatory) proposed "Core drilling under the Ocean" in 1943 to IUGG (International Union of Geodesy and Geophysics).

To drill one thousand core-producing holes in the deep ocean bottoms each one thousand feet deep and preserve the cores for specialist study, with worldwide drill-hole distribution.

Maurice Ewing (director of Lamont Geological Observatory): ...*The entire record of terrestrial conditions from the beginning of the ocean is there in the most undisturbed form it is possible to find anywhere–and the dream of my life is to punch that hole 2000 feet deep and bring the contents back to the lab to study them*.

Geophysical Research Shaft Frank B. Estabrook (U.S. Army) Science *124*, 249, 1956.

A far-reaching modem social development is the massive financial backing which can, with increasing ease, be obtained for organized group attacks on new areas of basic knowledge. One thinks immediately of the large accelerators of the AEC, of the upper-air exploration programs, of the IGY, and of the artificial satellite. In general, none of these programs has immediate economic or national defense purposes; rather, their support by various governmental and private agencies reflects a general understanding of the ultimate utility of all physical knowledge. Although massive public support of science undoubtedly entails some undesirable consequences, the very technologic resources thus made available for scientific purposes mean the opening up of research areas otherwise inaccessible. Scientists in all fields should be aware of this opportunity.

The purpose of this note is to suggest one such possibility: a geophysical penetration of the earth's crust. I am not a geophysicist, nor am I qualified expertly to discuss the novel engineering problems involved. Nevertheless, a comparison of such an exploration with, say, the artificial satellite project (with regard to basic scientific worth, to possible practical uses, and to the expense of developing the technology involved) would seem immediately to confirm the suggestion that crustal penetration should be thought about, discussed, and evaluated by the scientific community. If the consensus is then that such a project would be valuable and feasible, we might expect on the afore-mentioned general grounds to find support forthcoming.

There appear to be many geophysical problems that could be profitably investigated by a physical penetration of the earth's crust and by an examination of the composition, properties, and physical condition of the mantle below the Mohorovičić Discontinuity. Among these are the following. (i) Knowledge of the variation of the earth's magnetic field below the surface could show whether its origin is in the crust or, alternatively, is the result of magnetohydrodynamic mechanisms in the core. (ii) Knowledge of the temperature variation below the surface is important for discussions of the earth's heat balance, radioactivity, and evolution. (iii) Knowledge of pressure, temperature, and density conditions at the outer boundary of the mantle are required for the numerical integrations in geophysical theories of Earth, Venus, and Mars. (iv) Geophysical theories of continent building require knowledge of the ultrabasic mantle material and of its relation to the basalt layer and to the granitic continental basement. (v) Penetration of the crust could shed light on the validity of the isostasy concept; this in turn has important and practical geodetic consequences. (vi) The earth's crust apparently has an unusually high radioactive content; it is important to determine whether this is actually so, and whether the radioactive elements have been fractionated out of the mantle. (vii) Knowledge of the composition of the mantle and, hence, of by far the largest part of the earth's mass is of great interest for astrophysical discussions of cosmic abundances. Furthermore, as in any scientific exploration, one cannot estimate in advance the importance of the new and unexpected phenomena and conditions that would be encountered; for example, it was suggested to me, not necessarily in jest, that the mantle might prove diamondiferous.

The site of the research shaft would be chosen so that the depth of the Mohorovičić Discontinuity was there a minimum. While this indicates drilling from an oceanic island, the logistic convenience of a continental location would also be a factor. Presumably seismic and volcanic complications should be voided. Sedimentary overlay per se is uninteresting, and ground water and other seepages could be avoided by seeking exposed Archean rock. I cannot adequately judge the relative importance of these factors.

It is, however, clear that present well-drilling technology would be inadequate to achieve the vertical depth required- perhaps 10 miles. One might, instead, imagine a small-bore (perhaps 12 inches in diameter, 300 down-slant) shaft, drilled into the granitic and basaltic rock by remote-controlled equipment. The power transmission from surface to drill could be by electric cable; rock removal, by belt or hydraulic means. The temperatures encountered should not be excessive (perhaps a few hundred degrees centigrade); the extreme pressures would probably require the use of heavy drilling muds for hydrostatic compensation.

Although estimation of costs for such a project is extremely difficult until preliminary site surveys and a technologic feasibility study have been made, I might point out that the large-scale rock tunneling on the surface costs perhaps $1 million per mile. We might expect that the proposed small bore, the use of modern remote-controlled instrumentation, and especially the absence of complicating seepage and ventilation problems would greatly reduce the cost from that of conventional tunneling. So this cost might well be commensurate with that of many modem group attacks on other basic areas of science, as is indicated in the first paragraph. I should like to thank James Garvey for many discussions, and for encouragement in this matter.

1957: Harry Hess and Walter Munk asked themselves, "How could the earth sciences take a great stride forward?" Munk suggested that they should consider what project, regardless of cost, would do the most to open up new avenues of thought and research. He thought that the taking of a sample of the earth's mantle would be most significant.

NSF turns down the proposal by American Miscellaneous Society's feasibility study on "taking of a sample of the earth's mantle."

IUGG Resolution #11 adopted. … Urges the nations of the world and especially those experienced in deep drilling to study the feasibility and cost of an attempt to drill to the Mohorovičić discontinuity at a place where it approaches the surface.

AMSOC becomes AMSOC Committee of the National Academy of Sciences (NAS).

April 1958: Meeting in the Great Hall of the NAS preparatory to conducting a study to determine the feasibility of drilling to the Mohorovičić discontinuity.
You won't prove anything! You shouldn't do it! You can't do it!
"What good will it do to get a single sample of the mantle?..."
"Perhaps it is true that we won't find out as much about the earth's interior from one hole as we hope. To those who raise that objection I say, If there is not a first hole, there cannot be a second or a tenth or a hundredth hole. We must make a beginning." Harry Hess.

"... If that amount of money were divided up among the existing institutions, we would be able to do more and better geophysics."
"I imagine that an argument like that was used against Columbus when he asked Queen Isabella for funds for his adventurous project. One of the Queen's advisors stepped forward and said, 'Your Majesty, it won't be important even if this crazy Italian does reach India by sailing west. Why not put the same amount of money into new sails and better rigging on all the other ships? Then the whole fleet will be able to sail half a knot faster!'" Roger Revelle.

April 1959: William Bascom christens the new project Mohole, in an article in *Scientific American* "The Mohole."

Project Mohole, 1958-1966

Project Mohole was an attempt to retrieve a sample of material from the earth's mantle by drilling a hole through the earth's crust to the Mohorovičić Discontinuity, or Moho. The project was suggested in March 1957 by Walter Munk, NAS member (1956) and member of the National Science Foundation (NSF) Earth Science Panel.

Project Mohole represented, as one historian has described it, the earth sciences' answer to the space program. If successful, this highly ambitious exploration of the intraterrestrial frontier would provide invaluable information on the earth's age, makeup, and internal processes. In addition, evidence drawn from the Moho could be brought to bear on the question of continental drift, which at the time was still controversial.
The Mohorovičić Discontinuity marks the boundary between the earth's crust and mantle. (The Moho was named for Andrija Mohorovičić, a Croatian geologist who first proposed the existence of such a discontinuity.) The plan was to drill to the Moho through the seafloor, at those points where the earth's crust is thinnest. Attempting such an effort on land would have been impractical, since the drilling equipment would not have withstood the depths and temperatures involved. Ocean drilling offered a further advantage in that undersea samples, undistorted by atmospheric and surface actions, would provide better evidence of long term geological activity than would samples drawn from land.

The American Miscellaneous Society (AMSOC), an informal group of scientists of which Munk was a member, endorsed Munk's idea. The group was formed in 1952 when Office of Naval Research geophysicists Gordon Lill and Carl Alexis found themselves handling research proposals that fit into no existing scientific categories. Out of that "precarious miscellany" AMSOC emerged, as a forum for scientific speculation. When funds for Project Mohole had been obtained from NSF, AMSOC in 1958 took charge of the effort as an official study unit of the National Research Council's Division of Earth Sciences.

Project Mohole was to include three phases, the first consisting of an experimental drilling program, the second consisting of an intermediate vessel program, and the third consisting of the final drilling to the Mohorovičić Discontinuity. After ocean-going trials off La Jolla, California, Phase I began in earnest with a set of drillings off Guadalupe, Mexico, in March and April 1961. Five holes, one of which extended 601feet beneath the seafloor, were drilled under 11,700 feet of water. Cores obtained from the holes showed that the first layer of crust extended 557 feet and consisted of sediment Miocene in age. The second layer of crust was sampled for the first time, and this was found to consist of basalt. After the unprecedented success of Phase I, it was decided to shift operational control to NSF while maintaining the AMSOC Committee as project adviser. This relationship proved to be unsatisfactory, and after a series of negotiations and redefined agreements with NSF, the AMSOC Committee in 1964 dissolved itself. Following the AMSOC Committee's dissolution, two new National Academies committees continued to advise the NSF Mohole activity until Congress, objecting to increasing costs, discontinued the project toward the end of 1966, before Phase II could be implemented.

Although Project Mohole failed in its intended purpose, it did show that deep ocean drilling was a viable means of obtaining geological samples. Since Mohole's demise a number of related programs have been undertaken, the most recent one being the NSF's Ocean Drilling Program.
http://www.nationalacademies.org/history/mohole/

Gallery: Project Mohole, Phase I

Phase I of Project Mohole involved drilling near Guadalupe Island, off the coast of Mexico, in spring of 1961. The ship used was a converted Navy barge that had been fitted with experimental deep-water drilling equipment and a dynamic positioning system invented for the occasion by Willard Bascom, oceanographer and project director. In April the rig succeeded in drilling over 600 feet into the seafloor beneath nearly 12,000 feet of water -- approximately 30 times the then-existing drilling record.

Overhead view of CUSS I, the converted Navy barge used for Project Mohole's deep-sea drilling tests in spring of 1961 (NSF photograph).

Part of the 13,500 feet of specially-manufactured drill pipe, shown racked in 60-foot double lengths on deck of CUSS I(NSF photograph).

CUSS I crew lowering one of the six taut line submerged buoys used for dynamic positioning. The six buoys were lowered into a circular pattern at a depth of about 200 feet. The ship would then use sonar to position itself

From Mission Moho Workshop Report (2007)

Project Mohole Meeting

Men discuss the Project Mohole around a table abaord the vessel CUSS I off Guadalupe Island in the Pacific Ocean, 1961. The project was originated as a scientific exercise to drill into the Earth's crust. Pictured are, from left, John Steinbeck, Josh Tracey, unidentified, William Riedel, Roger Revelle, Walter Munk, Gustav Arrhenius, and Willard Bascom.

Photo: Fritz Goro

Jan 01, 1961

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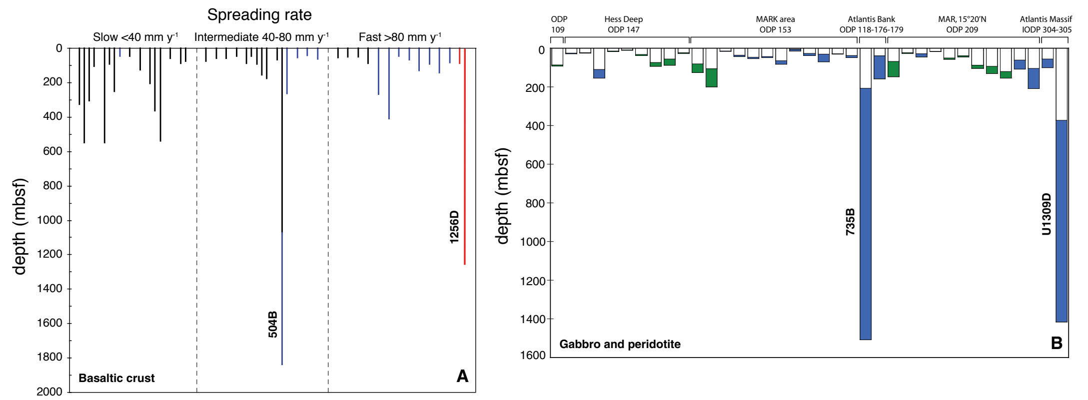


Figure 1. Summaries of existing scientific drill holes into oceanic crustal and mantle rocks. [A] Depth of penetration for all holes penetrating more than 50 meters into basaltic basement, as a function of spreading rate. Hole 1256D has reached the base of the sheeted dike complex at a shallower depth than the bottom of Hole 504B, which is still in sheeted dikes. Black = DSDP holes, blue = ODP holes, red = IODP holes. Modified from IODP Expeditions 309 and 312 scientists (2006). [B] Depth of penetration for all ODP and IODP holes deeper than 10 meters below seafloor into gabbroic rocks or residual mantle peridotite. Blue = dominantly gabbro, green = dominantly peridotite, white = no recovery. After Blackman et al. (2006).

From Oceanic Crustal Structure and Formation Thematic Review Report (2009)

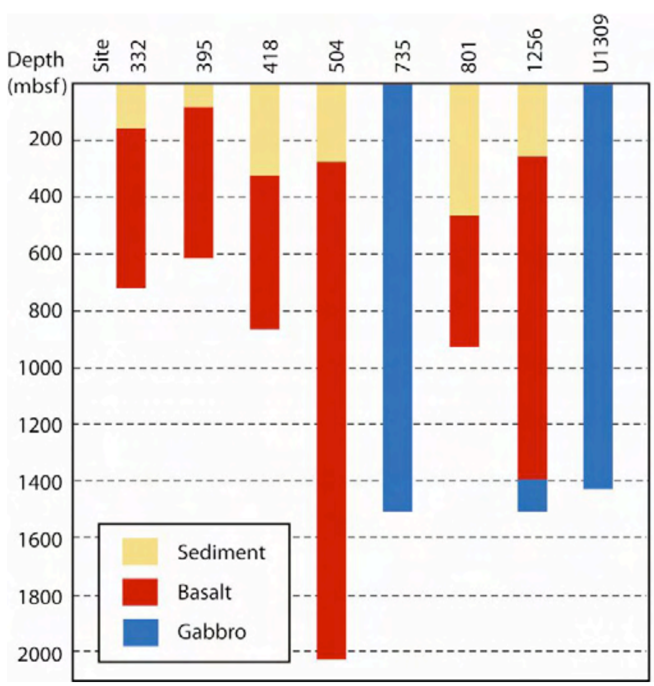


Figure 1.1 DSDP, ODP and IODP sites where significant (> 500 m) basement penetration was achieved. Excluded are deep basement sites 642 and 917 that were drilled in transitional crust along rifted margins and most likely floored by continental crust. Two (1256 and U1309) of the four deepest basement holes have been drilled by IODP. Sites with sediment and basalt on top represent efforts within intact oceanic crust. Sites with gabbro represent tectonic windows of opportunity to sample lower units of dismembered ocean crust (compiled by Jay Miller).

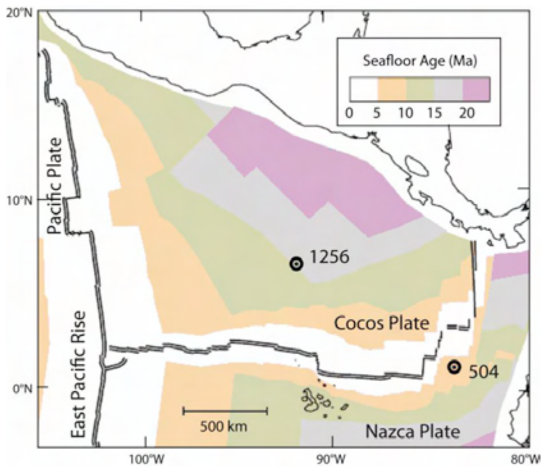


Figure 2.1 Age map of the Cocos Plate and East Pacific Rise, showing location of ODP Sites 1256 and 504 (from Wilson et al., 2006).

Excerpt from Thematic Review Report:

The review panel does not feel in a position, or for that matter, mandated to either recommend or reject such an enormous scientific endeavor. However, we did discuss the potential of recent findings achieved by late ODP and within IODP to impact an assessment of a Mission Moho. We here would like to provide specific comments:

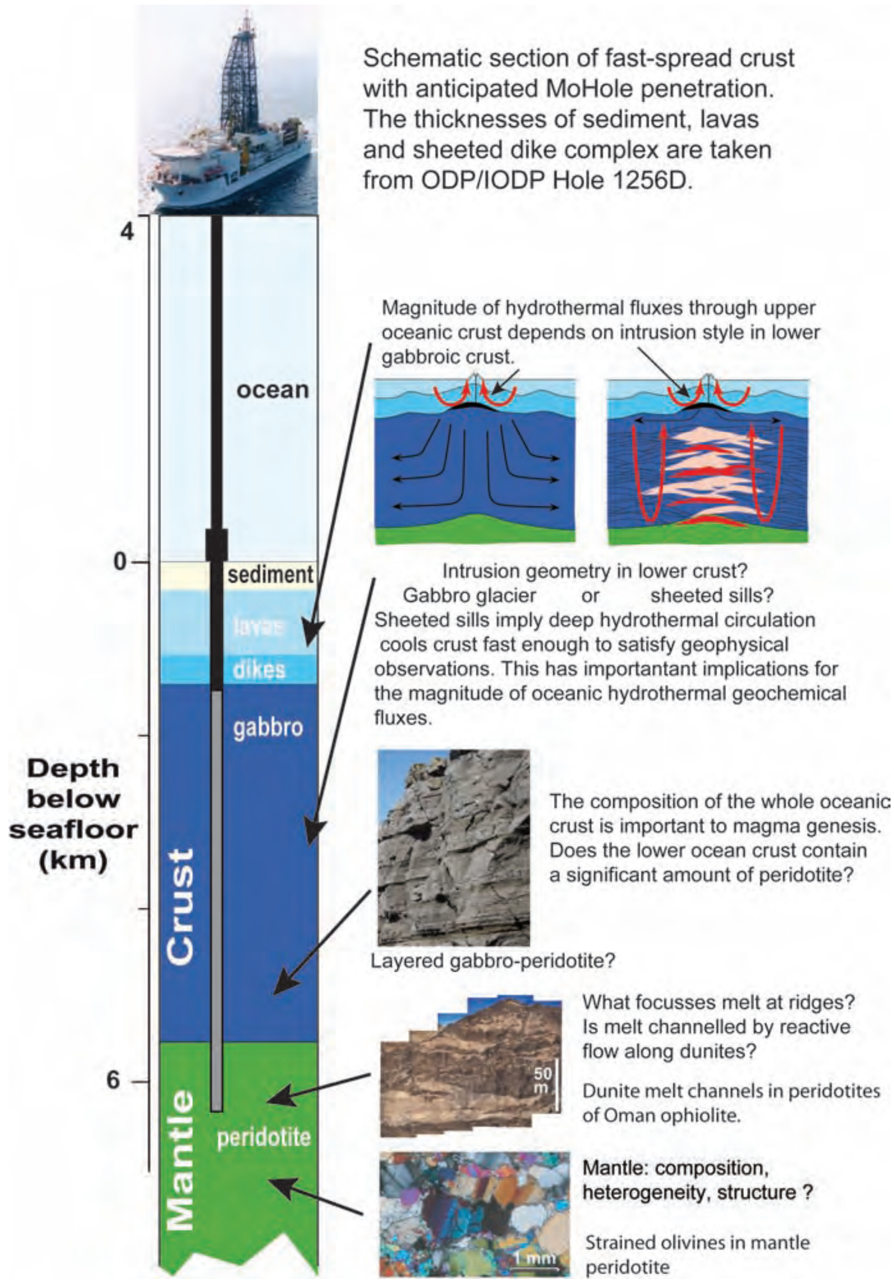
1) The findings at Site 1256 position the program to make an important step towards the ultimate goal of a Mission Moho. A moderate deepening of this site has the potential to establish a critical link to gabbroic crust found within ophiolites.

2) The findings from slow spread, dismembered crust (i.e. ODP Leg 209, IODP Expeditions 304 & 305) illustrate the enormity of lateral variation within ocean crust, and have proven exceptionally educational in terms of comparative studies of ophiolites, and their potential bearings on ocean crust formation.

3) The combined lessons from 1 and 2 above is that truly concerted efforts involving marine geophysics, ocean drilling and land studies of ophiolites are needed in order to enable a higher level of understanding of the nature of the crust that covers 2/3 of the planet's surface, and the dynamic processes forming the ocean basins. A deep reference hole sampling the entire crust and the upper most part of the mantle remains in view of the recent ODP and IODP discoveries a pivotal target in a concerted mission to understand formation and structure of the ocean crust and lithosphere.

4) The panel strongly recommends that IODP be honest with the ocean crust community in terms of the programmatic commitment of time and engineering to this kind of research. Designing the most efficient drilling efforts for such a challenging environment cannot be done in a vacuum, and may, without realistic guidelines, lead to poorly spent resources and/or disengagement of scientific community.

Quest for the Mantle: MoHo (figure from draft New Science Plan (2013-2023))



KTB German Continental Scientific Deep Drilling Program

Websites: ktv.icdp-online.org; ktbto.icdp-online.org

Description

- One of the major goals of the KTB is the elucidation of structure and evolution of the interior zones in a former mountain chain. The drill site near Windischeschenbach is at the boundary between the Saxothuringian and Moldanubian, two major tectonostratigraphic units of the Hercynian fold belt in Central Europe. This boundary is regarded as a suture zone formed by the closure of a former oceanic basin 320 million years ago. This process gave way to a continent-continent collision and the formation of a mountain chain comparable to the today's extension of the Himalayan mountain chain. Today the high mountain relief is eroded and, therefore, once deeply buried rocks are exposed at the surface. Therefore, this area is an ideal place for the study of deep seated crustal processes.
- Furthermore, detailed geophysical surface experiments have shown that the area around the drill site is characterized by an anomalous high electrical conductivity and pronounced gravimetric and magnetic anomalies.
- Key questions to be addressed by continental deep drilling include the evaluation of fundamental processes occurring in the lithosphere, the outer skin of our planet and resource base for mankind. Among these are the understanding of earthquake activities and the formation of ore deposits, important questions in a world of growing population and vast development. The drilling activities near Windischeschenbach form the German contribution to worldwide efforts on understanding our planet.
- Major research themes are:
    - Evaluation of geophysical structures and phenomena
    - Investigation of the thermal structure of the continental crust
    - In-situ investigation of rock-fluids and their contribution to formation of ore deposits
    - Elucidation of structure and evolution of the continental crust
    - Determination of the earth's stress field
    - Ultradeep drilling also makes great demands on drilling and borehole measurement technology. Thus, the experience and technical development acquired during the project greatly enhances knowledge in the drilling and service industry.

Location

- Germany, Bavaria, Upper Palantine, Windischeschenbach, 49° 48.983' N, 12° 16.67' E

Project Start and End

- Pilot Hole
    - Begin drilling September 22, 1987
    - End drilling April 4, 1989
- Main Hole
    - Begin drilling October 6, 1990

- End drilling October 12, 1994

Programs and Funding

- German Continental Scientific Deep Drilling Program
- German Science Foundation

Principal Investigators

- **Rolf Emmermann** GeoForschungsZentrum Potsdam, GFZ
- Heinrich Rischmüller (†) Niedersächsiches Landesamt für Bodenforschung (NLfB)

Partners

- GeoForschungsZentrum Potsdam, GFZ
- Niedersächsiches Landesamt für Bodenforschung (NLfB)
- German Research Foundation
- The Federal Ministery of Education, Science, Research and Technology (BMB+F)
- UTB ULTRATIEF Bohrgesellschaft
  - DEUTAG
  - DST
  - ITAG

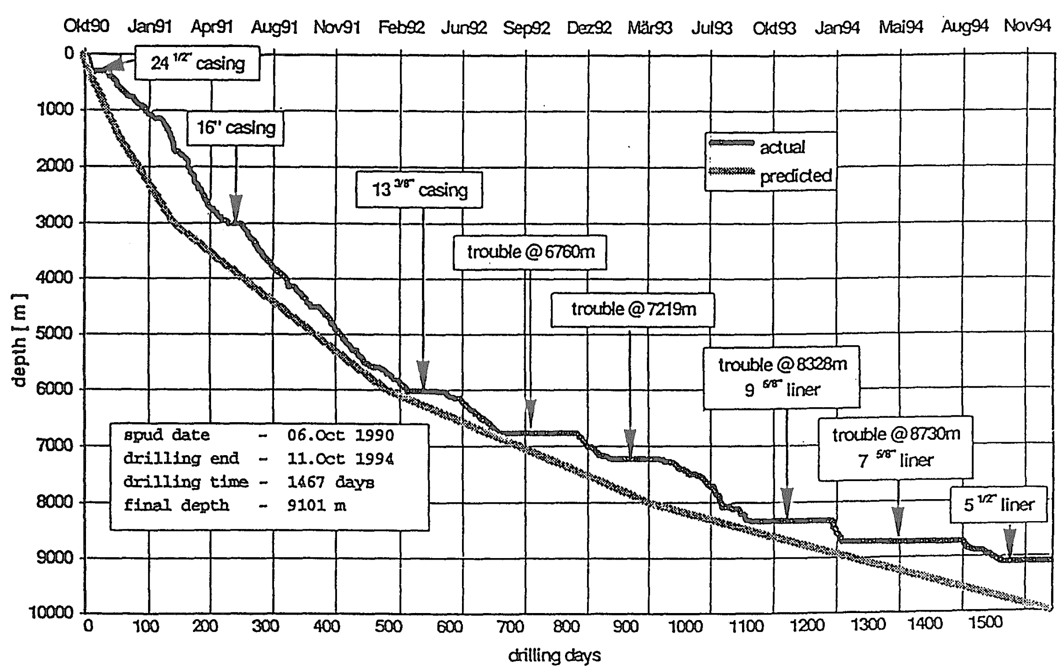
Keywords

- Convergent Margins, Collision Zones, Thermal Regimes, Deep Biosphere

Current State

- Drilling operations and scientific evaluations have been finalized

Bram, K., J. Draxler, G. Hirschmann, G. Zoth, S. Hiron and M. Kühr, The KTB borehole- Germany's superdeep telescope into the Earth's crust, Oilfield Review, 7, 4-22, 1995.
Wohlgemuth L, Tran Viet, T. and Engeser, B., Drilling experiences at the ultradeep well KTB–HB, Proceedings 8th International Symposium on the Observation of the Continental Crust Through Drilling, 39–45, 1996.



Wohlgemuth et al. (1996)

KTB – Major Goals:

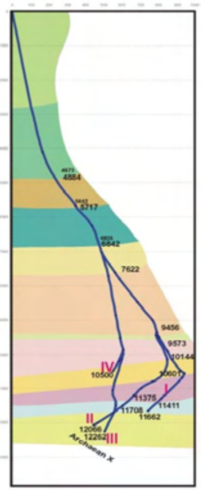
- **Nature of geophysical structures and phenomena:** Seismic reflectors, electric, magnetic and gravimetric anomalies; *calibration of methods of deep sounding*
- **The Earth´s stress field and the brittle - ductile transition**: orientation and amount of mechanical stress versus depth; *Formation and nucleation of earthquakes*
- **The thermal structure of the Earth´s crust**: Temperature distribution, heat flow, heat production; *Geothermal energy*
- **Fluid and transport processes**: Fluid sources, fluid pathways and household; *Occurrence and distribution of mineral deposits*
- **Structure and evolution in the internal zone of the Paleozoic crust of Central Europe**: Characteristics,deformation mechanism and dynamic of a reactivated crust. M*ineral deposit prospection*
- **Long-term DEEP CRUSTAL LABORATORY**

KTB – Technical Strategy:

- **2 Drillholes Concept**
- **Pilot hole of 3 – 5 km length with complete coring through new 6´´ WL coring system integrated in heavy 5 km rotary rig.**
- **Avoiding time consuming coring operations and allow to drill 4 - 5 km vertically.**
- **Development of 10 – 12 km concept during Pilot drilling based on pilot experience and trials e.g. lithology, dip, temperature, mud systems, tools, bits.**

Kola Superdeep:

>20 years of ultradeep drilling in Sovie
Union

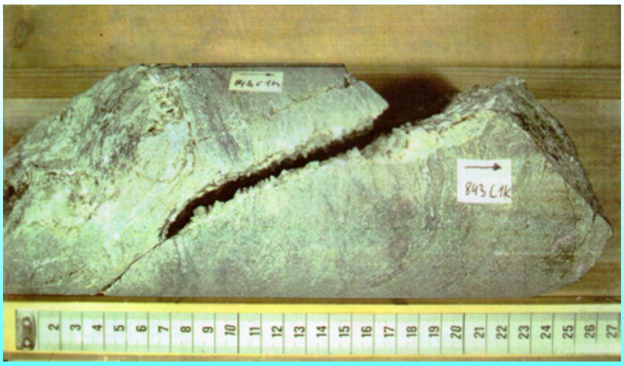


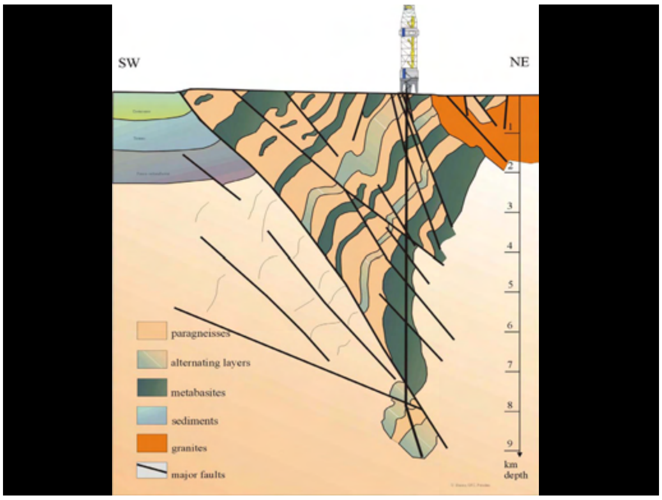
KTB - Kontinentales Tiefbohrprogramm der Bundesrepublik Deutschland

Preparatory Phase	Location Survey	1984 - 1986
Pilot Phase	4 km Pilot Drill Hole	1987 - 1989
	Test Programme	1989 - 1990
Main Phase	9.1 km Main Hole	1990 - 1994
	Key Experiments	1994
Final Phase	Deep Crustal Lab -	1996 - 2006

2002: Long-term (12 month) fluid withdrawel (60 l per min)

Status and processes of the deep continental crust

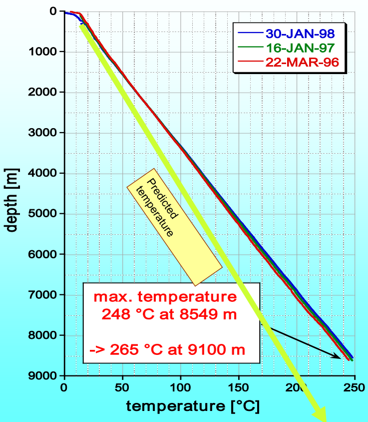




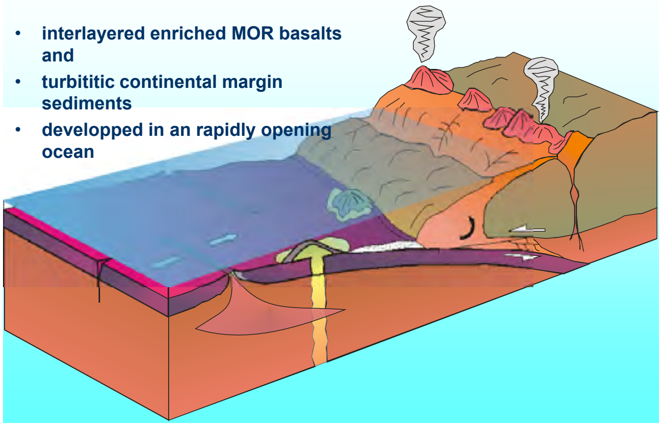
0 - 1000 m - 21 K/ km 1 - 9 km - 28 k/km
0 - 1000m - 55 mW/m²
1 - 9 km - 85 mW/m²

T underestimated from shallow boreholes (500 m) due to:

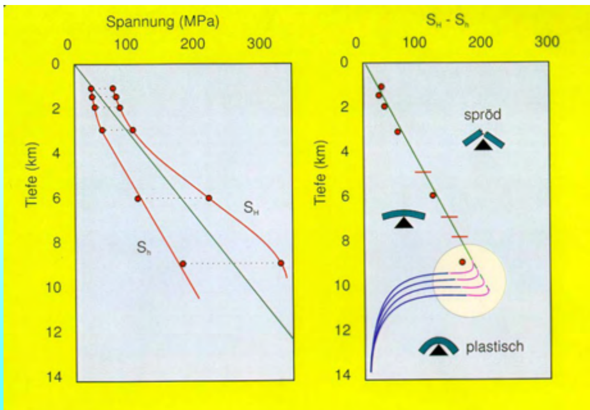
- groundwater circulation
- ice age cooling
- anisotropy in thermal conductivity



- interlayered enriched MOR basalts and
- turbititic continental margin sediments
- developped in an rapidly opening ocean



- 49 m height
- 2943 kN hook load
- 1249 kW elevator
- 22 m/s velocity
- 250 rpm table
- 360 kW pwr swivel
- 0 – 600 rpm
- 590 kW pumps
- Special WL string
- WL equipment



- Remote joystick-operated drilling rig
- Pumps, drawwork, hook, safety installlations
- Pipehandling system incl. retractor and pipe conveyor


JOYSTICK OPERATION OF DRAWWORKS

Drilling Strategy developed during VB:

- **Hi-automated extra heavy drilling rig**
- Vertical hole through vertical drilling system
- Downhole motor driven bits until 190° BHT
- Slim clearance casing concept due to VDS
- Super strong steel for drill pipes for enhanced tensile strength (+100 to reserve!)
- Special coring technologies (LDCS) based on WL experience in 12 ¼´´ and 8 ½´´
- High temperature polymer mud (Hectorite, +)
- Online data acquisition and storage
- Integrated Technical-Sciene-Logging Plans

Drilling Strategy developed during VB:

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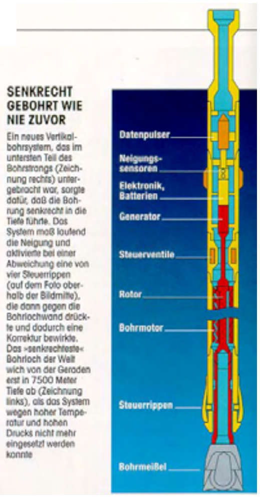
- 83 m height derrick
- 800 to hook load
- 2220 kW gear-driven draw works
- 3 x triplex pumps
- 35 MPa pump pressure
- 40/140 - 20/270 kNm/min table
- 70 MPa preventer
- Supplied by public power
- Automated pipehandling with retracting system
- 3 x 13.3 m drill pipe stands

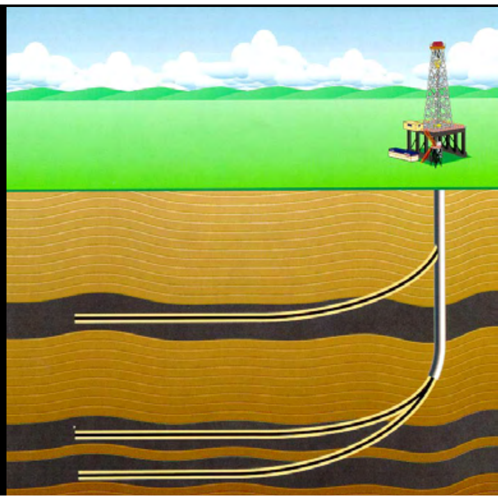
KTB Main Hole

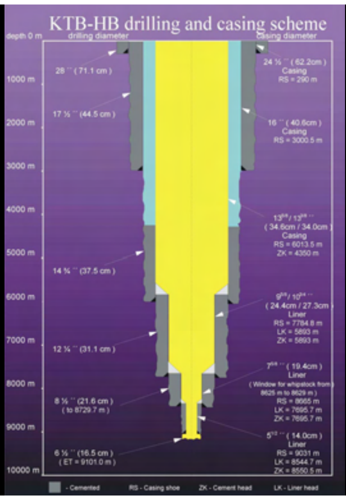
- Vertical Drilling System
- < 10 m deviation until 7.5 km
- Operation til 7.5 km depth
- Limitation due to BHT temperature and breakouts
- Controls on dev., T, P, function with mud pulsing
- major spin-off for hydrocarbon exploration with horizontal drilling techniques (>9 km horizontal drilling)



automated pipehandler with 12 km pipe capacity

6 km casing 13 3/8´´ in 14 ¾´´ OH (slimhole clearance concept); (720 to max. load)

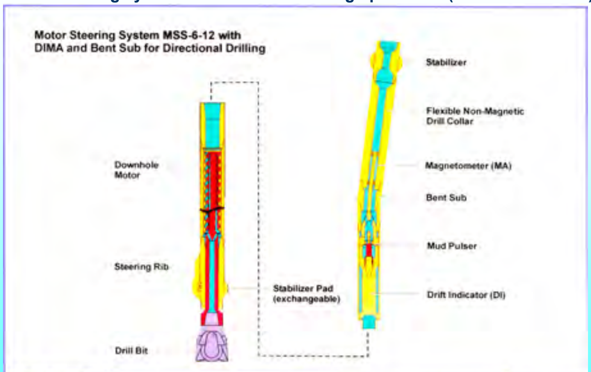




icdp

GFZ POTSDAM

motor steering system for directional drilling operations (based on on VDS)



GFZ POTSDAM | KTB Drilling Technology | ICDP/OSG

icdp

GFZ POTSDAM

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icdp

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- Vertical hole through vertical drilling system
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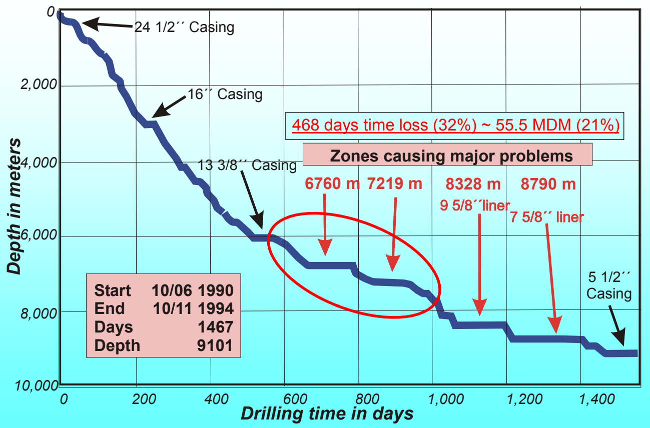
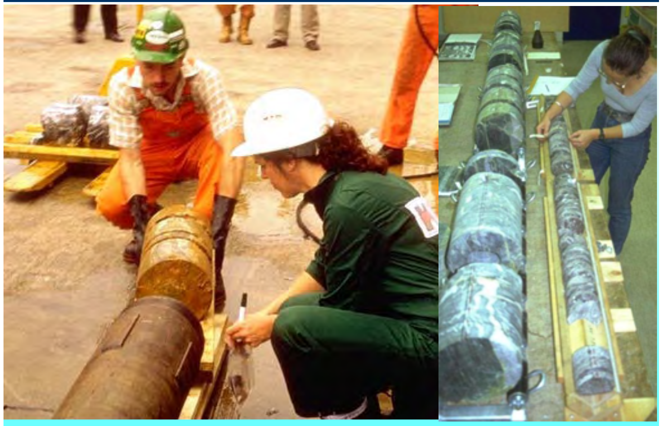
- **Slim clearance casing concept due to VDS**
- **Super strong steel for drill pipes for enhanced tensile strength (+100 to reserve!)**
- Special coring technologies (LDCS) based on WL experience in 12 ¼´´ and 8 ½´´
- High temperature polymer mud (Hectorite, +)
- Online data acquisition and storage
- Integrated Technical-Sciene-Logging Plans



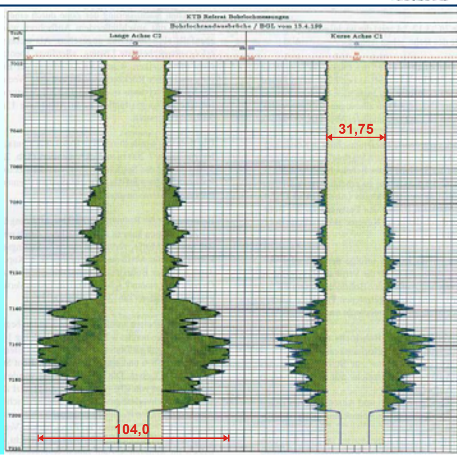


Caliper Log of the Fault Zone SE1 KTB-HB;

7000 – 7200 m;
Diameter in cm

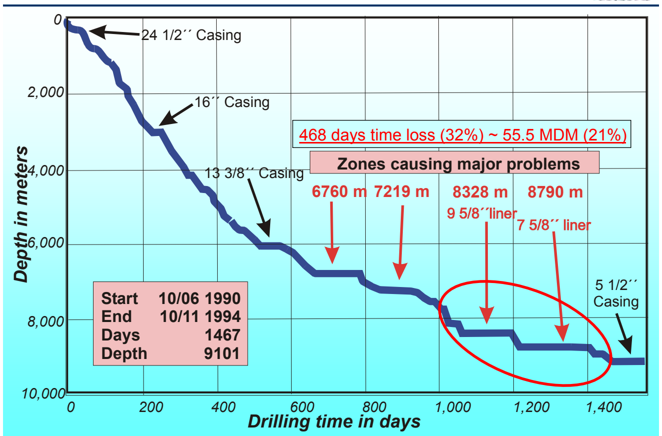
Volume increase:

31,75 cm = 79,1 l/m
104,0 cm = 849,1 l/m

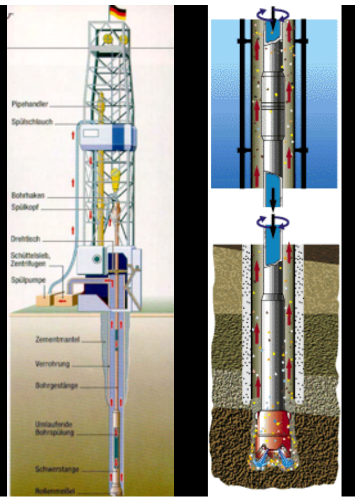


Drilling Strategy developed during VB:

- Development of extra heavy drilling rig
- Vertical hole through vertical drilling system
- Downhole motor driven bits until 190° BHT
- Slim clearance casing concept due to VDS
- Super strong steel for drill pipes for enhanced tensile strength (+100 to reserve!)
- Special coring technologies (LDCS) based on WL experience in 12 ¼´´ and 8 ½´´
- **High-T polymer mud (Hectorite, +)**
- **Online data acquisition and storage**
- **Integrated Technical-Sciene-Logging Plans**



- Heavy large rig
- Elongated pipe stands
- Automated Pipehandler
- Vertical drilling system
- Slim clearance casing

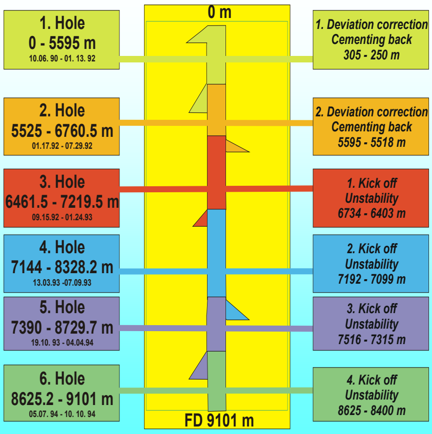


icdp GFZ POTSDAM

KTB Main Hole: major flaws

- Vertical Drilling Systems worked until 7.5 km, limits only due to technical problems (batteries/rubber seals) and financial shortage.
- No topdrive or powerswivel was installed (39 m reaming sections would have been possible). Without topdrive 13 m reaming only, interruptions in reaming, pumping and cooling causing more breakouts.
- The borehole walls were instable and produced not only large breakouts but also a caliper decrease! SHRINKING BOREHOLE due to induced stresses (e.g. cooling through mud) were completely unexpected and unknown! No defense available except more casings and higher costs or casing while drilling.

icdp GFZ POTSDAM



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KTB Main Hole: greatest achievements

- Vertical Drilling Systems (extreme reduction of torque)
- Slim Clearance Casing (tools size reduction plus extended casing capabilities)
- Huge rig, pipehandler, gear driven draw work, safety installations, high automatization (reduced tripping)
- HT Downhole motors (torque reduction)
- Special Coring Systems (successful coring at great depth)
- HT Mud System (stable, lubricating, but not contaminating)
- Integrated technical-science-logging teamwork

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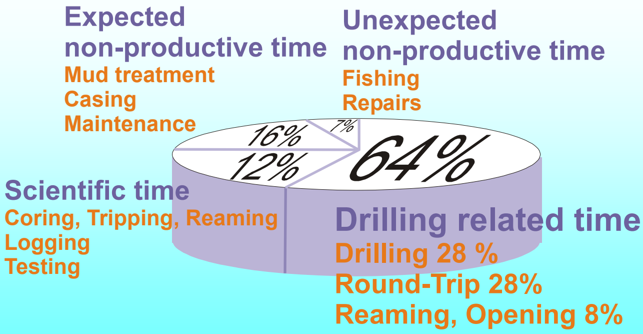
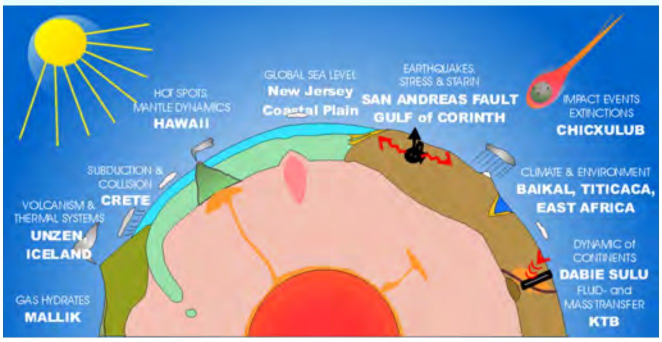


icdp GFZ POTSDAM

ICDP themes and projects:



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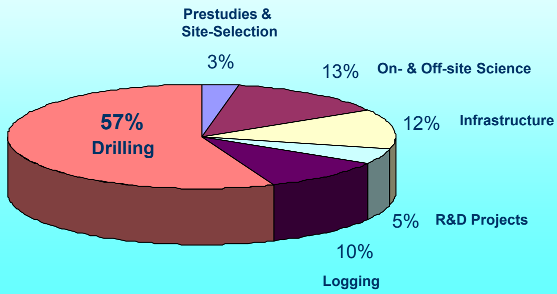
KTB total project costs

(1982 - 1995; incl. all pre-drilling studies):

527,800,000 DM

(26.5 MDM VB; 267 MDM HB)



Key Areas for Technological Improvements:

Borehole stability -	Breakout control with *Casing While Coring* or T and P mud control
Ultradeep Sampling -	Ultradeep ´WL coring´ or other rapid sampling (double-string counterflash coring)
Time and costs reduction -	bit life extension, round trip time reduction, slim-hole techniques, coring time = drilling time
HT/HP capabilities -	MWD, LWD, Fluid sampling

ICDP technical project characteristics

- **Lake Baikal 900 - modified rig and rebuilt coring tools**
- **Long Valley 3000 - com. rig, Hybrid WL Coring System**
- **Hawaii 3100 - com. rig, Hybrid WL Coring System**
- **Dabie Sulu 2000 - commercial rig and coring system**
- **Lake Titicaca 400 - new rig and barge, rebuilt coring tools**
- **Chicxulub 1510 - com. rig, Hybrid WL Coring System**
- **Mallik 1200 - commercial rig and coring system**
- **San Andreas 2000 - commercial rig and coring system**
- **Dabie Sulu 5000 - commercial rig, new WL system**
- **Corinth 1200 - commercial rig and WL system**
- **Unzen 2000 - commercial rig and drilling system**
- **Lake Malawi 1000 - modified barge, commercial rig**
- **Lake Bosumtwi 1000 - new rig and barge, rebuilt coring tools**

No Deep Drilling (5 – 8 km), no Ultradeep Drilling (8 – 14 km)

General KTB and ICDP lessons

Scientific drilling will:

1. **take place in extreme difficult environment**
   (volcanoes, faults, seismic zones, impacts, unconsolidated sediments, difficult environs.)
2. **be more expensive!**
   (10 – 20% contingency necessity [oil 200%])
3. **start later and take more time!** *(Planning flexibility)*
4. **encounter serious drilling problems**
   (Worst case planning)
5. **truncate unpredicted lithologies and structures**
   (Falsification of models and predictions)

Necessities for Seismogenic Zone drilling:

- **Vertical Drilling System, Active Steering System and downhole motors to final depth!**
- **Casing while drilling for loose and instable formations or extended casing scheme with additional casings planned beforehand!**
- **Feasibility investigations for new drilling and coring technologies including e.g. mud temperature and mud pressure adapted to formation temperature and fluid pressure!**
- **Use of (expensive) downhole M/L-WD systems available in oilfield industry (175°C) or alternative HT-HP tools in academia** (Mag, Sus, SP, hi-res-image)!

Soviet Kola Peninsula Drilling Project

Excerpts from Kozlovsky (1984).

Introduction

…Beyond all doubt, a clue to the mystery of origin and evolution of the Earth's crust is hidden in the unexplored depths of the Earth, which contain unknown mineral resources…

Three stages can be defined in the studies of the deep structure of USSR territory. The first covers the 1960's, when the general tasks were formulated, the problem was thoroughly studied from the scientific point of view, and Soviet-made technical means for ultra-deep drilling and geological-geophysical investigations in boreholes of 10-15 km on depth were developed. The second stage was in the 1970's, when the experimental drilling of the Kola and Saatly ultra-deep holes, as well as a number of key regional studies of deep geophysics, were undertaken. The third stage of research, begun in 1981, is a transitional stage planned to lead to the integrated study of the Earth's crust and upper mantle throughout the USSR.

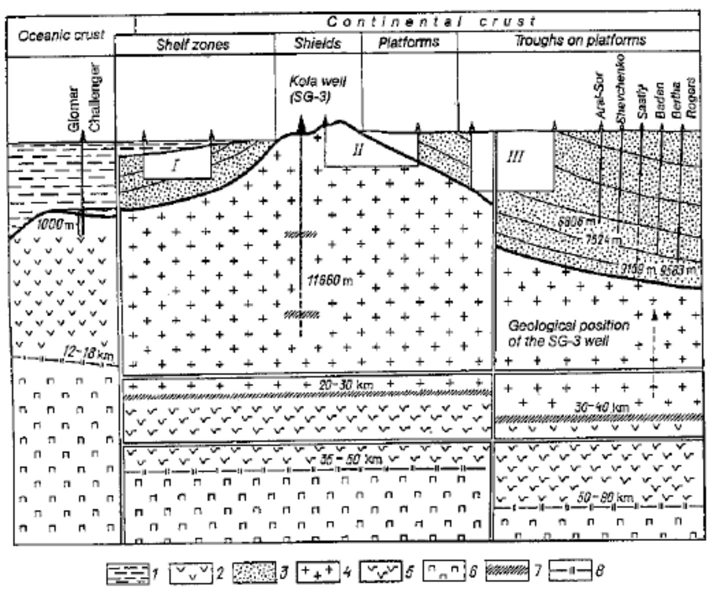


Fig. 1.1. Schematic section of the Earth's crust according to deep drilling data. Depths of deep exploratory drilling: *I* in the shelf zone; *II* for solid materials; III oil and gas wells. *1 Earth's hydrosphere; 2* oceanic basalts; *3* Phanerozoic sedimentary and volcano-sedimentary rocks (500Ma old); *4* Precambrian crystalline rocks of the granitic layer (1000-3000 Ma and older); *5* rocks of the continental basaltic layer; *6* mantle rocks; *7* high-velocity rocks – Conrad discontinuity (V_p = 6.6-6.8 km/s); *8* Mohorovičić discontinuity (velocityof elastic wave propagation (V_p = 8.0 km/s).

At the beginning of the 1960's, it became possible to start work on the study of the deep interior of the Earth, as standard drilling technology made it possible to foresee the design and drilling of ultra-deep wells to a depth of 15 km within the next few years.

Several wells have been already drilled in the USSR and USA to depths of 7-9 km in the search for oil and gas fields. These wells were spudded in sedimentary basins, and usually penetrated through the sedimentary layers which also outcropped at the surface on the flanks of these basins. Due to this, information obtained in such wells was insufficient for fully understanding the structure and composition of the deep parts of the Earth's interior.

Special tasks to be solved by superdeep wells and possible sites for their drilling were discussed by Soviet specialists at special meetings and in the press (Beloussov 1966; Belyaevsky and Fedynsky 1961; Khiatrov 1961). It was proposed that these wells could be aimed at studying:

a) the sedimentary cover of the deepest depressions on platforms;
b) the sedimentary fill of the geosynclines;
c) the composition and structure of the lower granitic layer, the nature of the Conrad discontinuity, the composition of the basaltic layer;
d) the nature of the Mohorovičić discontinuity, the composition and structure of the upper mantle layers;
e) the process of the differentiation of matter in the Earth's crust;
f) sources of intrusion;
g) solution and gases present in the Earth's crust;
h) the geothermal regime of the Earth's crust

The following areas were proposed for drilling wells from 10 to 15 km depth: Pre-Caspian depression, the Urals, Kareliya, the Kura depression, the Caucasus, the central regions of the East European platform, the kimberlite pipes of Eastern Siberia, Tien Shan, and the Kuril Islands.

1960-1969. In 1960-1962 proposals for organizing investigations of the deep crustal structure were worked out.

To ensure efficient organization, coordination, and management in investigations of the deep Earth's interior, the Inter-Departmental Scientific Council for the Study of the Earth's Interior and Superdeep Drilling was set up under the auspices of the USSR State Committee for Science and Technology (GKNT). ...

Professor N. S. Timofeev, Doctor of Technical Science, has been Chairman of the Interdepartmnetal Council since 1963. ...Professor Ye. A. Kozlovsky, Doctor of Technical Sciences, has been the Council since 1975…

All the work on the deep study of the USSR territory has been carried out under the guidance of the Interdepartmental Scientific Council, during which time more than 80 meetings and 75 visiting sessions have been held. The Council and its departments organized and developed work on the study of the Earth's interior by geological and geophysical methods and the drilling of deep and superdeep wells.

In 1965, a comprehensive joint scientific and technical programme of study of the deep crust was planned, according to which the Kola and Saatly superdeep wells were the first to be drilled. The Kola well was planned to penetrate the oldest Archean rocks of the Baltic Shield on the Kola Peninsula in the area of the Pechenga group copper-nickel deposits, 10 km north of the town of Zapolyarny, and probably enter the basaltic layer which, according to preliminary geophysical data, was thought to occur at a depth of about 7 km. It was proposed to sink the Saatly well within the limits of the Kura depression of the Azerbaijan Soviet Socialist
Republic, at a site confined to the known gravity maximum, presumed to have been caused by local uplift of the basaltic layer.

1970-1980. In accordance with this extended programme, a model of the Earth's crustal structure and upper mantle was planned, together with maps showing the estimated mineral resources and promising directions for further exploratory work throughout the country. Some tasks of the programme involved studies to solve those questions of applied geology closely associated with the fundamental theories of the deep structure and evolution of the Earth's crust, including further research into the processes responsible for mineral ore formation, and the laws governing their distribution pattern.

The USSR Ministry of Geology is the leading organization responsible for the study programme of the deep Earth's interior. Additionally, more than 150 research and industrial organizations are also engaged in the programme. The drilling of the Kola superdeep well was entrusted to a specialized exploration unit of the USSR Ministry of Geology - the Kola geological superdeep drilling expedition.

By the beginning of the 1970's, preparatory work for drilling the Kola superdeep well had been completed. This initiated the second stage, during which, besides drilling the Kola and Saatly wells, the Earth's interior was studied with the help of geophysical methods.

The drilling of the Kola SG-3 well (Fig. 1.2) started in May 1970. The following tasks were to be solved by this well:

1. to study the deep structure of the nickeliferous Pechenga complex and Archean crystalline basement of the Baltic Shield within the limits of the KolaPeninsula, to elucidate peculiar features of geological processes, including processes of ore formation;
2. to find out the geological nature of the seismic intersurface boundaries in the continental crust and obtain new data about the thermal regime of the Earth's interior, deep water solutions, and gases;
3. to obtain as much information as possible about the material composition of rocks and their physical state, to drill in and study a boundary zone between the granitic and basaltic layers of the Earth's crust;
4. to modernize existing equipment and technology and create new, as well as to perfect methods of geophysical investigations of both rocks and ores at great depth.

By 1980, long-term geophysical profiling, aimed at studying the crust and upper mantle, was completed in some regions. Data on industrial explosions were also used in the course of these investigations. A total of 18,000 km of deep seismic sounding profiles were conducted. On the strength of the data thus obtained, it became possible to elucidate the deep structure of the Earth's crust, i.e., trace the hypsometric position and relief of the Mohorovičić discontinuity and pre-Riphean basement in Eastern Siberia, and a series of intermediate boundaries in the consolidated crust and sedimentary cover, delineate zones of major faults boundaries and determine their vertical extent, outline with greater accuracy regional boundaries and the deep structure of positive and negative tectonic elements, which may be areas of endogenic mineral concentrations and oil and gas accumulation. New information was accumulated on the structure and physical parameters of the Earth's upper mantle within the limits of the old East European and Siberian platforms, fringing young plates and folded structures. Velocity seismograms to a depth of about 400 km were constructed, the absorbing properties of various environments were studied, and a generalized geological interpretation was given to areal zones with anomalous longitudinal seismic wave velocity propagation. Theoretical models of the crust and mantle were elaborated for some major tectonic units of USSR territory, including Western Siberia.

A combined study of different geophysical material from various geotectonic zones made it possible to establish that the previous model-based interpretation of geophysical data was too simple. For instance, the following facts were established:

a) a considerable non-uniformity in the vertical and lateral structure of the Earth's crust and lithosphere;
b) a complex relationship between the deep crustal structure and near-surface geological structures, i.e., a discrepancy between geophysical parameters (velocity, in particular) and anomalous objects caused by the presence of this discrepancy at different structural levels, which may be indicative of the bilayer disharmony of the lithospheric structure;
c) the presence of boundaries of probably differing geodynamic states of the Earth's crust, fixed at relatively shallow depth (10- 15 km); these boundaries were encountered in addition to geological (structural-material) boundaries.

In 1980, the Kola superdeep well reached a depth of 10.7 km. As a result of the drilling, unique geological information was obtained about the deep structure of the Baltic Shield (Kozlovsky 1981; Kajiawava and Krause 1971; Kozlovsky 1981). This information substantiates previous theories. On the basis of a direct study of the mineral and geochemical composition of core samples and a series of geophysical investigations conducted in the borehole, new data were gathered on the material composition and physical state of rocks at depth; these data differ considerably from those of previous modelling data, and are important for prognosticating hidden deposits of mineral resources (iron ores, copper. nickel, mica, and rare metals) not only in the Kola Peninsula but also on other ancient massives. On the basis of these data reliable interpretation of geophysical materials became possible, which plays an important role in elaborating tectonic problems in geology.

It was established that the composition and properties of rocks change regularly with depth. For the first time the vertical zonality of rock metamorphism was revealed in one continuous section, again different from the theoretical model. The facts obtained can be used for future elaboration of the petrogenetic theory.

The experimental studies permitted an understanding of the geothermal regime of the ancient Earth's crust. The geothermal gradient proved to be higher than was anticipated; the role of mantle and radiogenic sources in the total heat balance at depth was identified. A substantial contribution was made to working out a thermal model of the formation of the Earth's crust by taking into account effective endogenic heat.

A vertical geochemical section of the Earth's crust to a depth of 11.6 km was constructed for the first time, and depth-dependent regularities of acidity and alkalinity of rocks and the behavior of ore, and rare and radioactive elements, depending on these changes, became evident. A model of the chemical composition of the primitive continental crust was built, with inclusion of data on deep seismic sounding.

New basic data on the ore-forming processes occurring in deep crustal layers were found. Commercial copper-nickel ores were discovered in an interval of 1665 - 1830 m, confined to an unknown "ore horizon"; this extends the possibilities of discovering new copper and nickel ore accumulations in the Pechenga region. Nickel ores were found to extend down to a great depth, their content of valuable elements remaining constant. At a depth of 6500-9500m, zones of copper, lead, and nickel mineralization were found for the first time, showing that not only the upper layers, but also deep layers of the Earth's crust favour mineral formation. This conclusion is important for further development of the theory of mineral resources, and extends the possibility of searching for new ore deposits.

It was established for the first time that zones of highly porous, fractured rocks saturated with deep subsurface waters exist at depth in older shields; their presence had previously not been assumed. Some special features of the chemical composition of subsurface waters were found, which represent a substantial contribution to a model of the hydrophysical zonality of the Earth's crust.

The physical state and properties of rocks at a depth exceeding 10 km were identified by the new data obtained. At places a high permeability of the rocks was fixed, which is important for prognosticating underground "hollows" and assessing the possibility of their use for burying highly toxic industrial wastes.

According to data from geochemical, geophysical and nuclear-geophysical investigations conducted in the borehole, as well as from laboratory studies of core samples, a correlation was established between chemical composition, structure, and physical properties of the rocks encountered by the Kola SG-3 borehole. On the basis of this material, the real geological nature of deep seismic intersurface boundaries was revealed. These data did not confirm the geophysical model of the Pechenga region deep structure. Instead of drilling through the basaltic layer, which, on the basis of geophysical data, was expected to occur at a depth of 7000- 7500 m, the borehole encountered compact Archean gneisses. This allows a new interpretation of data on surficial geophysical investigations, not only on the Baltic Shield, but also in other areas composed of old crystalline rocks.

The Kola section may be used as an area of reference. This will increase the reliability of geophysical survey, and particularly, the accuracy .of the deep seismic sounding being carried out intensively in the USSR and in other countries.

The unique material on the structure of the Earth's crust and the state of rocks at great depths provided by the Kola well allows a more reliable assessment of various endogenic processes in the formation of rocks and ores and consequently makes different metallogenic constructions possible on this basis. The new technical means and elaborated methods, successfully put into practice, have raised geophysical studies in wells to a higher level, which is very important for increasing the efficiency and quality of geological exploration for oil, gas and other minerals.

Another superdeep well, the Saatly well, was sunk in 1977 within the limits of the Kura depression (Azerbaijan Soviet Socialist Republic). The drilling site is confined to a gravity anomaly. This gravity maximum was assumed to have been caused by a locally uplifted top of the basaltic layer. The well penetrated loose Cenozoic and Upper Mesozoic rocks and entered a thick layer of volcanogenic rocks probably of Cretaceous and Jurassic age. These strata seem to be a cause of the gravity maximum. The well is planned to penetrate the entire thickness of the volcanogenic sequence and reach the Paleozoic basement.

In drilling the Kola and Saatly wells a number of important technological problems of superdeep drilling were solved and new equipment developed.

In other countries superdeep wells (e.g., the USA) are usually drilled with the help of units working under great strain (load capacity 6-8 Mega-Newton, pump pressure 50MPa). However, superdeep wells drilled outside the USSR have not exceeded a depth of 9100-9600m. An analysis of trends in constructing drilling units shows that reserves for increasing the unit load capacity further are practically exhausted. Soviet specialists worked out a technology of well drilling which made it possible to sink a well to the planned great depth (exceeding 10 km) with the help of a drilling unit of lesser load capacity (5 MN) and pump pressure (40 MPa). The sinking of the Kola well has induced innovations in drilling technology, based on the principle of the advance hole. The well is run with the help of a bottom-hole turbine. The drill string is made of lightweight aluminium pipe.

A new drilling unit for driving the well to previously inaccessible depths was created by a group of scientists and workers of the Uralmashzavod (Figs. 1.3, 1.4).

They have devised and put into practice rock-crushing instruments and bottomhole engines capable of working at great depths, including bits and speed-reducing turbodrills, which work very steadily at optimum rotation speeds. Another innovation introduced in the Kola well was a system of devices which controls the turbodrill work at the well bottom. In the absence of these controlling devices, drilling of a well with the help of the down-hole motor at depths exceeding 8 - 9 km becomes impossible. Light alloy drilling pipes of high strength (yield strength reaches 500 MPa) and thermostability (up to 200T) have been designed and used in the well, which made it possible to drill the well at great speeds in round trip operations.

The high standard of the technical means created, their novelty and efficiency became an acknowledged fact: more than 40 patents were granted to their inventors, about 20 units of new equipment were put into serial production, their use allowing record drilling depths.

The complex scientific-technological experiment of the Kola superdeep drilling was accomplished solely by Soviet technology and technique.

The fulfillment of the drilling programme for this unique well provided important practical results: explorers have been provided with the modern technical-technological means enabling them to study and exploit the Earth's natural resources at a depth previously inaccessible.

1981 – 1985. Analysis of data of superdeep drilling and regional geophysical investigations undertaken in the USSR prior to 1981 shows that only a basically new approach to planning and carrying out of this work could have resulted in an increase in efficiency. However, this task could only he implemented if a regional study of the Earth's crust and upper mantle was carried out throughout the whole territory of the USSR on the basis of an integrated nation-wide system (Belousov 1982; Kozlovsky 1982).

The principal basis of the system is a network of coordinated geophysical profiles based on deep and superdeep key wells (Fig. 1.5). It has also been suggested that the prediction of geophysical testing grounds for the study of variations in geophysical fields should he included in this system. The main framework of the network is a reference basis for more detailed study within a particular region. Data from aerospace and aerogeophysical surveys for the complex interpretation of investigation results will help in constructing much-improved three-dimensional geological-geophysical models for the entire territory of the USSR.

The principle task of the studies along the extended framework profiles of long distances, so-called geotraverses, is to reveal the fundamental differences in structure and state of the lithosphere in regions of different geodynamic development throughout the country. Smaller profiles are laid within homogeneous tectonic blocks or across a system of such blocks and their confinements (junction zones, major faults, contacts). They should help in solving structural-tectonic, lithological (material composition) and other regional problems. Surveys within the geotraverses are detailed and aimed at studying more local inhomogeneities of the upper parts of the crust, faults, and contacts. They are primarily intended to solve problems of medium- and large-scale prediction and to assist in the search for mineral deposits.

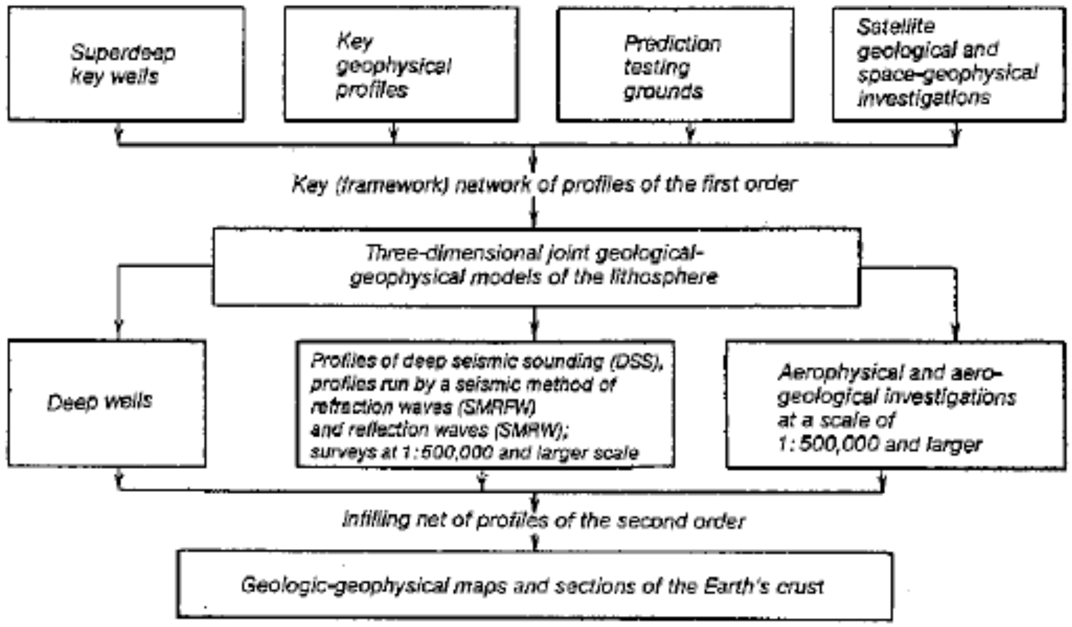


Fig. 1.5. Scheme of the regional study of the Earth's crust and mantle within the limits of USSR territory.

The systematic study of the crust and upper mantle is a distinctive feature of the whole programme, according to which a network of large interlinked key profiles runs over to extensive areas. This makes it possible to trace changes in physical parameters from one region to another of different geodynamic development regimes.

The integration of geological-geophysical and geochemical investigations, coinciding both spatially and temporally, allow a higher degree of reliability in the conception of the structure and dynamic state of the domain studied.

Further expansion in the drilling of superdeep and deep wells was planned. The drilling of the Kola and Saatly wells will be continued; other superdeep wells to he drilled were the Tyumen, Anastasievsko-Troitskaya and Ural wells (down to 12-15 km). At the same time, six deep wells were to be sunk in 1981 -1985, three of them (Dnieper-Donetsk, Pre-Caspian, Timan-Pechora) to be drilled in oil and gas-bearing regions and the other three (Muruntau, Norilsk, Krivoi Rog) in ore-bearing regions.

According to the plan, by 1985 the Kola well was to reach a depth of 13,000 m and penetrate new intersurface boundaries in the crust, as established by seismic investigations. It was assumed that the so-called granulite-basite layer would be encountered. In deepening the borehole the further industrial testing of the *Ultramash-15000* drilling unit was planned, the technology of superdeep drilling perfected, new geophysical devices for work under conditions of high pressure and high temperature devised, and all put to practical use.

When the drilling of the Kola well is completed, the well is envisaged as becoming a unique natural laboratory for studying processes deep in the Earth's crust, for conducting permanent observations of temperature regimes, studying conditions and possibilities of burying industrial wastes at great depths, and testing and perfecting devices and methods of geological-geophysical, geochemical and hydrogeological investigations. The drilling and combined geological-geophysical investigations of the Saatly well will be continued to a depth of
11,000m.

The drilling of the Tyumen superdeep well should offer the possibility of evaluating the oil and gas potential of the Jurassic and pre-Jurassic rocks in the northern part of Western Siberia, and elucidating the deep structure of this area and assessing its prospects. The Ural superdeep well was planned to penetrate a section of the major ore-bearing folded region, with the aim of resolving basically important problems of geology and prognosticating new deposits in this region. Results of superdeep drilling, together with geophysical investigations, should allow a higher degree of reliability in directing prospecting and exploratory work for the period 1990- 1995 and to the year 2000.

The present state of drilling technology and techniques in the Soviet Union allows the assumption that Soviet industry is in possession of all the means necessary to implement the study programme of the country's deep structure.

In 1981-1985 work in research and experimental design to perfect the technology and techniques of superdeep drilling will continue. The production must be speeded up of experimental and industrial high-strength drilling pipes and tool joints; rock-crushing instruments to ensure effective drilling and core sampling at high temperatures; thermostable turbodrills with reduction gears; geophysical equipment for conducting geophysical studies at depths exceeding 10,000m; blocks of bottom-hole devices for registering drilling regimes; chemical reagents and lubricating additives for treating thermostable drilling muds; special thermostable materials for manufacturing drilling instruments and bottom hole engines. A special model of conditions in wells drilled to a depth of 15 - 20 km, with temperature and pressure at the bottom hole at to 300° -400°C and 200- 300 MPa, respectively, is now being built.

It is planned to build highly mechanized drilling units with load capacities reaching 5 Mega Newton and working pump pressures of 40 - 50MPa for the Ural, Tyumen and Anastasievsko-Troitsk wells. The technology of further Kola drilling using the advanced-hole method to a depth below 12 km must be worked out and tried. Designs must be made for the Saatly well to secure its sinking to a depth of 13 km.

The programme plans to develop a drilling method which could effect core sampling without pipe-lifting operations.

In the programme of the study of the Earth's deep crust by deep and superdeep wells, great importance is attached to the problem of developing technical means for conducting geophysical investigations in wells under high temperature conditions (up to 350°C) and pressures up to 30MPa. A stationary well-logging truck hoist, needed for running and lifting operations in wells drilled to a depth of 15 km, is being put to work at present at the Kola and Saatly wells. It is also necessary to make load-bearing three-core logging cable 15,500 m in length.

There is every reason to believe that the comprehensive study of the Earth's interior within the borders of the Soviet Union will increase and deepen our knowledge of the characteristics of the crustal structure and its evolution. This will be a valuable contribution to expanding and strengthening the basis of raw minerals of the national economy of the USSR. This programme will further help to elucidate a series of general problems of the Earth's tectonosphere, structure and evolution.

This joint programme is principally aimed at studying the continental crust and upper mantle. With this in mind, it is interesting that at the time that this work was being planned and developed, American scientists proposed a project of ocean drilling, which later became an international project, in which a number of countries, including the USSR, took part. The American vessel *Glomar Chal*lenger drilled a total of more than 500 ocean wells; these wells were the first to give information about the composition, age, and structure of the sedimentary cover on the ocean floor and about the uppermost horizons of an underlying consolidated layer of the oceanic crust composed of basalts which had erupted on the ocean floor. The Soviet continental project, and the international oceanic project supplement each other.

There is no doubt that the oceanic project is of great scientific significance, for which reason the Soviet Union participated. It must be emphasized that the Soviet Union, as the largest continent, is particularly interested in discovering the principles of continental crustal structure and evolution. This will allow the creation of a well-grounded scientific basis for the prognostication of mineral resources. Apart from this, it should not be forgotten that mankind lives on continents and extracts the major part of raw minerals from the continental crust.

In spite of the fact that in recent years sea and ocean areas are being intensively explored by man, the mineral resources beneath sea and ocean floors (preferentially resources of oil and gas), are mainly concentrated within the limits of shallow shelves, i.e. in the same continental crust covered by water. In view of the fact that the composition and structure of the continental crust are less homogeneous than those of the oceanic crust, it may be anticipated that also in the future the greater part of minerals will be discovered mainly in the continental crust.

The USSR is not the only country to recognize the importance of the study of the continental crust. American scientists, after a long period of enthusiastic oceanic research, decided to proclaim the 1981 - 1990 period as a decade of intensive study of the North American continent. When a programme for the international project *Lithosphere*, which later took over from the *Geodynamic project*, was being prepared, it was especially emphasized that continents deserve greater consideration than they had previously been given in the international projects.

The Soviet Union has always been more consistent in carrying out large-scale studies of the structure and regularities in the evolution of the continental crust than other countries. This is a deeply rooted tradition in our country, and it is still very much alive, thus promoting the further development of the basis of USSR mineral resources.

Table 3.13. Drilling performance of *Ultramash-4E*

Indices	Total in the interval 0-11 500 m	***Uralmash-4E*** drill rig				***Uralmsh-15006*** drill rig		
		0-2000 m	2000-4000 m	4000-6000 m	6000-7263 m	7263-9000 m	9000-10000 **m**	L0000-11500 m
Penetration in m	11500	2000	2000	2000	1263	1737	1000	1500
Overall drilling rate, m/rig month	96	313	175	103	99	62	69	55
Penetration rate, m/h	*1,8*	*2.0*	*1.4*	*1.3*	*2.0*	*2.0*	*2.5*	*2.5*
Penetration per run, m	*7.2*	*7.9*	*5.8*	*6.8*	*7.2*	*6.9*	*8.6*	*9.7*
Single round trip, h	10	2	6	9	14	14	15	17
Overall round trip velocity, m/s	0.32	0.24	0.29	0.29	0.28	0.33	0.34	0.34

Table 3.14. Time distribution in Kola well drilling

Indices (per 1 m of drilling)	Total in the interval of 0-11 500 m	***Uralmash-4E*** drill rig				***Uralmsh-15006*** drill rig		
		0-2000 m	2000-4000 m	4000-6000 m	6000-7263 m	7263-9000 m	9000-10000 **m**	L0000-11500 m
Total calendar time of drilling, h %	7.5	2.3	4.1	7.0	7.3	11.7	10.4	13.1
	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Including net drilling, h %	2.0	0.8	1.7	2.2	2.5	2.5	2.2	2.2
	26.7	34.8	41.5	31.4	34.4	21.4	21.2	16.8
								Of which:
On-bottom, h %	*0.6*	*0.5*	*0.7*	*0.8*	*0.5*	*0.5*	*0.4*	*0.4*
	8.0	*21.7*	*17.1*	*11.4*	*6.9*	*4.3*	*3.9*	*3.1*
Round trip, h %	*1.4*	*0.3*	*1.0*	*1.4*	*2.0*	*2.0*	*1.8*	*1.8*
	18.7	*13.1*	*24.4*	*20.0*	*27.4*	*17.1*	*17.1*	*13.7*
Auxiliary operations, h %	3.1	1.0	2.0	3.1	2.5	5.4	3.5	5.1
	41.3	43.5	48.8	44.3	34.3	46.1	33.6	38.9
Repairs, h %	0.6	0.1	0.2	0.6	0.5	0.5	1.0	1.5
	8.0	4.3	4.9	8.6	6.8	4.3	9.6	11.5
Problem control, h %	1.0	-	0.1	0.3	1.3	2.2	1.3	2.9
	13.3	-	2.4	4.3	17.8	18.8	12.5	22.1
Overall drilling time, h %	6.7	1.9	4.0	6.2	6.8	10.6	8.0	11.7
	89.3	82.6	97.6	88.6	93.2	90.6	76.9	89.3
Unproductive time, h %	0.8	0.4	0.1	0.8	0.5	1.1	2.4	1.4
	10.7	17.4	2.4	11.4	6.8	9.4	23.1	10.7
								Including:
Accident elimination, h %	0.5	-	0.1	0.5	0.2	0.9	2.3	0.8
	6.7	-	2.4	7.2	2.6	7.7	22.1	6.1
Idle time, h %	0.3	0.4	-	0.3	0.3	0.2	0.1	0.6
	4.0	17.4	-	4.2	4.2	1.7	1.0	4.6
								Of which:
Delay in supply of new equipment and tools, h %	*0.1*	*0.4*	-	*0.1*	*0.1*	*0.1*	-	*0.6*
	1.3	*17.4*	-	*1.4*	*1.4*	*0.8*	-	*4.6*
Delay in supply of Geophysical instrumentation, h %	*0.2*	-	-	*0.2*	*0.2*	*0.1*	*0.1*	-
	2.7	-	-	*2.8*	*2.8*	*0.9*	*1.0*	-

Table 3.28. Core recovery data

Depth range, m	Section No	Number of runs	Penetration, m	Core recovery		Average per run, m	
				m	%	Penetration	Core recovery
0-1059	1	108	942	386	41	8.7	3.6
1059-2805		239	1674	913	54.5	7	3.8
2805 -4673		265	1570	940	59.7	5.9	3.5
Total:		612	4186	2239	53.4	6.8	3.7
4673 - 5624	2	80	644	103	16	8.1	1.3
5642 - 6823		125	865	260	30.1	6.9	2.1
6823-7263		35	334.7	46.8	14	9.6	1.3
Total:		240	1843.7	409.8	22	7.7	1.7
7263-7943	3	39	291.3	105.8	36.3	7.5	2.7
8043-9008.4		105	742.5	308.1	41.4	7.1	2.9
Total:		144	1033.8	413.9	40	7.2	2.9
9008.4- 10028	4	104	835.8	248.3	30	8	2.4
10028-10772		56	612.2	163.9	26.8	10.9	2.9
10772-11500		61	723.7	225.2	31.1	11.9	3.7
Total:		221	2171.7	637.4	29	9.8	2.9
Grand total:		1217	9235.2	3700.1	40.1	-	-

Conclusion

1. Geology
2. Geophysics
3. Drilling

Effective penetration deep into the Earth's interior has been made possible by the Soviet-made high-performance drilling equipment and tools and advanced technologies. Surface and downhole equipment and tools feature light weight and simple design. They can be successfully employed wherever there is insufficient information on drilling conditions in crystalline rocks. The breakthrough has largely been due to new technical approaches, such as open-hole advance drilling, low-speed turbodrilling, the use of light-alloy aluminium drill pipes and instruments for monitoring the turbodrill operation at the bottomhole with data transmitted to the surface, etc.

The drilling technology has proved highly effective - a depth of 12 km was reached using a drilling rig with a load capacity of only 4 MN, the open pilot hole had an unprecedented length of more than 9.5 km, the weight of the run-in drill string was within 160- 170 t and the full cycle of round trip operations did not exceed 18 h.

Previously existing purely theoretical concepts of rules of variation of the drilling process have been verified. For instance, rock drillability at great depths was not affected at all. The maintaining of the stability of the crystalline rock mass in the zone surrounding the hole has proved to be a more complex problem than expected. The procedures for drill string design had to be essentially modified to allow for resistance forces and loss of strength of light-alloy pipes at high temperatures. A technique of core recovery from the bottomhole in a state of composite stress has been improved. New features have been established to control hole path and other drilling parameters. With the sample information available, one can effectively plan both the drilling process and development of high-performance equipment with prescribed characteristics on a scientific basis....

PLAN: JUDGE Project

Urabe, T., N. Morita, T. Kiguchi, T. Miyazaki and S. Kuramoto, JUDGE Project: A Continental Scientific Drilling into Plate Subduction Zone.（1）Executive Summary, Bull. Geol. Surv. Japan, 48, 122-125, 1997.

Abstract: The Japanese Islands locate at the plate boundary which is, geologically speaking, one of the most active region on our globe. At this region, oceanic plate diagonally descends under continental plate. This phenomenon, called plate subduction, causes various kinds of natural hazards such as volcanic eruption, earthquake and tsunami. On the other hand, it gifts us variety of natural resources. For example, the gold, a representative mineral resource in Japan, contributed the fertility of the Japanese culture in ancient era: The treasures of Imperial Warehouse *Shosoin* and a large amount of scriptures of Buddhism which represent *Tempyo Culture* of the 8th Century were bartered with *T'ang Dynasty*, China for gold from Japan (Shiba, 1990). All the geological characteristics of Japanese Islands are derived from the subduction and relevant activities.

Japanese Ultra–deep Drilling and Geoscientific Experiments (JUDGE project) is a proposal of a big science project to conduct land–based drilling at southern Kanto region to intersect the subduction zone that exist at a depth of 10km and to perform scientific observation with this well as if it is a telescope to look into the earth's interior. This special issue presents the societal and scientific rationale of the project as well as its summary, technical review of its feasibility, and required technology innovation.

Southern Kanto is a very rare locality where we can reach subduction zone from the surface at a depth less than10km. The area is also unique in the world since there is fully furnished seismometer network that enables us to monitor seismicity related to the subduction. In this subduction zone, we can observe geologic unit called accretionary prism in which sediments on the oceanic plate are rolled up as if they were scraped up by a bulldozer. The basement of the Japanese Islands has been accumulated throughout the geologic time as accretionary prism formed along the eastem margin of the Asian continent. The JUDGE project gives us an opportunity to observe active processes of "mountain building" and global geochemical cycle which occur in a malor scale at the subduction zone. Therefore, the JUDGE well is regarded as a natural laboratory to test critical hypotheses on earth processes.

The JUDGE project is also able to answer questions of societal interest; JUDGE well is expected to penetrate through the earthquake source fault of giant interplate earthquake which did and wiIl continue to attack Kanto area. *In situ* monitoring at the fault gives us a chance to possibly contributes to the prediction of the giant inter–plate earthquake. The JUDGE prolect contributes to widen the option on geological disposal of high Ievel radioactive waste for a country like Japan that locates in the subduction zone. Therefore, nformation obtained by the JUDGE project is not only indispensable for the security of Japanese nation but also useful for the circum pacific nations who suffer similar natural hazards.

The estimated temperature of the JUDGE hole at a depth of10km ranges between 200 and 400°C, according to the various methods of estimation. If we assume the highest value of400°C as the bottom hole temperature, maximum operation temperature of present drilling tools and mud should be raised by 110°C. Besides, a completely new concept of drilling operation should be developed to get as many data as possible. Therefore, it is essential, at an early stage of the program, to determine geothermal gradient accurately to set the goal of the technology development. The JUDGE project is based upon the systematic integration of technology which will give us strong incentives to expand the industrial horizon toward the unexplored domain like Apollo project

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Fiction

Reality

Newsweek

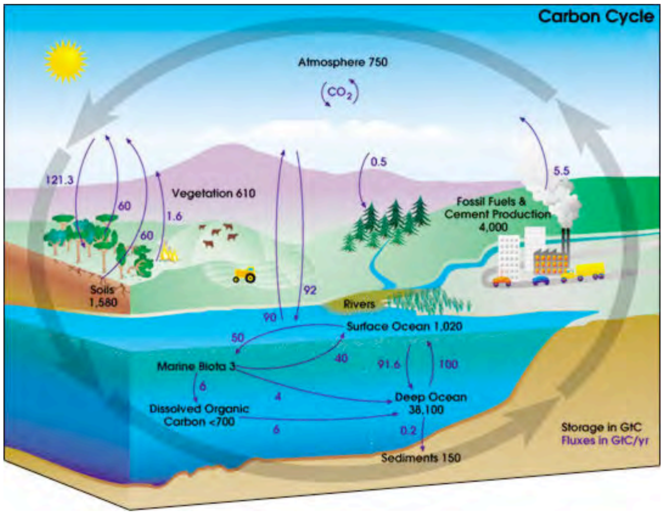
Drilling To The Core

by Hideko TakayamaSeptember 12, 2005

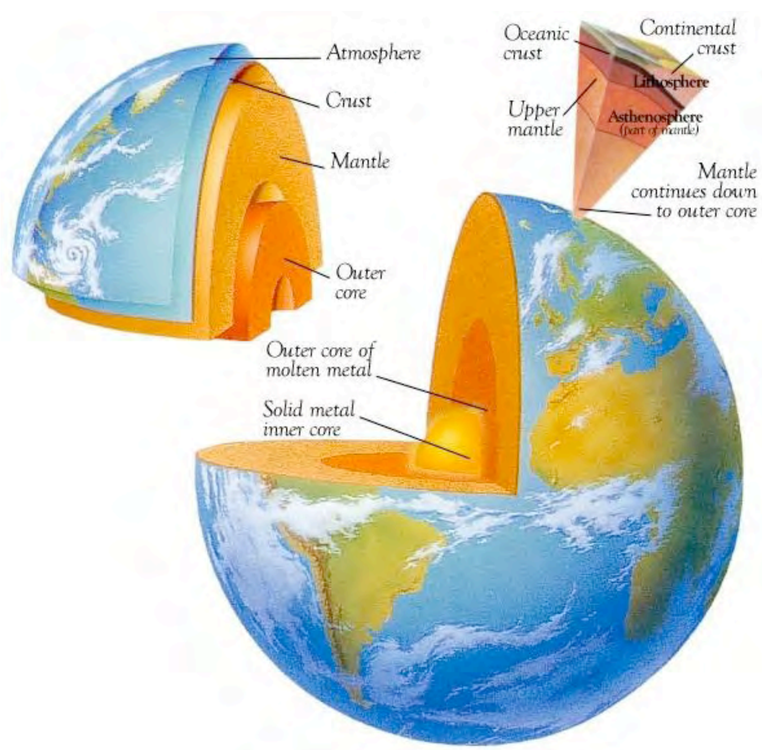
In Jules Verne's classic 19th-century novel "Journey to the Center of the Earth," Professor Lidenbrock travels to a mysterious subterranean world. Now a Japanese ship is aiming to replicate his adventure, striking out on its own quest to explore the earth's depths. In August, the massive 57,000-metric-ton Chikyu ("Earth"), a cutting-edge deep-sea drilling vessel, left Nagasaki on a test run. Though the Japanese venture may not reveal the prehistoric monsters or hidden oceans that Lidenbrock's journey did, it is hoping to reach unprecedented depths.

Expectation

Carbon Cycle (NASA)



Earth's Carbon: How much and where?



Atmospheric CO_2 380 ppm
Seawater C: 30 ppm
Crust: 200 ppm
Continental crust: 4000 ppm
Mantle: ???
Core: ???