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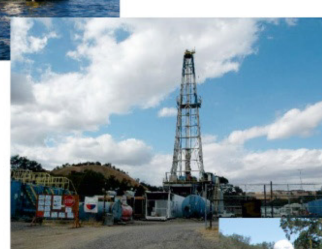
International Continental Scientific Drilling

ICDP Primer

Planning, Managing, and Executing Continental Scientific Drilling Projects

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Preface

Present day system Earth research utilizes the tool "Scientific Drilling" to access samples and to monitor active processes that cannot be addressed by other means. Unlike most laboratory experiments or computer modelling at geoscience departments, drilling projects are always large field endeavours requiring concerted interactions of researchers, engineers, and service providers. In the framework of the International Continental Scientific Drilling Program, ICDP, more than thirty drilling projects have been developed, from multi-year big research programs such as the "San Andreas Fault Zone Observatory at Depth" to short, small-scale deployments such as lake drilling projects. The ICDP has supported these projects not only through grants covering operational costs but also through operational support.

The GFZ - German Research Centre for Geosciences in Potsdam as the ICDP Executive Agency provides expert manpower in the form of the ICDP Operational Support Group (OSG). OSG helps to organize drilling projects, provides tools and services and supports project scientists in all aspects of the preparation and execution of a drilling scheme. In addition, scientists and engineers of the OSG have sustained also a range of non-ICDP scientific drilling projects. This collective expertise is used to train participants of upcoming drilling projects of the ICDP through the annual ICDP Training School as well as through individual training programs.

The key steps and important challenges in planning and executing continental scientific drilling have been distilled by the OSG into this primer as best practice brochure. As training courses and projects will change over time this document will change alike: Accordingly it will be made available mainly through the Internet as downloadable electronic file.

Potsdam, October 2015

Operational Support Group ICDP:

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ICDP Primer

Planning, Managing and Executing Continental Scientific Drilling

Introduction

Scientific drilling projects start when in a research project the lack of appropriate samples or data from depth experienced in field campaigns drive the idea to drill and existing data justify a preliminary siting and depth determination for a borehole. At this point a pre- or workshop proposal to the ICDP will help to evaluate if the project can be acceptable for funding and what issues need to be addressed. A workshop proposal will already seek financial support to assemble an international team, discuss science, engineering and management of a drilling project and strive to prepare the submission of a full proposal. When finally a full proposal has been accepted by ICDP and other co-funding agencies a funding agreement will be signed with the Principal Investigators that determines the rights and duties of the parties. At this point schedules will be fixed and companies providing drilling and other needed commercial services will be contracted.

As soon as the drilling operations are underway scientists will start documenting and investigate samples in the field. Research that cannot be performed on site will be done in the labs of the participating scientists. The curation of samples and reporting must also be done in parallel but the data gained in this phase are usually under a period of confidentiality. The duration of this moratorium period is to be determined by the science team according to funding regulations.

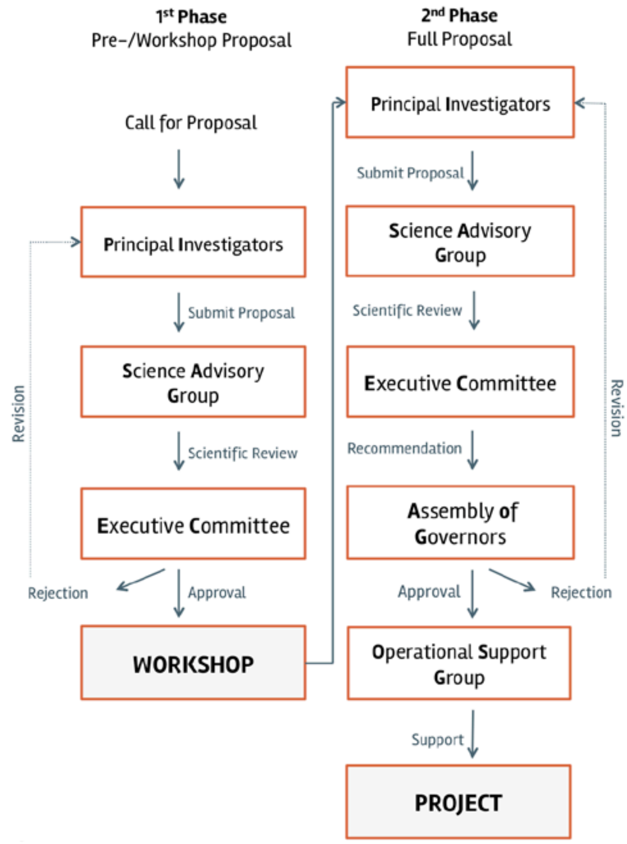

Fig. 1.1: Scheme of ICDP proposal flow

After the end of field operations the laboratory work continues in most drilling projects for years, as samples have to be taken to perform high-resolution analyses. Once results from this work are available a coordinated approach to publish initial scientific articles, detailed reports and also results of single working groups will be needed. A general rule of thumb is that this time period of data-access exclusivity for participating scientists lasts from the time of data and sample acquisition for 2 years (as a reasonable time frame to publish at least preliminary data), or for a well-defined time period based on certain research criteria (e.g., the forecast that a certain measurement cycle will take longer than the 2 years). However, this time period wants to be clearly defined by the time the actual field measurements start, and preferably already upon signing the MoU (Memorandum of Understanding). After the end of the moratorium time data sets gained over the period have to be published and sample materials have to be stored and made available for other scientists (see: Table 1 below for more details).

Phases of a scientific drilling project

Phase	Purpose
Project Preparation • Pre-Site Surveys • Team Building • Pre-Proposal • Workshop Proposal • Full Proposal • Contracting • Training (e.g., Drilling Information System – DIS)	Select site(s) with best science for low costs Select, motivate a group of scientists Raise and test the idea Internationalize, prepare a full proposal Acquire funding, detailed plans Secure funding, select service companies Prepare crew for duties before, during and after the actual drilling phase of the project; conduct thorough expectation management on 'what', 'when', 'who', 'where', 'how much', and including safety and hazard issues prior to any field operation
Operation • Engineering Operation • Scientific Field Work • On-site Science • Sample Curation • Reporting • Outreach and Education	Drill holes, gain samples Document samples and data from well Perform initial science study on samples and data accompanied by 'Site Report' Distribute samples and store archive materials Document the Operational Work and Site Report with preliminary data description (whatever is available in that respect)
Scientific Work • Lab-based investigations	Examine, evaluate, test, model, develop research ideas
Publication • Scientific Articles • Data Sets • Sample Material and Curation	Publish articles in journals Publish data sets in data centres Provide access to and clarify once more distribution of sample material post-moratorium period

Table 1: Phases of a typical drilling project. Details vary from project to project, and must be discussed and negotiated up-front and prior to any drilling operation.

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CHAPTER 2

Project Management

Thomas Wiersberg and Ulrich Harms

Continental scientific drilling projects are complex undertakings bringing together scientists, drilling engineers as well as funding agencies and other stakeholders. These parties have different professional backgrounds and often speak their own languages. Most Earth scientists are neither familiar with drilling engineering nor large project controlling and budget management tasks. Drilling contractors in turn are generally used to drill commercial projects with predefined targets rather than scientific paths with very special demands. Therefore, all parties involved must be fused together to work for a drilling project. This is a key prerequisite for the success of any drilling project.

Phases of drilling projects

Like any other complex project scientific drilling consists of a sequence of four tasks to be executed: Definition, Planning, Realization and Completion. Monitoring and controlling steps accompany each task. The project definition corresponds to the identification of a scientific question of global significance that critically needs drilling, followed by evaluation of existing data and surveys around potential drill sites.

For further planning purposes, a workshop should be held to define the project objectives in detail, implement a drilling strategy to achieve these goals and discuss funding options. Building of an assertive team and defining a sample and data policy are other critical workshop issues. The workshop should pave the way for the preparation of a proposal to be submitted to different funding agencies. ICDP explicitly supports this kind of scientific-technical meeting proposals. Fig. 2.1 depicts a typical life cycle of a project as carried out since the late 1990-ties and corresponding management structures to plan, start, conduct and complete a project, and will be discussed in greater detail below.

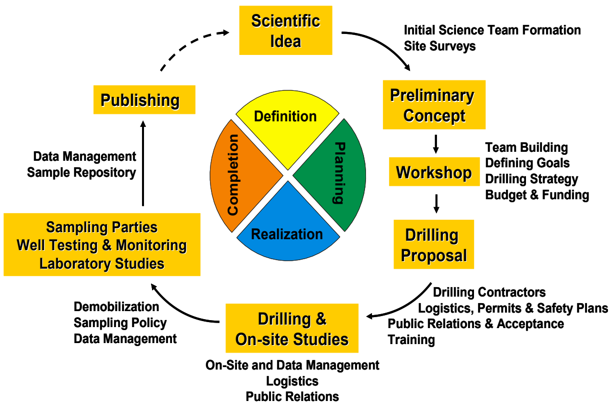

Fig. 2.1: Roadmap of a scientific drilling project in project management and controlling view

If drilling funding is at hand, the next operational and logistical steps must be scheduled. Permitting must go ahead and a drilling operator and other necessary contractors must be selected and hired. Furthermore, an oversight panel can be implemented to provide advice about operations, work safety and to make recommendations during all different kinds of problems. An additional science advisory board can support Principal Investigators (PIs) in all major decisions that may jeopardize the scientific goals. Scientific drilling projects will attract a great deal of attention and maybe concerns by local communities, authorities and politics. Therefore, carefully planned outreach activities are crucial for a successful project realization. Planning of the on-site logistics, sample and data management and training of the on-site staff must be conducted prior to spud in as well.

If PIs cannot be permanently present at the site during drilling, an on-site chief scientist coordinates all activities concerning the recovery, handling, in-situ analysis, and shipping of samples. Sample and data storage and their distribution to the science team are important steps to accomplish the project.

Workshop

A workshop is a key element in the philosophy of the ICDP for planning of a scientific drilling project (Fig. 2.2). The workshop brings together leading experts from the respective field of science with drilling professionals to assess engineering requirements and costs. The aim of a scientific drilling workshop is to:

- define the scientific goals of the project in agreement with the international scientific community
- form a team of scientists and drilling experts, and
- prepare a drilling proposal, which will be submitted to funding agencies.

ICDP financial support is based on a co-mingled funding principle. This means that PIs are requested to acquire additional funding from sources others than ICDP. Therefore it might be necessary to broaden the scientific goals to make a drilling project attractive for different funding agencies.

The following issues are to be addressed by a scientific drilling workshop before any further preparation of a full proposal:

- Have the scientific goals been clearly identified?
- Is there agreement among the science team on what drill hole(s), samples and measurements are needed to achieve project goals?
- Is there a "critical mass" of committed and enthusiastic participants for the project to succeed?
- Have the PIs and engineers made an adequate assessment of the technology required to archive the project goals?
- Are project goals and the drilling strategy in balance with the funding concept?
- Have other potential funding sources been identified?
- Are additional site surveys or feasibility studies necessary?
- Have the next steps and timelines been discussed?

The outcome of a successful workshop will create the fundament for a full drilling proposal to be submitted to different funding agencies, including the ICDP. An accepted drilling proposal is then the basis of the project master plan, which includes detailed information about 1) the drilling target and additional site surveys, 2) the concrete scientific goals including sampling, logging, and monitoring strategies, cost/budget projections and schedules for producing scientific results 3) outreach activities 4) the project management concept, 5) permits, and 6) a health and safety/environmental plan.

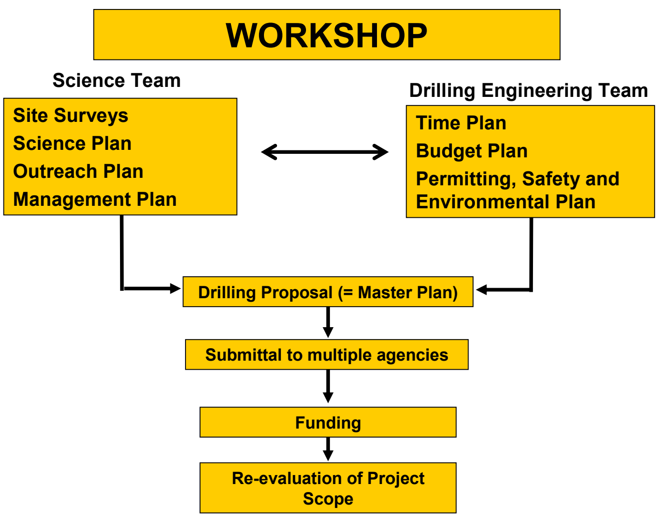

Fig. 2.2: From workshop to proposal

Roles and Responsibilities

Any drilling target must be identified and characterized in the best possible way by geologic and geophysical site surveys before drilling (Fig. 2.3). Interpreted data from site surveys are mandatory for submission of a full proposal to the ICDP. A not clearly identified drilling target can be the exclusion criterion of a drilling proposal. ICDP does not provide funding for additional site survey tasks.

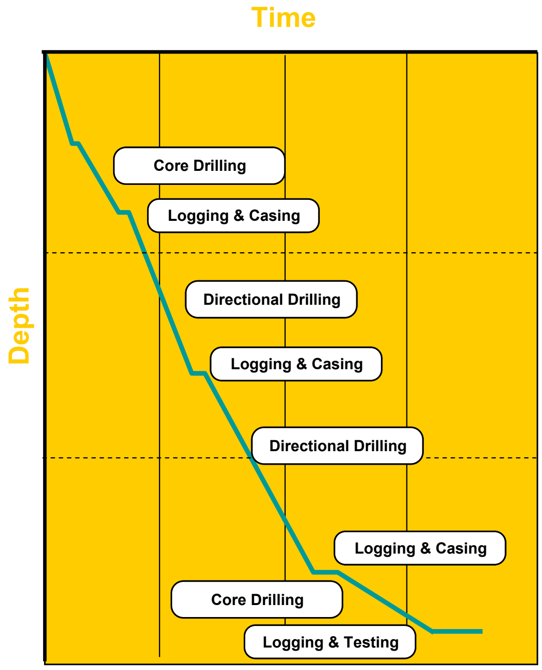

Fig. 2.3: A typical time vs. depth diagram for an evolving and maturing drilling project.

The science plan must include a concrete list with guidelines and instructions for sampling, logging and monitoring. Based on such a list, technical and personnel requirements can be estimated and time and costs calculated. A top-down project management approach can help to define the pathway from a generally formulated scientific goal to the level of concrete scientific investigations. Successful ICDP full proposals can serve here as benchmarks (Fig. 2.3).

Project PIs should not hesitate to engage external consultants for planning of a scientific drilling project if they are not familiar with these issues. Little additional expense for external know-how at the beginning of a drilling project can help to save money and to achieve the project objectives in time. A science advisory board should be implemented to give advice on all major decisions.

A management plan clarifies the roles and responsibilities of everyone in the project so that all involved know what everyone is supposed to do (Fig. 2.4). Principal Investigators' duties and responsibilities should be clearly defined in a management plan

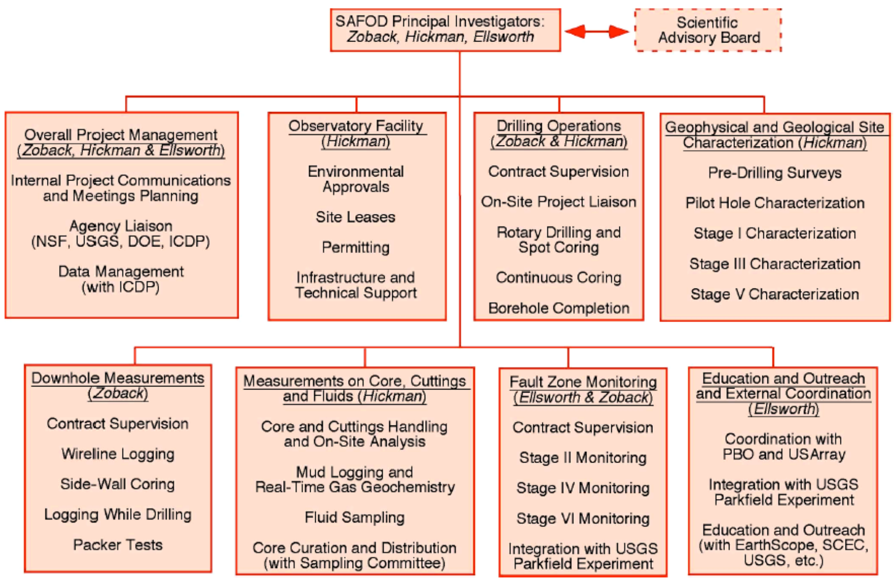

Fig. 2.4: Management plan of the San Andreas Fault Zone scientific drilling project.

Consulting and Project Controlling

It is a real truism that no scientific drilling was ever executed the way it was originally planned. The problem of many drilling experiments in science is that they face increasing costs and cannot reach targets as planned due to geological unknowns at depth and technical failures during drilling. In this case, a science advisory board involved in all major decisions can help to increase acceptance of decisions and to acquire contingency funding if necessary. However, for every decision on modification, careful consideration must be given to the overall project objectives, timeline, resources, and quality. No topic can be changed without affecting the others.

Experience in prior drilling or similar projects are essential, but a real difference can be made through an experienced project manager with a strong background in drilling. Depending of the scale of the project, this can be a "company man" who reports to the Principal Investigators and oversees operations, budget and safety issues. Regular communication with the science team, partners, and funding agencies help to address issues early. The interconnection of Time, Quality (Control), Costs and Target (Drill Sites) as managed through the "Company Man" is summarized in Fig. 2.5.

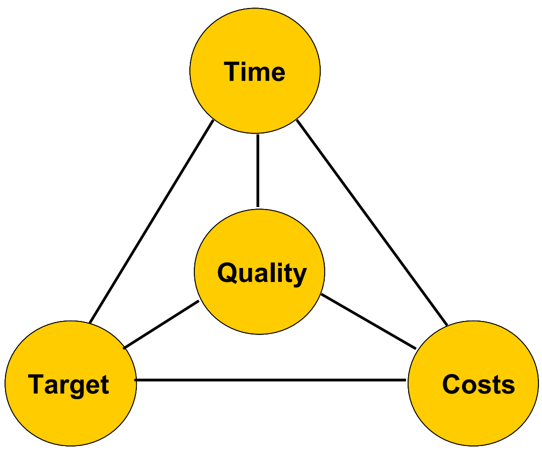

Fig. 2.5: The project management tetrahedron

On-site management

During drilling, a close collaboration between the drilling crew (which is generally not familiar with scientific demands) and the on-site science team is crucial (Fig. 2.6). Responsibilities of the on-site science team include:

- Retrieval of drill-cores and rock chip samples
- Inventory and documentation of samples
- Routine logging of samples according to specified on-site program
- Preparation of preliminary lithological log (litho-log)
- Transfer and deposition of samples in the final repository
- Compilation and preparation of interim and final reports

A core flow procedure from the drillers to the science team and the further handling of the core is and must be firmly implemented in a protocol before the first core arrives on deck – primarily based on the "Safety-First" principle, and secondly on scientific objectives as defined in the science plan.

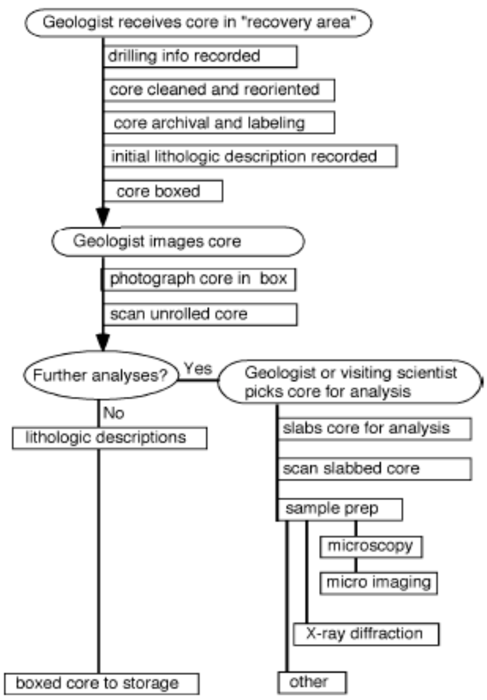

Fig. 2.6: Core handling protocol.

The core protocol can significantly vary from project to project – for example, the imaging could be conducted prior to boxing; certain microbiological studies require special handling of sample material, and depend on several factors (logistics, priorities in the science goals, budget and overall costs, etc.)

The on-site science team

It is important to know the right number of personnel needed to assure a proper and successful conduct and execution of the project. The drillers define the base for the working routine, as they are normally required to work 24/7. In this context the following considerations attain significance in deciding the strength of the crew:

- How extensive is the scientific on-site program?
- How quickly is the information required to be available?
- How many activities are scheduled within the given timeframe?
- What is the proposed life span of the drilling project?
- What are the specific regulations about regional labour laws, if any?

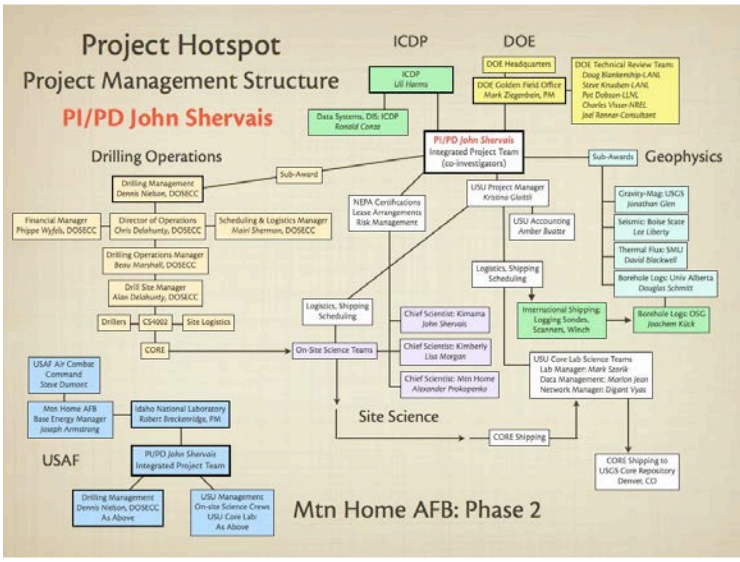

Fig. 2.7: Project management structure of Hotspot, an ICDP project conducted in the Yellowstone Park area of the Snake River in 2011/2012.

The following distribution serves only as broad guideline; things may be different in reality and need to be adjusted to the specific drilling project – without compromising any pre-determined safety considerations.

The chief scientist is overall and ultimately in charge, and coordinates all the activities of the drilling project concerning the recovery, handling, analyses and distribution of samples. He/she informs the PIs and keeps them updated on the day-to-day progress of the project. He advises contractors and receives operation reports. Furthermore, this individual is responsible for organizing the field laboratory, sampling parties, budget and procurement and maintenance of equipment. Therefore somebody who has a thorough understanding of the entire process of drilling and related issues should serve in this function. A detailed knowledge of the geological setting and expected lithologies at the drill-site will be a big advantage.

The field geologists take over the recovered cores at the derrick and carry out the core description as per standards as agreed upon by the Science Team. If only cuttings are available, they should be washed, dried and analyzed. Data of any kind must be compiled in log sheets and a project-specific database (Chapters 5 and 8) to keep the litho-logs up-to-date.

The data manager is responsible for the maintenance and proper operation of the computer systems and software. This specialist has to configure and setup the data Drilling Information System DIS (see: Chapter 5, "Data and Sample Management") prior to drilling, which then will allow data input simultaneously with the drilling operation. Installation and maintenance of Internet connections at the drill site and providing all necessary computer-related assistance in report preparation are also part of the duties (see also: Chapter 5, "Data and Sample Management").

Field technicians, scientists and/or even field volunteers prepare and label core-boxes and take the cores from the drilling rig to the field lab, where they wash and clean the cores, and label core pieces. They can also be employed to assist in sample documentation, e.g. with a camera or core scanner. For drilling projects where cores ought to be split into working and archive core halves, this field crew can help to saw the full cores. Experts in structural geology draw orientation lines and designated curators make inventory lists to assure a proper handling and logging of all core/sample material for future storage and/or sample material distribution around the world.

Risk Management

A sober view on any deep scientific drilling project reveals that it cannot be compared to scientific work at a university or in a research institute: hard-hat-work, high costs plus an unknown outcome. So, on one hand drilling is always risky, while on the other hand funding agencies want desperately a safe and predictable outcome for a large investment. Therefore, *Risk Assessment* is becoming an important planning and management tool for scientific drilling.

A simple approach is to identify potential *Risks*, classify their *Likelihood* and *Impact* and estimate the resulting factor of *Risk Potential*. For each risk category, a *Mitigation Strategy* must be developed and their *Probability as well as*, *Impact Severity* re-estimated after a *Mitigation Strategy* has been applied. Usually, the responsible *Person in Charge* and *Costs for Mitigation* associated with the risk should also be included in this process. A simplified *Risk Matrix* is shown in the figure below with colour coding for high (unacceptable), moderate and low risk conditions (Fig. 2.8).

No	Description	Likeli-hood	Impact	Risk Pot.	Mitigation Strategy	Likeli-hood*	Impact*	Risk Pot.*
A	Delays, due to weather, incidents, permits	High	Low	Mode-rate	Flexible planning w/ variable time plans	Mode-rate	Low	Low
B	Cost overrun	High	Low	Mode-rate	Professional project management, better site survey, contingency funding (due diligent preparation)	Mode-rate	Low	Low
C	Missing 3rd party funding	Mode-rate	High	High	Planning in phases or de-scoping opts	Low	High	Mode-rate
D	Understaffing	Mode-rate	Mode-rate	Mode-rate	Prof. project management, training courses, reducing on-site science to the minimum, increase budget	Low	Low	Low
E	Poor engineering planning and operational management	High	High	High	Prof. project management, training courses, implementation of drilling-well-on paper (DWOP) and QHSE procedures	Mode-rate	Mode-rate	Mode-rate
F	Unexpected geology	High	Mode-rate	High	Better site survey, flexible planning, contingency drill plans, <DWOP>	Mode-rate	Low	Low
G	Missing or short supplies of services and equipment	High	Mode-rate	Mode-rate	Prof. project management, detailed planning w/ Plan B	Low	Mode-rate	Low
H	Missing coordination	Mode-rate	Low	Low	Detailed planning workshops with all groups involved, DWOP, professional wellsite management	Low	Low	Low
I	Missing communication in Science Team and with OSG	High	Mode-rate	Mode-rate	Prof. project management with constant updates, involvement of key players, detailed planning workshops with all groups involved, kick-off meeting	Low	Mode-rate	Mode-rate
J	Late recognition of obstacles	Low	Mode-rate	Low	Early warning, daily communication between groups on site	Low	Low	Low
K	Missing documentation and reporting	High	Mode-rate	Mode-rate	Require DIS utilization and Initial Science Report in SD	Mode-rate	Low	Low
L	Missing safety planning and implementation	Mode-rate	High	High	Require safety planning in JRV according to host countries law, implementation of QHSE strategy and procedures	Low	Mode-rate	Mode-rate
M	Loss of equipment, loss of hole	Mode-rate	High	Mode-rate	Drilling engineering well planning, written operational procedures on site, DWOP, insurance coverage Contingency funding, Plan B	Low	Mode-rate	Mode-rate
N	Injury and/or fatality	Low	High	High	Increase safety planning and implementation	Negligible	High	Low
O	No public acceptance, NIMBY	Mode-rate	High	High	Outreach actions before drilling	Low	High	Mode-rate

* risk after treatment

Fig. 2.8: Simplified risk matrix for a drilling project with some typical risks

Setting up a risk matrix for a project does not require a huge paperwork, but focused brainstorming with key personnel on site and in the back office. What kind of critical accidents or health, financial, or technical incidents might happen in a drilling venture, what the consequences will be, and how these can be mitigated, or even avoided.

The project risk matrix should be set up by each project already early in the planning phase, but at least a few months prior to drilling. They are especially important for technical and operational planning in terms of Health, Safety and Environmental (HSE) performance and require regular check-ups and information confirmed by those individuals who are in charge of certain segments of the operation.

In the ICDP, drilling projects are divided into three categories according to the associated risks. Simple drilling and coring of less than a 1 km depth with no planned well casing, no borehole tests or other complex in-hole operations are regarded as *Low Tier*, for which ICDP will only require Safety Procedure and Reporting in the planning. *Medium Complexity* missions comprise up to 2 km deep drilling without complex cementation, no completion, no long-term monitoring installations, and alike. In addition to safety procedures a detailed budget and cost tracking as well as a drilling engineering plan is required. Finally, for *High End* deep drilling projects ICDP will request in addition to the above the following (Fig. 2.9):

i) a *Drilling Well On Paper* meeting for which representatives from all involved contractors and parties discuss in detail all procedures and operational steps in a pre-spud workshop
ii) A *Review of the Operational Plan*, which will be conducted independently by the Operational Support Group (OSG)

In any event: For all projects an estimated *Budget Plan* and a project *Risk Assessment Matrix* will be required as early as in the full proposal to the ICDP.

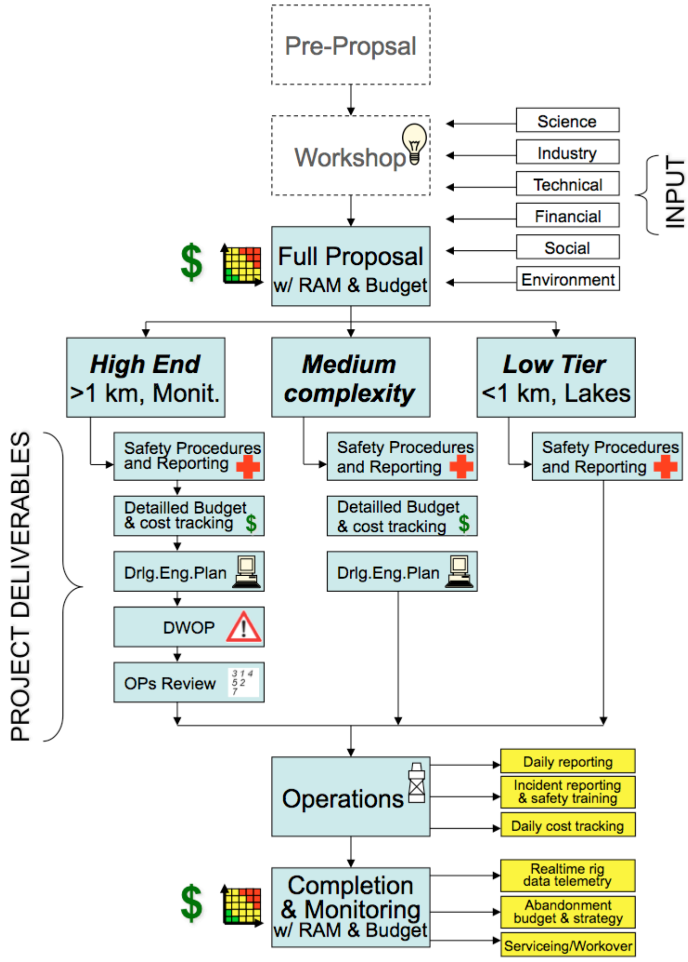

Fig. 2.9: Risk management for ICDP projects; see text for detailed description. (RAM: risk assessment matrix; DWOP: drilling well on paper); OPs review: post drilling operational review)

Financial Planning

Full proposals forwarded to ICDP for funding have to be supported with a detailed estimated project budget plan outlining the pre-drilling preparation, the drilling operations and the post-drilling phase. The budgeted items need to include all the estimated labour (man-months) by category (technicians; researchers; senior researchers), subcontractor expenses, material & supplies, rental, financing and software cost. All budget items need to include the applicable VAT (Value Added Tax) for the relevant country where the expense will be incurred.

Usually quotations are not yet available at this stage and the budgeted items will have to be based on best guesses from previous projects and the current market conditions. Assistance in this budget phase can come from the pre-selected drilling contractor, associated research institutes, or the OSG.

After project award the estimated budget from the proposal will have to be confirmed and forwarded by the PIs as the actual project budget, including updated cost estimates and valid price quotations. Deviation to the first budget estimate will have to be reported to ICDP for approval prior to start of the drilling. ICDP requires third party expenses over US$100,000, and must be supported by 3 competitive quotations not older than 3 months. National or multi-source funding may be obliged to follow other regulations and require national or international public tendering for services and supplies over a given value.

In the course of the project invoices and/or request for money advances will be forwarded by the project with supporting documentation to ICDP for payment. Deviations to the approved budget will have to be explained in sufficient detail. Transfer of funds between the budget categories over a value of US$10,000 will require written approval from ICDP prior to the incurrence of the expenditure. PIs or their nominated sub-PI are responsible for financial project accounting and are advised to track the actual project expenses on a daily base and report the current financial project status on a weekly basis to ICDP-OSG, with a look-ahead for the next month.

Three months after the project ends a full financial report has to be produced and submitted to ICDP for financial review and/or auditing purposes. All book keeping documentation, receipts as well as money transfer bank reports have to be filed by the PIs institution after project end for a period of 5 years. Fiscal regulations in some countries may even require a longer time period, and PIs have to ensure compliance with such regulations even after the completion of the project.

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CHAPTER 3

Pre-site survey and drill site selection

Ulrich Harms

Scientific drilling does not start on unexplored ground but is based on hypotheses that have been justified by specific fieldwork and intensive research in a region. A sustainable drilling idea can only be developed into a scientific drilling program if the so-called pre-site survey data support compellingly the drilling experiment and related research. Pre-site survey means in this context scientific investigations serving to validate drilling in a wider area while site survey means specific research in a smaller area to select a site (Fig. 3.1). The most important criterion site survey data have to fulfill is to allow very precise site selection with the best-possible illumination of both the drilling target and drilling depth. Furthermore, these data must underpin that the scientific objectives of a drilling project can be met. In addition to the reasoning for drilling and site selection, the site survey has to address aspects of safety, environment and health.

Regional surveys

Pre-site survey includes the compilation of all existing geological and geophysical data in a region. Geological maps, sample investigations, geophysical research and all other kinds of geoscientific information will be utilized to form a decision base for further research in more detail. Target specific investigations often supported by geophysical sections or even 3-or 4D seismic cubes serve to identify that drilling is the only way to gain urgently needed samples or test important hypotheses.

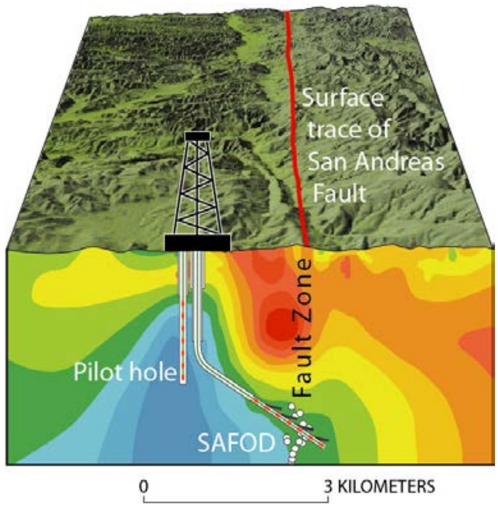

Fig. 3. 1: Geoelectrical conductivity section with projected drill path showing site location approach for the SAFOD project, California (2004/2005)

Although seismic lines are often the best way to characterize a sedimentary basin or an upper crustal section this does not work in lithologies were impedance contrasts are too low to depict structures. Magnetic, electric, magnetotelluric, gravimetric or airborne data such as LIDAR can be extremely useful to characterize a target feature or anomaly. There are also examples were geological surface mapping produces much more insight then geophysical data. In some instance on-land costs and infrastructural efforts for geophysical data will be extremely excessive and therefore not useful to justify a drilling campaign. But in marine and lacustrine research, bathymetric and seismic lines are relatively easy to acquire, and produce in most cases tremendously useful data sets. They have become a standard tool and must be acquired before drilling.

Site survey

Site surveys in specific marine and lacustrine environments usually comprise high-resolution bathymetric data, obtaining short cores or dredge sample material, and include detailed investigations on these samples and seismic sections. For land-based projects, surface data, existing well logs and seismic or geophysical data support and supplement the determination of location and drill depth. In general, site survey data have to fulfil a number of key criteria including that:

- detailed plans for drilling are based on an adequate site imaging from the site survey data
- the site is selected in a way that all posed scientific questions can be answered
- the site is in a location that is feasible for the drilling method and tools planned for
- the site survey information provided for the scientific review contains sufficient information to support both the science and the drilling operations

In addition to active seismic data (Fig. 3.2) a number of different geophysical methods can be applied to shed light on the deep geology around a site:

- passive seismic methods
- electric or electromagnetic methods
- magnetics, magnetotelluric methods
- gravimetric methods
- ground penetrating radar
- and others

Water saturated lake-sediments very sensitively influence reflection seismic data. Seismic profiles shot and interpreted with state-of-the-art equipment provide excellent insight into stratigraphy and major lithological changes of non-deformed sediment layers. Seismic methods are also extremely useful to illuminate thick sediment strata on land while volcanic and crystalline rocks are in most cases less receptive to seismic methods.

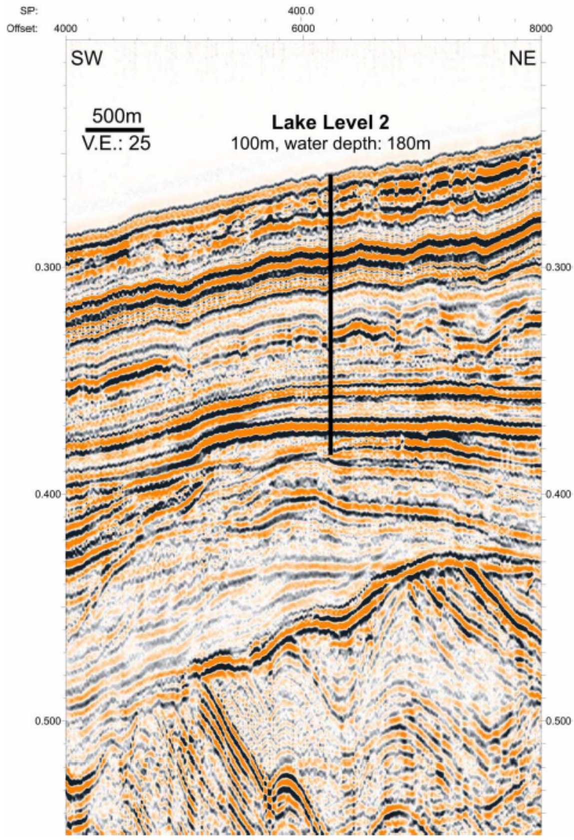

Fig. 3.2: High-resolution seismic profile of lake sediments with projected well path

Hazard Survey

Safety and health of a drill site and crew are of paramount importance in a drilling project. Accordingly not only the scientific objectives and geological conditions will govern the selection of a drill site, but also safety must be a leading criterion. First of all, geological and geophysical site knowledge of potential hazards that may affect a drill site is critical. Central matters are:

- Hydrocarbon occurrences
- Shallow gas
- Gas hydrates
- Fluid overpressures
- Borehole instabilities, stress, strain
- Salt, clay or other rocks affecting drilling
- Variable hydraulic conditions
- Well site, slope instability

- Lack of foundation (stability) for rigs

Before drilling can start or applications for permits can be applied for, it must be excluded that hydrocarbons, over-pressured fluids, H_2S, magma or very unstable zones will be encountered during the drilling phase, or that the technical planning of the drilling will include tools and measures to handle such issues in a way that the environment is not endangered and/or drill-site safety is compromised.

Depending on the permitting authorities and national laws, pre-site surveys may include environmental impact studies, which must cover additional safety and health-related necessities and be obtained and/or conducted in advance to any drilling operation.

For permitting procedures, a safety or drilling-hazard report is normally required. Key elements for composing such reports are the site survey data. Since consequences and costs of hazards are in most cases extensive, every effort must be made to minimize the risk. Drilling contractor, lead scientists as well as permitting authorities have to work closely together to achieve this goal.

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CHAPTER 4

Drilling Operations and Engineering

Bernhard Prevedel and Ulrich Harms

Drilling operations are highly professional tasks requiring special expertise and skills. Therefore Principal Investigators (PIs) usually contract service companies to execute scientific drilling. Accordingly, the PIs have the duty to oversee the contractors operations as well as to control schedules and budget. In the past, for several projects financed by ICDP, this oversight role has been either entrusted to independent experts or to ICDP-OSG (Operation Support Group) engineers. They acted as so-called "company man" and reported to the PIs while they worked closely with the contractor at the site to supervise operations. This chapter summarizes some key aspects of drilling and engineering.

Basics of drilling

In the majority of drilling operations for scientific goals either rotary drilling or diamond wireline coring techniques have been used. In both cases a bit is mounted on a rotating steel pipe and lowered into the ground by a drilling derrick (Fig. 4.1). The drill string is propelled by a rotary table, or a top-drive, and consists of connected pipe elements through which a drilling fluid is pumped down the well. The drill mud, usually water with clay minerals and some other minor additives to adjust density, viscosity and lubrication, cools the bit and carries cuttings of the destroyed volume of rock to the surface through the annulus between the borehole wall and the drill-string. The drilling progress (rate of penetration) is controlled by rotary speed and weight-on-bit. Once a pipe length is completely drilled down, an additional pipe is connected to extend the drill string. When drilling from a ship or floating platform, the borehole remains open to the sea/lake floor, so mud and cuttings do not return to the drill rig. In this set-up drilling must be performed with water in place of drilling mud allowing cuttings spilling out on sea or lake bottom around the well. However, if pressure control and mud return is required, an outer second pipe, a so-called riser, is put in place so the mud and cuttings can be pumped back to the deck.

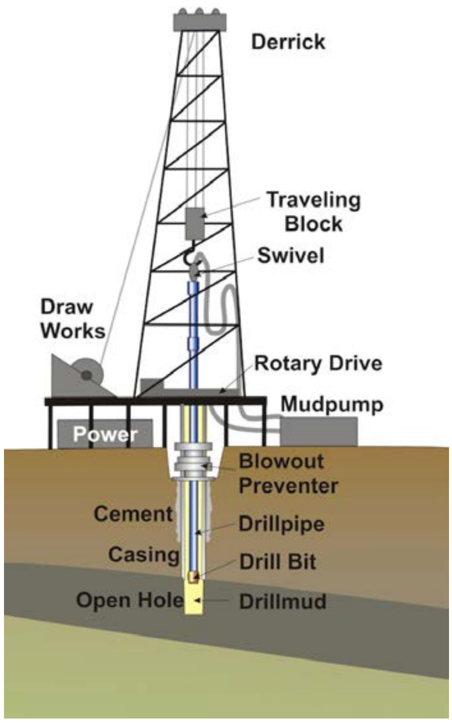

Fig. 4.1: Key components of rotary drilling on land

Coring is performed with a hollow core bit that leaves a central column of rock. This core slides into a pipe barrel while drilling progresses. In the oilfield rotary coring technique, after some meters of coring, the whole assembly has to be pulled back out of the hole (pipe tripping) to get the core to the surface. In many scientific drilling projects, by contrast, continuous coring by wireline coring technique is utilized to avoid time-consuming round trips. The core barrel is retrieved through the drill string by sinking a wireline catching device that connects to the retrievable inner coring assembly with the drilled-out rock column inside.

Type	Hole Size	Core OD
PQ	123 mm	85 mm
HQ	96 mm	64 mm
NQ	76 mm	48 mm

Table 1: Standard Diamond Coring Sizes for typical hard-rock coring operations.

The actual formation-cutting method varies depending on the type of rock or sediment present. Typically, thin-kerf diamond core bits with high-rotation speed are used for hard rock drilling, roller cone abrasion bits are used for softer sedimentary rock, and non-rotating sharp edged hollow metal pistons of several meters length are hydraulically shot (forced) into soft sea/lake-floor sediments to collect cores and such advance the borehole.

Instable well conditions, as well as saline or over-pressured fluids often require that PVC or steel casings have to be installed into boreholes and cemented in place. The subsequent hole- section has then to be drilled with a smaller diameter bit size. Health, safety and environmental issues often require additional measures to ensure safe drilling procedures such as fluid control through mud density variation and blowout-prevention devices.

Wireline coring

Exploration diamond core drilling is used in the mining industry to probe rock formations in search of mineral resources. A thin-kerfed diamond core bit is rotated by slim drilling rods at high speeds. The core barrel is retrieved via wireline to the surface. The technique has been widely adapted in scientific drilling because of the capability of continuous coring without having to pull the drill pipe out of the hole. In addition, the slim diameters utilized allow minimizing the rock volume drilled and hence reduce costs. The disadvantages of this method are the small core diameters and reduced drilling depth.

Fig. 4.2: Truck-mounted wireline coring rig of DOSECC of HOTSPOT project

In several shallow to medium deep ICDP projects, diamond wireline coring has been utilized very successfully. For example, in the Snake River Plain HOTSPOT project in Idaho three almost 2000 m deep wells have been drilled with this continuous coring technique. A wireline coring rig (Fig. 4.2) has been used that can deploy 1000 m of PQ, 1500 m HQ or 2500 NQ drill string.

In general, drilling starts with the large size diameter and continues as long as possible, until the formation in the open hole has to be stabilized. The string with the core bit may remain in the well as provisional casing, and then the next, smaller size drill pipe has to be used to continue coring.

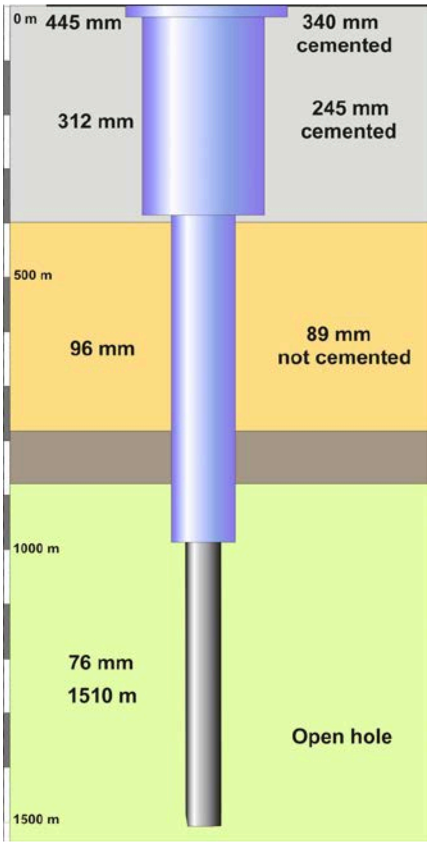

Fig. 4.3: Sketch of ICDP Chicxulub well with hole size on the left and casing diameter of the right

Combined techniques

Wireline diamond coring has also been utilized with oilfield drilling rigs deploying a hybrid coring system. ICDPs Chicxulub Drilling Project started with cementing an 8 m deep conductor casing. A section of Tertiary limestones (392 m) was penetrated without coring by standard rotary drilling (312 mm), cased (245 mm) and cemented (Fig. 4.3). The following two sections have been continuously cored with a HQ string to about 1000 m depth until the pipe got stuck. The following NQ section was deepened to 1510 m and left open.

Lake sediment drilling

Undisturbed, lacustrine sediment cores serve as important archives for high-resolution studies in environmentally sensitive areas. One of the major issues in sampling those archives is the lack of suitable and cost-effective sampling tools. A very successful approach in the recent past has been achieved through the redesign of available wireline drilling technology. The Global Lake Drilling unit GLAD800 and its successor, the Deep Lake Drilling System (DLDS) are owned by ICDP and operated by DES. The major components are:

- a wireline drilling rig (Atlas Copco T3WDH)
- four-motor rotary top-head drive
- a container-size modular and versatile barge (24.4 x 7.3 m, Damen system)
- anchor winches or dynamic positioning systems, mud tank, crane and other auxiliary equipment

Fig. 4.4: Deep Lake Drilling System on Dead Sea

The diamond wireline drilling technique utilizes various special coring tools and can reach depths of up to 1400 m depth (CHD 134 string) in 400 m deep waters. The

DLDS is a complex and modern drilling unit, which requires a crew of experienced, well-trained technicians and engineers for drilling and marine operations on a 24/7 basis (Fig. 4.4).

The GLAD800 was deployed with ICDP funding in Lakes Titicaca, Bosumtwi, Peten Itza and as arctic version in Lake Elgygytgyn. When severe weather hampered GLAD800 operations significantly during Lake Qinghai and Laguna Potrok Aike operations, a new barge system was designed and built as Deep Lake Drilling System by DOSECC. This new DLDS was subsequently deployed thereafter in deep-drilling ICDP projects on Lake Van and the Dead Sea.

During the Lake Ohrid drilling expedition of ICDP in Macedonia using the DLDS, 480 m coring depth could be reached twice within less than 17 days of drilling, with core recovery rates of over 90% per site. There is hence no doubt that the DLDS is a very capable tool. Nevertheless, it is also limited to wave heights < 1 m and wind speeds of less than 4 Beaufort. Furthermore, mobilization and demobilization is cost intensive transportation as it comes in about 14 containers. Furthermore, staging the barge containers into water requires a 100 t crane and a rigid quayside or slipway. Safety and hazard considerations for and around the entire operation of the DLDS ought to be specified as part of the science and operations plan. Depending on site location and logistics this can further complicate its usage for an ICDP project.

Soft sediment coring

Loose sand to clay sediments are not easy to probe continuously. First, all coring devices may lose the lowermost section from the so-called core-catcher during each coring run. Therefore, to ensure complete core coverage it is necessary to deploy these systems at two or three parallel holes per site, which allows a data processing called 'splicing' (aka: depth-matching of geological horizons across neighbored locations (Chapter 5 for more details). Second, there is no coring device that is capable to recover the uppermost water-rich and very unconsolidated sediments at the same recovery percentage as deeper consolidated sections. Accordingly, different coring tools for different lithologies are needed.

A set of coring devices is used at the DLDS to collect different types of sediment (Fig. 4.5). The different kits are deployed via wireline through a standard outer assembly producing a 139.7 mm (5.5´´) hole:

- Hydraulic Advanced Piston Corer (APC)
- Extended shoe, non-rotating (EXN)
- Extended core bit, rotating (XCB)
- Diamond core bit (mining)
- Non-coring assembly using rotary bit

The APC device produces by far the best recovery rate - often near 100% - and delivers the most intact, neat, undisturbed samples. This APC method has been developed in the international ocean drilling programs. It works through mud pressure built-up on a metal tube ending in a tapered sharp cutting shoe. Shear pins break when a certain pressure is reached, driving the tube into sediments, usually in 3 m steps (note: 9.5 meters of advancement for IODP drilling operations). After each shot the core barrel is retrieved through the drill string. On deck, the inner plastic liner with the sediment section is retrieved from the core barrel. The barrel is loaded with a liner and shear pins. Then it is dropped back into the hole for the next shot. At 50 to 200 m sediment depth, HPC/APC progress finally stops due to increasing compaction or coarse-grained deposits.

Whence the APC system stops penetrating deeper and more compacted formations, the most appropriate next coring tools are either the non-rotating extended nose (EXN), or the rotating extended core bit (XCB) - also called "alien tool", which consists of an inner core bit preceding the outer rotating bit. In this way the progressing well deepening is separated from the core cutting process. It allows for reaching greater coring depths, but usually results in a slightly lesser degree of core recovery.

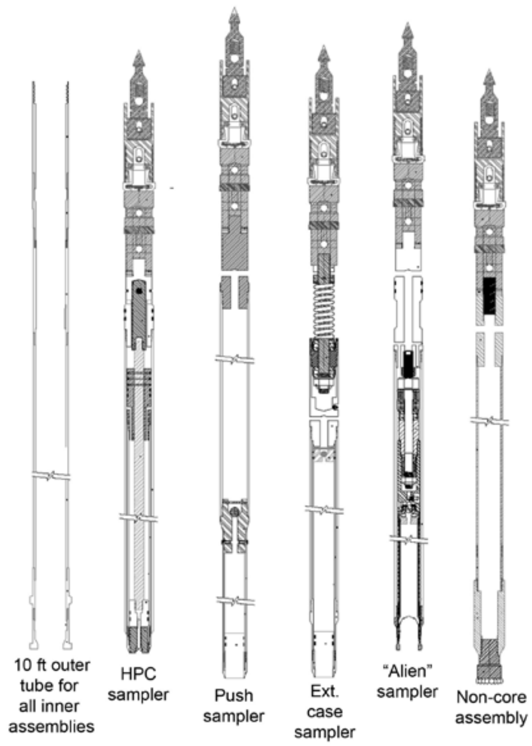

Fig. 4.5: Tools used for drilling lake sediments

Well planning and engineering

Professional planning and drilling engineering needs to be performed for all deep and complex operations. The ICDP OSG can provide assistance for ICDP projects in that task. The essential software tools for planning and optimization of a deep drilling operation are a well plan module, a structural geologic model, a casing design & cementation, a drilling hydraulics and a drilling dynamics package in order to place a borehole correctly in the subsurface 3D space. These planning software solutions are most often delivered as single, unified Microsoft Windows application, with integrated multiple software components.

Geology, petrophysics and geophysics

Modern Geology and Geophysics (G&G) software for drilling planning takes subsurface information to generate geological knowledge and parameters out of these diverse data sources. The power of today's advanced computers, combined with broad data integration, allows geologists to apply many methods and technologies to evaluate their science data (Figs. 4.6 and 4.7). The final goal is to achieve a geologically consistent base for a thorough project planning process.

These processes can be evaluated and qualified for the uncertainties that are inherent in both the input data and the variability of geology. The full capability of today's advanced geological interpretation and modelling software is generally defined by a few distinct functionalities:

- The efficient and thorough processing and interpretation of borehole measurements for optimal formation evaluation
- Advanced modelling tools used to construct structural and stratigraphic models, in order to validate and refine the geologic interpretation utilizing digital structural analysis tools
- The capacity to handle any amount of complex faults, under avoidance of simplifications
- Application of multiple geostatistical methods in order to assess and mitigate data uncertainties, and
- A seamless integration with seismic, oil field production and other data sources that enrich geological workflows, towards a direct process for generating geo-cellular simulation grids

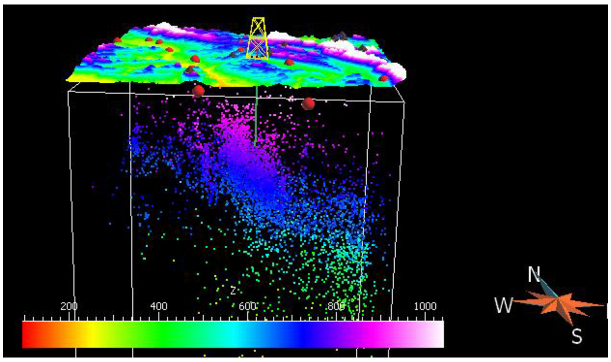

Fig. 4.6: 3D attribute integration in a model

When a project starts, the initial data screening will evaluate geologic formations and petrophysics of the projected subsurface area. In the project definition phase, the basic questions that a geologist will initially be challenged with are, for example, facies classification, borehole image interpretation from offset wells, lithological core interpretation, and saturation determination.

In order to build the 3D geologic model, correlation and building of geologic cross sections will initially have to be performed. Interpreted well sections will be constructed from wireline logs that carry the data needed to perform stratigraphic correlation, while seismic data may also be incorporated at this stage. The G&G software then constructs net thickness maps while markers are interpreted and geologic zones of research interest identified. Stratigraphic information created during this interpretation phase is then directly used for the construction of the 3D stratigraphic model (Fig. 4.7).

Modern G&G software suites will construct structural 3D models automatically based on the stratigraphic column, as well as on interpreted faults and salt body structures. They are capable to define fault-fault and fault-salt contacts automatically, and they can build horizons following the rules of sequence stratigraphy.

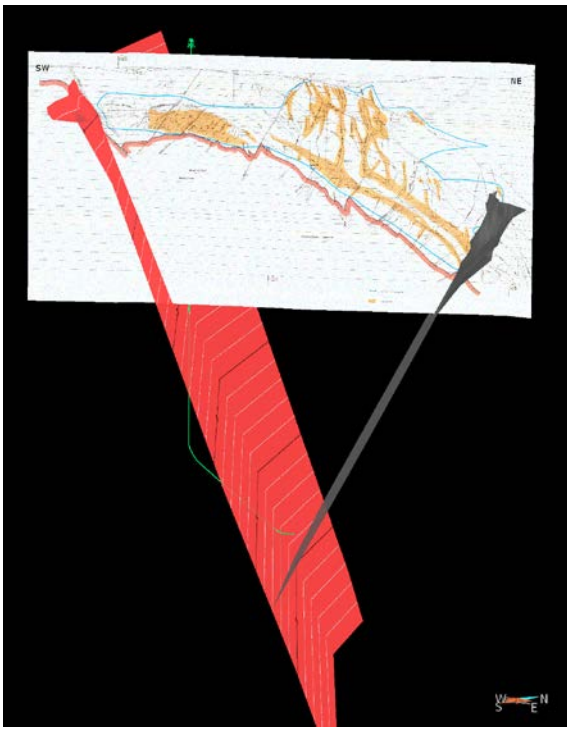

Fig. 4.7: Faults (red, grey) visualization in geologic section with well path (green) of Schneeberg-1 research well (courtesy: LfULG, State of Saxony)

Horizons and faults will be identified by the software in order to create and suggest a sealed model that can be used later to generate consistent maps, velocity models, geological and flow simulation grids. An advanced 3D model should have none of the limitations of pillar-based models. It should be able to handle any kind of faulting, and can therefore efficiently represent any stratigraphy between horizons.

The 3D geologic model contains further information about the paleo-geographic coordinates of all the cells of the geologic grid created inside the 3D model. Geostatistical algorithms may then be run inside the paleo-space in order to undo post-deposition deformation.

By applying a dynamic uncertainty-considerate workflow, the user can construct based on this analysis a reservoir property model by first performing a facies distribution per each layer, using a complete set of categorical simulation algorithms. For each facia, it should be possible to populate all the petrophysical parameters needed using kriging (statistical) or simulation methods.

As data uncertainty always heavily hampers or influences geological interpretation due to sparse information and being very interpretative, a uniform approach to uncertainties in petrophysics, structure and properties is therefore required. Uncertainty is not only present in the algorithm that the modeller chooses to apply; it is also present in all the parameters and the data used in those algorithms. Uncertainty about correlation coefficients, variogram range, or with porosity distributions requires a sensitivity analysis of all modelling input parameters. When dealing with uncertainty, the most important factor is to know which parameters govern and dominate a geological setting or model, so that the workflow can be optimized and steps can be taken to reduce this uncertainty. Integrated G&G software suites can help and guide the user in this process to substantially reduce model uncertainty.

The ultimate output resulting from a G&G software is the mathematical transform from static to dynamic models. The 3D model may be discretized to automatically construct a flow simulation grid, where all necessary faults are taken into account and all cell geometries are optimized for a high performance flow simulation. Up-scaling between the fine-scale geologic grid and the coarser flow simulation grid should assure spatial integrity.

As the final step in G&G modelling, the reservoir flow simulation grid can now be constructed in any geological setting for reservoir simulation and a so-called history matching. This includes fault geometry or fault inclusion in the flow simulation model by incorporating all faults, which are needed to perform an acceptable history matching. This is crucial and critical in all reservoir characterization tasks.

Most of the G&G software application suites are built atop of a multi-user, multi-site and multi-OS data management platform. All modelling processes are encapsulated inside workflow management guides to assist also the occasional user, as well as to store all the parameters used to construct a model for audit ability and QC purposes.

Special attention should be given to the fact that all G&G software applications are open, allowing outside vendors to add proprietary or third-party technologies as added on software solutions. This can involve plugins that have full access to other data models or an open framework for a fast prototyping environment that allows developers to creating new commands into the 3D visualization window and dialog boxes, and insert them into existing menus. Some G&G solutions even offer a high-level programming language to add new algorithms and processes directly within the user interface.

Well planning and data management

The drilling engineer usually starts the well planning process with the collection of topographical field information, e.g. available GIS data and the global position of fields, sites and borehole locations in geographic coordinates (Fig. 4.8) On the computer screen the planner visualizes and identifies targets, including their shape, dimension, thickness, rotation, dip and offset in that planning stage.

Geological surfaces and faults can also be incorporated at this stage for visualization, and intersections by the planned well computed and displayed. The well planning software runs typically from of a common database for all wellbore data, including mechanical, directional, geophysical, petrophysical and geologic well information.

Fig. 4.8: Horizontal well trajectory for the Campi Flegrei deep drilling project in Italy

A drilling planning package is consequently used to plan new wells as well as side-tracks, multilateral and re-entry from existing wells by tying to existing wellbore information and trajectories stored in the common database (Fig. 4.9). All critical well information, like casings, borehole sections, comments and survey tools error margins can be defined therein, as well as lease lines and local boundaries visualized at this stage of the planning process.

In reference to wellbore position uncertainty, the planning engineer has a full range of modelling techniques at hand for evaluating the different magnetic and gyroscopic survey data of the bore. This allows him to define the critical confidence level of calculated borehole subsurface coordinates for the present position of the borehole. These confidence areas are typically represented by cones of uncertainty, as they need to be determined after Wolff and de Wardt, in SCWSA magnetic models, or in the manufacturer's gyro models (Fig. 4.10).

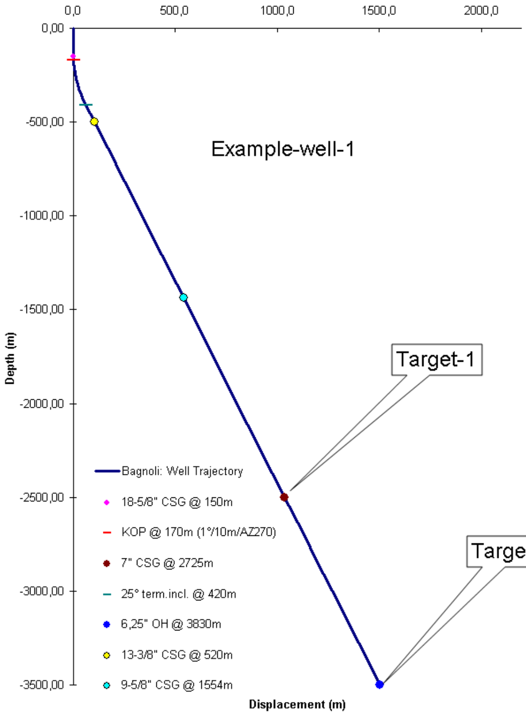

Fig. 4.9: Directional well plan for Campi Flegrei project in Italy

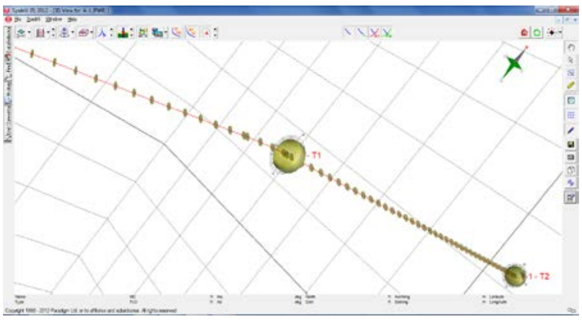

Fig. 4.10: 3D view of uncertainties ellipses of planned Monte Civitello well in Umbria, Italy

In addition many packages do allow creating user defined error models based on survey instrument manufacturer specification data. These position uncertainty models are particularly helpful in crowded borehole areas as they furnish an anti-collision analysis from the drilled and the neighbouring boreholes against offset wells stored in a common database. This way they assure at all time avoidance with neighbouring wells during the drilling in their vicinity. Results of this analysis do typically include wellbore separation, ellipse separation, clearance factor and diverging depth ranges. The results are displayed in the form of ladder plots, a travelling cylinder or tabular formats, and accordingly highlighting high, medium and low collision risks with a traffic light indicator.

For survey management, all recorded directional survey data during drilling or from logging runs, including overlapping surveys, are entered and stored in the systems database. The definitive wellbore is finally created by specifying proximity calculation and travelling cylinder plots. 3D views to/from depths for each survey section can be performed in order to eventually decide on a definitive and wellbore position and its final positional uncertainty. Once the final survey has been loaded, it is locked, thus ensuring the integrity of the database for anti-collision analysis or future side-tracks and new well drillings thereafter.

When the drilling is underway, a current drilling trend can be analysed with the so-called project–ahead functionality in order to determine whether drilling corrective action is needed. If a correction is required, a revised trajectory is usually calculated by the drilling engineer based upon one of the selected modes "return to plan", "nudge/steer" or "project to target" definitions. Projections, including positional uncertainty, are at this stage visualized in 3D viewers and can be compared to the drillers' target or the earth model from the G&G suite for clarity and decision taking purposes. All projections at this stage should be saved for quality-control (QC) purposes for later engineering analysis and decision-taking on the rig.

Ideally the deepening progress of the actual wellbore can be interactively monitored in the 3D viewer and continuously compared to the planned wellbore and other wells in the vicinity. Thus, geological surfaces, casings, positions of uncertainty and drillers' targets are incorporated in the 3D viewer. The data should be written in electronic HTML format, allowing interactive viewing in a standard Web browser by other groups of researchers who can then remotely log into the data base. All visualisations and calculations ought to be documented by an advanced well-planning software package through an extensive set of pre-defined plot and report templates. Users should be able to define plots and reports that can be saved and their settings later re-used. Customizable plan section, travelling cylinder, 3D and survey comparison plots should be standard by the majority of the advanced drilling planning software tools.

Drilling engineering

One of the first steps in drilling engineering is to validate the selected geometric well bore profile mechanically and dynamically, so that the drilling can actually achieve its objectives without drill string failure, injuries to people and loss of rig time. For this task the Torque (TQ) & Drag optimization and analysis software package is typically used by the drilling planning engineer in order to model all types of Bottom-Hole drilling Assemblies (BHA), casing and completion strings with respect to their suitability (Fig. 4.11). A pick & choose BHA string constructor is embedded in these engineering packages allowing complex BHA's to be quickly constructed by rapidly filtering through and selecting from extensive catalogues of industry supplied drilling equipment.

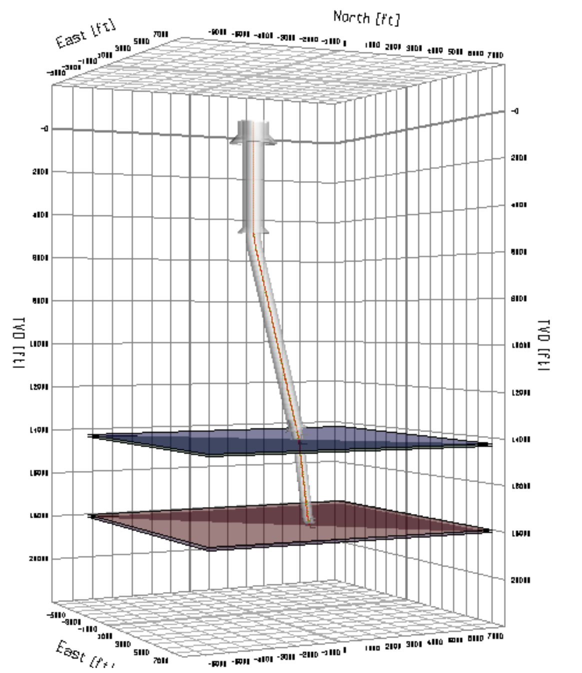

Fig. 4.11: Casing scheme with 3D well profile and geologic targets in Monte Civitello project in Italy

Often a customizable material selector user interface allows new grades of steel to be incorporated into the drill assembly. The functionality of API (American Petroleum Institute) rotary shouldered drill pipe as well as the most common API casing connections should be pre-loaded in the software, which is capable to be individually extended by the user. This allows the calculation of connection thread properties and connection strength of customized thread connections. BHAs that have been created in past projects preserve selected catalogues for future re-use, as well as new industry catalogues, which can be added upon availability. The planning engineer should be able to generate a customizable graphical view in order to combine mechanical properties and physical dimension plots.

BHAs must not only be analysed for their mechanical suitability, but as well for predicting their directional behaviour. Soft -&- stiff string analysis options allow calculating all forces acting upon the BHA during the drilling process, including torque, drag, stresses and side forces (Fig. 4.12). The calculated loads are compared to buckling, string yield and rig operating limits, and the results presented to the drilling engineer using a "traffic light" approach for quick identification of potentially hazardous drilling conditions.

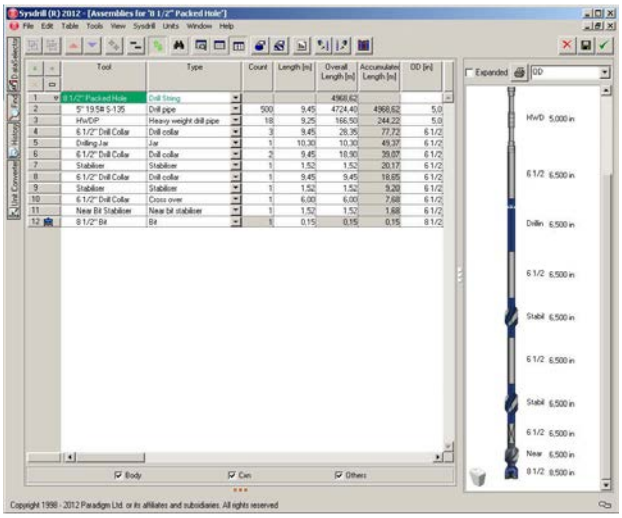

Fig. 4.12: BHA builder with Sysdrill well planning and engineering software suite

User-defined operating modes, like reaming, sliding, steering or rotary can be incorporated in the calculation, allowing forward-modelling of the drilling process for a given hole-section. In relation to directional prediction of BHAs, a range calculation performs a full drilling dynamic analysis at varying depth and provides a summary of surface results. Hook load and surface torque readings gained from the rig site are entered and displayed in such range graphs. This allows comparing modelled with observed loads during drilling.

The modelling and analysis of axial and torsional friction factor conditions and reduction effects from special torque-reducing drilling tools is a further important output of a TQ & Drag engineering package. Initial friction factors will be obtained from industry reports or by using well data from previously drilled wells. While drilling the well, friction factors are back-calculated, allowing realistic analysis and prediction for sections ahead and future wells in the area to come. By including hydraulic effects, the additional viscous forces and pressure induced stresses can be further included in this advanced analysis.

One of the most valued products of real-time drilling dynamics is the stuck-pipe calculator, which is used to predict a potential stuck point depth during the drilling process. Its analysis is based on measured surface torque, pipe twist, and surface over pull and stretch, taking into consideration hole inclination friction factors and borehole stability conditions. Modelling results are typically presented in traffic light display for ease of reaction to upcoming hazards.

Another important output of the TQ & Drag package is the critical rotary speed analysis. It predicts the rotational speeds at which resonant frequencies may develop. This analysis is taking into account axial, lateral and torsional vibration modes, and highlights rotary speeds to increase chances of avoiding and preventing excessive string damage and BHA failure during drilling.

Drilling hydraulics

Core of a hydraulics optimization and analysis package is to model downhole circulating pressures during drilling, tripping and running casing in order to enhance bit hydraulic performance and ensure effective hole-cleaning as well as bit cutter cooling.
Basis for hydraulic engineering is the rheology model selection, a software-supported fluid builder device, which allows accurate definition of fluid properties for use in all subsequent hydraulic engineering calculations.

Properties of selected drilling fluids are typically stored in catalogues for re-use in other analysis models. A rheology modelling tool, for example, can analyse drilling fluids and automatically selects the most suitable rheology model based upon viscometer readings. Power Law, Bingham Plastic, Herschel Bulkley & Robertson Stiff models are supported by most hydraulic packages.

Swab/surge and equivalent circulating density (ECD) analysis are performed to reduce the risk of formation breakdown or swab-induced influxes during tripping operation and drilling. Drill string geometries and cuttings concentration in the mud column are equally considered in the ECD calculation for defining the operable mud window. Cuttings transport ratio and annular critical velocities are additional outputs of the model.

Most hydraulic software packages feature a fluid temperature modelling functionality, which provides a quasi-steady state temperature model, incorporating an advanced compositional density and HPHT rheology model. This allows to simulating a number of drilling scenarios, i.e. complex geothermal gradients, horizontal wells and dual-gradient mud systems. This functionality is in particular required for an accurate prediction of ECDs, and equivalent downhole mud density as well as rheology under high-pressure, high-temperature (HP/HT) conditions

As an output, the hydraulic software package includes several modes of optimization, including pump pressure, flow rate, % bit pressure loss and bit total flow area (TFA) calculations. Bottom hole horsepower curves can be generated, showing hydraulic power and impact force with varying flow rate and bit TFA. Nozzle configuration and TFA can be calculated depending on flow rate and surface pressure conditions, thus enhancing and optimizing the bottom hole hydraulic energy for maximized drilling speed. Other responses and feedback mechanisms from a hydraulic software package are the calculation of the maximum running speed for BHA's and casing strings (with both open and closed pipe) in order to avoid borehole damage.

For the selection of most efficient parameters, a sensitivity analysis allows the calculation of all pressure limits and tolerable ECDs at varying flow rates, indicating minimum and maximum flow rates.

Casing and tubing analysis

A modern casing design package lets the drilling engineer allow to design the minimum number of casing strings required to safely complete a well, thereby maximizing drilling efficiency under minimization of well capital cost (Fig. 4.13).

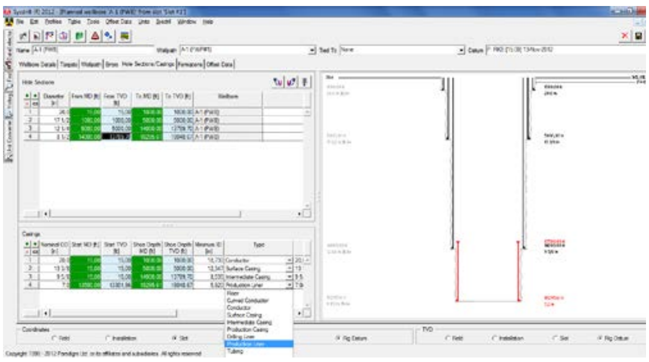

Fig. 4.13: Casing design and calculation template from Sysdrill well planning & engineering suite

For each casing selection, the casing setting depths are automatically calculated in the casing analysis package based upon pressure data and user-defined constraints such as trip margin, kick tolerance and maximum open-hole distance.

The design procedure of a casing string and its strength analysis should include: 1) uni-axial, half bi-axial, full bi-axial and tri-axial stress checks for axial load cases; 2) bust and collapse load cases for all stages of the well's life cycle, including all drilling phases with their changing mud properties or pressure imbalances; the latter includes well-kicks or mud losses and the analysis of the well production phase after drilling under different temperature and pressure conditions; 3) graphical plots, tabular data and traffic light pass/fail indicators should allow rapid identification of problematic loading conditions.

As casings do wear with time and with the deepening of the well, a casing wear module should be applied to predict internal casing wear for a number of drilling operation and should be able to de-rate casing thickness for burst and collapse calculation accordingly. Alternatively a calliper log can be incorporated as a percentage-wear identification measurement device and used to planning ahead the drilling process.

Cementing engineering

A cementing engineering and analysis module is used to plan cementing operations in order to ensure the safe installation of casing strings or cement plugs. It optimizes pumping operations for variable flow rate schedules, i.e. fixed flow rate, fixed bottom hole pressure, and free fall cement in order to safely manage down-hole pressures during such operations. This software module stands most often as a back-up and Quality-Control (QC) check to service company proprietary cementing programs.

An animated wellbore cementing analysis calculation display allows the monitoring of the fluid flow regimes, bottom hole pressures, ECDs and flow rates as cement is circulated into position. Simultaneously, expected pump, choke and hydrostatic pressures and pressure losses are calculated. Bottom-hole pressures depict kick-pressure plotted against fracture gradient and formation breakdown pressure in order to prevent fracking of the formation due to the drilling impact. The cement volume calculator, which is available via the cementing or hydraulics software modules, will further provide solutions to many common well site volumetric problems, including pill spotting and balanced cement plugging.

In addition, a well control-kick tolerance calculator is used to verify that casing shoes are further set and cemented safely at safe depths in order to avoid formation breakdown. This way a kick of a given size can easily be simulated and compared to the actual casing shoe depth or the maximum allowable influx for a hole section calculated. Kill sheets will be produced, including dynamic maximum allowable surface pressure (MAASP), volumes, strokes and a pressure step down chart required to safely control the well in such an emergency situation (Fig. 4.14).

Integrated workflows

Many well-planning and engineering packages today offer a tight integration with other software applications, running on one data management infrastructure. Thereby a common data management environment is essential for multidisciplinary teams of geoscientists and drilling engineers who plan and monitor wells to ensure optimal wellbore design and drilling progress.

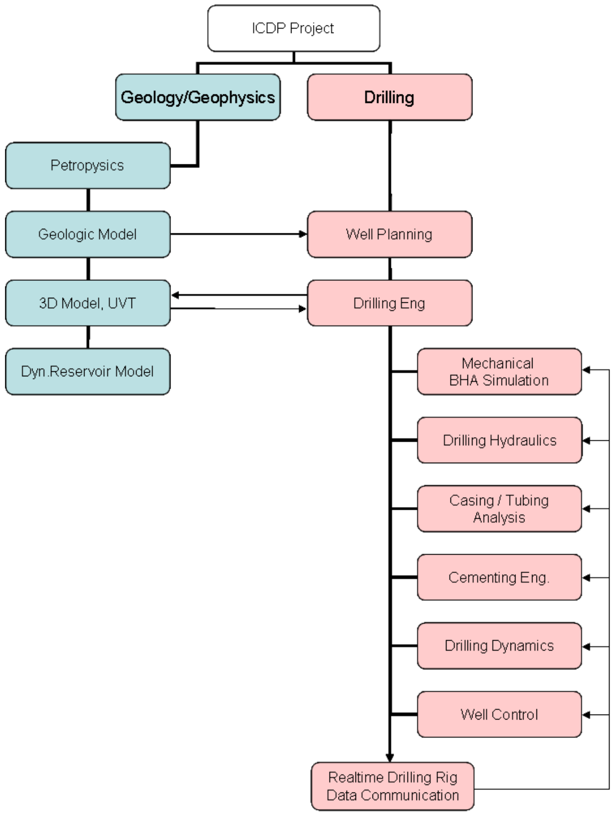

Fig. 4.14: Well engineering flow chart for oilfield type drilling incl. casing, cementing, reservoir model

A two-way link with seismic interpretation applications could be integrated for interactive well-design and trajectory monitoring workflows in a 3D interpretation environment, which interconnects the well database into combined well-planning, engineering and geo-steering workflows.

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CHAPTER 5

Data and Sample Management

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The main objective of Data and Sample Management is to acquire key information about the technical and scientific works performed during the operational phase. Works are typically performed in the field, in the lab, or at the sites where sample material is stored. Ideally, the resulting output provides a comprehensive data set that can serve as a common reference. Validation of this data set should be completed when most of the science team members start their scientific work. Therefore, data and sample management is an important service during the lifecycle of a drilling project. Dedicated planning including the definition of data management policies is a prerequisite for success.

Lifecycle

The general Data Management Lifecycle is outlined in Figs. 5.1 and 5.6 from the data and sample management point of view. Starting with the first proposal (see: Chapter 11 on Proposal Writing), principal investigators should describe in detail which financial means and resources will be needed during the operational phase for the data and sample management. The proposal should include budgets for hard- and software, transport of devices such as the core scanner, or the sample material from the site to the lab and/or repository, and the travel costs for a training course or workshop that is focused on the planned operational data and sample management in the field, the labs, and storage of sample material of that specific project. Beginning with the first shift onsite, the acquisition of the primary or basic data commences. Regularly, staff should upload these field data to an official Project Web Site (e.g., http://cosc.icdp-online.org/), and store raw and processed data in an archive for secure long-term preservation.

As long as the fieldwork is going on, each shift will collect data in a way which is almost always unique and project-specific. In many cases, after the final hole has been drilled, a certain period of lab work happens next. This phase is also part of the primary data acquisition. Toward the end of the operational phase, the sample material should be ready for sampling and distribution to remotely operating members of the science team. An important final document, the "Operational Report" comprises all this information and serves as the common reference for all follow-up activities, such as scientific and engineering analyses, that usually are published in scientific journals. The Operational Report is a public document. Typically, during the operational phase, physical sample material and online data can exclusively be accessed only by registered science team members (secure access). However, after a project-based, pre-defined moratorium time period, eventually most locked-up publications and the rest of the sample material become publicly accessible. This kind of data management Lifecycle (Fig. 5.1) is repeating itself in a similar way for each new drilling project, independent of the scope of the project.

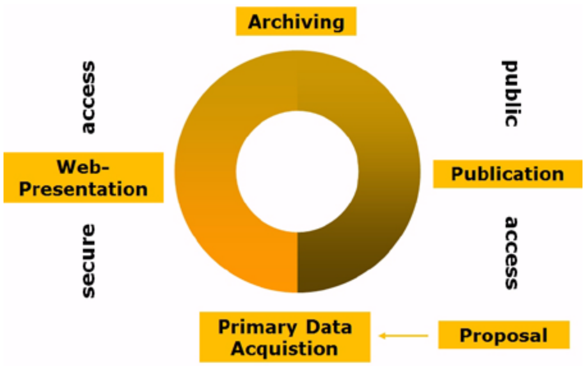

Fig. 5. 1: Lifecycle of data management in drilling

The Science Team

The Science Team is of central importance for the data and sample management because here the producers and consumers are the same people. The Principal Investigators (PIs) and cooperating PIs (CO-PIs) are naturally the major stakeholders of the project. They set priorities for incoming sample requests and proposals. They have to work out the specific plans and budgets needed for data and sample management. If needed, they also designate Chief Scientists for the different subprojects, and they finally assign scientists, students, technicians and volunteers to the science team. It is imperative to identify and prepare certain individuals to key responsibilities early in the project. This also holds for the data and sample management tasks as they arise during the project (e.g. through aforementioned training courses, workshops, etc. – see also: Chapters 10 & 11 on Outreach, Education and Training, and Proposal Writing). In most cases, the total number of science team members is larger than the group which is doing the field work and lab work during the on-site operational phase (Fig. 5.2). Therefore it is important to set up a-priori policies (see also: Chapter 12 on Project Funding and Policies) among all key players of the project to avoid conflicts of interest that may create data and sample management issues later on.

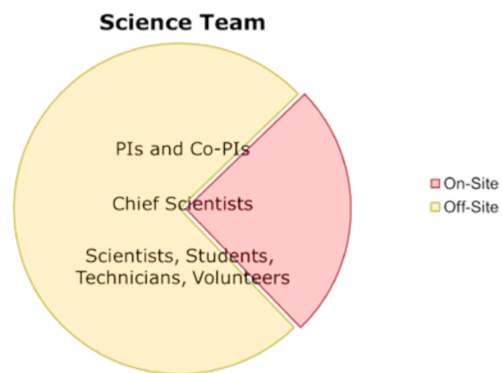

Fig. 5.2: Typical composition of a science team

In addition to the science team, a number of service companies, sub-contractors, and other project-aids (sometimes in form of volunteers) are involved throughout the various project segments. They often contribute to data acquisition in different ways, and thus are an important integral part of the science plan. These topics and fine details of a project have to be negotiated carefully beforehand.

Policies

Sound and reasonable policies for a proper project management are required throughout every successful ICDP project (see also: Chapter 12 on Project Funding and Policies). The content of these policies should already be discussed and confirmed during the proposal development phase. Each science team member should commit to these rules and guidelines before the planned start of the operational work. The main topics are:

- Moratorium periods and milestones along the timeline
- Science Team – Selection of participating scientists, responsibilities, duties and privileges
- Data acquisition and sharing
- Scheduling and distribution of reports
- Sampling strategy and sample distribution
- Publication guidelines along the timeline
- Public outreach issues and internal confidentiality agreements

Information system for Scientific Drilling

Any information system for scientific drilling projects can be divided into three levels according to the main purposes of the data and sample management as shown in Fig. 5.3:

- Data acquisition
- Data dissemination
- Data publication

For data acquisition purposes, ICDP provides the Drilling Information System (DIS) which can easily be adapted to the individual requirements of any specific project. The task of running and maintaining the project-specific DIS is usually established and located on-site, nearby the drilling operations, in field laboratories, shore bases, buildings of institutes and/or storage places for sample material. DIS is designed for the use in a small 'closed shop' environment (a small, private, local area network) and optionally communicates project data via the Web-based eXtended DIS interface (X-DIS).

The DIS-Administrator is able to define which data are shown, which forms, reports, or data views can be selected, and who is authorized to edit (insert, overwrite, delete) which subset of data via X-DIS. One advantage is that the DIS-administrator can perform certain maintenance features remotely, another benefit is that certain project members, e.g. principal investigators or chief scientists can use it for remote cross-checking and quality control (QC) purposes.

For data dissemination it is recommended to use modern Web based transfer mechanisms and online media. This online interface platform acts as user interface for the public in order to fulfill outreach purposes and as user interface for the science team members to access internal project data and information.

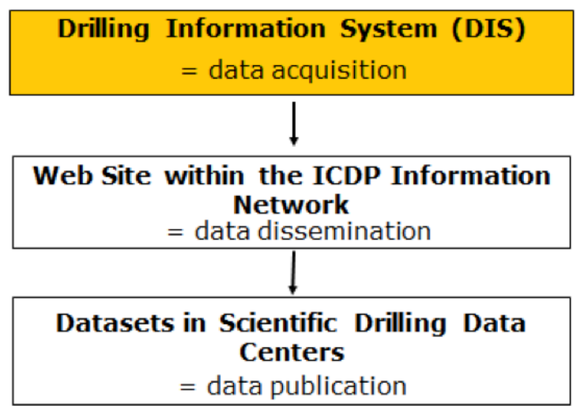

Fig. 5.3: Three level architecture of an information system for scientific drilling projects

For data publications, it is recommended to use established data-sharing services from institutional or commercial data centers, sometimes labeled as "World Data Centers". Many publishers allow adding Supplementary Materials to online versions of already published papers.

The Drilling Information System DIS

ICDP provides the Drilling Information System DIS for operational support and on-site data management. It is designed as a software toolbox to build and maintain customized DIS instances for any distinct drilling project. The software is based on a project-specific and internally consistent database, which integrates different types of information (various measurements and data sets). The graphical user interface of DIS utilizes specific but still customizable data-input forms, and templates for both tabular data-views and printable reports. The main purpose of the DIS is data acquisition for the documentation and administration of:

- basic – initial – primary data
- initial measurements and reports
- sample requests, sample curation and sample distribution

in order to establish a common data set and reference for all science team members.

The DIS is designed to be used on-site in parallel with daily operations to perform the data acquisition alongside a defined workflow. This is helpful for avoiding the excessive creation of non-synchronized and non-authorized data files. Toward the end of the on-site drilling phase, the collected data should go through a depth matching process to synchronize different depth regimes and to integrate downhole logging data. Finally, the built-in templates of DIS can be used as source for the Operational Report.

However, the DIS will never be an active online real time monitoring system, or an active measuring or logging system. The DIS does not include any applications performing sophisticated exploratory data analysis for interpreting or evaluating data. These software design-decisions have been made on purpose. Experience shows that researchers prefer their own toolsets for analyzing and visualizing science data anyway.

The concept of DIS defines data-acquisition workflows that focus on certain automated data-consistency checks and human quality controls. Data integrity is enforced in terms of measurement units, date and time formats and naming conventions at the time of data capture, before it is safely stored within relational tables within the DIS project database. The data contents of the measurements can easily be transferred into external data-processing applications and spreadsheets.

Technical setup and scalability

The DIS can be installed as a single standalone, even mobile system, or in context of a local area network depending on the environmental options on-site (Fig. 5.4). The central part is always a dedicated personal computer acting as DIS server which contains the data base system and the DIS user interface. If data acquisition facilities are being distributed across a larger area, such as a large field site, or a fleet of research vessels, the DIS server can be cloned into several instances. These can be kept in synchrony by means of a built-in mechanism known as data base replication.

Any number of DIS client computers can connect to the dedicated DIS server. They can be added using wired or wireless network connections. A DIS client does not store any data locally, but instead has only the user interface for data input installed. Other external devices such as core scanners or core loggers can be also part of that network. The simplest interface is a shared file system of the used network. If the device allows, a DIS interface can be added.

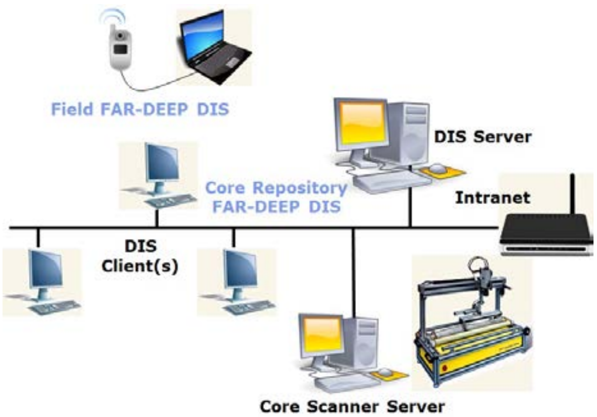

Fig. 5.4: Set up of a typical field or core repository DIS, showcasing the DIS of the FAR-DEEP

If the DIS system at the field site can be connected to the internet, it is possible to upload daily updates and progress reports to the dedicated project website and/or archive servers. It is also useful for remotely supporting the DIS operator and the DIS system itself. Under certain circumstances it might be required to configure and enable the eXtended DIS interface, which allows a secure remote access to the operational DIS on-site. For more details and valid versions of the DIS operational procedures please **click here** (www.icdp-online.org – Support – Data Management –Technical Requirements)**.**

Standards and naming conventions

For describing the most important features and attributes of wellsite data and geological field data, ICDP uses similar terms and naming conventions as IODP has introduced. In both data-models, the terms are arranged in a relational hierarchy:

- *Expedition* is the operational phase of a scientific drilling project
- One or more *Sites* can be visited during an Expedition
- One or more *Holes* can be drilled on a Site

The data model of the German data center PANGAEA also includes an extension:
One or more *Events* can take place on a Site, e.g. the event 'Drilling a Hole' (or 'Water Sampling')

ICDP / IODP	ODP	PANGAEA
Program		
Expedition	Leg / Cruise	Project / Campaign
Site	Site	Site
Hole	Hole	Event

Table 5.1: Conceptual schemes and terms of IODP, ICDP, and PANGAEA

As shown below, the used naming conventions can be quite different. To overcome these differences, the DIS allows unconstrained/free-formatted naming schemes as long as these are used consistently throughout a single expedition or project.

	Expedition	Site	Hole
IODP	312	M0005	A
ICDP	5023	1	A
LacCore	GLAD5-BOS04	1	A

Table 5.2: Conceptual schemes and terms of IODP, ICDP, and PANGAEA to define expedition, site and hole for each project

Main tasks and personnel requirements

The Chief Geologist is responsible for maintaining the integrity of the pre-defined science plan and sampling plan. Accordingly the chief geologist selects supervisors and helpers (program-aids called within IODP) who perform the daily work of data and sample acquisition and management (Fig. 5.5). For installing and operating DIS, a staff member with a certain expertise and skill set should act as IT expert for the administration and maintenance of the system. Additional responsibilities of this IT manager role are:

- guide and educate additional data entry staff,
- take care of shift plans of the data entry teams,
- oversee consistency and quality/security of the data acquisition (Fig. 5.5),
- interface as relay for distributing reports.

Rule: Data and sample management is not a just technical issue.

Expedition

It is good practice to consider Data and Sample Management as long-term tasks that start with the field work and extend throughout the entire period of the expedition and project duration. Therefore data management deserves a high-level of attention from both the project management and entire science team.

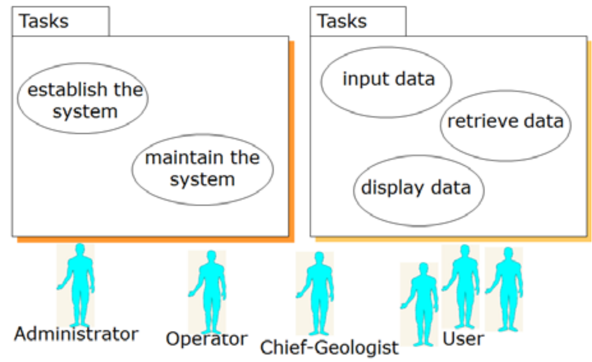

Fig. 5.5: Tasks and personnel for data and sample management

In a typical timeline of a scientific drilling project, a training course or workshop is the first major event to kick-off data- and sample management activities. Such a training and/or workshop should be conducted within a six-month period prior to starting drilling operations. Generally, the crucial phase of the expedition starts with rigging up for the first hole and ends with the completion of the operational and/or operational report. During the drilling phase, the initial project data are collected as they relate to a multitude of drilling parameters and the intrinsic details of the drilling operations, the recovery of the material extracted from the hole, its sampling, creation of descriptions and documentation, downhole logging data, and so forth. However, in many cases not all of these tasks can be executed and performed on-site due to harsh environmental conditions and/or a lack of available space. Consequently, the expedition is then divided into two phases of drilling operations and lab work. This often takes place with a significant lag time due to the transfer of all the sample material from the sites to the target lab (Fig. 5.6).

Rule: Avoid any task which is not directly important for decisions regarding field operations, and which can be taken care of better in the lab than in the field.

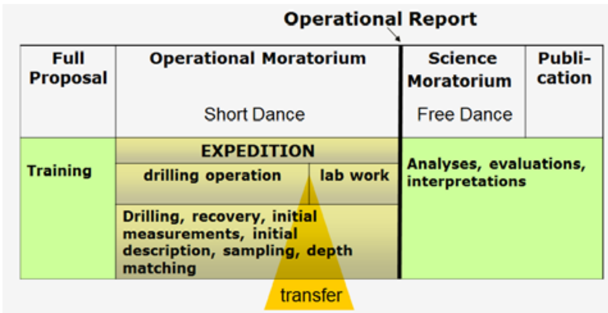

Fig. 5.6: Typical timeline of a scientific drilling project

Expedition DIS

The Expedition DIS is designed for use in the field or on board (onsite/offshore) and in the lab (onshore). Due to its relatively simple technical setup and scalability it is easy to handle. The basic architecture of a typical data acquisition and workflow model is shown in Fig. 5.7.

Ideally the grant proposal and the science plan contain the outline of a data management workflow. This only exists in conceptual form on paper. The DIS operator must convert the predefined, conceptual workflow into an individually designed ExpeditionDIS of the project.

This should happen before drilling starts. The ExpeditionDIS can be customized according to the actual environmental situation and requirements. This customization can be a complex, unfamiliar task to most people on the science team. The ICDP OSG offers training and support before and during the field operations as well as remote support after the initial set-up in the field.

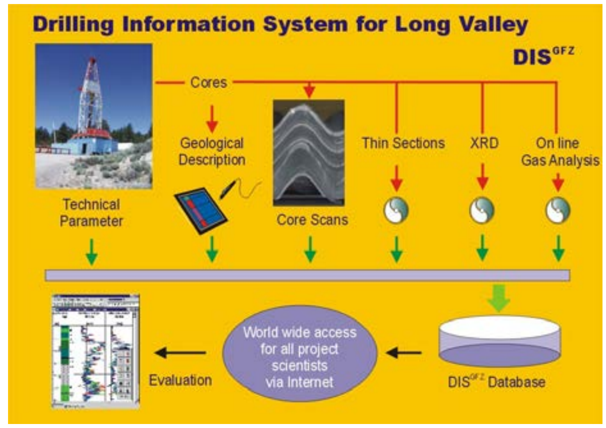

Fig. 5.7: Scheme of data management for the Long Valley project in ICDP

Many drilling projects limit the onsite workflow to capturing the technical parameters of the drilling operations and producing corresponding reports, citing recovered sample material such as cores, cuttings, mud, fluids, and gases. Other drilling projects perform imaging and initial lithological descriptions onsite as additional part of the project documentation. Additional measurements for continuous petrophysical and/or geochemical properties can be included. If sampling is allowed for reasonable special cases, these samples have to be tracked. To this end, persistent identifiers can be used. Recently, the capability to tag samples with "International Geo Sample Number" (IGSN) identifiers has been added to the ExpeditionDIS system. IGSNs are worldwide unique IDs that can be used as digital link to almost all information related to the object. These samples may be treated for onsite thin section preparation and analyses or even XRD measurements. Preferably the basic data acquisition can be entirely done onsite, as demonstrated by the Chinese Continental Scientific Drilling Project near Donghai.

The scope of subsequent analyses encompasses mainly descriptive methods and automated measurement procedures. Each method and each step along the workflow can produce various data formats in different units and scales of resolution. The DIS allows for configuring specific scripts (“data pumps”) to harmonize these data using a common naming convention and standards for date and time, depth scales and units. As soon as the data are stored in DIS tables the data can be copied to the project specific Web sites and/or further processed for reports.

Sample strategy

The statement below is fully applicable to scientific drilling although it is derived from planetary and space science (Allen Carlton et al. 2013, Curating NASA’s extraterrestrial samples. EOS 94(29):16.7.2013):

“Through nearly a half century of work on analyzing and curating samples from places beyond Earth, a few key messages stand out.

First and foremost, the main point of any sample return mission is laboratory analysis. Everything must be designed, built, and operated to get the highest-quality samples to the best laboratories.

Further, curation starts with mission design. Samples will never be any cleaner than the tools and containers used to collect, transport, and store them. Scientists and engineers must be prepared in case missions do not go according to plan. Really bad things can, and do, happen to missions and to samples. Careful planning and dedicated people can sometimes save the day, recover the samples, and preserve the science of the mission.

Every sample set is unique. Laboratories and operations must respond to the diversity and special requirements of the samples.

Finally, curation means that those involved are in it for the long haul. Samples collected decades ago are yielding new discoveries that alter scientific understanding of planets, moons, and solar system history. These discoveries will inspire new generations of scientists and research questions and will drive future exploration by robots and humans. Curation is—and will remain—the critical interface between collecting samples and the research that leads to understanding other worlds.”

Sample requests and sample distribution

The central rule is ‘No sampling without sample requests’. In order to achieve this it is recommended to publish ‘Calls for Sample Requests’. This can be done already before the planned drilling operations actually start. This call should be repeated, but be announced not later than the closing sampling party or science workshop toward the end of the expedition. These reasons are important:

- To inform the science team about the actual drilling targets
- To review the individual sample requests
- To detect sections which are over-sampled, or which are not requested enough
- To review and adjust the general sampling strategy
- To improve the sampling procedure

The first “call for sample requests” is especially important for samples that have to be taken on-site simultaneously with the drilling operations. Here is the chance to check whether this type of sampling is really necessary, and if yes, how it can be integrated into the on-site workflow. The second “call for sample requests” should be done when the holes and the sample materials have been initially measured and documented. In both cases, the Web based project site is very useful as interface to the science team members. Images, scans, lithological descriptions, logs along the sample material and inside the holes are basic information about the quality of recovery and geo-properties that can support the selection of appropriate sampling spots.

Rule 1: No sampling without sample requests.
Rule 2: On-site sampling is restricted to special requirements based on a consolidated science plan and accepted through an approved sample request.

Sample curation

ICDP does not maintain its own storage sites (repositories) for sample material. In general, the project has to take care of appropriate facilities and accessibility for a long-term period after the end of the project. Additional to that, ICDP is allowed to use storage facilities from IODP, LacCore and GESEP.

Repository	Program	Country	Envir.
Bremen Core Repository (BCR)	IODP	Germany	cooled
Gulf Coast Repository (GCR)	IODP	U.S.A.	cooled
Kochi Core Center (KCC)	IODP	Japan	cooled
National Lacustrine Core Facility (LacCore)	NSF, CSDCO	U.S.A.	cooled
Rutgers … Core Repsoitory	IODP	U.S.A.	cooled
National Core Repository	BGR, GESEP	Germany	not cooled

Table 5.3: Core Repositories cooperating with ICDP

ICDP is offering the CurationDIS as a Drilling Information System administrative tool for managing inventory stored in data repositories (e.g. Tab. 5.3). These repositories host and preserve sample material and conduct professional sample curation. One big advantage of the DIS work philosophy is that the content of an ExpeditionDIS can easily be transferred into a CurationDIS. Another advantage is the assignment of International Geo Sample Numbers (IGSN). Already on ExpeditionDIS level IGSNs are assigned to holes, cores and sections, mud, cuttings, gas or other material extracted from the project drill holes. IGSNs are assigned to any on-site sample; corresponding labels can be printed already in the field (Fig. 5.8). As sampling continues in a core repository, the same procedure is performed by the CurationDIS.

Fig. 5.8: IGSN encrypted in QR code on core sample

Depth matching and composite profiles

Depth Matching is an important issue of wellbore data consistency. Typically, during the operational phase of a drilling project, many different depth systems are being used:

- The Driller Depth is calculated from the length of lowered drill string
- Lag Depth (see: Glossary) is a calculated depth derived from the mud circulation and is used for any kind of mud samples, e.g. cuttings or gas

- Log Depths derive from downhole measurements. Log depths are usually continuous and most accurate

If log depths are available, it is recommended to correlate or match all other depth systems to log depth. Composite Depths are resulting from splicing selected sections retrieved from different holes. True Vertical Depth can be calculated if the trajectory of the hole is known.

These three features are supported by the DIS:

- Transfer any depth measures in meter units
- Define common reference level for all holes of a site
- Build composite or spliced profiles in case of multiple, partly overlapping holes on a site

These two features that require specialized software tools such as WellCAD and/or CORRELATOR:

- Correlate all types of depths with a selected master of the downhole logs
- Calculate true vertical depth

Spliced data profiles (including line scan images) can be generated by using, for example, the open-source tools CORRELATOR and CORELYZER to produce a composite site image overlaid by the various data sets (e.g., from logging or physical property measurements). This also extends into the task of 'Depth -&- Data Matching', which is, generally speaking, a mandatory prerequisite for the overall quality of the data set(s) obtained in the field and laboratories after the field operation has been concluded.

Operational/Expedition reports

The often short expedition period has a more standardized structure compared to the longer, subsequent period of the science moratorium. The moratorium period has essentially no predefined workflows, because it is strongly dependent on the outcome of the drilling phase, the general financial situation, participant turnover, and other factors (Fig. 5.6). Therefore, the Operational Report is an important milestone and landmark between these two phases. The Operational Report must be finalized not later than six months after a sampling party where the samples are distributed to the science team. All data sets and results produced during these scientific analyses, evaluations, simulations, and interpretations become parts of the science papers to be published toward the end of the pre-defined science moratorium.

To make the operational report more attractive

- it should be reviewed by external reviewers
- all science team members are authors and have to contribute (this makes the selection of science team members even more important)
- it should be published as digital supplement including the basic data sets under open access license of a regular journal such as the Scientific Drilling Journal (see: Chapter 10 on Education and Outreach)
- it should be a public document
- it can be a door opener for an additional post-drilling workshop where all science team members gather to discuss the gained knowledge and sample material, and plan the next steps of the subsequent scientific work

A template for a Table of Contents is shown below:

- Title page
- Publisher's notes
- Expedition participants
- Abstract
- Introduction
- Geological Setting
- Scientific Objectives
- Strategy
- Synthesis
- Site Overview
- Preliminary Scientific Assessment
- Topics according to the specific expedition (e.g. lithostratigraphy, micropaleontology, sedimentation rates, petrophysics, chemistry, microbiology, others)
- Operations
- Site Operations
- Acknowledgements
- References
- Tables
- Figures

One example is available **here**.

The project web site

In addition to providing the operational tools and procedures for the data and sample management in the field, labs, and repositories for sample material, the project is hosted on ICDP's Web site on the World Wide Web. ICDP usually creates a Web site for each ICDP project after the first grant proposal for a workshop has been approved.

Within the conceptual design of ICDP, each project receives the same initial screen space and weight within the ICDP Web site structure. Generally, each project is described on a project profile that derives from the proposals. Topics such as News, Scientists, Press & Media, Publications, Workshops, etc. are updated as required. With the project developing and according to actual project activities, the project Web site also grows. When the project is ongoing, it usually receives more attention from the general public. Accordingly, the project will be featured as an ICDP Highlight on the web site.

In order to enhance the outreach effect, a project can also maintain its own Web site. Project PIs can use their own preferred choice of modern social media. ICDP web site creates an abundance of links to the project-specific contents of these external media. More scientific project data are usually confidential and under secure access for registered science team members only. This protected area serves as a knowledge transfer platform within the science team, and is very useful for selecting samples.

Long-term monitoring equipment

Some projects are using the drilled holes for long-term measurements and observations. Typical examples are downhole seismometers as part of large scale seismic networks; or pressure/temperature sonde in conjunction with geological injection or production of fluids. The latter are often supported by surface installations such as tanks and power stations.

Generally, these sensor systems in the holes and in surface installations are measuring and transferring data to their own central control system, or they store their data locally. Data read-out happens often manually, and regularly.

It is possible to couple such sensor control systems with a data acquisition system such as the DIS. When they are indeed coupled, custom programming is needed to ensure that the different time series and other data are synchronized.

Information Technologies

Drilling technologies have been in existence at least since the 19th century. Before the computer age a huge number of explorations have been carried out, and many of these were even scientific wells – and it worked. The modern computerized techniques provide a lot of enhancements and new options to make the operations around drilling easier. The crew -&- staff members on-site should not be overloaded with technical features that distract them from performing their actual work. Therefore information technology used on-site should be as simple as possible, yet as much as necessary. Training is essential. This holds even today as almost everyone is working with computers. The use of IT in drilling projects is a special field that has to be prepared for carefully. The DIS, for instance, is technically not a big deal, but its customizable scientific workflows and its rigorous focus on data integrity requires some training sessions and possibly remote follow-up training and online support during the field operation. Nowadays this can often be accomplished with efficient video-conferencing tools.

Emerging technology trends affecting science projects such as mobile technical and social networking are becoming more important. This holds for outreach issues as never before, as well as for the intra-project coordination.

The publishing landscape is changing rapidly, pushed by open access media, Digital Object Identifiers (DOIs) for data sets and International Geo Sample Numbers (IGSN), digital supplementary materials added to publications. Big data deriving from monitoring of ultra-high resolution are demanding even more powerful technology infrastructure highly integrated Internet services, and more skillful users.

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CHAPTER 6

Downhole Logging

Jochem Kück and Simona Pierdominici

Wireline downhole logging is a powerful and universal method to gain continuous, in-situ measured and highly depth-reliable data of various physical or structural rock and sediment parameters: natural radioactivity, resistivity, density, sonic velocity, porosity, magnetic field & susceptibility, borehole wall images, concentration of some elements and additional data. It provides a depth reference for the correction of core and cutting depths as well as for depth of seismic data and is able to bridge gaps of core data in case of core losses (core-log integration). Furthermore, logging is the base of formation evaluation, lithological classification, structural mapping and many other geological interpretations. It is necessary for the identification and characterization of discrete borehole features like fluid and fracture systems, ore bearing zones, and so on. And it is essential for the investigation of the in-situ stress field and supports the drilling process with important information about borehole geometry and orientation, drill mud condition, cement bond quality etc. Special logging tools are also capable to deliver fluid and rock samples from discrete zones of interest.

Logging basics

Downhole logging is the continuous measurement of one or more parameters versus depth in a borehole. Synonymously used terms are: downhole log, well log, borehole log, wireline log or just 'log'. Downhole logging data is measured under the in-situ conditions given in a borehole and delivers the most accurate and closest-to-reality depth measurement in a borehole.

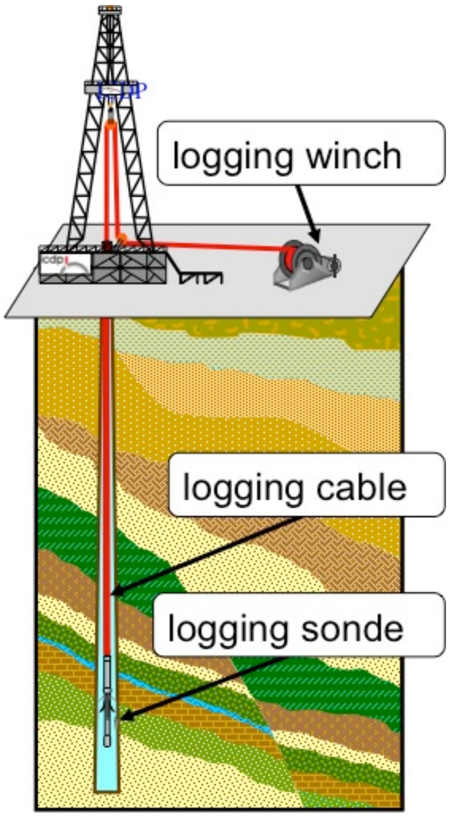

Fig. 6.1: Downhole logging scheme

Various types of logging sondes, containing one or more sensors for different parameters, acquire downhole logs. The sondes are connected to a downhole logging cable (wireline) that is pulled by and stored on a special wireline logging winch. The cable holds the sonde´s weight and contains electrical wires for power supply and telemetry (data transmission between sonde and surface and verse visa; Figure 6.1.) A logging winch has a rotatable lead-out of the cable wires allowing to continuously measure while the winch drum is revolving, i.e. moving the sonde up or down in the borehole (to run a log). The logging cable lines coming from the winch are connected to a data acquisition unit, consisting basically of an interface panel for power supply and sonde communication and a computer for control and data storage. Some sondes can be combined (sonde strings) to be logged together in order to reduce the number of necessary borehole runs (Fig. 6.2).

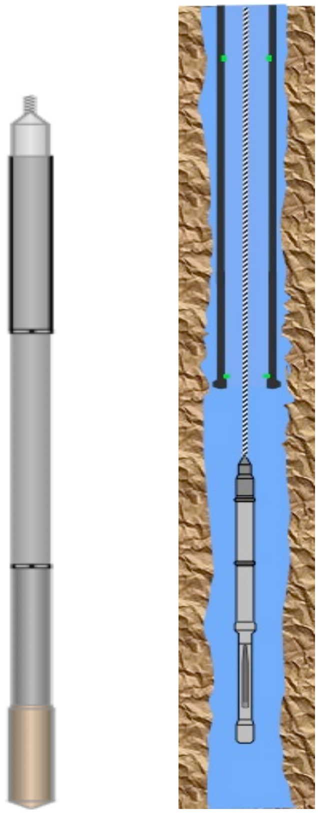

Fig. 6.2: Sonde combination comprising GR – SGR – MSUS from top to bottom (left). A logging sonde is run through the drill string and out of the coring bit after the inner core barrel has been tripped out (right).

Most downhole logging is performed in open borehole sections (without a protective steel or plastic pipe inside) but some sondes can also be run inside a steel pipe like a casing or a drill pipe. Commonly the drill pipe and bit will be tripped out of hole to allow the wireline sondes to be run in for logging. In case of core drilling it might be possible to lift the drill string up to the top of the desired borehole section and the sonde is run in through the drill pipe and core bit into the open hole section below. This very time saving method is the standard procedure for boreholes of the so-called mining drilling type, of which the very most lake drillings are (Fig. 6.2).

Sonde size

Logging sondes come in a variety of sizes (diameters). They may be separated into two groups, standard sized sondes and slimhole sondes, but there is no strict definition. Commonly sondes with a diameter less than about 60 mm are regarded to be slimhole sondes, whereas standard sondes have a diameter of 86 mm (3 3/8") and up. There are intermediate sondes available with a diameter of around 60 to 75 mm. Obviously big sondes cannot be run in a slim borehole because they simply do not fit into the hole, while slim sondes placed in a wide borehole is usually not recommended either. Most of the slimhole sondes lose their performance in holes that are too wide. Slimhole sondes perform best in boreholes with a diameter less than 130 mm.

Developing a logging plan

In an early planning stage of a drilling project it is possible to include logging demands such as limitations on hole size, hole deviation, drilling method, drill mud type, logging section length etc. into the drilling plan to provide the best possible logging conditions. This is usually the case in projects where downhole logging has a high priority (Case A). In other projects logging has to be adjusted to the given borehole conditions (Case B). Furthermore, in an ongoing project technical or financial reasons can cause significant changes to the original drilling plan and hence suddenly impose very different conditions for the logging technique or preclude such downhole measurements.

Scientific questions for logging in a project will usually be defined by the whole project team. A list of borehole parameters necessary to answer these questions has to be derived by a group of 'logging scientists' constituted by individuals who want to use downhole logging data, Table 6.1. They select a responsible leading scientist as logging manager for the time of the entire project that coordinates planning, on-site oversight, data analysis and publishing.

The logging manager with backing support from his logging group identifies not only downhole methods (see table below) for scientific purposes but also methods that support the project at large (e.g. depth correlation, lithology reconstruction, drilling technical support etc.). Furthermore, a classification scheme is needed which logging method is appropriate for the given type of rocks and expected pressure/Temperature (pT) conditions, e.g. high or low electrical resistivity, soft or hard formation, high or low geothermal and hydraulic pressure gradient (Figure 6.3.)

In Case A requirements for the drilling plan are listed to gain best possible borehole conditions for logging including: drilling location (accessibility), hole size, hole deviation, mud type, mud weight, cooling rates by mud circulation, length of logging sections and frequency of logging runs.
In Case B the drilling scheme and a plan for the mud system is needed to identify the imposed constraints on downhole logging:

- hole size
- hole deviation
- mud type
- mud weight
- expected temperature and pressure
- achievable cooling by mud circulation
- available time for each logging session or single runs (see also table below)

Further constrictions limiting or even prohibiting the use of some sondes are, for example, deployment and/or import (cross-border transportation) of nuclear sources. It is recommended to create at least two logging scenarios, one with the maximum desired amount of logging and one with a minimum, indispensable amount of logging runs. Reality will lie somewhere in-between.

Fig. 6.3: OSG slimhole logging sondes at drillsite

A general minimum set of logs could be like this:

- caliper (preferably 4-arm & oriented)
- borehole orientation (azimuth & deviation, at least the deviation)
- total natural GR (gamma ray)
- temperature (and maybe mud resistivity)

This set may be extended by other tools depending on the scientific focus of the project, including:

- magnetic susceptibility
- sonic velocity
- rock resistivity
- natural gamma spectrum
- rock density

A list of prioritized downhole measurements will help in the early stage of project discussions about the project and budget. It is also useful when project delays reduce the effective time available for logging. The question which tool providers and sondes are available for the specific borehole conditions needs to be addressed during an early project stage. We recommend to consulting with OSG or other trustworthy experts who do not have a commercial interest in your project.

Logging sondes and other logging equipment must be technically appropriate for the planned campaign involving

- hole size
- mud type
- temperature & pressure
- cable type & length, weak point
- winch type (min/max speed
- transportability
- power supply requirements
- footprint size
- requirements of the data acquisition

Once the decision on the logging provider is made a representative of the provider should participate in the preparation and kick-off meetings of the drilling project. An early involvement avoids unnecessary misunderstandings and double work on both sides and hence will save time and money (and nerves).

A logging plan must be adjusted to the drilling constraints and has to be self-consistent and cost transparent, flexible enough to encounter delays, sonde drop-outs and even minor budget cutbacks (Figure 6.4.) Of course all logging group members must accept it. The plan has to consider the time necessary for logging of all sondes with their commonly very different logging speeds and the time necessary to run the sondes down into the logging section. All logging is carried out while moving upwards, except for the temperature log, which is measured downwards. For time contingency, at least one repeat run of each sonde over a typically section length of 30 to 50 m should be planned to check the reproducibility. In deep boreholes this will be a substantial time component.

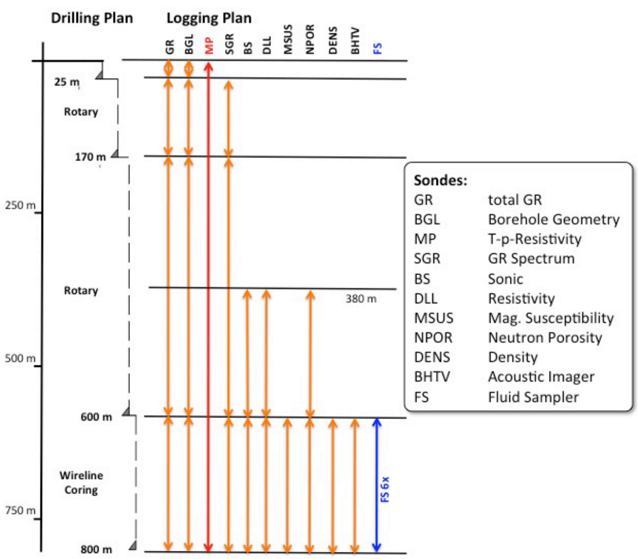

Fig. 6.4: Example of an optimized logging plan

A lost in-hole scenario will complete a logging plan. This is needed because a lost sonde that cannot be fished (retrieved from the borehole) will cause several consequences: 1) The borehole will be inaccessible below the sonde stuck depth; 2)

The logging service provider might not be able to continue logging in other boreholes of the project because essential equipment components were lost. Further questions for such scenario comprise

- Can the sondes be fished?
- Has the cable head a 'fishing neck'
- Is fishing equipment available?
- Are fishing guidelines available?

A contingency plan for options of equivalent sondes and/or providers will reduce planning times.

A logging contract/agreement between the project and each logging provider has to lay down the responsibilities, liabilities and duties of both sides. The most important components are:

- the lost-in-hole case
- explicit naming of the responsible persons and decision makers
- terms for data handling/processing and data ownership
- technical requirements for the logging operations
- cancellation terms
- payment terms

Health and Safety Measures

A Logging Safety Instruction including the emergency & escape plan according to the general regulations of the drilling project must be held on-site before any logging campaign begins. All personnel involved have to study and sign these logging safety regulations. Any personnel at the site have to be instructed before getting to work. Safety equipment such as hard hats, glasses, gloves and shoes are compulsory for all logging activities. Several other restrictions on safety measures may apply depending on national laws, drilling contractor and others. Generally all logging work is limited to shifts of 12-hours at maximum.

The risk of blowouts of dangerous fluids and gases needs to be estimated because the standstill of mud circulation during downhole logging time might favor rise and outflow of gas. Interaction with drilling engineering is critical and safety measures such as gas detectors for several gas types need to be installed.

OSG downhole logging support

The OSG offers support for downhole logging in ICDP projects. The support encompasses evaluation and support of planning and management of downhole logging programs within ICDP proposals, the actual performance of entire or parts of downhole logging sessions, and the scientific interpretation of the acquired data. OSG's level of assistance in preparing downhole logging programs primarily depends on the requests of the ICDP project PI's. It can comprise:

- check of time and availability of equipment & expertise
- equipment acquisition
- cost assessment
- developing and optimizing a downhole logging plan, which accommodates scientific targets and project conditions
- assisting in preparing an entire logging plan

If desired the OSG can carry out down hole logging measurements with an equipment fitting most ICDP logging conditions (Fig. 6.5). The close in-house cooperation with our other OSG experts (drilling, core handling and data management) assures smooth and optimized operations. If desired the OSG may also assist in the management of logging activities.

OSG logging can complement any other logging plan or carry out all downhole logging of a project. Costs are minimal and comprise only a very low tool utilization fee, travel/transport costs of personnel and equipment and insurance of the equipment. No depth/measurement charges and personnel costs are imposed as these are covered by overall ICDP funds. The low costs enable downhole logging even for ICDP projects with a low budget.

Fig. 6.5: Small and lightweight OSG downhole logging equipment ready to be shipped

OSG participation in downhole logging operations is not mandatory. OSG consulting is free of charge for ICDP projects. For OSG logging service the costs of traveling, shipping, insurance, and sonde fees are charged. OSG cannot and will not compete with commercial logging service providers. OSG preferably recommends the use of commercial services if these provide higher resolution and/or quality and if the project budget allows.

The acquired downhole logging data are often used only for depth correlation and the integration of core and downhole logging data, but without further evaluation of their scientific potential. The downhole logging team of the ICDP-OSG provides geoscientific analysis and interpretation of downhole logging data. In case an ICDP project has no resources to fully analyze and interpret the logging data, the OSG logging team can perform the analysis and interpret the borehole measurement data, thereby adding value to the ICDP project. Some of these analyses have to be combined with additional data (i.e. core/cuttings data, seismic data) from other research teams. In such cases the OSG logging team becomes member of the project's science team.

Following a downhole logging campaign a logging job report is compiled comprising the operational details: logging tools used, logging depth intervals, depth reference, number of runs, problems encountered, statistics, and first findings if possible. Logging data itself is usually not handed out on-site but after depth correlation and environmental corrections applied at the office. In the case that OSG logging provides also an interpretation of downhole logging data, the results will be submitted to the PIs for approval and will be published according to the Science Team plan.

OSG downhole logging equipment

Based on the most frequent requirements of ICDP projects OSG established an ICDP downhole logging equipment with slimhole probes and suitable logging winches. The tool specifications allow utilization in very different hole conditions. The lightweight equipment allows low cost shipment to remote locations and at difficult conditions (Figures 6.5 and 6.6.) The acquired logging data is quality checked and depth corrected by OSG. MSUS, GR and SGR data are corrected for hole size and casing effects. OSG does not offer other borehole environmental corrections. The data output format is LIS/DLIS, ASCII and WellCAD format.

The OSG slimhole tool set covers basic

geophysical logging parameters:

- electrical resistivity (dual laterolog)
- sonic velocity (two receiver, one transmi.)
- natural gamma spectrum (full spec. SGR)
- total gamma
- 4-arm caliper, borehole orientation, structural data (4-arm dipmeter)
- magnetic field (magnetometer inside dipmeter)
- magnetic susceptibility
- acoustic borehole wall images (televiewer)
- mud parameters (temperature, pressure, resistivity)
- fluid samples
- seismic (3-component borehole geophone chain, 17 levels)
- resistivity)
- fluid samples
- seismic (3-component borehole geophone chain, 17 levels)

OSG does not operate tools with nuclear sources. All tools are rated for a minimum of 150 °C and 80 MPa, except for the televiewer (70 °C/20 MPa), and can be used in hole sizes to a minimum of 75 mm. The maximum borehole size differs for each tool. These tools are best run on our special slimhole logging winch and also operated with any logging winch system utilizing at least a 4-conductor cable.

Fig. 6.6: Logging winch with 2.2 km of a 4-conductor cable

Limitations

Hole Size. Not all sonde types (measured parameters) are available for slimhole, normal sized and big boreholes. Consider that if one provider cannot offer the desired sonde another might be able to do so. Always ask for a drilling scheme with explicitly provided hole diameter(s). Do not rely on hole type names like HQ, NQ, etc. A drilling that delivers an HQ core not necessarily has to drill an HQ borehole (95-98 mm) but could drill a far wider size (> 200 mm).

Hole Deviation. A high borehole inclination can prevent sondes from slipping freely down the hole, in general the maximum angle is about 45-50 degrees (with otherwise normal hole conditions). If strong hole enlargements are abundant, sondes may get blocked already at an inclination of 5-10 degrees. Some sondes with mechanical sensors can be used only within a certain inclination range, such as seismometer and geophone sondes or tilt-meters.

Mud Type. Resistivity sondes of the laterolog type cannot be used in oil-based muds and in air or foam filled holes. Therefore, choose an induction type resistivity sonde instead. Mud constituents can erroneously affect sonde readings, e.g. many water muds (e.g. bentonite) contain potassium, and hence add a contribution to the measurement of the natural gamma spectrum sonde, thus yielding K values that are too high. A very thick mud (high solid contents) will likely obstruct the port of a pressure sensor, clog the cage around a temperature sensor, hinder flowmeters, prohibit downhole fluid sampling, and will reduce (maybe strongly) the quality of acoustic borehole wall images (televiewer).

Mud Weight. The mud weight raises the downhole pressure, which may lead to conditions in the target depth unsuitable for some sondes with low pressure limits. Always make sure the sondes will be used in their given pressure specifications. Do not just rely upon a given depth specification.

Temperature and Pressure. Not all sonde types (measured parameters) are available for high temperature and/or pressure, where usually temperature is the most limiting factor. Consider that if one provider cannot offer a hi-temp sonde version another may be able to do so.

Drill Bit Type. In case the logging sondes will be run through a core drill string into the open borehole section (i.e. lake drillings), the core bit has to have a shape that allows the wireline sonde to safely reenter the drill string while coming up. Especially in the case of a wide borehole, but a small core size, a thick core bit with high cutting blocks can catch the sonde head while trying to reenter the drill string and prohibit a safe exiting of the probe from the hole. In such a case the loss of the sonde is very likely.

Additional information

Details about logging and equipment such as sondes, their limits and possibilities can be found on the ICDP website.

Overview on parameters and applications of downhole logging sondes

Parameter	Applications	Sonde Names	Examples of typical Sonde Mnemonics	Type
borehole wall images	borehole condition/stability, structural features, bedding/ lamination, breakouts, stress field orientation by breakout direction & induced vertical fractures	Acoustic Imager (Televiewer)	BHTV, ABI, UBI, CBIL, CAST	d
	like above but stress field orient. only by induced vertical fractures	Electric Imager	FMS, FMI, STAR, EMI	d
	like Acoustic Imager but works only in clear water not in drill mud	Optical Imager	OPTICAL SCANNER	d
	structural features, bedding/ lamination, stress field orientation by breakout direction (multiple runs)	Dipmeter	DIP, SHDT, HDT	i
caliper, borehole geometry/ orientation	borehole condition: size, shape, volume, orientation/direction, path, stress field orientation by breakout direction (multiple runs), technical hole inspection	Caliper, Oriented Caliper, Geometry Tool, Gyro Survey	BGL, CAL-ORI, DIP	d
density	lithostratigraphy, core-log correlation, derived: porosity, mineral identification	Density	LDT, DENS, FDC	i
electric resistivity	lithostratigraphy, conduction type metallic/electrolytic, fluid invasion, porosity, ground truthing of	Laterolog Resistivity	DLL, LL3	d
		Induction	DIL, IND	d

	magnetotelluric & electromagnetic models	Resistivity		
		Micro-Resistivity	MSFL, MRS	d
elements Si,Ca,Fe,S, Ti,Cl,H	mineral composition for some rock types, lithostratigraphy	Elemental Sonde	ECS, GLT	i
gas saturation	reservoir characterization	Reservoir Parameters	RST	i
gravity	large scale density profile (even in cased holes), ground truthing of gravimetric models	Borehole Gravity Meter	BHG	d
magnetic susceptibility	core-log depth correlation, depositional stratigraphy, inter- & intra lava flow differentiation, lost-in-hole metal detection, lithology	Sus-Log	MS, MSUS, MagSUS	d
magnetic field	profile of the magn. field vector	Magnetometer	BHM	d
	total magnetic field magnitude	Borehole Geometry	DIP, BGL, CAL-ORI, Imagers	d
natural radioactivity	lithostratigraphy, shale volume, core-log depth correlation	Total Gamma Ray	GR	d
	U, Th & K contents, litho-stratigraphy, heat production, fracture localization	Natural Gamma Spectrum	SGR, NGR, NGS, GRS	i
porosity	reservoir characteristics, fracture/flow zones, lithology, texture, compaction	Neutron Porosity	NPOR, PORO	i
		Nuclear Magnetic Resonance	NMR, CMR	i
sonic velocity	lithostratigraphy, compaction, reservoir characteristics, fracture/flow zones localization, seismic ground truthing	Sonic	BS, BCS, DSI	d
mud parameters: temperature, pressure, resistivity, flow, fluid samples	fracture and flow zones localization & characterization, fluid regime, deep fluid circulation patterns, heat flow, fluid flow, hydraulic transmissivity & permeability, mud density, cement head localization, gas detection, fluid samples; often combined with hydraulic tests	Mud Parameter, Temperature, Salinity Flowmeter	TEMP, MP TEMPSAL, MRES FLOW, FM, MPFM, DIGISCOPE	d
rock samples	rock anisotropy, structural analysis, fill core gaps	Sidewall Coring Tools, Formation Sampler	MSCT, RFT	d

d = directly measured, i = indirect, i.e. derived by processing

Table 1: Overview on parameters and applications of downhole logging sondes.

Sonde	Speed m/min	Speed ft/hr	Time/h for 0-500m	Time/h for 1000-1500m	Time/h for 2500-3000m
Caliper/Geometry	≈ 13	< 4000	1	1.8	3
Resistivity	10-15	2000-3000	1.2	2	3.2
Density	9	1800	1.3	2.1	3.3
Porosity (Neutron)	9	1800	1.3	2.1	3.3
Sonic	7-10	1400-2000	1.8	2.4	3.6
MagSUS	8-10	1600-2000	1.4	2.2	3.5
Temperature /Pressure	8-12	1600-2400	3.6	6	10
GR Spectrum	2-5	400-1000	4.8	5.7	7
Elemental Log	2-3	300-600	4.8	5.7	7
Electric Imager	3-10	600-2000	3.3	4.1	5.4
Acoustic Imager	2-5	200-1000	4.8	5.7	7
Gravity	20-30 per day		-	-	-
Fluid Sampler	1-3 per day		-	-	-

Table 2: Typical logging speed and time of some sonde types, times are exclusive of sonde rig-up time

OSG Downhole Logging Tools - *Slimhole*

J.Kück DEC-12

Tool Type	Sonde Name Parameter	Specs: T/p/Ø/length/weight/min.OH Ø/ max. hole Ø /log speed
Telemetry	**TS** telemetry, total natural Gamma Ray, motion detector	150°C/80 MPa/43 mm/1.29 m/7 kg/ ≈75 mm/-/10-20 m/min
Electric	**DLL** dual laterolog resistivities deep & shallow	150°C/80 MPa/43 mm/2.2 m w/o bridle/ 13 kg/ length bridle cable: 6.0 m ≈75 mm/250 mm/12-20 m/min
Sonic	**BS** borehole sonic, full waveforms (tool with centralizers)	150°C/80 MPa/52 mm/≈4.5 m/23 kg/ ≈75 mm/ 250 mm/6-8 m/min
Gamma	**SGR** spectrum of natural Gamma Ray activity: U/Th/K, total natural GR	150°C/80 MPa/52 mm/1.24 m/11 kg/ ≈75 mm/250 mm/< 3 m/min (9m/min only GR)
Magnetic	**MS** magnetic susceptibility **DIP** slim 3-component magnetometer inside dipmeter tool	150°C/80 MPa/43 mm/1.9 m/9 kg/ ≈75 mm/500 mm/8-12 m/min see under the following item
Geometry	**DIP** oriented 4-arm dipmeter, four independent caliper readings, oriented borehole geometry	150°C/80 MPa/52 mm/2.69 m/13 kg/ ≈75 mm/250 mm/9 m/min
Imager	**FAC40** acoustic televiewer, BHTV (tool with centralizers)	70°C/16 MPa/40 mm/ 2.2 m/8.5 kg/ ≈60 mm/300 mm/1-2 m/min
Mud Parameter	**MPslim** mud temperature, pressure & resistivity, combinable w/ all tools	150°C/80 MPa/43 mm/0.8+2.0 m/14 kg/ ≈75 mm/-/5-15 m/min
	TEMPslim mud temperature	150°C/80 MPa/43 mm/1.05 m/8 kg/ ≈75 mm/-/ 5-15 m/min
Seismics	**SW** incl. **GR, CCL** *SlimWave* borehole geophone chain, 3-comp, 15 Hz, 17 levels	135/150 °C/100 MPa/43 mm/1.1 m/ 6.5 kg/≈75 mm/178 mm/stationary level spacing: 10m, max. weight 260 kg
Fluid Sampler	**FS** 600 cm^3, positive displacement type, combinable w/ MPslim	180°C/100MPa/43 mm/3.9 m/30 kg/ ≈65 mm/-/stationary

The telemetry sub has a GO7 cable head connection and must be combined with all other sondes, except the FAC40. All slimhole tools are digital and require at least a single-conductor cable, except for DLL and FAC40 which require for a 4-conductor cable. Adaptor for Schlumberger 31-pin cable head and connection to Schlumberger 7-conductor rope socket via 'torpedo' is easily possible.

Table 3: Typical downhole logging tools of type Slimhole.

Some most common logging methods

Borehole Caliper & Geometry

A caliper sonde measures the size of the borehole cross section. The standard caliper sonde has 4-arms arranged in 90 degrees, which are pressed against the borehole wall. Other types are 6-arm or also very widespread 3-arm calipers. 3-arm calipers are unable to depict an oval-shaped borehole cross section.

A combination of a caliper sonde with an orientation sonde gives an oriented caliper sonde, also called borehole geometry sonde. The spatial orientation determines the borehole's deviation from vertical (DEVI), the direction of this deviation with respect to magnetic north (hole- or drift-azimuth), and the orientation of the caliper arms with respect to the sonde axis and to north.

Caliper data is used scientifically e.g. to determine the stress field orientation by measuring the direction of induced breakouts, but mainly for technical purposes like to know the borehole shape and volume (e.g. before running in casings or to determine the necessary cement volume), its direction and trajectory (e.g. to apply directional drilling corrections) etc.

Natural Gamma Ray

The total gamma ray log (GR) is a measure of the natural radioactivity of the formation. It is measured by counting all incident gamma rays (gamma counts). The tool calibration converts the counts into a standardized unit named gamma-API [gAPI]. This log is particularly useful for distinguishing lithology, facies, conducting cyclostratigraphic analysis and analyzing deposition environments, e.g. to distinguish between sands and shales. This is due to the fact that sandstones contain usually non-radioactive quartz, whereas shales are radioactive due to potassium isotopes in clays and adsorbed uranium and thorium. The GR log is the standard log for depth correlation amongst several logging runs as well as between downhole log data and core/cutting data.

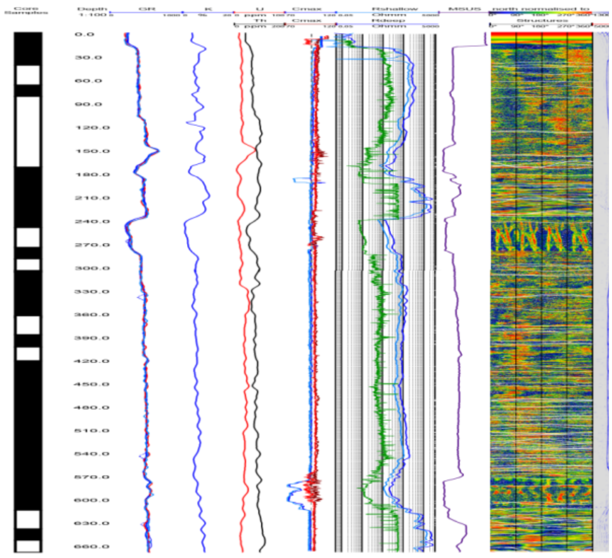

Fig. 6.7: Core recovery (left; black zone core recovery) and summary of downhole log measurements (right, including natural gamma ray, spectrum gamma ray, calipers, resistivity (shallow and deep), magnetic susceptibility, borehole televiewer, and sonic log)

The total gamma ray log records the total radiation in the formation, and does not distinguish between the individual radioactive elements in the specimen. For this purpose a spectral gamma ray or natural gamma spectrum sonde delivers the contents of the three natural radioactivity bearing elements: potassium (^{40}K), thorium (^{232}Th) and uranium (^{238}U). The sonde measures not only the total counts of the incident gamma rays but a full spectrum of their energies from which a calibrated best-fit algorithm derives the U, Th, and K content in parts per million [ppm] and percent [%]. The SGR is used for e.g. lithostratigraphy construction, determination of heat production, identification of fracture zones, and estimation of the clay content.

Electric Resistivity

Resistivity logging measures the capability of the formation to conduct electric currents. Formation´s resistivity is mainly controlled by the amount and distribution of saline water (electrolytic conduction) and/or the existence of conductive minerals (metallic conduction, e.g. graphite, pyrite). For instance a porous and saline water filled formation shows low resistivity values, whereas formations filled with hydrocarbons (poor conductivity) show higher resistivities. Resistivity logs are e.g. used for lithostratigraphy and to estimate the water saturation. The unit of resistivity is ohmmeter [Ωm]. Different resistivity sondes with different depth of investigation allow to radially distinguish borehole-surrounding zones with varying resistivity due to the mud invasion during the drilling process. In massive rocks with very low matrix porosity/perm resistivity logs identify fluid filled fracture zones (fracture permeability).

Sonic

The sonic sonde measures the velocity of sound waves of formations, which varies depending on lithology, rock texture and porosity. It is determined by measuring the travel time of sonic pulses between acoustic (sonic) transmitters and at least two, often more, acoustic receivers. The velocity unit is meters or kilometers per second [m/s] or [km/s]. In logging data also common is the slowness, the reciprocal value of the velocity given in [μs/m], sometimes named interval transit time (dt). The sonic velocity is used for stratigraphic correlation, identification of compaction of lithologies, facies recognition and fracture identification and furthermore for ground truthing of surface seismic data and to derive the porosity of a formation.

Density

A density sonde provides the formation´s bulk density, which is the sum of the solid matrix density (minerals forming the rock) and the density of fluids enclosed in the pore space. The sonde contains a radioactive source, which emits gamma rays. These are back-scattered by the formation and registered by gamma ray detectors (scintillation crystal) in the sonde. The more dense the formation, the more gamma rays are absorbed on their way through the rock and hence less gamma rays reach the detectors. The density is an important parameter for lithostratigraphy construction. It is also used to calculate the porosity of a formation. In conjunction with the sonic velocity data it is possible to calculate the acoustic impedance, and with the full sonic waveform to calculate rock strength.

Porosity

There are two downhole logging methods to determine formation porosity. The neutron porosity sonde measures the hydrogen content in the formation. A radioactive source emits neutrons, which are back-scattered and attenuated by hydrogen in the formation.

The nuclear magnetic resonance sonde delivers porosity by measuring the decay signal of the spin of hydrogen nuclei excited by an ultra-strong magnetic field generated by the sonde. This sonde directly determines porosity, pore size distribution and permeability. This sonde contains no radioactive source.

The traditional porosity tools (density, neutron and sonic) can calculate only a total porosity, whereas the NMR is able to divide the porosity into different pore size ranges (large pore for free fluids, pore in which the fluids are capillary-bound or irreducible, and clay-bound fluid). The NMR is almost independent of matrix type. The latter should be well known to calculate the porosity with traditional porosity logs. NMR can provide also information about fluid type (oil, gas, water).

In many sedimentary formations hydrogen content is equivalent with the pore space and hence a measure of the porosity. In other rocks, e.g. metamorphic and igneous rocks, hydrogen is also abundant as bound water in the mineral crystals yielding too high porosity values. This log is useful not just to derive porosity and formation water content, but also to identify lithologies as sand, limestone and shale/clay and fluid type. In oil & gas exploration density and neutron logs are run together to provide a good source of porosity data, especially in formations of complex lithology.

Dipmeter

The dipmeter sonde is a caliper sonde with electrode bearing pads mounted to the ends of the caliper arms. It provides both borehole geometry (caliper, deviation & azimuth) and the spatial orientation (dip and dip azimuth) of planar structures intersecting the borehole like planes of bedding, lamination, folding, faulting, fractures etc. These structures are detected by the electrodes as resistivity contrasts.

Magnetic Susceptibility

The magnetic susceptibility is the ability of the formation to be magnetized. The sonde imposes a magnetic field to the formation and measures the induced magnetic field. The magnetic susceptibility reflects the amount of magnetic minerals contained within the formation, in particular magnetite, as it has the strongest magnetic susceptibility of the major rock-forming minerals. This method determines the stratigraphic changes in mineralogy and lithology. It helps to localize boundaries of overlying lava flows and to identify zonation within a flow. In paleoclimate investigations of lake sediments it can act as a proxy for depositional conditions. In lake sediment drilling projects it is the most powerful parameter for both the core-log depth correlation as well as to fill in data at core gaps to provide a continuous profile.

Borehole Imager

For drillings using a drilling mud two imaging sonde types are available: acoustic imager and electric imager.

The acoustic imager (also called borehole televiewer) emits an ultrasonic pulse to the borehole wall and measures the amplitude and the travel time of the reflected signal. The sonic emitter rotates around the sonde axis and hence takes many measurements per revolution (typically between 70 and 300 pulses/rev). The amplitude of the reflected signal depends strongly on the acoustic impedance of the borehole wall yielding an acoustic impedance contrast image of the wall. The travel time measurement depicts variations of the borehole diameter, i.e. the caliper. This gives a caliper image of he borehole, which is at the same time a multi-arm caliper log with very fine vertical resolution. Depending on the hole diameter an image resolution (pixel size) of better than 5x5 mm can be achieved. The sonde is magnetically and gravitationally oriented.

The electric imager is basically an advanced dipmeter sonde but with much more and smaller electrode buttons on bigger pads. The small electrodes yield a pixel size of also 5x5 mm. This imager creates an image of electric resistivity contrasts. The sonde is magnetically and gravitationally oriented.

In result both imagers yield oriented high-resolution images of the borehole wall.

The analysis of both the acoustic and the electric images allows to detect and orient natural and induced fractures as well as breakouts in order to gain the present stress field orientation; moreover it allows in general to detect very thin beds, bedding, lamination, and layering. The set of fully oriented structures derived from imager logs and those derived from cores or core images can be used to orient these cores. Acoustic imager logs can also be used to inspect casing conditions.

Temperature and Fluid Resistivity

Logs of temperature and resistivity reflect the temporary status of the mud column inside the borehole. Both parameters show strong variations caused by drilling or testing activities inside the well but also by flow of fluids into or out of the formation due to the usually different salinity and temperature of formation fluids compared to the drill mud. Therefore these logs are the best indicators of active flow zones or open fractures respectively.

A temperature log almost always shows the mud temperature, and not the formation temperature. It represents a superposition of the original, undisturbed temperature field before drilling and the effects of mainly the mud circulation and other drilling process as well as hydraulic tests. Usually a deep borehole is cooled down in the lower half and heated up in the upper half. To estimate the original formation temperature several temperature logs have to be carried out repeatedly during several days without hydraulic disturbance in-between.

Log interpretation examples

Core-log integration

Downhole logging data can be used to augment core-derived data and to fill the usually unavoidable gaps in the core record.
Core-log integration very often is taken synonymous as core-log depth correlation although this is only one part of it, albeit the most widespread one.

Comparison of parameters from the discontinuous core sequence with the continuous profiles of logging parameters enables to correct the core depth according to the logging depth (depth matching). In principle any parameter can be used for this but in practice the total natural gamma radiation (GR) and/or the magnetic susceptibility (MS) are used by far most often. The reason is that a downhole GR log is run in almost every project. The MS is an even better depth correlation parameter being very easy to measure on the core, a very high repeatability without statistical variations as the GR has and the same good vertical resolution as the GR of approx. 20 cm. Of course not all formations feature articulated variations of the MS or GR profile, which are necessary for a good depth correlation quality. The traditional depth matching is done by a visual correlation of peak patterns or peak-to-peak.

The spatial orientation of the core takes much longer time and requires more complex data sets. This method only works if there are a sufficient number of planar features in core and log. Cores from massive rocks with only very few structural elements but also very soft sediments with missing non-horizontal structures are impossible to be oriented. Formations with pronounced bedding and lamination or frequent folding structures or fractures are best.

The most simple but also tedious way is to compare the core pieces with the oriented borehole images. A faster way is to compare the sine curves picked in the borehole images and in the core scans. This can happen visually or with help of orientation software.

Electrofacies analysis

The electrofacies analysis is part of the core-log integration with a far bigger logging component. The main goal is to construct a very detailed lithological profile derived from downhole logging data, called the electrofacies log. It commonly has a higher vertical resolution than an initial core description has and is valid even in long and frequent core gap sections. Its quality increases with the number of available logging parameters, i.e. the more log types can be used, the more rock types can be differentiated.

The analysis is based on the fact that any rock type, even an alteration of the same rock type has a distinct value of each of the logging parameters. The method identifies zones with uniform values in each log and for all logs by drawing boundary lines across all logs. This results in a number of rock types each characterized by a unique combination of log values. A further multi-dimensional cluster analysis for all logs identifies all similarities and dissimilarities across the logs, in order to group these features into classes called electrofacies. Therefore an electrofacies represents a set of log responses, which characterizes a lithological unit (rock type with fluids and alteration). These units have to calibrated by comparison with cores. The analysis can yield an even higher number of units than derived from the core. Once the electrofacies log is calibrated it equivalently fills gaps in the core stratigraphy. The electrofacies log of other close boreholes in the same geological environment can completely substitute cores (hole-to-hole or site-to-site correlation). The method usually is also able to identify fracture zones.

Fluid flow and fracture systems

Downhole logging data is the superior tool to identify, localize and characterize fracture and flow systems and to investigate fluid regimes, at best in combination with hydraulic tests. Obviously the prime parameters are temperature and resistivity (MRES) of the borehole fluid but also other logs are strong indicators.

So-called chevron patterns in the sonic waveform log are indicators for open fractures as well as the difference of deep to shallow resistivity logs. The acoustic imager will also localize fractures very precisely and allow differentiating open and closed fractures. Temperature and MRES logs allow to precisely localizing flow zones. Repeated runs at constant hydraulic conditions and better with a technically lowered fluid level even allow the quantification of the individual flow zones and of cross-flow within the borehole.

Structural analysis and stress field

The analysis of acoustic & electric borehole images and dipmeter data provides useful information regarding borehole size (breakout, washout, key-seat; Fig.6.8), dips of bedding planes (to identify folding, faulting and unconformity features), the present-day stress field, sedimentological studies (turbidites, beds, bioturbation, concretions, and clasts), and igneous features (veins, alteration, basalt pillows, breccias, and flows).

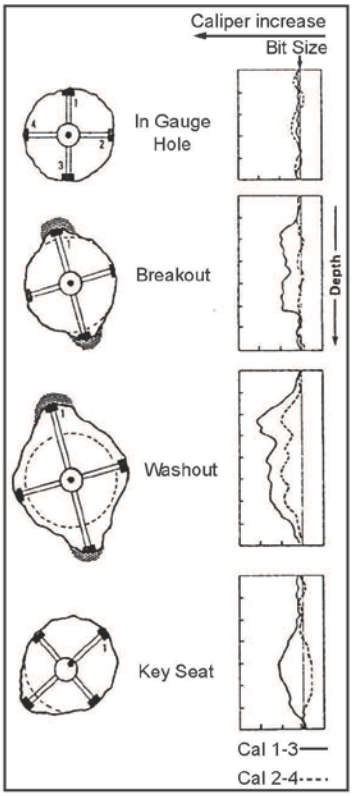

Fig. 6.8: Borehole size and shape

The analysis of the BHTV images allows to detect the structural features and identify breakouts in order to characterize the present stress field. Moreover it allows to detect thin beds, determine bedding dip, orient core samples, and to inspect the casing conditions. Stress feature interpretation from boreholes serves identifying stress features (i.e. borehole breakouts, natural fractures and drilling induced tensile fractures "DITFs"), and to characterize the local and current stress field. Borehole breakouts are stress-induced elongations of a borehole cross section, which can be interpreted in terms of crustal stress (the borehole is deformed according to the minimum principal horizontal stress orientation, Fig. 6.9).

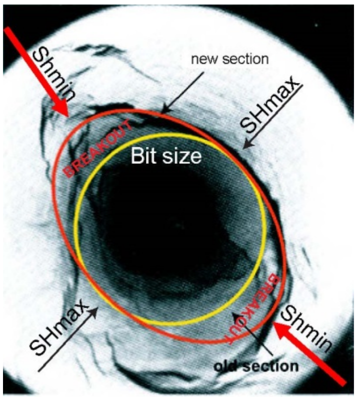

Fig. 6.9: Borehole breakout shape

On borehole images, borehole breakouts appear as dark features, and in some cases, incipient breakouts have been identified by conjugate shear fractures, where no spalling of the borehole wall has occurred. DITFs appear as dark, electrically conductive fractures, observed as features, which are mainly parallel to the axis of borehole and showing a discontinuous nature. On the contrary, the natural fractures are often seen as continuous sine curve and appear as electrically conductive or resistive features (Fig. 6.10).

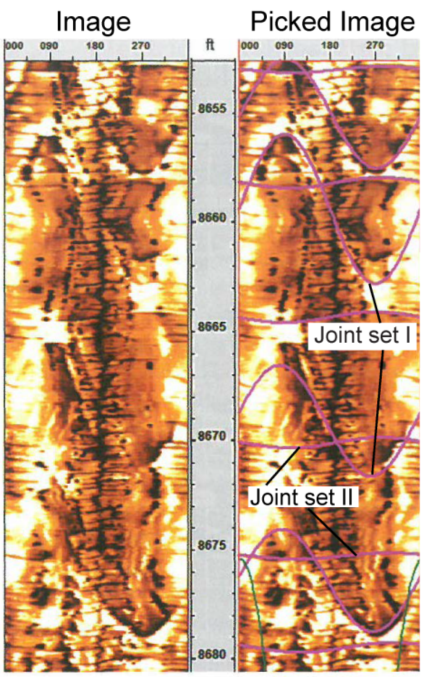

Fig. 6.10: BHTV original image (left) and with detected sine structures (right)

A consistent population of natural fractures are identified and interpreted to reconstruct the paleo-stress field. These data are compared with existing stress records of the area to obtain an improved knowledge of present-day stress field in the area. A detailed understanding of the regional field is a fundamental contribution in several research areas such as geothermal reservoir studies, or exploration and exploitation of underground resources.

Orientation and magnitude of stress

Knowledge of orientation and magnitudes of the present-day stress field at depth is relevant both for the geologic sciences and engineering applications. The orientation is determined by borehole breakout analysis (BHTV and Dipmeter) explained in the section *"Borehole size and tectonic features"*, whereas the magnitude of principal vertical stress (Sv) is calculated from density measurements; the magnitude of the least horizontal principal stress (S3, which is usually Shmin) is mainly determined from well testing (hydraulic fracturing data, leak-off tests), and the maximum horizontal principal stress (Shmax) is generally calculated by empirical formulas. The magnitude of the three principal stresses is a good indicator to determine the kind of stress regime (normal faulting SV>SHmax>Shmin; strike-slip faulting SHmax>Sv>Shmin; thrust faulting SHmax>Shmin>Sv). Stress orientation and relative magnitudes permit to define the first, second and third-order stress pattern acting in the study area.

Lithology/mineralogy identification

The potassium content of various clay minerals varies considerably, for example illites (which are micas) contain a large amount of potassium. On the contrary smectite and kaolinite (both clay minerals) have little or absent content of potassium. The potassium is present as K-feldspar in microcline and orthoclase minerals. Carbonates usually display a low gamma ray signature. An increase of potassium can be related to an algal origin, or to the presence of glauconite. Thorium is abundant in acid and intermediate igneous rocks and frequently found in ash layers, in bauxite, in shales, and in heavy minerals, such as epidote, thorite, zircon, sphene and monazite. Thorium is also concentrating in sediments of terrestrial and marine origin such as kaolinite and glauconite, respectively. Uranium is found particularly in acid igneous rocks, black shales (stagnant, anoxic water with slow rate of sedimentation), phosphatic rocks and is often associated with organic matter. The Th/K ratio can be applied to the recognition of clay minerals and distinction of micas and K-feldspars because the ratio is a relative measure of K abundance relative to Th. The Th/U ratio also has proven to be useful as indicator of redox conditions, and it can also help to detect ash layers.

Porosity

The resistivity log can be used to compute the rock porosity from Archie's equation because the formation´s resistivity is controlled by the amount and distribution of water. When a formation is porous and contains saline water, the overall resistivity will be low, whereas if a formation contains hydrocarbon, the resistivity will be higher although low resistivity may simply indicate low porosity in the formation. The behavior of resistivity logs over the same lithology, but filled with different fluids, and, in the latter case, no porosity is extremely different and diagnostic. The formation´s resistivity depends not just on the amount of water content, but gives information also on conductive minerals, texture, lithology, facies, compaction and overpressure. Resistivity logs can be used to suggest a lithology as certain minerals have distinctive although not exclusive values. Generally, high resistivity may be diagnostic of salt, anhydrite, gypsum and coal, and also associated with tight limestones and dolomites. On the contrary, low resistivity is generally not diagnostic, although shale has usually low values.

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CHAPTER 7

Permanent Downhole Monitoring

Bernhard Prevedel and Martin Zimmer

This chapter summarizes the current state of the art in *P*ermanent *D*ownhole *M*onitoring (PDM), continuous fluid sampling and it provides an outlook and recommendation for future development and research needs. It also proposes suggestions and decision aids for Principal Investigators (PIs) and scientists in reference to their selection criteria for a specific measurement sensor or PDM installation. The PDM systems available today in industry and academia represent a final wellbore installation, similar to a borehole completion in oil or geothermal wells, but in this case not for energy but data production to surface. They are generally categorized in 2 types of installations:

- Type 1: Outside the casing, facing the rock formation and permanently cemented in place
- Type 2: Inside a cased or open hole by means of wire-line or pipe deployment with an option to be retrieved to surface for repair or inspection

Common to both types is the requirement for a long downhole life expectancy in the form of system reliability of a minimum of 5 years mean-time between failures (MTBF) combined with safe measurement repeatability over comparable periods. In the array design criteria special emphasis has to be given to redundancy of sensors and telemetry lines in order to mitigate the risk for premature or a system failure. In an attempt to cover the majority of the potential scientific PDM applications a minimum environmental regime of 125 °C at 500 bar for +20.000 hours continuous operation should be targeted for the components selection. High temperature and deep installations will require a much more constrained specification envelope. Therefore cost of PDM hardware and installation could easily come into the range of the cost of drilling. Every PDM system will consists as a minimum of a deployment system, hole-anchoring system, sensors and data recording and data management units.

Fig. 7.1: Truck-based GFZ wireline unit

Deployment system

A deployment or conveyance system is the means to transport the instrumentation in and out of the hole, which serves at the same time as the instrument's umbilical to the surface. Fundamental basis for a PDM system is therefore a reliable deployment mechanism for a safe installation downhole.

The most common and versatile way to deploy borehole instrumentation in a borehole is by means of a wireline (Fig. 7.1). The value of a wireline operation lies in its independency from any rig or special surface installation. It requires typically only a tripod over the wellhead or sometimes a crane if long tool strings have to be handled.

Wire ropes and slick line cables are the simplest well servicing tools and come in the form of truck-mounted winches with several 1000 m rope length to small hand portable winches with a few hundred meters. But they do not have any electric conductor and were used in the past primarily for the installation of mechanical measurement devices or memory gages. Complex surface powered or fibre-optic sensors systems can also be deployed by clamping their non-armoured PU data cables (Polyurethane) to a tubing string or rope line. Rigid clamping needs to occur in discrete intervals minimum every 15 m in order to sufficiently support the weight of the PU cables and avoid slippage along the carrier and prevent cable tear.

There is no standardized procedure or commercial clamp design available on the market, and designs in the past were always customized solutions. Some installations worked perfect for years of downhole operation (i.e. Long Valley, USA) and some failed before even reaching the depth of installation. Careful planning and calculation of instrument weight and buoyancy as well as cable tension, frequent selection of clamping intervals and enough room for installation time is a good basis for achieving best results.

Armoured electric cables were originally developed for electric wireline logging under very harsh conditions in the oil & gas drilling. The design typically consisted of two components, the mechanical outer armor and the electrical core. The armour was two layers of counter-helically twisted steel wires. Inside is a core of individually insulated conductors (copper lines) wrapped in a plastic coating (Fig. 7.2).

The required outer diameter (typically: 7/16" or 3/16") depended on the desired breaking strength of the logging cable and the number of electrical conductors needed. There are cables available with 7, 4, 3, or only one electric conductor and with or without fiber-optical leads. Usually the outer armor is used for the electric return. It is made of galvanized high-strength steel, rarely of stainless alloys or even titanium and may be plastic coated or silver-plated depending on borehole temperature and corrosive borehole conditions. For special sensors and very high data transmission armoured electric cable can be augmented by a small metal tube containing typically 3-4 fibre-optic (FO) leads.

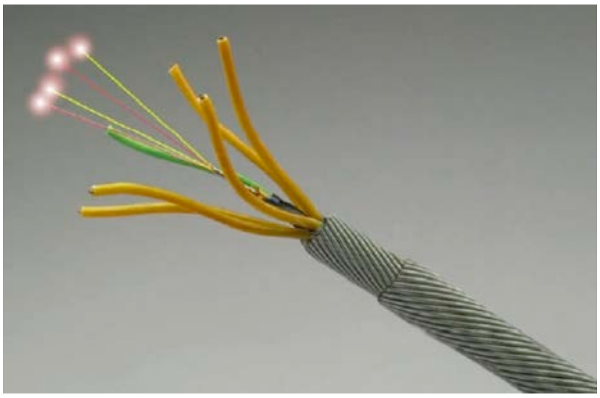

Fig. 7.2: Armoured wireline cable with 6 electric and 1 steel tube containing 4 optical leads (photo: Oyo-Geospace)

The oil & gas industry promoted the development of a steel material to be employed as endless production tubing stored on a reel, called coiled tubing (CT). With that device operators were no longer in need of a rig to repair and work-over live production wells. This ability turned out to be extremely cost effective in particular for offshore production fields, allowing the expensive rigs to concentrate on drilling projects.

Coiled tubing is made from a highly ductile steel alloy that recovers its initial strength even after being plastically deformed beyond yield. On the other hand, it is also a material that had a greatly reduced breaking stress capacity at very much reduced fatigue cycles compared to high graded steel. Therefore the number of cycles (off/on reel motion) combined with the actual stress in the material from pull and internal/external pressure needs to be carefully monitored for each CT unit in the field to avoid premature failure in the hole. But a CT well intervention is also a heavy and expensive operation. It requires on a land location approximately the same footprint and access roads as for a mid-sized medium-to- heavy drill rig (Fig. 7.3).

Fig. 7.3: Coiled tubing operation from a flat-bed truck with truck-mounted derrick

In horizontal and highly deviated wells (> 60 degrees from vertical) sensor packages cannot be deployed by gravity only on a standard wireline, but instead special techniques are necessary to position the sondes downhole. One option is to use the much stiffer coiled tubing with a conventional armored wireline cable installed inside to push the logging tools down in such high angle well sections. This procedure is also applied with CT Logging. However, in long high angle and horizontal open-hole sections even the CT also has at the same point the tendency to helically lock in the well bore, if the friction force exceeds downward thrust. The CT then behaves under loss of compressive strength like a wire rope. In such an event, the only further option is conveyance on drill pipe or production tubing.

In order to improve life and the number of safe bending cycles a material other than steel was looked for and found in Composite Coil Tubing (CCT) with embedded conductors or lines in the body of the composite structure. Composites are the logic answer, however it took many years of research to arrive at a material technology that was able to sustain the typical downhole well temperatures of 150° C and higher**.** Today CCT sizes are available in the range from 1” to 24” with mechanical performances similar to steel pipe, but only half its weight and a multiple of bending cycle capacities. In addition, electric wires, FO strands and even hydraulic lines can be woven into the composite fabric and such becoming an integral part of the pipe body. The procedure of installing the monitoring instrumentation with a CCT is the same as with classic CT via an injector head and crane or truck mounted derrick support.

Installation on drill pipe for permanent downhole monitoring is rather seldom done for reasons of high cost and a drill rig required for such an operation. However, when the risk of getting stuck in the hole exists and extreme pull-free forces are expected, then this mode of conveyance has to be favoured over all other options, despite of the high costs involved.

Hole-anchoring system

Hole-locks are positively activated devices that anchor repeatedly a monitoring device firmly in a hole and assure no relative motion of the tool vis-à-vis the borehole wall over weeks or even years. Different types of measurements require a different quality of locking mechanism, which is generally described by its lock force to instrument weight ratio and duration of locking period. Typically, geo-mechanical measurements require the highest quality hole-locking, followed by seismic sensors. Geochemical and geo-electrical sensors are almost insensitive to hole positioning and some require no hole lock at all.

Mechanical, hydraulic and free-suspended settable locking devices on cable or pipe are mostly based on mechanical spring bow wireline logging centralizers and represent the simplest but also most versatile type of maintaining a reference to the borehole in space. The oldest but at the same time very efficient concepts is a spring supported steel bow design that created enough friction on the side of the hole that the tool would not move voluntarily except by pulling on the cable from surface (Fig. 7.4) Enhanced designs had electric actuators or stepper motors in the tool downhole that pumped-up the bows or steel claw enforced lock arms and released it again on command (Fig. 7.5). Failsafe mechanical overrides, like shear pins or burst discs ensured that the tool could be recovered even when the release mechanism could not be reactivated for various reasons.

Fig. 7.4: Spring bow de-centralizer hole lock concept (photo: SAFOD project)

Hydraulic locking devices are almost entirely confined to CT or pipe conveyance, as hydraulic actuation lines can typically not be installed together with cables. Mechanically or hydraulically inflatable packers are reliable and efficient hole locking devices to anchor instruments firmly in the hole for very long monitoring periods. Releasing them even after years is almost uncritical due to the presence of pipes for applying the required pull-free force. In addition, these devices can be set and released multiple times with virtually any lock force that is acceptable by the borehole. If required, the anchoring can also be done in an oriented mode and even with mechanical decoupling of the anchored array from the conveyance pipe string above in order to avoid pick-up of noise frequencies from above hole sections.

Fig. 7.5: Three stages of DS 250 3c geophone package with activated hole locks (photo: SAFOD project)

However, from the logging experience at the German KTB boreholes and other deep PDM installations all over the world, the preferred way for an optimum sensor coupling to the rock formation seem to be today (1) downhole installations with permanent anchor systems or (2) permanently in the hole cemented and non-retrievable sensor arrays.

Sensors

The availability of measurement sensors in the industry and academia is actually quite large and they basically divide themselves into 2 families:

- active powered sensors
- passive operating sensors

As the definition indicates, active powered sensors do require external power in order to take a measurement. They usually also come with a digital output so that an array of these sensors can easily be combined into one single electric transmission line. By comparison, passive sensors are mechanical or optical devices that do not need external power. They take measurements all the time and provide in general analogue signal output only.

The choice of sensor type selection depends on many factors like the chosen type of measurement, the expected resolution of the sensor's output signal, the number of measurements in space, the desired survival time of the array, the temperature exposure downhole, etc., and last but not least the cost for such a PDM observatory.

In today's PDM application one can observe a growing interest in following families of sensors:

- Seismic – geophones, hydrophones, accelerometers, optical geophone arrays (DAS)
- Geometric – mechanical and optical tilt meter, pendulums and fibre optic sensors
- geo-mechanical – mechanical and optical strain meters and fibre optic sensors
- environmental – optical distributed temperature sensing (DTS), pressure & temperature gages and fibre optic sensors
- geo-chemical – gamma-ray, down-hole sampler, pH meter

For detail information on sensors visit our homepage at: www.icdp-online.de

Data recording and data management

Early downhole data acquisition systems were recording the measurements mechanically by means of a needle head writing analogue data in the downhole instrument on a rotating aluminium foil. The entire tool had to be retrieved to the surface before being able to remove the recording foil for manual data reading and interpretation. Today's acquisition systems for passive as well as active sensor arrays use a state-of-the-art 24-bit resolution digital surface acquisition module for data collection and downhole sensor operation. Data is typically stored at surface on peripheral data storage devices and/or sent via mobile or copper line telephone communication, or via Internet data link to a central storage place for further processing.

Field solutions of data acquisition depend a lot on the measurement type and data volume, and can range from small PC-based systems to container-housed computer centres (Fig. 7.6) The specific measurement scope and data volume is typically driving the size of such a surface installation.

Fig. 7.6: Recording container on top of the monitoring wellhead Tuzla-1 (courtesy: GONAF)

ICDP experience with PDM installations

The ICDPs Operational Support Group has supported in the past a fair number of permanent installations in deep and shallow boreholes all over the world. Many of them are still working today after >10 years of downhole service. Some have been discontinued on schedule and some had premature downhole failure. Some of the highlight activities are listed below:

GONAF, Turkey

A Deep Geophysical Observatory at the North Anatolian Fault. Borehole Seismometer Network at the Eastern Sea of Marmara. Instrument array at 298 m with sensor (2 Hz / 15 Hz), at 225.64 m 1 sensor (1 Hz), at 153.28 m 1 sensor (1 Hz), at 74.89 m 1 sensor (1 Hz). 8 ½" borehole, static temperature <40°C, max. depth 300 m. October 2012: Successfully cemented to surface in the hole by means of a PVC pipe string. Cementing string cemented in the hole. All sensors in operation to date. (Fig. 7.6)

SAFOD-Main Hole, USA

The SAFOD project drilled and instrumented an inclined borehole across the San Andreas Fault Zone to a subsurface depth of 3.2 km, targeting a repeating micro earthquake source. It required sensors with very low noise floors and high signal fidelity at high sampling rates. The array includes: Fibre-optic cable head, DS325 locking arm, Pinnacle high-temperature tilt meter, GERI DS250/DS150 adaptor, GERI DS150 65m interconnect, GERI DS150 seismometer, GERI DS150 65m interconnect, GERI DS150 seismometer, GERI DS150 3m interconnect and weight bar. 8 ½" borehole, 125°C static temperature, max. depth 3998 m, longest operation: 2 months. September 2006: the array had to be recovered due to cable transmission failures and gas influx in the instrument packages.

SAFOD-Pilot Hole, USA

The SAFOD project drilled and instrumented a vertical borehole across the San Andreas Fault Zone to a depth of 2.3 km, targeting earthquake source from the San Andreas Fault prior to drilling the main hole (MH). The array included: 80 stations of P/GSI's 3c analogue geophones. 8 ½" borehole, 115°C static temperature, max. depth 2347 m (7112 ft), longest operation: 16 months. March 2004: the array had to be recovered due to an intersection of the MH with the PH trajectory and array failure as well as gas influx in the cable jackets.

TCDP, Taiwan

The Taiwan Chelungpu-fault Drilling aims to monitor the fault where large displacements occurred during the Chi-Chi earthquake and to measure the physical properties and mechanical behaviour, as well as to document the state of stress of the rocks above and below the fault zone over a long time period. The instrument array included: p(ressure)T(emperature) gauges, chemical sensors, U-tube sampling line and 7 stages of 3c seismometer (analogue) package. 6 ¼" borehole, 48°C static temperature, max. depth 1300 m, still operating. December 2004: successful installation on steel rope, cables and tube attached to rope with bands. Sensors in operation to date.

DGLab, Gulf of Corinth, Greece

Investigating the mechanical behaviour of active faults by means of downhole monitoring as well as the physics of earthquakes and aseismic fault motion. The instrument array included: pT gauges, optical strain meter, 6 pcs electrical electrodes and a 3c accelerometer package. 6 ¾" borehole, 31°C static temperature, max. depth 1001 m. September 2002: successful installation on wire line and outside the cemented casing. Sensors in operation to date.

MALLIK, Canada

Full-scale field experiments were conducted to monitor the physical response of the gas hydrate deposits to depressurization and thermal production stimulation. 8 ½" borehole, 15°C static temperature, max. depth 1150 m. Still operating. March 2002: installed sensor was a temperature gauge and an optical multimode DTS cable on the outside of a cemented casing string. Sensors in operation to date

LVEW, USA

The objective of this installation is to monitor over long periods of time the mid-crustal deformation in a magmatic-seismogenic dome of the Long Valley caldera in east-central California.

The instrument array included: 1c – strain meter, pressure gauge and 2 stages of 3c seismometer (analogue) packages. 6 ¾" borehole, 110°C static temperature, max. depth 2996 m, still operating. September 1998: successful installation on steel rope, cables attached to rope with bands. Sensors in operation, strain-meter was lost shortly after installation.

Decision strategy: design and selection

There are many ways to collect data and information from a borehole and not all of them are to be considered as permanent downhole monitoring programs. They can spread from short-term logging and mud sampling to temporary installations of measurement sensors (Fig. 7.7).

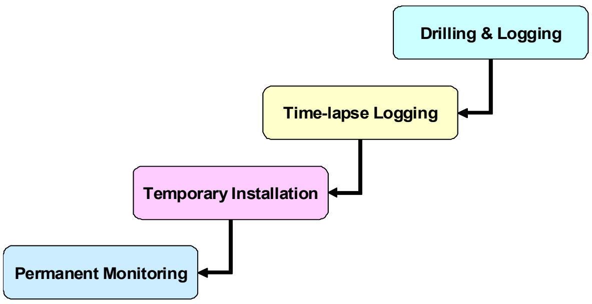

Fig. 7.7: Evolution of measurement suites from standard borehole acquisition to PDM

In today's terms a geophysical/geological monitoring installation is considered only a Permanent Downhole Monitoring (PDM) when a borehole is converted into a downhole observatory with a permanent installation of a sensor array in place. The final technical decision regarding measurement resolution and the type of sensor coupling to formation ultimately depends on the particular research tasks and the financial funds available. A guideline through this decision tree could be taken from Fig. 7.8.

Continuous Fluid Sampling

Water or fluid pumps can be deployed in a well as submersible pump. One example is the Grundfos MP1 with a 2" diameter and made of inert material and specifically designed for pumping of contaminated /polluted groundwater for purging sampling and water quality monitoring from e.g. shallow boreholes (Fig. 7.8). It has been specially developed for pumping of small quantities of water to be sent to the laboratory for analysis.

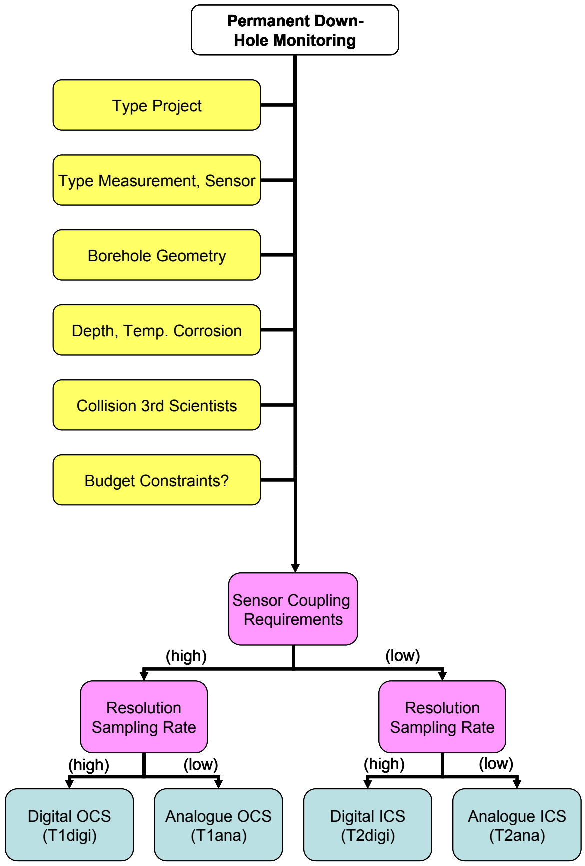

Fig. 7.8: Decision strategy for the design and selection for a typical PDM system

The pump performance is adjusted by means of the converter that controls the pump speed via the frequency. In this way a steady, air free water flow can be achieved. The MP 1 offers efficient purging of the well before sampling as a high pump performance is achieved when the frequency is raised. Maximum performance is at 400 Hz. The pumping system is not approved as explosion-proof. Power input is 1.3 kW at 3 x 220 V, 400 Hz and a maximum current of 5.5 A. The supply voltage is 1 x 220-240 V –15 %/+ 10 %, 50/60 Hz. Allowed maximum water temperature is +35 °C.

Fig. 7.9: MP 1 pump and converter

Gas Membrane Sensor

The Gas Membrane Sensor (GMS) is a device for real-time gas measurements and gas sampling in boreholes; it is patented for the continuous detection and analyses of gases in deep boreholes. The field capability of the system was proven at the CO_2-sequestration pilot test site Ketzin, Germany, where it operated continuously for 9 months in a 650 m deep borehole. It consists of a phase separating membrane element in combination with a special cable for installation in a borehole. The cable permits the conduction of the subsurface gas phase into an analytical device, (e.g. mass spectrometer, gas chromatograph, alpha-scintillometer) for real-time gas analysis at the surface and for the collection of gases for special investigations.

The method, developed and provided by the GFZ, allows for tracing of the concentration and composition of the gas phase down to depths of 2000 and temperatures to 120°C. Additionally, it is possible to obtain gases from deep reservoir horizons for detailed geochemical and isotope studies (Fig. 7.10).

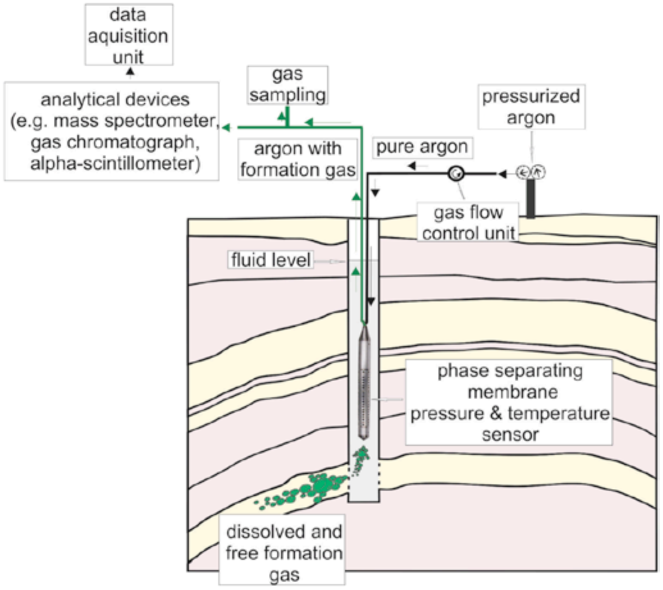

Fig. 7.10: Mode of operation of Gas-Membrane Sensor (GMS) and experimental work flow

The method uses a phase separating silicone membrane, permeable for gases, in order to extract the gases dissolved in borehole fluids, water and brines. The extracted gases mix in a prevailing argon stream provided from a pressure vessel and conducted via a capillary into the membrane element. Via a second capillary, the argon together with all gathered borehole gases is led back to the surface. Both capillaries are embedded in an especially developed borehole cable. At the surface, the gas phase can be analyzed directly and/or can be sampled for more detailed investigations in the laboratory.

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CHAPTER 8

Drill Site Science and Instruments

Thomas Wiersberg and Ronald Conze

Most of the research in continental scientific drilling projects is performed after drilling operations in labs. However, there are investigations that, for several reasons, need to be executed during drilling. This includes:

- on-site investigations to provide rapid information for aiding decisions, e.g., core/borehole correlation studies for depth matching or the identification of target depths related to formation testing, sidewall coring, or side tracking
- studies (downhole logging, fluid sampling) which need access to the open borehole before it becomes cased or otherwise will not be accessible
- studies that can provide a fundamental database for all subsequent research activities (e.g., lithological log)

Given the limitations in manpower, time and space at most drill sites and the rough on-site conditions (e.g. fluctuating power supply), the set of scientific on-site investigations should be limited to the absolute minimum. Generally, sampling should be performed after completing the drilling operations, e.g. during sample parties in core repositories. Some studies, however, require sample material to be obtained immediately after fresh core arrives at the surface, e.g. microbial sampling for deep biosphere studies, or any sampling of material that would otherwise suffer decay, degradation or contamination at the surface. Furthermore, sampling of fluids and gases from downhole fluid sampling, drilling mud gas and core voids require immediate action at the drill site. The sampled material must be stored immediately after sampling under special conditions regarding temperature and pressure (e.g., vacuum) to avoid degradation or contamination. On-site sampling must be requested from and approved by the Principal Investigators prior to spud-in.

On-site science in lake drilling

During lake drilling projects, where mostly soft sediments are retrieved, the drill cores remain~~s~~ in their respective plastic core liner until they reach~~es~~ the designated core repository, which naturally limits the applicable on-site research to non-destructive methods which penetrate through the core liner (e.g., Magnetic Susceptibility measurements on un-split cores conducted on with multisensor-type scanner). Core opening, washing, sawing, lithological description (except of core catcher material), optical and X-ray based investigations and sampling will therefore be conducted after drilling.

For lacustrine and lake sediment drilling, the completeness of a core record from a drill site is crucial, which can be provided on site by core/borehole correlation. For this purpose, magnetic susceptibility and gamma density measurements on drill core and downhole logging are the most common tools. Gamma density measurements require logging with radioactive sources that is logistically challenging and therefore not provided by the OSG. Magnetic susceptibility, obtained from drill core by core logging (using a Multisensor Core Logger - MSCL), in combination with downhole logging builds therefore the base for site-to-site core/borehole correlation, and is therefore strongly recommended for lacustrine drilling projects.

On-site science on land

In contrast to lake sediment drilling, where several holes are drilled at one site for the completeness of a sediment record, land drilling projects with a multi-hole approach follow~~ing~~ different objectives. The purpose~~s~~ of two or more holes (Monitoring Hole/Pilot Hole/Main Hole) at one site ~~are~~ is here i) to get background information on the lithology for later Main Hole drilling, ii) for seismic or hydraulic cross-hole investigations, and iii) for long-term monitoring. While some ICDP drillings have retrieved an almost complete core record by wireline coring (e.g., COSC, Donghai, HOTSPOT, Barberton), other projects (e.g., SAFOD, Mallik, Iceland) recovered only spot cores from target horizons. Depending on the drilling techniques used in scientific drilling projects (slimhole or oilfield-drilling), rock sample types (cuttings or core), and project objectives, different ~~on~~ on-site investigations are recommended for aiding rapid decisions, including the lithological description of core or cuttings, drilling data (Lag depth, RoP, WoB, Time in/out, drilling mud volume etc.), MWD/LWD (if available), core scanning, core and downhole logging, and on-line gas monitoring (if available).

Mining drilling mostly delivers continuous core that can be opened, described and measured at the drill site (core scanning and logging). The lithological description of core, core scanning, and downhole logging build the data base for making decisions on site and furthermore provide an important dataset for later sampling parties.

Most projects applying oilfield-drilling technique have to deal with cuttings: small rock chips of variable size dragged out of the bore hole by circulating drilling mud. Drill core is only available from few target horizons, if ever. The lithological description on-site is therefore based cuttings analysis. In contrast to mining drilling, continuous technical drilling data are often available in oilfield drilling which are important for e.g. cutting analysis (Lag depth) and for making on-site decisions. As for the other drilling techniques, downhole logging is performed during drill stops, but oilfield drilling also allows integration of logging tools to the Bore Hole Assembly (BHA) (MWD, LWD) which can deliver data in almost real-time. Cutting analysis can prove in almost real-time if side-tracking is successful.

Drilling Technique	Lake Sediment Drilling	Mining Drilling	Oil-Field Drilling
Borehole Diameter	PQ, HQ, NQ, …	PQ, HQ, NQ, …	26-22-17 ½-12 ¼-8 ½-6 ¼ inch
Average number of holes per site	>1	1-2	1-3
Coring technique	Wireline, continuous core	Wireline, continuous core	Roundtrip, spot core
Most common sample type	Core	Core	Cuttings, spot core, sidewall core
On-site core handling	Marking, packing, labelling	Opening, cleaning, sawing, description, marking, labelling, packing	If applicable: opening, cleaning, sawing, description, marking, labelling packing
On-site Scientific Investigations on core	Core logging (MSCL)	Core logging (MSCL), core scanning	Core scanning
On-site Lithological Description	--	Based on core	Based on cuttings
Use of Drilling Data	Limited, data not continuously recorded	Limited, data not continuously recorded	Continuously recorded (RoP, WoB, Lag depth,…)
Other methods	Downhole logging	Downhole logging	Downhole logging, MWD/LWD, OLGA

Table 1: Different drilling methods and sizes for the various drilling scenarios as part of planning and conducting drill experiments on land and on lakes

Available tools

Instruments and tools acquired through ICDP grants are integrated and maintained in the ICDP Equipment Pool by the Operational Support Group (OSG). Project scientists can operate a number of these scientific instrument sets at drill sites. The tools will be provided to ICDP projects as needed. Requests are to be made as early as possible (first-come first-serve policy). The OSG usually introduces on-site scientists of individual projects to the use of these devices. These instruments have been used at several drill sites in support of the core handling procedures and the initial core description.

Multi-Sensor Core Logger

The Multi-Sensor Core Logger (MSCL, Geotek) measures a suite of geophysical parameters rapidly, accurately and automatically on sediment or rock cores. The rugged nature of the equipment makes it suitable even for use in a laboratory container on-site (Figure 8.1). Core sections up to 10 cm diameter and up to 1.55 m long can be logged at spatial intervals as low as a few millimetres. ICDP's Multi Sensor Core Logger is configured to measure:

- P-wave velocity (250-500 kHz piezo-electric ceramic transducers, spring-loaded against the sample. Accurate to about 0.2%, depending on core condition)
- Gamma density (bulk density): ^{137}Cs gamma source in a lead shield with optional 2.5 mm or 5 mm collimators. Density resolution of better than 1% depending upon count time
- Magnetic susceptibility: Bartington loop sensor of 100 mm diameter, or point sensor (on split cores) giving 5% calibration accuracy over two ranges: 1 x 10^{-6} and 10 x 10^{-6} cgs

Fig. 8.1: Multi-sensor core logger in field lab

Data can be obtained from whole core sections and core sections contained in plastic liners. More details on instrument functionality, calibration and so on can be found under: http://www.geotek.co.uk/products/mscl-s. Additional information on typical parameters measured for drilling projects: www-odp.tamu.edu/publications/tnotes/tn26/TOC.HTM.

Prerequisites for core logging

MSCL measurements are essential for depth matching of drill core from lake and soft sediment drilling. ICDP owns only one MSCL; For on-site operation, space must be provided in a laboratory trailer, container or similar makeshift lab space. The size of the MSCL is 4.5 x 1.2 m plus some additional space (0.6 x 0.6 m) is required for the electronics bench. Trailer space can be utilized alongside other instruments (e.g. Core Scanner) if no liquids (e.g., water) are used in the trailer. Power supply (220 V) must be buffered or electrically disconnected and independent from rig power (e.g. external generator or public power supply). The power input of the MSCL is ~2000 VA.

Scientists should state in their full proposal to use the ICDP MSCL to ICDP if they are interested in this type of measurement. Requests to use the devices are to be made to OSG as early as a drilling timeline is fixated. In case of overlapping requests, ICDP's OSG will try to organize one device from other sources for the group, which placed the request at a later time. The equipment will be provided on the base of a lending agreement. Shipping costs, custom fees, etc., are to be covered by the project.

Operating scientists for the MSCL have to be designated by the project. ICDP will not provide the manpower to operate and maintain the experiment during drilling but technical support if necessary. Training of on-site operator(s) can be conducted by OSG in Potsdam some weeks prior to drilling operations start. Costs for training are to be shared between the project and ICDP. The on-site instrument operator with OSG support will assemble the experiment immediately before spud in.

Optical Core Scanner

ICDP provides two DMT Core Scan Colour (Figure 8.2) and one DMT Core Scan3 line scanning devices. These instruments allow optical high-resolution scanning of whole or slabbed hard rock drill cores and soft rock half cores in diameters from 4 to 22 cm and maximum length of 1 m. The devices can also be used to scan cuttings and other sample specimens in close-up views. Additionally, the DMT Core Scan3 is capable to acquire core box overview scans. Image sizes are up to 25 MB with a resolution of 5 – 10 pixel/mm = 127 – 254 dpi.

Fig. 8.2: Optical core scanner in operation

Prerequisites for scanning

Optical scans of whole round cores are essential for initial and long-term digital documentation (and distribution) with the ICDP Drilling Information System. Ideally this happens in the field, right after core retrieval. Thereafter, cores are cut and sampled, annotations of characteristics and sampling made, and/or digital geological profile construction, core-log integration or well correlation, re-orientation, tectonic, petrographic and image analyses are performed.

Interested scientists should apply to use one of the ICDP scanners in their full proposal to ICDP. Requests to use one of the devices are to be made to OSG as early as a drilling timeline is fixed (first-come first-serve policy), but ICDP cannot guarantee that a scanner will be available. The equipment will be provided free of costs on the base of a lending agreement but shipping and related fees are to be covered by the project. If not part of an ICDP grant a maintenance fee may be necessary.

A core scanner requires at a drill site about 2.5 x 2 m space in a dry place such as a laboratory trailer, container or similar. Trailer space can be shared with other instruments (e.g. MSCL). Power supply (220V) must be buffered or electrically independent from rig power (e.g. external generator or public power supply).

OSG cannot provide the manpower to operate and maintain the experiment during drilling, but will support it remotely as necessary. Hence, an operating scientist or program-aid (student; temporary technician hired for the project, or project volunteers) has to run the tool. On-site operator(s) of a scanner can be trained by OSG at the GFZ in Potsdam. Costs for specific instrument training are to be shared between the project and ICDP. The on-site operator with OSG support will assemble the experiment immediately before spud in.

OnLine GAs monitoring OLGA

Continuous mud gas logging during drilling as well as offline mud gas sampling are standard techniques in oil and gas exploration, where they are used to measure hydrocarbons in reservoir rocks while drilling. ICDP's online gas monitoring OLGA extends this technique for scientific drilling in hydrocarbon and non-hydrocarbon formations to sample and study the composition of crustal gases. Hydrocarbons, helium, radon and with limitations carbon dioxide and hydrogen are the most suitable gases for the detection of fluid-bearing horizons, shear zones, open fractures, sections of enhanced permeability or permafrost methane hydrate occurrences. Offsite isotope studies on mud gas samples serve to reveal the origin and evolution of deep-seated crustal fluids.

OLGA has been proven to be a reliable and inexpensive source of information on the composition and spatial distribution of gases at depth in real time. It is suitable to detect fluid-bearing horizons, shear zones, open fractures, sections of enhanced permeability and methane hydrate occurrences in the subsurface of fault zones, volcanoes and geothermal areas, permafrost regions, and other rheological formations. Offsite isotope studies on mud gas samples help reveal the origin, evolution, and migration mechanisms of deep-seated fluids. It also has important applications to aiding decisions if and at what depth rock or fluid samples should be taken or formation testing should be performed. The method had been successfully applied on several continental scientific drilling projects of the ICDP (Mallik, SAFOD, Corinth Rift, Unzen Volcano, Long Valley Caldera) and IODP (Chikyu Exp. 319, 338.

Operation Flow

Drilling mud gas that circulates in the borehole comprises air and gaseous components that are mechanically released by the drill bit, including components present in the pore space of the crushed rock and gas entering the borehole through permeable strata, either as free gas or, more likely, dissolved in liquids. Continuous inflow of fluids in the borehole along the entire borehole wall is mostly hampered through the rapid formation of mud-cake that covers the borehole wall and acts as a seal.

Back at the surface, a portion of the circulating mud is admitted to a mud gas separator and gas dissolved in the drilling mud is extracted mechanically under a slight vacuum. The separator is composed of a steel cylinder with an explosion-proof electrical motor on top that drives a stirring impeller mounted inside the cylinder. The gas separator is normally installed in the "Possum belly" above the shaker screens as close as possible to the outlet of the mudflow line to minimize air contamination and degassing of the drill mud immediately before gas extraction (Figure 8.3). A small membrane pump is used to build up vacuum and to pump the extracted gas into a laboratory trailer, which should be installed not more than a few tens of meters away from the gas separator.

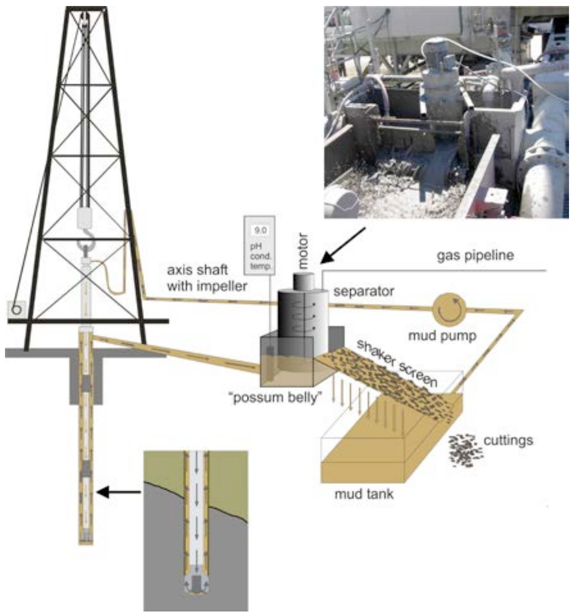

Fig. 8.3: Scheme of drill mud flow and gas extraction by gas separator; inset photo shows gas separation device

N_2, O_2, Ar, CO_2, CH_4, He, and H_2 are determined by a quadrupole mass spectrometer (QMS) of the type OmniStar™ (Pfeiffer Vacuum, Germany). A complete QMS analysis with detection limits between 1 and 20 ppmv (parts per million by volume) is achieved with this setup after an integration time of less than 20s (Figure 8.4.). However, a sampling interval of one minute is mostly chosen to reduce the amount of data produced. Hydrocarbons (CH_4, C_2H_6, C_3H_8, i-C_4H_{10}, and n-C_4H_{10}) are analysed at 10-min intervals with an automated standard field gas chromatograph (GC), which is equipped with a flame ionization detector. Detection limits for the hydrocarbons are at about 1 ppmv. Gas samples for further studies e.g. of isotopes are taken automatically when a given threshold level at the QMS is exceeded.

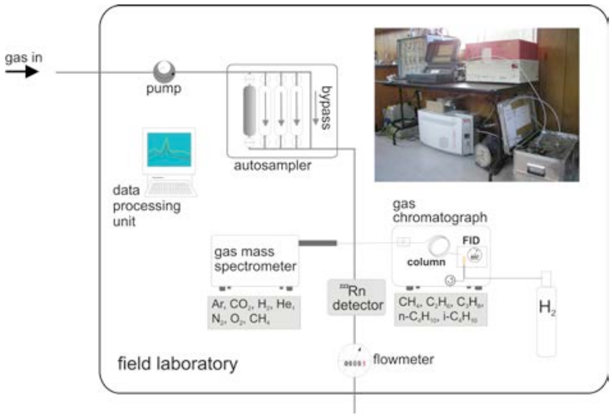

Fig. 8.4: Flow path of gas analyses steps

Prerequisites for gas monitoring

The drilling mud acts as carrier for fluids and gas transport to the surface. Drilling mud circulation is therefore crucial to apply OLGA. The method is, for example, not applicable for lake drilling. OLGA will not replace commercial mud logging for hazard purpose.

ICDP will provide all necessary equipment for a successful execution of the experiment. In turn, the project must provide space (2 x 3 m) in a laboratory trailer, container or similar facility. Trailer space can be shared with other groups if no liquids (water) are used in the trailer. The lab trailer should be placed in close vicinity (not more than 50m) to the shale shakers to keep the travel time of the gas short. Power supply (220 V) for the analytical devices in the lab trailer must be electrically separated from rig power (e.g. external generator or public power supply). The power input of the analytical devices is ~1000 VA.

Gas composition data are recorded versus time. Additional data are needed to convert the raw data set into gas composition at depth. These data (lag depth, ROP) must be provided, for example, from mud logging or the drilling company on a minute base (ideally), but at least every five minutes. The equipment will be provided on the base of a lending agreement. Shipping costs, custom fees, etc., are to be covered by the project.

The OSG will offer the OLGA system upon request if a project scientist can run the instrument on the drill site. ICDP will not provide the manpower to operate and maintain the experiment during drilling, but will provide technical support from outside if necessary. In addition, OSG will train the on-site operator(s) before a drilling project starts. The costs for this training will be partly covered by ICDP. The on-site operator and the OSG gas geochemist will assemble the experiment immediately before spud in. OSG offers OLGA as part of a scientific cooperation for joint data evaluation and interpretation. Additional lab investigations on, for example, noble gas isotopes can be arranged by OSG if prepared beforehand.

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CHAPTER 9

Core Handling

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This chapter provides two examples of workflows on core handling of hard rock and soft sediment core material. The examples described below may serve as a guideline for similar drilling projects during their planning phases.

Core Handling Procedure Example 1: Crystalline Rock – COSC-1

The Collisional Orogeny in the Scandinavian Caledonides (COSC) scientific drilling project drilled its first drill hole, COSC-1 (ICDP 5054-1-A), from early May to late August 2014 (Lorenz et al., 2015a). COSC-1 is located in the vicinity of the abandoned Fröå mine, close to the town of Åre in Jämtland, Sweden. This is a typically slim hole hard rock coring project using a wireline exploration triple-tube diamond coring system. During the drilling operations an elaborated core handling workflow was applied. The following chapter is an excerpt from the COSC-1 Operational Report (Lorenz et al., 2015b).

COSC scientific operations

The scientific operations were coordinated by Uppsala University, Sweden. The on-site scientific work was performed in two 12 h shifts per day. Normally, three scientists were on-site at any time during the operational phase. Two groups were rotating on a 10-day schedule, partly with changing personnel. The first group began its work on April 26, 2014, two days before planned spud in, and the last scientists left the drill site on August 29, 2014. The complete on-site scientific work from mobilization to demobilization is estimated to about 4.75 man-years. The personnel are listed in chapter 1 of the COSC-1 Operational report (Lorenz et al., 2015b).

Fig. 9.1: Whole round core scan of core section showing double reference line in upright position with red line on the right (COSC project)

COSC workflow drill core handling

The on-site science team received the drill core from the drilling team at the drill rig, noting top and bottom depths and possible comments on the core run protocol. For cores drilled with 3 m triple tube core assemblies, this was done on the pipe handling rack, where the drill core in its aluminium split-liner was hydraulically extracted from the inner tube (Fig. 9.4). The

Fig. 9.2: Core boxes 648 and 649 from COSC-1. The core boxes are used in portrait format (=upper left corner = Top, lower right corner = Bottom. Top and bottom of core runs are marked with labelled foam blocks. Each box was photographed with the cm/ft ruler and a standard colour chart.

closed liner was then transferred to the geologist's core handling table for further processing (Fig. 9.5). The 6 m core barrel assembly had to be split in two halves. To guarantee that core extraction without an inner liner was done in the most careful way, the drilling team removed the core from each half of the inner tube piece by piece, handing them immediately over to the science team who placed them in empty core liners (from the triple tube system), always under rigorous control of top and bottom. In this way, the drill cores from the double and triple tube systems could be processed in the same way.

At the geologist's working table, the core pieces were restored to their original position (with few exceptions where this was not possible) and marked with two coloured lines for orientation (red line on the right when looking upwards, and blue). Not until this was finished were the other tasks performed. These were (1) measuring the total length of the drill core along the red line, (2) washing with a sponge and clear water and subsequent drying with a paper towel (usually enough since the only additive in the drilling fluid were biodegradable polymers) and (3) placing the drill core into core boxes.

Fig. 9.3: *Sample location filled with a labelled foam block showing the sample number and IGSN (lower left: ICDP5045EX2W501)*

From the geologist's working table, full core boxes were transferred to the first science container. Here the core run protocol was scanned and archived, and its data together with information about the core's position in the respective core boxes was registered in the Drilling Information System (DIS). Unrolled core scans were acquired for each section (Fig. 9.1) after drying with a hair dryer and the images were added to the DIS. Afterwards, each core box was photographed on a repro-stand and the photos added to the DIS (Fig. 9.2). Colour profiles were calculated along each core section with the help of a GNU Octave script. Subsequently, geophysical parameters of the core sections were logged on a Geotek MSCL-S core logger (provided by ICDP).

Fig. 9.4: The first drill core (bedrock in the lower part, cement in the upper part) was pushed out of the inner tube of a triple tube core barrel assembly. Clearly visible is the split aluminium liner that protects the drill core from external forces. The second tube is also called core barrel, and the third tube is the drill string, hence "triple tube".

For the last step of core documentation, the core boxes were transferred to the second science container where a working place for geological drill core logging was installed. The geologists entered this description directly into the DIS. Finally, the core boxes were packed for transport and temporarily stored at the drill site.

COSC sampling

All samples in the COSC scientific drilling project are marked with an International Geo Sample Number (IGSN), a hierarchical unique identifier (Fig. 9.3) that is used to track samples and relationships between samples (see also: http://www.geosamples.org/igsnabout).

On-site sampling of the drill core was very restricted and only permitted for the following purposes: study of changes in thermal conductivity in relation to time after drilling (sample to be returned), matrix gas extraction and analysis (samples have been returned), microbiology (destructive). In addition, the on-site science team took DNA and ATP swab-samples on fracture surfaces.

The tracer used for microbiology was fluorescein dye. More advanced setups to employ tracers together with NQ triple tube drilling were ready for employment, but not used due to the strategic decisions to only use the faster double tube drilling in the lower part of the drill hole.

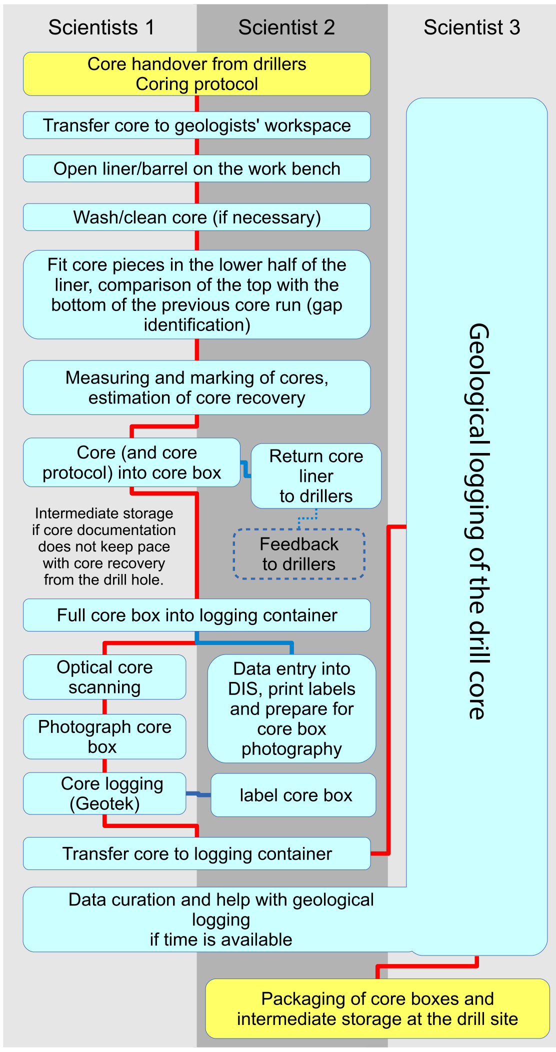

Fig. 9.5: Workflow for the COSC-1 drill core handling procedure

Core Handling Procedure Example 2: Lake Sediments – Lake Ohrid

The ICDP project "Scientific Collaboration on Past Speciation Conditions in Lake Ohrid" (SCOPSCO) recovered more than 2100 m of sediments from five different drill sites between 2011 and 2013 (Wagner et al., 2014). During the first drilling campaign in summer 2011, short sediment successions <10 m were recovered using an UWITEC piston corer. This drilling technique uses a re-entry cone on the sediment floor to recover a continuous sediment record and is suitable for soft sediments down to about 20-25 m below lake floor (blf).

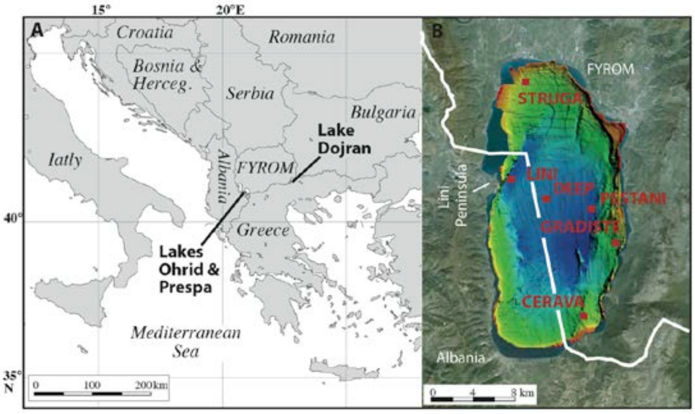

Fig. 9.6: Location (left) and map of Lake Ohrid (right) with color-coded depth and drill sites, modified after Wagner et al., 2014.

Between April and May 2013, a deep drilling campaign was carried out using ICDP's Deep Lake Drilling System (DLDS) operated by DOSECC (Drilling, Observation and Sampling of the Earth's Continental Crust's) consortium. At the drill sites DEEP, CERAVA, and GRADISTE boreholes were cored at water depths of 243 m, 119/131 m, and 131 m down to 569 m blf, 90 m blf, and 123 m blf, respectively (Wagner et al. 2014). In order to obtain a maximum composite profile recovery, multiple boreholes were cored at each drill site. At the PESTANI site, limited time and bad weather conditions enabled the recovery of only one sediment succession at a water depth of ~262 m down to a maximum penetration depth of ~194 m blf. The composite field depth recovery adds up to more than 90 % at each individual drill site.

Fig. 9.7: Drill core handling on the barge. Small holes were drilled into plastic liners to prevent excessive core expansion from high gas pressure in the liner (Photo: N. Leicher).

Ohrid on-site scientific work

The on-site scientific operations were coordinated and conducted by the University of Cologne (Germany), the University of Kiel (Germany), the Faculty of Natural Sciences of Skopje (Macedonia), and the Hydrobiological Institute Ohrid (Macedonia). Scientific work on the drill barge was performed 24/7 in two 12-hour shifts. The platform team consisted of three scientists led by Post-Doctoral researchers and experienced PhD students. This group was responsible for the on-site documentation, core handling, and initial sampling. Additionally, the scientific shift leader was also responsible for taking decisions in close collaboration with the driller team on type and progress of daily coring activities and depth calculations. General decisions about the drilling strategy and the selection of the subsequent drill holes and sites were made after consultations between the Principal Investigators (PIs), on-site scientific shift leader, and driller team. The shore-based PI was in particular responsible for the overall organization of the field campaign, including financial and political issues during the drilling operation, and to ensure the timely fuel and drill mud supply to the drill barge.

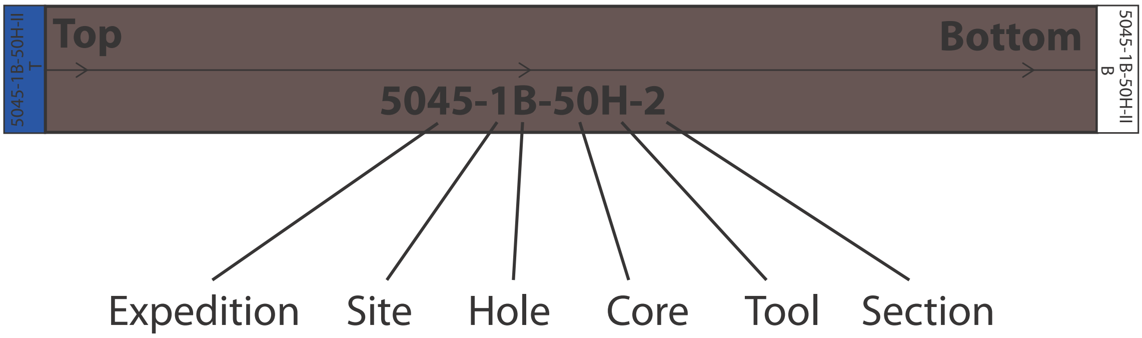

Fig. 9.8: ICDP standard core labelling routine. Arrows point to the bottom of the core, blue caps are attached to the top, white caps to the bottom of each core section.

Workflow Ohrid core handling on barge
After each core run, when the drill tool was successfully pulled back to the platform and disassembled by the driller's crew, the 3m long PVC liner containing the recovered sediment core was transferred to the platform science team. Immediately, small holes were drilled into the plastic liner with a cordless screwdriver whenever gaps in the sediment structure indicated a high gas pressure in the PVC liner. Although drilling these small holes might have caused specimen contamination with oxygen, it prevented the substantial loss of core material when the sediment was pushed out of the PVC liner (Fig. 9.6).

Simultaneously, caps were attached to the bottom and top of the PCV liner. The 3m long PVC liner was then split into 1m long core sections. Gaps in the sediment succession, which unambiguously occurred due to the gas pressure in the PVC liner, were closed by gently pushing the sediment back in position with a sediment pusher. Finally, caps were taped tightly on top and bottom of each core section, and then cores were labelled following ICDP standard routines and workflow (Fig. 9.8).

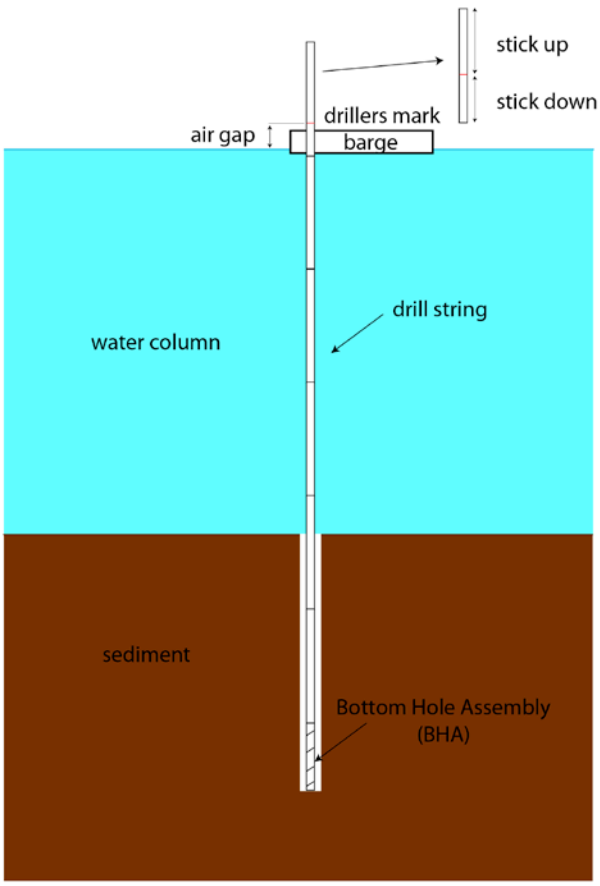

Fig. 9.9: Simplified scheme for the illustration of the drill depth calculations

Oriented samples were taken directly on the platform from the core catcher (CC) by pushing small cubic plastic vials into the sediment. Subsequently, the remaining sediment material from the core catcher was replaced into a plastic bag. The cubic plastic vials were shipped to the GFZ (Potsdam) for initial paleomagnetic analyses, and in addition small aliquots of this material was used for total inorganic carbon and total organic analyses at the University of Cologne. A first description of the recovered sediments from the core catcher provided first insights into the lithology, which is a prerequisite for decisions about succeeding drill progress and drill strategies. This brief material description was also used to provide a first overview about the recovered sediments down to the base of each hole (see for example Wagner et al., 2014).

In addition to information about the lithology, on-site documentation of the recovered core sections further highlighted problems or issues that occurred during the drilling activities and regarding calculated drill depths. Depth calculations were crosschecked between the science and driller team before each core run.

The basis of the depth calculations is the length of the drill pipe (P_{lenght}) and of the Bottom Hole Assembly (BHA_{length}), i.e. the lowermost drill pipe to which the drill tool is connected during the drilling activities (Fig. 9.9). Corresponding calculations always refer to the driller's mark on the barge, which must be always denoted in the drill table in form of a depth/length scale entry in order to keep track of the driller's depth. The "stick down" and "stick up" refer to the distance between the drillers mark and the lowermost and uppermost end of the last drill pipe of the entire drill string, respectively. The air gap is measured routinely during the drilling operations and corresponds to the distance between the water surface and the drillers mark (Fig. 9.9).

In the first step, the water depth (w_{depth}) at the coring location is determined by using the equation (1):

$$w_{depth} = (P_{length} * P_{amount}) + BHA_{length} + \text{stick down} + HPC_{max\ length} - \text{air gab} - \text{recovery}_{1st\ HPC\ run} \quad (1)$$

Subsequently, the drillers constant d_c can be calculated with the equation (2):

$$d_c = w_{depth} + \text{air gap} \quad (2)$$

The drillers constant is the basis for the calculation of the sediment depth (s_{depth}) (3):

$$s_{depth} = d_{depth} - d_c \quad (3)$$

whereby the drillers reference depth (d_{depth}) equals to the total length of the drill string (4):

$$d_{depth} = (P_{length} * P_{amount}) + BHA_{length} + \text{stick down} + b_{correction} \quad (4)$$

The bit correction ($b_{correction}$) depends on the selected coring device (Chapter 4), and refers to the distance the coring device protrudes over the BHA.

Drilling strategy

Decisions about the onsite drilling strategy encompasses the selection of the coring devise, the sediment depth to be cored, and the maximum penetration depth with respect of the individual scientific targets of the drill site. Stratigraphic information obtained from hydro-acoustic pre-site surveys are rather imprecise, and more profound decisions about the selection of the coring devises can be made based on lithological information from the core catcher material of previous boreholes. Thus, higher sediment recovery percentages are frequently gained in boreholes, which were drilled later during an on-going drilling campaign. If multiple boreholes can be drilled at on drill site, spot coring for gaps in the sediment sequences of the neighbouring boreholes can be conducted. In order to save time during the drilling activity, the non coring assembly can be used between the target depths.

Onsite drilling strategy should also carefully balance the risks during the drilling and the scientific gain to be expected in order to prevent the loss of coring devices. For example at the DEEP site in the central part of Lake Ohrid, the hydro-acoustic data imply an overall sediment infill of more than 680 m (Wagner et al., 2014). However, very coarse, unconsolidated material with gravel and pebble could have destabilized the borehole and thus, coring was stopped at 569 m sediment depth (Wagner et al., 2014).

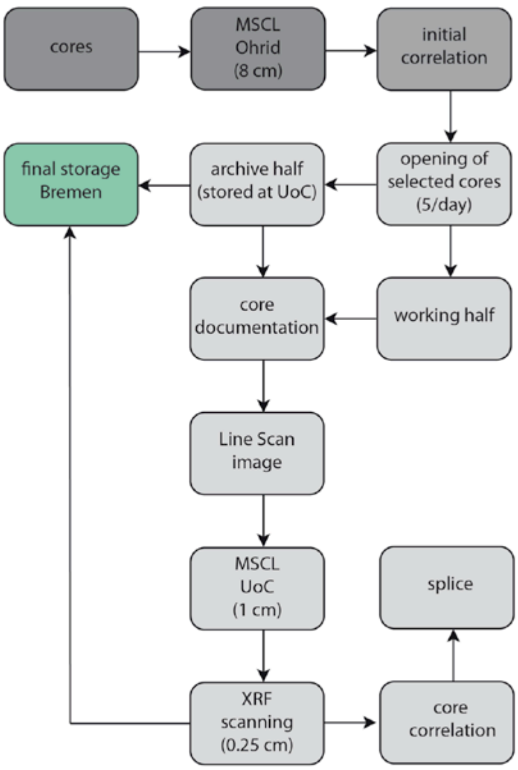

Fig. 9.10: Core handling workflow during the Lake Ohrid drilling expedition.

Ohrid core handling at shore base

At the shore base, geophysical parameters of the core sections were measured with the [Geotek MSCL-S core logger](). The volume-specific magnetic susceptibility (MS) was detected over an integral of 8 cm in 2 cm resolution steps on the whole core using a Bartingon loop sensor. Smear slide samples from core catcher material were prepared for preliminary diatom analyses. The slides were directly analysed at the shore base using an incident light microscope. During the deep drilling in 2013, the sediment cores were stored in the dark at 4°C in a 20 feet overseas cooling container. At the end of the drilling activities, the cooling container was directly shipped to the University of Cologne (Fig. 9.10).

Ohrid core handling in science lab

The sediment cores recovered during the SCOPSCO 2013 field campaign at Lake Ohrid are stored under temperature-controlled conditions (4°C) at the University of Cologne, Germany. The archive halves are permanently stored in the Bremen Core Repository (BCR). Core splitting, description, documentation and measurements such as MSCL and X-ray fluorescence (XRF) scanning are performed at the University of Cologne. For the XRF scanning, the resolution was set to 2.5 mm, which accounts for the homogenous structure of the sediment and is likely high enough to decipher decadal sediment property variations. Visual inspection, MS and XRF scanning data combined are used to identify horizons with tephras or cryptotephras. Corresponding results are tied into paleomagnetic measurements and chronostratigraphic tuning methods to establish an age-depth model. Subsampling for geochemical, pollen and diatom analyses were carried out at consistent intervals of 16 cm on the composite core after core correlation and splicing was performed based on visual inspection and XRF data. Aliquots of the subsamples were distributed to the Ohrid science community for further analytical work (Fig. 9.11).

Ohrid core correlation and splicing

Core correlation and splicing of core data obtained from neighbouring bores is a critical and essential task to improve the data quality, which is often compromised due to spotty and incomplete core recovery. Simply speaking, not every core retrieved during a drill run exhibits a full recovery, which requires additional drilling a Hole-B (and sometimes even a Hole-C) close to the original hole of a particular site to fill a particular data gap over drill depth.

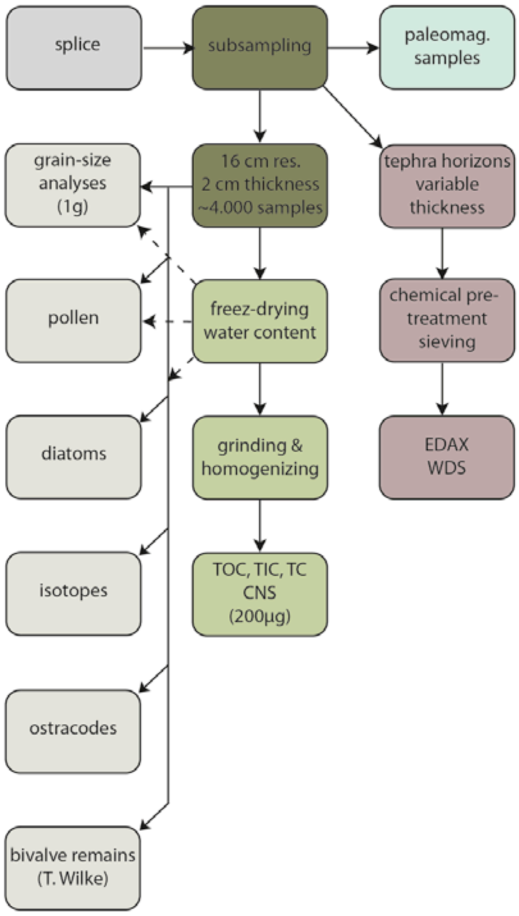

Fig. 9.11: Specific analyses and sampling along the core handling workflow during the Lake Ohrid drilling expedition. Subsequent to the subsampling, the working halves are shipped to Bremen for final core storage.

One standard software application used in academia to showcase and feature data from the various drill holes is, for example CORELYZER. This program is routinely utilized for data analysis of this kind during ICDP and IODP projects around the world. The software package, which originates from the Lamont-Doherty Earth Observatory (LDEO) allows to fetch various data sets obtained in a bore hole and placed on a world wide web-based server, to cross-correlate them into a 'spliced' composite-like data profile – be it images or any other data (magnetic susceptibility; GRAPE, XRF core scanning data) The splicing itself is based on the idea to match data of a certain kind (e.g., GRAPE or Magnetic Susceptibility) downhole as they can be obtained between two or three drilled holes.

For the long core from the central part of Lake Ohrid (DEEP site), core correlation and splicing was carried out in two steps. First, a preliminary composite profile (splice) was established by using the magnetic susceptibility data, which was measured onsite at Lake Ohrid over an integral of 8 cm in 2 cm steps. The cores of this preliminary composite profile were subsequently processed using the descripted workflow. Information from the visual core descriptions and the XRF core scanner data was then compiled to establish a re-fined, final core correlation and composite profile. If an unambiguous core correlation was not possible, additional core segments from the respective sediment depth were opened, likewise analysed, and included into the composite profile. Core sections, which are not part of the final composite profile were opened, descripted, and a high-resolution line scan image was taken. In order to optimize the laboratory capacities, XRF and MSCL core scanning was not conducted on these core sections, and they were directly shipped to Bremen for final core storage.

Other individualistic attempts to further enhance the experience of working with scaled images and data sets from the aforementioned data processing have been contributed to the scientific community (Fig. 9.11, pers. comm. Roy Wilkens, Hawaii; Thomas Westerhold, MARUM/Bremen; Thomas Gorgas, ICDP/GFZ). However, this approach is still dependent on the correct data input from someone who knows how to apply the CORELYZER software to produce so-called 'splice' and 'off-set' tables. Upon retrieving such tables from the various databases (i.e., IODP's LIMS or ICDP's DIS systems), self-standing macros based on IGOR PRO allow the trained user to splice and overlay all sorts of data sets in a computed and scaled form. This skill allows the trained user to go through the entire data set in a relatively fast fashion in order to further clean and represent the data in a publishable manner.

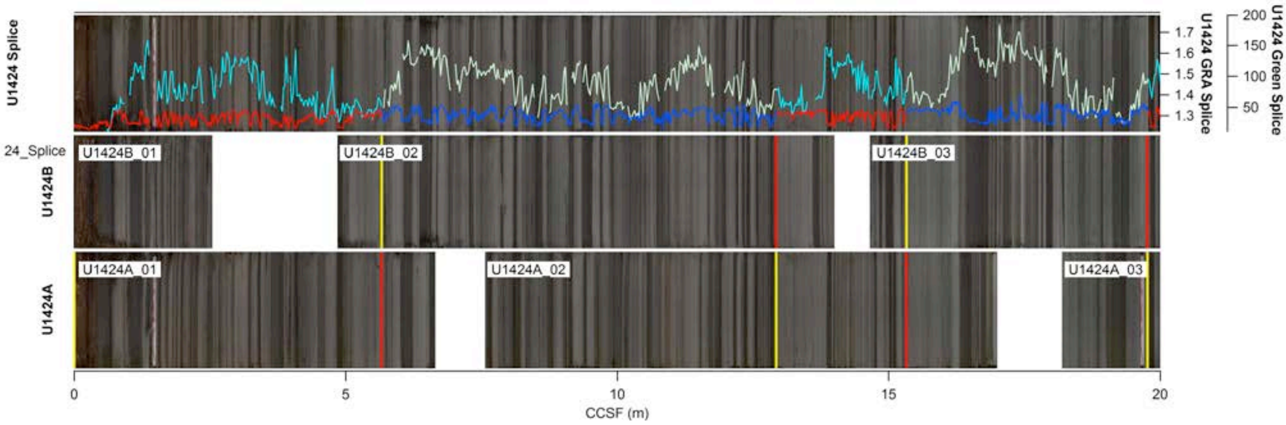

Fig. 9.11: Spliced line-scan images produced on cores from Hole-A -and- B during IODP Exp 346 overlaid by corresponding physical property data (GRAPE and RGB) for the top 20 mbsf. Note that both images and data from corresponding holes are computed into a scaled composite profile based on splice and offset (i.e. "affine") tables which are an essential output produced with the CORELYZER and CORRELATOR applications.

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Further readings

LacCore, University of Minnesota: Lab Procedures - LacCore Standard Operating Procedures
MARUM, University of Bremen: Core storage and sampling - BCR Practices and Procedures
DOSECC, Lake and Marine Drilling Planning and Operations Manual
IODP, Texas A&M University: IODP Core Lab and Sample Handling Cookbook

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CHAPTER 10

Education and Outreach

Thomas Wiersberg

Scientific Drilling addresses fundamental questions of societal relevance including sustainable resources, environmental change and natural hazards. They are mainly financed by science funding agencies and based on taxpayers' money. Therefore, Scientific Drilling actions and outcome must have an educational potential and must be made visible to the public, to media and decision makers in all levels. Furthermore, the recent discussions about new drilling-related technologies such as exploitation of unconventional gas resources, carbon capture and storage (CCS) and geothermal energy brought deep drilling into the focus of public's attention. In many countries in the world drilling has nowadays often a negative connotation. Education and Outreach are therefore very important to ensure acceptance and must be an integral part of projects from early beginning on.

Media

TV, radio and press can be duplicators of great importance for science and require attention by a drilling project manager in charge in any case. Proactive information to embed media about a project by is usually the best approach to deal with public attendance. In addition, printed materials and internet-based information can be used to reach neighbours and the community surrounding a drilling experiment. If goals, methods and risks are communicated in an open and transparent way, credit can be gained in the public (Figure 9.1).

Drill site visit

Acceptance by authorities, politicians and landowners is a decisive prerequisite for scientific drilling projects and drill rigs are landmarks attracting a great deal of local attention. Invitations to guided tours for school classes and open house activities reach the neighbouring community best. Further target audiences for this kind of public outreach measures include funding organizations, stakeholders, politicians, media, schools and universities and the public at large.

Fig. 9.1: Interview at the drill site

An open house is a great opportunity for the public not only to look "behind the scenes" but also to generate positive public and media interest for a project and to address potential negative prejudices upfront. Furthermore it allows emphasizing scientific aims and societal benefit.

Open House activities - Action items

- Arrange date and terms with drilling contractor, permitting authority and landowner as early as possible
- Make sure that an open house will neither interfere with drilling operations nor jeopardize safety
- Inform local and regional media (press, radio, TV) to invite the local community, local politicians and landowners
- Invite neighbours, schools and locals via flyers at public places
- Do not forget to invite representatives of funding agencies, authorities, politicians and other decision makers
- Announce the "Open House" on social media (see below)
- Provide information how to reach the drill site, about nearby service facilities and infrastructure (next gas station, restaurant, supermarket, mobile phone reception)
- Prepare sufficient parking space for the visitor's cars at the drill site
- Keep a sufficient number of hard hats and, if needed, also safety goggles and safety boots ready
- Display drilling in action such as rotating drill strings, circulating drilling mud but avoid a visit during risky operations
- Organize group tours over the drill site by guides familiar with drilling techniques and scientific objectives
- Tours can be guided preferably by PIs, their drilling supervisor and possibly personnel of the drilling company (Figure 9.2)
- Pay special attention to school classes and their teachers as an important target group for science outreach
- Display informational materials such as project flyers and organize give-aways
- Get in contact with OSG for ICDP brochures and flyers on scientific drilling

Fig 9.2: A guided tour of the drill site helps visitors to understand the drilling process

Project website and social media

ICDP will create a project website for each project as soon as a workshop proposal is approved by ICDP. As part of the MoU (Memorandum of Understanding) between ICDP and the project PIs, the project is encouraged to provide daily news during the operative phase for this website which mostly serves as information platform for the science community. In addition to the specific ICDP project website, social media (SM), such as Facebook, Twitter and blogs, have potential to share information to a general audience at very little monetary costs. It will be necessary to keep such media regularly updated during the operational phase of a project with emphasis on project success, but not drawbacks. Attracting a broader readership outside science requires content that is not too complex for the average person, full of jargon or acronyms, or cause for more adverse attitudes against the drill project. Social media can serve as platform to share information about other project-related outreach activities (Fig. 9.3).

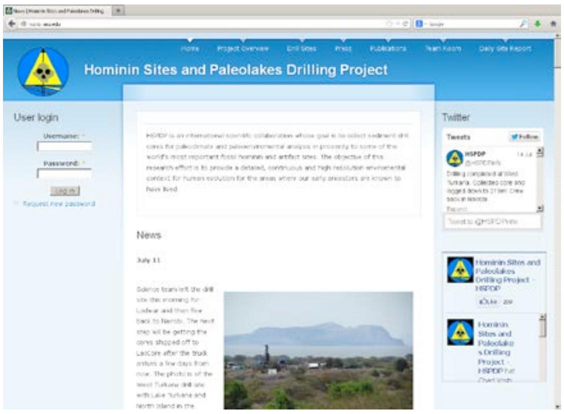

Fig. 9.3: Social media page of the Hominin Sites and Paleolake Drilling Project in Kenya, Ethiopia

Press release

A press release (or, more general, media release) is a written or recorded communication directed at members of the news media for the purpose of announcing something ostensibly newsworthy. Typically, they are mailed, faxed, or e-mailed to assignment Editors at newspapers, magazines, radio stations, television stations, or television networks. A press release can be useful to generate public interest for your project in particular at the beginning of drilling operations. It generally serves to answer questions of what, why, when, where and who. It can be organized such as a pyramid with key information on top and more details at the base. The less relevant information at the end of the body text will possibly be shortened by media writers if used for a newspaper article. The text should consist of 4 to 5 paragraphs with a word limit ranging from 400 to 500 followed by contact information and web link. High-resolution photos available for media use should be provided as well. Press officers of university associated with the project will help to prepare and publish a press release.

Video documentation

A well-produced video documentation on a drilling project serves as science outreach tool presented at schools, universities, meetings of all kinds, conferences and to the general public, possibly including on nationally syndicated broadcast services (TV, Radio, etc.). A trailer of short length (1-2 min.) is especially useful for online video platforms such as Youtube. ICDP displays on its website several science~~s~~ movies about some of its drilling projects ~~play~~. The videos have been produced with financial support through ICDP and other co-funding agencies (Fig. 9.4). Funding for the movies has been granted upon a proposal to ICDP. The Operational Support Group will provide information about video production companies.

Fig. 9.4: DVDs with ICDP science movie trailers

Outreach to the science community

ICDP unites a growing, large science community of about 3000 individuals all over the world. This diverse Earth science community engaged in scientific drilling spans many very different fields of expertise whose protagonists do not communicate with each other automatically. Sharing information about the program and promoting interaction is therefore a must. ICDP carries out Town Hall meetings at international conferences such as AGU and EGU to inform the scientific drilling community about the status of the program and current or upcoming scientific drilling activities. These meetings are a good opportunity to make scientists aware on upcoming drilling projects and the possibilities for collaborations. PIs and leading scientists from current or future continental scientific drilling projects are invited to use this occasion to communicate and deliver important news or messages to the community.

Scientific sessions at major conferences are another tool to address the science public. ICDP and IODP/ECORD regularly carry out a joint scientific drilling session at the EGU meeting, where new technical developments and scientific results about completed and current drilling projects are presented. Conferences and workshops can be used to increase awareness through outreach material (flyers, posters, brochures). At large Earth Science conferences often a booth is set up by ICDP in partnership with IODP to provide information and display instruments and videos on operations, technologies and projects.

The journal Scientific Drilling is an open access journal jointly issued by ICDP and IODP and published semi-annually by COPERNICUS Publications. Scientific Drilling (SD) is a multi-disciplinary journal focused on bringing the latest news about scientific drilling – especially scientific-technical expedition-reports – to the community. It delivers peer-reviewed science reports from recently completed and ongoing international scientific drilling projects as well as on engineering and other technical developments on ocean and continental drilling, workshops, progress reports, and includes short news sections for updates about community developments.

As part of the MoU, PIs are requested to submit a workshop report to SD after the workshop and a science report after drilling was completed. Both reports are to be published in one of the two volumes of SD issued after the workshop was held respectively drilling was completed. For submission details see the Scientific Drilling website.

Fig. 9.5: The ICDP/IODP Open Access Journal "Scientific Drilling"

Education

Drilling is the ultimate method to retrieve matter from and yield information about the Earth's interior structure, processes and evolution, but unfortunately drilling is not taught at most Earth science faculties of universities worldwide. Therefore an important component of the ICDP is training of Earth scientists, engineers, and technicians in drilling-related know-how and technologies. ICDP offers a suite of different training courses, like the general Annual ICDP Training (see: below), or those ones which focus on specific technical topics, such as geophysical downhole logging, ICDP's Drilling Information System DIS and ICDP's Online Gas Monitoring System OLGA. PIs can request ICDP Training camps even at their respective project drill site.

Fig. 9.6: Training at the drill site

Fig. 9.7: Tool inspection at a drill site during training

Training Courses

The annual ICDP Training covers all relevant aspects of scientific drilling, including fundamentals of drilling technology, borehole measurements and interpretation, data management, sample handling and storage, and project management. The training courses are normally 3-5 days long ~~last one week~~ and are free of charge for the attendees (Fig. 9.6.). The lessons are taught by a team of instructors who are specialists in their fields and with an extensive practical industrial experience. Most of them have been involved in different ICDP projects worldwide. Specialists from the industry or scientific institutes will be engaged for special topics or individual courses if necessary. The current basis of the ICDP training is a set of eight courses covering the topics:

- Fundamentals of Drilling Technology
- Fundamentals of Sampling, Cores and Cuttings, On-site Sample Handling
- Drill Core Scanning and Logging
- Downhole Gas and Fluid Sampling and Monitoring
- Downhole Logging Fundamentals and Application
- Data and Information Management
- Project Planning, Management, Education and Outreach
- Downhole Seismic Monitoring

The training can be adapted to specific topics, depending on the themes covered by upcoming drilling projects. ICDP publishes calls inviting interested individuals to apply for the annual Training Course on the Website and in the journal EOS about six months prior to the event. PIs and scientists who intend to serve during planning and operation of upcoming projects are especially encouraged to apply for these training courses. Courses are preferably carried out at active drill sites of the ICDP and are taught by engineers and scientists who are experienced in scientific drilling. ICDP has allocated funding for invited participants to cover costs, such as travel and accommodation.

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CHAPTER 11

Proposal Writing

Ulrich Harms and ICDP Science Advisory Group

A convincing proposal outlines a clear idea of the goals and objectives, and promises a significant progress in understanding the Earth and in developing the society. It convinces not only the peers of the specific subject, but also scientists and decision makers from other fields and regions.

Prerequisites for success

Bright and novel scientific leading thoughts in Earth Science to study a process or testing a hypothesis as they are only accessible through drilling are key. In addition, the expected results promise high impact in the broader science community and bear potential for the society at large. A proposal to the International Continental Scientific Drilling Program (ICDP) should address such notions very clearly. Furthermore, there are a number of specific prerequisites to be laid out in a proposal to the ICDP including:

- Drilling at sites of global scientific importance and societal relevance
- Excellent geophysical and geological site surveys to justify drilling target, drilling depth, and to reduce drilling risks
- Technical feasibility and budget realities
- Environmental and societal compliance
- Acceptance and support through national authorities early in the project planning phase
- High degree of international cooperation in best possible science teams with excellent educational potential

Organizational prerequisites

ICDP does support parts of the field operations of a project including drilling and drilling-related work. Therefore, ICDP-funded projects need to acquire additional financing from other funding agencies or industry. Full funding for site survey and post-drilling science needs to be raised by the PIs. At the same time, co-mingled support of third-parties is required for operations, too. Accordingly, PIs have to orchestrate the interplay of national and international partners for project financing. Although this seems to be a difficult and time-consuming issue, many ICDP projects made very positive experiences and created several precedence cases of successful cooperation once a first major share of funding has been acquired. The ICDP Operational Support Group (OSG) will support PIs in organizing co-mingled funding.

A clear and transparent leadership of a project helps to establish a science team with a strong and continuous momentum during the usual multi-year duration of scientific drilling missions. The formation of an enthusiastic and diligent team and the combining of individual capabilities are major tasks for the PIs. The information pathways within a group and to the related organizations such as ICDP must be clear and remain intact and operative throughout the full project time. Excellent communication and management skills as well as planning competencies and experience with other large international Earth science projects of the project leaders are of paramount importance and will help project directors to succeed. A drilling operation will benefit not only from international cooperation and support, but should be rooted in the home institutes of PIs and within a broader national community. The complex multi-source funding needed for drilling requires that project team members need sustenance and backing on the broadest possible base. Early communication with colleagues, deans, universities, ministries, authorities can help to pave the road towards wealthy drilling operations, especially for PIs from countries hosting the drilling project.

An outstanding group addressing all the requirements mentioned above cannot achieve success without establishing good relationships to commercial service providers such as engineering consultants or drilling contractors. A full proposal to ICDP will need a drilling plan and include a detailed budget with reliable and justifiable numbers, which must be accepted by independent project reviewers. Furthermore, sufficient contingency planning based on a critical risk analysis will provide a profound base for a sound proposal. The data needed for such considerations cannot be compiled without the support of drilling professionals.

Chances

Proposals to ICDP have a very high rate of success. About three quarters of the proposals that are submitted to acquire substantial funds (>$US100.000) for drilling are accepted for funding or have been asked to resubmit a rewritten proposal or an addendum. About 60% of workshop and pre-proposals have either received a grant to conduct a meeting or have been asked to develop their ideas further and to re-submit their pre-proposal again by the next deadline. This remarkably high success rate is not because ICDP funding is easy to achieve but because science teams develop drilling proposals very carefully and stepwise after usually long-established research in a field or region; accordingly a long history of funded research has been conducted. The usual pathway of proposals and reviews to ICDP is a two-step process with a workshop proposal first followed by a full proposal later (Fig. 11.1).

Fig. 11.1: Flow of proposals through ICDP panels

If your proposal is declined

Be aware that your proposal may not be successful in a first attempt. Even the most prominent drilling projects have been developed usually over several years. A resubmission of a proposal is no failure but a great chance to improve your outstanding idea and make it acceptable for review boards in ICDP and for other agencies.

Consider the assessments of the review panels and the comments from ICDP and others seriously. Do not hesitate to contact ICDP to get additional information and direction. Unless your objectives have not been rejected principally, revise your draft with critical views of colleagues and resubmit your proposal by the next deadline.

Main reasons to fail

Most proposals to ICDP are accepted after revisions or addenda have been resubmitted. Only very few proposals are rejected by ICDP because most projects are developed through side survey or similar studies which have been funded *after* a rigorous peer review as part of developing the funding base. In this way a certain type of success filter is already installed before ICDP comes into play. Reasons for rejections over the past ten years can be compiled as follows:

- The proposal does not comply with ICDP criteria such as convincing management and engineering plans and budget
- The application does not provide a novel idea, has not the best site in the world, has no focus on a clear scientific objective or is not well written for international reviewers
- No sufficient pre-site survey exists or proof that key methods will work
- SAG and EC recommendations have been neglected in follow-up proposals
- The proposal does not generate enough scientific impact through PI group - often coupled with missing international participation
- Lack of (non-ICDP) support or competitors and opponents
- Internal team problems
- No coordination with other programs such as IODP, not sufficient multidisciplinary direction
- Not enough patience and persistence for the timely preparation and lobbying necessary for costly international projects

Guidelines for proposals

Full instructions for ICDP proponents can be found on the ICDP website, a shortened version is given in this and the following paragraphs.

The guidelines for proposals should be observed and essential elements must be clearly outlined, page limitations followed, references correct and pages and figures numbered. Abbreviations should be avoided or define at first time used. Apply a spell checker tool while a native English speaker should make language corrections as required. A final very careful editing and proofread is needed before submission. Relevant "negative" information such as previous proposal rejections should be addressed. Transparency is better than leaving reviewers with a negative impression.

The following paragraphs are part of the guidelines for proposals which can be obtained in full length on the ICDP website.

The ICDP offers international scientific teams the opportunity to compete for funds to support drilling operations as well as technical-scientific planning and on-site support. Calls for proposals will be published every year on the ICDP website and in EOS. An independent Science Advisory Group evaluates all proposals submitted to ICDP. The ICDP office in Potsdam, Germany, in cooperation with the Chairman and the Secretary of ICDP's Science Advisory Group (SAG) and the Executive Committee, handles all aspects of the proposal submission and review process.

ICDP will consider for evaluation four types of proposals: preliminary proposals, workshop proposals, full proposals, and addenda to already accepted proposals. All proposals must arrive in the ICDP Office by the annual deadline of 15 January. Proponents should submit the proposal as a single PDF document, with all pages in A4 or US letter size and using an 11 point font and 2.5 cm margins. The ICDP Office does not accept items that arrive late or do not meet the specified requirements.

Requirements for Workshop Proposals

A group of scientists representing several countries (including ICDP member countries) who intend to submit a full proposal for scientific drilling to ICDP should first submit a workshop proposal. The goal of an ICDP-funded workshop would be to fully review the scientific motivation behind a project (including why drilling is necessary), develop a preliminary drilling and experimental plan, discuss and compile site surveys, and form an international cooperative science team, eventually leading to the preparation of a full ICDP drilling proposal.

A workshop proposal should not exceed 15 pages in length, including text, tables, figures, and references, and it must include the official proposal cover sheet, which will not count against the page limit. Workshop proposals should also include the items listed under Section E (see: below), some of which will not count against the page limit (where indicated).

A workshop proposal must include the following information, with level of detail to be commensurate with their respective 15 page length limits:

1. Discuss the scientific objectives and explain how those objectives relate to or advance ICDP's scientific themes.
2. Explain why the drilling site and research goals are of global and far-reaching importance and why drilling is needed to achieve these goals (ICDP does not consider topics of only local relevance.)
3. Discuss the societal relevance of the project, including plans for education and outreach.
4. Discuss the expected scientific outcome of drilling and any subsequent work required to complete the overall project.
5. Identify an international science team that is balanced in both expertise and geographical representation, with preference to ICDP member states or those in membership negotiations. Proposals from single PIs, or those representing only one country, will not be considered.
6. Present a well-defined strategy for addressing the scientific objectives through drilling, core/cuttings/fluid sampling, down-hole measurements, laboratory testing on recovered samples, and integration of such with existing or planned surface-based studies.
7. Describe the proposed drill sites, including geologic maps, seismic sections and other geophysical data, penetration depths, expected lithologies, and relevant information from prior drilling operations.
8. Include a workshop budget.
9. Workshop proposals should also indicate the types of available site survey data and present examples of that data, as appropriate.
10. Include standard two-page CVs for all PIs, containing a short list of relevant publications.
11. Describe briefly any relationships of the drilling project or supplemental science investigations to other international geoscience programs.
12. Workshop proposals should also include a preliminary list of participants to ensure international participation and a broad range of expertise. Workshop proponents should note that, if a proposal is accepted, an open call to the international scientific community is required for possible participation in the workshop.

Please note that items 10 and 11 do not count against the 15-page-limit.

Requirements for Full Proposals

An international group of proponents who has previously carried out an ICDP-funded drilling workshop or who can otherwise demonstrate that they have held comprehensive, international and open scientific and technical planning meetings, may submit a full proposal. Lead PIs of a proposal must be based in ICDP member countries. A full proposal should not exceed 25 pages in length, including text, tables, figures, and references, and it must include the official proposal cover sheet, which will not count against the page limit.

A full proposal must include the following information, with level of detail to be commensurate with their 25 page length limits:

1. Discuss the scientific objectives and explain how those objectives relate to or advance ICDP's scientific themes.
2. Explain why the drilling site and research goals are of global and far-reaching importance and why drilling is needed to achieve these goals (ICDP does not consider topics of only local relevance.)
3. Discuss the societal relevance of the project, including plans for education and outreach.
4. Discuss the expected scientific outcome of drilling and any subsequent work required to complete the overall project.
5. Identify an international science team that is balanced in both expertise and geographical representation, with preference to ICDP member states or those in membership negotiations. Proposals from single PIs, or those representing only one country, will not be considered.
6. Present a well-defined strategy for addressing the scientific objectives through drilling, core/cuttings/fluid sampling, down-hole measurements, laboratory testing on recovered samples, and integration with existing or planned surface-based studies.
7. Describe the proposed drill sites, including geologic maps, seismic sections and other geophysical data, penetration depths, expected lithologies, and relevant information from prior drilling operations.
8. Include paragraph(s) on project budget and cost oversight.

Full proposals must also include the following information, which does not count against the page limit:

9. Include standard two-page CVs for all PIs, containing a short list of relevant publications.
10. Describe briefly any relationships of the drilling project or supplemental science investigations to other international geoscience programs.
11. A detailed budget, including site preparation, drilling, downhole measurements, onsite sample handling and analyses, downhole monitoring, logistics/travel, etc.
12. A permitting plan and authority, environmental impact review, and drilling safety review.
13. A detailed drilling, testing and logging schedule.
14. A management plan, including roles and responsibilities for key personnel in all essential scientific and operational aspects of the project.
15. In addition to item 7 above, a detailed description of available site-survey data and any plans for acquiring additional data, and a discussion of how the drilling targets relate to those data.
16. A description of special logistical requirements or potential natural or drilling-induced hazards that might impact the project.
17. Plans for data management and long-term sample curation.

Proposal Structure and Content

1. Summary. A proposal abstract (part of the official cover sheet) must be convincing within a very short time of reading a few hundred words because reviewers often follow a first impression. Answer basic questions about your idea such as *What and Where*?, *Why*?, *How?* , *Who, and How Much?*
2. Introduction. Summarize information on location, background as well as project history. A simple project logo or impressive illustration can help to depict the idea clearly.
3. Motivation and Goals of Drilling Project
4. Geology/Geophysics of Study Area
5. Previous and Relevant Work
6. Global Importance of Study Area
7. Drill Site Selection and Proposed Work
    a. Site Selection and Drilling/Sampling Strategy
    b. Site Survey Information (seismic profiles, etc., can go in Appendix)

    c. Geophysical Downhole Logging and Log Interpretation
8. Initial Field-Based Core Logging, Analysis, Processing and Storage.
    a. Off-Site Testing and Analyses of Samples and Data.
9. Expected Benefits of the Proposed Work (scientific benefits; societal benefits; education and outreach)
10. Project Management (including PIs and their roles and responsibilities)
11. Project Collaborators/Science Team
12. Time Table
13. References
14. Appendices (site surveys, permitting and environmental issues, detailed budget)

Evaluation

The Science Advisory Group (SAG) meets to review all proposals in March or April of each year. SAG reviews proposals and assigns priority based on the criteria listed below:

- Quality of Science. Does the project address fundamental scientific issues of global significance, rather than just local problems? Is it international in scope and thus the best drilling targets worldwide being selected to address these scientific issues?
- Need for Drilling. Is drilling necessary to achieve the stated scientific objectives, or can they be achieved with surface-based studies at lesser expense?
- Qualifications of Proponents. Is the experience and productivity of the PIs plus the breadth and international diversity of the science team/workshop attendees sufficient?
- Societal Relevance. Is the project relevant to societal needs, such as energy, mineral and water resources, environmental/climate change, geologic hazards, etc.?
- Budget. Is the budget carefully prepared and reasonably describes the scope of the workshop or drilling project?
- Responsiveness. Where appropriate, have previous SAG/ICDP recommendations been taken into account in the present proposal?

As shown in Fig. 11.1, SAG forwards the proposal ranking and written reviews to the Executive Committee (EC) for authorization as an ICDP project, modification of request, or rejection. The EC meets a few weeks after the SAG meeting. Full drilling proposals also need to be approved by the Assembly of Governors (AOG), which meets after the EC. Following the panel reviews, PIs will receive the SAG review and a written summary from the EC and AOG instructing them of any requirements, conditions, or recommendations. The reviews and decisions will be made available to the PIs in the summer of each year.

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ICDP Science Advisory Group

The SAG (Science Advisory Group, ICDPs scientific review panel) consists of 15 renowned international scientists acting as independent experts. SAG has developed guidelines over the past 15 years that are included in part in this text. The current members of the SAG are listed here.

CHAPTER 12

Project Funding and Policies in ICDP

Ulrich Harms and Ronald Conze

An accepted ICDP proposal opens the avenue for funding and support. The proposal is becoming a project and receives the branding 'ICDP Project'. But this branding obliges the participating project scientists to follow a number of critical duties.

Acceptance of a drilling proposal by ICDP and other agencies is also the start of detailed project planning that includes the implementation of financing of the drilling operations and of the related science. Funding for the latter is usually well established in academia while the large funds needed for drilling operations require often unprecedented additional managerial, legal and budgetary work. Once ICDP has approved co-funding the first threshold to tap funds will be the establishment of a funding agreement, which is coined within the ICDP structure the Joint Research Venture (JRV). From a legal point of view this is a Memorandum of Understanding (MoU) that defines the rules and rights for the partners during the course of the project.

Contracting and Funding

Each JRV needs to be adapted to the specific project requirements while maintaining the critical issues ICDP compels for any of its projects. Partners of this agreement are the ICDP Operational Support Group (OSG) at the GFZ in Potsdam and the project's Principal Investigators (PIs) who sign the JRV on behalf of the Science Team of the project. A typical JRV is available on the ICDP website.

ICDP funds projects upon approval by its Assembly of Governors and the establishment of the JRV. The JRV regulates how ICDP's financial contribution is directed to cover parts of the project's operational and other costs that are directly related to the operation, while scientific off-site work has to be covered through other sources.

There are two principle pathways to retrieve ICDP funds:

- Operational costs are directly covered by ICDP; contractors such as drilling service companies issue an invoice to the PIs, the PIs check and approve – if appropriate – this invoice, and forward it with their approval to the OSG for direct payment of the service firm, or
- One of the PIs establishes a project account at his or her institute, the office of sponsored programs or alike, and issues invoices or calls for funds to ICDP along major project steps, milestones, etc.

The Science Team

An ICDP project is based on the Science Team concept. A Science Team consists of a group of scientists and engineers that have been formed with the help of an ICDP workshop and an open Call for Participation on the ICDP webpage. An ICDP project is guided by Principal Investigators (PIs) and Co-PIs who usually develop the proposal and plan the project. The Science Team may be divided in groups of different scientific fields led by group leaders. Further leading roles are Chief Geologists/Scientists and Staff Scientists. Chief Geologists are leading the on site science team and define for example standards in sample description while Staff Scientists are supporting the scientists on site and are supervising on-site and lab processes. They act in addition as link between the project and the OSG and ICDP. Other individuals involved, such as technicians, voluntary or temporary project-aids and subcontractors are usually not part of the Science Team. Members have a number of rights and duties (see below), which can be independent from their actual participation on-site, the labs, repositories or affiliated institutes. The PIs jointly decide who is a member of the Science Team.

Reporting

Reporting is a central issue for continental scientific drilling projects. In most cases, the main working units within ICDP, such as the ICDP Operational Support Group, the institutes of the PIs, and the drilling contractor are acting at separate locations at different times. It is therefore of paramount importance that a working communication between the representatives is set up and is previously determined (see chapter Timeline below). This is usually done in the JRV that defines all reporting issues.

Timeline

A drilling project is a long-term task that starts with an idea, proposal writing, pre-site surveys, planning, and the fieldwork, and extends throughout not only the drilling phase but also the entire scientific evaluation phase and publication time. Therefore it deserves a high-level of attention from both the project management and entire science team. In a typical timeline of the operational phase of a scientific drilling project, a kick-off meeting serves to assemble the on site crew of science and contractors, discuss operational milestones, HSE, as well as policies.

Data and sample management have here central controlling functions. A training course on these topics will be conducted within a six-month period prior to starting the drilling operations accordingly. Generally, the "hot phase" of the expedition starts with rigging up and ends with the completion of the operational and/or initial data report. During the drilling phase, the initial project data are collected as they relate to a multitude of drilling parameters and the intrinsic details of the drilling operations, the recovery of the material extracted from the hole, its sampling, descriptions and documentation, down hole logging data, and so forth. However, in many cases not all of these tasks can be executed and performed on-site due to harsh conditions and a lack of available space. Consequently, the expedition is then divided into two phases of drilling operations and lab work. This often takes place with a significant lag time due to the transfer of all the sample material from the sites to the target lab (Fig. 11.1)

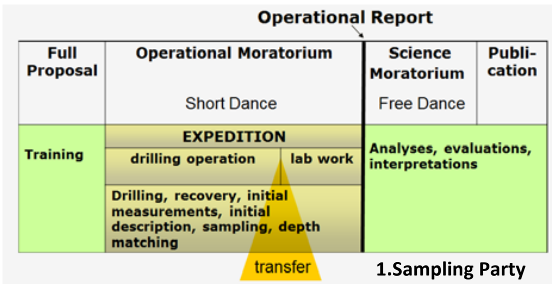

Fig. 11.1: Typical timeline of a drilling project

Policies

ICDP requires through a Memorandum of Understanding a number of deliverables. In addition, the Science Team of a drilling project agrees upon some key rules, rights, and duties for all parties involved. Some of the main corner stones in ICDP are listed below.

Two main Moratorium Periods are usually applied (Figure. 11.1):

- The Operational Moratorium is distinct by the course of Mobilization, Drilling, Demobilization, and the subsequent lab work. It should end with the first Sampling Party no later than six months after the beginning of the lab work.
- The Science Moratorium starts with the first Sampling Party and should usually not extend beyond two years. With the end of the Science Moratorium all data and sample material become available for open access under certain Creative Commons (CC) licenses (CC-BY or CC-BY-SA) to be defined by the PIs and ICDP.

Data and Sample Rights

- each Science Team member can use all internal project data and all sample material for his/her own investigations within the context of the project
- each Science Team member gets a personal login (username, password) to access the internal project pages of the ICDP Web-site.

Data and Sample Duties

- ICDP webpage login information has to be kept confidential
- Science Team members are neither allowed to use internal project data nor sample material for other projects
- Science Team member agree to share their data and sample material, results and publications within this team
- Science Team member are obliged to follow rules of best scientific practice and cite data, information and samples as utilized
- PIs have to define the composition of the Science Team and the duration of Moratorium periods.

Data Access

During a project three main areas of access should be discerned:

- Internal access - restricted to the PIs on behalf of the Science Team, ICDP, and the drilling contractor.
- Moratorium controlled access - restricted to the PIs and the Science Team until the Moratorium ends. Afterwards, project data and information is available under open access under Creative Commons (CC) (see below).
- Open access – available for everyone under certain Creative Commons (CC) licenses (CC-BY or CC-BY-SA) to be defined by the PIs and ICDP.

Reporting Periods

All kinds of reports have to be in English.

- While Mobilization, Drilling, and Demobilization
    - Internal: Daily Drilling Reports from the drilling contractor to PIs and ICDP
    - Internal: Weekly Status Reports from the drilling contractor to PIs and ICDP
    - Moratorium: Daily Data Updates from the on-site science crew to the PIs, ICDP, and the rest of the Science Team
    - Open: Daily Messages from the PIs to the ICDP outreach team
- After Demobilization
    - Open: Science Report from the PIs to be published in Scientific Drilling
    - Moratorium: Supplemented by a digital Operational Report and
    - Moratorium: Operational Data Sets and Explanatory Remarks to the data sets

Sampling

In order to assure registration of all samples removed from the initial sample material, the strict rule must be: No sampling without Sample Request. A call for Sample Requests should be published before or while drilling. The requests should specify among other topics the time of sampling. Only Sample Requests approved by the PIs or curators acting on their behalf are valid. Within the Moratorium periods samples can be taken directly after recovery (on-site sample), during lab work, or from the repository, e.g. in the course of a Sampling Party. The PIs and ICDP in cooperation with the corresponding repository have to define Creative Commons (CC) licenses for the sampling after the end of the Moratorium periods.

Reporting Publications

All publications including contributions to conferences (abstracts, posters) by the whole Science Team and PIs have to be reported to the ICDP; most co-funding agencies will require the same reporting of papers. Copies should be sent to ICDP and other funding agencies once a paper is accepted and pre-prints or prints are available in order to allow recording and long-term availability of project references. This rule does not end with the Moratorium period.

Acknowledgement of Support

The Science Team and all cooperating scientists are obligated to acknowledge ICDPs support and help of co-funding agencies on any publication of any material, whether copyrighted or not, based on, or developed under this international project. The title and/or the keyword listed in publications should include the items 'ICDP' and the project acronym. The ICDP logo including text marker 'International Continental Scientific Drilling Program' should be visible placed on posters or similar graphical material such as flyers, brochures, as well on CDs, DVDs, videos, etc. The ICDP logo is available for download on the ICDP webpage.

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Glossary

ALN	Alien bit coring
AOG	Assembly Of Governors, ICDP
APC	Advanced Hydraulic Piston Corer
API	American Petroleum Institute
ATP	Adenosine Triphosphate
BCR	Bremen Core Repository, Germany
BGR	Bundesanstalt für Geowissenschaften und Rohstoffe (Federal Institute for Geosciences and Natural Resources), Germany
BHA	Bottom Hole Assembly
BHTV	BoreHole TeleViewer
blf	below lake floor
CC	Core Catcher
CC licenses	Creative Commons, non-profit organization released several copyright-licenses known as Creative Commons licenses
CCS	Carbon Capture and Storage
CCT	Composite Coil Tubing
CNS	Carbon-Nitrogen-Sulfur
Corelyzer	Open access, free application for visualization and annotation of scanned core sequences and log data
Correlator	Open access, free application for log data splicing, composing and matching
CSDCO	Continental Scientific Drilling Coordination Office, U.S.A.
CT	Coiled Tubing
CurationDIS	Drilling Information System for a specific storage place for sample material
CV	Curriculum Vitae
DAS	optical geophone arrays
DCO	Deep Carbon Observatory
DFG	German Research Foundation
DGLab	Deep Geodynamic Laboratory-Gulf of Corinth
DIS	Drilling Information System, tool for data acquisition of scientific drilling projects
DITF	Drilling Induced Tensile Fractures
DLDS	Deep Lake Drilling System
DLIS	Digital Log Information Standard
DMT	Deutsche Montan Technologie www.dmt.de
DNA	Deoxyribonucleic Acid
DOI	Digital Object Identifier for publications, data sets
DOSECC	Drilling, Observation and Sampling of the Earth's Continental Crust's
DTS	Distributed Temperature Sensing
DWOP	Drilling Well On Paper
EC	Executive Committee, ICDP
ECD	Equivalent Circulating Density

EOS	Transactions, American Geophysical Union, Earth & Space Science News
EXN	Extended shoe, non-rotating
Expedition	Time period of drilling operations and lab work
ExpeditionDIS	Drilling Information System for a specific Expedition
FAR-DEEP	Fennoscandia Arctic Russia - Drilling Early Earth Project
FO	Fibre-Optic
GC	Gas Chromatograph
GCR	Gulf Coast Repository, TAMU, Texas, U.S.A.
Geotek	Geotek (http:// www.geotek.co.uk/)
GESEP	German Scientific Earth Probing Consortium e.V.
GFZ	German Research Centre for Geosciences, Helmholtz Centre Potsdam
GLAD	Global Lake Drilling unit
GMS	Gas Membrane Sensor
GNU	General Public License for software
GONAF	Geophysical Observatory at the North Anatolian Fault
GR	Gamma Ray
GRAPE	Gamma Ray Attenuation Porosity Evaluator
HPC	Hydraulic Piston Coring
HP/HT	High-Pressure, High-Temperature
HQ	diamond coring diameter (core diameter=64 mm)
ICDP	International Scientific Continental Drilling Program
IGSN	International Geo Sample Number, unique IDs for sample material and samples
IODP, ODP	International Ocean Discovery Program (since fall 2013), previously Integrated Ocean Drilling Program (2003-2013), Ocean Drilling Program (1985-2003)
HPC	Hydraulic Piston Corer
JRV	Joint Research Venture – funding agreement between ICDP and the Principal Investigators
KCC	Kochi Core Center, Japan
KTB	Deep Crustal Lab of GFZ
LacCore	National Lacustrine Core Facility in Minneapolis, Minnesota, USA
LIS	Log Information Standard
LIMS	Laboratory Information Management System
LWD	Logging While Drilling
MAASP	MAximum Allowable Surface Pressure
MoU	Memorandum of Understanding, legal agreement, e.g. between ICDP and ICDP member country
MRI	Magnetic Resonance Imaging
MS,MSUS	Magnetic Susceptibility
MSCL	Multi-Sensor Core Logger
MTBF	Mean-time between failure

MWD	Measurements While Drilling
NMR	Nuclear Magnetic Resonance
NSF	U.S. National Science Foundation, U.S.A.
NQ	diamond coring diameter (core diameter=48 mm)
Off-site	Laboratory or storage place away from the drill site (= on-shore)
OLGA	On-Line Gas monitoring of circulating drilling mud
On-site	Nearby the drill rig, on land or on water (= off-shore)
OSG	Operational Support Group, a team of scientists, engineers and technicians hosted at GFZ to assist in planning, management and execution of ICDP projects
PANGAEA	Data Publisher for Earth & Environmental Science
PDM	Permanent Downhole Monitoring
PhD	Philosophiae Doctor
PI, Co-PI	Principal Investigator, Cooperating Principal Investigator
PQ	diamond coring diameter (core diameter=85 mm)
PSE	Personal Safety Equipment
PU	Polyurethane
PVC	Polyvinyl Chloride
QC	Quality Control
QMS	quadrupole mass spectrometer
QR-code	Quick Response - matrix barcode (or two-dimensional barcode)
RGB	Red-Green-Blue colour scheme
RLF	Reduced Label Format
ROP	Rate of Penetration, depth progress
RW	Resistivity of Water
SAFOD	San Andreas Fault Zone Observatory at Depth
SAG	Science Advisory Group, ICDP
Sample	Any sample material (incl. fluids, gas) out of a hole, including the hole virtually Material
Samples	Parts and pieces taken from the stock of sample material for further investigations
SCOPSCO	Scientific Collaboration on Past Speciation Conditions in Lake Ohrid
SD	Scientific Drilling journal
SGR	Spectral Gamma Ray
SM	Social Media
SP	Self Potential
Spud-in	Beginning of a drilling, when the drill bit touches the ground for the first time
TAMU	Texas A&M University
TC	Total Carbon (inorganic and organic carbon content)
TCDP	Taiwan Chelungpu-fault Drilling Project
TIC	Total Inorganic Carbon
TOC	Total Organic Carbon
TQ	Torque
TV	Television

UWITEC	UWITEC Sampling Equipment (www.uwitec.at)
VAT	Value Added Tax
WDS	Wavelength Dispersive X-ray Spectrometry
WellCAD	Commercial tool for log data processing and visualization
WOB	Weight On Bit
XCB	Extended Core Bit, rotating
XDIS	eXtended Drilling Information System
XRD	X-Ray Diffraction analysis to determine minerals and mineral content of a sample
XRF	X-Ray Fluorescence
XTN	Extended Noose coring