CHAPTER 4.4

Sample Management and Distribution

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Science is characterized by the acquisition of high-quality data, its interpretation in context with existing knowledge, and its publication. In the majority of cases, the quality – and quantity – of these data depend on sample quality, identification and storage. In the context of an ICDP project, sample management is a long-term task that starts with a management plan as part of the project proposal and extends throughout the expedition, project duration and beyond.

Holistic sample management plans (SMP) contribute significantly to the success of the project and allow the best possible use of the samples and consequently the data obtained. Therefore, sample management and data management as described in the previous chapter deserve a high level of attention from the project leaders and the entire science team. Both, sample and data management plan (DMP) and the SMP, are dynamic documents adapted throughout the proposal, planning, project and post-drilling phase. This chapter summarizes the key components of a successful sample management plan for an ICDP drilling project over the entire lifecycle. The application of these key components allows the FAIR principle (Findability, Accessibility, Interoperability, and Reuse) to be satisfied, which is in line with ICDP´s sample and data management policy. For a best practice example of the on-site core handling the reader is referred to Chapter 4.5.

Sample Management Plan

Starting with the full proposal, principal investigators should include the financial means and technical/scientific personnel needed for the implementation of the SSs SMP.

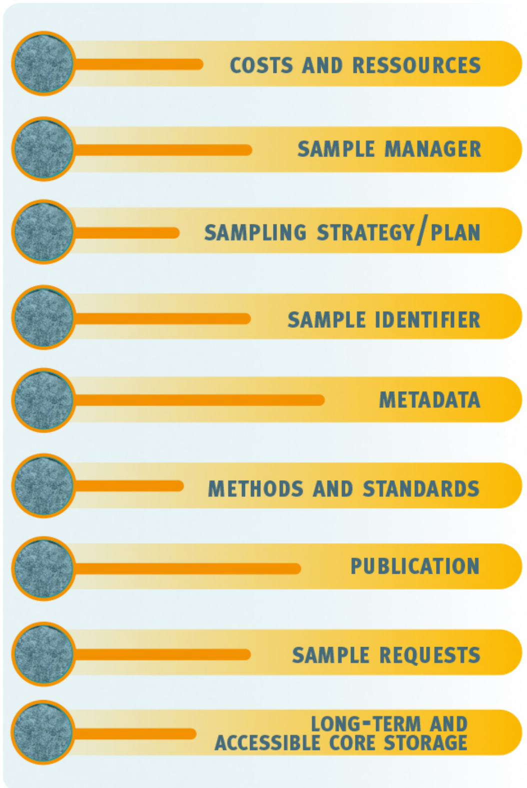

Fig. 4.4.1: Sample Management Plan elements

This includes costs related to sampling (e.g., instrumentation and consumables), shipping, long-term storage in an appropriate core repository and costs for a sampling party at the end of the drilling and lab science phase. The budget should also cover travel costs related to the obligatory training course on data and sample management offered by OSG (Data and Sample

Management training course, see Chapter 4.4). Regarding the personnel resources, the PIs should consider appointing an exclusive sample manager (or sample & data manager), who is responsible for the implementation of and adjustments to the SMP and oversees the preparation for the field work, the sampling workflow, sample curation, day-to-day business at the site, during the sampling party and beyond.

An excellent example highlighting the importance of well-designed core handling and sampling curation for scientific projects is the NASA curation plan for extraterrestrial samples as provided by Allen Carlton et al. 2013 (Curating NASA´s Extraterrestrial Samples, EOS 94 (29) doi:10.1002.2013eo290001)

- '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.'

Personnel resources and costs will be associated with this post. The SMP may also consider other staff responsibilities with respect to core sampling and data entry (the Science Team). Early on, the PIs, the sample manager and experienced technical personnel need to develop a sampling strategy to facilitate the organizational operation and provide all resources needed for sampling to ensure high quality samples and allow for the largest scientific output possible. The strategy should consider which steps and samples need to be taken at the site. The sample quality is often higher and logistics easier if sampling takes place once the cores were transferred to an appropriate laboratory or core repository.

The projects main scientific objectives determine the sampling strategy; the logistics of sampling and the sampling plan depend on availabilities, lead times and environmental conditions and are therefore subject to change. The finalization of the sampling plan and the core handling are topics of the training course on data and sample management that the OSG provides for each approved ICDP project (see Chapter 4.3). Chapter 4.5, and particularly Figures 4.5.10 and 4.5.11 provide sampling plans.
To allow for the best and most effective handling and utilization of the core material, the core needs to be persistently and distinctively marked and curated together

with the appropriate metadata. This standardized and unique sample identification and metadata collection is indispensable for a successful drilling project. It is also a prerequisite according to the FAIR principle (see Fig. 4.4.3).

The IGSN (International Global Sample Number) is a global persistent identifier for all kinds of samples with any IGSN number being unique and registered by the IGSN e.V. in cooperation with allocating agents, one of them being the GFZ in Potsdam, Germany. An IGSN is automatically assigned to any hole, core, section, sample, and should also be assigned to mud, cutting, gas or other material extracted from the drill holes and entered in the obligatory mDIS database (see Chapter 4.3). This applies to any on-site sample as well as samples taken in the core repositories during the sampling party or any other time. When forwarded to the registration office, the metadata will be registered with the IGSN. This makes the sample and metadata 'findable' and 'interoperable' (Fig. 4.4.2) for the science community and others. Usage of IGSNs combined with the long-term storage of the samples in a publicly accessible core repository are essential parts of the FAIR principle applied in ICDP projects.

The data, associated metadata of all sample material taken as well as standards and methods used for core or sample measurements are made available to the science team – and later on the public – as part of the project's Operational Data Set and Operational Report (see Chapters 2 and 4.3 and Supplements for Guidelines).

Since part of the IGSNs used by ICDP is a random number, human readable combined IDs will be assigned to cores, sections, and samples for quick and easy identification. The combined IDs used by ICDP are comparable to e.g., the naming conventions of IODP.

Tab. 4.5.1: Conceptual schemes and terms of ICDP, IODP, and the German data center PANGAEA

ICDP / IODP	PANGAEA
Program	
Expedition	Project /Campaign
Site	Site
Hole	Event

One or more Holes/Events can take place at a site, such as 'Drilling a Hole'. In both, ICDP and IODP models, the terms are arranged in a relational hierarchy:

- Expedition is the operational phase of a scientific drilling project, which has a number assigned to it (e.g., COSC-1: 5054 (Fig. 4.5.XX)
- One or more Sites (ICDP: Number) can be visited during an Expedition
- One or more Holes (ICDP: Letter) can be drilled on each of the Sites

Table 4.5.2: Conceptual schemes and terms of IODP, ICDP, and CSD Facility in Minneapolis

	Expedition	Site	Hole
IODP	372	U1519	A
ICDP	5054	1	A
LacCore	GLAD5-BOS04	1	A

Since naming conventions in different core repositories can be quite different, the mDIS allows listing a second unconstrained/free-formatted naming scheme as long as it is used consistently throughout a single expedition or project.

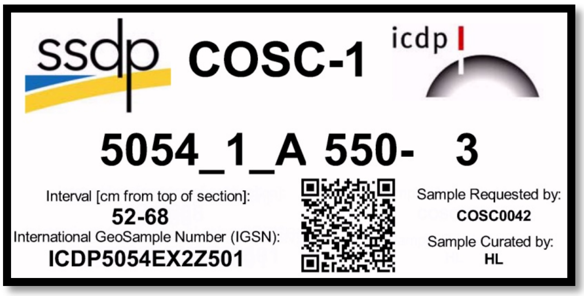

Fig. 4.4.2: Sample label with ICDP sample ID (middle), IGSN number, and IGSN QR code (lower)

To be able to keep track of all samples and to append them to the database, there is a central rule: 'No sampling without sample requests'. In order to achieve this, it is recommended to repeatedly publish 'Calls for Sample Requests' starting early on in the project, even before the start of planned drilling operations. The majority of samples will be taken during the sampling party that preferably takes place soon after the cores have been transferred to the core repositories, whereas on-site sampling should be restricted to unavoidable, immediate sampling based on the SMP.

Reasons for repeated 'Calls for Sample requests' include:

- To review the individual sample requests in consideration of the project objectives
- To detect sections that would be over-sampled or are not requested sufficiently
- To review and adjust the general sampling strategy
- To improve the on-site and laboratory sampling procedure

Logistically, an early first 'Call for Sample Requests' is especially important for samples that are requested to be taken on-site simultaneously with the drilling operations. At this point, the sample manager can validate whether or not this is inevitable and how to best integrate the sampling into the on-site workflow. During the drilling and after the collection of the Operational Data Set, additional 'Calls for Sample Requests' allow for a refinement of the sample distribution. This could also minimize the number of additional sample requests during the sampling party, and thus, make sampling more efficient.

The project's Operational Data Set is the collection of information, which the sampling strategies of the science team members is based upon. It will be made accessible for science team members only during the moratorium period on the ICDP projects website and maintained by the OSG. The PIs assemble the science team. Amongst others, the data set includes: uploaded images, scans, lithological descriptions, core logs, well logs and corrected sample depths. The data provide basic information about the quality of recovery and geo-properties that can support the selection of appropriate sampling spots. The Operational Data Set will be published online after the moratorium. See Chapter 4.4 for details on data management.

Table 4.5.3: Selection of some of the core repositories curating ICDP samples

Repository Name	**Funding Program**	**Host Country**	**Condition**
Bremen Core Repository (BCR)	IODP	Germany	cooled
Gulf Coast Repository (GCR)	IODP	U.S.A.	cooled
Kochi Core Center (KCC)	IODP	Japan	cooled
CSD Facility (formerly LacCore and CSDCO)	NSF, CSD	U.S.A.	cooled
Rutgers Core Repository	IODP, NJGWS	U.S.A.	cooled
National Core Repository	BGR, GESEP	Germany	not cooled

The early planning of the long-term core and sample preservation and storage is crucial to guarantee the long-lasting success of a project. Unlike IODP, ICDP does not maintain its own storage sites (repositories) for sample material. Accordingly, each project has to take care of appropriate facilities and accessibility for a long-term period after the end of the project (10 years minimum). However, ICDP samples can be stored in trusted facilities of IODP, LacCore and others that operate according to scientific best practice and warrant long-term access.

A list of major core repositories already storing ICDP cores is provided in Table 4.5.3. For a more comprehensive collection of suitable repositories, the PIs are referred to the ICDP repository website and the OSG team as needed. The listed repositories host and preserve sample material, conduct professional sample curation and are accessible for any scientist.

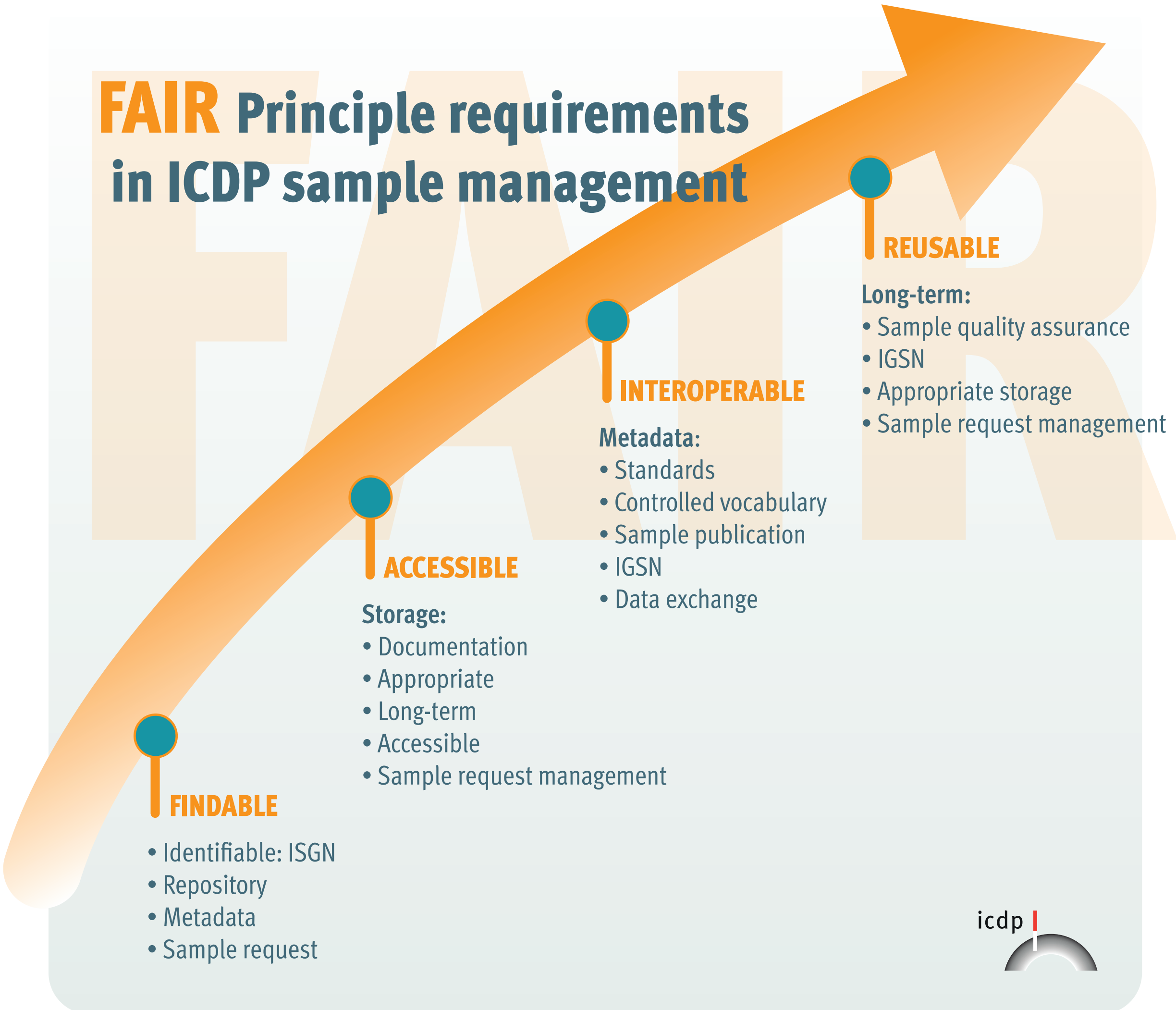

Fig. 4.4.3: How key components contribute to the FAIR principle in ICDP sample management

Depth Scales and Measurements

Depth matching is an important issue of wellbore data consistency and described in detail for IODP drilling. Typically, core and sample depths can be based on a number of different approaches including:

1. the cumulative length of the drill pipe (Drillers Depth below rig floor, DRF)
2. the depths below surface/lake floor based upon the drill pipe length minus distance from rig floor/drillers reference point to the surface (minus water depth given lake drilling) (Drilling depth below surface, DSF)
3. Core recovery might be >100% compared to the advances given by the drillers if the curated length is greater than drilled length (Core depth below seafloor/surface- A, CSF-A). The depth is given as the top depth of each core (DSF) plus the curated section length (+ sample/data offset). If the core recovery is greater than advancement, cores can overlap (correction method:

overlap). Units used are either m CSF-A or mbsf/mbs.

4. Core recovery is not allowed to be greater than drilling advancement. Instead of an overlap, a compression algorithm is applied such that core recovery equals 100%. Core depth below seafloor/surface-B, CSF-B) or (correction method: no overlap). Units used are either m CSF-B or mbsf/mbs.
5. If there is no drill core, lag depth applies, e.g., for cuttings or fluids. The lag depth is a calculated depth derived from the drill mud circulation.
6. True Vertical Depth (TVD) can be calculated if the trajectory of the hole is known.
7. Subsequent wireline logging can be used for depth corrections by referring the length of wireline used during logging equivalent to the DRF and DSF (Wireline log depth below rig floor, WRF; Wireline log depth below surface/lake floor, WSF, also called Log Depth). Wireline 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. The corrected depth is in meters corrected depth (mcd) or in mbs, mbsf or mblf.
8. If there is more than one borehole, depth correlation of data from logging or physical property measurements can be used to calculate the Composite Depth that splices selected sections retrieved from multiple holes. Units are either core composite depth below seafloor/surface, (CCSF) or meters composite depth (MCPD). For details on the splicing method see Chapter 4.5.4.

Workflow for depth corrections

1. Transfer any depth measures in meter units
2. Calculate DSF and CSF depth scales
3. Define reference level for all holes of a site
4. Build composite or spliced profiles in case of multiple, partly overlapping holes on a site.

Simple depth calculations are supported by the mDIS. In cases 3 and 4 software tools such as WellCAD (RockWare) and/or CORRELATOR and CORELYZER (open source from CSD Facilities) assist the depths calculations. Both software programs allow for the correlation of all types of depths. Using a selected master downhole log can provide the true vertical depth.

Spliced data profiles (including line scan images) can be generated by using, e.g., CORRELATOR and CORELYZER to produce a composite site image overlaid by the various data sets. This also extends into the task of ‘Depth -&- Data Matching’, which is 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. For detailed information on depth calculations and spliced data profiles see Chapter 4.6.4.

Field Report: How to make the most of your core material

When beginning to plan a drill project some aspects are prone to falling into oblivion: the data and sample management and the practical work involved from predrilling until the scientists can actually work on samples.

On the drill site, PIs, Co-PIs or other scientists will want to prioritize tasks such as – deciding where to drill, how far to drill or initial logging. It is equally important and almost as time consuming to take care of the initial core inventory, measuring, counting and packing core sections, entering box numbers, slot numbers,

box positions, depths, times, drilling parameters, etc. into the database, communication with the OSG, taking contamination samples, labelling boxes, stacking and preparing core boxes for shipping and so forth.
This work continues in the core repository collecting the basic data; labelling, scanning and logging 1000s of meters of whole and split sections, entering data, uploading files, handling and documenting sample requests. Samples need to be entered, cut, labelled, placed in sample bags and packed for shipping. The obligation to store and make the cores accessible for the public remains for at least 10 years. If the project has chosen to use a core repository, the hours needed for data and sample management will be considerably less once the moratorium has passed. Nevertheless, sample requests and follow-up are still tasks that need to be handled.

Without the use of a core repository, sampling parties and sample requests need to be organized once or twice a year. Realizing sample requests, entering new data into the database, cutting, labelling and bagging samples, preparing customs documents and shipping are the tasks that will arise again. Regular database backups, new data entries, handing out overview lists and answering questions about samples received are regular exercises throughout the year.

In the FarDeep project, the idea emerged to ask scientists to send back unused or leftover materials. Since all projects run the risk of handing out samples that are never processed, it seemed important not to waste these precious materials. This system of sample recycling does mean scientists using samples need to be contacted regularly, asked for return of unused material, incoming samples need to be weighed, screened, labelled and re-entered into the database as existing samples. Between 2014 and 2019 an average of 600 of these returned samples have been handed out each year in addition to new samples that were taken. Many researchers are happy to subsample existing sample sets, especially when they are already crushed or powdered for analysis. This might not sound a lot, but after all - drilling was completed in 2007 and the interest still persists as recent (2020) publications show.

In conclusion, it can be said that the curation of data and samples is demanding, but a project is worth nothing without it. An experienced data and sample manager can help to plan the practical aspects of sampling strategies for the project from the time the drilling starts until far beyond the active phase of the project, allowing scientists to concentrate on drilling and science and at the same time make the most of the treasured core material. This person should stay with the project for the entire time it is still running. Continuity will save time, resources and will help not to lose valuable information along the way. Initially, 500-700h a year should suffice to carry out these tasks and can probably be reduced over the years. While a background in geoscience might be helpful, being involved in the science of the project might not. At times, conflicts of interest can arise and a technician could feel more objective or approachable. Since that person will be the contact person for sample requests, data and sampling routines, this can be an advantage.

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CHAPTER 4.5

Handling of cores and cuttings, and core correlation

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This chapter provides two examples of workflows on core handling, one on hard rock (COSC, Sweden) and the other on soft sediment core material (SCOPSCO, Lake Ohrid, Macedonia). In addition, examples on handling cuttings from three different drilling projects (SAFOD, San Andreas Fault, USA; DFDP, New Zealand; NanTroSEIZE, Japan) described below may serve as a guideline for similar drilling projects during their planning phases (Zoback et al. 2011; Townend et al., 2009; Tobin & Kinoshita, 2006). Illustrated instructions (core marking, naming convention, packing of core boxes, etc.) are provided in Supplements S2 to S7.

4.5.1 Core handling in crystalline rocks

The Collisional Orogeny in the Scandinavian Caledonides (COSC) scientific drilling project drilled its first drill hole, COSC-1 (ICDP 5054-1-A) in 2014 (Lorenz et al., 2015a), in the vicinity of the abandoned Fröå mine, close to the town of Åre in Jämtland, Sweden. The drilling project 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 on site science team

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 two days before planned spud in. The complete on-site scientific work from mobilization to demobilization is estimated to about 4.75 man-years (see COSC-1 Operational report for details; Lorenz et al., 2015b).

Fig. 4.5.1: First COSC drill core (gneiss below cement) in opened inner tube of a triple tube core barrel assembly. Clearly visible is the split aluminium liner protecting core from external forces, the second tube, and the drill string tube, hence 'triple tube'.

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. 4.5.1).

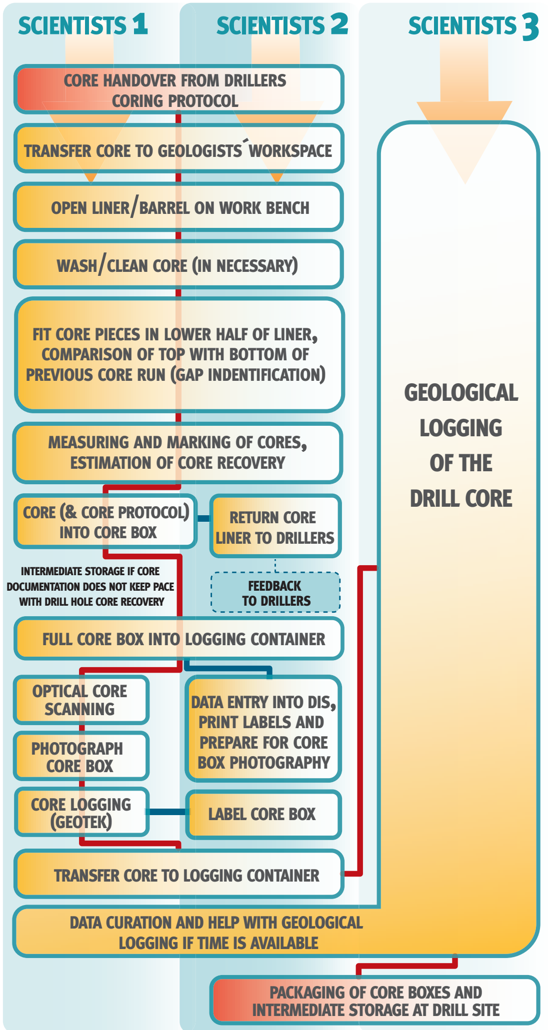

Fig. 4.5.2: Workflow for the COSC-1 drill core handling procedure

The closed liner was then transferred to the geologist's core handling table for further processing (Fig. 4.5.2). 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, Fig. 4.5.3). 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 including the labels (on foam blocks; Figs. 4.5.4 & 4.5.5).

Fig. 4.5.3: Whole round optical core scan of gneiss core section showing double reference line in upright position with red line on the right

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).

Fig. 4.5.4: 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.

Fig. 4.5.5: *Sample location filled with a labelled foam block showing the sample number and IGSN (lower left: ICDP5045EX2W501)*

Unrolled core scans were acquired for each section (Fig. 4.5.3) 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. 4.5.4). 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).

For the core documentation, the core boxes were transferred to the working place for geological drill core logging. 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 (Combined-ID) (Fig. 4.5.5) that is used to track samples and relationships between samples (see also: Chapter 4.5).

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.

4.5.2 Core handling for lake sediments

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 (Fig. 4.5.6) (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).

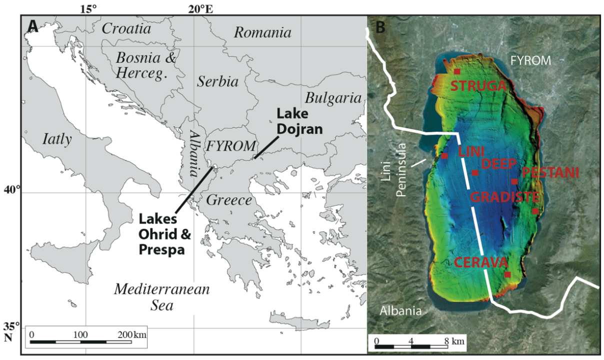

Fig. 4.5.6: Location (left) and map of Lake Ohrid (right) with color-coded depth and drill sites, modified after Wagner et al., 2014.

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, the maximum penetration depth was ~194 m blf. The composite field depth recovery adds up to more than 90 % at each individual drill site (see Chapter 12 for depth correction methods).

Ohrid on-site science team

The on-site scientific operations were coordinated and conducted by the Universities of Cologne and Kiel (Germany), the Faculty of Natural Sciences of Skopje (Macedonia), and the Hydrobiological Institute Ohrid (Macedonia). Scientific work on the drill barge was performed 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 making 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 required 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, e.g., financial and political issues and the timely fuel and drill mud supply to the drill barge.

Fig. 4.5.7: 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).

Workflow for core handling on the 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 core material pushed out at top and bottom of the PVC liner (Fig. 4.5.7).

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 standards (Fig. 4.5.8).

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 placed into a plastic bag. The cubic plastic vials were shipped to the GFZ in Potsdam, Germany, for initial paleomagnetic analyses, and small aliquots were 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 on the recovered sediments down to the base of each hole (see for example Wagner et al., 2014).

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

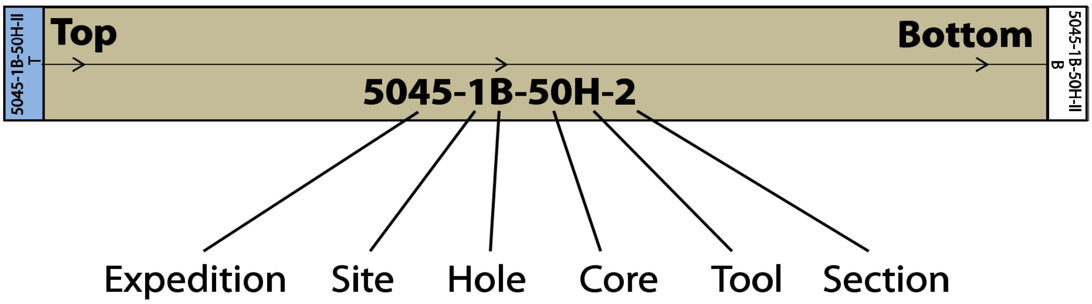

Fig. 4.5.8: ICDP standard core labelling routine. Arrows point to the bottom of the core, blue caps are attached to the top, white caps to the bottom of each core section.

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. 4.5.9). Corresponding calculations always refer to the driller's mark on the barge, which must be noted in the drill table 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. 4.5.9).

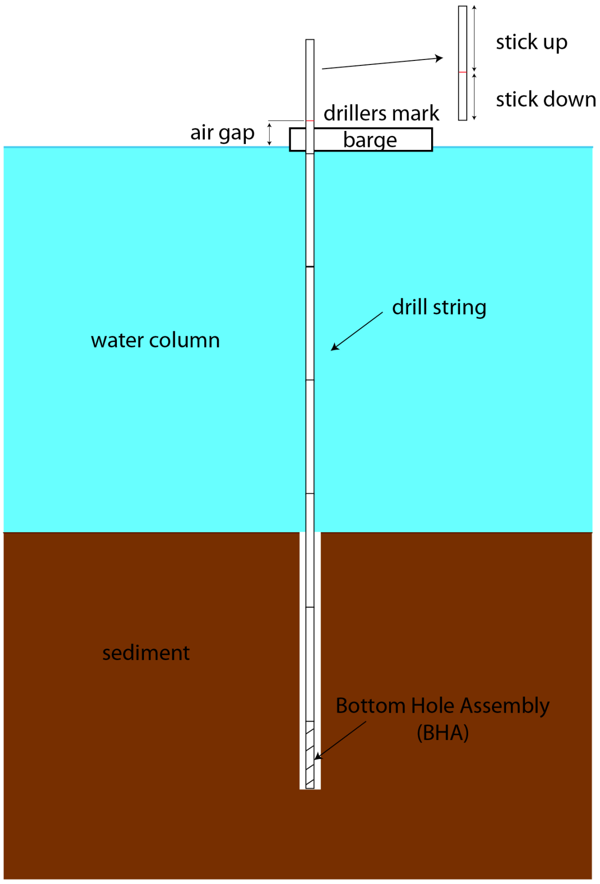

Fig. 4.5.9: Simplified scheme for the illustration of the drill depth calculations

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} + stick down + $HPC_{max\ length}$ – air gab – $recovery_{1st\ HPC\ run}$ (1)

Subsequently, the drillers constant d_c can be calculated:

d_c = w_{depth} + air gap (2)

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

s_{depth} = d_{depth} - d_c (3)

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

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

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

Drilling strategy

Decisions about the onsite drilling strategy encompass 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 devices can be made based on lithological information from the core catcher material of previous boreholes. Thus, higher sediment recovery percentages are often 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).

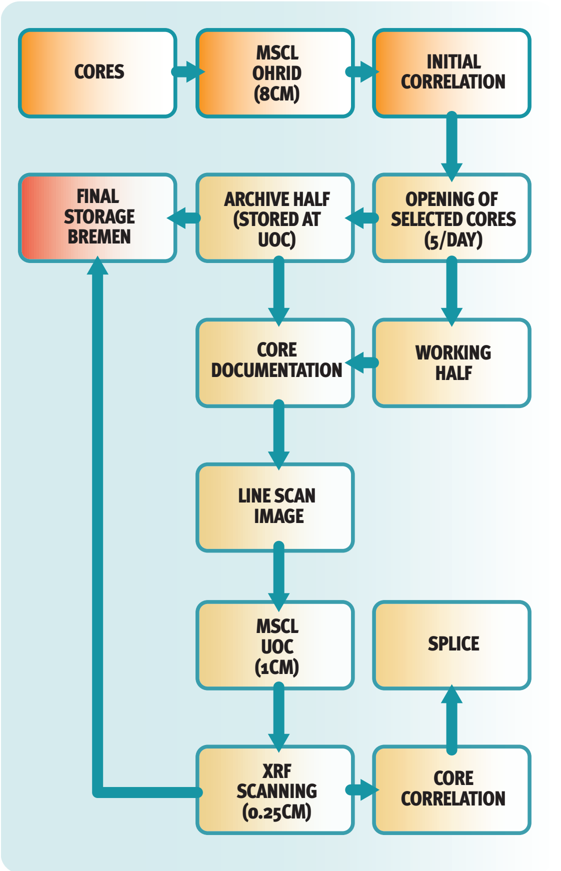

Fig. 4.5.10: Core handling workflow during the Lake Ohrid drilling expedition.

Ohrid core handling at shore base
At the shore base, geophysical parameters of the core sections were measured with a 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 (round) 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.

Ohrid core handling in the laboratory
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 were 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 were used to identify horizons with tephras or cryptotephras. Corresponding results were tied into paleomagnetic measurements and chronostratigraphic tuning methods to establish an age-depth model.

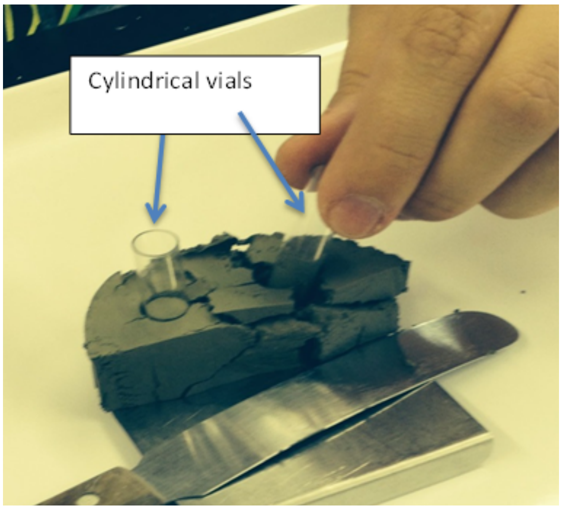

Fig. 4.5.11: Sub-sampling of a 2 cm-thick sample slide using cylindrical vials. The latter collect pre-defined volume samples parallel to the long axis of the core in a top to bottom direction, which enables the calculation of the water content, and thus dry and wet bulk density, respectively.

Subsampling for geochemical, pollen and diatom analyses were carried out at consistent intervals of 16 cm on the composite core (Fig. 4.5.11) after core correlation and splicing was performed based on visual inspection and XRF data (Chapter 4.4.3). Aliquots of the subsamples were distributed to the Ohrid science community for further analytical work (Fig. 4.5.12).

Ohrid core correlation and splicing

Core correlation and splicing of core data obtained from neighbouring bore holes 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 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.

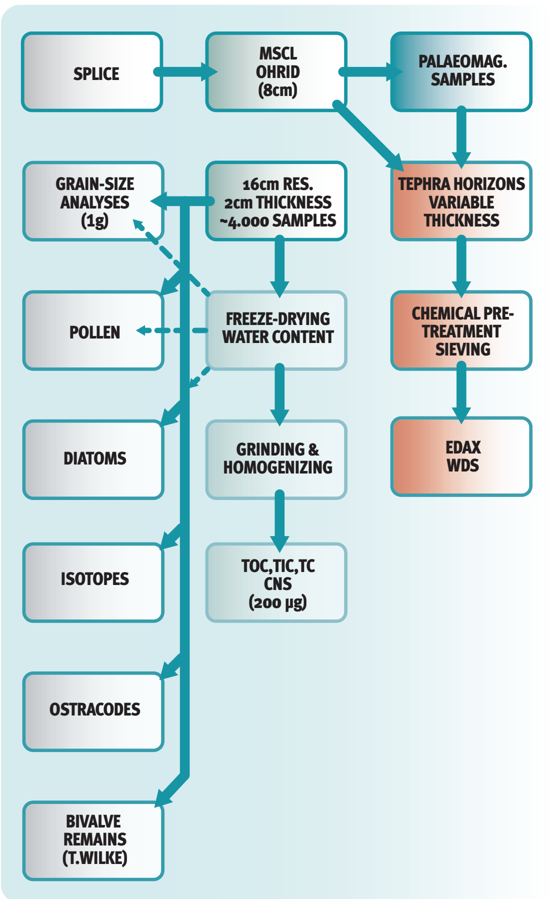

Fig. 4.5.12: Specific analyses and sampling workflow for the Lake Ohrid expedition. Sub-sequent to the subsampling, the working halves were shipped to Bremen Core Repository for core curation.

Two standard software applications used in academia to showcase and feature data from the various drill holes are CORELYZER and CORRELATOR. The latter software package allows fetching various data sets obtained in a borehole, placing them on a world wide web-based server, and cross correlate them into a 'spliced' composite-like data profile. The program processes 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 were 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 described workflow (4.5.10). Information from the visual core descriptions and the XRF core scanner data was then compiled to establish a refined, final core correlation and composite profile.

4.5.3 Core Correlation Software

ICDP lacustrine drilling projects mostly target paleoclimatic and environmental topics typically covering young Quaternary times in high-sedimentation rate regimes (>100 m/my). The combination of short time periods of interest and high sedimentation rates ask for a robust sampling strategy for the various disciplines as well as accurate depths calculations and core depths correlation.

Where multiple boreholes at one drill site are available, a **composite profile/splice record** consisting of the overlapping core segments from the individual boreholes should be created at first (Supplement 6). Afterwards, sampling can be carried out at a regular interval on the final composite record. By applying this sampling strategy, redundant sampling of core sections outside the composite profile/splice record is avoided.

Figure 4.5.13 depicts a detailed 'road map' for an optimized workflow for lake sediment drilling campaigns based on laboratory work on cores from Lake Ohrid. The cores were processed at the University of Cologne (Germany) and detailed information about, e.g., core correlation, can be found in Francke et al. (2016). To get familiar with the software packages mentioned in Fig. 4.5.13, OSG holds a training course on mDIS, 2 – 6 months ahead of the field campaign. For the open-source software packages 'CORELYZER' (real-time core description) and 'CORRELATOR' (stratigraphic correlation), which are recommended for the 'splicing' method, OSG recommends retrieving instructional videos and manuals from the homepage of the CSD Facility: http://csdco.umn.edu/resources/software.

Core and Data Handling

Core processing and data management in a science lab build on information obtained in the field, such as the core and section inventory, field depth measurements and on-site analyses such as MSCL (Multi Sensor Core Logger) data recorded at low resolution on whole cores.

MSCL data of magnetic susceptibility and/or bulk density are applied for core correlation using the software packages CORELYZER/CORRELATOR (see below).

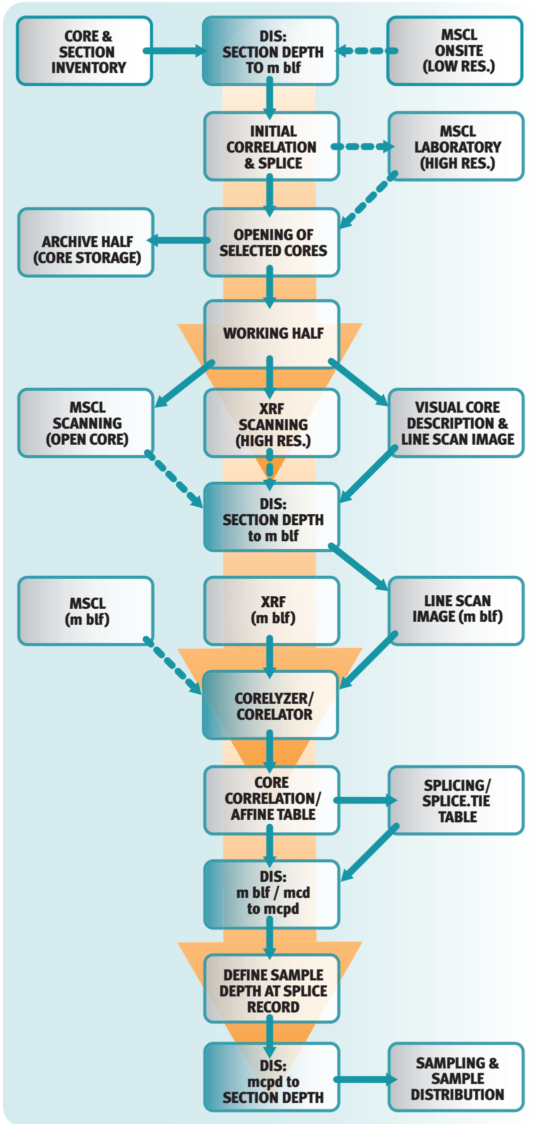

Fig. 4.5.13: Schematic workflow for the laboratory work and data management for lake drilling projects (mblf: meters below lake floor, mcd: meters corrected depth, mcpd: meters composite depth). The workflow is adopted using the workflow applied for Lake Ohrid data using the old DIS data management tool. The new workflow is work in progress.

Core correlation and splicing are ideally accomplished in the field, in order to detect possible gaps in the recovered sediment succession and to improve the drilling strategy while drilling. Further, the preliminary splice record can support core processing in the science lab by reducing the number of core sections to be processed. Core sections of this preliminary splice record can be selected for core processing, which shall routinely encompass:

- High-resolution (1-2 cm) MSCL logging and/or CT-scanning on whole-round ('unrolled") cores
- Core splitting
- Surface cleaning of the core (working and archive) halves
- High-resolution line-scan imaging of individual core sections
- Visual Core Description (VCD) and smear slide analyses
- XRF (X-ray fluorescence scanning) and high-resolution MSCL logging on split core halves

Core correlation, splicing, sub-sampling
Before sub-sampling begins, the final core correlation and splicing shall be carried out on the basis of the lithological information from visual core descriptions in conjunction with high-resolution XRF (or other equivalent) core scanning data (cf. Fig. 4.5.14). The splicing itself is based on the idea to match data of a certain kind (e.g., XRF; RGB; etc.), when obtained between two or three adjacent drilled holes.

CORRELATOR/CORELYZER are used in academia to showcase and feature data from the various drill holes and allow collecting various data sets obtained in a borehole and to cross-correlate them into a 'spliced' composite-like data profile (Figs. 4.5.14 and 4.5.15). This can include images depicted with CORELYZER or any other data, i.e., magnetic susceptibility, GRAPE, XRF, showcased with, both, CORELYZER and CORRELATOR. CORRELATOR and CORELYZER can be used in concert and allow a direct crosscheck of the established correlation and splice record between the data records and the line-scan images.

A visual correlation between two horizons (such as tephra layers), which can unequivocally be correlated between two boreholes mostly provides more precise results (Fig. 4.5.15) than a comparison of patterns and shapes of certain data, for example from XRF core scanning (Fig. 4.5.14), and is therefore preferable over a data-based correlation. An example for a spliced line scan image is shown in Figure 4.5.16.

Core correlation is commonly carried out from top to bottom of the drilled record and defines the offset of each core run, i.e., the distance a core has to be moved up or down for identifying proper connection (tie) points with the overlying core from the other/adjacent borehole(s). Offsets can be either negative (core shifts upwards) or positive (core shifts downwards). Due to gas expansion and pressure release of the overlying formation, core runs frequently achieve more than 100% recovery resulting in positive offsets for most of the core runs, and thus, in an elongation of the splice record compared to the original boreholes. On the basis of the defined offsets, the original mblf measurements are commonly converted into the mcd (meters corrected depth) (see Supplements S6, S7).

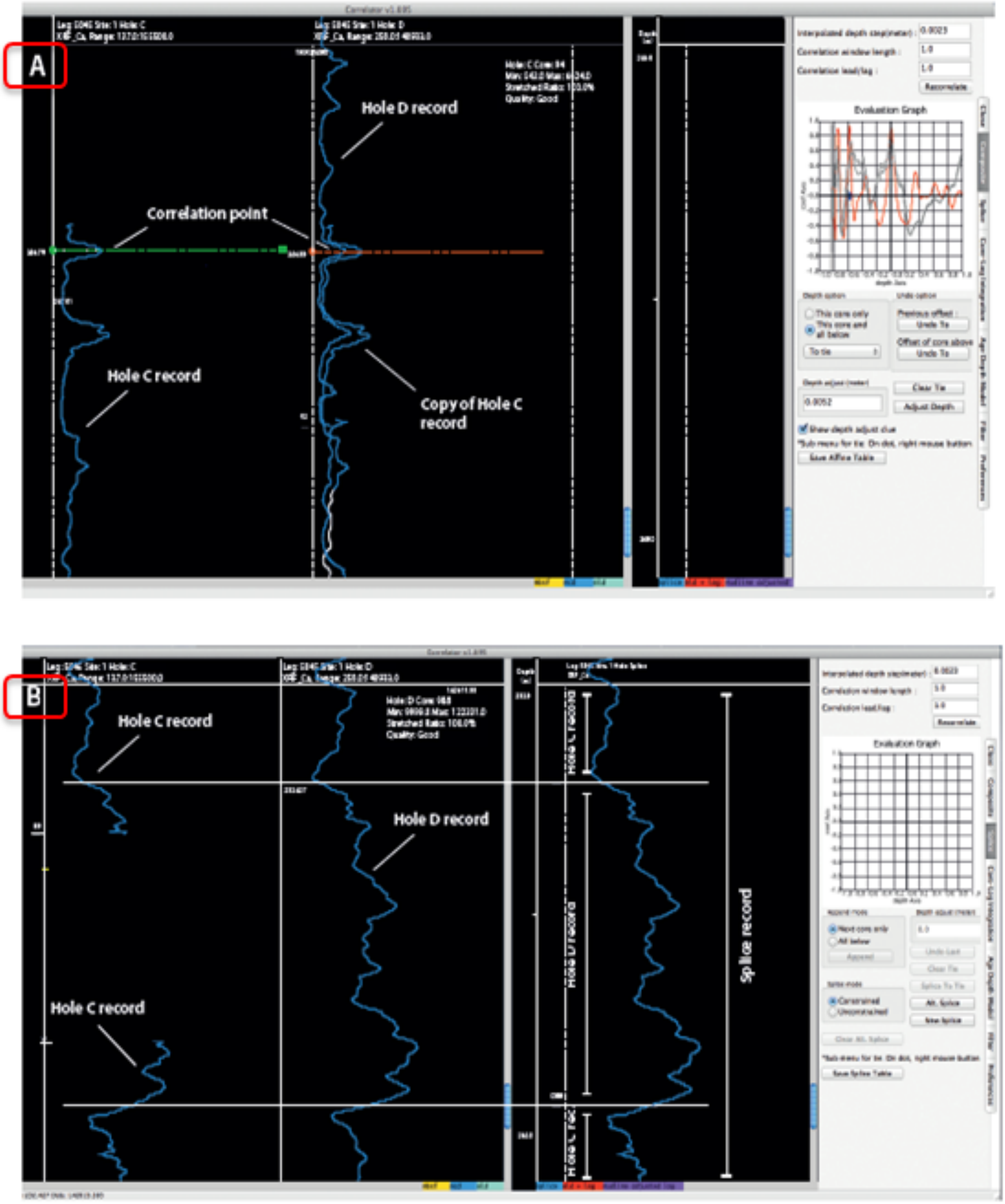

Fig. 4.5.14 The CORRELATOR software package is commonly used by Earth scientists for visual drill core description and data composition. ***A:*** *Core correlation using high-resolution XRF core scanning data (Ca=calcium). The data were filtered using the Gaussian filter as provided by the software package. Two representative peaks in the Ca-counts at ~246.8 mblf were used as correlation point between core runs from Hole C (left panel) and Hole D (right panel).* ***B:*** *After core correlation, the individual core runs can be combined to a continuous splice record (right panel) by using intervals from Hole C (left panel) and Hole D (middle panel). The horizontal lines mark the correlated horizons between Holes C and D and the splice point in the splice records, respectively*

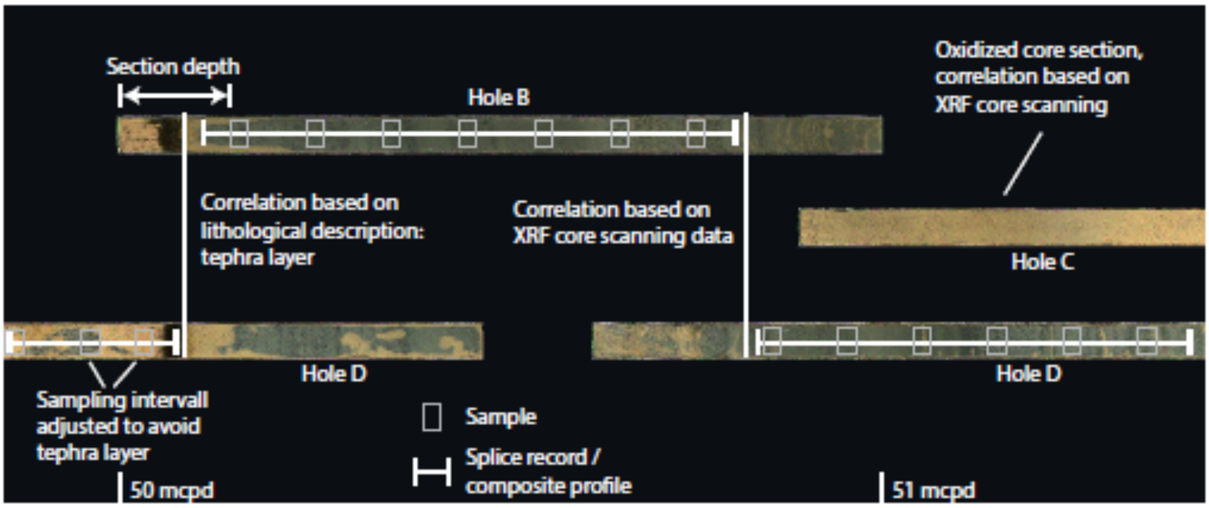

Fig. 4.5.15: The CORELYZER tool allows for core correlation on data obtained in adjacent Holes B and D. In the case of Lake Ohrid, core correlation was performed using lithological information (tephra layer/volcano-stratigraphy) and information derived from correlating high-resolution XRF scanning data loaded into the CORRELATOR software package. Marked are the 'splice record' and the 'samples', which were taken from the splice record on a regular interval. Special care ought to be taken regarding the various depth scales involved.

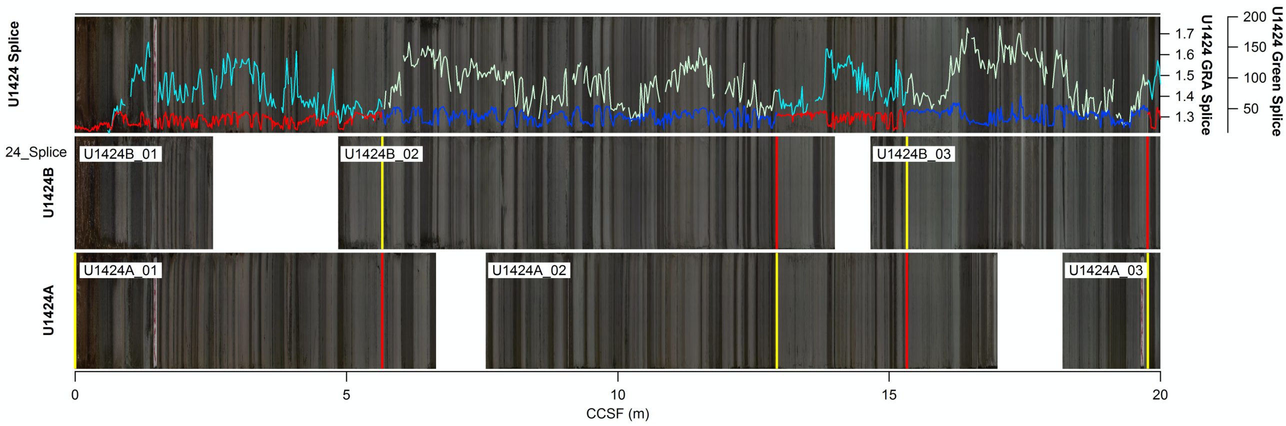

Fig. 4.5.16: Spliced line-scan images produced on cores from Hole-A -and- B during IODP Exp 346 overlaid by corresponding physical property data (GRAPE and RGB) for the top 20 mbsf. Note that both images and data from corresponding holes are computed into a scaled composite profile based on splice and offset (i.e. 'affine") tables, which are an essential output produced with the CORELYZER and CORRELATOR applications.

After defining the splice record, i.e., the respective core intervals required to obtaining a continuous sediment profile, the mblf and mcd measurements are re-calculated to mcpd (meters composite depth). Information about offsets and splice ties are saved by the CORRELATOR software as so-called Affine and Splice-Tie tables, respectively. The quality of all approaches is dependent on the correct data input from someone who knows how to apply the CORRELATOR software to produce 'splice' and 'off-set' tables (Fig. 4.5.16). Upon retrieving such tables from the various databases, self-standing macros based on time series analysis software (IGOOR PRO) allow the trained user to splice and overlay all sorts of data sets in a computed and scaled form.

If an unambiguous core correlation was not possible on the basis of the selected core sections from the preliminary splice record, additional core segments from the respective sediment depth of additional boreholes can be split, likewise analyzed and included into the composite profile. In order to optimize the laboratory capacities, XRF and MSCL core scanning is potentially not conducted on the core sections excluded from the splice record, however, splitting and VCD is.

After core correlation and splicing has been performed to a level of agreeable satisfaction a regular subsampling interval (e.g., for geochemical, pollen and diatom analyses) can now be defined for the splice record and corresponding depth (in mcpd scale) of each individual sample (Fig. 4.5.14). For the laboratory work, mcpd is re-calculated into section depth (Fig. 4.5.15). For this purpose, the respective composite depths in mcpd of each individual sample can be imported to the mDIS database. Thereby, it is highly recommended to crosscheck the position of each individual sample in the splice record, e.g., by using the CORELYZER tool, in order to avoid event layers such as tephra layers or MWD (Mass Wasting Deposits) and/or section boundaries during the sampling.

Field Logging Workflow

1. Input/Check of core-section data into the mDIS including measurements logged on the mblf (meter below lake floor) scale
2. Printing field Core/Section labels to identify cores and sections using IGSN, core/section number (combined-ID) and possibly sections top-bottom depths (mblf)/drillers depths. The depths are likely to change, so new labels are likely added in the lab
3. Create initial 'Core Correlation' while drilling by using low-resolution MSCL data in order to avoid drill gaps; creation of preliminary composite profile/splice record

Laboratory Workflow

4. Optional (depending on core retrieval situation): Re-do the MSCL measurements at high-resolution (cm to mm scale) and/or obtain CT-Scanner data on whole-round core sections
5. Core Section Opening: if more than enough core material is available consider splitting selected core sections of the preliminary composite profile first
6. Possibly, yet very carefully, 'clean' and prepare the surface of the core material prior to core section imaging and other scanning activities; import high resolution line-scan images into mDIS
7. Conduct Visual Core Description (VCD) possibly comprising smear-slide description (sediment) on printed VCD sheets and enter information into the mDIS or conduct VCD directly using PSICAT (open-source software maintained by CSD Facilities)
8. Perform logging of high-resolution XRF (recommended) and/or high-resolution MSCL (optional) data on split core halves
9. Import XRF / other data (MagSus etc.) into CORELYZER for visual inspection including mblf measurements as provided by the mDIS
10. Perform Core-Correlation & Splicing using CORRELATOR/CORELYZER tools
11. Decide whether Core-Correlation requires analyzing additional core sections (if yes, go back to Topic 7 and continue from there)
12. CORRELATOR tool: AFFINE & SPLICE tables
13. AFFINE table contains and defines the OFFSET of individual cores and requires entering it into the mDIS for each core; re-calculation of mcd via mDIS
14. SPLICE table (incl. TIE POINTS for the splicing) are being produced; used for re-calculation of mcdp (meters composite depth) in mDIS
15. Re-do export of Line-Scan Images & Composite mDIS data (e.g., XRF, MagSus, etc.) to CORELYZER or other visualization software
16. Import SPLICE table into CORELYZER for visual inspection of composite sections and sampling spots

17. Sampling on a predefined sample interval on the final composite profile / splice record with respect to specific event layers (e.g., 'Ash Layer') and section top/end
18. Enter pertinent information of all samples obtained from the core material into the mDIS featuring composite (core) depth (mcpd) and calculated corresponding section depth for laboratory work
19. Prepare a representative 'Downhole-Logging Record Master' (spliced and depth corrected data set from Total Gamma Ray, Mag Sus, and/or FMI/BHTV borehole logs
20. Combine Downhole-Logging and final composite profile for detailed 'Core-Log Integration' studies

The method and techniques outlined and presented in this PRIMER Chapter are 'work-in-progress'. Much of the described methodology is standard procedure during expeditions of the International Ocean Discovery Program, IODP, but not yet for lake-drilling ICDP projects. Here, the procedure will need to be standardized for new ICDP projects allowing for opportunities to further optimize and improve the techniques. This pertains to both, sediment and hard rock drilling campaigns and represents a great opportunity for users to get actively involved and participate in this process of continuous improvements as 'Beta Testers" and power users.

4.5.4 Cuttings handling at the drill site

Cuttings generally occur as small rock fragments produced during drilling operations (Fig. 4.5.17). Especially when core samples are unavailable, cuttings are often the only method of getting physical samples of the rock formation for mineralogical, geochemical, and/or physical property analyses. The cuttings handling presented in this section is based on the experience gained on-site during the SAFOD drilling project (San Andreas Fault Observatory at Depth, USA), the DFDP drilling project (Deep Fault Drilling Project, New Zealand), and the NanTroSEIZE drilling project (Nankai Trough Seismogenic Zone Experiment, Japan). It includes examples of workflows on both hard rock and soft sediment material.

Collecting and washing cutting samples

Before sampling, the amount (usually 1-4 litre) and the depth range of cutting samples (e.g., every 5, 10 or 50 m drilling advance) are agreed upon. The cuttings-drilling mud mix can then be collected in a bucket at the shale shaker (e.g., SAFOD, Fig. 4.5.18a), or directly at the drilling mud outlet (DFDP, Fig. 4.5.18c).

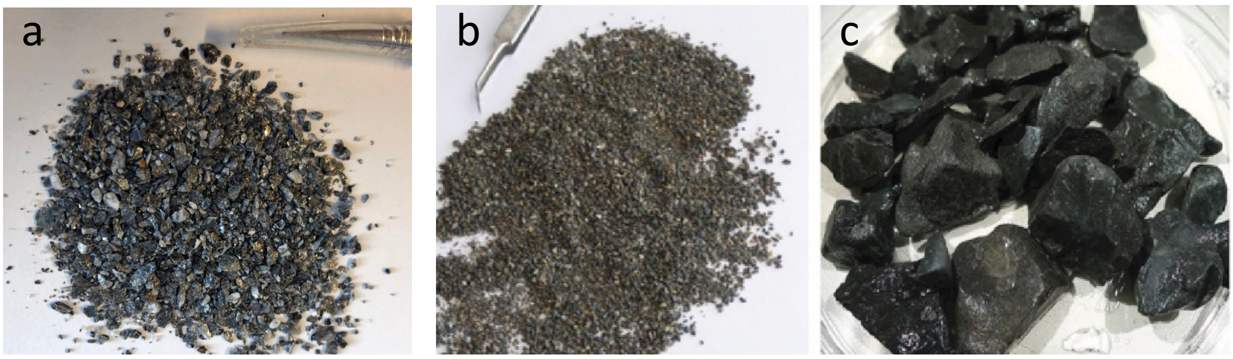

Fig. 4.5.17(a) cuttings of mica schist taken during the DFDP drilling project in New Zealand, (b), cuttings of a mixture of sand/silt and claystone taken from the SAFOD drilling project in USA, (c) cuttings of silty claystone, siltstone and sandstone taken during the NanTroSEIZE drilling project in Japan (cm scale).

Fig. 4.5.18: a) and b) cuttings were separated from the liquids at the shale shaker and later washed with tab water (SAFOD); c) and d) cuttings were collected directly at the drilling mud outlet and rinsed later with tab water (DFDP); e) and f) chip size separation (< 2mm, 1-4 mm, > 4mm) and rinsing of cuttings after collection at the shale shaker (NanTroSEIZE).

During the NanTroSEIZE Expeditions, 2 – 4 liter of cuttings were collected at the shale shaker per 5 – 10 m drilling advance (e.g., Tobin et al. 2015). The cuttings were routinely separated in an archive portion and a working portion, and only the working portion was used for further analysis.

After collection, the cuttings were washed thoroughly to remove the drilling mud (Fig. 4.5.18b and d-f). Generally, the use of very fine sieves prevents losing fine material such as clay. For a chip size separation (< 2mm, 1-4 mm, > 4mm), several sieves can be used (Fig. 4.5.18e). In these projects, the cuttings were washed with tab water, seawater, or diluted drilling mud fluid. The dilutant should always be discussed beforehand as, for example, deionized water (and eventually also other fluids) may affect the elemental ratios in the cuttings (depending on the rock type). Metal pieces (from the drill bit), plastic or organic material (e.g., cable and nut shells), or cement (from the casing procedure) may be mixed in the cuttings-drilling mud mix, and should be removed as soon as possible with a magnet or trough rinsing.

Cuttings contaminated with drilling mud

Drilling mud (or drilling fluid), usually a heavy, viscous fluid mixture of water, clay and polymers, is used to carry the rock cuttings to the surface and to lubricate and cool the drill bit during drilling operations.

It can physically and chemically alter the cuttings, and is therefore the main source of rock contamination. Especially chemicals such as calcium carbonate, sodium chloride or potassium chloride, barium sulfate or hematite are sometimes added to the drilling mud in order to control formation pressure, mud pH, mud viscosity, wellbore stability, or temperature. In fact, all drilling additives hamper the quantification of the true mineral content, especially when clay minerals are present. These chemicals should be washed out as soon as possible using rinsing water. However, any kind of soaking of the cuttings in the cleaning fluid for longer periods should also be avoided.

Labelling and imaging

Labelling the cuttings can be handled individually, but should best be adjusted to the core labelling (see above). Photographs can be taken before or after the initial visual description. At the NanTroSEIZE project, cuttings were washed and separated into the different mineralogy before a photograph was taken (Fig. 4.5.19a). At the DFDP drill site, a photograph of the washed cuttings was added to the petrographic description report (Fig. 4.5.19b).

On-site description

The initial visual examination of the cuttings usually includes descriptions of:

- the color of the cuttings
- the range and average of the different chip sizes
- the ratio of dispersed grain from disaggregated lithologies (e.g., sand) to cuttings chips
- the induration state of the cuttings
- the cohesion (stickiness) of cuttings
- the abundance of special categories (e.g., wood, coal, large fossils)
- the degree of contamination by metal shards, paint chips, or fragments of casing cement

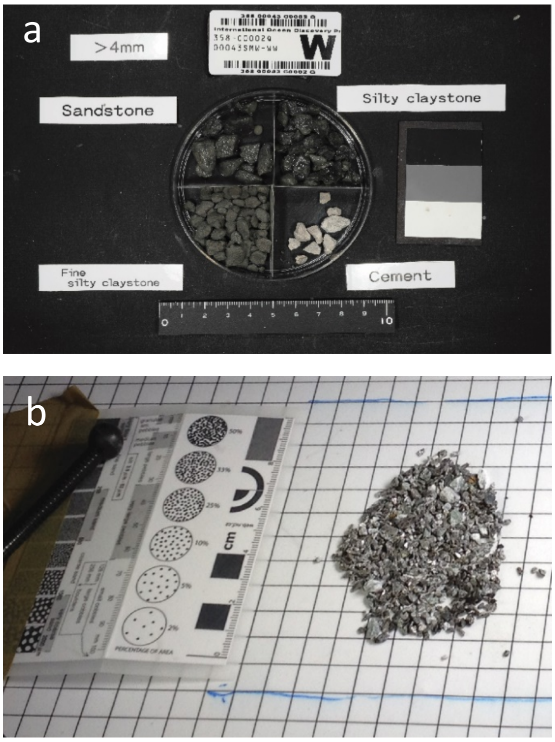

Fig. 4.5.19: Photographs of a) NanTroSEIZE cuttings (> 4 mm) separated in sandstone, silty claystone, fine silty claystone, and cement (from casing). The label in the upper part shows the expedition, drill site, drill hole, material number, method (solid taken from mud water), and the working portion; b) DFDP cuttings (all grain sizes) with percentage of area, sorting, roundness etc. for later description.

Examination of the washed cuttings is done visually, with an optical microscope or a binocular, depending on the availability at the drill site.

Descriptions with the petrographic microscope can be done based on:

- grain and mineral composition
- relative abundance of constituents
- average and range of grain size
- grain sorting
- grain roundness

At the DFDP and the SAFOD drill sites, cuttings chips were mostly described based on their mineralogy (mica, serpentine, quartz etc.), whereas at the NanTroSEIZE drillsite, cuttings chips were first separated in sandstone, siltstone, silty claystone. In some soft sediments, the preparation of smear slides can be helpful for visual examination of the mineralogy. They can be prepared from washed and gently crushed chips after grain separation and washing. As lithification of sediments advances with increasing depth, more effort should be directed toward segregation of each interbedded lithology for smear slides (e.g., mudstone, siltstone, fine sandstone, volcanic material). This can be accomplished by hand-picking chips of each lithology. Descriptions using the petrographic microscope are similar to the visual description. Depending on the lithology, thin sections may be more useful for this description. The cutting chips need to be impregnated with epoxy prior to the preparation of the thin section.

Final remarks

Cutting samples are valuable in that they provide a direct insight into the nature of drilled formations but their composition can be affected by several biasing effects related to the retrieval procedure, including:

1. chemical contamination of the cuttings due to drill mud interferences (e.g., infiltration of drilling fluid or precipitation of unknown phases);
2. mixing of the cuttings with other borehole material, thus containing grains from above the depth to which the sample is associated with based on drilling mud circulation velocity;
3. disaggregation of poorly consolidated sediment chips leading to preferential survival of certain lithologies in the cuttings;
4. physical drilling artefacts such as polished surfaces on cuttings chips due to drill friction (bit metamorphosis).

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Further readings

CSD Facility, 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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