1. INTRODUCTION

1.1. Objectives of Physical Properties Measurements

Physical properties of rocks and sediments are indicators of composition, formation, and environmental conditions of the deposits. Some physical properties can be measured rapidly and easily at high spatial resolution (core logging) and serve as proxies for processes such as paleoclimatic changes. Physical properties data are usually well defined and quantitative, which helps constrain the complex mineralogical and fluid systems in rocks and sediments. They are used increasingly by a wide scientific community for various scientific objectives. For these reasons, physical properties data form the bulk of all core data collected on board the *JOIDES Resolution* on each leg.

In soft and semiconsolidated sediment sections, physical properties data serve mostly as proxies for sediment composition, which is controlled by provenance, depositional and erosional processes, oceanographic and climatic changes, and postdepositional processes such as consolidation, and early diagenesis. In consolidated sediments and igneous rocks, diagenetic processes, including cementation, major lithological changes, and major faults, tend to dominate many physical properties. Hydrothermal circulation can be detected in sediment and rock environments by using physical property measurements.

A major application of data collected at small sampling intervals (a few centimeters), such as magnetic susceptibility, color reflectance, gamma-ray density, and natural gamma radiation, is for core-to-core and hole-to-hole correlation and for correlating core data to wireline log data. These correlation procedures are essential for stratigraphic studies, and some of the most important ocean drilling projects are unthinkable without the high-performance acquisition of physical properties data.

1.2. Shipboard Laboratory Stations and Sampling

OVERVIEW

After cores arrive on deck they are cut into 1.5-m-long sections and stored in racks for temperature equilibration. The first measurement station is the multisensor track (MST), where the whole-core sections are loaded on a motorized core conveyor “boat” for the automatic measurement of gamma-ray density, compressional (*P*-)wave velocity, magnetic susceptibility, and natural gamma radiation. The MST is used most effectively with cores completely filled with soft to semiconsolidated sediments that were retrieved with the advanced hydraulic piston corer (APC). Intact sedimentary or igneous rock cores cut with the extended core barrel (XCB) or rotary core barrel (RCB) also give good MST measurements. Coring disturbance such as severe “biscuiting” (typical for XCB cores) and fracturing (typical for RCB cores) associated with torquing significantly reduces the accuracy and usefulness of MST measurements, sometimes to a degree that MST measurements should not be performed.

For soft sediment cores, the second station is the thermal conductivity station, where needle probes are inserted into the whole cores. Next, the cores are split either with a wire (soft sediment) or with a saw. The half-cores are designated as archive-half cores and working-half cores. Figure 1—1 shows the relative core orientation conventions established to place core measurements, particularly paleomagnetic data, in a geographic reference frame using absolute core orientation measurements when the core is cut. The same conventions are used for other physical properties measurements that can be performed in multiple directions and that may reveal anisotropy (e.g., acoustic measurements) or for structural measurements. The archive-half cores are preserved in a pristine condition whereas the working-half cores are available for measurements that physically disturb parts of the cores and for theremoval of specimens for shipboard as well as shore-based studies.

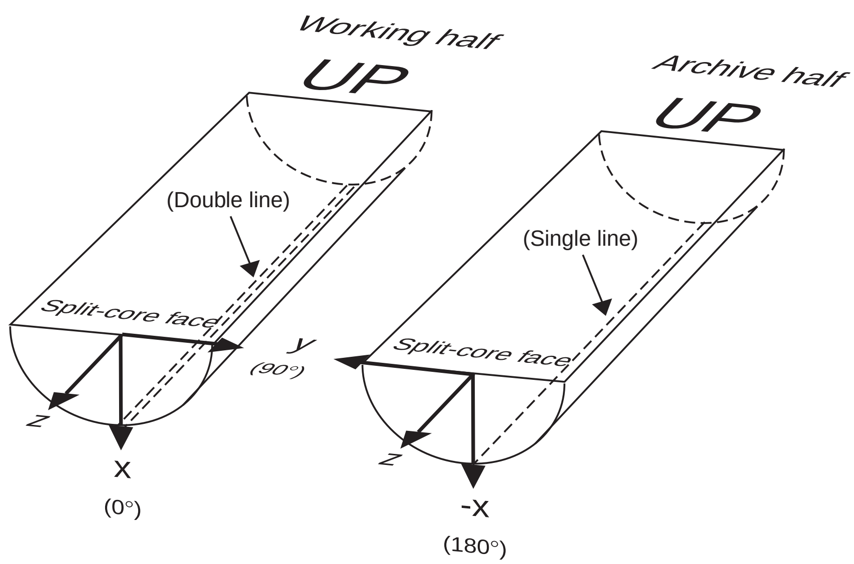

Figure 1—1 Core orientation conventions.

The archive-half core is used for the visual core description, paleomagnetic measurements using the cryogenic magnetometer, noncontact color reflectance measurements (to be implemented), and photography. A track system is in development that will measure the two physical properties of magnetic susceptibility and color reflectance along with the acquisition of color images of the core surface. After core photographs have been taken, the archive-half cores are stored in plastic tubes and refrigerated.

The working-half core is used for the measurement of color reflectance (the present mode of manual operation requires contact with sediment), *P*-wave velocity by using probes that are inserted into the soft sediment, vane shear strength by inserting a miniaturized vane into the sediment, and similar strength measurements with the hand-held Torvane and penetrometer devices. Half-core pieces of rocks are used for the measurement of thermal conductivity by using the “half-space” needle probe. In the future, a gamma-ray densiometer will be added to the working-half station. Along with the use of a caliper (associated with the *P*-wave system on this track) gamma-ray densities may be more accurate and precise than those obtained currently from the MST.

For the final physical properties measurement, specimens are extracted from the working-half core to determine moisture content and average mineral density (MAD station). *P*-wave velocity can also be determined on specimens of sedimentary or igneous rock extracted using a parallel-blade or cylindrical saw.

The working-half core then proceeds to the “sampling table” where one to three individuals extract specimens for analysis on shore. The sampling voids are filled with Styrofoam, and the working-half core is stored in plastic tubes and refrigerated along with the archive-half core.

MULTISENSOR TRACK (WHOLE-CORE MST) STATION

Measurement Systems

The MST is an automated core conveying and positioning system for logging core physical properties at small sampling intervals. At present, the MST system includes the following measurements:

- gamma-ray attenuation densiometry (GRA)
- *P*-wave velocity logging (PWL)
- magnetic susceptibility logging (MSL)
- natural gamma ray (NGR) measurements

The MST is one of the most routinely used devices onboard the *JOIDES Resolution*. No other shipboard instrument produces a comparable amount of core data, and the MST data set is among the most widely used ODP data and represents a worldwide standard of core analysis. The MST is designed to handle the sampling of whole cores automatically, and all measurements except the PWL can also be used on split cores and for measurements on individual core specimens. A new flexible, intuitive control interface was implemented in 1996.

Sampling

One of the most useful new features is the improved sampling parameter interface. The user can set sampling intervals and periods for all sensors and the program returns the calculated total measuring time for a core section based on an optimized measuring sequence. A graphical display shows the sampling points with depth. Typically, the time permissible for a whole core (typically seven core sections) is about 1 hr on legs with high core recovery (about 4 km of core or more). Therefore, if full-time attention is given to the MST, about 10 min can be allowed for measuring one core section. An overview of useful sampling parameter settings is given in this section. More data and information are presented in the individual sensor sections as appropriate.

When selecting sampling intervals, consideration should be given to the depth interval each sensor can resolve (see Table 1—1). For the GRA and PWL sensors, the depth intervals are less than 1 cm, for the MSL loop it is about 4 cm, and for the NGR it is about 15 cm. Because the sensitivity of the MSL and NGR sensors decreases away from the center of the sensor, better resolution can still be achieved by taking measurements at intervals smaller than the intrinsic interval of influence. Generally, ideal sampling intervals for the GRA, MSL, and PWL are 1 cm and should not exceed 5 cm. For the NGR, the best depth resolution possible is at about 5 cm. Intervals should not exceed 30 cm, which is about the depth resolution of downhole logging tools.

Sampling periods are directly related to the data quality (precision) particularly for the nuclear sensors. Because of the high flux provided by the ^{137}Ce gamma-ray source, 2-s sampling with the GRA is sufficient. The MSL has an internal integration time of 0.9 s (1.0 range) or 9 s (0.1 range); it should be set at 1 s. The MST program is best set to 2-s sampling time to allow for minor electronic and communications delay. The NGR is most sensitive to the sampling period because of the low intensity and random nature of natural gamma ray emissions. The more counts are accumulated, the more reliable the signal (the error is is proportional to $N^{-0.5}$, where N is the number of counts; see “Natural Gamma Radiation” chapter for more discussion). If spectral analysis is attempted to estimate abundance of K, U, and Th (which is not implemented for routine application yet), at least 1 min should be counted. (One hour would probably be more appropriate to reduce the statistical error to a level that would yield a good estimate of K, U, and Th). If only a total counts signal is desired, as little as 15 s is sufficient in terrigenous sediments, whereas 30 s should be measured in carbonates. The PWL system takes five measurements (data acquisitions or DAQs) at each point that are averaged for the sample and provide a sufficiently precise value.

Table 1—1 MST sampling parameters.

Sensor	Sensitivity interval (cm)	Interval (cm)			Period (s)		
		Best	Typical	Maximum	Best	Typical	Minimum
GRA	<1	0.5	1	5	4	2	1
MSL	4	1	1	5	10	4	1
PWL	<1	0.5	1	5	10[a]	1[a]	1[a]
NGR	15	1	10	30	>100	20	5[b]

Notes: [a]Five DAQs are averaged per second. [b]For amoving average applied to data taken at close spacing.

For optimized sampling parameter settings it is important that intervals and periods are multiples of each other. This ensures that the idle time of sensors is minimized and data quantity and quality are maximized for a given total core section scan period. For example, if GRA is set to 2 cm and MSL to 3 cm, one of the two sensors is partly idle while the other is taking a measurement. It is more efficient to set both at 2 cm so they measure simultaneously. Similarly, if the core stops every 1 cm for GRA and MSL measurements and 4 s are required for the MSL, the GRA sampling period should also be 4 s rather that 2 s because the additional time improves data quality but it does not require any additional time.

A further optimization can be considered for NGR measurements. Rather than taking a 20-s reading every 20 cm and leaving the other sensors mostly idle during that time, a 5-s reading can be taken every 5 cm, simultaneously with the other readings. This shortens total scanning time considerably. To get data quality (statistical error range) equivalent to a 20-s counting time, the user simply runs a moving average with a four-point window on the data.

THERMAL CONDUCTIVITY (TC) STATION

Measurement Systems

Thermal conductivity is the only property measured at this station. Two systems are available currently:

- Thermcon-85 system customized for ODP use and
- new TK04 system not customized for ODP.

A project plan exists to replace these with a fully integrated system that would incorporate the best features of both existing systems. However, no resources have been allocated yet.

Soft-sediment cores are measured before they are split because the larger volume of material surrounding the needle probe reduces geometrical problems (edge effects). If the core material is too hard to be penetrated by the needles without excessive force, thermal conductivity is measured on working-half core pieces using the half-space needle probes.

Sampling

Given the minimum time available until a soft sediment core must be split (about 1 hr), at least 5-10 measurements can be performed (1- to 2-m sampling interval). This is usually sufficient because thermal conductivity variations are strongly proportional to, but less sensitive and less precise than, bulk density measurements. Density can be used as a proxy and calibrated against a limited number of thermal conductivity measurements if higher spatial resolution is required.

ARCHIVE-HALF CORE LOGGER (A-LOGGER, TO BE IMPLEMENTED)

Measurement Systems (to be implemented)

The archive-half core logger is under development and scheduled for deployment later this year (1997). It will include the following measurement systems:

- color line-scan images,
- color reflectance spectrophotometry and colorimetry, and
- magnetic susceptibility.

The main goal for this development is to acquire color images of the cores (not discussed in this note) and to automate the routine acquisition of visible light color reflectance measurements. In addition, the spacial resolution and sensitivity of magnetic susceptibility logging will be improved with a “point-sensor” that requires contact with the core surface. Although line scans are truly noncontact and nondestructive (i.e., ideally suited for archive-half logging), photospectrometry and magnetic susceptibility require contact with the core surface and these implications still must be evaluated. These measurements may haveto be obtained from working-half cores.

Present Measurement System

The present "proto-A-logger" consists of a manually operated track for color reflectance measurements. Measurements are usually performed on working-half cores because imprints are left on the core surface from the manual operation. A simple computer program writes the data directly to disk and assists the operator further by incrementing sampling intervals automatically.

Sampling

Color reflectance should be measured at the smallest intervals possible because it is very sensitive to compositional changes. Variations in color reflectance serve as an excellent proxy for detailed correlation and compositional interpretation. A measurement with the Minolta spectrophotometer covers an 0.8-cm-diameter area. The manual mode sampling intervals used by shipboard scientific parties are 2 to 20 cm. With the future automated system, intervals should be set at 1 cm or less.

WORKING-HALF CORE STATION (W-LOGGER)

Measurement Systems

The working-half core station is semiautomated currently. It includes the following measurements (Figure 1—2):

- *P*-wave velocity with the PWS1, PWS2, and PWS3 systems,
- Shear strength using the automated vane shear (AVS),
- Shear strength using the manual Torvane (TOR), and
- Compressional strength using a pen-size penetrometer (PEN)

A component analyzer is available for resistivity measurements, but these measurements are not supported by ODP at present. Users are required to provide their own probes, perform their own calibrations, and develop their own procedures.

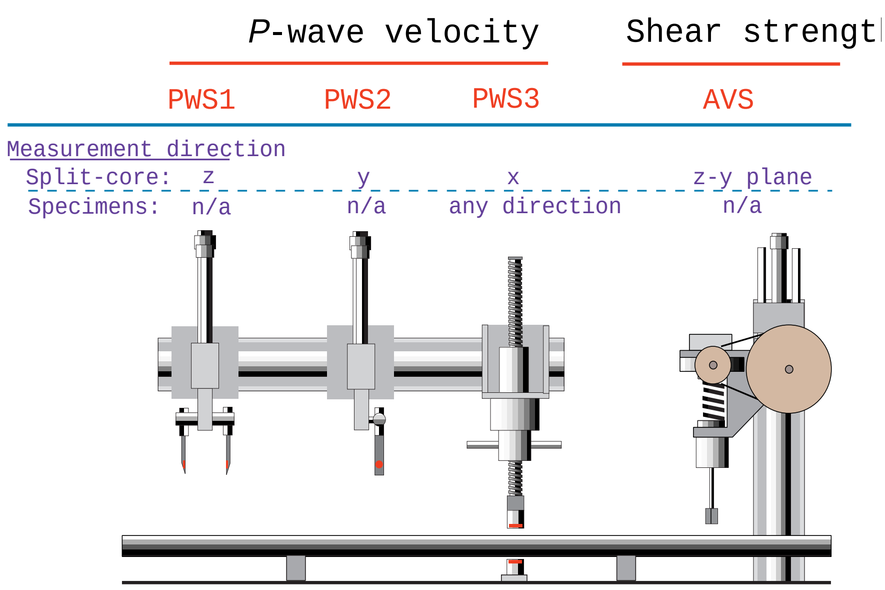

Figure 1—2 Schematic view of the semiautomated instrumentation on the working-half core track. n/a = not applicable.

Sampling

Sampling intervals for these measurements are mainly a function of available time at a given core recovery rate and how much core destruction (particularly using the AVS system) is permissible. The minimum sampling frequency on soft sediment cores is one per core section; a more typical sampling rate is two per section (75-cm sampling interval). If numerous measurements are desired on specimens that must be extracted from the working-half core or that disturb the core, the ODP staff representative must be consulted.

Whenever possible, the same sampling location should be coordinated for *P*-wave velocity and strength measurements, as well as for subsequent extraction of specimens for moisture and density measurements, carbonate, X-ray diffraction (XRD), and/or magnetic rock properties measurements.

For velocity measurements on split cores in liners, no sample preparation is necessary. An undisturbed interval is chosen for the measurement. For measurements on specimens that require two parallel faces to obtain optimum values, there are several ways to obtain such samples. In semiconsolidated sediment, use a spatula or knife to cut a cube of approximately 20 cm^3. For indurated sediment, use a hammer and chisel or the Felker saw. The Torrance double-bladed saw cuts good parallel faces. The easiest way to obtain a velocity sample in hard rock is to “drill” cylindrical minicores. These samples are particularly useful for sharing with the paleomagnetics laboratory (note the orientation when taking the sample).

MOISTURE AND DENSITY (MAD) STATION

Measurement Systems

At the MAD station, the following are measured:

- wet-bulk mass and dry mass of the same specimen (for moisture content and density) and
- volume of dry (and optionally wet-bulk) specimen using gas pycnometry.

From these measurements, basic phase relationships such as porosity, bulk density, grain density, dry density, and void ratio can be calculated. At present, a convection oven is used to dry the specimens. Ideally, a freeze-dryer should be used to avoid excessive extraction of interlayer water from clay minerals, particularly smectite.

Sampling

Sampling is typically 1-2 specimens per section, 10-mL volume per specimen. If possible, the same sample interval should be used as for strength and/or *P*-wave velocity measurements. Where numerous lithologic changes occur, denser sampling may ensure measurements from all significant lithologies throughout the core. Where cyclic changes in gamma-ray density are observed, a denser sampling program over a characteristic interval may be desirable. In XCB and RCB cores, which commonly show the biscuiting type of disturbance, particular care should be taken to sample undisturbed parts of the core sections and to avoid the drilling slurry.

1.3. New Shipboard Data Management Environment

BACKGROUND

In the early 1990s, the JOIDES advisory structure, through input from shipboard participants identified the need to design and implement a new database system on the ship as well as on shore. The complexity and level of productivity of the shipboard data acquisition environment made this a multiyear, multimillion dollar project. The physical properties laboratory was the first shipboard laboratory to be integrated into the new data management environment once the basic operational, curatorial, and depth calculation functions were redefined and implemented.

The process of redefining the entire ODP data structure offered the opportunity to implement more rigorous data acquisition, calibration, and control measurement protocols for physical properties measurements and to give the user access to these quality control data. A uniform data structure, compatible with the rules of relational data management, was created wherever possible. Leg 173 (April to June 1997) was the official "acceptance leg" for the new data management system, as described in this first edition of the note.

From the user's perspective, the data management system includes the following components:

- data acquisition interfaces and controls,
- data upload utilities,
- database and data models, and
- data access and standard queries.

The following section briefly introduces these components.

COMPONENTS OF SHIPBOARD DATA MANAGEMENT

Data Acquisition Interfaces and Controls

DAQ programs are written in various programs depending on the most suitable software tools and available expertise and hardware at the time and place they were written. During the past two years, two dominating standards have evolved: Neuron Data for operational and curatorial functions and descriptive data types (excellent for PCs, but performs poorly on Macintosh computers); and Labview for instrumental data (Macintosh or PC). The Neuron Data applications are integrated into a common user interface, called the Janus Application. Most physical properties DAQ programs are written in Labview now, including the MST control, MAD program, *P*-wave velocity and vane shear strength on half cores (PWS, AVS), and control of the Minolta photospectrometer (COL). Thermal conductivity remains in a state of development, and both available systems controls are written in QuickBasic.

Data Upload Utilities

Once data are acquired and located on a local drive, they must be uploaded to the Oracle database. Although procedure this could be fully automated and become part of the DAQ program, it was decided that an interactive user quality control should separate the two functions. Invalid or erroneous data are frequently acquired, particularly on highly automated systems that are operated in a conveyer-belt mode. The user has the option to delete such data from the local directory before triggering upload to the database, which avoids excessive editing within the database, a process that involves significantly more risk and effort.

Data upload utility programs are written in Neuron Data and are closely integrated with DAQ programs written in Neuron Data. For DAQ programs written in Labview or another language, a separate data upload utility must be operated. This is the responsibility of the ODP technical support representative, but scientists may learn the procedure and operate it themselves.

Database and Data Models

The new ODP Oracle database is designed specifically for ODP's unique shipboard environment and user needs. The system includes more than 250 data tables in a complex relational scheme, capturing data from the initiation of a leg, through core recovery and curation, physical and chemical analyses, core description, and sampling. Physical properties alone use 65 tables at present, not counting related tables for sample identification and depth data shared with other laboratories, and will involve more than 100 tables once the remaining measurement systems are integrated. The tables pertaining to a particular measurement system are presented in the "Data Specification" sections to help the user understand how the data are structured and how they can be accessed.

Data Access and Standard Queries

At this early stage of using the new database, there are three different technical approaches to data access, and the next few legs will show which is the most efficient and user-friendly one. The three approaches are referred to as

- Janus Application,
- Report Access Program, and
- World Wide Web Data Access.

The first solution integrates an off-the-shelf reporting utility, Business Objects, into the Janus Application. Many reports are available through this main interfacefrom which the user selects a particular report from a submenu.

The Report Access Program (RAP) was written as an alternative manager for the Business Objects reports. The advantage is that the user does not have to log on to the Janus Application, which may be somewhat time-consuming, and that access to and expansion of Business Objects reports and queries could be more efficiently managed by ODP. This environment allows the user to create special reports using existing Business Object macros relatively easily.

The third approach is for ODP personnel to write standard queries in C-language and make them available through a World Wide Web (WWW) browser. This approach has the advantages that routines are directly suitable for global data access and that accessing data on the ship on the local web may be the fastest method. It will not provide the freestyle access to the database that Business Objects in the RAP environment offers to the user. However, recent information indicates that Business Objects will not continue to be supported on the Macintosh, which rules out its future use. The third approach will therefore most likely be fully implemented.

SAMPLE IDENTIFIERS AND DEPTH CALCULATION

Links to Curatorial Identifiers

In the relational ODP database, redundancy of information is minimized for efficient data management. For example, site, hole, core, and section information is entered in specific tables linked in a logical way, and all measurement locations in a particular section are linked to the <Section> table. Similarly, if a core specimen is extracted for shipboard or shore-based analysis, the basic curatorial information is accessed through the <Sample> table, which is linked to the <Section> table, etc. In the physical properties database models presented in the following chapters, the field <section_id> alone or with the fields <interval_top> and <interval_bottom> are the links to the more specific information in the appropriate tables. The <Sample> and <Section> tables are listed in Table 1—2.

Depth Types

Depth below seafloor of a core specimen or measurement location can be calculated in different ways. The standard way is to measure the distance in the recovered and physically expanded core and add it to the measured drill string depth datum for the top of the core. This depth scale is known as “meters below seafloor” (mbsf). Of course, this is only an approximation to the true depth below seafloor. Problems inherent in this scale are that the recovered core length may be greater than the interval advanced by the drill string, and some of the material from this interval was lost between successive cores. With APC material, this results in apparently overlapping sections between successive cores when in fact there is a coring gap.

If a complete stratigraphic section is to be constructed, multiple holes are drilled at the same site and a composite section is developed at the “meters composite depth” (mcd) scale. This scale is at the physically expanded state of the recovered cores and does not match the drilled interval. However, it is a much more continuous scale that can be fit approximately to the drilled interval using the core-top data (mbsf) or fit more precisely if good-quality downhole logging data are available.

There are additional corrections that can be applied to derive a more accurate approximation to depth below seafloor. These and other depth issues are explained in detail in a workshop report (Blum et al., 1995), and a technical note dedicated to these issues will be produced. The redefined concepts are integrated in the new database, which features a depth map that allows the rapid calculation of any depth type provided that pertinent data have been acquired and entered (see Table 1—2).

Standard data queries prompt the user to specify the desired depth type. The default map type (mbsf) is referred to (map_type_name) as “standard.”

Table 1—2 Database model for some essential s.

Map Type
map_type [PK1]
description
map_type_name
map_type_date

Depth Map
section_id [PK1] [FK]
map_type [PK2] [FK]
sect_interval_top [PK3]
sect_interval_bottom [PK4}
map_interval_top
map_interval_bottom

Section
section_id [PK1]
section_number
section_type
curated_length
liner_length
core_catcher_stored_in
section_comments
leg
site
hole
core
core_type

Sample
sample_id [PK1]
location [PK2]
sam_section_id . section_id
sam_archive_working
top_interval
bottom_interval
piece
sub_piece
beaker_id . mad_beaker_id
volume
entered_by
sample_depth
sample_comment
sam_repository . repository
s_c_leg . leg
s_c_sam_code . sam_code
sam_sample_code_lab . s_c_l

1.4. Physical Properties Standards

Standard materials used to calibrate instruments are an essential part of the analyses and should be integrated into the measurement systems accordingly. The goal is to enter all standards used into database tables so that calibration data and results can be tracked to the particular standard used at a given time. Our plan is to populate a <Physical Properties Standard> table shown in Table 1—3. The table is generic enough to accommodate any type of standard, and the value of any property can be linked to any calibration utility and file in the physical properties environment. This table may principally include standards from other laboratories as well.

Table 1—3 Physical properties standards database model.

Physical Properties Standard
standard_id [PK1]
standard_name
standard_set_name
date_time_commissioned
date_time_decommissioned
lot_serial_number
comments

Physical Properties Std Data
standard_id
property_name
property_description
property_value
property_units

A table of existing standards is in preparation.

Unfortunately, ODP has not made significant efforts to share standards and calibration procedures with other core laboratories (with rare exceptions). Such efforts would benefit ODP as well as other laboratories, and therefore the scientific drilling community, because reliable and widely endorsed calibration standards for systems that measure complex natural systems are difficult to find.