6. *P*-WAVE VELOCITY

6.1. Principles

PHYSICAL BACKGROUND

The basic relationship for sonic velocity is

$$v = d / t, \quad (1)$$

where d is the distance traveled through the material (in meters) and t is the travel time through the material (in seconds). The ODP user can choose among four measurement systems, each using a piezoelectric transducer pair. The basic equation is adapted to reflect the particular measurement condition.

The PWL system is mounted on the whole-core MST and measures d and t horizontally through the whole core, with or without the core liner. The measurements are anywhere in the x-y plane in the conventional core orientation system (Figure 6—1). PWS1 and PWS2 transducer pairs are designed to be inserted into the soft and semiconsolidated sediment of split cores. The two systems are mounted orthogonal to each other to measure along the core axis (PWS1, z-direction), and perpendicular to the axis and within the split plane (PWS2, y-direction). The core liner is not involved in these measurements. The PWS3 system allows measurements on split cores in the x-direction, with or without the core liner. In addition, other directions can be measured with the PWS3 system on cubic or cylindrical, consolidated or lithified core specimens.

Total travel time measured between the transducers includes three types of "delays":

- delay related to transducer faces and electronic circuitry (t_{delay}),
- delay related to the peak detection procedure (t_{pulse}), and
- transit time through the core liner, if applicable (t_{liner}).

These delays are explained in detail in the "Calibration" sections. Travel distance measurements must also be corrected for the liner wall thickness, d_{liner}, if core liners are involved.

For routine measurements on whole cores in core liners (PWL system):

$$v_{core} = (d'_{core} - 2d_{liner}) / (t_0 - t_{pulse} - t_{delay} - 2t_{liner}) \times 1000, \quad (2)$$

where

v_{core} = corrected velocity through core (km/s),
d'_{core} = measured diameter of core and liner (mm),
d_{1iner} = liner wall thickness (mm), and
t_0 = measured total travel time (µs).

For the PWS3 system measuring the transit time through the core material and a split liner, Equation on page 1 is modified only by the factor of 2 for the core liner correction:

$$v_{core} = (d'_{core} - d_{liner}) / (t_0 - t_{pulse} - t_{delay} - t_{liner}) \times 1000. \quad (3)$$

The liner wall correction is applied by default. If rock cuboids or cylinders are measured with the PWS3 system, the liner correction must be disabled by the user.

For the PWS1 and PWS2 systems as well as the PWS3 system measuring discrete core specimens:

$$v_{core} = d'_{core} / (t_0 - t_{pulse} - t_{delay}) \times 1000. \quad (4)$$

With the PWL and PWS3 systems, d'_{core} is determined for each measurement. For the PWS1 and PWS2 systems, the constant d'_{core} is obtained through calibration in water.

ENVIRONMENTAL EFFECTS

Core Quality

Core quality strongly affects the data quality or the ability to aquire *P*-wave velocity data. Even if good acoustic coupling with the core liner is achieved, there may be insufficient coupling between the core material and the core liner. A typical observation is that the uppermost sediment (seafloor to 10–50 mbsf) yields good data, presumably because the high porosity and limited elastic expansion maintains cohesion in the soft sediment. Below this and to depth of a few hundered meters, the signal is often strongly attenuated. This effect is more severe if gas escape is observed on the core cutting platform. Free gas in the sediment expands greatly upon recovery and may create voids and microcracks that make *P*-wave measurements impossible. Once the sediment becomes sufficiently consolidated and lithified, measurements tend to be more successful.

Signal Strength and Attenuation

The measured signal degenerates because of incompletely filled core liner or voids or because of attenuation caused by microcracks that formed during core recovery. This degeneration is partly reflected by the gain (signal strength) factor applied to the original signal by the automated gain control. However, signal strength also represents the grain size of the sediment, and low-strength signals can therefore not simply be interpreted as proportional to attenuation. If a filter is applied for data reduction, the relative decrease in signal strength from one sample to the other should be taken into consideration as well as the absolute signal strength.

Temperature Equilibrium

P-wave velocity in water is sensitive to temperature. Cores should therefore be at equilibrium when they are measured. Cores are routinely left to equilibrate for at least 4 hr (ODP technicians monitor the temperature with a thremistor probe). The core temperature should be entered by the operator (see “Data Specifications” section; currently this is a manual operation).

In Situ vs. Core Measurements

Measurements on sediment or rock cores differ from in situ measurements because cores expand on recovery because of lithostatic rebound and, possibly, gas expansion and other factors. Calibration of the measurements with corresponding sonic well logs is recommended. Velocities from sediment cores originating from more than a few hundred meters below seafloor typically are compatible with downhole measurements to within less than 3%, whereas shallower core measurements tend to be up to 5% lower than corresponding downhole measurements.

USE OF *P*-WAVE VELOCITY DATA

P-wave velocity varies with the lithology, porosity, and bulk density of the material; state of stress, such as lithostatic pressure; and fabric or degree of fracturing. In marine sediments and rocks, velocity values are also controlled by the degree of consolidation and lithification, fracturing, occurence and abundance of free gas and gas hydrate, etc. Together with density measurements, sonic velocity is used to calculate acoustic impedance, or reflection coefficients, which can be used to estimate the depth of reflectors observed in seismic profiles and to construct synthetic seismic profiles. Core measurement should be calibrated with in situ measurements wherever possible.

6.2. MST (Whole-Core) *P*-Wave Logger (PWL)

EQUIPMENT

The PWL system was purchased from GEOTEK Ltd. (UK) and modified for the specific requirements of ODP routine core logging. The core travels between two piezoelectric transducers mounted in epoxy and stainless-steel housings. The two transducers are used as a transmitter and receiver. Acoustic coupling is through an epoxy resin surface and is enhanced by a water film supplied by an automated sprinkler system. Firm contact is ensured through spring-loaded transducer housings. Two serially mounted linear variable-displacement transformers (LVDT) measure the diameter of the core (plus liner). A hydraulic piston system displaces the transducers by several millimeters at the beginning and end of a core section log to prevent the end caps from catching on to the transducers.

A 500-kHz pulse (2-µs wave period; 120 V) is produced at a repetition rate of 1 kHz. The pulse is sent to the transmitter transducer, which generates an ultrasonic compressional pulse at about 500 kHz. Pulse timing is measured with a resolution of 50 ns. The *P*-wave propagates through the core, is received by the receiver transducer, and is amplified by an automatic gain control amplifier to produce the received signal. A delay pulse is generated after the transmit pulse (Figure 6—1). The delay time must be set (thumbwheel control) to a few microseconds less than the arrival of the signal. A 20-µs gate pulse follows the delay pulse; during this period a peak detector senses the peak voltage of the received signal after gain control. A threshold detector is used for automatic peak detection: it is set low when a preset fraction of the peak level (the threshold level) is crossed. In addition, a zero-crossing detector detects all zero voltage crossings. A count pulse, which is displayed on the instrument unit in microseconds, is generated at a time corresponding to the first zero crossing after the first low-threshold event. The resulting pulse detection delay is one wavelength (2 µs) if the the first peak is positive and 1.5 wavelengths (3 µs) if the first peak is negative, because the threshold is always detected on the negative signal. By detecting the travel time using a zero-crossing technique, the travel time recorded is independent of the signal amplitude.

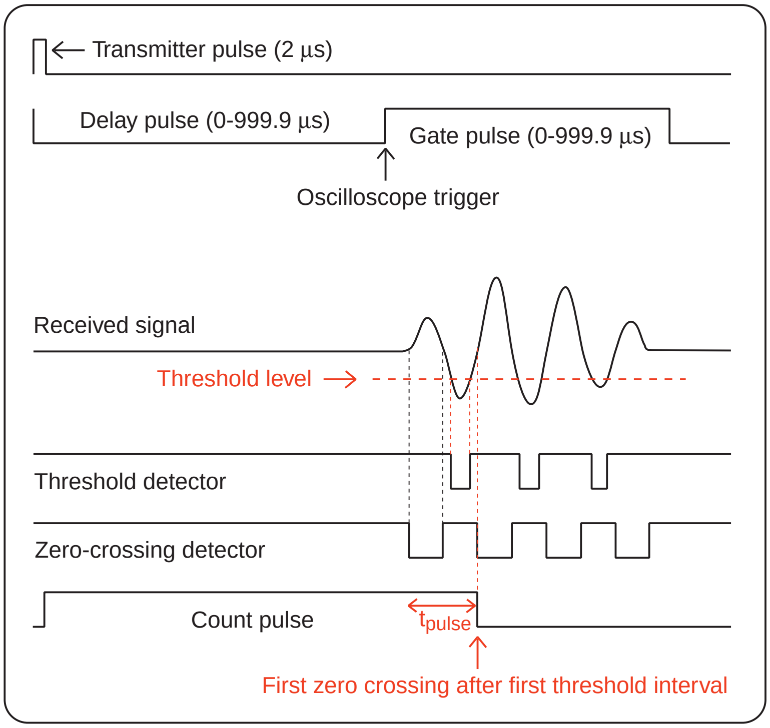

Figure 6—1 Schematic diagram of pulse timing and threshold peak detection (modified after GEOTEK manual).

CALIBRATION

Pulse Detection

Pulse detection settings are checked by ODP personnel on a regular basis and should not require any adjustment by the user. It may become necessary to adjust the pulse from time to time (e.g., when equipment is replaced or materials of different geometry are measured). The oscilloscope normally connected for the user to monitor the received signal can be used for adjusting pulse timing and threshold detection. The following procedure is modified after the GEOTEK manual:

1. Place a water core (large signal) between the transducers. Ensure a good (wet) coupling. The “Level” indicator should be high. A clear received pulse should be visible on channel 1 and the delay pulse on channel 2. Use the thumbwheel to adjust the delay time such that it ends just prior to the start of the received signal (approximately 35 µs).
2. Check that the count pulse occurs at the first zero-crossing after the first (or second, if wired in the opposite sense) negative excursion. If this is not the case, the threshold voltage level requires adjustment (procedure follows).

3. Remove the water core and observe the signal through air (small signal; “Level” indicator low). Check again that the count pulse occurs at the first zero-crossing after the first (or second, if wired in the opposite sense) negative excursion. If this is not the case, the threshold voltage level requires adjustment (procedure follows).
4. Check that the travel time shown on the LCD is in approximate agreement with the travel time shown on the oscilloscope.

If the threshold level requires adjustment:

1. The purpose is to ensure that that the threshold operating level V_{op} consistently picks first negative excursions over as wide an amplitude range as possible.
2. Place the water core (large signal) between the transducers. Adjust “Set high” so that the threshold operates just on the first (or second, if wired in the opposite sense) negative excursion.
3. With a very small signal (through air with the transducers at their closest position), adjust the threshold operating voltage using “Set low” such that the threshold operates above the noise level but detects the first (or second, if wired in the opposite sense) real negative excursion.
4. Repeat this procedure until the threshold operates correctly over the entire range of signal levels.

Pulse Time

The pulse time is a time constant included in the total time measured as a result of the threshold peak detection procedure used. This constant may not be apparent with peak detection or calibration procedures different from those described here. ODP subtracts this constant from raw measurements of time because (1) it allows a more precise monitoring of system performance (pulse time and “hardware delay”, discussed in the following section) and (2) it renders measured time values that are independent of a particular peak detection procedure.The constant t_{pulse} is therefore subtracted from the raw measurement of time t_0 so that

$$t'_0 = t_0 - t_{pulse}. \tag{5}$$

The important thing to note is that the pulse time value changes depending on the wiring of the system. If the first received peak voltage is positive (Figure 6—1) the pulse time will be one wavelength, or 2 µs, for the 500 kHz transducers. However, if the wiring is in the opposite direction, as was the case for the ODP system at least for some time, the pulse time is 1.5 wavelength, or 3 µs, because the threshold detection is always on the negative signal.

Transducer Displacement and Traveltime Delay

These two calibrations are performed simultaneously in one procedure (Figure 6—2). They should be executed once per leg on a routine basis. They should also be performed when changes or replacement of equipment have occurred, transducer surfaces have experienced extraordinary wear, or if other problems are suspected.

Variation in the thickness of the sediment-filled core liner (d'_{core}) is measured using an LVDT connected to the spring-loaded transducer housings. Displacement measured in volts must be calibrated to give millimeters. At least three of the available standard acrylic cylinders are measured. A linear least-squares fit to the points defined by the voltage readings (x-axis) and the known standard thicknesses in millimeters (y-axis) yields the linear coefficients m_{d1} (mm/V) and m_{d0} (mm). Then, for any calibration standard or core measurement, respectively:

$$d_{cal} = m_{d0} + m_{d1}V_0 \quad (6)$$

$$d'_{core} = m_{d0} + m_{d1}V_0 \ , \quad (7)$$

where V_0 is the voltage reading.

As previously mentioned, the total travel time (t_0) measured between the transducers includes three types of "delays":

- delay related to the peak detection procedure (t_{pulse}; see "Pulse Time" section),
- transit time through the core liner, if applicable (t_{liner}; see "Liner Correction" section), and
- undifferentiable delay related to transducer faces and electronic circuitry (t_{delay}), which is determined with this procedure.

Although it is not necessary for the routine logging of sediment cores, ODP differentiates between these types of delay because it allows for more rigorous system monitoring and more flexibility in measurements. The constant t_{pulse} is subtracted from the raw measurement of time t_0 so that

$$t_{cal} = t_0 - t_{pulse}. \quad (8)$$

The "hardware delay" of t_{delay} is then determined from another least-squares regression. Here, the x-axis is defined by the d_{cal} values of the standards determined previously, and the y-axis is t_{cal}. The linear coefficient, m_1 (µs/mm), is the inverse of the velocity of the standards ($1/v_{standard}$), and the intercept, m_0 (µs), is t_{delay} (Figure 6—2). Thus, the corrected transit time through a core is

$$t'_{core} = t_0 - t_{pulse} - t_{delay}. \quad (9)$$

If no core liner correction must be applied (i.e., if the material to be measured is directly in contact with the transducers), the velocity is calculated as

$$v'_{core} = d'_{core} / t'_{core}. \quad (10)$$

Liner correction

In most cases (i.e., when logging whole cores in core liners), measured travel distance and time must be corrected for twice the liner thickness. The liner calibration is a measurement of thickness and transit time through core liner material and is performed by ODP personnel. The liner correction is applied by default (unless disabled by the user), using a constant liner thickness, d_{liner}, and sonic velocity for the liner material, v_{liner}:

$$d_{core} = d'_{core} - 2d_{liner} \quad (11)$$

$$t_{core} = t'_{core} - 2d_{liner}/v_{liner} \quad (12)$$

$$v_{core} = d_{core} / t_{core}. \quad (13)$$

At present, we have no means of routinely measuring and correcting for variations in liner wall thickness during logging. Vendor specifications for the wall thickness are 5.64 to 4.70 mm, and we use 5.17 mm, or $2d_{liner}$ = 1.03 cm.

P-WAVE LOGGER (FULL-CORE)

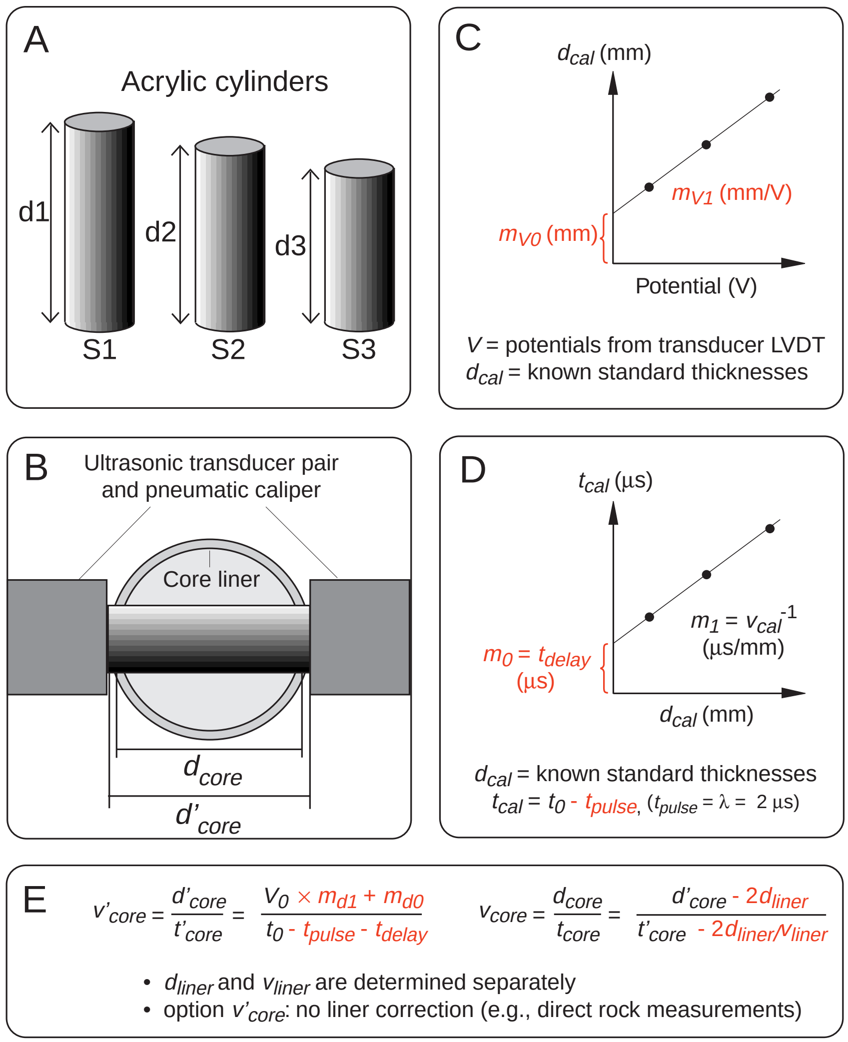

Figure 6—2 Schematic of PWL calibration. A. Physical standard used. B. Measurement geometry. C. and D. Calibration principle. E. Application of calibration to core measurement.

PERFORMANCE

Precision

Measurements on standard materials (e.g., water, acrylic calibration standards) are repeatable within ±1 km/s. (Systematic evaluation required.)

Accuracy

Accuracy can be evaluated by measuring pure water at varying and exactly known temperatures. Past experience shows that for a properly calibrated system and good acoustic coupling, the disagreement with published $v_{(T)}$ values is less than ±2 km/s. (Systematic evaluation needed.)

MEASUREMENT

P-wave velocity is logged downcore automatically.

DATA SPECIFICATIONS

Database Model

Table 6—1 PWL Database Model.

PWL section
pwl_id [PK1]
section_id
run_number
run_date_time
core_status
liner_status
liner_correction
liner_standard_id
requested_daq_interval
req_daqs_per_sample
pwl_calibration_id
acoustic_signal_threshold
core temperature
mst_pwl_ctrl_3_id

PWL control 1
pwl_ctrl_1_id [PK1]
run_number
run_date_time
core_status
liner_status
liner_correction
requested_daq_interval
req_daqs_per_sample
pwl_calibration_id
standard_id
acoustic_signal_threshold
core temperature
standard_liner_id

PWL control 3
pwl_ctrl_3_id [PK1]
run_number
run_date_time
req_daqs_per_sample
pwl_calibration_id
standard_id
acoustic_signal_threshold
core temperature
core_status
liner_status
meas_separation_mean
meas_separation_sd
meas_time_mean
meas_time_sd
acoustic_signal_mean
attempted_daqs
valid_daqs
liner_thickness
standard_liner_id

PWL calibration
pwl_calibration_id [PK1]
calibration_date_time
run_number
system_id
req_daqs_per_sample
acoustic_signal_threshold
pwl_frequency
pulse_time_correction
separation_m0
separation_m1
separation_mse
delay_m0
delay_1_m1
delay_mse
comments

PWL section data
pwl_id [PK1] [FK]
mst_top_interval [PK2]
mst_bottom_interval
meas_separation_mean
meas_separation_sd
meas_time_mean
meas_time_sd
acoustic_signal_mean
attempted_daqs
valid_daqs
liner_thickness
liner_standard_id

PWL control 1 data
pwl_ctrl_1_id [PK1] [FK]
mst_top_interval [PK2]
mst_bottom_interval
meas_separation_mean
meas_separation_sd
meas_time_mean
meas_time_sd
acoustic_signal_mean
attempted_daqs
valid_daqs
liner_thickness

PWL calibration data
pwl_calibration_id [PK1] [FK]
standard_id [PK2] [FK]
mst_top_interval
mst_bottom_interval
standard_length
meas_separation_mean
meas_separation_sd
meas_time_mean
meas_time_sd
acoustic_signal_mean
attempted_daqs
valid_daqs

Notes: PWL Ctrl 1 are control measurements run the same way as a core section. PWL Ctrl 3 are control measurements from a standard mounted on the core boat (pure water).

Standard Queries

Table 6—2 PWL report.

Short description	Description	Database
A: results		
Sample ID	ODP standard sample designation	Link through [PWL Section] section_id
Depth	User-selected depth type	Link through [PWL Section] section_id
Velocity	Calculated *P*-wave velocity	= ([PWL Section Data] meas_separation_mean - 2* [PWL Section Data] liner_thickness) / ([PWL Section Data] meas_time_mean - {2* [PWL Section Data] liner_thickness / [PP Std Data] liner_velocity} - [PWL Calibration] delay_m0)
B (optional): Parameteres and measurements		
Run	Run number	[PWL Section] run_number
Date/Time	Run date/time	[PWL Section] run_date_time
Core Status	HALF or FULL	[PWL Section] core_status
Liner Status	NONE, HALF or FULL	[PWL Section] liner_status

Table 6—2 PWL report.

Liner correction	Liner correction (Yes/No)	[PWL Section] liner_correction
Req. Interval	User-defined sampling interval (cm)	[PWL Section] requested_daq_interval
Req. Sample	Requested DAQS per sample	[PWL Section] requested_daqs_per_sample
Signal	Acoustic signal threshold	[PWL Section] acoustic_signal_threshold
Core Temp	Core temperature	[PWL Section] core_temperature
Sep. Mean	Mean of transducer separation	[PWL Section Data] meas_separation_mean
Sep. S.D.	Standard deviation of transducer separation	[PWL Section Data] meas_separation_sd
Time Mean	Mean of transit tme	[PWL Section Data] meas_time_mean
Time std. dev.	Standard deviation of transit time	[PWL Section Data] meas_time_sd
Signal	Mean of acoustic signal	[PWL Section Data] acoustic_signal_mean
Attempted DAQS	Attempted numnber of data acquisitions	[PWL Section Data] attempted_daqs
Valid DAQS	Valid number ofdata acquisitions	[PWL Section Data] valid_daqs
Liner Thickness	Liner thickness (entered manually)	[PWL Section Data] liner_thickness
Standard name	Standard name	[Phys. Properties Std.] standard_name
Standard Set	Standard set name	[Phys. Properties Std.] standard_set_name
Std. Expected	Expected value (range) (g/cm^3)	[Phys. Prop. Std. Data] property_value
Cal. Date/Time	Calibration date/time	[PWL Calibration] calibration_date_time
Cal. Separ. m0	Intercept of transducer separation calibration	[PWL Calibration] separation_m0
Cal. Separ. m1	Slope of transducer separation calibration	[PWL Calibration] separation_m1
Cal. Separ. mse	Mean squared errorof transducer separation cal.	[PWL Calibration] separation_mse
Cal. Time m0	Intercept of transit time calibration	[PWL Calibration] delay_m0
Cal. Time m1	Slopeof transit time calibration	[PWL Calibration] delay_m1
Cal. Time mse	Mean squared error of transit time calibration	[PWL Calibration] delay_mse

Table 6—3 PWL control 1 measurements (to be implemented).

Short description	Description	Database
Velocity	Calculated *P*-wave velocity	= ([PWL Ctrl 1 Data] meas_separation_mean - 2* [PWL Ctrl 1 Data] liner_thickness) / ([PWL Ctrl 1 Data] meas_time_mean - {2* [PWL Ctrl 1 Data] liner_thickness / [PP Std Data] liner_velocity} - [PWL Calibration] delay_m0)
Run	Run number	[PWL Ctrl 1] run_number
Date/Time	Run date/time	[PWL Ctrl 1] run_date_time
Core Status	HALF or FULL	[PWL Ctrl 1] core_status
Liner Status	NONE, HALF or FULL	[PWL Ctrl 1] liner_status
Liner Corr.	Liner correction (Yes/No)	[PWL Ctrl 1] liner_correction
Req. Interval	User-defined sampling interval (cm)	[PWL Ctrl 1] requested_daq_interval
Req. Sample	User-defined DAQs per sample	[PWL Ctrl 1] requested_daqs_per_sample
Signal	Acoustic signal threshold	[PWL Ctrl 1] acoustic_signal_threshold
Core Temp	Core temperature	[PWL Ctrl 1] core_temperature
Interval	Interval top	[PWL Ctrl 1 Data] mst_top_interval
Sep. Mean	Separation mean	[PWL Ctrl 1 Data] meas_separation_mean
Sep. S.D.	Separation standard deviation	[PWL Ctrl 1 Data] meas_separation_sd
Time Mean	Time mean	[PWL Ctrl 1 Data] meas_time_mean
Time S.D.	Time standard deviation	[PWL Ctrl 1 Data] meas_time_sd
Signal	Acoustic signal mean	[PWL Ctrl 1 Data] acoustin_signal_mean
Daqs Attempt	Attempted data acquisitions	[PWL Ctrl 1 Data] attempted_daqs
Daqs Valid	Valid data acquisitions	[PWL Ctrl 1 Data] valid_daqs
Liner Thick	Liner thickness (entered manually)	[PWL Ctrl 1 Data] liner_thickness
Standard	Standard name	[Phys. Properties Std.] standard_name
Std. Set	Standard set name	[Phys. Properties Std.] standard_set_name
Std. Expected	Expected value (range) (g/cm^3)	[Phys. Prop. Std. Data] property_value
Cal. Date/Time	Cal. date/time	[PWL Calibration] calibration_date_time
Cal. Separ. m0	Cal. separation intercept m_0	[PWL Calibration] separation_m0
Cal. Separ. m1	Cal. separation slope m_1	[PWL Calibration] separation_m1

Table 6—3 PWL control 1 measurements (to be implemented).

Cal. Separ. mse	Cal. separation mean squared error	[PWL Calibration] separation_mse
Cal. Time m0	Cal. time intercept m_0	[PWL Calibration] delay_m0
Cal. Time m1	Cal. time slope m_1	[PWL Calibration] delay_m1
Cal. Time mse	Cal. time mean squared error	[PWL Calibration] delay_mse

Table 6—4 PWL control 3 measurements (to be implemented).

Short description	Description	Database
Velocity	Calculated *P*-wave velocity	= ([PWL Ctrl 3] meas_separation_mean - 2* [PWL Ctrl 3] liner_thickness) / ([PWL Ctrl 3] meas_time_mean - {2* [PWL Ctrl 3] liner_thickness / [PP Std Data] liner_velocity} - [PWL Calibration] delay_m0)
Run	Run number	[PWL Ctrl 3] run_number
Date/Time	Run date/time	[PWL Ctrl 3] run_date_time
Core Status	HALF or FULL	[PWL Ctrl 3] core_status
Liner Status	NONE, HALF or FULL	[PWL Ctrl 3] liner_status
Req. Interval	User-defined sampling interval (cm)	[PWL Ctrl 3] requested_daq_interval
Req. Sample	User-defined DAQs per sample	[PWL Ctrl 3] requested_daqs_per_sample
Signal	Acoustic signal threshold	[PWL Ctrl 3] acoustic_signal_threshold
Core Temp	Core temperature	[PWL Ctrl 3] core_temperature
Sep. Mean	Separation mean	[PWL Ctrl 3] meas_separation_mean
Sep. S.D.	Separation standard deviation	[PWL Ctrl 3] meas_separation_sd
Time Mean	Time mean	[PWL Ctrl 3] meas_time_mean
Time S.D.	Time standard deviation	[PWL Ctrl 3] meas_time_sd
Signal	Acoustic signal mean	[PWL Ctrl 3] acoustic_signal_mean
Daqs Attempt	Attempted data acquisitions	[PWL Ctrl 3] attempted_daqs
Daqs Valid	Valid data acquisitions	[PWL Ctrl 3] valid_daqs
Liner Thick	Liner thickness (entered manually)	[PWL Ctrl 3] liner_thickness
Standard	Standard name	[Phys. Properties Std.] standard_name
Std. Set	Standard set name	[Phys. Properties Std.] standard_set_name
Std. Expected	Expected value (range) (g/cm*3*)	[Phys. Prop. Std. Data] property_value
Cal. Date/Time	Cal. date/time	[PWL Calibration] calibration_date_time
Cal. Separ. m0	Cal. separation intercept m_0	[PWL Calibration] separation_m0
Cal. Separ. m1	Cal. separation slope m_1	[PWL Calibration] separation_m1
Cal. Separ. mse	Cal. separation mean squared error	[PWL Calibration] separation_mse
Cal. Time m0	Cal. time intercept m0	[PWL Calibration] delay_m0
Cal. Time m1	Cal. time slope m_1	[PWL Calibration] delay_m1
Cal. Time mse	Cal. time mean squared error	[PWL Calibration] delay_mse

Table 6—5 PWL calibration data (to be implemented).

Short description	Description	Database
Date/Time	Cal. date/time	[PWL Calibration] calibration_date_time
Run	Cal. run number	[PWL Calibration] run_number
Req. Sample	User-defined DAQs per sample	[PWL Calibration] requested_daqs_per_sample
Signal	Acoustic signal threshold	[PWL Calibration] acoustic_signal_threshold
Frequency	PWL frequency	[PWL Calibration] pwl_frequency
Pulse Time	Pulse time correction	[PWL Calibration] pule_time_correction
Separ. m0	Cal. separation intercept m_0	[PWL Calibration] separation_m0
Separ. m1	Cal. separation slope m_1	[PWL Calibration] separation_m1
Separ. mse	Cal. separation mean squared error	[PWL Calibration] separation_mse
Time m0	Cal. time intercept m0	[PWL Calibration] delay_m0
Time m1	Cal. time slope m_1	[PWL Calibration] delay_m1

Table 6—5 PWL calibration data (to be implemented).

Time mse	Cal. time mean squared error	[PWL Calibration] delay_mse
Comments	Cal. comments	[PWL Calibration] comments
Time mse	Cal. time mean squared error	[PWL Calibration] delay_mse
Interval	Interval top	[PWL Calibration Data] mst_top_interval
Std. Length	Length of standard	[PWL Calibration Data] standard_length
Separ. Mean	Mean of transducer separation	[PWL Calibration Data] separation_mean
Separ. S.D.	Standard deviation of transducer separation	[PWL Calibration Data] separation_sd
Time Mean	Mean of transit time	[PWL Calibration Data] time_mean
Time S.D.	Standard deviation of transit time	[PWL Calibration Data] time_sd
Signal	Acoustic signal mean	[PWL Calibration Data] acoustic_signal_mean
Daqs Attempt	Attempted data acquisitions	[PWL Calibration Data] attempted_daqs
Daqs Valid	Valid data acquisitions	[PWL Calibration Data] valid_daqs
Standard	Standard name	[Phys. Properties Std.] standard_name
Std. Set	Standard set name	[Phys. Properties Std.] standard_set_name
Std. Expected	Expected value (range) (g/cm^3)	[Phys. Prop. Std. Data] property_value

6.3. PWS1 and PWS2 Insertion Probe Systems

EQUIPMENT

The current equipment has replaced the Digital Sonic Velocimeter (DSV) developed at Dalhousie University and the Bedford Institute of Oceanography, Nova Scotia, which was first used on ODP Leg 138 in 1991 (PWS1 and PWS2). The principles remain the same, but hardware and computer control have been improved significantly, and calibration and measurement procedures are simplified at this upgraded station.

A vise-like frame holds the two transducers pairs. Their use is limited approximately to the depth range of APC cores (i.e., a maximum depth of 50 to 300 mbsf), depending on the lithology.

A Tectronix signal generator, differential amplifier, and oscilloscope are used to transmit and receive signals from all three transducer pairs and to digitize analog waveform data. The instrument can record two voltage inputs with a minimum sampling time of 5 ns and a digitizing signal to noise ratio of 50 dB.

An external digital thermometer is used to record core temperature. The values are recorded in the database but are not used for shipboard reporting. Correction algorithms must be researched, selected, and applied by the user.

CALIBRATION

Delay

The distance d between the transducers is measured with calipers once every few days (or even once per leg) and then assumed to be constant. The distance between the probe surfaces does not exactly correspond to the distance between the transducers. In addition, there is some electrical delay. The total “delay” t_{delay} is determined in this calibration by inserting the probes into a container filled with distilled water of known temperature and therefore of known sound velocity v_{water}. Because d is known, transit time in water, t_{water}, can be computed as

$$t_{water} = v_{water} \times d. \tag{14}$$

The measured total transit time, t, is:

$$t = t_{water} + t_{delay}. \tag{15}$$

Combining these equations, the delay can be expressed as:

$$t_{delay} = t - v_{water} \times d. \tag{16}$$

This calibration should be performed when the operator suspects a change in the distance between the probes because of heavy use or from other reasons.

PERFORMANCE

No performance evaluation data exist at present.

MEASUREMENT

An on-line guide is available at the neasurement station.

DATA SPECIFICATIONS

Data Mode

l

Table 6—6 PWS1 and PWS2 data model.

PWS1/2 section
pws_id [PK1]
section_id
run_num
run_date_time
system_id
pws_calibration_id
direction
core_temperature
raw_data_collected

PWS1/2 control 1
pws_ctrl_1_id [PK1]
run_number
run_date_time
system_id
standard_id
pws_calibration_id
direction
core_temperature
raw_data_collected
transducer_separation
measured_time

PWS1/2 calibration
pws_calibration_id [PK1]
calibration_date_time
run_num
system_id
water_temperature
standard_velocity
measured_time
delay
freq
comments

PWS1/2 section data
pws_id [PK1 [FK]
pp_top_interval [PK2]
measurement_no [PK3]
pp_bottom_interval
transducer_separation
measured_time

PWS1/2 raw data
pws_id [PK1 [FK]
pp_top_interval [PK2] [FK]
measurement_no [PK3] [FK]
voltage [PK4]
time

PWS1/2 control 1 raw data
pws_ctrl_1_id [PK1 [FK]
voltage [PK2]
time

Notes: Control 1 measurements are run like core measurements, using a standard of known velocity.

Standard queries

Table 6—7 PWS1 or PWS2 report

Short description	Description	Database
A: Results		
Sample ID	ODP standard sample designation	Link through [PWS1/2 Section] section_id
Depth	User-selected depth type	Link through [PWS1/2 Section] section_id
Direction	Direction (PWS1 = z; PWS2 = y)	[PWS1/2 Section] direction
Velocity	Calculated *P*-wave velocity	= [PWS1/2 Section Data] transd_separation / ([PWS1/2 Section Data] measured_time - [PWS1/2 Calibration] delay)
B (optional): Measurement parameters and raw data		
Run	Run number	[PWS1/2 Section] run_number
Date/Time	Run date/time	[PWS1/2 Section] run_date_time
Core Temperature	Core temperature	[PWS1/2 Section] core_temperature
Raw Data	Raw data collected flag (yes/no)	[PWS1/2 Section] raw_data_collected
Meas. No	Measurement number	[PWS1/2 Section Data] measurement_no
Separation	Transducer separation	[PWS1/2 Section Data] transducer_separation
Time	Measured time	[PWS1/2 Section Data] measured_time
Cal. Date/Time	Cal. date/time	[PWS1/2 Calibration] calibration_date_time
Cal. Delay	Cal. delay	[PWS1/2 Calibration] delay

Table 6—8 PWS1 or PWS2 control 1 measurements (to be implemented).

Short description	Description	Database
Velocity	Calculated *P*-wave velocity	= [PWS1/2 Ctrl 1] transd_separation / ([PWS1/2 Ctrl 1] measured_time - [PWS1/2 Calibration] delay)
Run	Run number	[PWS1/2 Ctrl 1] run_number
Date/Time	Run date/time	[PWS1/2 Ctrl 1] run_date_time
Direction	Direction (PWS1 = z; PWS2 = y)	[PWS1/2 Ctrl 1] direction
Core Temp	Core temperature	[PWS1/2 Ctrl 1] core_temperature
Raw Data	Raw data collected flag (yes/no)	[PWS1/2 Ctrl 1] raw_data_collected
Separation	Transducer separation	[PWS1/2 Ctrl 1] transducer_separation
Time	Measured time	[PWS1/2 Ctrl 1] measured_time
Cal. Date/Time	Cal. date/time	[PWS1/2 Calibration] calibration_date_time
Cal. Delay	Cal. delay	[PWS1/2 Calibration] delay
Standard	Standard name	[Phys. Properties Std.] standard_name
Std. Set	Standard set name	[Phys. Properties Std.] standard_set_name
Std. Expected	Expected value (range) (g/cm^3)	[Phys. Prop. Std. Data] property_value

Table 6—9 PWS1 or PWS2 calibration data (to be implemented).

Short description	Description	Database
Date/Time	Cal. date/time	[PWS1/2 Calibration] calibration_date_time
Run	Cal. run number	[PWS1/2 Calibration] run_number
Water Temperature	Water temperature	[PWS1/2 Calibration] water_temperature
Velocity	Velocity of water at given temperature.	[PWS1/2 Calibration] standard_velocity
Time	Measured time	[PWS1/2 Calibration Data] measured_time
Delay	Delay time derived from calibration.	[PWS1/2 Calibration Data] delay
Frequency	Transducer frequency	[PWS1/2 Calibration Data] freq
Comments	Comments	[PWS1/2 Calibration Data] comments
Standard	Standard name	[Phys. Properties Std.] standard_name
Std. Set	Standard set name	[Phys. Properties Std.] standard_set_name
Std. Expected	Expected value (range) (g/cm^3)	[Phys. Prop. Std. Data] property_value

Table 6—10 PWS1 or PWS2 wave form data (to be implemented).

Short description	Description	Database
Sample ID	ODP standard sample designation	
Measurement	Measurement number	[PWS1/2 Raw Data] measurement_no
Voltage	Voltage	[PWS1/2 Raw Data] voltage
Time	Time	[PWS1/2 Raw Data] time

Table 6—11 PWS1 or PWS2 wave form control 1 data (to be implemented).

Short description	Description	Database
Date/Time	Run date/time	[PWS1/2 Ctrl 1] run_date_time
Voltage	Voltage	[PWS1/2 Ctrl 1 Raw Data] voltage
Time	Time	[PWS1/2 Ctrl 1 Raw Data] time

6.4. PWS3 Contact Probe System

EQUIPMENT

The current equipment has replaced the Hamilton Frame used on the ship since the beginning of ODP. The principles remain the same but the hardware and computer control have been improved significantly, and calibration and measurement procedures are simplified at this upgraded station. The PWS3 is equipped with a digital scale unit that allows rapid, precise determination of sample thickness and enters the value into the database.

A pressure gauge is built into the monitor, and pressure is applied to the sample when lowering the transducer onto the specimen or split core in the liner. In the split core (logging) mode, the core section liner rests on the bottom transducer and the upper transducer is lowered manually (procedure to be automated soon) onto the core surface. In the specimen mode, the sample is placed directly between the two transducers in the desired orientation.

CALIBRATION

Delay

This calibration procedure is equivalent to the one employed for the *P*-wave logger on the MST. Delay time t_{delay} is obtained by measuring a standard material of different thicknesses $d_1, d_2, \ldots d_n$, and total transit times $t_1, t_2, \ldots t_n$. The coefficient m_0 (intercept) obtained from a linear least-squares fit represents the delay t_{delay}. The inverse of the coefficient m_1 (slope) of that regression is the velocity of the standard material.

PERFORMANCE

No performance evaluation data exist at present.

MEASUREMENT

An on-line guide is available at the neasurement station.

DATA SPECIFICATIONS

Database Model

Table 6—12 PWS3 database model.

PWS3 section
pws_id [PK1]
section_id
run_num
run_date_time
system_id
pws_calibration_id
direction
core_temperature
liner_correction
raw_data_collected
standard_liner_id

PWS3 control 1
pws_ctrl_1_id [PK1]
run_num
run_date_time
system_id
standard_id
pws_calibration_id
direction
core_temperature
standard_liner_id
raw_data_collected
transducer_separation
measured_time
contact_pressure
liner_thickness

PWS3 calibration
pws_calibration_id [PK1]
calibration_date_time
run_number
system_id
delay_1_over_m1
delay_m0
delay_mse
freq
comments

PWS3 section data
pws_id [PK1] [FK]
pp_top_interval [PK2]
measurement_no [PK3]
pp_bottom_interval
transducer_separation
measured_time
contact_pressure
liner_thickness

PWS3 calibration data
pws_calibration_id [PK1] [FK]
standard_id [PK2] [FK]
transducer_separation
measured_time
contact_pressure

PWS3 raw data
pws_id [PK1] [FK]
pp_top_interval [PK2] [FK]
measurement_no [PK3] [FK]
voltage [PK4]
time

PWS3 control 1 raw data
pws_ctrl_1_id [PK1] [FK]
voltage [PK2]
time

Notes: Control 1 measurements are run like core measurements, using a standard of known velocity.

Standard Queries

Table 6—13 PWS3 report.

Short description	Description	Database
A: Results		
Sample ID	ODP standard sample designation	Link through [PWS3 Section] section_id
Depth	User-selected depth type	Link through [PWS3 Section] section_id
Velocity	IF (liner_correction = TRUE)	= ([PWS3 Section Data] transducer_separation - [PWS3 Section Data] liner_thickness) / ([PWS3 Section Data] measured_time - [PWS3 Section Data] liner_thickness / [PP Std Data] liner_velocity} - [PWS3 Calibration] delay_m0)
Velocity	IF (liner_correction =FALSE)	= ([PWS3 Section Data] transducer_separation / ([PWS3 Section Data] measured_time

Table 6—13 PWS3 report.

		- [PWS3 Calibration] delay_m0)
B (optional): Measurement parameters and raw data		
Run	Run number	[PWS3 Section] run_number
Date/Time	Run date/time	[PWS3 Section] run_date_time
Direction	Direction (PWS1 = z; PWS2 = y)	[PWS3 Section] direction
Core Temp	Core temperature	[PWS3 Section] core_temperature
Liner Corr.	Liner correction required (yes/no)	[PWS3 Section] liner_correction
Raw Data	Raw data collected flag (yes/no)	[PWS3 Section] raw_data_collected
Standard	Standard name	[Phys. Properties Std.] standard_name
Std. Set	Standard set name	[Phys. Properties Std.] standard_set_name
Std. Expected	Expected value (range) (g/cm^3)	[Phys. Prop. Std. Data] property_value
Meas. No	Measurement number	[PWS3 Section Data] measurement_no
Separation	Transducer separation	[PWS3 Section Data] transducer_separation
Time	Measured time	[PWS3 Section Data] measured_time
Pressure	Contact pressure applied	[PWS3 Section Data] contact pressure
Liner Thick	Liner thickness	[PWS3 Section Data] liner thickness
Cal. Date/Time	Cal. date/time	[PWS3 Calibration] calibration_date_time
Cal. m0	Cal. time intercept m_0	[PWS3 Calibration] delay_m0
Cal. 1/m1	Cal. time inverse of slope $_1/m_1$	[PWS3 Calibration] delay_1_over_m1
Cal. Time mse	Cal. time mean squared error	[PWS3 Calibration] delay_mse

Table 6—14 PWS3 control 1 measurements (to be implemented).

Short description	Description	Database
Velocity	IF (liner_correction = TRUE)	= ([PWS3 Ctrl 1] transducer_separation - [PWS3 Ctrl 1] liner_thickness) / ([PWS3 Ctrl 1] measured_time - [PWS3 Ctrl 1] liner_thickness / [PP Std Data] liner_velocity} - [PWS3 Calibration] delay_m0)
Velocity	IF (liner_correction =FALSE)	= ([PWS3 Ctrl 1] transducer_separation / ([PWS3 Ctrl 1] measured_time - [PWS3 Calibration] delay_m0)
Run	Run number	[PWS3 Ctrl 1] run_number
Date/Time	Run date/time	[PWS3 Ctrl 1] run_date_time
Direction	Direction (PWS1 = z; PWS2 = y)	[PWS3 Ctrl 1] direction
Core Temperature	Core temperature	[PWS3 Ctrl 1] core_temperature
Liner Correction	Liner correction required (yes/no)	[PWS3 Ctrl 1] liner_correction
Raw Data	Raw data collected flag (yes/no)	[PWS3 Ctrl 1] raw_data_collected
Separation	Transducer separation	[PWS3 Ctrl 1] transducer_separation
Time	Measured time	[PWS3 Ctrl 1] measured_time
Pressure	Contact pressure applied	[PWS3 Section Data] contact pressure
Liner Thick	Liner thickness	[PWS3 Section Data] liner thickness
Cal. Date/Time	Cal. date/time	[PWS3 Calibration] calibration_date_time
Cal. m0	Cal. time intercept m_0	[PWS3 Calibration] delay_m0
Cal. 1/m1	Cal. time inverse of slope $_1/m_1$	[PWS3 Calibration] delay_1_over_m1
Cal. Time mse	Cal. time mean squared error	[PWS3 Calibration] delay_mse
Standard	Standard name	[Phys. Properties Std.] standard_name
Std. Set	Standard set name	[Phys. Properties Std.] standard_set_name
Std. Expected	Expected value (range) (g/cm^3)	[Phys. Prop. Std. Data] property_value

Table 6—15 PWS3 calibration data (to be implemented).

Short description	Description	Database
Date/Time	Cal. date/time	[PWS3 Calibration] calibration_date_time
Run	Cal. run number	[PWS3 Calibration] run_number
Cal. m0	Cal. time intercept m_0	[PWS3 Calibration] delay_m0

Table 6—15 PWS3 calibration data (to be implemented).

Cal. 1/m1	Cal. time inverse of slope $_1/m_1$	[PWS3 Calibration] delay_1_over_m1
Cal. Time mse	Cal. time mean squared error	[PWS3 Calibration] delay_mse
Frequency	Transducer frequency	[PWS3 Calibration] freq
Comments	Comments	[PWS3 Calibration] comments
Separation	Transducer separation	[PWS3 Calibration Data] transducer_separation
Time	Measured time	[PWS3 Calibration Data] measured_time
Pressure	Contact pressure	[PWS3 Calibration Data] contact_pressure
Standard	Standard name	[Phys. Properties Std.] standard_name
Std. Set	Standard set name	[Phys. Properties Std.] standard_set_name
Std. Expected	Expected value (range) (g/cm^3)	[Phys. Prop. Std. Data] property_value

Table 6—16 PWS3 wave form data (to be implemented).

Column Head	Description	Database
Sample ID	ODP standard sample designation	
Measurement	Measurement number	[PWS3 Raw Data] measurement_no
Voltage	Voltage	[PWS3 Raw Data] voltage
Time	Time	[PWS3 Raw Data] time

Table 6—17 PWS3 wave form control 1 data (to be implemented).

Short description	Description	Database
Date/Time	Run date/time	[PWS3 Ctrl 1] run_date_time
Voltage	Voltage	[PWS3 Ctrl 1 Raw Data] voltage
Time	Time	[PWS3 Ctrl 1 Raw Data] time