

2. EXPLANATORY NOTES¹

Shipboard Scientific Party²

INTRODUCTION

In this chapter, we have assembled information (primarily references to existing Ocean Drilling Program [ODP] volumes) that will help the reader understand our descriptive process and assist the interested investigator in selecting samples for further analysis. Procedures explicit to Leg 169 are outlined in the individual specialty notes that follow.

Authorship of Site Chapters

The sections in the site chapters to follow were prepared by the following shipboard scientists (authors are listed in alphabetical order; no seniority is implied):

Principal Results: Fouquet, Miller, Zierenberg
Background and Objectives: Fouquet, Zierenberg
Operations: Fouquet, Gröschel-Becker, Miller, Pollard, Zierenberg
Lithostratigraphy: Baker, Bjerkgård, Duckworth, Goodfellow, Lackschewitz, Peter, Rigsby, Shanks, Teagle, Zuffa
Biostratigraphy: Brunner
Sulfide Petrology and Geochemistry: Bjerkgård, Duckworth, Goodfellow, Peter, Shanks, Teagle
Igneous and Metamorphic Petrology: Teagle
Structural Geology: Marquez, Nehlig
Inorganic Chemistry: Gieskes, Ishibashi, James
Organic Chemistry: Simoneit
Microbiology: Summit
Physical Properties: Bahr, Schultheiss
Downhole Measurements: Gable, Gröschel-Becker, Guèrin, Iturrino
Paleomagnetism: Urvat

The summary core descriptions (“barrel sheets”) and photographs of each core are in the volume section following the site chapters.

Numbering of Sites, Holes, Cores, and Sections

Specifics of the ODP drill site numbering convention can be found in the “Explanatory Notes” chapter of any *Initial Reports* volume before Leg 168. In summary, all holes drilled during Leg 169 positioned with a single acoustic beacon were given a site number, and each hole drilled was denoted by adding a letter, starting with A, to the site number. Data are curated as and referred to in meters below seafloor (mbsf). Cores are numbered serially from the first core recovered from a hole to the last. Each core is divided into 1.5-m sections for handling; the sections are also numbered serially from the

top of the cored interval to the bottom. Cores are also given a letter code to designate the type of coring device used to collect the core. For this leg, the following identifiers were used: H = advanced hydraulic piston core (APC); X = extended core barrel (XCB); B = drill-bit recovery; N = motor-driven core barrel (MDCB); R = rotary core barrel (RCB); W = wash-core recovery; and M = miscellaneous material. For example, Section 169-1035A-1H-5 is the fifth 1.5-m-long section taken with the advance piston corer that was in the first core drilled at Hole 1035A during Leg 169.

LITHOSTRATIGRAPHY

Leg 169 used a modified version of the lithostratigraphy, sedimentology, and massive sulfide data collection and recording procedures used during Leg 139 (Davis, Mottl, Fisher, et al., 1992). All data obtained during the shipboard analysis are summarized on “barrel sheets.” This information represents a summary, at the scale of one sheet per 10 m core, of field notes taken aboard ship. The original handwritten notes (visual core descriptions or VCDs), at the scale of one sheet per section, are included on the CD-ROM in the back pocket of this volume. Because production schedules prohibit modification of these items, occasional ambiguities or discrepancies may be present. The following discussion explains the deviations from the Leg 139 procedures that were adopted by the Leg 169 Scientific Party.

Classification of Sediments, Sedimentary Rocks, and Sulfides

The rock/sediment classification scheme used to describe Leg 169 cores is illustrated in Table 1. Eight major rock/sediment types are recognized in Leg 169 cores: hemipelagic sediments, interbedded hemipelagic and turbiditic sediments and sedimentary rocks, clastic sulfides, clastic sulfates, massive and semi-massive sulfides, sulfide feeder zone and mineralized sediments, basaltic sills, and basaltic flows. Subtypes were defined based on dominant or diagnostic minerals and/or textures.

The standard grain-size classification scheme is used for siliciclastic rocks, with the principle name derived from the grain size and minor and major modifiers used for composition and texture. The only deviation from the Leg 139 classification scheme is that a compositional or textural component qualifies as a major modifier when it makes up at least 10% of the sediment or sedimentary rock.

Hydrothermally altered sediments were distinguished from unaltered sediments, and three facies of hydrothermal alteration were differentiated based on the dominant alteration minerals. Sedimentary units were assigned to one of four groups as follows:

1. Unaltered;
2. Carbonate concretions and cement;
3. Anhydrite concretions and authigenic crystals; and
4. Silicate alteration, locally dominated by silicification, chloritization, or epidotization.

¹Fouquet, Y., Zierenberg, R.A., Miller, D.J., et al., 1998. *Proc. ODP, Init. Repts.*, 169: College Station, TX (Ocean Drilling Program).

²Shipboard Scientific Party is given in the list preceding the Table of Contents.

Table 1. Classification scheme for sediments and hydrothermal rocks recovered during Leg 169.

Barrel sheet lithologic symbol patterns (in caps)	Clastic			
	Sediments/ sedimentary rocks (<2% sulfides)	Sediments/ sedimentary rocks with clastic sulfide (2%–25% sulfides)	Clastic sulfide (25%–100% sulfides; sulfide > sulfate)	Clastic sulfate (25%–100% SO ₄ ; sulfate > sulfide)
Nomenclature for visual core descriptions:				
MUD/ MUDSTONE	Clay/claystone	Clay/claystone interbedded with sulfide	Sulfide clay/ claystone	Sulfate clay/ claystone
SILT/SILTSTONE	Silt/siltstone	Silt/siltstone interbedded with sulfide	Sulfide silt/ siltstone	Sulfate silt/ siltstone
SAND/ SANDSTONE	Very fine, fine, medium, very medium, or coarse sand/ sandstone	Sand/sandstone interbedded with sulfide	Sulfide sand/ sandstone	Sulfate sand/ sandstone
SEDIMENTARY BRECCIA	Sedimentary breccia	Sedimentary breccia with sulfide	Sulfide breccia	Sulfate breccia

Notes: * = nonsulfide marine sediments or altered sedimentary material. For clastic materials, the principal name is based on dominant grain size. Lithologic modifiers are sandy, silty, and clayey. Modifiers must be >10% and precede name in order of increasing abundance. Alteration modifiers are calcite, dolomicrite, and pyrite, etc. Modifiers for hydrothermal lithologies are pyrrhotitic, pyritic, chalcopyritic, etc., or with anhydrite, quartz, silica, and/or chlorite, etc.

For sulfide-rich and sulfide-bearing sediments and rocks, percent sulfide and morphology of sulfide occurrences are used in the classification scheme. The following sulfide percentages are used:

1. *Massive and semi-massive sulfides* contain >50% sulfide minerals.
2. *Clastic sulfides* contain 10%–75% sulfide minerals and refer to sulfides deposited by sedimentary processes as clastic grains, including primary accumulations of sulfide and resedimented sulfide.
3. *Sulfide Feeder Zone and mineralized sediments* contain 2%–50% sulfide minerals of hydrothermal origin.

Massive and semi-massive sulfides were further subdivided into four subgroups based on mineralogy and texture. The subgroups are designated by small letters; the numbered types shown in parenthesis show how these subgroups relate to sulfide types defined during Leg 139:

1. Fine-grained pyrrhotite (Po)-sphalerite (Sp)-isocubanite (Is)-chalcopyrite (Cp) (Type 1);
2. Fine- to medium-grained pyrite (Py)-Po-magnetite (Mt)-Sp-Is-Cp (Types 2 and 3);
3. Sp-Po-Py-Mt (Sp-rich Types 2, 3, 4, and 6); and
4. Colloform and vuggy Py (Type 5).

The principal name for all sulfide-bearing sediments and sedimentary rocks is the name of the siliciclastic host sediment/sedimentary rock. That principal name is preceded by a modifier that describes the morphology of the sulfide accumulation. Three modifiers were used for Leg 169 sulfide-bearing sediments and sedimentary rocks:

1. *Sulfide-veined sediment*: Sulfide occurs predominantly as vertical to subvertical veins that cut across original bedding, 10%–50% total sulfide.
2. *Sediment with sulfide veins and/or impregnations*: Sulfide occurs as vertical to subvertical veins that cut across original

bedding and/or as horizontal or subhorizontal layers or bands, 2%–10% total sulfide.

3. *Sulfide-banded/impregnated sediment*: Sulfide occurs predominantly as horizontal or subhorizontal, usually bedding parallel, layers or bands, 10%–50% total sulfide.

In addition to the principal name, each sulfide-bearing sediment or sedimentary rock and all massive sulfide units are classified according to the degree of sulfide mineralization. The abundances are estimated using the following categories:

Very high = >75%,
High = 30%–75%,
Moderate = 10%–30%,
Low = 2%–10%, and
Negligible = <2%.

Barrel Sheets

The lithology of the recovered material is summarized on the barrel sheets. This summary utilized lithologic patterns and symbols (Fig. 1), as well as a grain-size log and a percent sulfide mineralization log. The pattern shown in the graphic lithology column represents the most abundant lithology of the interval being represented. The symbols shown in the “Sedimentary and Diagenetic Features,” the “Structures,” and the “Drilling Disturbance” columns are flags that indicate intervals that contain structures or features of interest. The reader is referred to the visual core description forms for more detailed information on intervals of interest.

Smear-Slide Summary

Tables summarizing data from smear slides are located on the CD-ROM in the back pocket of this volume. Because smear slides are generally unreliable for quantitative analysis, relative abundances are estimated qualitatively using the following categories:

A = abundant (51%–100%),

Table 1 (continued).

Barrel sheet lithologic symbol patterns (in caps)	Sediment with sulfide impregnations (2%–10% sulfides)	Hydrothermal*				
		Sulfide-veined sediment (10%–50% sulfides)	Sulfide-banded/impregnated sediment (10%–50% sulfides)	Massive/semi-massive sulfide with sediment (>50% sulfides)	Semi-massive sulfide (50%–75% sulfides)	Massive sulfide (>75% sulfides)
Nomenclature for visual core descriptions:						
MUD/ MUDSTONE	Clay/claystone with sulfide veins, spots, or impregnations	Sulfide-veined clay/claystone	Sulfide-banded clay/claystone	Massive/semi-massive sulfide with clay/claystone	Semi-massive sulfide	Massive sulfide
SILT/SILTSTONE	Silt/siltstone with sulfide veins, spots, or impregnations	Sulfide-veined silt/siltstone	Sulfide-banded silt/siltstone	Massive/semi-massive sulfide with silt/siltstone		
SAND/ SANDSTONE	Sand/sandstone with sulfide veins, spots, or impregnations	Sulfide-veined sand/sandstone	Sulfide-banded sand/sandstone	Massive/semi-massive sulfide with sand/sandstone		
SEDIMENTARY BRECCIA	Breccia with sulfide veins, spots, or impregnations	Sulfide-veined breccia	Sulfide-banded breccia	Massive/semi-massive sulfide breccia		

C = common (11%–50%), and
R = rare (<10%).

Atomic Absorption Spectrophotometry Analysis (AAS) of Sulfide Base Metal Concentrations

To monitor the grade of iron and base metals (Fe, Cu, Zn, and Pb) throughout the cores recovered during Leg 169, massive sulfide and sulfide-bearing sediments were sampled from representative pieces in intervals of hydrothermal mineralization. Approximately 10 g of samples were cleaned of saw cuts and drilling debris by grinding and repeated rinses in deionized (Nanopure system) water and agitation in an ultrasonic bath. Pieces were then reduced to a coarse sand size or finer by pulverization in a steel sleeve mortar and pestle and then ground by hand to a very fine powder (<–200 mesh) in an alumina mortar and pestle. X-ray diffractograms (XRD; 2–90° 2 θ) were run for all samples, and the component sulfide, gangue, and host rock minerals were identified. A thin section was taken for most samples from the same or neighboring, but representative, interval. Total sulfur was determined on a separate split of the powders using a Carlo Erba NA 1500 CHNS analyzer.















































































Approximately 1 g of powdered sample was weighed to the nearest milligram into a polytetra-fluoroethylene (PTFE) beaker and then digested using HCl, HNO₃, and HF. The first batch of samples was dissolved following the modified procedure after Bouvier (1991), as used during Leg 139 (Davis, Mottl, Fisher, et al., 1992). This method was further modified as outlined in Table 2. No attempt was made to keep either Ag or Ba in solution. This new dissolution recipe resulted in much lower amounts of insoluble residues, and the first step of weak acid digestion greatly reduced the ferocity of the initial aqua regia sulfide reaction. Following multiple stages of acid digestion, solutions were filtered through a 0.45- μ m Millipore filter, transferred to a volumetric flask, and made up to 100 mL with Nanopure water. Residues for all samples were absent to trace.

Fe, Zn, Cu, and Pb were analyzed by flame atomic absorption spectrophotometry (Varian SpectrAA-20) using standard techniques. Standards were matrix-matched to the samples. Cu standards were prepared from a Cu reference standard (RICCA Chemical Co.). All other standards were prepared from laboratory reagents or other ma-

terials available aboard ship by the following methods: Fe standards were prepared from FeCl₃ (AnalaR-grade reagent), Zn standards were prepared from ZnBr₂ and were standardized by titration of Br with AgNO₃, and Pb standards were prepared by dissolving ~1.8 g of lead sheeting in 30% HNO₃. The solution was made up to 1L with Nanopure water and standardized by precipitating PbSO₄, following the addition of a known quantity of H₂SO₄ and the determination of excess SO₄ remaining in solution. The analytical error is <2% for Fe, <3% for Zn and Pb, and <4% for Cu. Detection limits are <0.1 ppm for all elements. Results in data tables are reported to two significant figures.

BIOSTRATIGRAPHY

Planktonic and benthic foraminifers were washed from bulk sediment as described in the “Explanatory Notes” chapter of the Leg 157 *Initial Reports* volume (Shipboard Scientific Party, 1995b). All core-catcher samples are 20 cm³ in volume, all section top samples are ~2 cm³, all intra-section samples are 10 cm³, and all mudline samples are variable in size, because they were caught in a No. 230 sieve as water runoff from the top of the core. Group abundance was estimated as the number of specimens per volume of bulk sediment as stated above, with intervals set as during Leg 139 (Shipboard Scientific Party, 1992b). Species abundance was estimated by relative frequency, where abundant (A) was >50%, common (C) was 25%–50%, few (F) was 1%–25%, and rare (R) was <1%. Preservation was based on the percentage of specimens that were not identifiable because of dissolution or recrystallization, where poor was >25% of the tests not identifiable, moderate was 10%–25%, and good was <10%. Dissolution was determined by the proportions of broken tests, where strong was >25% broken, moderate was 10%–25%, weak was <10%, and zero meant that no broken tests were noticed under a dissecting microscope. Alteration was classified by types: (1) no alteration; (2) carbonate crusts; (3) carbonate protuberances, which included horns, warts, and bumps; and (4) brown discoloration caused by the maturation of organic test membranes or other causes. Paleodepth zones were modified from Leg 139 (Shipboard Scientific Party, 1992b) so that neritic was <150 m, bathyal was 150–2500 m, and abyssal was

BARREL SHEET LEGEND			
LITHOLOGY			
 Sand/sandstone	 Silt/Siltstone	 Mud/Mudstone	 Semi-massive sulfide
	 Massive/semi-massive sulfide with sediment	 Sulfide-veined sediment	 Clastic sulfate
		 Clastic sulfide interbedded with sediment	 Clastic sulfide
			 Sulfide-banded sediment
			 Massive sulfide
			 Mafic igneous
PHYSICAL & DIAGENETIC FEATURES			
 - Planar laminae	 - Cross-laminae	 - Fining-upward sequence	
 - Soft sediment deformation	 - Wavy laminae	 - Scoured contact with graded beds	
 - Slump	 - Sharp contact	 - Gradational contact	
 - <i>Zoophycus</i>	 - Bioturbation	 - Ash layer	
 - Vein	 - Anhydrite vein	 - Quartz vein	
 - Sulfide vein	 - Chlorite vein	 - Calcite vein	
 - Sulfide nodule	 - Anhydrite nodule	 - Disseminated anhydrite	
 - Anhydrite molds	 - Calcite nodule	 - Disseminated calcite	
 - Pyrite nodule	 - Disseminated pyrite	 - Pyrrhotite nodule	
 - Disseminated pyrrhotite	 - Dolomite nodule	 - Disseminated dolomite	
 - Chloritization	 - Epidotization	 - Silification	
 - Sulfide layer			
STRUCTURES			
 - Extension fracture	 - Joint	 - Shear fracture	
 - Normal shear fracture	 - Reversed shear fracture	 - Strike-slip shear fracture	
 - Dissolution seam	 - Hydraulic breccia	 - Mineralized extension fracture	
 - Bedding parallel replacement	 - Dipping bedding	 - Tension gash	
 - Fold	 - Anastomosing vein network	 - Crack seal veins	
 - Strong veining	 - Moderate veining	 - Weak veining	
 - Cataclasis			
DRILLING DISTURBANCE			
 - Drilling breccia (hard sediments)	 - Highly fragmented (hard sediments)	 - Moderately fractured (hard sediments)	
 - Slightly fractured (hard sediments)	 - Slightly deformed (soft sediments)	 - Moderately deformed (soft sediments)	
 - Highly deformed (soft sediments)	 - Soupy (soft sediments)		
INTENSITIES OF MINERALIZATION			
 - Very high (> 75%)	 - Moderate (10–30%)	 - Negligible (< 2%)	
 - High (30–75%)	 - Low (2–10%)		
SAMPLE TYPES			
CNS - Carbon, nitrogen, sulfur analysis	PP - Physical properties	XRD - X-ray diffraction	
IW - Interstitial water	SS - Smear slide	PAL - Paleontology	
XRF - X-ray fluorescence	AA - Atomic absorption analysis	TS - Thin section	

>2500 m. Interglacial intervals were recognized by a transitional planktonic foraminifer assemblage that occurred during oxygen isotope minima (Brunner, 1994; Moffett, 1995). Informal zones were named as during Leg 139 (Shipboard Scientific Party, 1992b) after the convention of Lago and Thompson (1988). Where over-recovery occurred, the core-catcher samples, which were all from the bottom 2 cm of the core, were assigned to the 2-cm-thick interval above the top of the subjacent core.

IGNEOUS AND METAMORPHIC PETROLOGY AND GEOCHEMISTRY

Igneous and metamorphic rocks sampled during Leg 169 were curated according to standard ODP hard-rock conventions as outlined in the Leg 139 *Initial Reports* volume (Shipboard Scientific Party, 1992b). Hard-rock barrel sheets were produced on a section-by-

Table 2. Dissolution procedures for AAS analysis of sulfide base metal concentrations.

Reagents	
	<ol style="list-style-type: none"> 1. Concentrated HCl, HNO₃, and 48% v/v HF (all Trace Metal Grade if available) 2. Nanopure H₂O 3. ≈30% v/v HNO₃ 4. ≈2.5 N HCl
Apparatus	
	<ol style="list-style-type: none"> 1. HF/strong acid fumehood 2. Hot plates (temperature stable at 150°C) 3. PTFE Teflon beakers (100 mL) with lids 4. 100-mL volumetric flasks 5. HDPE measuring cylinder (25 mL) 6. Glass measuring cylinder (25 mL) 7. 5-mL pipette with disposable tips 8. Wash bottles for Nanopure H₂O, acetone, and methanol 9. 1-L HDPE bottles for dilute acids 10. 400-mL glass beaker with watch glass cover for aqua regia preparation 11. 125-mL HDPE bottle for each sample (acid cleaned) 12. Appropriate but not excessive laboratory clothing, safety glasses, and gloves
Digestion procedure	
	<ol style="list-style-type: none"> 1. Clean PTFE beakers, flasks, and measuring cylinders by soaking overnight in 10% HCl, then rinse with Nanopure H₂O. 2. Accurately weigh ~1.000 g of powdered sample onto weighing paper and transfer to a clean 100 mL PTFE beaker. 3. Rinse beaker with less than 5 mL of Nanopure H₂O to wet sample and collect fine sample dust on the beaker walls. 4. Add a further 15 mL of Nanopure H₂O. 5. Prepare fresh aqua regia from 3 parts concentrated HNO₃ and 1 part concentrated HCl. 6. After vigorous degassing has subsided, incrementally add 15 mL of aqua regia and cover with watch glass. Leave cold until vigorous reaction subsides (1 to 2 hr). 7. Place on 150°C hot plate for 2 to 3 hr, then remove watch glass cover and reduce to incipient dryness. Remove beakers from hot plate and allow to cool. 8. Incrementally add 15 mL of aqua regia and cover with watch glass. Place on 150°C hot plate for 2 to 3 hr, then remove watch glass cover and reduce to incipient dryness. Remove beakers from hot plate and allow to cool. 9. Add 10 mL of HF and 2 mL concentrated HNO₃. Periodically agitate in an ultrasonic bath for 1 to 2 hr. Cover and place on 150°C hot plate for 2 to 3 hr, then remove watch glass cover and reduce to incipient dryness. Remove beakers from hot plate and allow to cool. 10. Add 20 mL of 30% HNO₃. Cover and place on 150°C hot plate for 1 hr, then remove watch glass cover and reduce to incipient dryness. Remove beakers from hot plate and allow to cool. 11. Add 20 mL of 2.5 N HCl. Cover and place on 150°C hot plate for 1 hr, then remove watch glass cover and reduce to incipient dryness. Remove beakers from hot plate and allow to cool. 12. Repeat Step 11. 13. Add 35 mL of 2.5 N HCl. Cover and place on 150°C hot plate until sample has completely dissolved. If visible residue persists, repeat Steps 9 through 12. 14. Vacuum filter solution through a 0.45-µm Millipore filter and quantitatively transfer the filtrate to a 100-mL volumetric flask. Make up solution to 100 mL with Nanopure H₂O. Repeatedly swirl solution to homogenize, then transfer fluid to a clean, labeled 125-mL HDPE bottle. 15. Determine Fe, Cu, Zn, and Pb concentrations using AAS methods.

section basis and archived as digital graphics files. Thin-section descriptions were archived as text files and are also available on the CD-ROM (back pocket, this volume). Geochemical analyses (X-ray fluorescence [XRF] and XRD) were also performed in similar fashion to the methods described in the Leg 139 *Initial Reports* volume (Shipboard Scientific Party, 1992b). Analytical conditions used during Leg 169 are given in Table 3.

STRUCTURAL GEOLOGY

Geometrical Reference Frame

To orient structures within the drill core, we employed the convention adopted during Leg 135, which was modified from the orientation method used during Legs 131 and 134 (Shipboard Scientific Party, 1991, 1992a, 1992d). We assumed that the core axis was always vertical within a horizontal slice of the core. All measurements were made with respect to the cut face of the archive half. Pseudo-north, 000°, was defined as the plane perpendicular to the cut face that bisects the working half of the core extending down from the cut face; the right side was designated 270°, and the left side as 090° (Fig. 2). Most orientations were measured as dip directions relative to the core reference frame on perpendicular sections of the core. A true strike and dip for each two apparent dips measured per structure were calculated using a conversion program developed during Leg 153 (Shipboard Scientific Party, 1995a). If the structure was exposed in three dimensions, the true dip and working azimuth were entered directly into the structural geology spreadsheet. Structure orientations were recorded relative to core piece and section depth. Depths were measured from the top of the core section in centimeters. The top and

bottom of a vein's depth range were recorded if it extended over a depth interval.

Data were recorded with reference to the structural geology checklist (Fig. 3) on the structural geology description form (Fig. 4). These data were entered in the core description spreadsheets (see Table 4) under the following descriptions:

1. Core, section, interval, piece number, and depth (meters below seafloor [mbsf]) for top of section;
2. Oriented sample (Y = yes, N = no);
3. Structural identifier: v = vein (vein crosscutting relationships are indicated as v1...vn from earliest to latest), va...vx = veins without crosscutting relationships, D = clastic dike, F = fault with offset, and So = bedding;
4. Interval in centimeters that the feature covers on the cut surface (top and bottom);
5. Composition of material in feature: abbreviations used are those defined in the "Lithostratigraphy" section, this chapter;
6. Width of structure (millimeters);
7. Wallrock lithology: MAS = massive sulfide, DIA = diabase, SED = sediments, and BAS = basalt;
8. Orientation of feature: two apparent and one calculated strike and dip; and
9. Comments regarding the continuity and the geometry of the feature are recorded, as well as information regarding thickness, alteration halos, offsets, and crosscutting relationships.

Although depth in mbsf was recorded for each piece, we note that pieces recovered from 10 m of drilling are curated by shunting the pieces to the top of the core liner. In low recovery cores, the depth be-

Table 3. X-ray fluorescence operating conditions and detection limits.

Oxide or element	Line	Crystal	Detector	Collimator	Peak angle (°2θ)	Background offset (°2θ)	Total count time (s)		Detection limit
							Peak	Background	
Major elements (wt%):									
SiO ₂	Kα	PET	FPC	Medium	109.21		100		0.03%
TiO ₂	Kα	LIF200	FPC	Fine	86.14		100		0.01%
Al ₂ O ₃	Kα	PET	FPC	Medium	145.12		100		0.01%
Fe ₂ O ₃	Kα	LIF200	FPC	Fine	57.52		40		0.01%
MnO	Kα	LIF200	FPC	Fine	62.97		100		0.005%
MgO	Kα	TLAP	FPC	Medium	45.17	±0.80	150	150	0.05%
CaO	Kα	LIF200	FPC	Medium	113.09		40		0.005%
Na ₂ O	Kα	TLAP	FPC	Medium	54.10	-1.20	150	150	0.1%
K ₂ O	Kα	LIF200	FPC	Medium	136.69		100		0.005%
P ₂ O ₅	Kα	GE111	FPC	Medium	141.04		100		0.005%
Trace elements (ppm):									
Rh	Kα-C	LIF200	Scint	Fine	18.56		100		
Nb	Kα	LIF200	Scint	Fine	21.40	+0.30	200	200	1 ppm
Zr	Kα	LIF200	Scint	Fine	22.55	-0.35	100	100	1 ppm
Y	Kα	LIF200	Scint	Fine	23.80	-0.30	100	100	1 ppm
Sr	Kα	LIF200	Scint	Fine	25.15	-0.35	100	100	1 ppm
Rb	Kα	LIF200	Scint	Fine	26.62	+0.40	100	100	1 ppm
Zn	Kα	LIF200	Scint	Fine	41.81	+0.40	100	100	2 ppm
Cu	Kα	LIF200	Scint	Fine	45.03	-0.40	100	100	2 ppm
Ni	Kα	LIF200	Scint	Fine	48.67	-0.40	100	100	2 ppm
Cr	Kα	LIF200	FPC	Fine	69.35	-0.50	100	100	3 ppm
Fe	Kα	LIF220	FPC	Fine	85.64	+0.80	100	100	
V	Kα	LIF220	FPC	Fine	123.06	-0.50	100	100	4 ppm
Ti	Kα	LIF200	FPC	Fine	86.14	-0.50	100	100	
Ce	Lα	LIF220	FPC	Medium	128.16	+1.89	100	100	10 ppm
Ba	Lβ	LIF220	FPC	Medium	128.78	+1.31	100	100	15 ppm

Notes: Analyses were performed using a rhodium-target X-ray tube operated at 30 kV and 80 mA for major elements, 50 kV and 50 mA for trace elements. Detectors: FPC = flow proportional counter (P₁₀ gas), and Scint = NaI scintillation counter. Elements Rh, Fe, and Ti were measured by the trace element program for matrix and interference corrections only.

low seafloor is only accurate within 10 m. When appropriate, we measured the vein density (expressed as m⁻¹ along the core axis, not accounting for the percentage of recovery).

Statistical Representativity of Measurements

Several problems are inherent in any drill core structural study. In most cases, only part of a drilled interval in any hole is actually recovered. This leads to a sampling bias, that for structural purposes, is particularly acute. Specifically, how do we know what is missing? When faulted or fractured rock from shear zones is recovered, it is often highly disturbed. It is also possible that fault zone material is preferentially destroyed during the drilling process and not recovered. Determining the orientation of observed structures is also problematic.

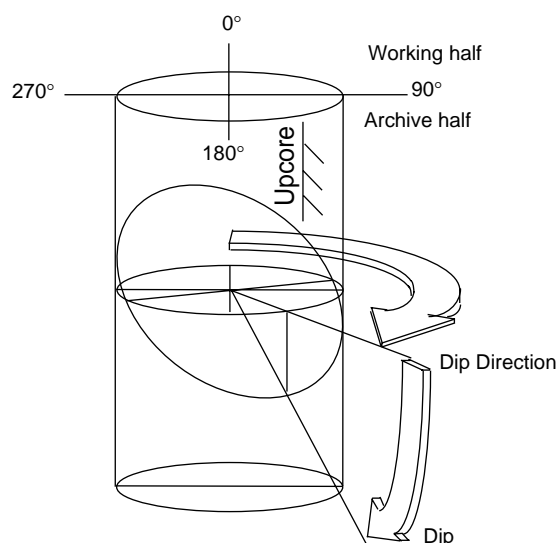


Figure 2. Orientation convention used to orient structures.

ic. Features initially must be oriented relative to local reference coordinates and subsequently corrected to true north and true vertical. The drilling process causes fracturing and rotation of core, such that individual pieces have rotated during drilling. Furthermore, the reference line for each piece is drawn arbitrarily, following visual inspection by the structural geologist, so the reference orientation may be consistent over only a few tens of centimeters. Individual pieces therefore must be oriented back to true north.

Reorientation

Reorientation of a few discrete core samples was tried by using both paleomagnetic and downhole logging data. The logging program during Leg 169 included the Formation MicroScanner (FMS), a tool that makes a resistivity image of the borehole wall by measuring variations in resistivity by means of pads pressed against the wall (see "Downhole Measurements" section, this chapter). The FMS carries fluxgate magnetometers that allow orientation of the processed images. The difference between the diameter of the borehole and that of the core is such that identification of individual samples on both cannot be made directly and may be difficult.

INORGANIC GEOCHEMISTRY

Pore waters were obtained immediately after retrieval of the cores using routine shipboard squeezing procedures as described in the "Explanatory Notes" chapter of the Leg 139 *Initial Reports* volume (Davis, Mottl, Fisher, et al., 1992). In addition, occasional in situ samples of pore waters were obtained using the water sampler temperature probe (WSTP; Davis, Mottl, Fisher, et al., 1992). Borehole fluids were obtained using a special flow-through Leutert sampler from Los Alamos National Laboratory, which was also deployed during Leg 139. Additional borehole fluid samples were obtained with the WSTP. Analytical methodologies used are described by Gieskes et al. (1991). Analyses were performed for the following: salinity, pH, alkalinity, chloride, calcium, magnesium, strontium, lithium, potassium, boron, and silica.

STRUCTURAL GEOLOGY CHECKLIST - LEG 169	
Fractures	Cataclasites
-fracture density per section (1.5 m)	-clast size
Veins	-clast shape
-orientation	-clast composition
-average width	-matrix composition
-mineral infilling	(gouge or secondary minerals)
-fabric	Breccias
-crack seal events (number of events)	-matrix or clast supported
-vein density per section	-percent matrix
-wall rock alteration	-matrix composition
(width and characteristics of halo)	-clast size
-crosscutting relations of veins	-angular vs. rounded clasts
-vein array	-clast composition
array thickness	-origin (hydraulic vs. fault)
number of veins in array	Sedimentary Structures
composition of veins	-layering
orientation	(spacing between laminae)
Shear Zones	-clastic dikes
-thickness	Igneous Contacts
-lineations	-chilled margins
-deformation bands	-dike width
color	Crosscutting Relations
thickness	
mineral composition	
number of bands within array	
Faults	
-orientation	
-thickness	
-shear sense	
(offset, Reidel shears, mineral lineation)	
-amount of offset	
-nature of gouge	
-composition of mineral infilling	
-slickenlines orientation	

Figure 3. Structural geology checklist.

ORGANIC GEOCHEMISTRY

Shipboard organic geochemistry analyses during Leg 169 were conducted to monitor volatile hydrocarbons, hydrogen sulfide, and other gases for safety considerations and as an initial characterization of the content and type of bitumen for assessing the thermal alteration of the sedimentary organic matter. These analyses provide a basis for the preliminary site summaries, for comparison with data from Leg 139, and background for the more detailed shore-based studies.

Gas Analyses

The compositions and concentrations of hydrocarbon and other gases were monitored in the sediments at intervals of generally one per core. The gases were extracted from bulk sediments utilizing headspace sampling techniques as described for Leg 139 (Shipboard Scientific Party, 1992b). Gas-pocket (expansion void) or interstitial fluid gas samples were taken, if present, into pre-evacuated and sealed glass tubes (vacutainers). The sediment samples were taken from core section ends immediately upon retrieval on deck and sealed. All headspace gas and vacutainer samples were injected into one of the following gas chromatographs (GC), depending on gas concentration, using a gas-tight syringe:

1. A Hewlett-Packard Model 5890 II Plus GC equipped with a flame ionization detector (FID) and a 2.4 m × 0.32 cm stainless steel column packed with Hayesep S (100–120 mesh); or
2. A Hewlett-Packard Model 5890 II Plus modified natural gas analyzer (NGA) GC fitted with FID and thermal conductivity detector (TCD). The GC triple-column setup and operating conditions were as described for Leg 139 (Shipboard Scientific Party, 1992b).

All GC operation controls, data acquisition, and data processing were conducted with a Hewlett-Packard Chem Station. Hydrocarbons from methane to hexanes, carbon dioxide, hydrogen sulfide, nitrogen, oxygen, and carbon disulfide were monitored. All gas concentrations are reported in parts per million (volume/volume).

Fluorescence and Black Soot

Fluorescence measurements can indicate the presence of aromatic compounds in petroleum and its products. In hydrothermal systems, the fluorescence of pyrolysis products (bitumen) is an approximate indicator of the evolution of the petroleum potential of a sediment. It reflects the aromaticity of the hydrocarbons in the bitumen (cf. Shipboard Scientific Party, 1992f). Fluorescence data were measured on bulk sediment samples, generally one per core, as methanol/*n*-hexane extract solutions. The fluorescence was estimated under an ultraviolet lamp, and the extract color was also monitored.

The residue from the hydrothermally altered organic matter (kerogen) can remain in the sediments as amorphous, finely disseminated carbon (Curry, Moore, et al., 1982; Shipboard Scientific Party, 1992f). This was monitored on the same samples by qualitatively observing the black soot accumulation at the liquid interface between the hexane and methanol/water mixture. The carbonaceous soot is less dense than the methanol/water mixture.

Bitumen Analyses

Initial screening of sediment extracts was performed on the solvent supernatant (hexane) from the fluorescence-black soot extraction. It was removed and concentrated under nitrogen blow-down to volumes of 10 to 40 µL for GC analysis. Additional wet sediments were extracted as described for Leg 139 (Shipboard Scientific Party,

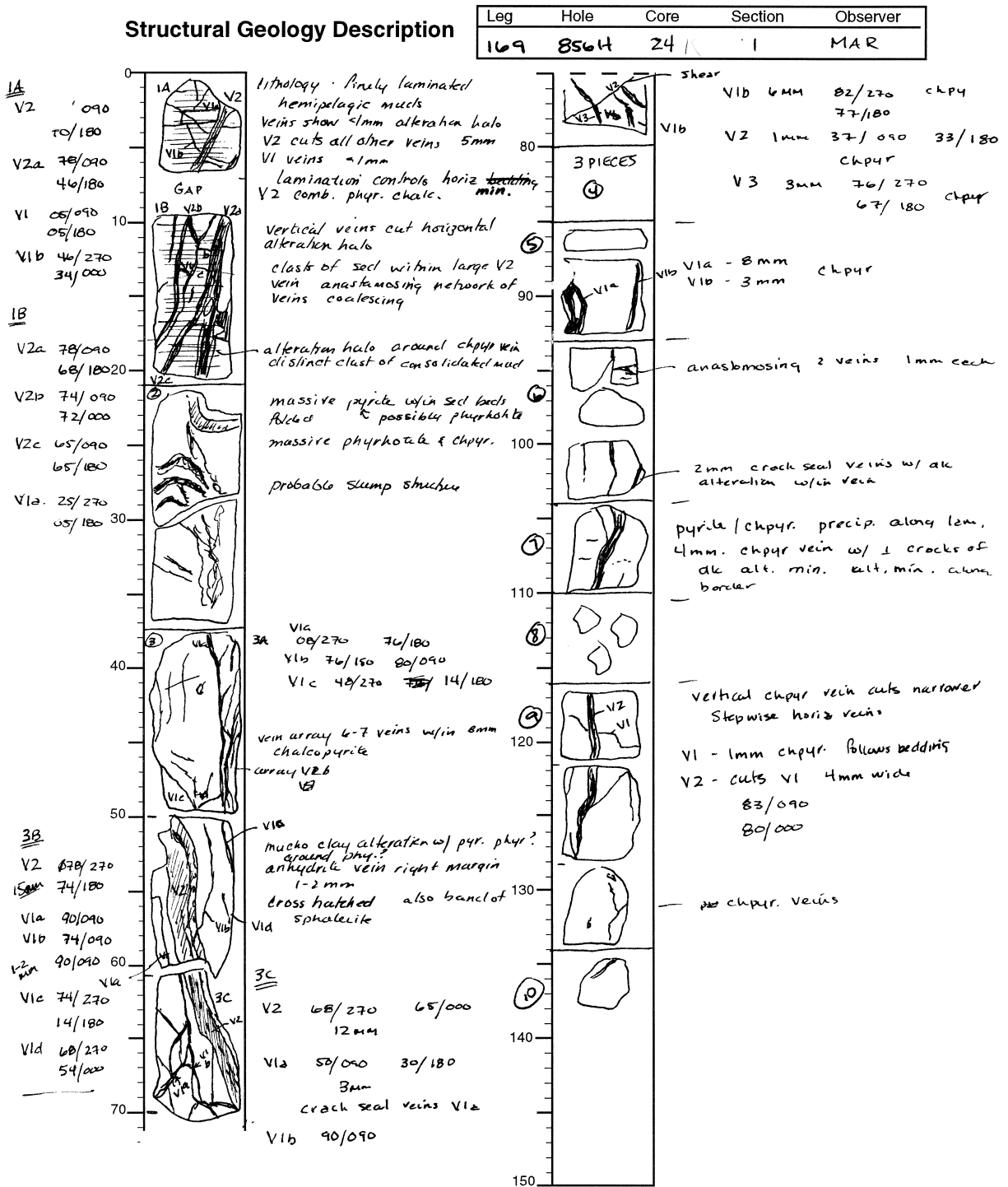


Figure 4. Example of structural geology description form (provided in extenso in the appendix on CD-ROM [back pocket, this volume]).

1992b). A 1- to 3- μ L sample was injected using normal GC protocol. Hydrocarbons were identified by comparison of the retention times with those of authentic standards. Relative yields were calculated from the integration of the total GC signal area multiplied by the dilution factor. Solvent and procedural blanks were also analyzed. Additional GC data for this area were reported for Leg 139 (Davis, Mottl, Fisher, et al., 1992; Simoneit, 1994).

The GC analyses were conducted on a Hewlett-Packard Model 5890 Series II instrument, fitted with a 50 m \times 0.20 mm capillary column coated with methyl silicone gum (Hewlett-Packard Ultra 1, 0.11- μ m film thickness). The temperature was programmed as isothermal for 3 min at 30°C, 10°C/min to 220°C, 4°C/min to 300°C, and as isothermal for 15 min, with the injector at 290°C, and FID at 300°C. Helium was used as the carrier gas.

Elemental Analyses

Sediments were analyzed aboard ship for total carbon, hydrogen, nitrogen, sulfur, and inorganic carbon (in carbonate). Hydrogen is not reported because adsorbed water in the varied sediments and minerals yielded extraneous results. The total organic carbon (TOC) content of the sediments was then calculated by subtraction of the inorganic carbon content from the total carbon content. It should be noted that the presence of refractory carbonates (e.g., dolomite) may introduce errors because of incomplete dissolution in the coulometric method. The analyses were performed on routine shipboard samples collected for carbon-nitrogen-sulfur (CNS) analysis, atomic absorption (AA), and for XRF. Sediments were freeze- or oven-dried and ground in an agate mortar or shaker mill before analysis.

Total carbon, nitrogen, and sulfur were determined using a Carlo Erba NA 1500 CNS analyzer. Bulk samples were combusted at 1000°C in an oxygen atmosphere with additional vanadium pentoxide in tinfoil sample holders. The gases (CO₂, SO₂, H₂O, and N₂) were separated by GC and measured with a TCD.

MICROBIOLOGY

The goal of the microbiological sampling during Leg 169 was to determine the size and composition of the microbial assemblage in hydrothermal sediments, with special emphasis on high-temperature microorganisms. Sediment plugs were taken from the tops of core sections for microbial abundance measurements, and whole-round cores of sediment were used for an additional suite of shipboard and shore-based microbial measurements. Exploratory samples were taken from the reentry cone seal (CORK) body, submersible/remotely operated vehicle landing platform, and thermistor string, WSTP samples, and selected porous hard-rock specimens.

To obtain a representative sample of the in situ microbial assemblage, sediment must be protected from external contamination and processed as soon as possible after removal from the environment to minimize the potential for selective microbial growth or death. Samples therefore were taken on the catwalk and processed immediately. Contamination was reduced by sampling central plugs from the core after removing the surface with a sterile spatula. The top and bottom of the core were avoided (except in the case of mudline cores) as were regions of drilling-induced disturbance. Samples of drilling fluids were also examined for reference. Any material that came into contact with a sample was sterilized. A portable autoclave was brought aboard for this purpose. Some material was sterilized using concentrated ethanol.

Sampling Protocol

Sediment plugs (~4 cm³) were taken from the tops of Sections 2 through 6 as soon as the sections had been cut. Sterile 5- or 10-cm³ truncated syringes were inserted 3 to 4 cm into the working half, as close to the center of the core as possible. In the laboratory, the top (innermost) 1 cm³ of the subcore was removed with an ethanol-sterilized spatula or razor blade and discarded, and the next 1 to 2 cm³ were sectioned into a scintillation vial containing 5 mL of sterile, filtered 4% formalin in artificial seawater (ASW). At least 1 cm³ remained in the subcore after sampling and was discarded; this interval included the contaminated cut surface of the section top. The vials were shaken or vortexed to disperse the sediment and stored at 4°C.

Whole-round cores of 10 cm length were taken from sediment cores at depths selected on the basis of in situ temperature measurements. No acetone was used to seal the end-caps of these samples. They were immediately transported to the paleontology lab for processing, where they were placed inside an ethanol-sterilized glove bag filled with argon. Central sample plugs were taken as described

above. A 2-cm³ plug of sediment was preserved in formalin and ASW, as above. Another 2-cm³ plug was preserved in sterile, filtered 2% grade 1 glutaraldehyde (electron microscopy grade) in ASW and stored at 4°C. A 5-cm³ plug of sediment was taken for culture of high-temperature, anaerobic microorganisms, and 80 cm³ of sediment was preserved by four different methods for further DNA extraction.

Water samples from the WSTP were taken with a sterile syringe and needle from the overflow chamber. The overflow chamber of the WSTP was sterilized with ethanol before water sampling when possible. Sampling protocols for more esoteric samples (e.g., the CORK thermistor string) are described in their respective sections.

Preliminary Microbial Abundances from Microscopic Counts

Selected fixed sediment and water samples were microscopically counted aboard ship to provide an order of magnitude estimate of microbial abundances. Fixed sediment samples were diluted 1:100 and stained with acridine orange (final concentration 0.01%) for 5 min in the dark. Ten mL of the stained, diluted samples was vigorously mixed by vortex action with a drop of Triton X-100 (0.5%) detergent to help disaggregate particles and bacteria. Water samples were stained with acridine orange but did not have detergent added. A fraction of each sample was vacuum filtered onto a 0.2 µm black polycarbonate membrane filter (Poretics). The filter was rinsed with filter-sterilized ASW and 1 mL of isopropanol as an acridine orange destaining solution. For water samples, the filter was overlaid with a 20 ppm solution of 4', 6-diamidino-2-phenylindole (DAPI), allowed to stain for 10 min, and rinsed with filter-sterilized ASW. Filters were mounted on slides with Resolve low-fluorescence immersion oil (VWR) and viewed with the shipboard Axiophot (Zeiss) microscope, using Zeiss filter sets 2 and 9.

Micrometer-sized particles that had a circular or elongated smooth outline and stained bright green with acridine orange were counted as microorganisms. DAPI provided good information for water samples, but was not useful in viewing microbes in sediment samples. If microorganisms averaged >10 per microscopic field of view, 30 random fields were counted and averaged. If microorganisms averaged <10 per field, a swath across the center of the filter was counted (~1% of the filter area). The average number of microbes per field was converted to microbes per filter, depending on the filter size and magnification, and then to microbes per cubic centimeter of sediment. Most sediment samples had less than 10⁷ microorganisms per cm³ of sediment; shipboard estimates of numbers this low have uncertainties of one half order of magnitude, and the detection limit is ~10⁵ microbes/cm³ of sediment.

Culture of High-Temperature Microbes

High-temperature anaerobic enrichments were attempted at 55°C and 90°C in ASW-based microbiological culture media tailored for sulfur-reducing heterotrophs (elemental sulfur and 0.3% yeast extract and peptone), methanogens (0.1% yeast extract), and sulfate-reducers (0.03% formate, acetate, and propionate; 0.01% yeast extract). Culture media and tubes were prepared onshore according to Baross (1993), using sodium sulfide as a reducing agent (final concentration 0.05%). The headspace of culture tubes for sulfur-reducing heterotrophs contained prepure argon, and the other tubes contained a mixture of 20% carbon dioxide and 80% hydrogen.

Samples of water from the WSTP were simply introduced with a sterile syringe and needle through the butyl rubber stopper of the culture tube. Culture tubes were inoculated with sediment inside a glove bag. The tubes were opened, sediment or sediment slurry was dispensed with a syringe corer or syringe, and the tubes were resealed. For quantitative enrichments, tubes were inoculated with serial dilutions of sediment in sterile anaerobic ASW.

Table 4. Example of structural core description spreadsheet.

Core, section, interval (cm)	Piece	Feature			Position		Veins		
		Depth (mbsf)	Oriented	Identifier	Top (cm)	Bottom (cm)	Mineralogy	Width (mm)	Wall rock
169-1035H-	1A	133.73	Y	V1a	3	3	Cpy	1	SED
24R-1	1A	133.73	Y	V1b	3	5	Cpy	1	SED
24R-1	1A	133.72	Y	V2	2	7	CpyPo	5	SED
24R-1	1B	133.83	Y	V1a	13	13	Cpy	1	SED
24R-1	1B	133.80	Y	V2a	10	20	Cpy	5	SED
24R-1	1B	133.80	Y	V2b	10	18	Cpy	2	SED
24R-1	1B	133.87	Y	V2c	17	20	Cpy	1	SED
24R-1	2	133.91	Y		21	37	CpyPo		
24R-1	3A	134.07	Y	V1a-7	37	50	Cpy	8	SED
24R-1	3A	134.19	Y	V1b	49	50	Cpy	1	SED
24R-1	3A	134.17	Y	V1c	47	50	Cpy	1	SED
24R-1	3B	134.25	Y	V1a	55	60	Cpy	1	SED
24R-1	3B	134.20	Y	V1c	50	54	Cpy	1	SED
24R-1	3B	134.25	Y	V1d	55	57	Cpy	1	SED
24R-1	3B	134.20	Y	V2	50	70	CpyPoSphAn	15	SED
24R-1	3C	134.37	Y	V1a	67	69	Cpy	3	SED
24R-1	3C	134.31	Y	V1b	61	70	Cpy	1	SED
24R-1	3D	134.47	Y	V1b	77	80	Cpy	6	SED
24R-1	3D	134.45	Y	V2	75	78	Cpy	1	SED
24R-1	3D	134.45	Y	V3	75	80	Cpy	3	SED
24R-1	5	134.57	N	V1a	87	93	Cpy	8	SED
24R-1	5	134.57	N	V1b	87	93	Cpy	3	SED
24R-1	6	134.65	N	V-2	95	95	Cpy	1	SED
24R-1	6	134.73		V	103	104	Cpy	2	SED
24R-1	7	134.74	N	V	104	110	Cpy	4	SED
24R-1	9	134.88	Y	V1	118	121	Cpy	1	SED
24R-1	9	134.86	Y	V2	116	127	Cpy	4	SED

Notes: Y = yes, and N = not oriented. Cpy = chalcopyrite, CpyPo = chalcopyrite-pyrrhotite, CpyPoSph = chalcopyrite-pyrrhotite-sphalerite, and CpyPoSphAn = chalcopyrite-pyrrhotite-sphalerite-anhydrite. SED = sediments, and dir = direction. E = east, and W = west.

Only part of this table is produced here. The entire table appears on CD-ROM.

Inoculated tubes had an additional 150 KPa of the appropriate gas added to the headspace before incubation; if the tubes had been opened in the glove bag or elsewhere, they were first flushed with gas before being pressurized. Tubes were incubated in sand-filled trays placed in ovens provided aboard ship. All samples were checked for growth by phase contrast microscopy, and, if necessary, epifluorescence microscopy.

DNA Extraction from Sediments for Shore-Based 16S Ribosomal RNA Analysis

Sediment from whole-round cores was preserved for DNA analysis by four different methods. The effectiveness of DNA extraction in any given solution varies with the environment; as DNA has never been extracted from hydrothermal sediment, four methods of preservation and lysis will be compared post-cruise.

Aboard ship, one 20-cm³ aliquot of sediment was lysed at 42°C in an equal volume of sarcosyl buffer/proteinase K (20 volumes sarcosyl buffer: 0.3% sodium lauryl sarcosate, 0.14M NaCl, 50 mM sodium acetate, pH 8, and 1 volume proteinase K solution: 10 mg/mL proteinase K, 0.5 mM CaCl₂, and 50 mM Tris, pH 8) and the DNA extracted using the Isoquick Kit (Orca Research). A micro-centrifuge was brought aboard for this purpose. Duplicate volumes (20 cm³ each) of sediment were preserved in GIT solution (5 M guanidinium thiocyanate, 25 mM ethylenediaminetetraacetic acid [EDTA], 50 mM Tris, pH 7.4) and SET buffer (10% sucrose, 50 mM EDTA, and 50 mM Tris, pH 8) and stored at -20°C. Another 20-cm³ aliquot was simply frozen at -20°C. Water samples were concentrated on 0.2-µm Sterivex syringe filters (Millipore) and lysed with sarcosyl buffer and proteinase K solution as above. Amplification, cloning, sequencing, and alignment of 16S ribosomal RNA will be carried out ashore to determine the composition of the microbial assemblage.

PHYSICAL PROPERTIES

Physical properties measurements were collected at all sites drilled during Leg 169. There were two main objectives to the measurements: (1) to collect high-quality data that could be used in conjunction with other data sets to understand the geological processes and (2) to evaluate the performance of the GEOTEK Multisensor Split Core Logger (MSSCL) and compare how MSSCL data relate to other parameters measured aboard ship. The physical properties of the sediments and rocks when combined with in situ downhole data will provide important constraints on thermal and hydrologic models for the hydrothermally active sites.

The protocols for data collection were varied according to the types of sediment/rock material encountered, as well as the intrinsic quality of the cores. Typically, all cores were logged with the Multi-sensor Track (MST) unless the material was disturbed to an extent where valid data processing and filtering became impossible. When collecting large amounts of physical properties measurements, it is inevitable that some data are erroneous, either through poor sample selection or operator error. We believe that this has caused significant problems for investigators in the past who, wishing to use the data, did not know how to filter the data regardless of extensive documentation. The MST data sets are particularly prone to this type of difficulty. We have been careful to ensure that most dubious or erroneous data have been filtered out before reporting the results.

Unlithified sediment samples were generally collected from the working half using a sample tube or spatula shortly after core splitting, packed into 10-mL Pyrex beakers, and covered with parafilm to prevent drying. In cases where the cores were run through the MSSCL, index properties samples were not collected until after MSSCL logging, but cores were kept covered with plastic film during the MSSCL runs. Two types of samples were collected for index properties measurements on indurated sediment, sulfide, and basalt.

Table 4 (continued).

Core, section, interval (cm)	Piece	Apparent dips		Planar		Calculated		Dip direction	Comments
		App dip/ dir1	App dip/ dir2	Strike	Dip	Strike	Dip		
169-1035H-	1A	05/090	05/180			045	07	E	Finely laminated hemipelagic muds; veins show <1-mm alteration halo; chalcocopyrite controlled by laminations
24R-1	1A	46/270	34/000			213	51	W	
24R-1	1A	60/090	70/180			058	73	E	
24R-1	1B	25/270	05/180			169	25	W	
24R-1	1B	65/090	68/180			049	73	E	Alteration halo; clast of mud within vein, anastomosing network
24R-1	1B	74/090	72/000			319	78	E	
24R-1	1B	78/090	65/180			025	79	E	
24R-1	2								Chalcocopyrite block of contorted replaced sediments; probable slump structure
24R-1	3A	08/270	76/180			092	76	W	
24R-1	3A	76/180	80/090			035	82	E	
24R-1	3A	48/270	14/180			167	49	W	
24R-1	3B			330	90	330	90	W	
24R-1	3B	74/270	14/180			090	90	W	
24R-1	3B	68/270	54/000			176	74	W	
24R-1	3B	78/270	74/180			209	71	W	Vein with sphalerite and distinct anhydrite vein; pyrite, pyrrhotite, chalcocopyrite main mineralogy
24R-1	3C	50/090	30/180			143	80	W	Crack seal
24R-1	3C	90/090				026	53	E	
24R-1	3D	82/270	77/180			180	90	W	
24R-1	3D	37/090	33/180			149	83	W	
24R-1	3D	76/270	67/180			041	45	E	
24R-1	5					150	78	W	
24R-1	5								Anastomosing
24R-1	6								Crack seal
24R-1	6								Perpendicular cracks of dark altered minerals; alteration halo; pyrite, chalcocopyrite replacement along laminae
24R-1	7								Follows bedding
24R-1	9								
24R-1	9	83/090	80/000			325	84	E	

Rock fragments from the working half of the core, with volumes of 3–10 cm³, were collected shortly after core splitting, placed in 50-mL beakers, and immersed in seawater to prevent them from drying out. These samples were first used for discrete velocity measurements. They were then returned to the seawater-filled beakers and placed in a vacuum for 12 to 24 hr to ensure resaturation before index properties measurements were made. Oriented minicore samples of 10 cm³ were cut from selected portions of the working half for additional index properties measurements. These were first used in paleomagnetic studies and then for velocity measurements prior to the index properties measurements. Minicores were also resaturated in seawater under a vacuum for 24 hr.

Index Properties

Measurements of wet and dry weights and dry volumes and calculations of porosity, grain density, wet bulk density, water content, and void ratio were made using procedures similar to those employed during Leg 139 (Shipboard Scientific Party, 1992b). Samples were placed in an oven for 24 hr before dry weight and volume measurements were taken. Sulfide samples were dried at 45°C, unlithified and lithified sediments at 110°C, and basalt at 65°C. Both wet and dry volume measurements were made on unlithified sediment samples. Wet volumes were initially determined for lithified samples, but repeatability trials indicated that the data were questionable. Other workers have noted problems in wet volume measurements of indurated samples utilizing the Penta-Pycnometer (ODP Shipboard Measurements Panel, 1991). They were discontinued as they are not necessary to calculate the full suite of index properties.

Thermal Conductivity

Thermal conductivity measurements on soft sediments were made similarly to those from Leg 139 (Shipboard Scientific Party, 1992b), using a full-space needle probe inserted through the core liner preceding core splitting. Thermal conductivity of rock samples was measured with the TK04 thermal conductivity meter, using a half-space probe and procedures similar to those employed during Leg 139 (Shipboard Scientific Party, 1992b), with samples and probe immersed in a saltwater bath. Split core samples from the archive half were selected shortly after splitting; when necessary, they were polished lightly to ensure a smooth surface. The TK04 meter uses drift measurements to determine that the sample, probe, and saltwater bath are in thermal equilibrium before the start of a test. Equilibration times varied considerably, ranging from a few minutes up to 1 hr or more. The half-space probe, which is factory calibrated, was checked periodically by measurements on a reference basalt sample. Discussion of calibration errors and limitations for sulfide samples is given in Gröschel-Becker et al. (1994).

Ultrasonic Velocity Measurements

Discrete velocity measurements were made using a variety of available instruments, depending on the nature of the material. For rock/sediment fragments and minicores, either the Hamilton Frame or the MSSCL was used. After initial trials and calibration tests, the MSSCL was preferentially used. The sample is placed between the transducers, and the velocity measured is displayed on the monitor. Intercalibration experiments (using aluminum and plexiglass standards) ensured that the data from both devices were comparable.

The rock fragment samples were placed between the transducers such that a direct rock/sediment path existed between the center of the transducers. In this way accurate measurements can be obtained without the need to prepare parallel faces even though they are not oriented. When compared with oriented samples, the data show this to be a valid measurement technique.

Two measurements were made on the small number of minicores: (1) parallel to the core axis to obtain the vertical propagation velocity (V_v); and (2) perpendicular to the core axis to obtain the horizontal propagation velocity (V_h). Velocity anisotropy (V_a) was calculated as during Leg 139 using the following expression:

$$A = 200 \times (V_h - V_v) / (V_h + V_v)$$

In soft unindurated sediments, velocity values were obtained from both the MST and MSSCL.

Multisensor Track

The MST has been described in its various guises over the years in past volumes. The sensor suite of instruments used during Leg 169 measured gamma density (GD), *P*-wave velocity (PWV), sediment thickness, magnetic susceptibility (MS), and natural gamma (NG) activity. Although a few minor problems were encountered initially, this new design is far better than the previous version and worked well. The MST was used on a routine basis to log all sections of APC and XCB cores and most RCB cores, especially where the cores were dimensionally regular enough to provide good data. Cores that consisted mainly of rock fragments that had no dimensional regularity were not logged; therefore, we relied on data from the discrete samples and minicores.

All cores were logged at close to room temperature, and hence PWV values are reported without any temperature correction. MS values are reported as meter readings, (10^{-5} SI) and are not true volume susceptibility data as no loop-diameter/core-diameter correction has been applied. Prior to Site 1037, GD was reported using the standard calibration protocol of aluminum and air. The “Boyce correction” (Boyce, 1976) for the effects of water was not applied, resulting in GD values ~5% greater than bulk densities in most materials. However, for Site 1037 and subsequent sites, the calibration protocol was changed by using an aluminum and water standard. This automatically accounts for the water effect and therefore more accurately reflects the bulk density for most materials.

GEOTEK Multisensor Split Core Logger

In principal, the split core logger is similar to the whole core MST that has been used routinely for many years on the ship. However, the data from the MST are often difficult to interpret because it is unclear whether the character of the logs is caused by genuine changes in sediment properties or primarily by the nature of various factors caused by the coring process. The main purpose of the MSSCL is to complement the data acquired from the MST. Higher quality data can be obtained from cores where there is significant drilling disturbance (i.e., XCB and RCB cores). The system provides a track for other measurement techniques that require an exposed sediment surface.

The data quality obtained with the MSSCL for cores with more disturbance is enhanced for several reasons. The nature of split cores enables the system to measure the thickness of material being measured, whereas in the whole-core mode, the thickness of material is assumed to be the same as the inner diameter (ID) of the liner. The user can visually identify areas of the core where the data are suspect and either not take measurements or immediately edit the data set.

The MSSCL is designed to operate in either split-core mode or in whole-core mode like the MST. It has a similar sensor suite enabling measurements of *P*-wave velocity, gamma attenuation, and magnetic

susceptibility. However, the general orientation of the sensors on the MSSCL is vertical (as opposed to horizontal in the MST), which allows measurements through the half-split core to be made. In addition to these primary measurements, the MSSCL also provides magnetic susceptibility measurements on the split surface using a point sensor. This provides a much better spatial resolution compared with the normal loop sensor. The other major difference is that the MSSCL uses a different tracking system than the MST, which has a number of advantages when operating on split cores. The MSSCL utilizes a pusher to move the core through the sensor array, instead of a core boat as used by the MST. The pusher system enables adjacent core sections to be butted against each other during the logging process. This eliminates some of the end effects that occur in the data at the end of each core section. This is particularly true for volume-based measurements such as magnetic susceptibility (loop sensor) and natural gamma activity. The capability of butting adjacent core sections together also increases the overall rate at which cores can be logged.

Criteria for running split cores through the MSSCL during Leg 169 were different than those for the MST. The MSSCL was installed during Leg 169 as part of an evaluation program, and initially a large number of sections were run to ensure that the system was performing well. As the cruise progressed, it was used in a more discriminatory fashion on core sections where either the data from the MST were not satisfactory or where cores of particular interest were encountered. Special data sets were also collected to determine the relative merits of different logging protocols.

Data Presentation

The detail contained in high-resolution logs from cores is often difficult to convey accurately by simply displaying summary plots of the data. Even after removing unreliable data from the data sets, it is normally impossible to distinguish good data from data collected at a scale suitable for complete holes in both sediments and rocks disturbed by the drilling process.

Previous presentations of MST data in the ODP literature often have plotted the data as scatter plots of different parameters vs. depth. During this leg, we tried to convey the data in a slightly different way. All the data presented in the graphs were first edited to remove most (if not all) spurious data points caused either by instrumental or sediment problems (e.g., lack of acoustic coupling of the *P*-wave transducers). This includes most data collected through obvious voids in the cores. Such problems are normally detected in the case of *P*-wave and gamma density as unreasonably low values. The remaining data were plotted as line plots. In the case where the line plot is not considered a fair representation of the undisturbed material, a further plot is superimposed that picks out a maximum line (averaged over 10 sample points). The original data line is then displayed in gray.

DOWNHOLE MEASUREMENTS

The Lamont-Doherty Earth Observatory Borehole Research Group (LDEO-BRG), in conjunction with Schlumberger Well Logging Services, provides the geophysical well logging aboard the *JOIDES Resolution*. Primarily designed for use in hydrocarbon exploration, logging tools have been adapted to meet ODP requirements and hole conditions, including reduction of tool diameters to allow insertion into the 3.8-in drill-string bore.

Downhole logs are used to directly determine the physical, chemical, and structural properties of formations penetrated by drilling, and complement discrete core measurements. The data are collected rapidly, and interpretation of the continuous in situ measurements allows the formation's stratigraphic, lithologic, geophysical, and mineralogic characteristics to be quantified. When core recovery is incomplete, log data may serve as a proxy for physical properties and

Table 5. Temperature tolerances and data resolution of the various tools deployed for downhole temperature measurements.

Downhole tool name	Deployment cable	Maximum temperature	Resolution
UHT-MSM Tool	Coring wireline (sandline)	400°C for 4–5 hr; $T_{avg} = 232^\circ\text{C}$ for 10 hr	28 Hz/°C
BRGM probe	Logging wireline	400°C	0.01°C
WSTP	Coring wireline	200°C	0.01°C
DVTP	Coring wireline	100°C	0.01°C at 100°C
LDEO temperature tool	Logging wireline	150°C	0.002°C
Wireline logging cable	NA	220°C	NA
Temp-Plate sensor	NA	204°C	NA

Note: NA = not applicable.

sedimentological data and permit the core to be placed in its proper stratigraphic position within the cored interval. Geophysical well logging is also used to aid in the characterization of lithologic sequences when integrated with core and seismic reflection data.

Standard well-logging techniques and instrumentation were adapted to the high-temperature conditions expected in various portions of the hydrothermal systems drilled in Middle Valley and Escanaba Trough. In addition, reentry Holes 858G, 857D, and 856H in Middle Valley were subjected to temperature measurements and water sampling prior to borehole disturbance by coring and logging operations. These tools were deployed at Holes 858G and 857D after removal of the data logger-thermistor string components of the circulation obviation retrofit kits (CORKs) installed during Leg 139. Temp-Plate press-on temperature sensing strips were placed on all tools deployed under unknown borehole temperature conditions.

In Situ Temperature Measurements and Water Sampling

The temperature tools used in the Middle Valley segment of Leg 169 were the Bureau de Recherches Géologiques et Minières (BRGM) high-temperature wireline probe, the Geothermal Resources Council (GRC) ultra-high temperature-multisensor memory (UHT-MSM) tool, the WSTP, and the Davis-Villinger temperature probe (DVTP). The temperature tolerances of the various tools are given in Table 5. Most of the experimental techniques are very similar to those used during Legs 111, 137, 139, 148, 164, 166, and 168.

BRGM, WSTP, DVTP, and Los Alamos Water Sampler

Operation of the BRGM tool is detailed in the “Explanatory Notes” chapters of the *Initial Reports* volumes for Legs 111 (Shipboard Scientific Party, 1988), 137 (Shipboard Scientific Party, 1992e), 140 (Shipboard Scientific Party, 1992c), and 148 (Shipboard Scientific Party, 1993), and in Gable et al. (1989). The WSTP is mounted inside a core barrel and run with the wireline; it can also be configured to obtain a fluid sample. The techniques used for temperature measurements and in situ pore-fluid sampling with this tool are given in Shipboard Scientific Party (1992b) and in the “Inorganic Geochemistry” section (this chapter). Characteristics of the Los Alamos Water Sampler also are discussed; this tool has a slimline configuration and can be deployed with the sandline.

The DVTP was deployed in Escanaba Trough. Its design and operation have been detailed by participants during Leg 164 (Shipboard Scientific Party, 1996) when the tool made its debut.

UHT-MSM Tool

The UHT-MSM slimline tool is run on the coring line and was used for the first time in Hole 858G, where borehole and formation temperatures were unknown, but expected to be very high owing to the hole’s location in a hydrothermal vent field. The probe is essentially an upgraded version of the Sandia tool that was run successfully during Leg 139 (Shipboard Scientific Party, 1992b) and was devel-

oped for the University of Miami by Geophysical Research Corporation (GRC, 1994a, 1994b, 1996). Improvements over the Sandia tool include the pressure sensor, for better depth control while logging, and a toughening of the running neck so the tool does not fall off the coring line as it did during Leg 139. The running neck now screws directly into ODP’s slim sinker bars, and the tool can be run through the orifice occupied by the data logger in CORK bodies.

The tool, shown schematically in Figure 5, contains internal and ultra-high external temperature measuring devices, a pressure gauge, a multisensor memory unit, and a Dewar flask that acts as an insulator to maintain a stable temperature and cool-down rate for the tool. The UHT-MSM heat shield is aircraft-grade aluminum bounded at both ends by brass heat sinks. The Dewar flask can maintain an internal

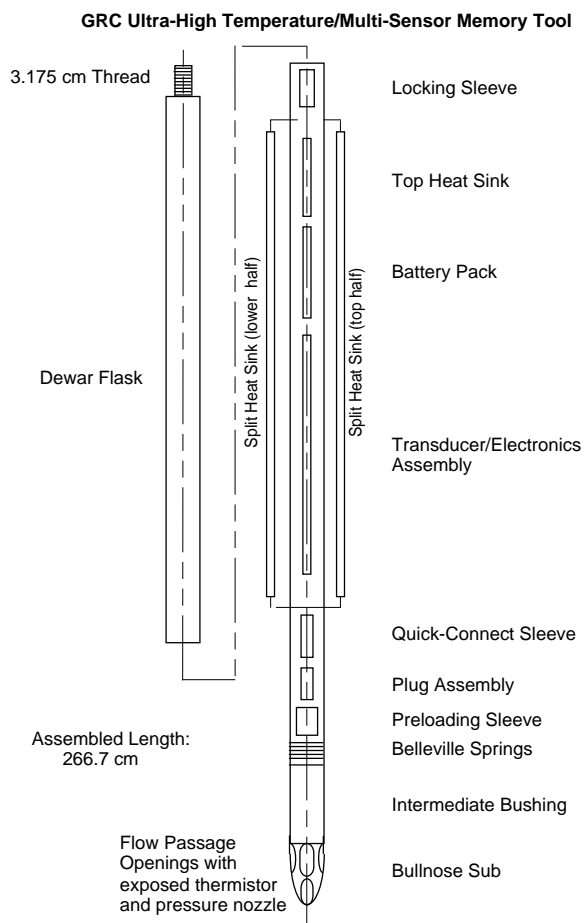


Figure 5. Schematic diagram showing the major components of the GRC UHT-MSM tool (not to scale). The slimline probe was developed at the University of Miami and deployed for the first time during Leg 169.

temperature suitable for tool operation for 4 to 5 hr at an external temperature of 400°C; operation for 10 hr is possible if the average temperature does not exceed 232°C (GRC, 1994a). The flask will operate at pressures up to 10,000 psi.

The dual temperature/pressure printed circuit board (PCB) contains circuits for converting the pressure and dual temperature signals for storage in the MSM PCB. The MSM PCB, with 1 MB of total memory, contains circuits used for multichannel data recording. The electronic erasable programmable, read-only memory (EEPROM) on this board contains 917 Kb of the total memory. The battery pack consists of four 2/5 lithium C-cells, with a dummy cell contact on its negative end that acts to ground the cell pack to the battery housing, and a positive adaptor assembly on its positive end. The male banana plug in the positive adaptor assembly makes contact with an electrical feed-through connector when the battery pack is placed in the housing and supplies power to the rest of the tool. Power passes through the nine-pin interface connector and is distributed to 5-V regulators in the tool electronics.

The tool is activated, programmed, and the data are analyzed with a support computer via a bidirectional nine-pin RS-232 cable link when the battery pack is removed from the tool. The nine-pin RS-232 connector within the adaptor probe of the serial interface cable assembly is attached to the probe, the 25-pin serial connector to the host computer, and a four-pin connector to an external power supply.

The UHT-MSM temperature gauge was programmed to record every 10 s, and the tool was run down the hole at a cable speed of 50 m/min in the drill pipe and 2 m/min in cased sections or open hole. The cable speed running out of the hole was 4 m/min from the bottom to the end of pipe and 50 m/min to the surface. Several station stops were included in each deployment as an added depth control check. Station 1, at the mudline, and Station 2, at the target depth and/or bottom of the hole, were taken on the way down; Stations 3 and 4 were taken on the way up about halfway up the open section and in the drill pipe, at 1500 meters below rig floor (mbrf). The stations are easily identifiable on temperature and pressure records and allow the interpolation of depths between station stops and the accurate tying of gauge depths to the coring line depth. An independent time-depth data set, acquired with a PC in the subsea shop that is interfaced with the coring line winch, was obtained from the SEDCO Electrical Supervisor after each deployment of the UHT-MSM tool.

CORK Recovery and Deployment

A primary objective of Leg 169 was to reCORK Holes 857D and 858G in the Middle Valley hydrothermal field, operations that required relatively quiet seas. Opening the sealed, instrumented boreholes allowed the first subsurface sampling of hydrothermal fluids from an ODP borehole. The CORK instrument packages placed in the holes during Leg 139 (fig. 4; Davis et al., 1992; Davis and Becker, 1994; Davis and Fisher, 1994) were removed, and new instrument packages were deployed. Hole 857D, 1.6 km to the south of Hole 858G, was also to be deepened before sealing and instrumentation. Four successful CORK deployments were realized during Leg 168 (Shipboard Scientific Party, 1997b), and several detailed manuals were left for Leg 169 CORK installers.

The original plan for Holes 858G and 857D was to unseal the instrumented CORKS installed during Leg 139 in 1991 by removing the data loggers and thermistor strings, obtain temperature logs and borehole fluid samples before recovery of the bodies of the CORKS, and finally reseal the holes with new CORKS. Operations at Hole 858G represented the first recovery attempt of a previously installed CORK and were the first part of a CORK-to-CORK experiment proposed for Leg 169 and detailed in Figure 6.

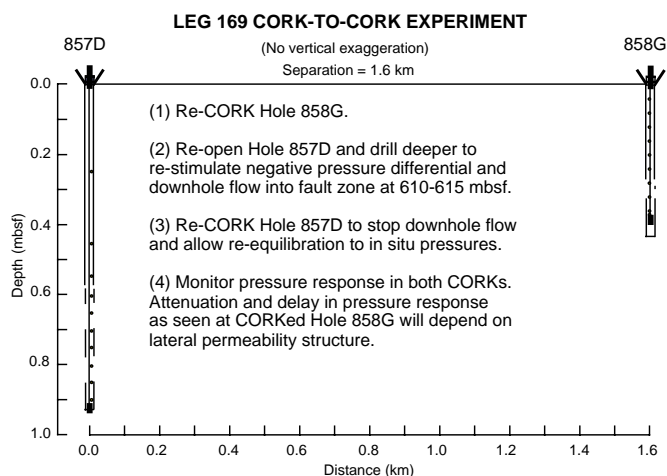


Figure 6. Objectives of the proposed Leg 169 CORK-to-CORK experiment in Holes 857D and 858G, located 1.6 km apart (K. Becker and E.E. Davis, pers. comm., 1996). The CORK configurations shown are those for the replacement Leg 169 thermistor strings/data loggers.

Logging Operations

The boreholes were flushed of debris and cooled in preparation for logging after coring was completed. A viscous drilling fluid (sepiolite mud mixed with seawater to a weight of 8.8 lb/gal or 1.11 kg/m³) was circulated through the drill pipe to the bottom of the hole. The bottom-hole assembly was pulled up to a depth of between 60 and 100 mbsf, run down to the bottom of the hole again to ream borehole irregularities, and the borehole was filled with mud. The pipe was again raised to 60–100 mbsf, and tool strings composed of one or more sensor combinations were lowered downhole by a seven-conductor wireline cable during sequential runs. A wireline heave compensator was employed to minimize the effect of ship heave on the tool position in the borehole.

The Triple Combo string and the Formation MicroScanner (FMS)–Sonic (SDT) combination were deployed during Leg 169. Tool string configurations, sampling methodology, and routine data processing specifications are given in the *Initial Reports* volumes of Legs 139 (Shipboard Scientific Party, 1992b) and 166 (Shipboard Scientific Party, 1997a).

Incoming data for each logging run were acquired, recorded on disk, and monitored in real time on the Maxis 500 logging unit. Data were transferred to shipboard computers for preliminary interpretation after logging was completed, and also beamed to LDEO-BRG via a satellite communication dish on the helipad for preliminary processing. Processed data were sent back to the ship in ~2 weeks time.

Shore-Based Log Processing

Processing, quality control, and display of the logging data of Holes 856H and 1037B were performed by the BRG at LDEO and the Institut Méditerranéen de Technologie using Schlumberger “Logos” software and additional programs developed by members of the BRG. Displays of most of these processed data appear with accompanying text at the end of the appropriate site chapter in this volume. Files of all processed logs (including FMS, dipmeter, temperature data, high resolution density and neutron data, and sonic waveforms not shown in printed form) and explanatory text are included on the

CD-ROM in the back pocket of this volume; a directory of CD-ROM contents is found in the Table of Contents in this volume.

Shore-based processing of data from each hole consisted of (1) depth adjustments of all logs to a common measurement below the sea floor, (2) corrections specific to certain tools, and (3) quality control and rejection of unrealistic values.

The depth shifting procedure is based on an interactive, graphical depth-match program that allows the processor to visually correlate logs and define appropriate shifts. The reference log and the log to be adjusted in depth are displayed side-by-side on a screen, and vectors connect the two at positions chosen by the user. The total gamma ray curve (SGR) from the natural gamma-ray spectrometry tool (NGT) or Hostile Environment Spectral Gamma Sonde (HNGS) run on each logging string was used in most cases to correlate the logging runs. In general, the reference curve is chosen on the basis of constant, low cable tension and high cable speed (tools run at faster speeds are less likely to stick and are less susceptible to data degradation caused by ship heave). Other factors, however, such as the length of the logged interval, presence of bottom-hole assembly, and the statistical quality of the collected data (better statistics are obtained at lower logging speeds) are also considered in the selection. A list of the amount of differential depth shifts applied at each hole is available upon request to LDEO-BRG.

Specific tool corrections were performed on the gamma-ray data (NGT) to account for changes in borehole size and for the composition of the drilling fluid. The HNGS data are corrected in real time during the recording.

Quality control was performed by cross-correlation of all logging data. If the data processor concluded that individual log measurements represented unrealistic values, the choices were to either discard the data outright and substitute the null value of “-999.25,” or identify a specific depth interval containing suspect values that must be used with caution. The latter are noted in the text that accompanies all processed log displays. Quality control of the acoustic data was based on discarding any of the four independent transit time measurements that were negative or that fell outside a range of reasonable values selected by the processor.

In addition to the standard 15.24-cm sampling rate, neutron data (accelerator porosity sonde [APS] tool) were recorded at a sampling rate of 5.08 cm during the repeat section of the resistivity probes (DIT)/APS/density probes (HLDS)/HNGS at Hole 856H only.

Some intervals of log data appeared unreliable (usually because of poor hole conditions) and were not processed. In general, a large (>12 in) and/or irregular borehole affects most recordings, particularly those that require eccentricization (HLDS, APS) and a good contact with the borehole wall. Hole deviation can also degrade the data; the FMS, for example, is not designed to be run in holes that are more than 10° off the vertical, as the tool weight might cause the caliper to close.

PALEOMAGNETISM

Monitoring the magnetic signal of hydrothermally altered sediment and basement cores recovered during Leg 169 combines paleomagnetic and rock magnetic measurements. The determination of qualitative and quantitative variations of the magnetic signal as a function of the vastly varying lithologies encountered during Leg 169 was accompanied by work on a magnetostratigraphy to date the sedimentary sections. Rock magnetic logging of the cores included isothermal remanent magnetization (IRM), backfield experiments, and the anisotropy of magnetic susceptibility (AMS) for selected discrete samples. Pass-through measurements of the natural remanent magnetization (NRM) of suitable split-cores from the sites drilled from the groundwork for the magnetostratigraphic work during the cruise. If the paleomagnetic measurements revealed a sufficiently stable sig-

nal, then the characteristic remanence direction of oriented minicores was used to reorient the cores and thus provide a declination frame for structural studies on the Leg 169 cores. These data contribute to the major Leg 169 objectives, specifically tectonics and the sedimentation history of sedimented rifts. They also provide a sound basis for future shore-based studies on scalar and vector information derived from the magnetic signal.

Laboratory Facilities

No major changes in routine magnetic measurements were required for Leg 169. The reader is referred to previous ODP volumes for a general overview on shipboard laboratory facilities, especially the new 2G direct current superconducting quantum interface device-magnetometer installed during the port call before Leg 168 (Shipboard Scientific Party, 1997c). During Leg 169, a LABVIEW software package to control the cryogenic magnetometer (ODPCryo.vi 1.0 by B. Mills) was developed and tested. It subsequently replaced the software in use during Leg 168. Additional tests were run and calculations were made during Leg 169 to remove problems initially encountered with data reduction.

Low-Field Susceptibility and AMS

AMS was measured using the Jelinek (1977) 15-position routine and algorithms on the Kappabridge KLY-2 susceptibility bridge. To further characterize the resulting AMS ellipsoids, the shape parameter, T (Hrouda, 1982) and the corrected degree of anisotropy, P_j (Jelinek, 1981), were calculated. The bulk susceptibility for all discrete samples, whenever AMS measurements were performed, was calculated from the three principal axes of the anisotropy ellipsoid. In all other cases, magnetic susceptibility was determined directly from single measurements on the Kappabridge.

Isothermal Remanent Magnetization

IRMs were imparted along the cylindrical axis of 10.5 cm³ minicores using the ASC Scientific Model IM-10 impulse magnetizer after alternating field (AF) demagnetization (60–80 mT) of the samples. Remanence acquisition was determined by applying incrementally increasing pulse fields (22, 51, 100, 200, 300, 500, 700, and 1000 mT). IRMs reported thus have been imparted at 1 T (IRM at 1 T). Whenever pilot analysis of the cores yielded magnetically homogeneous units, all remaining samples in this interval were magnetized in a single step (IRM at 1 T) only. Backfield IRMs were generally imparted at 0.3 T and mainly used to calculate the S-ratio (following Bloemendal et al., 1992). Remanence intensities were determined on the Molspin magnetometer that is interfaced with an IBM compatible PC and controlled by a BASIC program (Pmagic version 1.2).

Natural Remanent Magnetization

The NRM measurements were performed by passing continuous archive half-core sections in 10-cm intervals through the cryogenic magnetometer. All magnetic data are reported relative to the standard ODP paleomagnetic coordinate system (see Leg 153 “Explanatory Notes” chapter, Shipboard Scientific Party, 1995a). In general, the archive half was demagnetized in a 10- and 20-mT AF for the removal of any secondary magnetization. Deselection criteria of sections regarded as unsuitable to detect significant NRMs using the pass-through magnetometer include the different types of previously reported core disturbances (see ODP volumes) related to the individual coring methods applied. The NRM of discrete samples was measured accordingly on the cryogenic magnetometer, using 1-cm measurement intervals. AF demagnetization applied on dis-

crete samples was as high as 75 mT when required to reveal the characteristic vector component of the NRM. The polarity time-scale of Cande and Kent (1992) is the reference employed for the magnetostratigraphy during Leg 169.

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