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9. TAG-3 AREA[1]

Shipboard Scientific Party[2]

HOLE 957Q

Date occupied: 15 November 1994

Date departed: 16 November 1994

Time on hole: 18 hr, 30 min

Position: 26°8.198´N, 44°49.570´W

Bottom felt (drill-pipe measurement from rig floor, m): 3657.0

Distance between rig floor and sea level (m): 11.90

Water depth (drill-pipe measurement from sea level, m): 3645.1

Total depth (from rig floor, m): 3671.5

Penetration (m): 14.5

Number of cores (including cores having no recovery): 2

Total length of cored section (m): 14.5

Total core recovered (m): 5.91

Core recovery (%): 40.8

Hard rock:
Depth (mbsf): 14.5
Nature: Drill cuttings, chert, and silicified Fe-oxides

Principal results: Hole 957Q was drilled on the lower terrace of the mound about 55 m south of the Black Smoker Complex in a water depth of 3657 m. The objectives were to investigate the nature and degree of sulfide oxidation, and the vertical extent of the sulfide deposits in the southwestern quadrant of the mound. Hole 957Q was drilled to a total depth of 14.5 mbsf with 41% recovery.

The recovered cores consist of fine- to medium-grained drill cuttings and several larger pieces of pyrite and chert. The drill cuttings comprise silt- and sand-sized grains and fragments of pyrite, red chert, partially silicified Fe-oxides, and trace amounts of chalcopyrite. Geochemical analyses of this material indicate that it is composed of 36.8 wt% S and 33.0 wt% Fe. It has a high Cu content (6.6 wt%), but low concentrations of Zn (0.42 wt%), Ag (5.1 ppm), and Cd (9.2 ppm). These drill cuttings are more pyrite-rich than those recovered at Hole 957B (TAG-2, Kremlin area) about 40 m to the east. They are enriched in Fe-oxides and chert but depleted in anhydrite relative to the drill cuttings from Hole 957P on the upper terrace to the north of the Black Smoker Complex.

Larger pieces of porous red chert, red and gray chert, and massive porous pyrite were embedded in the drill cuttings and stuck in the core catcher. Similar material was collected at all locations drilled on the mound. The chert most likely results from precipitation of silica from hydrothermal fluids diffusing through the mound and forming a silica cap.

Physical properties measurements were made on four sections of drill cuttings. Bulk densities range from 2.8 and 3.2 g/cm^3, with the top section exhibiting more variable and very high magnetic susceptibility values (1200×10^{-5} SI). One partially silicified Fe-oxide fragment has a high total porosity of 18.1% and a bulk density of 2.60 g/cm^3.

STRATIGRAPHY

As the only material recovered in Hole 957Q was drill cuttings and a few small fragments of red and grey chert, pyrite, and partially silicified Fe-oxides, no stratigraphic information is available for the TAG-3 area.

SULFIDE PETROLOGY AND GEOCHEMISTRY

Introduction

The TAG-3 area is located 55 m south of the Black Smoker Complex on the lower terrace of the mound (see Fig. 3, Chapter 1, this volume). Hole 957Q was the only hole drilled at TAG-3, and it was located to the east of the low heat flow zone that extends down the western side of the TAG mound. The area surrounding Hole 957Q has diffuse low-temperature fluid discharge and noticeably fewer anemones than elsewhere on the mound. The purpose of Hole 957Q was to drill through the sulfide mound, to investigate the degree of sulfide oxidation, and to determine the nature of the stockwork zone and basalt basement at this locality.

Precipitates recovered in Hole 957Q, which was drilled to a total depth of 14.5 mbsf with recovery of 41%, consisted of fine- to medium-grained drill cuttings in Sections 158-957Q-1R-1 to 1R-4 (0–9.5 mbsf), and several small fragments of pyrite and chert in Section 158-957Q-2R-1 (Table 1, back pocket).

Drill Cuttings

The drill cuttings consist of silt and sand fragments and grains of pyrite, red chert (Type 2), partially silicified Fe-oxides (Type 1), and trace amounts of chalcopyrite. There is an overall coarsening of grain size downward from Section 158-957Q-1R-1 to 1R-4, which is most probably induced by drilling. Between 60 and 70 cm in Section 158-957Q-1R-1, patches and fragments of yellow-brown and red-brown Fe-oxyhydroxides and oxidized pyrite occur. At 120 cm in Section 158-957Q-1R-3, a 5-cm-long fragment of porous red chert was embedded in the drill cuttings. It contains fine-grained, disseminated pyrite crystals with polycrystalline, rounded aggregates of fine-grained pyrite in pore spaces, and fine-grained euhedral sphalerite lining a 1-cm-long cavity. Friable pebble-sized fragments of porous red chert with encrustations of fine-grained pyrite crystals and Fe-oxide were stuck in the core catcher from Section 158-957Q-1R-4.

Red and Gray Chert (Type 2)

Two samples of red and gray chert were recovered in Section 158-957Q-2R-1 (Pieces 1 and 2). The red chert consists of very fine-grained silica with very fine-grained, disseminated red Fe-oxides. The gray chert contains only trace amounts of Fe-oxides, and the

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[2]Shipboard Scientific Party is as given in the list of participants in the contents.

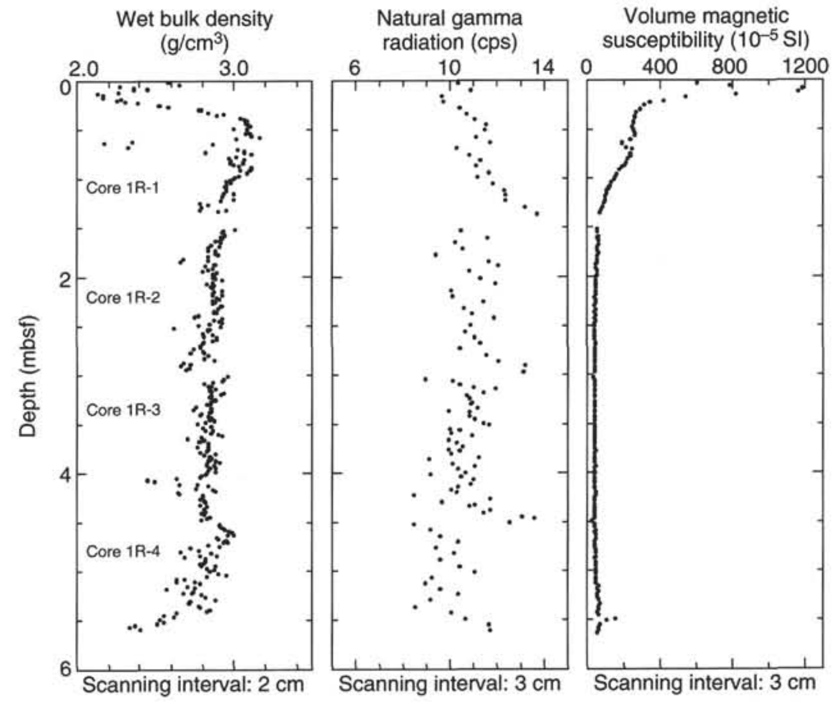

Figure 1. Results from multisensor track (MST) scans of drill cuttings in Sections 158-957Q-1R-1, 1R-2, 1R-3, and 1R-4. The measured physical properties are wet bulk density obtained by the GRAPE instrument, natural gamma radiation, and volume magnetic susceptibility.

boundary between the red and gray chert is gradational. Fine- to medium-grained, euhedral pyrite is disseminated in the gray chert and rims the fragment.

Massive Porous Pyrite (Type 5a)

Sample 158-957Q-2R-1 (Piece 3) consists of pyrite-silica clasts in a matrix of fine- to coarse-grained porous pyrite. The clasts are <1 mm to 1 cm, light gray silica with disseminated fine-grained pyrite. Pyrite fills fractures in the clasts. A single red chert clast (5 mm) occurs in the pyrite matrix. Trace amounts of fine-grained chalcopyrite are disseminated throughout the porous pyrite.

Sulfide Geochemistry

One sample was analyzed for S, Fe, Zn, Cu, Ag, and Cd using the AAS and CHNS techniques described in Chapter 5 (this volume). Sample 158-957Q-1R-3 consists of drill cuttings, and, because of the overall coarsening of the grain size downward in Section 158-957Q-1R-3, the sample was prepared by combining several aliquots taken along this section. The composite sample contains 36.8 wt% S and 33.0 wt% Fe. It has a high Cu content of 6.6 wt% but relatively low concentrations of Zn (0.41 wt%), Ag (5.1 ppm), and Cd (9.2 ppm).

Summary

The top 14.5 m of the TAG-3 area consists of red and gray chert, massive porous pyrite, and partially silicified Fe-oxides. However, because of the nature of the recovery, no stratigraphic information could be obtained from Hole 957Q.

Drill cuttings from the TAG mound were recovered at two other sites. A mixture of Fe-oxide, red and gray chert, and pyrite grains and clasts was recovered from the top part (0–9.9 mbsf) of Hole 957B in the TAG-2 (Kremlin) area. The drill cuttings recovered at TAG-3 differ from the material at TAG-2 by being more pyrite rich and Fe-oxide and chert poor. However, the samples recovered from the TAG-3 area contain more Fe-oxides and red and gray chert and no anhydrite compared to the pyrite-anhydrite-quartz sand and gravel with dark gray to black chert clasts (as large as 8 mm) recovered in Hole 957P from the TAG-5 area (see "Sulfide Petrology and Geochemistry" section, Chapter 11, this volume).

PHYSICAL PROPERTIES

Introduction

Physical properties measurements were made on four sections recovered from Hole 957Q on the southern side of the Black Smoker Complex (TAG-3). These sections consisted of drill cuttings of pyrite and red chert sand (see "Sulfide Petrology and Geochemistry" section, this chapter) and were scanned using the multisensor track (MST). One fragment of partially silicified Fe-oxide (Sample 158-957Q-1R-CC, 10–12 cm) recovered in the core catcher of Core 158-957Q-1R was measured for index properties.

Hole 957Q

Multisensor Track

A cumulative length of 5.5 m of drill cuttings comprising Sections 158-957Q-1R-1, 1R-2, 1R-3, and 1R-4 was sufficiently intact for multisensor track (MST) measurements, as shown in Figure 1. Because the recovered material filled the full core liner, no correction for the raw data of wet bulk density measurements by the MST GRAPE device was necessary. With the exception of the uppermost 40 cm of Core 158-957Q-1R, where wet bulk densities increased from 2.1 to 2.8 g/cm^3, the measured densities generally show a narrow range of 2.8 to 3.2 g/cm^3. A small range of values (9–14 cps) exists for natural gamma radiation throughout all sections of Core 158-957Q-1R (Fig. 1). The values for volume magnetic susceptibility show a sharp decrease in values from 1200 to 70 × 10^{-5} SI within Section 158-957Q-1R-1, whereas the remaining sections of Core 158-957Q-1R show an almost constant value of 40 × 10^{-5} SI (Fig. 1).

An attempt was made to measure compressional-wave (*P*-wave) velocities using the *P*-wave logger. The signal-to-noise ratio, however, was very poor, probably because of the unconsolidated nature of the sand and drill cuttings, and no meaningful data could be extracted.

Index Properties

Index properties were measured on one fragment of partially silicified Fe-oxide (Sample 158-957Q-1R-CC, 10–12 cm) recovered in the core catcher of Core 158-957Q-1R. Being a highly porous specimen (18.1%), it has a bulk density of 2.60 g/cm^3 (Table 2).

Summary

Multisensor track scanning of Core 158-957Q-1R shows a narrow range of bulk densities of 2.8 to 3.2 g/cm^3. Measurements on the top of Section 158-957Q-1R-1 reveal more variable densities and very high volume magnetic susceptibility values, indicating high concentrations of porous Fe-oxide pebbles and drill cuttings. One partially silicified Fe-oxide fragment shows a high total porosity of 18.1% and a bulk density of 2.60 g/cm^3.

FLUID GEOCHEMISTRY

Interstitial water (IW) was removed from material recovered at Hole 957Q from a 10-cm whole round taken from interval 158-957Q-1R-1, 140–150 cm, using standard Ocean Drilling Program IW squeezing techniques (see "Fluid Geochemistry" section, Chapter 5, this volume). Surface seawater was collected by bucket grab on the same day as the core was recovered. Bottom water in the vicinity of Hole 957Q is assumed to be similar to that collected near Hole 957C (WSTP-2) (see "Fluid Geochemistry" section, Chapter 7, this volume).

Results

Concentrations of major dissolved ions in interstitial water from Sample 158-957Q-1R-1, 140–150 cm, have values between those of surface seawater and bottom water (WSTP-2) in the vicinity of the TAG mound (Table 3). For example, concentrations of dissolved chloride in the IW sample, bottom water, and surface seawater are 552, 543, and 581 mmol/L, respectively; values of dissolved calcium are 10.3, 10.2, and 11.3 mmol/L, respectively; and measurements of dissolved magnesium are 55.8, 54.5, and 56.9 mmol/L, respectively. The dissolved silica content in IW Sample 158-957Q-1R-1, 140–150 cm, is near that of bottom water (55 and 57 µmol/L, respectively).

As pointed out in the Kremlin area "Fluid Geochemistry" section (Chapter 8, this volume), waters collected from the borehole and from porous materials immediately adjacent to the borehole walls are likely to be mixtures of fluids from several sources. Drilling operations introduce surface seawater into the borehole. Because of density differences between hydrothermal fluids and colder, more dense bottom water, bottom water may cascade into the borehole. Therefore, formation fluids, perhaps similar to the Black Smoker Complex (BSC) end-member hydrothermal fluids, with 636 mmol/L dissolved chloride (Rona et al., 1993), may be mixed with surface seawater and/or bottom water.

Because chloride behaves conservatively during mixing of formation, surface, and bottom waters, it can be used as an indicator of proportions of simple mixing between two end-member fluids. Dissolved chloride is higher in both surface seawater and in BSC fluids than in IW Sample 158-957Q-1R-1, 140–150 cm. Therefore, the IW sample cannot be solely a mixture of surface seawater and BSC fluids. The IW sample is influenced by mixing with a lower dissolved chloride fluid, such as bottom water. A simple mixing model based on dissolved chloride, with BSC fluid and bottom water as the two end-members, suggests that IW Sample 158-957Q-1R-1, 140–150 cm, could be a mixture of about 90% bottom water and 10% BSC fluid. However, this mixture seems unlikely because both dissolved magnesium (55.8 mmol/L) and sulfate (30.8 mmol/L) are higher than this simple mixture could produce, as BSC fluid is likely to be depleted in magnesium and sulfate based on conservative end-member mixing models (Edmond et al., 1995). As demonstrated in the TAG-2 (eastern side of the Black Smoker Complex) "Fluid Geochemistry" section, the slightly elevated dissolved magnesium and sulfate concentrations may be the result of drilling-induced anhydrite dissolution.

A second simple mixing calculation based on dissolved chloride with surface seawater and bottom water as the two end-members, suggests that IW Sample 158-957Q-1R-1, 140–150 cm, is a mixture of about 75% bottom water and 25% surface seawater. Section 158-957Q-1R-1 is described as Fe-oxide, chert, and pyrite sand; it probably consists of 100% drill cuttings. The presence of drilling-induced grain size stratification in the recovered sand suggests that the chemical composition of the interstitial water associated with the sand is dominated by drilling-introduced fluid, and thus must include a substantial portion of surface seawater. Based on changes in pump pressure during drilling, circulation was lost several times and drilling fluids were forced into the surrounding formation, probably displacing in situ formation fluids (G. Pollard, pers. comm., 1994). Therefore, we infer that IW Sample 158-957Q-1R-1, 140–150 cm, is a

Table 2. Index properties of one sample recovered from Hole 957Q.

Core, section, interval (cm)	Depth (mbsf)	Bulk water content (%)	Bulk density [B] (g/cm^3)	Bulk density [C] (g/cm^3)	Grain density [B] (g/cm^3)	Grain density [C] (g/cm^3)	Porosity [B] (%)	Porosity [C] (%)	Rock type (F = fragment)
158-957Q- 1R-CC, 10–12	5.59	7.11	2.78	2.60	3.20	2.95	19.26	18.05	Fe-oxide, partially silicified (F)

Note: [B] and [C] refer to the method used to calculate bulk and grain density (see "Index Properties" section, "Explanatory Notes" chapter, this volume.

Table 3. Dissolved ion concentrations in interstitial water from Section 158-957Q-1R-1, 140–150 cm, and in bottom and surface seawater in the vicinity of Site 957.

	pH	Alkalinity (mmol/L)	Salinity (‰)	K^+ (mmol/L)	Mg^{2+} (mmol/L)	Ca^{2+} (mmol/L)	Cl^- (mmol/L)	SO_4^{2-} (mmol/L)	SiO_2 (µmol/L)
158-957Q-1R-1, 140–150	7.1	1.88	34.5	10.5	55.8	10.3	552	30.8	55
WSTP-2	7.7	2.49	35.0	10.7	54.5	10.2	543	28.1	57
Surface seawater			36.5	10.8	56.9	11.3	581	31.5	>1

mixture of bottom water and surface seawater, with no detectable formation fluid.

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Rona, P.A., Hannington, M.D., Raman, C.V., Thompson, G., Tivey, M.K., Humphris, S.E., Lalou, C., and Petersen, S., 1993. Active and relict seafloor hydrothermal mineralization at the TAG hydrothermal field, Mid-Atlantic Ridge. *Econ. Geol.,* 88:1987–2013.

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NOTE: For all sites drilled, core-description forms ("barrel sheets") and core photographs can be found in Section 3, beginning on page 227. Thin-section data are given in Section 4, beginning on page 345.