JOIDES - Ocean Drilling Program at the Ridge Crest

Ocean Drilling Program Reveals the Subsurface Nature of the TAG Hydrothermal Mound

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The TAG hydrothermal field is located on the Mid-Atlantic Ridge at 26°N between the Atlantis and the Kane fracture zones (Fig. 1). The field extends over an area of at least 25 km^2 along the eastern wall of the median valley in the center of a 40 km-long ridge segment between 25°55'N and 26°17'N and consists of presently active low- and high-temperature zones as well as a number of relict deposits (Rona et al., 1993). Massive sulfides, black smokers and vent biota of the active TAG hydrothermal mound were discovered in 1985 (Rona et al., 1986), although first indications of hydrothermal activity in the area were documented much earlier (Rona et al., 1975).

The TAG active mound at 26°08'N, 44°49'W is a large (3-5 million tons), mature massive sulfide deposit and represents one of the closest modern analogs of ancient ophiolite-hosted massive sulfide deposits on land. A unique feature of TAG is the almost circular shape of the active mound which measures about 200 m diameter and 30-40 m in height. The TAG mound occurs at the junction between the rift-valley floor and the east wall and lies on oceanic crust at least 100,000 years old, based on a spreading half rate of 13 mm/yr to the east (McGregor et al., 1977). Recent bathymetry data indicate that the morphology of the mound is characterized by two relatively flat platforms at depths of 3650 and 3645 m which may represent two major phases of hydrothermal activity (Humphris et al., 1994).

The surface morphology and mineralogy of the TAG mound have been described in detail by Thompson et al. (1988), Herzig et al. (1991), Rona et al. (1993), and Tivey et al. (1995). A cluster of black smoker chimneys (Black Smoker Complex, Fig. 2) emitting fluids up to 363°C and consisting mainly of chalcopyrite and anhydrite is located on the upper platform northwest of the center of the mound on top of a 10-15 m high, 20-30 m diameter cone. The surface of this cone is covered by a 3-6 cm thick plate-like layer of massive chalcopyrite and marcasite, and large blocks of corroded massive anhydrite. Lower-temperature, sphalerite dominated white smoker chimneys with fluid temperatures of 260°-300°C (Kremlin area, Fig. 2) occur about 50-70 m southeast of the Black Smoker Complex. The Kremlin fluids have a low pH (3 at 23°C), which is unusual for white smokers, and they are thought to be derived from the black smoker fluids by a combination of conductive cooling (keeping the pH low) and mixing with seawater in the subsurface (Tivey et al., 1995).

Geochronological studies suggest that the TAG mound is on the order of 40,000-50,000 years old and that hydrothermal activity has been intermittent over the past 20,000 years. High-temperature pulses occurred about every 5000-6000 years and the present black smokers have been active for at least 50 years (Lalou et al., 1990, 1993).

Leg 158 of the Ocean Drilling Program was designed to investigate for the first time the subsurface nature of a volcanic-hosted, sediment-free, active hydrothermal system at the modern seafloor. Important issues that were addressed include the nature of water-rock and seawater-hydrothermal fluid interactions, geochemical fluxes, and associated alteration and mineralization. Between September 29 and November 22, 1994 a total of seventeen holes were drilled in five areas (TAG-1 to TAG-5, Fig. 2) across the TAG mound, including the active Black Smoker Complex and the white smoker Kremlin area. Drilling in the TAG-1 (Black Smoker Complex), TAG-2 (Kremlin), and TAG-4 (west of the Black Smoker Complex) areas revealed a northwest-southeast cross-section of the mound with a maximum penetration of 125 m. This was complemented by drilling south (TAG-3) and north (TAG-5) of the Black Smoker Complex in order to delineate lateral heterogeneity of the sulfide deposit, and the extent and nature of the underlying stockwork zone.

Recovery was highly variable, ranging from <1 to 63% with an average of about 12% (52 m of core out of 436 m total interval cored). Breccias of various types dominate the stratigraphy of the entire mound including the sulfide section and the upper part of the underlying stockwork zone. The complex assemblages of matrix and clast-supported breccias consisting of varying proportions of pyrite, anhydrite, and silica

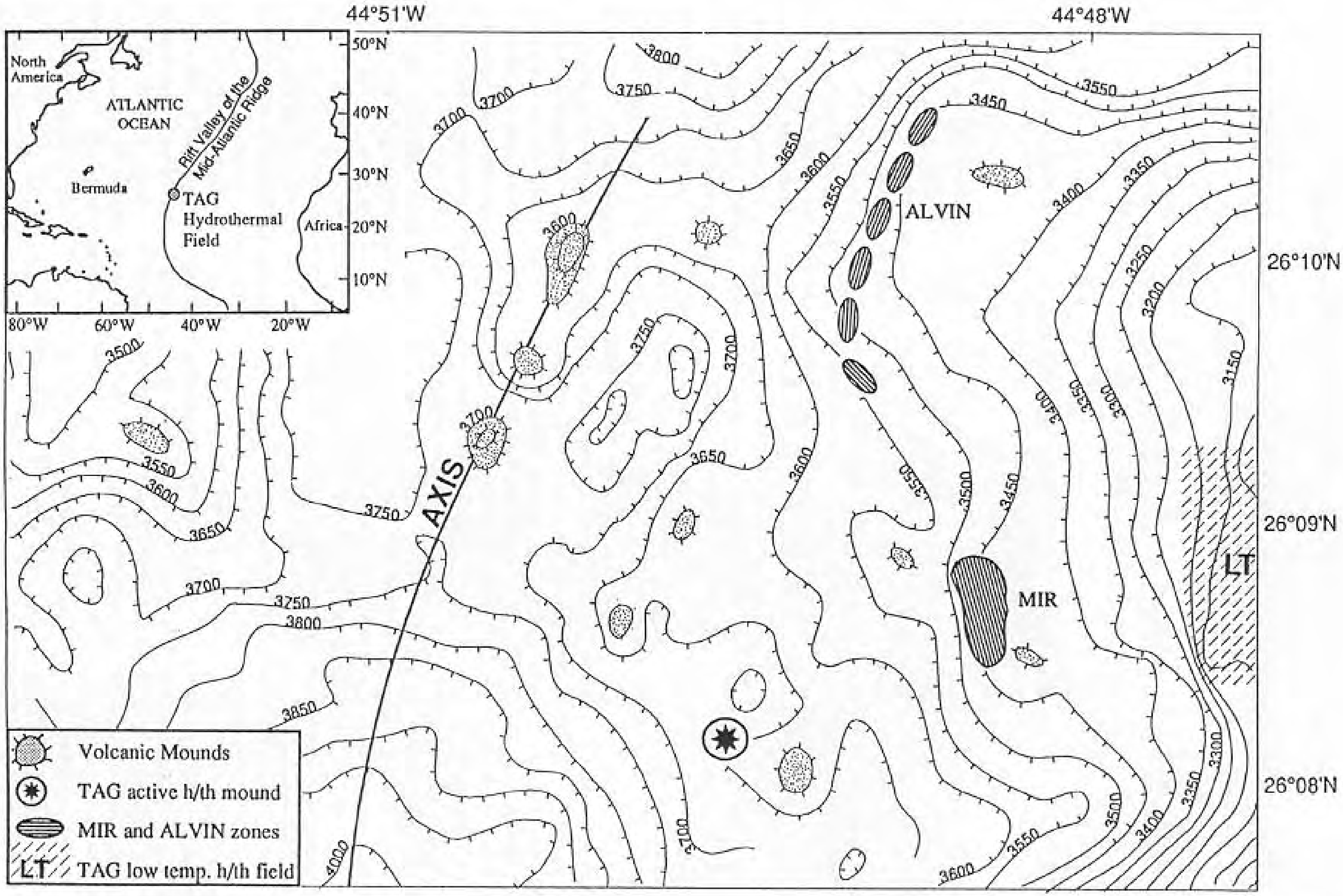

Figure 1. SeaBeam bathometry (50-m contour interval) of the TAG hydrothermal field, showing volcanic domes, the active TAG hydrothermal mound, the low-temperature hydrothermal field on the eastern rift-valley wall, and the Alvin and Mir relict hydrothermal zones (modified from Rona et al., 1993).

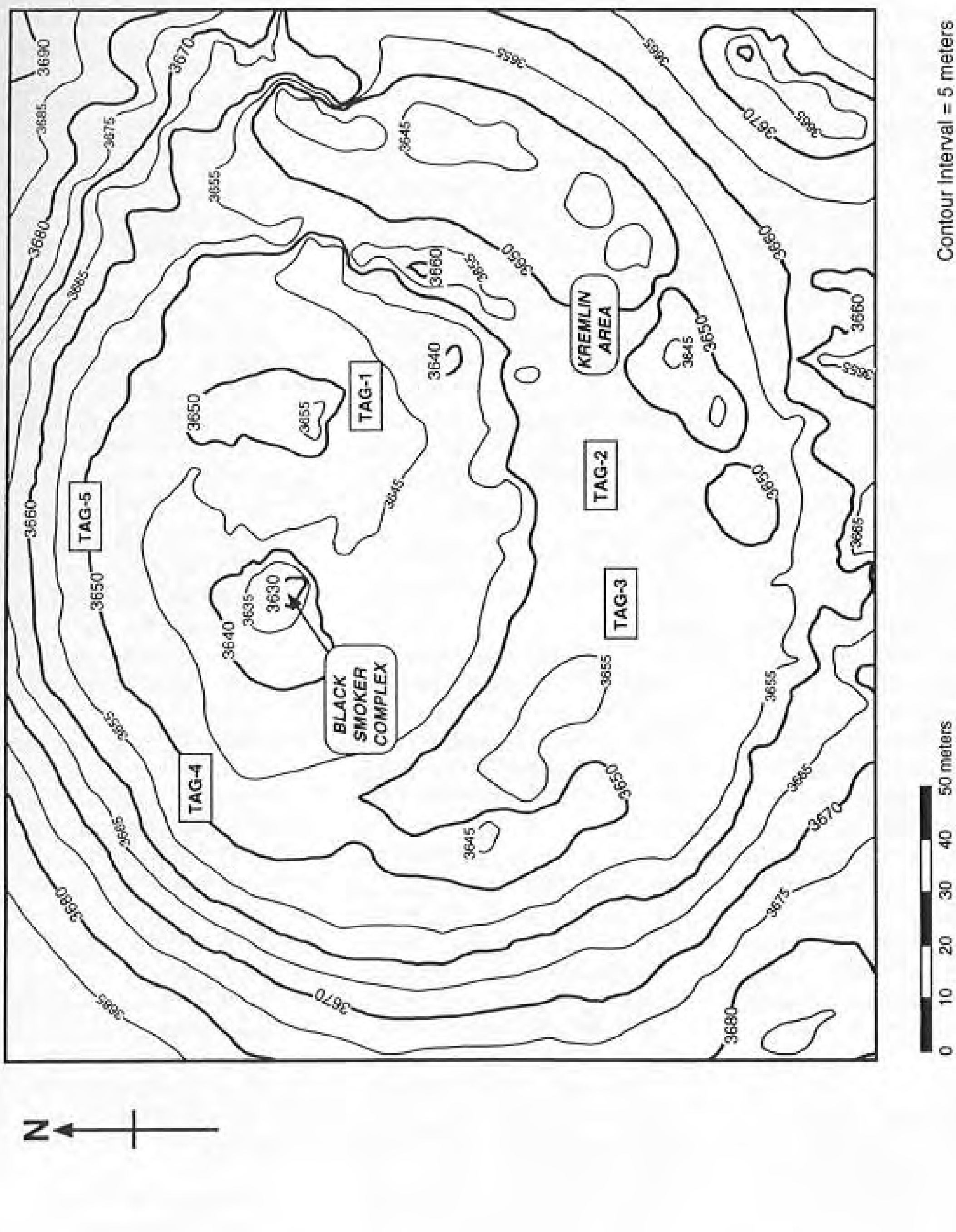

Figure 2. Bathymetry (5-m contour) of the active TAG mound showing the location of the ODP Leg 158 drilling areas TAG-1 to TAG-5.

is a product of the multistage development of the mound including episodes of chimney growth and collapse, mass-wasting, faulting, cementation, hydrothermal reworking, and replacement. The sulfide breccias that are now at the base of the mound likely accumulated at the seafloor through the collapse of large sulfide chimneys and by dissection of massive sulfides along active fault scarps and have since been buried, overprinted, replaced or cemented by quartz, sulfides, and sulfates during later hydrothermal events.

Based on the sequence of rock types recovered from each area, four major lithologic types were distinguished. The upper 10-20 m of the mound consist of massive pyrite and pyrite breccias. This is underlain (20-30 m) by an anhydrite-rich zone, consisting of matrix-supported pyrite-anhydrite breccias and pyrite-anhydrite-silica breccias, which is best developed in the TAG-1 area but was also found at TAG-5. At depths of about 40-45 m, quartz-pyrite mineralization and quartz veining increase and indicate the top of the stockwork zone. This suggests that the thickness of the mound in the TAG-1 area (Black Smoker Complex) is about 30-40 m. The sulfide assemblage is clearly dominated by pyrite with only minor amounts of chalcopyrite and sphalerite. Drilling in the TAG-2 area indicated that the thickness of the sulfide mound beneath the Kremlin is only about 25 m. The stockwork itself consists of quartz-pyrite breccias overlying silified wallrock breccias which grade into a quartz-chlorite zone below about 100 m depth. This zone contains abundant chloritized and only weakly mineralized basalt breccias consisting of 1-5 cm clasts of altered basalt in a matrix of quartz and pyrite.

The amount of anhydrite found in the TAG drill cores was unexpected. Anhydrite is most abundant between 15-40 m depth in the TAG-1 area east of the Black Smoker Complex. Here, the pyrite-anhydrite and pyrite-silica breccias are cross-cut by massive anhydrite veins up to 45 cm in width. These veins comprise complex, multistage fracture fillings and cavity linings, some of which include fine-grained, disseminated pyrite and chalcopyrite, and trace amounts of hematite. The presence of anhydrite is interpreted as a product of seawater heating by mixing with high-temperature fluids of the central upflow zone to temperatures above 150°C. The driving force for seawater inflow is obviously the high velocity discharge of hot fluids at the Black Smoker Complex.

Drilling at the TAG mound has documented the complex nature of subsurface sulfide formation at seafloor spreading centers. Hydrothermal replacement, rather than sulfide precipitation at the seafloor, appears to be the dominating process of sulfide accumulation at TAG. A complex program of detailed studies on the TAG drill core will address a number of fundamental questions related to the formation and evolution of hydrothermal systems and massive sulfide deposits at the modern seafloor and their ancient analogs on land.

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