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Thermal interaction between back-arc volcanism and basin sediments in the Bransfield Strait, Antarctica

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The Antarctic Peninsula formed as an island arc between early Jurassic and Miocene times when the Pacific plate was subducted beneath the antarctic plate. The South Shetland Island chain was originally part of this arc but has since become separated from it by opening of the Bransfield Strait. The separation is consistent with classical back-arc rifting but the duration and regional extent of this process have remained controversial as well as the type of crustal material from which magmatism is derived. The hydrothermalism in the Bransfield Strait is typical for volcanism-sediment interation in a marginal basin. The long-range scientific objectives are to understand the types of sediment-water-rock interactions and resulting gas and fluid circulation patterns at different types of plate boundaries. We wish to quantify and model reactions, transport of water, gases, and dissolved constituents generated by thermal action at plate boundaries and the sediment cover and to develop criteria for recognizing and differentiating reactions and mass fluxes at different tectonic environments. The specific objectives of the Bransfield basin project were:

- To ascertain the extent and type of reactions of thermally driven fluids advecting through the organic carbon-rich sediments of the Bransfield Strait basin;
- To map the distribution and isotope characteristics of thermogenic hydrocarbon gases emanating from the thick sediment cover over the ridge flanks;
- To determine the mineralogy and chemistry of basaltic dikes penetrating the sediments at the axis of spreading;
- To explore for other evidence of hydrothermal activity at the seafloor and in the lower water column along the thinly sedimented spreading axis.

Fiscal year 1986 was the first of 2 years of National Science Foundation supported investigations in the Bransfield Strait. With additional support from the Oregon State University Foundation we conducted, as scheduled, a field program during November and December, 1985, aboard the German polar research vessel PRSV *Polarstern* (Suess and Wefer 1987).

SEABEAM bathymetry. We completed a detailed bathymetric survey of the eastern part of the Bransfield Strait basin and significantly expanded our 3.5 kilohertz coverage begun under a previous Office of Naval Research supported project (figure 1a,b). Hydrothermalism in the sediments was delineated by the acoustic anomaly pattern adjacent to the presumed volcanic center. The southeastern part of the basin is bounded by faults and shows a symmetric subsidence with the depositional center delineated by significantly thicker turbidite layers (figure 2).

Sediment coring and pore fluids. We cored a transect across the area of acoustic turbidity and obtained pore water, dissolved gases, and sediment geochemical data. It was readily apparent from the pore water dissolved chloride and major cations that hydrothermal reactions are taking place between the basaltic intrusions and organic-rich sediments. These chemical anomaly patterns were used to simulate numerically rates and direction of a lateral flow of altered fluids across the basin (Han and Suess in preparation). The pore fluids move laterally across the basin, 5 meters below the seafloor, at the rate of approximately 7 meters per year northward with gradually decreasing flow rates of approximately 1 meter per year. The lateral flow is fed from a recharge area, where bottom water is drawn down through fault planes along the topographically lower southern margin of the basin and discharges along the topographically higher margin in the north.

Thermogenic hydrocarbons. The dissolved and adsorbed fractions of light hydrocarbon gases were used to diagnose a low-temperature alteration process generating hydrothermal petroleum. During migration these products mix with biogenic methane from microbial carbonate reduction which is typical for the rapidly accumulating organic-rich sediments of the Bransfield Strait. Methanogenesis and methane oxidation by sulfate reduction are important early diagenetic processes in the uppermost sediment column. It is during these microbially mediated reactions that precipitation of a rare calcium carbonate hexahydrate mineral takes place (Whiticar et al. in preparation).

Rock dredging. Fresh basalts were recovered from two seamounts and from two 100-meter high volcanic hills. Thin sections and microprobe analyses of some of the fresh glasses and coexisting phenocrysts indicate andesites and icelandites. Phenocrysts of olivine, plagioclase, augite, and iron-rich chrome spinel are common. The preliminary data indicate that some of the rocks are similar to iron-rich andesites found on rifted oceanic platforms, such as Iceland. Thus the volcanics of the Bransfield Strait offer an excellent opportunity to answer important questions about the formation of marginal basins and associated volcanic rocks.

Water column. The seawater composition in the Bransfield Strait basin showed several strong signals for hydrothermal input, namely helium-3 anomalies and high concentrations of manganese. The temperature and radon distributions were not significantly different from the background values, although, in concert with helium-3 and manganese, two small temperature anomalies were established. Over a ridge of the Low Island basin a change of $+0.025°C$ was measured, whereas in the eastern part of the King George basin only $< +0.005°C$ were registered. Helium-isotope measurements were performed in collaboration with Z. Top (Rosenstiel School of Marine and Atmospheric Science, University of Miami) and P. Schlosser (Institut fu;dir Umweltphysik, University of Heidelberg). The maximum helium-3-anomaly was approximately 20 percent in the lower portion of a hydrothermal plume (station 301) drifting off the submarine volcano at the eastern King George basin. Generally, the helium-3-anomaly was around 6–8 percent. Dissolved manganese contents mirror the data, and are shown in figure 3.

Our results clearly indicate tha the eastern portion of Bransfield Strait basin is a site of presently active submarine volcanism at water depths of about 2,000 meters. Volcanic activity is related to extensional tectonism in the Bransfield Strait, a phenomenon which would be expected from back-arc rifting. As a consequence, a great deal of hydrothermal interaction and fluid advection occurs at this heavily sedimented ridge crest segment. Hydrothermalism in sediments is delineated by the acoustic anomaly pattern adjacent to the presumed volcanic center. Within this zone of alteration, hydrothermal petroleum is generated and seeps to the seafloor. It is easily identified by stable carbon isotope and deuterium/hydrogen characteristics as well as by its compositional spectrum of light alkanes.

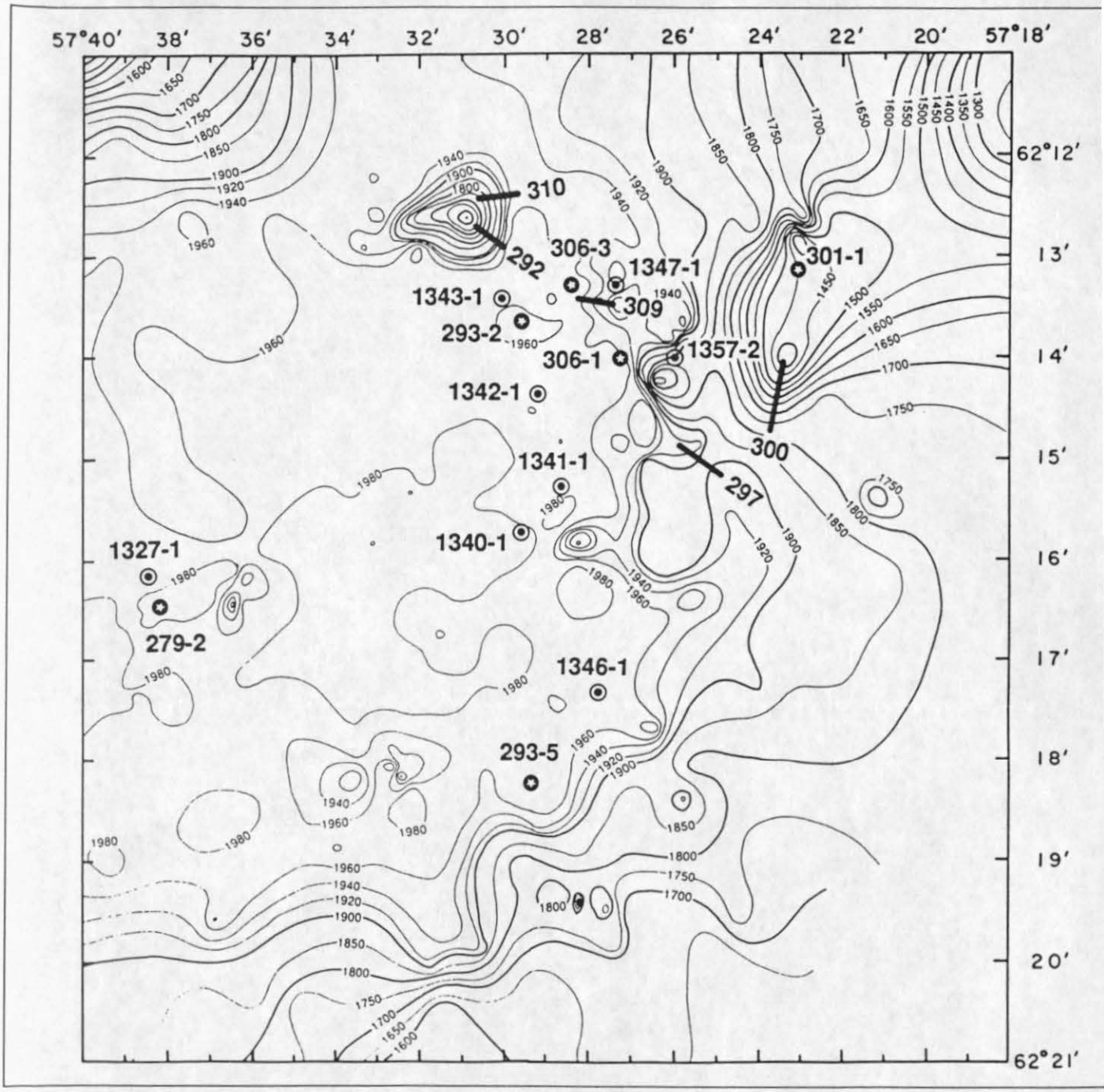

Figure 1a. Antarctic Peninsula, Bransfield Strait, and area of investigation. (Depth contours are in kilometers.)

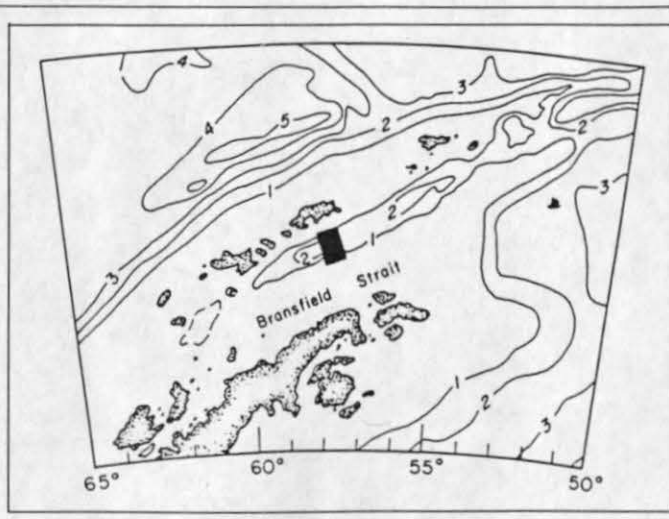

Figure 1b. Bathymetry: Eastern part of King George basin, Bransfield Strait. Contour interval: 20 meters > 1,900 meters; 50 meters < 1,900 meters (uncorrected meters). Bars denote dredge stations; stars denote hydrographic stations; dots denote coring stations.

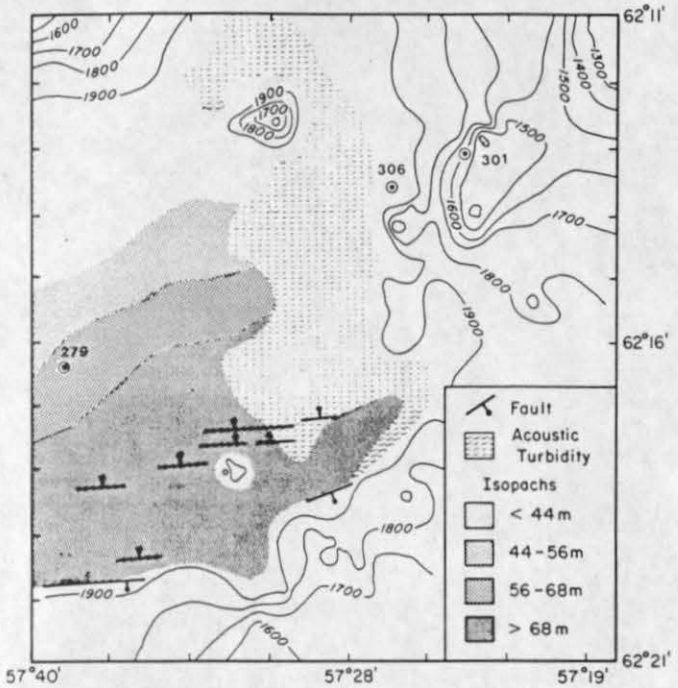

Figure 2. Bathymetry and sediment isopach map of the eastern part of the central Bransfield Strait basin. The sediment cover thickens toward the south of the basin. The acoustic turbidity pattern delineates the area of hydrothermal activity and submarine volcanism in the basin. Fresh glassy pillow basalts were dredged from the surrounding extrusions; hydrothermal petroleum was detected in all cores taken from this area; normal faults develop along the southern margin of the basin. From Han and Suess (in preparation).

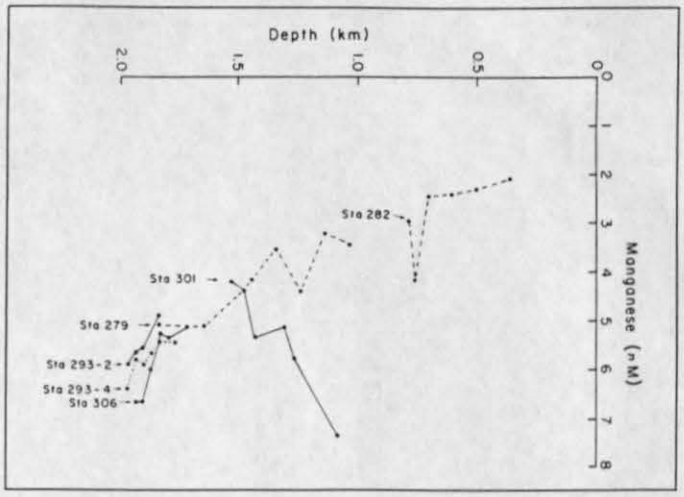

Figure 3. Dissolved manganese in the water column; the dashed line delineates background manganese of Bransfield Strait waters (Stations 282, 279). At station 301 the lower portion of a hydrothermal plume was encountered drifting off the submarine volcano; at other stations manganese input from the seafloor is evident (for locations see figure 2).

In pore fluids of the basin sediments the major seawater cations characteristically deviate from those in fluids unaffected by hydrothermalism. We think that an overall hydration reaction involving volcanic glass and pore fluids leads to uptake of dissolved magnesium, the release of calcium, and a significant increase in chlorinity of the pore fluids. This anomalous dissolved chloride pattern has been used to delineate the rate and flow direction of the hydrothermal circulation cell in the Bransfield Strait sediments. Submarine volcanic activity related to back-arc rifting appears to drive a fluid circulation cell by thermal input. The horizontal fluid pathways are preferentially through turbidite layers. The discovery of fresh pillow basalts and the distribution pattern of dissolved helium and manganese in the water column has helped to localize the centers of active submarine volcanism. These tracers will be used as well for flux estimates of hydrothermal input to the basin.

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