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Deep-penetration Heat Flow Probes Raise Questions about Interpretations from Shorter Probes

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More than 40% of the marine heat flow data collected since the early experiments of Sir Edward Bullard in 1949 were obtained using shallow penetration probes less than 5 m long [*Louden and Wright*, 1989]. The common belief that these data are reliable enough to model deep-seated thermal processes is supported by a few experiments in which heat flow measurements made in the Deep Sea Drilling Program (DSDP) and the Ocean Drilling Program (ODP) were compared to nearby surface heat flow measurements [e.g., *Hyndman et al.*, 1984]. However, thermal measurements made with 18-m penetrations recently collected on the northern flank of the South-East Indian Ridge (SEIR) bring a new perspective to this belief. In the study area, measurements of heat flow taken at the surface (0–5 m) and measurements taken at greater depths (3–18 m) did not always concur. Investigating this lack of agreement will help address difficult questions about the interpretation of shallow penetration (< 5 m) marine heat flow measurements.

The data were obtained during the MD120-ANTAUS expedition carried out by R/V *Marion Dufresne* that was conducted from October 12 to November 7, 2000 from Fremantle, Australia, to La Réunion Island. The primary objective of this cruise was to study marine heat flow variations along a 14-Ma isochron that parallels the South-East Indian Ridge (SEIR) between the Saint-Paul/Amsterdam hot spot and the Australian-Antarctic Discordance (AAD), an anomalously deep section of the Mid-Ocean Ridge that is often attributed to a mantle "cold spot." In the 1960s and 1970s, heat flow measurements were obtained near the AAD as part of reconnaissance surveys [*Von Herzen and Langseth*, 1966; *Langseth and Taylor*, 1967; *Anderson et al.*, 1977]. However, to interpret heat flow variations in this region of thin and patchy sediment cover, it is not only necessary to obtain more data, but to collect data that can be used to trace water circulation and discriminate between the conductive and the convective components of the measured heat flow. To accomplish this, we collected long sediment cores, along with heat flow data to greater depths, to study the physical properties of the sediments and tentatively investigate the role of water circulation using helium isotopic ratios $^3He/^4He$ as tracers of hydrothermal activity. If water has circulated within the crust, then the $^3He/^4He$ isotopic signature is expected to be that of the crust and upper mantle; if water circulation has been confined to the sediment layer, it is expected to be that of the ocean and atmosphere.

Despite rough weather and bad seas, a total of 25 thermal measurements was obtained using 9 autonomous digital temperature probes fitted on an 18-m-long, 13-cm-diameter gravity corer. Full penetration of 18 m was regularly achieved. Figure 2 shows examples of non-linear temperature gradients obtained at three different sites. Each temperature measurement was systematically duplicated by two sensors that were spaced 64 mm apart. Hence, experimental effects cannot explain the observed non-linearity. Tests performed onboard after recovery clearly preclude systematic errors due to problems with calibration or drift of a thermistor. The observed non-linearity, which is too important to be explained by variations in thermal conductivity, clearly results from the combination of two natural effects: vertical advection of water into the sediments and variations in bottom-water temperature. Advection of water affects the shape of the temperature versus depth curve: convex curvature indicates water flowing upward; concave curvature indicates water flowing downward; a vertical gradient indicates the presence of an aquifer [e.g., *Anderson et al.*, 1979]. Yearly variations in bottom-water temperature affect the thermal gradient in the first 3–4 m. Although further analysis is needed to determine the characteristics of the suspected bottom-water temperature changes, our results raise questions about the heat flow estimates that we would have obtained in this specific study area using shallow penetration probes of less than ~5 m.

The above describes some advantages of combining coring and heat flow measurements within the sediments at great depths. R/V *Marion Dufresne* has the ability to take ultra-long cores of up to 60 m using a giant corer.

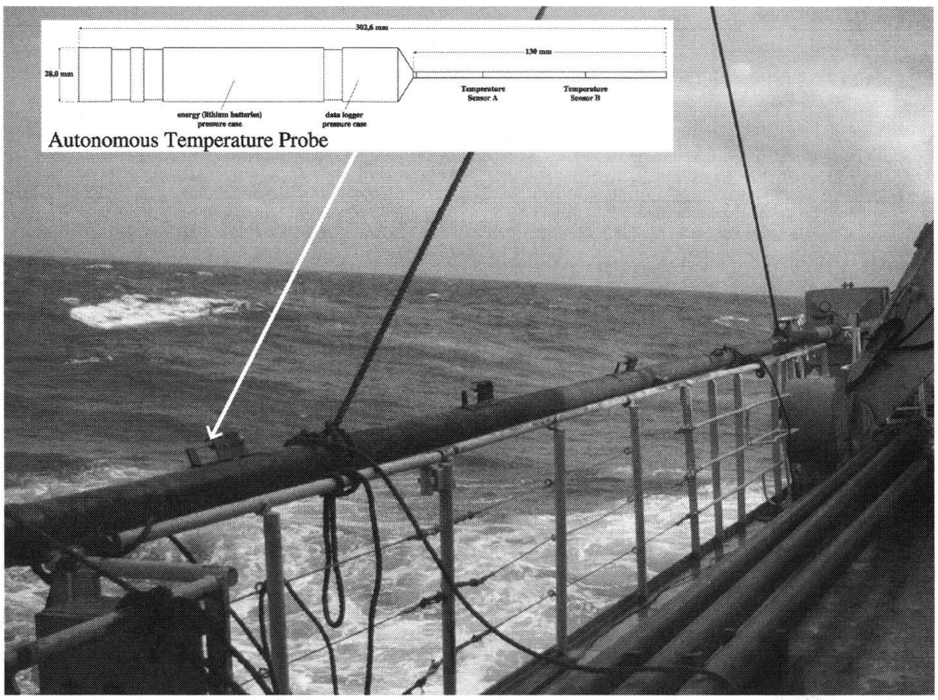

Fig. 1. Temperature probes welded onto the gravity corer onboard R/V Marion Dufresne. *Inset shows sketch of the autonomous temperature probe. R/V* Marion Dufresne *is a multi-purpose, 130-m-long research and supply vessel that both provides logistics for the French austral islands and conducts oceanographic research. Specifically designed for very severe weather conditions, the ship allows full performance in rough seas. The vessel, which is equipped with the full suite of geophysical facilities, including a system for multi-beam bathymetry and imagery, can raise 60-m sediment cores. Facing an increasing scientific demand, the French government decided in 1999 to reduce the ship time devoted to logistical operations to 120 days per year and allow the French Polar Institute (IFRTP) to conduct research throughout the world for 245 days per year. This paves the road for new approaches and the development of integrated, multi-disciplinary programs, as recently evidenced with the MD120-ANTAUS expedition.*

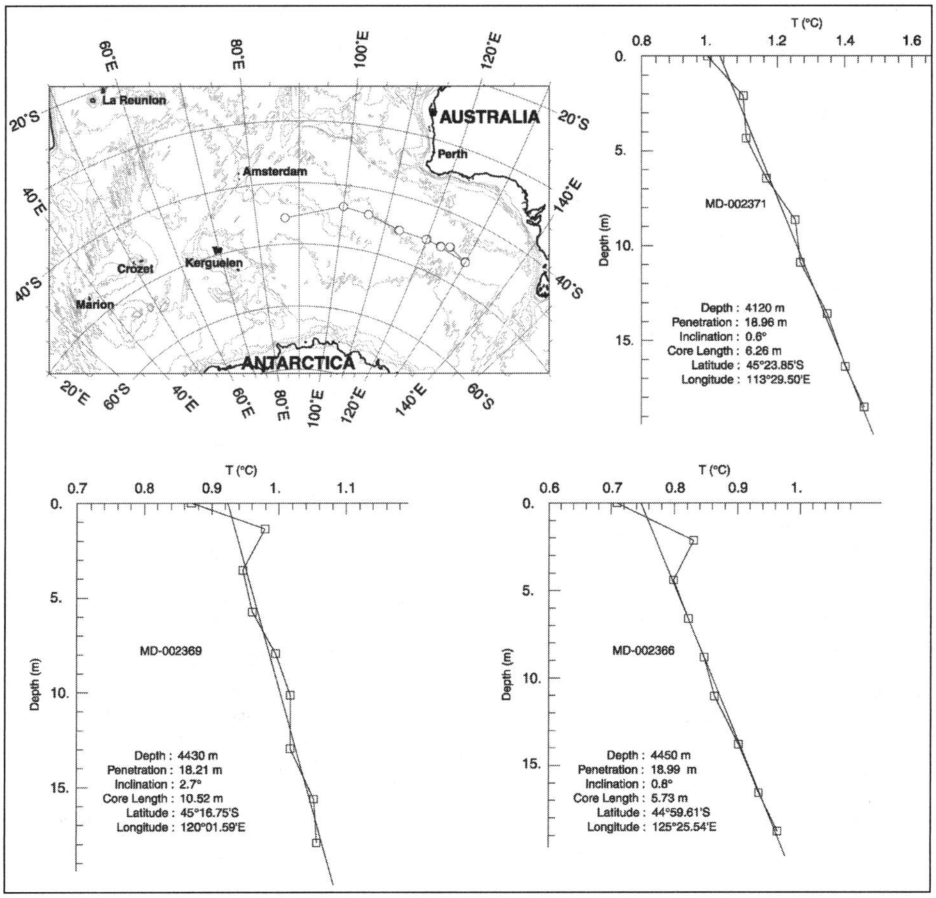

Fig. 2. Location of heat flow measurements sites of MD120-ANTAUS cruise (upper left) and temperature versus depth curves at core sites MD-002371, MD-002369, and MD002366 (coordinates are given on the figure). Temperature measurement uncertainties are ±1 m°C. Straight line is least square regression line.

In principle, the longer the core, the more precise are the temperature measurements. In practice, however, there are some limitations in core length. Tests performed on Meriadzeck plateau in 1999 using 25-m-long piston corers have clearly shown that adding temperature probes on the tube multiplies by a factor of two the traction required to pull the corer out of the sediments. Thus, heat flow measurement at depths of 30–40 m is an objective that seems feasible, but it is difficult to reach in common practice. However, for all R/V *Marion Dufresne's* coring programs that require gravity cores for preserving surface sediments, heat flow measurements could routinely and systematically be performed in the future without any additional ship time by using 15–25-m-long pipes. This would dramatically help improve our understanding of heat transfer processes from the crust to the ocean.

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Efforts Afoot to Stem the Flow of Invasive Species from Ballast Water

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With the U.S. National Invasive Species Act of 1996, or NISA, due for reauthorization next year by Congress, interest groups already are staking out their positions about how to protect the nation's waters from aquatic nuisance species that arrive in ballast water, and that can cause significant ecological and economic harm.

At a Capitol Hill briefing on July 9, representatives of the U.S. shipping industry called for mandatory ballast management and a ballast water management standard. They also called for certification of ballast water management technologies and practices, which they noted still require much research; and for federal preemption of state regulations that they said present shippers with a confusing patchwork of rules.

The industry representatives said that while any solution should protect trade and should not start with zero discharge standards, they are also concerned about environmental damage caused by invasive species.

"Look at the zebra mussel," said Kathy Metcalf, maritime affairs director of the Chamber of Shipping of America. "There are thousands, of 'zebra mussel situations' that are out there just waiting to happen," she said, referring to one of the more infamous invasive species.

While the International Maritime Organization (IMO) currently is negotiating a mandatory global ballast water management agreement, regulations drawn up under NISA by the U.S. Coast Guard currently only establish voluntary ballast water management guidelines under NISA. A mandatory reporting requirement has only averaged about 20% compliance nationwide, according to an October 2000 report by the National Ballast Water Information Clearinghouse. NISA authorizes the use of mandatory guidelines for mid-ocean ballast water exchange if voluntary guideline compliance is low, and the Coast Guard could revise the guidelines in the near future.

However, a number of state legislatures are not waiting for national or international agreements to protect their own waters. California, Hawaii, Maryland, Virginia, and Washington recently have enacted ballast regulations.

Metcalf denied that it is these regional initiatives that have prodded the shipping industry into becoming more concerned about the ballast water issue, and the need for national and international agreements.

However, Tom Chase, director of environmental affairs for the American Association of Port Authorities, told *Eos* that state regulations have pushed the industry to action. "No doubt that is an important driver. Absolutely," he said. "And it is also public concern about [ballast water]. It is a reaction to both of these.