GEOPHYSICAL CONSTRAINTS ON THE VOLUME OF HYDROTHERMAL FLOW AT RIDGE AXES

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ABSTRACT

Hydrothermal circulation at the ridge axis removes heat from the oceanic crust more rapidly than would conduction alone. The top of the axial magma chamber is thus deeper and possibly wider than the theoretical shape computed from conductive thermal models. At 9°N on the East Pacific Rise seismic reflection indicates that the roof of the magma chamber is relatively flat, 2 km deep, and extends 4 km from the axis. This is about a kilometer deeper than predicted by a purely conductive model.

We believe that the magma chamber is mostly filled with mush at ridges with both fast and slow spreading rates. At fast rates the mush is formed by crystallization at the top of a magma chamber that is wide and flat topped. At slow rates a narrow magma chamber is probably an anastomosing complex of partially molten dikes and associated cumulate layers. Thermal modeling indicates that the hydrothermal heat flux is between 0.7×10^8 and 1.5×10^8 cal/cm^2, or less than 1/10 of the total missing heat flux (the difference between observed and theoretical heat flow) at the ridge axis. By using the observation that Mg is totally depleted from exiting axial fluids, we find that the minimum amount of crust which
reacts with axial hydrothermal flow is equivalent to a 80 m thick section of crust. A minimum thickness of 200 m is obtained from K which is leached from the basalt into the hydrothermal fluid. These estimates indicate that there is no requirement that the bulk of the oceanic crust react strongly with the axial hydrothermal fluid.

INTRODUCTION

Even before seafloor spreading was well understood, it was noted that the heat flow on mid-oceanic ridges was lower than would be expected from cooling of hot lithospheric material derived from the interior of the earth. The "missing heat flow" was immediately attributed to the unmeasured escape of heat through hydrothermal vents (Hess, 1965, page 133). Conductive models calibrated to the heat flow on the flanks of the ridge, where hydrothermal heat flow is minor, and to the topography of the ridge confirmed this discrepancy (Sclater and Francheteau, 1970). The total heat loss from hydrothermal circulation can be estimated from the difference between observed and theoretical heat flow (Anderson and Hobart, 1976; Anderson et al., 1977; Wolery and Sleep, 1976; Sleep and Wolery, 1978; Sclater et al., 1980). The results as compiled by Sleep and Wolery (1976) are given in table 1.

There was little interest in the thermal state in the immediate few kilometers of the ridge axis because the sediment cover necessary for conventional heat flow measurements do not exist there. Conductive thermal models which are valid in the axial region were published by Parker and Oldenburg (1973), Oldenburg (1975), and Sleep (1974, 1975). After Sleep (1975) quantified the inferences of Cann (1974) on the formation of oceanic crust and the shape of the magma chamber, thermal constraints were explicit or at least implicit in later petrological studies.

Actual high temperature vents have been sampled on several intermediate and fast spreading ridges. The temperature of exiting water is about 350°C. The heat loss from an individual vent was estimated as 6×10⁷ cal/sec (Macdonald et al., 1980) and from a cluster of vents as 4 to 5×10⁷ cal/sec (Converse et al., 1982). The heat loss from these vents is too large to be steady state. For example, all the missing heat flow on a 60 mm/yr full-rate ridge is equivalent to 3.4×10⁷ cal/km-sec. Unless most of the hydrothermal heat flow exits from axial vents, axial vents must be intermittent and short-lived, as is indicated by studies of the vents themselves (Macdonald, 1982; Converse et al., 1982).

The long-term average heat flux from high temperature axial vents can be determined by balancing geochemical cycles or by determining the shape of the magma chamber from geophysics and modelling the heat and mass transfer. We use the latter approach in this paper, although a local average over time, rather than a global average, is obtained. The chemical fluxes then can be computed by extrapolation to the rest of the