Hydrothermal activity and the volume of the oceans

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Introduction

A few years ago I and James Kasting (1992) proposed that the volume of the Earth's oceans may be determined by a dynamic mechanism involving exchange of water between the crust and the mantle. The mechanism could explain why the continental freeboard has remained approximately constant since the Archean despite probable increases in continental area. Our proposal was based on the (apparent) coincidence that fast-spreading mid-ocean ridges are submerged to a depth at which the pressure is close to the critical pressure of seawater. This circumstance ensures optimal convective heat transport and maximal penetration of hydrothermal solution along the ridge axes. The current ingassing rate of water by subduction of hydrated oceanic crust is probably at least sufficient to balance the outgassing rate. If the oceans were shallower, as they may have been in the distant past, convective heat transport would be reduced and the depth of hydrothermal penetration and crustal hydration would decrease. Outgassing would exceed ingassing and ocean volume would increase. James Kasting and I remarked in our article that the system would be self-stabilizing as long as the depth of the oceans does not exceed its present value. The mechanism does not, however, preclude a much deeper ocean. Intuitively, one might imagine that the return flux of water to the mantle would increase if the oceans were to deepen. That is, however, not necessarily the case. The highest values of the Rayleigh number (R_w), and thus the water penetration depth, occur right near the critical point of water (fig. 1). Since the critical pressure for seawater is ca 300bar, the maximum in R_w should occur near a depth of 3km, or about 0.5km below the crests of typical fast-spreading ridges. This is right in the middle of existing hydrothermal circulation systems and should tend to optimize their efficiency. Any increase in ocean depth exceeding 0.5km would raise the pressure at the ridge crests to above the critical pressure and would therefore decrease the achievable values of the Rayleigh number and the water penetration depth. The return flux of water to the mantle would likewise decrease unless the added hydrostatic pressure resulted in a greater degree of hydration of exposed basalt or a marked decrease in seafloor permeability.

Discussion

The penetration depth (h) of seawater into oceanic crust depends on both the pressure of the overlying water and the heat flow (Q) through the ridges:

$$h = \frac{R_w^{1/2}}{Q^{3/2}}$$

At a change away from critical point the penetration of water does not respond to exactly opposite mechanisms when going to higher as compared to going to lower pressures. During a pressure decrease at a constant temperature the R_w-value would have to follow the saturation vapor pressure (fig. 1). Suppose, for example, that the Earth experienced a sea level regression by 1,000m, i.e. a decrease of the hydrostatic pressure

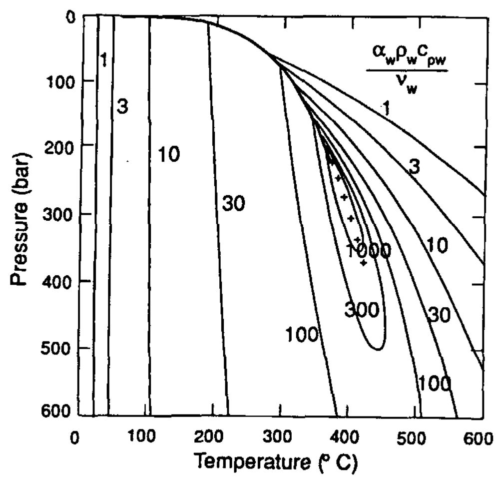

FIG. 1. Contours of the ratio $\alpha_w\rho_w c_{pw}/v_w$ for pure water. Values are expressed in MKS units divided by 10^5. The heaviest curve represents the saturation vapour pressure. The crosses mark 1-km depth increments along an adiabat originating at the critical point. From Kasting and Holm, 1992.

at the fast-spreading mid-ocean ridges by about 100bar. As illustrated for pure water by figure 1 a pressure drop from the critical point at about 220bar and 374°C by 100bar would result in a decrease of the R_w-value from over 1000 to about 100. A transgression by the same amount, on the other hand, would result in a hydrostatic pressure increase at the ridges by 100bar. Since the temperature will remain constant the R_w-value will change (drop) only along the y-axis in the diagram. In this case the Rayleigh number will only be reduced to 300. Let us assume a modern penetration depth of 1.5km and a constant heat flow through the ridges. The corresponding value for water penetration at a regression and a transgression by 1,000m would then be about 475 and 820m, respectively. In both cases the rate of generation of new seafloor would have to increase in order to cool the Earth's crust. The faster oceanic plate velocity would lead to much faster subduction rates (Gurnis, 1990). Ultrafast subduction rates (> 12 cm/yr) allow for large quantities of water to be subducted deep into the mantle (Staudigel and King, 1992), perhaps across the upper/lower mantle boundary. As discussed above the hydrated oceanic crust will be much thicker at high hydrostatic pressures compared to the conditions at low pressures. Therefore more water will be ingassed to the mantle during transgressions than during regressions. Once a cold slab of oceanic crust is subducted deep into the mantle the pulling force of the descending slab may tend to accelerate subduction and associated ingassing of water (Menard, 1986).

References

Gurnis, M. (1990) *Science*, **250**, 970–2.

Kasting, J.F. and Holm, N.G. (1992) *Earth Planet. Sci. Lett.*, **109**, 507–15.

Menard, H.W. (1986) *Islands*. Scientific American Books, New York.

Staudigel, H. and King, S.D. (1992) *Earth Planet. Sci. Lett.*, **109**, 517–30.