

Glacial-Interglacial boron isotope changes in the deep North Atlantic

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Despite many decades of research, the causes of the well documented pCO₂ changes that accompany, and partly drive, glacial-interglacial climate cycles remains elusive. The speed with which these changes take place points to the importance of changes in storage of carbon in the deep ocean, but the mechanisms involved remain uncertain. Recent modelling studies have suggested the volume of bottom water of southern origin that bathes the abyss may play a crucial role (“the standing volume effect”; Brovkin et al. 2011^[1]; Skinner et al. 2009^[2]).

Here we investigate this phenomenon by producing boron isotope records of epibenthic foraminifera, *Cibicides wuellerstorfi*, at three North Atlantic sites ([I]ODP 980, 1308 and 1313) from Marine Isotope stage six to the Holocene. These sites effectively form a depth profile from 2100 to 3900m. At these northern latitude sites, changes in the ocean storage of carbon, and in particularly northerly excursions of corrosive southern sourced water, are expected to be seen as changes in water column profile of the carbonate system parameters pH and [CO₃²⁻] which can be reconstructed by changes in δ¹¹B and B/Ca in epibenthic foraminifera (Rae et al. 2011^[3], Yu and Elderfield 2008^[4]). Our chosen sites therefore are a sensitive monitor of the “standing volume effect” and by comparing our results to records of atmospheric CO₂ we will gain new insight into the role of this phenomenon in driving glacial-interglacial CO₂ change.

[1] Brovkin *et al.* (2011) *Clim. Past Discuss.*, 7, 1767–1795 [2] Skinner *et al.* (2009) *Science* 328, 1147– [3] Rae *et al.* (2011) *Earth and Planetary Science Letters* 302 (2011) 403–413. [4] Yu and Elderfield (2008) *Earth and Planetary Science Letters* 258 (2007) 73–86

Direct magmatic input in geothermal systems of the Taupo Volcanic Zone

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In the last 20 years, insights on the content and behaviour of volatile constituents in magmas, particularly from melt inclusion studies, have enhanced our understanding of hydrothermal fluid-magma interactions, and volatile transfer from magma to active hydrothermal systems. Exsolved fluids from magmatic sources contribute to the evolution of geothermal systems, by influencing fluid (reservoir) chemistry and associated hydrothermal alteration.

Geothermal systems of the Taupo Volcanic Zone (TVZ), New Zealand, are large convective cells of heated, primarily meteoric-derived waters. CO₂, Cl, B and N contents in TVZ well discharges indicate magmatic fluids are present in small proportion, but until now no direct, unequivocal evidence of magmatic fluid input or magmatic-derived hydrothermal minerals have been identified.

Secondary (alteration) minerals can point to magmatic, meteoric or mixed fluid origins, and processes (e.g. boiling, fluid mixing) within active geothermal systems. In the future, tracking a magmatic fluid signature in geothermal systems is expected to be an important consideration for establishing the spatial distribution of deep-seated magma bodies in the TVZ and for potential delineation of green-field geothermal systems with resource potential. New oxygen and sulphur stable isotope analyses of anhydrite in drillcore from ~2000 mVD (vertical depth) within the Rotokawa Geothermal Field exhibit an arc-related magmatic-hydrothermal signature, similar to anhydrite from the Ladolam epithermal gold deposit (Lihir, Papua New Guinea, [1]) or Butte porphyry-copper deposit (Montana, USA [2]). Isotopic compositions of the Rotokawa anhydrite are δ¹⁸O_{anh} = +13.9 to +17.9 (± 0.5‰, with one anhydrite of δ¹⁸O = 0.4‰), and δ³⁴S_{anh} +10.1 to +13.0 (± 0.5‰). The calculated sulphur isotopic composition of H₂S in equilibrium with the Rotokawa anhydrite are -4 to -9‰, whilst δ³⁴S_{H₂Sg} in well discharges range between +4.1 and +4.8‰. The trace element composition of the Rotokawa anhydrite (e.g. Sr content up to 5000 ppm) also show similarities with inferred magmatic-derived anhydrite seen elsewhere (e.g. at Ladolam).

The trace element and isotopic compositions of Rotokawa anhydrite both point to sulphate in the hydrothermal system having a magmatic origin. In contrast, chemical analysis of discharge Rotokawa well fluids cannot have precipitated the anhydrite seen in core samples from >2000 mVD in several Rotokawa wells. We suggest that the anhydrite observed in Rotokawa core samples formed in equilibrium with magmatic-derived, low pH, sulphate-rich fluids, at some time during the evolution of the hydrothermal-magmatic system, as a result of magmatic degassing. This study provides the first direct evidence of magmatic fluid input to the otherwise dilute, meteoric-dominated, low-salinity geothermal systems of the TVZ, and is expected to impact future deep geothermal exploration strategies.

[1] Gemmill, Sharpe, Jonasson & Herzig (2004) *Economic Geology* **99**, 1711-1725. [2] Field, Zhang, Dilles, Rye & Reed *Chemical Geology* **215**, 61-93.