The Siqueiros Transform Fault MORB; A Tale of Sulfur-Saturation

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ABSTRACT. Geochemically diverse mid-ocean ridge basalts recovered from the Siqueiros Transform Fault, in the east Pacific Ocean, were sulfide-saturated at eruption, on the basis of the presence of immiscible sulfide globules and major and trace element variations of pillow-rim glasses. Previous workers have interpreted, from the chemistry of silicate melt inclusions in olivines which crystallised from liquids more primitive than the erupted basalts, that early Siqueiros liquids were sulfide-undersaturated (e.g., Saal et al. 2002). However, as the composition of these melt inclusions may not represent primary liquid compositions (as discussed by Danyushevsky et al. 2003) and inclusions of immiscible sulfides occur in the olivines, we interpret that at least some of these liquids were sulfide-saturated early in their fractionation history. The compositions of the immiscible sulfide inclusions in olivine are consistent with those from other MORB suites and estimates of sulfide liquid compositions from mantle rocks (e.g., Lorand 1988). Data from the erupted basalts and inclusions provides a well constrained natural dataset that has been combined with experimental data to produce a new sulfide saturation model (Bychkov et al. 2009) and can be used to test the results of this model.

1 INTRODUCTION

A suite of 41 basalt samples collected from the Siqueiros Transform Fault, at 8°20'-8°30N in the east Pacific Ocean, are chemically variable, ranging from normal- to enriched-MORB and from primitive to evolved (9.7-5.4 wt% MgO in glasses). The presence of immiscible sulfide globules in pillow-rim glasses (Figure 1A: see also Francis 1990; Roy-Barman et al. 1998) and the correlation between FeO^t and S for glasses analysed in this study (Figure 1B) indicate that the entire sample suite may be sulfide-saturated. In this contribution we document petrographic and geochemical evidence for sulfide-saturation history of the Siqueiros basalts and use this data to test the compositions of sulfide liquids produced by the sulfide-saturation model of Bychkov et al. (2009).

2 METHODS

Fragments of pillow-rim glasses were mounted in epoxy and glass compositions determined using a Cameca SX100 microprobe (EMPA) for major elements, S and Cl, with H_2O contents determined on a Bruker IFS 66 FTIR spectrometer. Trace elements in glasses were also determined by ablating with a New Wave 213nm solid-state laser microprobe coupled to an Agilent 4500 quadrupole ICPMS (LA-ICPMS).

The pillow-rim glass fragments were examined for the presence of immiscible sulfide globules, with major element compositions determined by EMPA for 'quenched' inclusions >4 μm in diameter. Olivine phenocrysts were separated from four samples and examined for the presence of immiscible sulfide inclusions. Suitable sulfide inclusions were reheated, to 1150°C, in a custom-

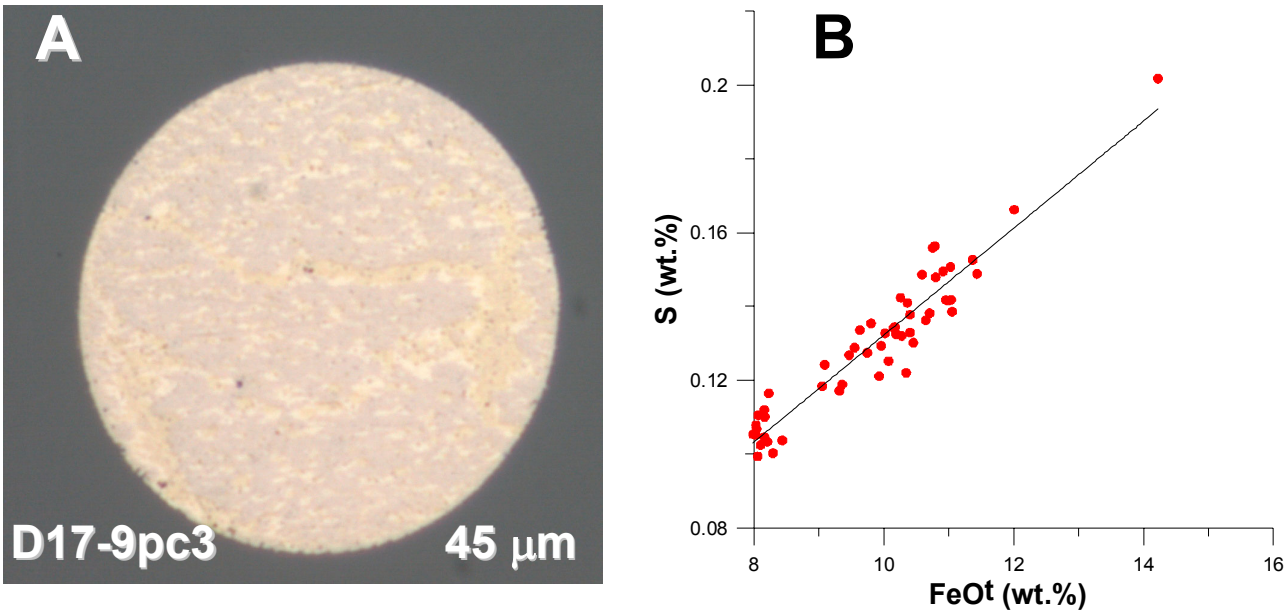

Figure 1. A) Reflected light photomicrograph of a 'quenched' immiscible sulfide globule in pillow-rim glass from sample D17-9 (7.7 wt% MgO). B) Relationship between FeO^t (all Fe as FeO) and S for Siqueiros Transform Fault pillow-rim glasses. The strong correlation indicates S-saturation (see Mathez 1976 and Wallace and Carmichael 1992).

built, low-inertia, high-temperature heating stage then quenched, as discussed by McNeill et al. (2009), polished open and then analysed for major and trace elements using EMPA and LA-ICPMS.

Further details of analytical methods, including standards used, are available on request from the authors.

3 RESULTS

3.1 Pillow-rim Glass Samples

Pillow-rim glasses from the Siqueiros basalts can be subdivided into four groups on the basis of major and trace element variations. These groups are not apparently related by fractionation and have variable trace element contents (e.g., Ni) at a given glass MgO, with the most depleted glasses forming Group 1. Fractionation of the most primitive Group 1 glass composition has been modelled (using COMAGMAT software) for sulfide-absent and sulfide-bearing cases. Results indicate that the Ni contents of more evolved glasses are consistent with S-saturated fractionation of the most magnesian Group 1 glass composition.

Immiscible sulfide globules were found in 39 of 41 basalt samples examined. They range in size from 1 to 70 µm and occur as six distinct types based on internal texture, morphology and relationships with other phases. Those inclusions with a finely intergrown, or 'quenched', texture (Figure 1A) have been analysed and variations in their composition, in terms of Fe and Ni, correlate well with host glass composition for samples from all glass groups.

3.2 S-saturation of More Primitive Liquids

The most primitive pillow-rim glass sample collected is in equilibrium with olivine ($Fo_{88.6}$). However, olivine phenocrysts with Fo up to $Fo_{91.6}$ are found in Siqueiros basalts, and must have crystallised from more primitive liquids. Silicate melt inclusions in the more forsteritic olivines have variable S contents (0-1100 ppm), which have been interpreted to indicate that at least some of the trapped liquids were sulfide-undersaturated (Sobolev and Hofmann 1999; Saal et al. 2002). However, an alternate explanation is that the low-S in some silicate melt inclusions do not represent primary liquid compositions, but rather are liquids affected by assimilation processes

(Danyushevsky et al. 2003). Evidence for the sulfide-saturation of the more primitive liquids is the presence of inclusions in olivine ($Fo_{89.9-91.1}$) of immiscible sulfide globules that have similar textures and mineralogy to globules in the pillow-rim glasses and other MORB samples (e.g., McNeill et al. 2009). A number of these inclusions have been analysed, after reheating, for major and trace elements, including PGE. The inclusions are Ni-rich (>16.5 wt%) and are similar to those from primitive olivines in other MORB and to estimates of sulfide liquid compositions reported from mantle rocks (e.g., Lorand 1988, Luguet et al. 2003).

4 CONCLUSIONS

All evidence points to the compositionally diverse Siqueiros Transform Fault mid-ocean ridge basalts being sulfide-saturated both early in their fractionation history and at eruption. Compositional data from this sample set has been combined with experimental data to produce a new sulfide solubility model (Bychkov et al. 2009) and can be used to test the results of this and other models.

5 ACKNOWLEDGEMENTS

This research was supported by the Australian Research Council funding to the Centre for Excellence in Ore Deposits (CODES) and through AMIRA project P962, funded by Anglo-American, BHP Billiton and Votorantim. The authors would like to thank K. Goemann and S. Gilbert for assistance with the electron microprobe and LA-ICPMS analyses, respectively, and R. Leslie for assistance in preparing samples.

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