

Magma to Molecules: Simulation of Abiotic Organic Synthesis at Mid-Ocean Seafloor Hydrothermal Systems

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The carbon content of mid-ocean ridge (MOR) magmas is well known from analysis of glassy rims on pillow basalts (1), is dissolved exclusively as carbonate ion, and provides a measure of the minimum CO₂ content of MORB magmas. The solubility of CO₂ in MORB liquids is well known (2) and shows that most MORB magmas were oversaturated in CO₂ at seafloor pressures so the CO₂ content of MORB magma could be greater than observed in MORB glasses. Possible hosts for C in MORB source regions are dolomite/magnesite or graphite/diamond depending on oxygen fugacity (4). Oxygen fugacities measured from MORB glasses (5) and mantle nodules (6) require that graphite/diamond is the C source (4). Assuming graphite is the source a model was constructed to calculate the CO₂ content of primary MORB magma and arrived at a probable value of 1800 ppm (7). That model predicts that 80 ppm of graphite/diamond in the MORB source mantle is consumed. That is a surprisingly low value; however simple mass balance shows that for an integrated melt fraction of 15 wt. % the amount of graphite required to generate 1800 ppm CO₂ in primary MORB magma is 74 ppm. The 1800 ppm value for the CO₂ content of primary MORB magma erupted at present-day rates for the last 3.3 AE equals estimates for Earth global crustal, oceanic and atmospheric carbon content (7,8). The magmatic-hydrothermal interface results from a profound phase change. In MORB systems there is a significant change in the REDOX state of the system during emplacement, crystallization and degassing. The change in fO₂ affects the speciation of volatiles in evolved fluids. Volatile speciation in MORB magma is determined by melting reactions in the source region and magma evolution.

MORB glasses are strikingly reduced (5) and contain dissolved CO₂ and H₂O. Concentrations of CO₂ and H₂O in MORB glass show that the magma was fluid saturated before and during eruption. Because H₂O is much more soluble in basaltic liquid than CO₂, CO₂ is the predominant degassing species, consequently during diking-eruptive events CO₂ is released. Magnetite crystallization generates H₂ by reduction of H₂O in glass, resulting in evolution of fluids containing H₂ and H₂S. In MOR settings this fluid mixes with CO₂ exsolving from the magma during transient diking-eruptive events so the fluids are initially in a grossly disequilibrium redox state. The same events may occur during crystallization of MORB magma chambers.

We have demonstrated in rapid flow experiments at seafloor hydrothermal system (SFHS) conditions that some of the released CO₂ and H₂ react in the presence of magnetite in crystalline MORB to form a significant proportion of methanol (9). We have also shown in a series of static experiments that an aqueous methanol solution in the presence of smectite clay at SFHS conditions forms a variety of more complex organic compounds, and the time dependence of compound synthesis correlates with the collapse of the smectite layers. The most abundant organic species observed is hexamethyl benzene (HMB), smaller amounts of other organic compounds are also observed (10). We hypothesize that the abundance of HMB could be due to a similarity between the size hexagonal rings of SiO₄ units in clay layers and the HMB ring size.

(1) Earth Planet. Sci. Lett. vol. 90: 87-104. (2) Geochim. Cosmochim. Acta 55: 1587-1595. (3) Chemical Geology 138: 81-92; (4) High Pressure Research in Geophysics. S. Akimoto and M. Manghnani. Tokyo, Japan, Center for Acad. Pubs: 237-250. (5) Earth Planetary Sci. Lett. 79: 397-411. (6) J. Geophys. Res. 95: 15,845-15,852. (7) Chemical Geology 147: 89-97. (8) Geochim Cosmochim Acta 61: 1565-1574. International Geology Review 42: 673-683. (9) Chemical Geology 180: 129-139. (10) Geology 33: 913-916.