

The effect of upper mantle oxygen fugacity on magmatic carbon dioxide production

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The source of the carbon dioxide in the Earth's atmosphere and oceans probably originated in the mantle and was transported to the surface by magmas. The greatest volumes of magma are generated at mid-ocean ridges in the form of mid-ocean ridge basalt (MORB). The fO_2 is determined by the ferric/ferrous iron ($Fe^{2+}/3+$) ratio observed in MORB glasses. The calculations involve consideration of the depth at which upwelling mantle begins to melt, the amount of CO_2 that is incorporated in the melt during partial melting, the depth at which the rising melt is saturated in CO_2 and the effect of crystal fractionation during magma ascent on amount of CO_2 released in the degassing process. The relation between the $Fe^{2+}/3+$ ratio in magmas and fO_2 was determined by Christie (1) who found a mean value of $\log fO_2$ of QFM-1.20 \pm 0.44. These values are within the graphite-diamond (GD) phase fields Frost and Wood (2). Newer analyses by Bezos and Humler (3) are somewhat outside the GD field, in the enstatite-magnetite field at 14 GPa and in the CO- CO_2 fluid field at lower pressures. MORB values do not include fractional crystallization during ascent from the mantle source region. Considered it, fO_2 falls in the GD field at pressures below about 5 GPa. Generation of CO_2 in upwelling diamond/graphite mantle can be calculated from the reaction: $C + 2 Fe_2O_3 = CO_2 + 4 FeO$. During decompression partial melting the amount of C consumed increases with the degree of partial melting, CO_2 concentration in the melt decreases, and the ferric/ferrous ratio and oxygen fugacity in the melt decrease.

Model calculations were done assuming a peridotite mantle source containing olivine, orthopyroxene, clinopyroxene and spinel or garnet, depending on pressure (4, 5, 6). The ascent trajectory closely follows adiabatic paths. In the example presented here, the ascent path intersects the solidus at 2.5 GPa, 1340°C. The melt fraction increases linearly with decreasing pressure. In basaltic melts CO_2 dissolves as the carbonate ion and its solubility was calculated using the model parameters in Holloway & Blank (4).

The results show that during magma ascent, the oxygen fugacity increases by 2 orders of magnitude, the amount of dissolved CO_2 decreases by a factor of 5, and the Fe_2O_3/FeO ratio in the melt decreases by a factor of 5. The concentration of carbon in the mantle source region decreases by 75 ppm during the processes. The graphite-saturated model oxygen fugacities and melt ferric/ferrous ratios are consistent with those observed in oceanic peridotites and glassy MORB, suggesting that graphite is present in the source region. Model calculations show that only small amounts of carbon in the source region are required to maintain graphite saturation in the mantle during partial melting. The calculated pre-emplacement CO_2 content of primary MORB liquids ranges from 900-1800 ppm and is comparable to estimates based on $CO_2/4$ helium ratios and C/3He ratios. The annual CO_2 magma flux from MOR is about 50 trillion kilograms/year. On a time-averaged basis, this flux would generate the carbon dissolved in the oceans in 2 Ma, the carbon in the oceanic crust in 300 Ma, and in all carbonate sediments in 3300 Ma.

(1) Earth Planet. Sci. Lett. Vol.79: 397-411. (2) Contrib. Mineral. Petrol. 121,303-308. (3) Geochem. Cosmochem. Acta vol. 69: 711-725. (4) Chemical Geology 147: 89-97. (5) International Geology Review 42:673-683.

(6) European Jour. Mineral. 4:105-114.