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Immiscible metallic melts in the upper mantle beneath Mount Carmel, Israel: Silicides, phosphides, and carbides

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Abstract

Xenolithic corundum aggregates in Cretaceous mafic pyroclastics from Mount Carmel contain pockets of silicate melts with mineral assemblages [SiC (moissanite), TiC, Ti_2O_3 (tistarite), Fe-Ti-Zr silicides/phosphides] indicative of magmatic temperatures and oxygen fugacity (f_{O_2}) at least 6 log units below the iron-wüstite buffer ($\Delta IW \leq -6$). Microstructural evidence indicates that immiscible, carbon-rich metallic (Fe-Ti-Zr-Si-P) melts separated during the crystallization of the silicate melts. The further evolution of these metallic melts was driven by the crystallization of two main ternary phases (FeTiSi and $FeTiSi_2$) and several near-binary phases, as well as the separation of more evolved immiscible melts.

Reconstructed melt compositions fall close to cotectic curves in the Fe-Ti-Si system, consistent with trapping as metallic liquids. Temperatures estimated from comparisons with experimental work range from ≥1500 °C to ca. 1150 °C; these probably are maximum values due to the solution of C, H, P, and Zr. With decreasing temperature (T), the Si, Fe, and P contents of the Fe-Ti-Si melts increased, while contents of Ti and C decreased. The increase in Si with declining T implies a corresponding decrease in f_{O_2}, probably to ca. ΔIW-9. The solubility of P in the metallic melts declined with T and f_{O_2}, leading to immiscibility between Fe-Ti-Si melts and (Ti,Zr)-(P,Si) melts. Decreasing T and f_{O_2} also reduced the solubility of C in the liquid metal, driving the continuous crystallization of TiC and SiC during cooling. The lower-T metallic melts are richer in Cr, and to some extent V, as predicted by experimental studies showing that Cr and V become more siderophile with decreasing f_{O_2}.

These observations emphasize the importance of melt-melt immiscibility for the evolution of magmas under reducing conditions. The low f_{O_2} and the abundance of carbon in the Mt. Carmel system are consistent with a model in which differentiating melts were fluxed by fluids that were dominated by CH_4+H_2, probably derived from a metal-saturated sublithospheric mantle. A compilation of other occurrences suggests that these phenomena may commonly accompany several types of explosive volcanism.

Keywords: Mt. Carmel, oxygen fugacity, metallic melts, immiscibility, mantle methane