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The origin of nelsonite constrained by melting experiments and inclusions in apatite: The Damiao anorthosite complex, North China craton

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Models for nelsonite formation are currently highly contentious, with liquid immiscibility and fractional crystallisation as frequently proposed formation mechanisms. The nelsonites in the Damiao massif anorthosite complex in the North China Craton are revisited here together with experimental evidence for the existence of silica-free CaO-FeO-Fe_2O_3-TiO_2-P_2O_5 immiscible nelsonitic liquids. Our results from differential scanning calorimetry and internally heated pressure vessels (IHPV) demonstrate that nelsonite with the composition of one-third apatite and two-thirds Fe-Ti oxides by weight 1) completely melts well above 1450 ºC at dry conditions, which is in good agreement with numerous experimental studies of the CaO-P_2O_5-Fe_xO system for metallurgical purposes; and 2) does not melt at temperatures up to 1200 ºC with the presence of considerable amount of volatiles, e.g., fluorine and water. Therefore, the composition of the nelsonite cannot be molten at temperatures relevant for crystallization of the Damiao magma. A review of experimental studies of liquid immiscibility and analyses of natural immiscible glasses shows that all the liquids on the Fe- and P-rich side of the miscibility gap have at least 20 wt. % of aluminosilicate components.

In addition, our new analyses of apatite-hosted melt inclusions in Damiao nelsonite provide a crucial clue for the nelsonite formation. The inclusions range from ~3 to 200 μm in diameter. They are ubiquitous and meet all the morphological criteria of primary melt inclusions crystallized into assemblages of daughter minerals. Almost all assemblages contain vermiculite and/or chlorite, and some contain biotite, amphibole, phlogopite, and Fe-Ti oxide. Bulk compositions of analyzed inclusions show large variations in SiO_2 (20.79-50.16 wt. %) and FeO_t (13.44-32.78 wt. %). With a few exceptions, the inclusions are very low in CaO (0.04-1.51 wt. %) and high in Al_2O_3 (10-21.17 wt. %). The re-homogenized inclusions at 1200ºC obtained by IHPV show similar compositional characteristics but incorporated excessive melting of the host apatite. Nevertheless, the compositions significantly differ from those of the typical immiscible Fe-rich melts despite the high Fe content and low silica. It appears that the cumulus apatite crystallized from Fe-rich, hydrated late-stage immiscible Fe-rich melt formed by liquid immiscibility that occurred in the relatively early stage, i.e., prior to the arrival of the aqueous fluid phase. We propose that the inclusions at Damiao record a trend of intercumulus melt evolution, which have been through liquid-liquid immiscibility but most likely have been strongly affected by separation of a hydrothermal fluid phase and the losses of alkali and Ca silicate components from the melt into the fluid.