Do Fe-Ti-oxide magmas exist? Probably not!

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ABSTRACT

Many Fe-Ti oxide bodies associated with anorthosite suites and with some tholeiitic plutonic bodies have cross-cutting relationships with their host rocks suggesting that they may have been emplaced as oxide melts. Pure Fe-Ti oxides melt at temperatures much higher than is considered to be geologically realistic, so various fluxes (mainly apatite, fluorine, or carbon) have been called upon to stabilize the melts down to plausible temperatures. This review traces our experimental attempts to test the effectiveness of proposed fluxes and therefore to demonstrate the existence of such melts at geologically realistic temperatures.

Neither F-apatite nor carbon act to stabilize Ti-rich Fe-Ti oxide melts at 1300 °C and below, and we conclude that—unless some totally unforeseen material does serve as a flux—Fe-Ti oxide magmas almost certainly do not exist. Although our data are not conclusive, it appears that increasing contents of FeO (and possibly TiO2) and P2O5 mutually enhance their solubilities in silicate melts, allowing extensive buildup of those components in melts residual to anorthosite. We interpret that oxide orebodies form by gravitational accumulation of crystalline oxides from such liquids. Once those melts become saturated with either Fe-Ti oxides or apatite, both phases will tend to co-precipitate, thus explaining the common occurrence of apatite with oxide orebodies (“nelsonites”). Cross-cutting oxide bodies were probably emplaced as crystalline oxides, possibly lubricated by small amounts of residual silicate liquid. Oxidation of the Fe2TiO4 component in initially ulvospinel-rich spinel and concomitant formation of ilmenite grains by granule-oxy-“exsolution” may have weakened the crystalline oxide and facilitated its flow during emplacement.

It seems clear, though, that the presence of carbon does stabilize Ti-poor iron oxide melts to very low temperatures (at and even below 1000 °C), consistent with the (disputed!) magmatic origin of the magnetite lavas at El Laco, Chile.

Keywords: Fe-Ti oxides, oxide melts, oxide magmas, orebodies, immiscible melts, anorthosite suite, apatite, flux, Invited Centennial article, Review article

INTRODUCTION

Large bodies of Fe-Ti oxides (mainly titaniferous magnetite and ilmenite) are important sources of titanium and are also significant reserves of iron (see, e.g., Gross 1996; and especially the comprehensive reviews by Woodruff et al. 2013 and Charlier et al. 2015). Their almost universal association with Proterozoic massif anorthosites strongly suggests a genetic relation to the anorthositic suite and anorthosites plus spatially and temporally associated rocks that go by a wide variety of names, including ferrodiorites (jotunites), syenites, and monzodiorites (broadly mangerites), and high-K granites (charnockites). Many of these oxide bodies contain apatite in varying amounts, and the more apatite-rich ones are sometimes called “nelsonites” despite the fact that the type nelsonite is an ilmenite-apatite rock with essentially no magnetite (Watson 1907, p. 300). It is probably fair to say that most workers today accept that the oxide bodies formed from melts residual to the anorthosites, but there is broad disagreement as to just how they formed and whether the oxides separated and were concentrated as crystals or as immiscible oxide melts. Some form “conformable layers...within oxide-rich gabbros,” but many are “massive ore bodies that exhibit sharp, irregular contacts with surrounding...anorthosites” (Ashwal 1993, p. 157). It is the latter, cross-cutting type of occurrence that has led many workers to conclude that the oxides were emplaced as liquids, presumably liquids immiscible with a corresponding silicate melt. Asklund (1949) proposed that the Ti-poor oxides at Kiruna formed from an immiscible iron oxide-apatite melt. Buddington et al. (1955) considered the possibility that Fe-Ti oxide deposits may have formed as immiscible oxide liquids, but considered the evidence inconclusive. Perhaps the first worker to propose the existence of immiscible Fe-Ti oxide liquids was Hargraves (1962, p. 175) who stated, “Despite the lack of any sound experimental or theoretical foundation, immiscibility between silicate-rich and oxide-rich phases [context suggests this refers to melts] is suggested.” Noting that the Allard Lake oxide ores typically contain 8–10 wt% apatite, Hargraves further