

CONSTRAINTS ON POSSIBLE FORMATION MECHANISMS OF THE POTASSIC-CHLORO-HASTINGSITE IN MIL03346 AND PAIRED STONES. P. A. Giesting¹ and J. Filiberto². ¹Illinois State University, Dept. of Geography-Geology, 206 Felmley Hall, Campus Box 4400, Normal, IL 61790-4400 (pagiest@ilstu.edu), ²Southern Illinois University, Dept. of Geology, Parkinson Laboratory, Mail Code 4324, Carbondale, IL 62901 (filiberto@siu.edu).

Introduction: The nakhlite MIL 03346 and its paired stones MIL 0900030, 0900032, and 0900136 contain high-Cl amphiboles, called potassic-chloro-hastingsite (Cl 5-7 wt%, 1.5-2.0 atoms per formula unit or apfu; Fig. 1), accompanied by glass and titanomagnetite within augite-hosted melt inclusions [1-2]. Although Martian magmas are generally enriched in Cl compared to normal terrestrial magmas (without input from subduction, evaporites, or other surface-derived Cl sources), other examples of Martian amphiboles have <0.4 wt% Cl [3-6]. Therefore, exceptional conditions must have been present in order to form such Cl-rich amphibole compositions. There are two theories for the formation of these Cl-rich Martian amphiboles: 1) incorporation of evaporitic material into the nakhlite parent magma [1], and 2) addition of an exogenous Cl-rich fluid to the chassignite-nakhlite magma body [2]; both theories require addition of excess chlorine to the system prior to amphibole crystallization. Here we discuss additional constraints on the formation environment of potassic-chloro-hastingsite in the MIL paired meteorites [1-2] using insights from recent synthesis experiments on Cl-rich (chlorian) pargasites and hastingsites [7-9] and terrestrial examples of Cl-rich amphibole [10-20], to explore the formation conditions needed to produce the Cl-rich amphibole in the MIL meteorites.

Examples of Terrestrial Chloro-amphiboles: Chloro-amphiboles (Cl > 1.0 apfu) [21] are rare in the terrestrial setting. Known localities for terrestrial chloro-amphiboles are high-grade metamorphic terranes where very Cl-enriched fluids encountered a protolith of suitable chemistry [10-16]. In some cases, chloro-amphibole is accompanied by other high-Cl silicate phases like marialitic scapolite [17]. On the other hand, extreme Cl-enrichment of an igneous or high-grade metamorphic mafic system is not necessarily adequate to create chloro-amphibole on its own [18-20]. High concentrations of K and Fe must be present, along with extreme Cl-enrichment, to crystallize chloro-amphibole [16,22-24].

Chlorian Amphibole Synthesis Experiments: Synthesis experiments have recently been conducted [7-9] that crystallized amphiboles in the presence of brines or chloride salts. Some runs were conducted with 10% NaCl brine of varying strength. Other runs contained hypersaline mixtures of NaCl or FeCl₂ and

H₂O added directly to the capsule without prior dissolution. Still other runs were conducted with FeCl₂ as the chloride source and H₂O limited to sorbed moisture.

K-free pargasite-ferropargasite samples synthesized with 0.1 to 5 *m* NaCl exhibit Mg-Cl avoidance with Cl contents increasing linearly with the Fe# (= Fe / (Fe + Mg)). The Cl contents reached a maximum of only 0.086 wt% in end-member ferropargasite [7-8]. Pargasite-series amphiboles synthesized from brines follow a Cl-poor trend [7,12]. Increasing the concentration of the brine to beyond the STP solubility limit of NaCl in H₂O, to as high as 26 *m* NaCl (X_{Cl} = 0.32), did not result in any further increase in Cl in endmember ferropargasite [8]. Interestingly, when synthesized in FeCl₂ hypersaline brines (X_{Cl} = 0.34-0.44), more Cl can be incorporated in pargasite (up to 1.4 wt% or 0.4 apfu Cl), but this is still well short of Cl dominance on the O(3) site.

K-free hastingsite-magnesiohastingsite synthesized with FeCl₂ and incidental moisture showed the expected trend with Fe content to an Fe# of 0.64; this amphibole had 2.2 wt% or 0.64 apfu Cl [9]. However, endmember hastingsite could only accommodate 0.21 apfu Cl [9]. There is unexpected complexity in the Cl incorporation mechanism for the hastingsite series compared to pargasite. Data from both series show an inability for calcic amphiboles to reach Cl-dominant compositions in the absence of K.

Discussion: Experimental data [7-9] and terrestrial analogs [10-20] make it clear that extremely Cl-rich amphibole not only requires abundant Cl to form, but also has other petrological requirements. We can use these to further constrain the conditions needed to form such amphibole in the MIL meteorites [1-2]:

First, the H₂O activity in the MIL 03346 melt inclusions needed to have been quite low in order for chlorine-dominant amphibole to crystallize [7-9].

Second, in MIL 03346 and pairs, late enrichment of Fe was required to crystallize amphibole that could accommodate near-completely Cl-dominant amphibole. Crystallization of extremely Fe-rich augite around the edges of the melt inclusions has been observed, and titanomagnetite is the other major crystalline phase in the melt inclusions [10,25]; this extreme Fe enrichment may have been caused by transport of FeCl₂-rich fluid

[26] upward from a deeper source region in or below the nakhlite parent intrusion [2].

Third, the melt inclusions in MIL 03346 and pairs must also have had a high K/Na ratio [16,22]. This is consistent with the interpretation of K enrichment in Nakhla relative to Na via metasomatism [27]. Contrasts exist between MIL 03346 and Nakhla, however, especially in that (sodic) plagioclase is common and (sodic) scapolite has been found in one melt inclusion in Nakhla [28], but these phases are rare or nonexistent in MIL 03346 and pairs [25]. Although it seems clear that both of these nakhlites were altered by Cl-rich metasomatic fluids, there are also previously unremarked differences in alkali metal chemistry and mineralogy between them.

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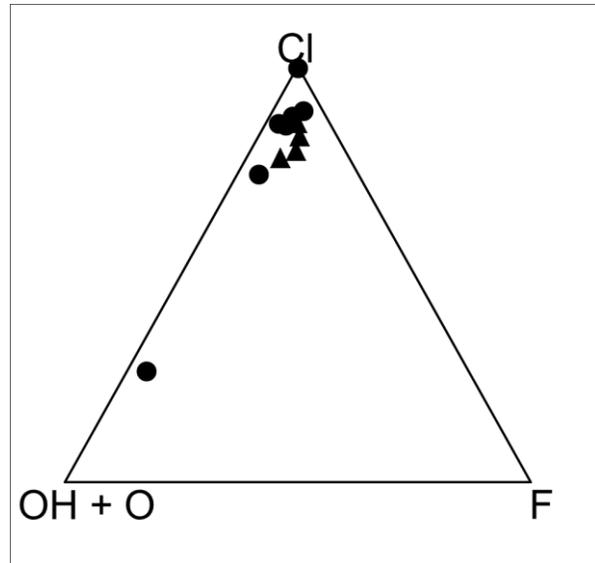


Fig 1. Atom populations on O(3) site in amphibole grains in MIL 03346 [1] and pairs [2]. Ref. 1 analyses normalized to 15 cations and ref. 2 analyses normalized to 16 cations to minimize chemical violations [16,24].