

The Earth/Mars dichotomy in Mg/Si and Al/Si ratios: Is it real? H. Nekvasil¹ and J. Filiberto^{2, 1,2} Department of Geosciences, SUNY Stony Brook, NY 11743-2100, ¹Hanna.Nekvasil@sunysb.edu, ²jfiliber@ic.sunysb.edu.

Summary: In light of the new Martian rock data, TES surface compositions, and larger number of known SNC meteorites, the use of Mg/Si vs. Al/Si ratios to distinguish between the Earth's crust and the Martian crust must be reconsidered. Magmatic fractionation and crystal accumulation strongly affect the Al/Si and Mg/Si ratios of bulk compositions, thereby obscuring information about mantle characteristics. Previously observed deviations between SNC and terrestrial igneous rocks are not robust when diverse terrestrial cumulates are considered. SNC meteorites could represent mixtures of cumulate ferromagnesian minerals and evolved terrestrial-like liquids.

Introduction: It has been noted by numerous workers that there appear to be significant differences in chemistry between Martian SNC meteorites and terrestrial rocks. These differences are often shown as deviations of the SNCs from the Mg/Si and Al/Si variation along the Earth's "geochemical fractionation line" (GFL; or "Earth's crust line") developed from ultramafic peridotite xenoliths [1] (Fig. 1). A GFL was formulated by [2] for Mars (i.e., the "Mars crust line") and they used this along with other SNC chemical characteristics to infer the Martian mantle composition, one that is significantly lower in Al and higher Fe than the terrestrial mantle. As the population of identified SNC meteorites has grown it is now clear that many Martian meteorites do not actually fall on the "Mars crust line" and in fact, lie in a broad field to the low Al/Si side of the Earth's crust line (Fig. 1). Furthermore, MER Rover Spirit data on Martian basalts [3], TES Surface Types I and II [4], and recent SNC findings (e.g. Yamato 980459 [5]) yield compositions much closer to the "Earth's crust line" [6], [3]. Before complex petrologic models are developed to explain the occurrence of both types of chemical characteristics on Mars, it is worth taking a closer look at the effects of mineral accumulation.

The effects of accumulation: The GFL can be considered a simple mixing line. As such, it can be used to evaluate accumulation processes, with bulk rock compositions displaced along the line from liquid compositions towards higher Mg contents during accumulation of mafic minerals to form cumulate rocks. As with any mixing line, however, the slope and intercepts will change depending upon the nature of the liquids and accumulated phases. This is exemplified by the mixing line between dunite and the basalt used to formulate pyrolite ([7]; Fig. 1); this line is displaced from the GFL [1] because of the use of a dunite rather than a pyroxene-bearing peridotite. The shift to lower

Mg/Si contents because of the accumulation of pyroxene or Fe-rich olivine (Fig. 1) suggests that terrestrial cumulate rocks may plot off of the Earth's crust line and into the field of SNC meteorites. That this is indeed the case for many intra-plate magmatic cumulates is exemplified in Figure 1 by cumulate xenoliths from Hawaii [8], Deccan Trap [9], and the French Massif Central [10]. This deviation of terrestrial cumulate materials from the GFL ("Earth's crust line") clearly calls into question the usefulness of this line as a unique indicator of terrestrial characteristics.

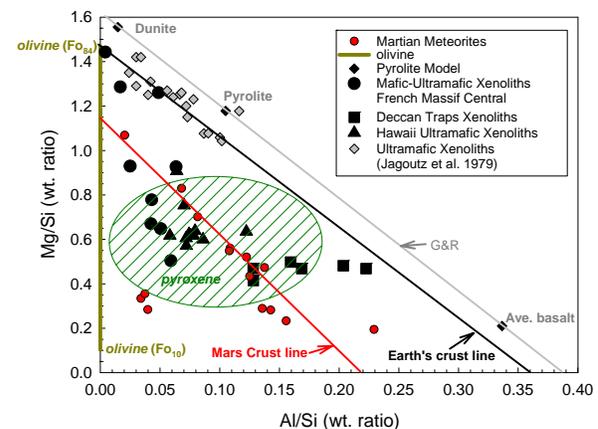


Figure 1. Mg/Si vs. Al/Si variation along the terrestrial "geochemical fractionation line" ("Earth's crust line" [1]) and the "Mars crust line" [2]. Also plotted are peridotite nodules of [1] and SNC meteorite bulk compositions ([2], [11], [6]). Mg/Si vs. Al/Si variation of terrestrial xenoliths from intraplate magmas (French Massif Central [10]; Deccan Traps [9]; Hawaii [8]) are plotted as larger symbols. Also shown are the compositional spaces of olivine (Fo_{34} - Fo_{10}) and Al-bearing pyroxene. A mixing line constructed from pyrolite, average basalt, and dunite (G&R; [7]) is shown for comparison with the Earth's "geochemical fractionation line" [1].

Accumulation and the SNC meteorites: Although it is assumed that the Al- and Mg-poor (Fe-rich) SNCs necessarily reflect a Fe-rich, Al-poor Mars mantle, an alternative possibility is that they simply represent accumulation of evolved minerals, minerals not from primary liquids but rather produced during fractionation. This would be the same interpretation accorded to terrestrial cumulate rocks having evolved compositions of olivine and pyroxene. But if SNC compositions reflect varied degrees of accumulation of fractionated magmatic mineral assemblages, could the accumulated mineral assemblages have coexisted with typical terrestrial-like magmas?

Terrestrial basalts are commonly plotted as the “crustal endmember” of the GFL; however, many basalts and intermediate rocks actually lie off of this line, particularly those of intra-plate magmatic suites. This is shown in Figure 2 by three typical liquid lines-of-descent of terrestrial intra-plate basalts (the silica-saturated alkalic trend of the Nandewar volcano [12], the low-pressure tholeiitic trend of Thingmulu [13], and the trend of Craters of the Moon and the Snake River Plain [14-17]).

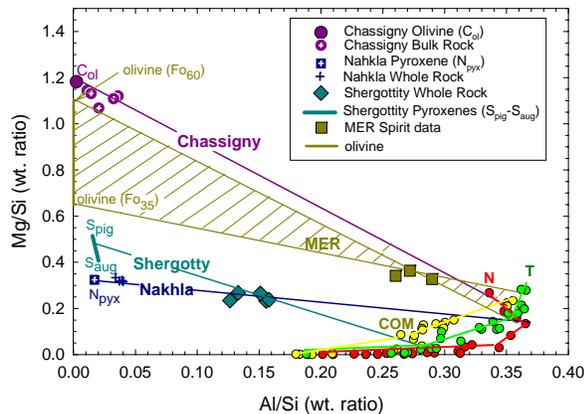


Figure 2. Mixing lines constructed for the Chassigny bulk meteorite composition and cumulate olivine (Floran et al. 1975); for the Nakhla bulk composition and cumulate pyroxenes [20-24]; and for the Shergotty bulk composition and pyroxenes ([22], [27],[24],[28]) extended to terrestrial liquids along the fractionation paths of the silica-saturated alkalic suite of the Nandewar volcano (N [12]), the potassic-silica saturated suite of the Snake River Plain and Craters of the Moon (COM; [14-17]), and the low pressure tholeiitic suite of Thingmulu, Iceland (T; [13]). Arrows along the liquid-lines-of-descent point in the down-temperature direction. Also plotted are the MER “ratted” bulk compositions of Adirondack, Humphrey, and Mazatzal [3] and the envelope (ruled region) of mixing lines from olivine [30, 31] through their bulk compositions.

Bulk compositions and cumulate phase compositions of Chassigny, Nakhla and Shergotty are shown in Figure 2. The Chassigny bulk composition [18] can be produced by a mixture of less than 10% typical terrestrial silica-saturated hawaiite and over 90% olivine of Fo₆₈ composition. In fact, this olivine could readily be part of the fractionating assemblage of hawaiite since its composition has been shown to be consistent with equilibrium between the observed cumulate pyroxene and a hawaiite liquid [19]. The Nakhla bulk rock composition [20-24] could similarly arise from a combination of ~10% terrestrial-like melt, albeit a more evolved one than for Chassigny (e.g., more andesitic), and 90% accumulated pyroxene [25]. The Shergotty bulk composition [24], [26-28] could arise from a

similarly evolved terrestrial-like liquid and about 50% accumulation of the observed pigeonite and augite [29].

It was suggested by [3] that the MER rover Spirit “basalts” contain up to 25% accumulated olivine. Figure 2 shows that any linear combination of MER “ratted” bulk compositions of Adirondack, Humphrey, and Mazatzal [3] and 20% olivine Fo₃₅-Fo₆₀ [30, 31] is consistent with terrestrial-like basalt to andesite as the liquid component.

Conclusions: We suggest that the Mg/Si vs Al/Si diagram no longer be used as a discriminator between martian and terrestrial rocks. We further invite workers to consider the possibility that many martian igneous rocks may have close similarities to terrestrial intra-plate magmatic suites, both in terms of composition and their petrologic history.

References: [1] Jagoutz E. H. et al. (1979) *LPSC X*, 2031-2050. [2] Wänke H. G. et al. (1984) *LPS XVII*, 919-920. [3] McSween H. Y. R. et al. (2004) *Science*, 305, 842-845. [4] McSween H. Y. et al. (2003) *JGR-Planets*, 108, E12. [5] Greshake A. J. et al. (2004). *GCA*, 68, 2359-2377. [6] Wyatt M. B. et al. (2003) *Mars VI*, Abstract # 3271. [7] Green D.H. and Ringwood A.E. (1963) *JGR*, 68, 937-945. [8] Bohrsen W. A. and Clague D. A. (1988) *Contrib. Mineral. Petrol*, 100, 139-155. [9] Dessai A. G. A. et al. (2004) *Lithos*, 78, 263-290. [10] Féménias O. N. et al. (2003) *Chem. Geol.*, 199, 293-315. [11] McSween H.Y. (1985) *Rev. Geophys.*, 23, 391-416. [12] Stolz A. J. (1985) *J. Pet.*, 26, 1002-1026. [13] Carmichael I. S. E. (1964) *J. Pet.*, 5, 435-460. [14] Leeman W. P. et al. (1976) *Contribs. Min. Pet.*, 56, 35-60. [15] Stout M. Z. and Nicholls J. (1977) *Can. Jour. Earth Sci.*, 14, 2140-2156. [16] Leeman W. P. (1982) *Cenozoic Geol. Idaho. Idaho Bureau of Mines and Geology Bull.*, 26, 203-212. [17] Stout M. Z. et al. (1994) *J. Pet.*, 35, 1681-1715. [18] Floran R. J. et al. (1978) *GCA*, 42, 1213-1229. [19] Nekvasil H. et al. (2003) *Mars VI*, Abstract 3041. [20] Duke M. B. (1968) *Shock Meta. Nat. Mat.*, 612-621. [21] Jérôme D. Y. (1970) Ph.D. Thesis Univ. Oregon. [22] McCarthy T. S. (1974) *Meteor.*, 9, 215-222. [23] Stolper E. M. and McSween H. Y. (1979) *GCA*, 43, 1475-1498. [24] Dreibus G. and Wänke H. (1982) *Meteor.*, 17, 207-208. [25] Treiman A. H. (1993) *GCA*, 57, 4753-4767. [26] McCarthy T. S. (1974) *Meteor.*, 9, 215-222. [27] Bunch T. E. and Reid A. M. (1975) *Meteor.*, 10, 303-315. [28] Lodders K. (1998) *Meteor. Planet. Sci.*, 33, A183-190. [29] Smith J. V. and Hervig R. L. (1979) *Meteor.*, 14, 121-142. [30] Christensen P. R. et al. (2004) *Science*, 305, 837-842. [31] Morris R. V. (2004) *Science*, 305, 833-836.