SIDERITE AND GYPSUM INTERGROWN WITH MAGNETITE-ILMENITE IN GOVERNADOR VALADARES. J. C. Bridges and M. M. Grady, Department of Mineralogy, Natural History Museum, Cromwell Road, London SW7 5BD, UK. jcb@nhm.ac.uk.

Introduction: We report some results of a petrographic study of carbonate and associated minerals in the martian (SNC) meteorite Governador Valadares. This is an olivine-bearing clinopyroxenite with a glassy, variolitic texture mesostasis. It has close petrographic similarities to Nakhla and Lafayette, and like them may have formed within a thick (> 100m) basic-ultrabasic lava flow or shallow intrusion [1]. These 3 nakhlites therefore have a good potential for preserving interactions of the parent rocks with the martian hydrosphere and any sedimentary deposits or soils.

Carbonate and associated salt minerals in SNC meteorites can provide information about crustal and atmospheric reservoirs on Mars. For instance, carbon isotopic ratios of siderite in Nakhla are thought to be the result of either this carbonate, or its sedimentary precursors, having undergone isotopic exchange with fluids that were in contact with the martian atmosphere [2]. Other isotopic signatures in these meteorites, such as $^{129}Xe/^{132}Xe$ ratios in Nakhla, probably also reflect the incorporation of martian atmospheric components into mineral assemblages of the parent rock [3].

The original provenance of salt assemblages in the SNCs is likely to have been sediments on, or near, the martian surface. These precursors might be evaporites precipitated in areas of enclosed drainage [4]. They could have been incorporated into the SNC parent rocks through one or a combination of processes: hydrothermal remobilisation [5], shock implantation [6], direct precipitation from percolating groundwater [7], or as we have suggested elsewhere [8, 9] by contamination of the melts. In this study of Governador Valadares we aim to further explore mechanisms for incorporating salt assemblages into the SNC parent rocks and the nature of martian sedimentary precursors.

Methods: Two polished sections of Governador Valadares (sample 1975, M16) were examined with EDS and WDS analyses (Cameca SX50 operated at 12 kV, 10 nA).

Results: Siderite grains are located in intercumulus parts of the meteorite and range in size up to 30 μm length. Gypsum is found in the interstitial areas, sometimes adjacent to siderite but veins of gypsum up to 450 μm long and less than 5 μm wide are also present within the augite and olivine. Minor chlorapatite is located in the interstitial areas.

Governador Valadares contains grains of magnetite with ilmenite exsolution lamellae. These are present at the margins of the augite and olivine grains, again like the siderite-gypsum-chlorapatite assemblage, in the intercumulus areas together with feldspathic glass and Fe-rich pyroxene. One magnetite grain (Fig. 1) encloses a rhombohedral area with siderite and lesser amounts of non-stoichiometric feldspathic glass. Another grain of siderite is located at the upper margin, and partially enclosed, within the same magnetite. A lamella of ilmenite, less than 5 μm wide, is present within a separate siderite grain in another part of the same section. Three other grains of siderite and chlorapatite have also been found that are intergrown with magnetite.

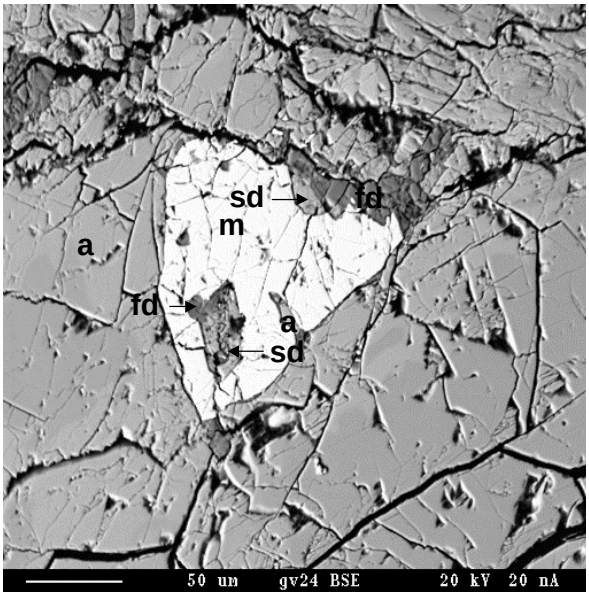

Figure 1. Magnetite grain in Governador Valadares that encloses siderite, feldspathic glass and augite. m Ti-rich magnetite, sd siderite, a augite, fd feldspathic glass. 50 μm scale bar. Back-scattered electron image.

Mineral compositions. Carbonate in Governador Valadares has the range (N=12) of compositions Cc 3.6 - 11.1 Rh 1.1 - 2.1 Mag 9.0 - 29.2 Sd 64.3 - 77.8 mol %. It also contains ≤1 wt % Cl. Sulphate is identified as gypsum, rather than the anhydrite present

in Nakhla [8, 9]. The magnetite consists of a magnetite-ulvospinel solid solution with composition Mt 61.6 - 72.2 Ulv 27.8 - 38.4 mol %, and the ilmenite lamellae are nearly pure $FeTiO_3$ with 0 - 2.8 mol % haematite.

Discussion: The location of the siderite and gypsum in the interstitial areas of Governador Valadares is similar to that of the siderite and anhydrite in Nakhla. Unlike in Nakhla, however, no halite has been found. Siderite compositions have lower Mn and slightly higher Ca contents than those of siderite in Nakhla [8, 9]. The most striking petrographic feature of the siderite-gypsum-chlorapatite assemblage in Governador Valadares is the association with Ti-rich magnetite and ilmenite grains. This could be coincidental, with siderite replacing glass or filling voids enclosed within or adjacent to magnetite and ilmenite. Alternatively, it could mean that the carbonate was associated with intercumulus melt from which the Ti-rich magnetite solid solution originally crystallised. The latter explanation would be consistent with the euhedral, rhombohedral outline of the larger siderite grain in Fig. 1. The magnetite in this grain does not show signs of alteration or breakdown to goethite.

Temperature and oxidation conditions for oxide mineral crystallisation. Titanium-rich magnetite is found in all 3 of the nakhlites [10, 11]. The intersection of magnetite-ulvospinel and ilmenite-haematite compositional contours in plots of fO_2-T can provide information about temperatures and oxidation states of ilmenite exsolution [12]. The compositional data for the Governador Valadares grains gives values of approximately -18 to -19 $\log_{10}fO_2$ and 700 ^{o}C. These values are close to those calculated for Nakhla [10] and lie close to the fayalite-magnetite-quartz buffer on the fO_2-T plot. They represent a subsolidus, oxidising event.

Conditions of siderite and gypsum crystallisation. The normal stability field of siderite at low pressures is < 500 ^{o}C and $-\log_{10}fO_2 < 25$ [13]. The relatively hydrous nature of the Governador Valadares assemblage also suggests that it was derived from a hydrous fluid. Some of the gypsum veining may be associated with the smectite-illite veins common to the nakhlites and which are a result of low temperature (< 200 ^{o}C) hydrothermal alteration of the meteorite parent rocks.

Textural considerations of the main salt assemblage in Nakhla (*e.g.* the intergrowth of siderite with Fe-rich augite, ilmenite and plagioclase) raise the possibility of a high temperature origin by crystallisation from a component of the melt [8, 9]. However, the normal stability fields of siderite and the presence of metastable mineral assemblages conflict with this interpretation and are more consistent with a low temperature model. Similarly for Governador Valadares, the textural association with Ti-rich magnetite suggests a high temperature origin but the associated oxidation state and temperatures mean that the siderite would have existed metastably. A possible explanation is given by the presence of Cl in the siderite, because halogens are known to stabilise Ca-carbonate melts [14] at low pressures. They may have a similar effect on the stability range of siderite.

Models for the formation of the siderite-gypsum-chlorapatite assemblage. Two main models are considered here. The first one involves crystallisation at relatively low temperatures. This could happen through either direct precipitation from percolating groundwaters (as proposed for carbonate in ALH84001 [7]) or by hydrothermal alteration [5]. An origin at low temperature is consistent with the normal stability range of siderite. The second, favoured, model entails crystallisation of siderite and the interstitial gypsum from a late-magmatic, hydrous fluid coexisting with interstitial melt at > 700 ^{o}C – which is the temperature at which Ti-magnetite existed as a solid solution. This scenario is consistent with the observed textures but requires special conditions to have existed in order to stabilise the siderite. The high temperature fluid could have been derived by contamination of the melt by ice-rich soil or sediment.

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