Investigation of Exsolution in Titanomagnetite Grains in NWA 7533 Martian Meteorite by STEM-EELS and STEM-EDX

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The meteorite Northwest Africa 7533 has Martian origin. The meteorite is a breccia and contains zircons with a crystallization age of ~ 4.4 Ga. It has been shown to be more indicative on processes that have occurred on the early crust of the planet than previous meteorites [1]. The medium and coarse grained clasts of the rock consist mainly of pyroxenes and feldspars, and include minor pyrite, apatite, magnetite and ilmenite crystals [2-4]. The microstructural investigation of the phase assemblage, their crystal defects, their chemistry and the oxidation state of the transition metal elements within is essential to the understanding of formation mechanisms that are related to the early Mars crust conditions.

In the study we focus on the investigation of large magnetite and titanomagnetite crystals by spectroscopic techniques (STEM-EELS and STEM-EDX) coupled with HAADF. The studied crystals exhibit several complex phase separation features. In the magnetite matrix, STEM-EELS and STEM-EDX revealed nano-domains, 5-10 nm in size, where Fe-Cr spinodal decomposition takes place, Figure 1(a)-(d). Minor elements such as Al and Mg, in correlation with Cr, are also present. The Fe-Cr separation is accompanied by slight structural distortions of the lattice, but the oxidation state of iron remains unchanged. Figure 2(a) shows a HAADF image of a thin Ti-rich bi-lamella appearing along the {111} planes of the magnetite (Fe_3O_4). These Ti-rich lamellae are usually separated by several unit cells (one to six) of magnetite. The walls of the bi-lamella and the inner magnetite unit cells are Cr enriched (Figure 2(b)-(e)). Thicker poly-crystalline rutile (TiO_2) exsolutions with a 2 nm thick Cr-rich interface are also present. In both cases the EELS fine structure of the Fe-$L_{3,2}$ reveals decrease in iron oxidation state at the Cr-rich rims of the exsolutions, Figure 2(f). Larger exsolution lamellae of ilmenite ($FeTiO_3$) and spinel ($MgAl_2O_4$) have also been observed. The investigation of the structure, chemistry and the oxidation state of the constituent transition metals of these complex features by spectroscopic techniques at the atomic scale should help to better understand the thermal history and the formation of the brecciated rock in its martian context.

References

[1] Humayun M., Nemchin A., Zanda B., Hewins R. H., Grange, M., Kennedy A., Lorand J.-P., Göpel C., Fieni C., Pont S., and Deldicque D. (2013) Nature 503:513 - 517.

[2] Lorand J.-P., Hewins R. H., Remusat L., Zanda B., Pont S., Leroux H., Marinova M., Jacob D., Humayun M., Nemchin A., Grange M., Kennedy A., and Gopel C. (2015). MAPS 50, 2099-2120.

[3] Leroux H., Jacob D., Marinova M., Hewins R. H., Zonda B., Pont S., Lorand J.-P., Humayun M. (2016), MAPS 51, 932-945.

[4] Hewins R. H., Zanda B., Humayun M., Nemchin A., Lorand J. P., Pont S., Deldicque D., Bellucci J. J., Beck P., Leroux H., Marinova M., Remusat L., Göpel C., Lewin E., Grange M., Kennedy A., Whitehouse M. J. (2017) MAPS 52, 89-124.

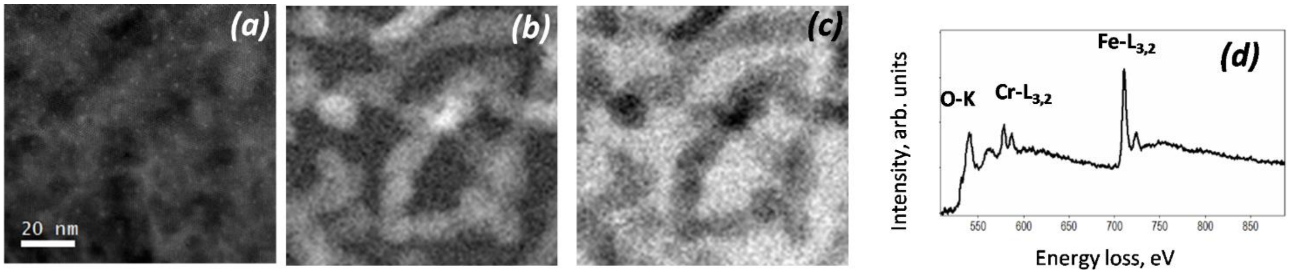

Figure 1(a)-(c) HAADF image, Cr-$L_{3,2}$ edge (575 eV) and Fe-$L_{3,2}$ edge (708 eV) intensity maps, respectively and (d) the EELS spectrum in the energy range between 500 eV and 900 eV.

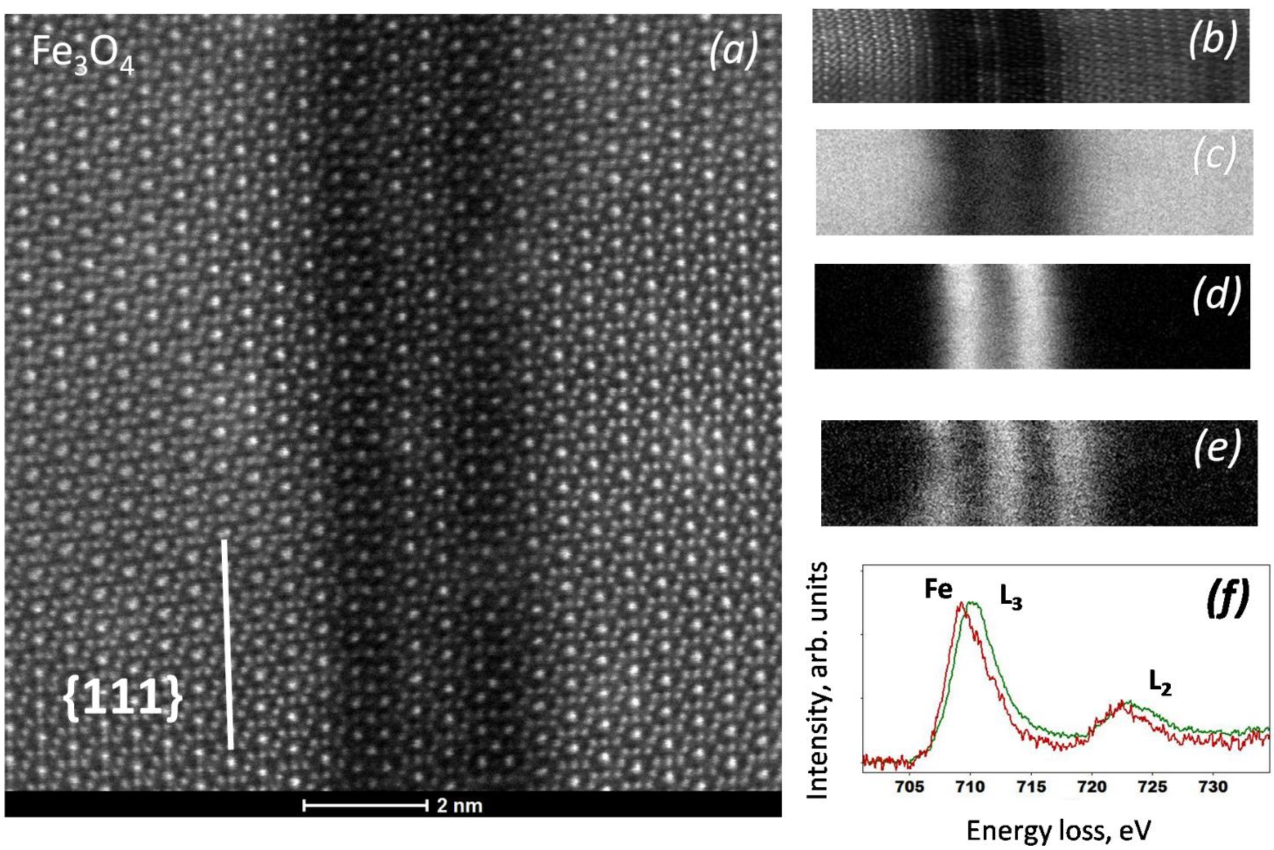

Figure 2. (a) HAADF image of the magnetite matrix in the (011) zone axis with Ti-rich bi-lamellae which appear along the {111} planes. (b)-(e) on-line HAADF image and EELS intensity maps of the Fe-$L_{3,2}$, Ti-$L_{3,2}$ and Cr-$L_{3,2}$ edges, respectively. (f) Change in the Fe-$L_{3,2}$ near edge fine structure at the Cr-rich walls (red line) of the rutile exsolution lamellae. The green line corresponds to the Fe-$L_{3,2}$ spectrum of the magnetite.>

< Acknowledgement

The TEM national facility in Lille (France) is supported by the Conseil Regional du Nord-Pas de Calais, the European Regional Development Fund (ERDF), and the Institut National des Sciences de l'Univers (INSU, CNRS).>