PRIMARY CHROMITE IN TWO MORE MAIN GROUP UREILITES–NWA 3109 (Fo 76) AND EET 96328 (Fo 85). WHAT DOES Cr IN UREILITES TELL US?

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Introduction: Primary chromite has previously been reported in only two main group ureilites – LEW 88774 and NWA 766 [1-10] – both of which are among the most ferroan ureilites (Fo ~75 and 76, respectively). In these samples, chromite grains are commonly associated with graphite and surrounded by complex assemblages of Cr-rich minerals. The latter include Fe,Cr-carbide(s), Fe,Cr-sulfide(s), eskolaite-corundum [1,2], and unusual Cr-rich symplectites [7-10]. The chromites themselves show various degrees of in-situ reduction (often locally correlated with presence of graphite), leading to Fe-loss and, at high degrees of Fe-loss, also Cr-loss (Fig. 1). This reduction is thought to be analogous to the in-situ reduction of olivine in most ureilites [11], with some or all of the surrounding minerals formed from Cr liberated in the reaction [1,2,7-10].

The presence of primary chromite in only the most ferroan ureilites would support the hypothesis that the range of olivine core compositions among ureilites (Fo 75-95) is related to primary differences in fO_2. We describe occurrences of chromite in two more ureilites, NWA 3109 and EET 96328. We discuss the behavior of Cr in ureilites and implications for petrogenesis.

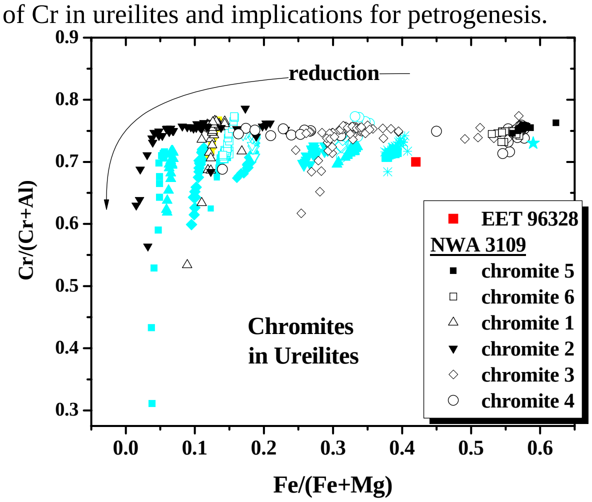

Fig. 1. Compositions of chromite in LEW 88774 (cyan, individual grains in different symbols), EET 96328 and NWA 3109. Chromites in NWA 766 are reported by [8] to be similar to those in LEW 88774. Data for LEW 88774 are unpublished data from author Goodrich, consistent with [1].

EET 96328: EET 96328 (paired with 5 other EET ureilites) is an olivine-orthopyroxene ureilite with a coarse-grained poiklitic texture and abundant melt inclusions in orthopyroxene oikocrysts [12]. Olivine is Fo 85.2, with 0.64 wt.% Cr_2O_3; orthopyroxene is Wo 4.6, *mg* 86.5, with 1.2% Cr_2O_3. We found one grain of chromite completely enclosed in orthopyroxene in section ,5. The grain is nearly circular in section, ~50 µm in diameter, and partially surrounded by Fe-oxide that probably represents terrestrially altered metal or sulfide (Fig. 2). A partial rim shows Ca-enrichment in surrounding pyroxene (Fig. 2). The chromite is homogeneous, with fe# (molar Fe/[Fe+Mg]) = 0.42 and Cr# (molar Cr/[Cr+Al]) = 0.7, similar to some of the most ferroan chromites in LEW 88774, though with slightly lower Cr# [Fig. 1]. Grain boundary metal/sulfide in EET 96328 is extensively weathered and no unaltered grains could be analyzed.

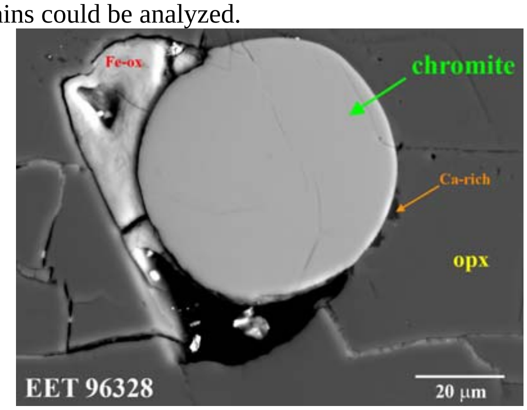

Fig. 2. Chromite in orthopyroxene (opx) in EET 96328.

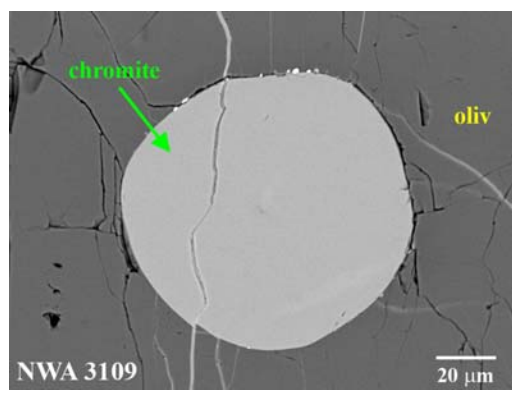

Fig. 3. Chromite grain #5 in olivine (oliv) in NWA 3109.

NWA 3109: NWA 3109 is an olivine-pigeonite ureilite, with a typical, non-foliated ureilite texture. Shock effects are minor and euhedral graphite is abundant. Olivine is Fo 76.3 with 0.55 wt.% Cr_2O_3. Pigeonite is Wo 12.8, *mg* 78.7, with 1.1 wt.% Cr_2O_3.

We observed 6 chromite grains in one section (NAU). Two of them (grains #5 and #6) are similar to the chromite grain in EET 96328 in being small (~30 and 90 μm diameter), highly rounded (Fig. 3) and completely enclosed in a silicate (in one case olivine, in the other pigeonite) with only minor rim phases. Both are near-homogeneous, with fe#=0.54-0.58 and Cr#=0.74-0.76 (Fig. 1). These compositions are similar to the rare, least-reduced chromites in LEW 88774 (Fig. 1).

The other 4 chromite grains are larger (~150-200 μm in maximum dimension), subhedral to anhedral, and variously located in olivine, pigeonite, or on olivine-pigeonite grain boundaries. They are rimmed by assemblages similar those in LEW 88774 and NWA 766, including graphite, lamellar intergrowths of daubreelite (ideally $FeCr_2S_4$) and troilite, one grain of brezinaite ($Cr_{2.82}Fe_{0.16}S_{3.99}$), Fe,Cr-carbides (cohenite with ~13 wt.% Cr, and an unidentified carbide with ~23 wt.% Cr), and Cr-rich symplectites. Unfortunately, weathering of these areas is extensive (Fig. 4a). These chromites show in-situ reduction compared to grains #5 and #6. Two have diffuse zonation patterns similar to LEW 88774, with fe# and Cr# decreasing core-to-edge (grains 1 and 2, Fig. 1). The other two show sharp transitions between homogeneous subhedral/euhderal cores, and zoned rims (Fig. 4). Cores (fe#=0.55-0.58, Cr#=0.74-0.76) are similar in composition to grains #5 and #6; rims are again zoned with fe# and Cr# decreasing toward edges (Fig. 1).

Weathering of grain boundary metal and sulfide in NWA 3109 is extensive, but a few grains are preserved. Metal has up to 0.8 wt.% Cr (avg. 0.4%, 8 analyses), which is significantly higher than in most ureilites (typically 0.1-0.2 wt.%; [13]). Sulfides include low-Cr troilite, and lamellar intergrowths of daubreelite and troilite.

Discussion: The occurrence and morphology of the chromite grain in EET 96328 and chromite grains #5 and #6 in NWA 3109 indicate that they are very early phases. The inferred near-spherical morphology is unusual for chromite. Compositions of grains #5 and #6 in NWA 3109 are more FeO-rich than most in LEW 88774, suggesting that little un-reduced chromite has been preserved in LEW 88774.

The presence of primary chromite in a ureilite of Fo ~85 (EET 96328) undermines the inference that olivine core compositions are correlated with fO_2 in ureilites (with the caveat that EET 96328 is a rare poikilitic ureilite containing melt inclusions and its petrogenesis may be differ from that of typical ureilites). Other aspects of the behavior of Cr in ureilites undermine this inference as well: 1) Cr contents of grain boundary metal in ureilites are not correlated with Fo [13]. 2) The high Cr contents of grain boundary metal in NWA 3109 are the opposite of what one would expect if the ratio of Cr^{3+} to reduced Cr was higher in NWA 3109 than other ureilites. (3) Cr-rich sulfides (at least daubreelite) occur over the whole range of Fo in ureilites [13,14], not just associated with in-situ reduction of chromite. 4) Cr contents of ureilite olivine (reported as Cr_2O_3) are not correlated with Fo, unless there is variation in Cr^{3+}/Cr^{2+} that has not been detected.

References: [1] Prinz M. et al. (1994) LPS 25, 1107. [2] Warren P.H. and Kallemeyn G.W. (1994) LPS 25, 1465. [3] Kallemeyn G.W. and Warren P.H. (1994) LPS 25, 663. [4] Chikami J. et al. (1997) MAPS 32, 343. [5] Goodrich C.A. (1998) MAPS 34, A44. [6] Goodrich C.A. and Keller L. (2000) MAPS 35, A60. [7] Goodrich C.A. and Harlow G.E. (2001) MAPS 36, A68. [8] Sikirdji M. and Warren P.H. (2001) MAPS 36, #5395. [9] Warren P.H. and Huber H. (2006) LPS 37, #2400. [10] Goodrich C.A. et al. (2007) LPS 38, #1434. [11] Mittlefehldt D.W. et al. (1998) In Planetary Materials, RIM 36. [12] Goodrich C.A. (2001) LPS 32, #1300. [13] Goodrich C.A. et al. (2009) LPS 40 #1132. [14] Ash R.D. et al. (2010) LPS 41, #1302.

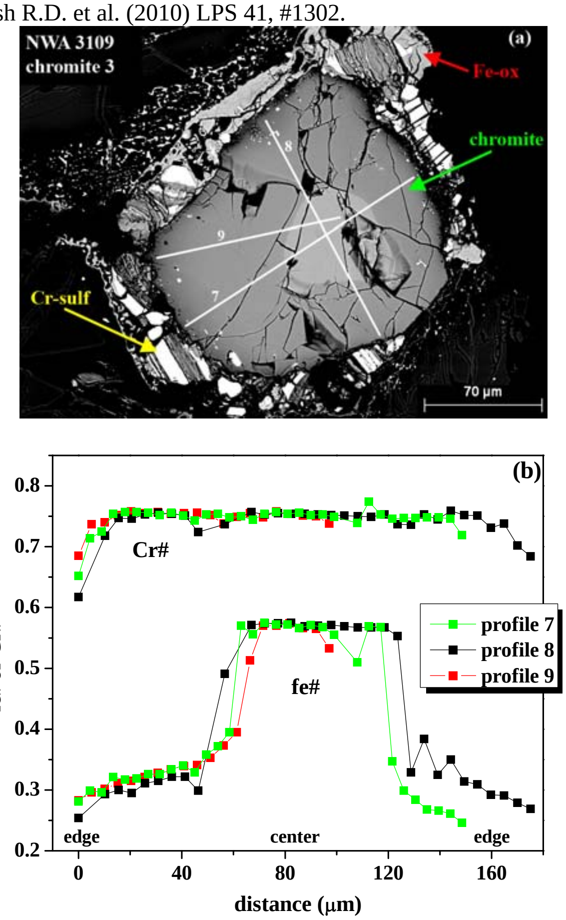

Fig. 4. Chromite #3 in NWA 3109 (a) BEI showing distinct FeO-rich core. Grain is surrounded by lamellar Cr-rich sulfides (daubreelite) and Fe-oxides (weathered metallic phases). (b) Profiles of fe# and Cr# along lines marked in [a].