

**ANHYDROUS AND HYDROUS R CHONDRITES: EVIDENCE FROM NWA 6491, 6492 AND THE NEWLY DISCOVERED NWA 7514.** A. Ruzicka<sup>1</sup> (ruzicka@pdx.edu), M. Hutson<sup>1</sup>, N. Jamsja<sup>1</sup> and T. Stout<sup>2</sup>, <sup>1</sup>Cascadia Meteorite Laboratory, Portland State University, 1721 SW Broadway, Portland, OR 97207, <sup>2</sup>P.O. Box 181, Hillsboro, OR 97123.

**Introduction:** Although terrestrial weathering complicates interpretations it is becoming clearer that some R chondrites formed under “dry” and others under “wet” conditions. A good example of the latter is the amphibole- and phlogopite-bearing LAP 04840 (R5), which appears to have been metamorphosed in the presence of an aqueous fluid [1]. Other candidates for pre-terrestrial alteration in R chondrites include LAP 02238 & 03645, which contain hematite [2], and NWA 6491 (R3-5) & 6492 (R3-6), which contain laihunite, goethite, hematite, and sulfates [3, 4]. In contrast, one of the best examples of an R chondrite that formed under “dry” conditions is the recently discovered NWA 7514 (R5), the largest R chondrite recovered to date (23.6 kg) and among the least altered [5]. Here we compare alteration effects in NWA 7514, 6491, 6492 and suggest that the dominant OH-bearing assemblage in NWA 6491 and 6492, composed of a mixture of Fe-hydroxides and oxides and other minerals, termed “HP1” (hydrous phase 1) [3, 4], was produced by the alteration of sulfide. Our data support the idea that sulfide alteration is responsible for the brown staining in R chondrites [6].

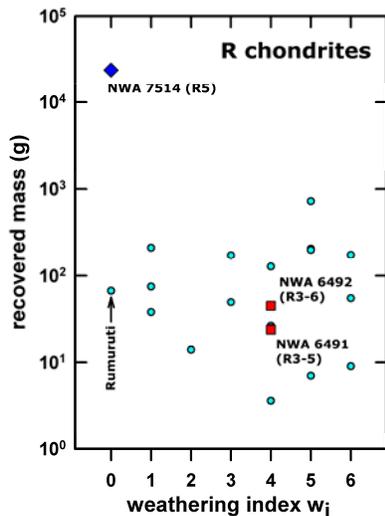


Fig. 1. Masses of all R chondrites classified by weathering index; data from this work (labeled NWAs), [6], and the MBDB [5]. NWA 7514 is both distinctively massive and unstained. The only fall is Rumuruti.

**Weathering index:** The weathering index ( $w_i$ ) of Rubin and Huber [6], applicable to R and CK chondrites, reflects the amount of brown staining of silicates in thin section, and is meant to measure terrestrial weathering. Available  $w_i$  values for R chondrites are shown in Fig. 1. Values of  $w_i = 4-6$  are common, which indicates that brown coloration is typical of R

chondrites. However, our thin section of NWA 7514, taken from the interior of the meteorite, is not stained at all and has  $w_i = 0$ ; furthermore, cut faces of the meteorite show a gray interior, and the fusion crust has a distinctive translucent appearance with olive-gray coloration. NWA 6491 and 6492 have ~80-85% staining (both  $w_i = 4$ ), but were considered to have experienced minimal terrestrial alteration as they show few cross-cutting weathering veins and show evidence for early formation of hydrous phases [3].

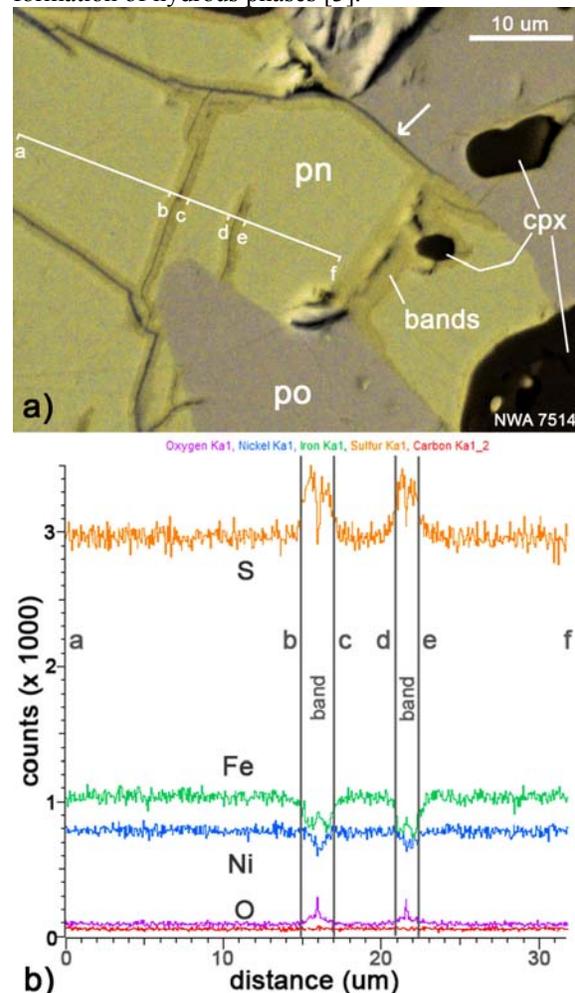


Fig. 2. a) SEM image of NWA 7514 colorized according to composition, showing pentlandite (*pn*, yellow), *pn* alteration bands (dark yellow), pyrrhoite (*po*, brown), clinopyroxene (*cpx*, black). The arrow marks a crack at the *po-pn* contact; here alteration proceeded only in *pn*. b) Traverse counts; features a-f correspond to the line shown in part a.

**NWA 7514 sulfide:** In thin section this meteorite with typical R5 mineralogy and texture appears nearly unaltered, and generally lacks the hydrous and oxidized phases noted in NWA 6491 and 6492. Sulfide minerals in NWA 7514, which consist of pentlandite (~1.2 area%,  $\text{Fe}_{0.49}\text{Ni}_{0.51}\text{S}_{1.0}$ ) and pyrrhotite (~2.6%,  $\text{Fe}_{0.81}\text{Ni}_{0.01}\text{S}_{1.0}$ ), show incipient alteration effects. Alteration is evident by narrow ( $\leq 5 \mu\text{m}$  wide) bands centered on crack-like features in pentlandite (Fig. 2). These alteration bands in pentlandite have a somewhat lower reflectivity and appear similar in brightness and color to pyrrhotite, but they have a chemistry more similar to that of pentlandite (Fig 2a). The typical band is enriched in O, especially at the center, and is depleted in Ni, enriched in S, and depleted in Fe, except that the very center of the band at the crack-like feature is depleted in S and has elevated Fe (Fig. 2b). Apparently an Fe-O phase has formed at the center of the bands. Other bands have slightly elevated Si, have stronger enrichments in Fe and O, and are strongly depleted in S. We have observed bands only in pentlandite, although crack-like features enriched in O are present in pyrrhotite as well.

**Sulfide alteration in R chondrites:** Fig. 3 shows the compositions of sulfide, altered sulfide (defined to be phases with  $>10 \text{ wt}\% \text{ S}$  but containing O) and HP1 ( $<10 \text{ wt}\% \text{ S}$ ) in NWA 7514 and 6491. In NWA 6491, sulfide is rare but altered sulfide and HP1 are common, whereas in NWA 7514, sulfide is common. The Fe-S-O diagram in Fig. 3 shows a chemical continuum between sulfide, altered sulfide, and HP1. This suggests that HP1 is formed by the alteration of sulfide. Evidently with progressive alteration: 1) O is added to sulfide from an oxidizing fluid, Fe is mobilized to form an Fe-O phase, S is mobilized to form an S-O rich phase, and Ni is removed from sulfide; 2) Si is added in addition to O, and S is removed; and ultimately 3) HP1 is formed. The latter in NWA 6491 chemically resembles a mixture of Fe-serpentine (cronstedtite) and ferric hydroxides (goethite, possibly ferrihydrite, and possibly  $\text{Fe}^{3+}(\text{OH})_3$ ). The Fe-O phase in the center of alteration bands in NWA 7514 may reflect the incipient formation of Fe-oxide or hydroxide that is more obviously present in NWA 6491. Similarly, the enhancements of Si in some bands from NWA 7514 may be a precursor to the formation of Si-bearing HP1 in NWA 6491. Given that Si is not present in sulfide initially, it likely derives by the leaching of Si from silicates. Such leaching probably accompanies the brown staining of silicates. The stain itself may be caused by the incorporation of Ni and/or Fe in silicate released from sulfide.

Whether this process of alteration results from terrestrial weathering or parent body alteration deserves

additional study, but the overall chemical and mineralogical transformations of sulfide in R chondrites are similar in many ways to the weathering of pyrrhotite in terrestrial systems [7]. Although pyrrhotite in terrestrial systems is relatively susceptible to oxidation and hydration [7], our data suggest that in R chondrites pentlandite is even more susceptible to alteration. This agrees with the conclusion of Rubin and Huber [6].

**References:** [1] McCanta M.C. et al. (2008), *GCA*, 72, 5757-5780. [2] McCanta M.C. and Treiman A.H. (2010), *LPS XXXXI*, Abstract #1394. [3] Jamsja N. et al. (2011), *MAPS*, 46, Abstract #5377. [4] Jamsja N. and Ruzicka A. (2011), *LPS, XXXXII*, Abstract #2324. [5] Meteoritical Bulletin Database, Accessed Nov. 30 2012, <http://www.lpi.usra.edu/meteor/metbull.php>. [6] Rubin A.E. and Huber H. (2005) *MAPS*, 40, 1123-1130. [7] Blowes D.W. and Jambon J.L. (1990) *Applied Geochemistry*, 5, 327-346.

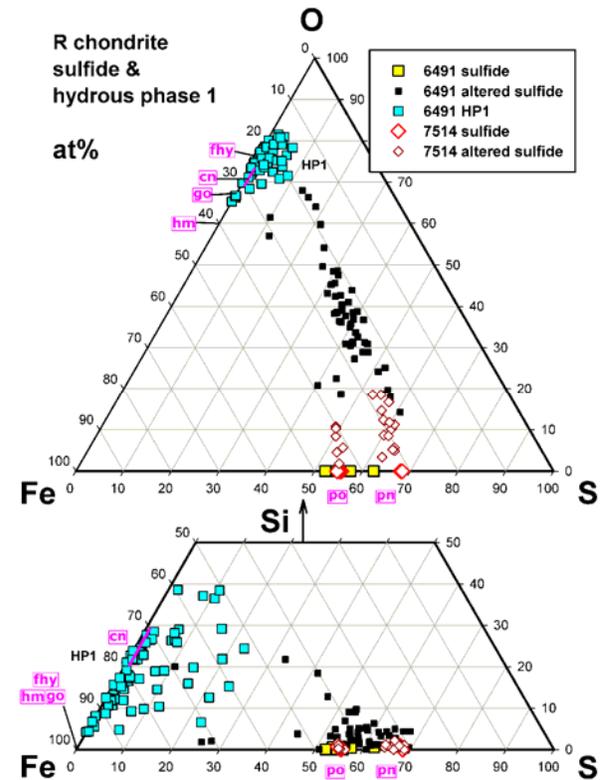


Fig. 3. Chemical ternary diagrams illustrating the composition of sulfides, altered sulfide, and HP1 in NWA 6491 and 7514 obtained with SEM methods. Analyses of altered sulfide in NWA 7514 are not of bands alone but rather of larger sulfide areas that include the presence of alteration bands and O enhancements along crack-like features. Pink labels indicate phase compositions: po = pyrrhotite, pn = pentlandite, hm = hematite, go = goethite, cn = cronstedtite, fhy = ferric hydroxide  $\text{Fe}(\text{OH})_3$ .