

## MINERALOGY AND MINERAL CHEMISTRY OF NOBLE METAL GRAINS IN R CHONDRITES.

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**Introduction:** Rumuruti-chondrites are a group of chondrites intermediate between ordinary and carbonaceous chondrites [1]. The characteristic feature of these chondrites is their highly oxidized mineral assemblage. Equilibrated olivine usually has a fayalite content around ~39 mole-% Fa. There is almost no free NiFe-metal in these chondrites [1]. As a consequence, noble metals form separate phases [1,2,3] which otherwise, due to their siderophilic behavior, certainly would be dissolved in the FeNi metal. Despite the occurrence of noble metal minerals the chemistry does not show any enrichment in these elements which are CI-like except for very volatile and chalcophile elements which are even lower [4]. Noble metal grains were described so far from carbonaceous chondrites, i.e., the so-called fremdlinge or opaque assemblages in the CAIs of CV chondrites [5,6] and from CK chondrites [7].

The occurrence, mineralogy and mineral chemistry of these phases is described in detail. Five R chondrites were investigated: Acfer 217 (R3.8-5), Dar al Gani 013 (R3.5-6), Hammadah al Hamra 119 (R4), Rumuruti (R3.8-6), and Hughes 030 (R3-6).

**Method:** Polished thin sections were carefully and completely scanned with a scanning electron microscope in the backscatter mode at high contrast and a magnification of 200-400x. Under these conditions, phases with high atom numbers become striking. It is estimated that the majority of noble metal grains equal or larger than 1  $\mu\text{m}$  could be detected in the thin sections. Analyses were performed with an EDX as well as with a microprobe.

**Size and occurrence:** The grain size of NM grains in R chondrites is generally in the range of 0.5-2  $\mu\text{m}$ . The largest grain is ~8x4  $\mu\text{m}$ , but also several grains only 200-300 nm in size could be detected. The modal abundance of NM grains is almost the same in all chondrites with approximately 1-2 ppm by volume. On average 10-15 grains per  $\text{cm}^2$  were found. Their shape is mostly rounded. Several grains show idiomorphic shapes (especially irarsite and sperrylite), other are irregular (e.g., tetraferroplatinum, and osmium metal).

The NM grains are spread through the whole chondrite and were found in almost all petrologic components except of chondrules. This is similar to the occurrence of NM grains in CK chondrites, but different to CV chondrites where they are restricted to CAIs. The NM grains are, however, most abundant within oval sulfide-plagioclase-chromite-assemblages

[1]. Mostly, NM grains can be encountered as monomineralic grains, but multiphase assemblages of two or three phases were found as well. Host phase of most NM grains are sulfides, either intact like in Rumuruti or weathered to Fe-hydroxides in the desert finds. Also silicates are frequent host phases (mostly olivine and plagioclase). Several grains were found in or adjacent to chromite.

**Mineralogy and mineral chemistry:** Table 1 lists the NM minerals detected in R chondrites. Summarizing the results for all R chondrites, tetraferroplatinum, sperrylite, irarsite, and osmium are the most abundant NM minerals. Gold seems to be a common phase, too, but was not so frequently observed due to the lower chemical abundance. Nevertheless, there are some significant differences between the five R chondrites indicating a formation under different conditions.

Table: Mineralogy of noble metal grains in R chondrites and their abundance

Phases	Formula	A	DaG	HaH	Hu	R	$\Sigma$
		217	013	119	030		
Tetraferroplatinum	PtFe	(1)	36	-	3	4	44
Sperrylite	PtAs <sub>2</sub>	9	-	7	2	19	37
Niggliite	PtSn	-	-	5	-	1	6
Rustenburgite	Pt <sub>3</sub> Sn	-	-	3	-	1	4
Unnamed	Pt <sub>2</sub> PdSn <sub>2</sub>	-	-	1	-	-	1
Moncheite	PtTe <sub>2</sub>	1	-	-	-	-	1
Osmium	Os	1	14	10	-	6	31
Ruthenium	RuOsIr	1	-	1	-	-	2
Erlichmanite	OsS <sub>2</sub>	2	-	-	-	-	2
Laurite	RuS <sub>2</sub>	4	-	-	-	-	4
Irarsite	IrAsS	14	7	6	4	10	41
Gold	Au	5	1	1	-	4	11
Grains [n]		38	58	34	9	45	184
Invest. area [cm <sup>2</sup> ]		4.1	~10	2.7	1.1	2.9	20.8
Grains per cm <sup>2</sup>		9	~6	13	8	16	9

*Pt-phases.* Sperrylite is the most abundant Pt-mineral in A 217 and Rumuruti. It was frequently observed in HaH 119 and Hughes 030, too. Often it is

almost pure PtAs<sub>2</sub>. In A 217 and Rumuruti microprobe analyses revealed several percent Ir either in solid solution or due to intimate intergrowths with irarsite. In HaH 119 sperrylite always contains approximately 5-10 atom-% Sn and Sb substituting As. Tetraferroplatinum is the major Pt-carrier (and only Pt-phase) in DaG 013 and perhaps in Hughes 030. It always contains Ni (6-10 atom-%) and up to ~10 % Ir. In Rumuruti an interesting difference has been observed with sperrylite being more abundant in equilibrated clasts and the sulfide-plagioclase-chromite-assemblages whereas tetraferroplatinum is more abundant in the matrix. HaH 119 is different from the other chondrites containing abundant Sn-phases like niggliite, rustenburgite (both with up to 8 % Sb), and Sn-containing sperrylite. Such tin phases were also found in Rumuruti. In A 217 a telluride, moncheite, was observed which was also described from CK chondrites [7].

*Ir-phases.* Irarsite is the major Ir-phase in all R chondrites. It is often intergrown with sperrylite and/or forms a solid solution with this mineral as indicated by petrologic evidence and up to ~8 atom-% Pt in the analyses, respectively. Tetraferroplatinum is another important Ir-carrier. The Ir-content in this mineral is variable from almost 0 to 10 % Ir. In DaG 013 almost half the Ir resides in tetraferroplatinum. Detectable amounts of Ir were also found in sperrylite (up to 10 %), osmium (up to 11 %), and ruthenosmiridium (~15 %).

*Os-phases.* Osmium metal with ~10-20 % Fe, ~10 % Re and Ir is the major Os-carrier in DaG 013, HaH 119, and Rumuruti. In A 217 Os metal occurs as well, but here erlichmanite (OsS<sub>2</sub>) is the major phase indicating a formation under higher S-fugacity.

*Ru-phases.* In HaH 119 and A 217 very small grains of ruthenosmiridium were found. In A 217 ruthenium occurs quite abundant as laurite (RuS<sub>2</sub>) forming a solid solution with erlichmanite.

*Other noble metals.* Gold occurs as native metal at least in four R chondrites. It contains several percent Fe, Cu, and Ag. Bischoff et al. described a gold sulfide from A 217 [2]. The only Pd-phase detected so far is a hard to define Pt-Pd-Sn compound found in A 217. Re was analyzed with up to ~10 % in Os metal. Microprobe analyses revealed traces of Rh (0.1-0.2 %) in tetraferroplatinum.

*Additional minerals.* In the course of this examination further noteworthy minerals were detected. Awaruite and/or nickel grains (up to 90 % Ni) were found in DaG 013 and Rumuruti. Kamacite and taenite occur here as well, mainly enclosed in Fe-poor pyroxene and olivine (as DaG 013 is almost unshocked these grains were treasured in the silicates and survived the weathering on Earth). Altogether

these grains are not much more abundant than NM grains and their modal abundance is estimated to be on average less than 10 ppm by volume. Detected sulfides comprise molybdenite in DaG 013 and Rumuruti (lath-like, up to 10 µm) and heazlewoodite (DaG 013).

**Discussion:** Noble metals in R chondrites occur in separate phases with manifold mineralogy. There are some common minerals, but also some remarkable differences. Most noteworthy are the S-rich mineral assemblage in A 217, the dominance of Sn-containing Pt-phases in HaH 119, and the „primitive“ assemblage in DaG 013 with tetraferroplatinum as the only Pt-phase and the lack of sperrylite.

Certainly, the minerals were formed under different conditions as there is no evidence of differences in the chemical composition. A metamorphosis model can explain some but not all of the facts. Clearly, good thermodynamic data are needed. Petrographic evidence indicates that tetraferroplatinum forms as the first Pt-phase. The major evidence for this assumption comes from the high number of PtFe-grains in the least metamorphosed chondrite DaG 013 with its type 3.5-clasts and in unequilibrated Rumuruti matrix. PtFe was probably formed after the matrix. This is indicated by an irregular shape of a large PtFe-grain in Rumuruti residing in clastic silicate matrix. The outer edges are precipitated with gold which obviously is a later product. If this assumption is right then also Os which is sometimes intergrown with PtFe formed under these conditions. Sn-compounds as found in HaH 119 probably formed at higher pT-conditions as it is out of the investigated R chondrites the only R4-chondrite [8]. This meteorite perhaps displays a narrow range of formation conditions as it is also the only unbrecciated R chondrite investigated so far. The arsenides irarsite and sperrylite are often intergrown and their formation probably occurred under similar conditions. They could be related to the equilibrated clasts as indicated by the enrichment of sperrylite in such a clast in Rumuruti. However, idiomorphic grains enclosed in silicates can have a different history as condensates. Furthermore, it is not clear how A 217 fits into a metamorphosis scheme or whether this meteorite formed under higher S-fugacity.

**References:** [1] Schulze H. et al. (1994) *Meteoritics*, 29, 275–286. [2] Bischoff A. et al. (1994) *Meteoritics*, 29, 264–274. [3] Schulze H. (1998) *Meteoritics & Planet. Sci.*, 33, A139. [4] Kallemeyn G. W. (1996) *Geochim. Cosmochim. Acta*, 60, 2243–2256.–1345. [5] Blum J. D. et al. (1989) *Geochim. Cosmochim. Acta*, 53, 543–556. [6] Bischoff A. and Palme H. (1987) *Geochim. Cosmochim. Acta*, 51, 2733–2748. [7] Geiger T. and Bischoff A. (1995) *Planet. Space Sci.*, 43, 485–498. [8] Weber D. et al. (1997) LPS XXVIII, 1511-1512.