Primary Nebular Sulfides in CR and CM Chondrites: Formation by Sulfidization and Crystallization

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Introduction

- Primary grains defined as having formed in the solar nebula
- Potential primary sulfides = troilite (FeS), pyrrhotite ($(Fe,Ni)_{1-x}S$) and pentlandite ($(Fe,Ni)_9S_8$)
- Primary sulfide formation:
  - Sulfidization: Fe,Ni-metal + H_2S = $(Fe,Ni)_{1-x}S$
  - Crystallization: partial to complete melting of pre-existing grains → cooling → crystallization of immiscible monosulfide solid solution (mss) melts → subsolidus unmixing yielding pyrrhotite-pentlandite (po-pn) exsolution
- Purpose: **Reevaluating sulfide mineralogy of CR and CM carbonaceous chondrites**
  - Determine if primary sulfides that formed from sulfidization and/or crystallization are present
  - If so, what can these tell us about nebular conditions?

Methods

- Meteorites studied, listed in order of increasing alteration, include:
  - CR2s QUE 99177, MET 00426 , EET 92042, and Renazzo
  - CM2s QUE 97990, Murchison, Murray, and Mighei
- BSE images obtained on FEI Quanta 3D FEGSEM in E&PS Dept. at UNM
- WDS compositional data collected using JEOL 8200 EPMA and Probe for EPMA (PFE) software in Institute of Meteoritics at UNM

Results

Textures

- Po-pn composite (COMP) grains (Figs. 1-3):
  - Dominated by po + lesser amounts of pn occurring as patches, blades, lamellae, and submicron rods
  - Similar in CRs and CMs (Fig. 1)
  - Snowflake texture [10,11] common (Fig. 2)
  - Some grains show po altering to mgt (Fig. 3)
  - Micron-sized metal inclusions (MMIs) [8,10] sometimes located in po with pn nucleating off them (Fig. 4)
- Sulfide rimmed metal (SRM) grains (Fig. 5):
  - Fe,Ni-metal core rimmed by sulfide displaying po-pn exsolution (pn patches, blades, rods)
  - In CR chondrites:
    - Only observed rimming chondrules
    - Mostly thin (5-10 µm) sulfide rims around metals in type IA chondrules
    - Thicker (up to 50 µm) sulfide rim around metals in intermediate type chondrule in EET 92042 (Fig. 5b)
  - In CM chondrites:
    - Rare and only observed in matrix
    - Thin (5-20 µm) sulfide rims around metal grains

Compositions

- Fig. 6 displays compositional data as element-element (a = sulfides, b = metals) and ternary (c) diagrams
- All sulfides plot on the solar Co-Ni ratio
- All metals, with the exception of MMIs, plot on the solar Co-Ni ratio
- MMIs show high Ni abundances as compared to SRM metals

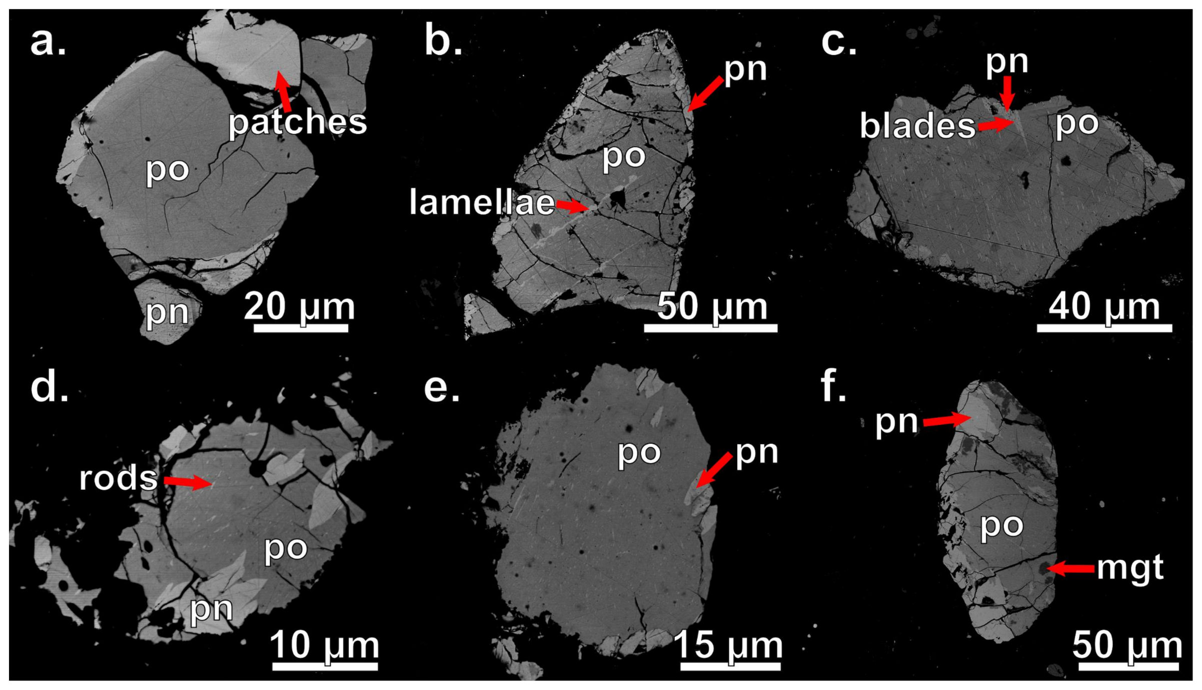

Fig. 1. BSE images of COMP grains displaying similar po-pn exsolution textures including pn patches, blades, lamellae, and submicron rods from CM2s (a) QUE 97990, (b) Murchison, (c) Murray and CR2s (d) QUE 99177, (e) EET 92042, and (f) Renazzo. po = pyrrhotite, pn = pentlandite, mgt = magnetite.

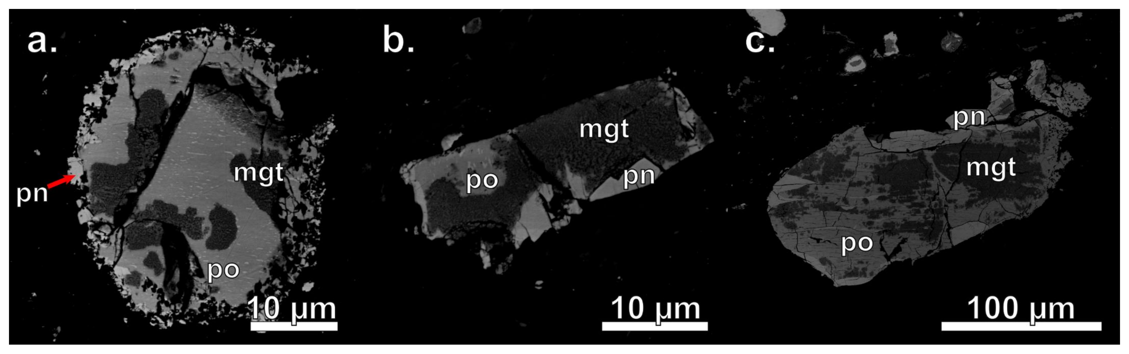

Fig. 3. BSE images of COMP grain po altering to mgt from more aqueously altered samples (a,b) CM2 Murray and (c) CR2 Renazzo. po = pyrrhotite, pn = pentlandite, mgt = magnetite.

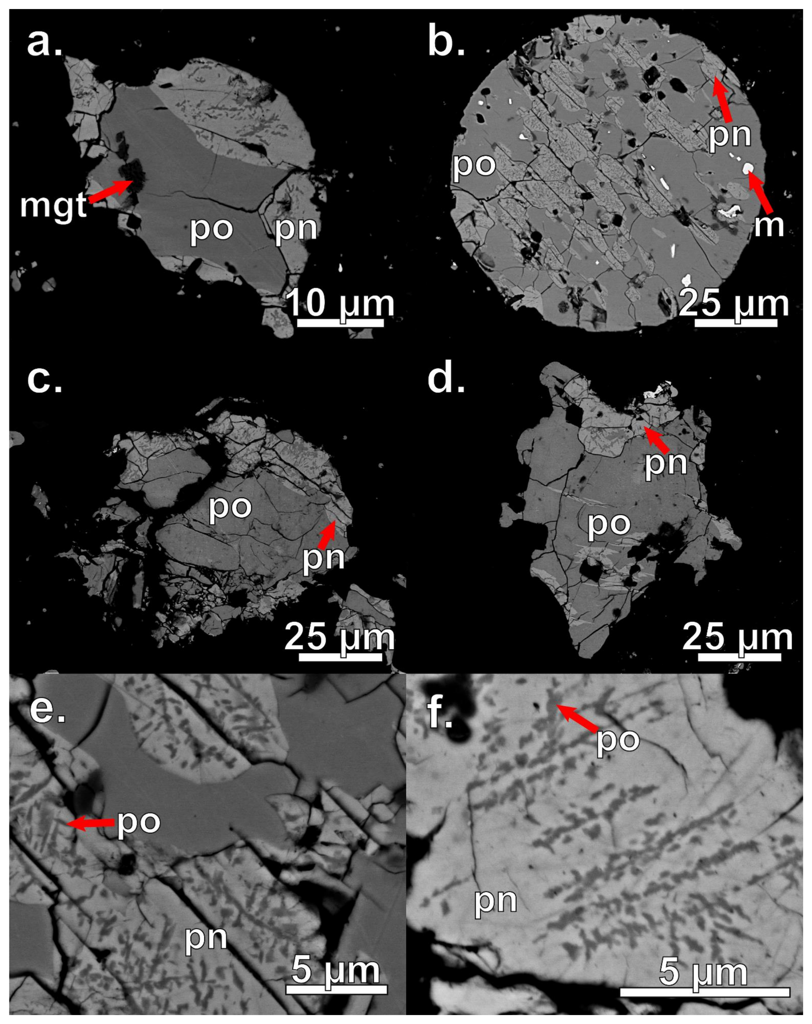

Fig. 2. BSE images of COMP grains with the snowflake texture from (a,b) CM2 QUE 97990 and (c,d) CR2 EET 92042. (e,f) are high magnification images from CM2 QUE 97990 illustrating the dendritic and graphic textures of the po within the pn patches. po = pyrrhotite, pn = pentlandite, m = Fe,Ni-metal, mgt = magnetite.

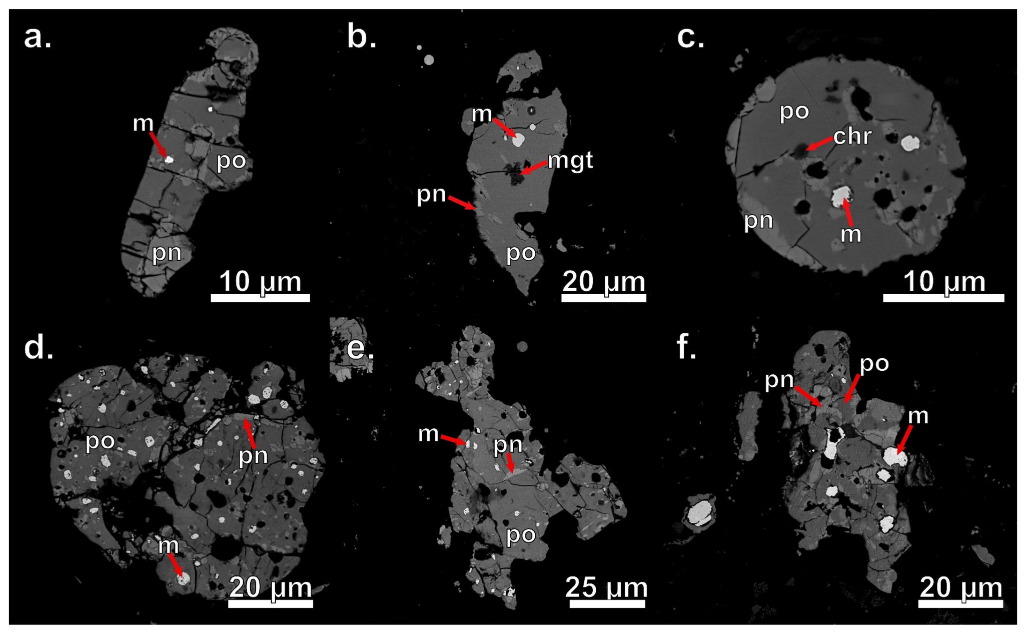

Fig. 4. BSE images of COMP grains containing MMIs from CM2 (a-c) QUE 97990 and CR2s (d,e) EET 92042 and (f) MET 00426. po = pyrrhotite, pn = pentlandite, m = Fe,Ni-metal, mgt = magnetite, chr = chromite.

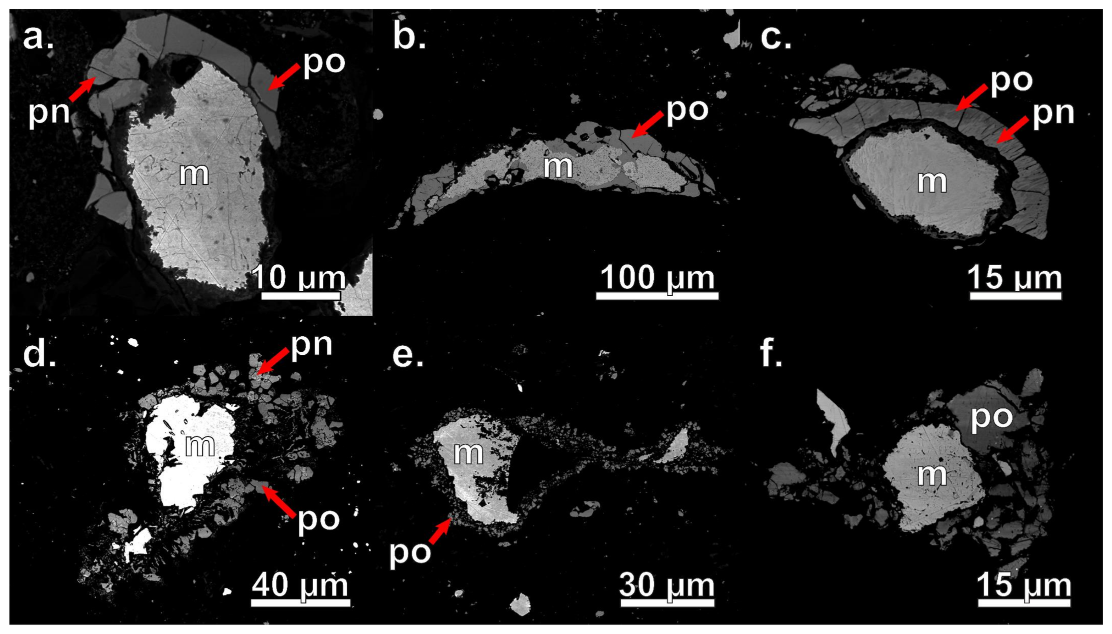

Fig. 5. BSE images of SRM grains from CR2s (a) QUE 99177, (b) EET 92042, (c) Renazzo and CM2s (d,e) QUE 97990 and (f) Murray. po = pyrrhotite, pn = pentlandite, m = Fe,Ni-metal.

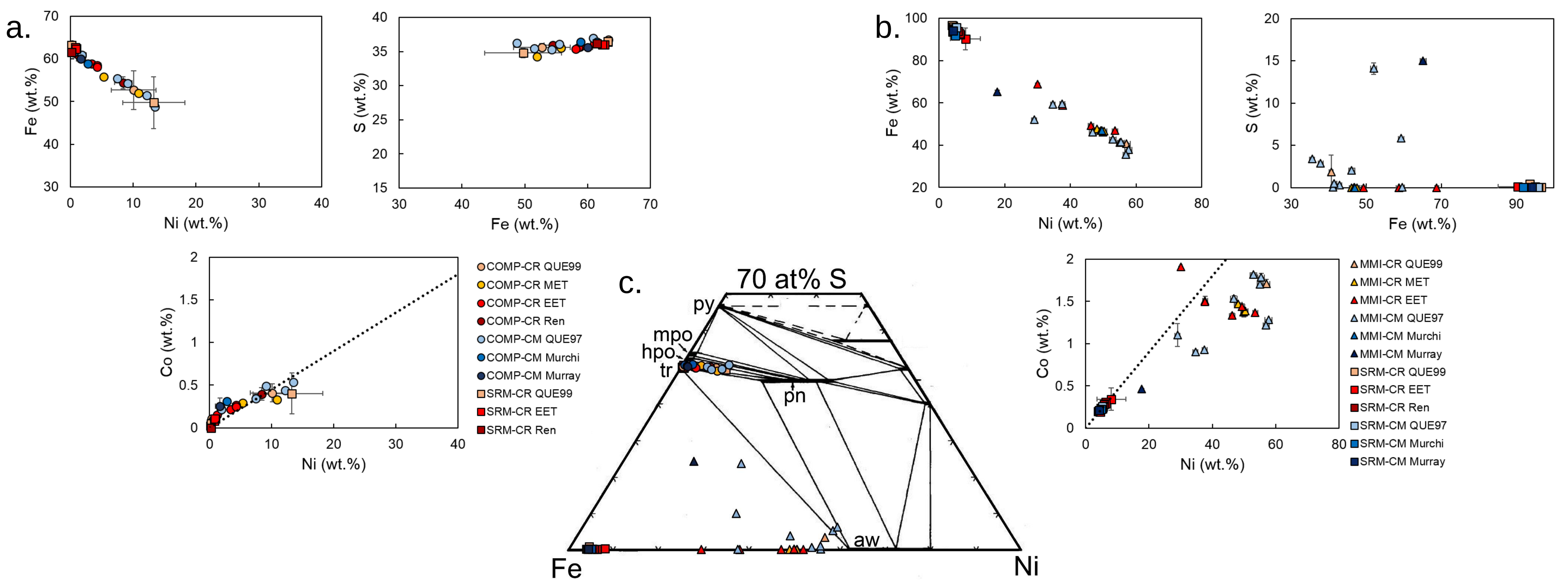

Fig. 6. Compositional data for sulfides and metals. Element-element diagrams for sulfides (a) and metals (b) illustrate that CRs and CMs have similar S, Fe, Ni, and Co concentrations as do the different textural groups (i.e., COMP vs. SRM). The dashed line represents the solar Co/Ni ratio [from 13]. The ternary diagram (after [15]) shows that the sulfides plot on tie lines between po and pn.

Discussion

- SRM grains = sulfidization
  - Appropriate morphology [14]
  - Metal = solar Co/Ni ratio (0.045 from [13])
  - More limited po-pn exsolution textures as compared to COMP grains
- COMP grains = crystallization
  - Many are present in chondrules
  - Display po-pn exsolution consistent with experimental work [15-17]
  - Primary grains since po sometimes altering during aqueous alteration (po goes to mgt, Fig. 3)
- MMIs = crystallization
  - Formed from melt that lost S by evaporation during chondrule melting similar to metal inclusions in troilite from chassignite NWA 2737 [18]

Conclusions

- SRM grains formed by sulfidization of Fe,Ni-metal in solar nebula
- COMP grains formed by crystallization of sulfide melt in chondrules
- MMIs formed by S loss from evaporation during chondrule melting
- Future Work:
  - TEM work on primary sulfides to determine monoclinic pyrrhotite versus hexagonal pyrrhotite (formation temperatures and cooling rates)
  - SXRF work on primary sulfides to obtain trace element compositions
  - Detailed SEM, EPMA, TEM, and SXRF studies on potential secondary sulfides in CR and CM chondrites

References

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