PENTLANDITE NI CONCENTRATIONS: FO2 VS. EQUILIBRATION TEMPERATURE.

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Introduction: Fe-sulfides are ubiquitous in chondrites and are sensitive indicators of formation and alteration conditions in the protoplanetary disk and small Solar System bodies [e.g., 1–15]. We previously constrained a minimum oxygen fugacity (fO$_2$) needed to form pentlandite, (Fe,Ni)$_9$S$_8$, [6,7] and identified a relationship between the at.% Fe/S ratio of pyrrhotite group sulfides and the fO$_2$ of formation, either in the protoplanetary disk or the parent body during aqueous alteration or thermal alteration [13]. Since pentlandite formed with pyrrhotite (they are typically intergrown in these chondrite groups [1–15]), fO$_2$ may have influenced pentlandite compositions. Alternately, the composition of pentlandite could instead be influenced by its equilibration temperature [e.g., 16]. Here we report the chemical compositions of pentlandite in chondrites that experienced a wide range of formation and parent body alteration conditions (including fO$_2$ [13]), and constrain sulfide equilibration temperatures. This will allow us to investigate a potential trend(s) between pentlandite Ni concentration and the pyrrhotite at.% Fe/S ratio, and by extension fO$_2$.

Samples and Analytical Procedures: We determined the major and minor element compositions of pentlandite and sulfide equilibration temperatures for each of the following 54 chondrites: CI (Alais), a C1-ungrouped (Miller Range [MIL] 090292), C2-ungrouped (Tarda, Tagish Lake, and Belgica [B]-7904), CM1/2 (Allan Hills [ALH] 83100 and Kolang [two lithologies]), unheated CM2s (Aguas Zarcas [multiple lithologies], Mighei, Queen Alexandra Range [QUE] 97990, Theil Mountains [TIL] 91722, and D'Angelo Bluff [DNG] 06004), stage I heated CM2 (Asuka [A]-881458), stage II heated CM2 (Yamato [Y]-793321), CM-like (Sutter's Mill), CO3.00 (Dominion Range [DOM] 08006), CR1 (Grosvenor Mountains [GRO] 95577), CR-an (Al Rais), CR2 (Elephant Moraine [EET] 87770, EET 92048, EET 96259, Gao-Guenie (b), Graves Nunatak [GRA] 95229, LaPaz Icefield [LAP] 02342, LAP 04720, MIL 090657, Northwest Africa [NWA] 801, Pecora Escarpment [PCA] 91082, QUE 99177, Shişr 033, and Y-793495), shock-heated CR2 (GRO 03116), CV3$_{OxA}$ (Allende), CV3$_{OxB}$ (Bali), and CV3$_{Red}$ (Vigarano), CK4 (ALH 85002 and Karoonda), CK5 (Larkman Nunatak [LAR] 06868), CK6 (Lewis Cliff [LEW] 87009), L3.05 (EET 90161 and QUE 97008), LL3 (Semarkona and Vicência), LL4 (Hamlet and Soko-Banja), LL5 (Chelyabinsk and Siena), LL6 (Appley Bridge and Saint-Séverin), R3 (MET 01149), R3.6 (LAP 031275), R5 (LAP 03639), and R6 (LAP 04840 and MIL 11207) chondrites. We acquired high-resolution backscattered electron images and quantitative chemical compositions with the JEOL-8530F Hyperprobe electron microprobe analyzer (EPMA) at Arizona State University (ASU) and the Cameca SX-100 EPMA at the University of Arizona following [13]; some compositions from [6,7,10,11,15].

Results and Discussion: Our data show that there is no relationship between the average or maximum Ni concentration of pentlandite and sulfide equilibration temperature, but there is a relationship between the at.% Fe/S of pyrrhotite (data from [13]) and Ni concentration of pentlandite. Since the at.% Fe/S ratio of pyrrhotite is a proxy for fO$_2$ [13], this demonstrates that there is a relationship between fO$_2$ and pentlandite Ni concentration. Therefore, pentlandite compositions were influenced by the fO$_2$ of formation. This is true whether pentlandite formed: (1) during chondrule formation in the protoplanetary disk (i.e., during chondrule cooling, as previously noted by [6,8,10,11] for CR2, CO3.00, and LL3.00 chondrites), (2) during thermal alteration on the parent asteroid under relatively reducing (i.e., LL4–6 chondrites) or oxidizing (i.e., R4–6 and CK chondrites) conditions, or (3) during oxidizing aqueous alteration (i.e., as in CI, CM1, C1-ung, and C2-ung chondrites). Therefore, in addition to the at.% Fe/S ratio of pyrrhotite, the Ni concentration of pentlandite can also be used as a proxy for the fO$_2$ of formation.

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