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ORIGIN OF Ti^{3+}- BEARING RHÖNITE IN Ca-, Al-RICH INCLUSIONS: AN EXPERIMENTAL STUDY

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Rhönite (Rhön) is a rare, Ti-rich silicate that occurs interstitial to or around spinel grains included within melilite (Mel) in Allende compact type A inclusions (CTA's). It is often associated with fassaite (Fass), perovskite (Pv) and/or spinel (Sp). In order to determine the T-f_{O_2} conditions under which Rhön formed, we have conducted crystallization experiments as in Beckett and Grossman (1986) at f_{O_2}'s 1.5 log units more reducing than those of a solar gas. A V-, Fe-free analogue, FR71 (wt % CaO, MgO, Al_2O_3, SiO_2, TiO_2 = 17.8, 16.6, 26.4, 21.5, 17.7), of the Rhön composition given in Fuchs (1971) was used.

The crystallization sequence for FR71 at low f_{O_2}'s is Sp (> 1356°C), Pv (1344-56), Rhön (1319-44) and Fass (1262-90). Ti^{3+}/Ti^{4+} is 1/3-2/3 in FR71 Fass and 2/3-3/2, based on $R_{28}O_{40}$ stoichiometry, in FR71 Rhön. Rhön compositions, mostly T_4R ($Ca_4Mg_6Al_{12}Ti_6^{4+}O_{40}$)-$T_3R$ ($Ca_4Mg_6Ti_{12}^{3+}Si_6O_{40}$) — MgR ($Ca_4Mg_{12}Si_{12}O_{40}$), are similar to those in CTA's, but synthetic Fass is Mg-, Ti^{4+}-rich compared to Fass in CTA's.

Four reactions involving Sp, Pv, T_3R, T_4R, MgR, $CaTi^{3+}AlSiO_6$(T_3P) and Di ($CaMgSi_2O_6$) are:

$$5/6\ MgR + 4\ T_3P = 1/3\ T_3R + 6\ Di + 2\ Sp \qquad (A)$$
$$5/3\ T_4R + 1/6\ MgR = 1/3\ T_3R + 10\ Sp + 6\ Pv + O_2 \qquad (B)$$
$$5/3\ T_4R + 6/5\ Di = 4/5\ T_3P + 4/15\ T_3R + 48/5\ Sp + 6\ Pv + O_2 \qquad (C)$$
$$5/3\ T_4R + 6\ Di = 2/3\ MgR + 4\ T_3P + 8\ Sp + 6\ Pv + O_2 \qquad (D)$$

Reaction (A) is a potential thermometer and reactions (B-D) oxygen barometers. The equilibrium constant for each of these reactions was determined from electron microprobe analyses of coexisting Fass and Rhön in experimental run products and from measured f_{O_2}'s. Free energies of reaction for (A-D) computed from these data are: -11.9 ± 0.9, $+129.4 \pm 0.4$, $+131.4 \pm 0.7$ and $+140.5 \pm 1.2$ kcal/mol, respectively, at 1520K.

FR71 liquids coexisting with Rhön have very high TiO_2 concentrations (10-16 wt %). In CTA's, such liquids could only be produced after 85-97% fractional crystallization. Application of reaction (A) to four literature (Fuchs, 1971, 1978; Mason and Taylor, 1982) Fass-Rhön-Pv-Sp assemblages from Allende and to analyses of Rhön and Fass phenocrysts from a CTA in USNM 3878 yields temperatures of 1416-1474K, consistent with late-stage crystallization from a melt. A Fass-Pv-Sp symplectite in contact with Rhön in the CTA in USNM 3878 yields a temperature of 1448K, suggesting that it also crystallized from a melt. The oxygen barometers (B-D) give f_{O_2}'s ranging from -17.8 to -18.3 at 1500K for these assemblages, consistent with those of a solar gas (-18.1 ± 0.4) and of f_{O_2} estimates for CTA's (Beckett and Grossman, 1986) based on Fass-Mel-Sp equilibria (-17.8 ± 0.3). CTA's equilibrated with a gas 1.5 ± 0.8 log units more oxidizing than did type B inclusions (Beckett and Grossman, 1986) from Allende and about two orders of magnitude more reducing than did hibonite from Murchison (Live *et al.*, 1986).

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MINERALOGICAL EVOLUTION OF THE ASTEROID BELT

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Recent advances in asteroid spectroscopy have made it possible to associate many meteorites with specific narrow zones in the main asteroid belt (or in a few cases, specific asteroids). The petrological and isotopic composition, inferred condensation temperatures, and metamorphic heating of the meteorites then can be used to infer the broad outlines of the condensational, thermal, and collisional history of the asteroid belt. This paper reports a first rough attempt to do so.

Broad-band photometry in the visual wavelength region has been used to divide the asteroids into 14 "taxonomic types" or "spectral classes," each of which occurs at a characteristic distance from the sun. Recent near-IR observing programs have measured the spectral features of olivine, pyroxene, plagioclase, and bound/adsorbed water in at least a few asteroids of most of these classes. These new spectral databases give us a much improved ability to assign meteorites to their parent asteroid classes, and thus to orbital position. Aubrites at 1.9 AU suggest a similar location for E chondrites. Basaltic achondrites, petrologically derivable from H-like material, are at 2.3 AU, near a variety of differentiated types linked to ordinary-chondrite-like material. Carbonaceous chondrites are concentrated near 3.0 AU, but are replaced at greater distances by types spectrally inconsistent with known meteorites. (These appear to be lower-temperature materials rich in organic polymers.) The known chondrite classes thus appear to reside in the inner asteroid belt in the relative sequence inferred from geochemical data. The apparent trend in FeO/(FeO + MgO) among asteroids is very much steeper than any suggested by the terrestrial planets. This suggests either that the asteroids have moved outward while preserving their relative spatial relationships, or that the planets accreted many planetesimals which had been scattered inward.

The 14 asteroid classes can be grouped into three "superclasses" according to the degree of metamorphic heating they have undergone. Igneous type dominate the belt sunward of 2.7 AU, metamorphosed types lie in a narrow zone around 3.2 AU, and primitive types are dominant outside 3.4 AU. It appears that the heating mechanism which metamorphosed the chondrites and melted the achondrites was one which rapidly declined in efficiency with solar distance. Al-26 decay can explain this striking pattern only if planetesimal formation slowly spreads outward over many half-lives of Al-26. Magnetic induction heating appears to be more consistent with the striking pattern seen.

The trends in condensation and metamorphic temperatures described above also may explain the lack of large, telescopically observable parent bodies in the asteroid belt for ordinary and enstatite chondrites; in their condensation zones the later heating event was so intense as to melt all large planetesimals. A few very small ($D < 5$ km) O.C.-like objects (spectral class Q) have been observed on planet-crossing orbits; future large telescopes will be capable of locating similar objects in the main belt. A remaining puzzle is the rarity of metal-free achondritic asteroids (classes V, R, A, E) relative to metal-rich objects (classes S and M) in the inner belt. An answer is suggested by the fact that most stony-irons are composed of discrete regions of silicates in a continuous metal matrix and are much stronger than stony meteorites. A differentiated or semi-differentiated parent body will be rapidly