PARNALLEE (LL 3.6) HEATING EXPERIMENTS: IMPLICATIONS FOR THE ORIGIN OF TYPE 6 AND 7 CHONDRITES.
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Summary: Experiments at one atmosphere, MW oxygen fugacity on Parnallee, LL 3.6, show that it is not affected texturally or chemically at temperatures of up to 1150°C with run durations on the order of a few days to over a week. However prolonged heating for 60 days at 1125°C, resulted in textural recrystallization and partial melting. The residual chondrite retains a few "ghost" chondrule structures as well as relict minerals. All mineral compositions were completely homogenized as was all zoning. The texture of this residue is similar to that of a type 6 chondrite. The newly generated melt is richer in MgO, FeO, CaO and poorer in Al_2O_3 and Na_2O compared to the feldspathic glass in the unequilibrated original meteorite. The total rock, residue plus melt, would resemble a type 7 chondrite after extensive annealing.

Introduction: Parnallee (LL 3.6) heating experiments were done in an attempt to experimentally produce the metamorphic textural and chemical characteristics of ordinary chondrites of higher petrologic type.

Starting material: Parnallee was chosen because it is a relatively unequilibrated chondrite and is coherent enough to withstand an experimental run. It contains the full variety of chondrule types, olivine-rich matrix with some pyroxene (mostly opx, some cpx), very little metal, sulfide and chromite. Olivine compositions vary within single grains and within chondrules and zoning, in olivine is common (Fo_{72-94}). Pyroxene is also variable in composition (Opx-En_{65-97}, $Wo_{0.2-3.0}$ and Cpx-En_{42-51}, Wo_{34-41}). Feldspathic glass of variabele compostion is present in chondrules as well as in the matrix. A small block of Parnallee (about 5x3x2 mm) was carefully cut, prepared and studied in detail using petrographic microscope, SEM and electron microprobe. After this the block was cleaned and used in the experiments.

Experimental conditions: A total of five experiments were done at one atmosphere pressure and at MW oxygen fugacity. The sample was wrapped in spec pure Fe or Mo foil and sealed in an evacuated silica tube. Run temperatures were varied between 850°C and 1150°C and run durations were varied from 4 to 60 days. Each run was quenched in air and the product was studied using the microscope, SEM and electron probe to determine any changes in texture and/or composition of the phases. Run temperatures and run times were increased with each successive run to promote metamorphic changes.

Results and discussion: None of the runs, with the exception of one, showed any textural or compositional changes. The 1125°C experiment was run for 60 days to improve diffusion and kinetics. It produced partial melting and homogenization of individual mineral compositions. The run product showed only "ghosts" of some chondrule structures with relict olivine and pyroxene. The remainder of the sample consisted of recrystallized areas with olivine and some pyroxene set in interstitial pools of feldspathic melt (some isotropic, but mostly cryptocrystalline or very fine-grained non-stoichiometric material). The composition of the melt (glass) is uniform in composition at 58.9% SiO_2, 0.45% TiO_2, 15.5% Al_2O_3, 0.10% Cr_2O_3, 9.2% FeO, 0.18 MnO, 4% MgO, 6.5% CaO, 3.6% Na_2O, 0.74% K_2O. The percentage of partial melting is difficult to determine. The newly generated melt is richer in MgO, FeO, CaO and poorer in Al_2O_3 and Na_2O

PARNALLEE (LL3.6) HEATING EXPERIMENTS: Nehru C.E. et al.

compared to the feldspathic glass in the unequilibrated original Parnallee meteorite. Some Fe, Mg, and Ca from the olivine and pyroxene migrated into the newly generated melt areas. The movement of Na needs to be determined. In the experimental run product we detected a plagioclase-like phase (in terms of composition) which differed from the rest of the glass, and this is being further investigated. Olivine is homogeneous at Fo_{69}, irrespective of its textural type and setting. This includes relict grains of variable size, recrystallized grains, small (1 to 25 micron) euhedral crystals in contact with melt areas, and overgrowths on relict olivine which developed euhedral to subhedral outlines. The compositions of the original olivines ranged from Fo_{72-94} and that of the reequilibrated relict olivine is Fo_{69}. The minor element compositions of the original olivines are now near-uniform and identical to the newly crystallized grains. Orthopyroxene is the major pyroxene type and is homogeneous at En_{70}. Minor elements are unchanged except for CaO which is higher compared to the unheated pyroxene. The original and relict pyroxene behaved in the same manner as the olivine, and is equilibrated. Cpx, metal and sulfide are rare and much less than that in the starting material. Chromites remain, as relict crystals.

Implications and conclusions: Parnallee, LL 3.6, was not affected texturally or chemically at temperatures of up to 1150°C and run durations on the order of a few days to over a week. This clearly indicates that the process of metamorphism of ordinary chondrites needs prolonged heating. This observation supports the conclusion of McSween et al. [1] who carried out similar studies. TL sensitivities of ordinary chondrites have been shown to be affected at temperatures less than a 1000°C and run durations of one week or less by Guimon et al. [2].

The 1125°C, 60 day experiment shows that ordinary chondrites can partially melt and homogenize individual mineral phases under these conditions. Zoning patterns in olivines and pyroxenes are all homogenized. The melt phase differes from that of the original glass in Parnallee and is higher in FeO, MgO, CaO and lower in Al_2O_3 and Na_2O indicating movement of these components. The texture of the residual solid part is similar to that of a type 6 chondrite, including ghost chondrule structures and relict olivine and pyroxene. The melt aspect of the texture is probably similar to that of the early melt in petrologic type 7 meteorites (e.g., Y 74160, PAT 91501, LEW 88663). Type 7 chondrites have probably experienced temperatures at or near partial melting of the meteorite, and textures and uniform mineral compositions have been cited as evidence [3,4,5]. However in order to produce the totally recrystallized type 7 chondrite, prolonged heating and annealing at lower temperatures after homogenization, with or without the melt phase was needed. Annealing the present run product would probably produce a type 7 chondrite, given enough time. Thus, mineralogic homogeniation and textural recrystallization of ordinary chondrites can take place relatively quickly, at a temperature of 1125°C (at the conditions cited above) or somewhat below this. Annealing takes a much longer time and ultimately masks the earlier stages noted in the experimental runs.

References: [1] H.Y. McSween et al. (1978) Proc. LPSC. *9* 1437-1447. [2] R.K. Guimon et al. (1985) Geochim. Cosmochim. Acta *49* 1515-1524. [3] M.Prinz et al. (1983) LPS XIV, 616-617. [4] H. Takeda et al. (1984) EPSL *71*, 329-339; [5] D.W. Mittlefehldt et al. (1993) Meteoritics *28*, 401-402.