U-Pb DATING AND REE SYSTEMATICS OF PHOSPHATE MINERALS IN THE H4 AND H6 LITHOLOGIES OF THE ZAG CHONDRITE

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Introduction: The Zag meteorite is an H3-6 chondrite regolith breccia that fell in 1998. Together with the Monahans (1998) H chondrite, Zag is unique in containing indigenous, extraterrestrial, halite that might have formed via evaporation of brines [1-4]. These brines may have originated from exogenous water delivered to the parent body by ice-rich cometary or asteroidal ice fragments [1,4], dehydration of the asteroid interior [2], or impact heating of phyllosilicates [3]. Alternatively, halite itself may be exogenous, derived from either a carbonaceous asteroid such as Ceres [5-6] or via cryovolcanism on a body such as the Saturnian satellite Enceladus [7]. Zag also contains OH-poor and CI-richapatite that records a complex fluid history: apatite composition is homogeneous and close to the CI-apatite end-member in the porous dark H4 matrix (where halite is observed), while apatite composition is heterogeneous in H6 clasts, extending towards F-rich compositions [8]. It is thought that heterogeneous apatite compositions in Zag may record multiple stages of regolith processing and shock at the surface of the H chondrite parent body, with apatite recording circulation of fluids with variable compositions or interaction with a single fluid whose composition evolved as it interacted with the chondrite regolith [8]. To investigate this further, we have carried out in situ U-Pb dating and rare earth element (REE) abundance analysis of apatite and merrillite in the Zag H4 and H6 lithologies.

Methods: The U-Pb systematics and REE inventory of target apatite were analysed simultaneously by laser ablation – inductively coupled plasma mass spectrometry (LA-ICP-MS), using a Teledyne Excite+ 193 nm ArF excimer laser ablation system coupled to an Agilent 8900 triple quadrupole ICP-MS at The University of Manchester. We also analysed the merrillite REE abundances using the same setup.

Results: The apatite grains analysed contain 0.8 to 15.2 μg.g⁻¹ U. Apatite U-Pb dating for all grains including both lithologies yielded an intercept date of 4516 ± 10 Ma (95% confidence, MSWD=1.3, n=22). Interestingly, apatite U/Pb ratios are more discordant, thus, more disturbed, in the H4 lithology compared to the H6 lithology, although all analyses are consistent with the single date within error. Apatite contains ca. 20 to 100 times CI chondrite REE abundances, and display slightly fractionated REE patterns characterized by CI chondrite normalized (La/Yb) ratios of 1.6-3.3, and both negative and positive Eu anomalies. There is no obvious apatite REE abundance difference between H4 and H6 lithologies. Merrillite REE abundances are homogeneous across all analyzed grains, at ca. 300-400 times CI chondrite REE abundances, and display slight HREE enrichment (CI chondrite normalized (La/Yb) ratios of 0.7-0.8) and pronounced negative Eu anomalies.

Discussion: REE abundances in apatite and merrillite in Zag H4 and H6 lithologies are consistent with those obtained on Ca-phosphates in other H chondrites [9], suggesting similar formation conditions. The date of 4516 ± 10 Ma obtained on Zag apatite, in both the H4 and H6 lithologies, is consistent with U-Pb and Pb/Pb dates obtained on Ca-phosphates in H6 chondrites (e.g., ~4500-4520 Ma) [10]. This is younger than Ca-phosphate U-Pb and Pb/Pb dates obtained in H4 and H5 chondrites (>4550 Ma), except for the H4 Avanhandava in which Ca-phosphates record a date of ca. 4515 Ma [10]. It is likely that apatite U-Pb dates in the Zag H4 lithology were reset when they came into contact with hot H6 clasts at ca. 4516 Ma, a mechanism that has also been proposed to explain the young apparent Ca-phosphate date obtained on the H4 Avanhandava [10]. Therefore, the U-Pb system in Zag apatite probably dates the disruption of the H chondrite parent body and reaccretion into a rubble pile. The halogen-rich nature of apatite in Zag, coupled with the similar diffusivity of halogens and Pb in apatite [11], suggests that disruption and reaccretion of the H chondrite parent body at ca. 4515 Ma must have been accompanied by pervasive circulations of water-poor and halogen-rich fluids. With an I-Xe age of ca. 4559 Ma [2], halite in the Zag H4 lithogy predates disruption of the H chondrite parent body. Dissolution of some of the pre-existing halite may have provided the F and Cl required for apatite formation; water-soluble halite extracts have f₃HCl/f₄HF ratios of 35-101 [4], which could have first promoted formation of fluor-chlorapatite in some H6 clasts, evolving toward chlorapatite compositions as the fluids became progressively depleted in F because it is taken up by apatite [8,12]. This scenario would preclude halite formation from late-stage, concentrated, brines from which apatite had already crystallized.