NEW U-Th AND Pb ISOTOPE DATA OF SNC METEORITES

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Recently Bouvier et al. [1] have presented new Pb isotope data on several SNC meteorites. Their results for Los Angeles and Nakhla fall within the range of previously reported data, but a discrepancy exists with the Pb isotopic composition of the maskelynite from Zagami. The data of Bouvier et al. on Zagami imply that the maskelynite has virtually the same Pb isotopic composition as Shergotty, whereas both Jagoutz et al. [2] and Chen and Wasserburg [3] show Zagami to have a considerably less radiogenic initial Pb than Shergotty. We have now re-analyzed maskelynite from Zagami and a comparison of results from the three laboratories is given in Fig 1.

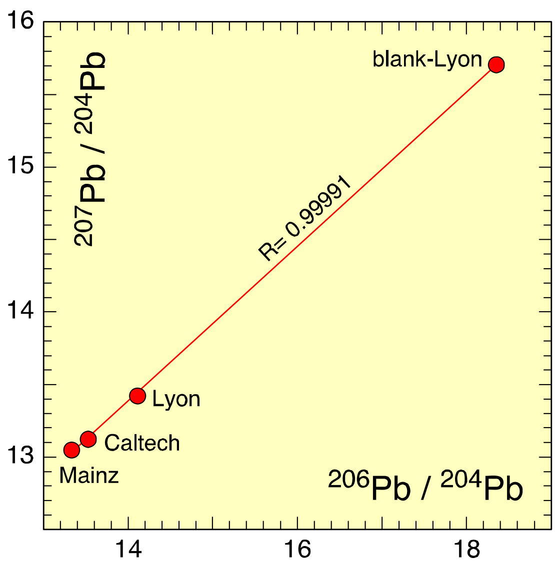

Fig. 1 Analyses of maskelinite from Zagami

Furthermore, although the $^{207}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$ for Dar al Gani 476 (DaG) whole-rock reported by Bouvier et al. is only slightly more radiogenic than Canyon Diablo, the $^{206}Pb/^{204}Pb$ is significantly evolved. If this isotopic composition were correct, it would have important consequences for the evolution of DaG, implying the addition of a young radiogenic component. In a comparable experiment we leached a sample of DaG whole-rock, analyzed the residual, and did not find such a primitive Pb. We wonder whether the DaG analysis of Bouvier et al. may not haver been overcorrected for blank Pb, but admit that a similar speculation about undercorrecting the Zagami maskelynite analysis would imply a extremely large Pb blank. Our main purpose in bringing attention to these inconsistencies is to express caution over the interpretation of even very precise isotope ratio measurements, which may nevertheless require uncertain assumptions about later disturbances, terrestrial or extra-terrestrial contamination, and blank Pb correction.

Nonetheless, the general trend of the data to form a linear array in a Pb-Pb diagram as presented by Bovier et al. was certainly recognized by Caltech [3] and our group, although we interpreted it to be a mixing line pointing towards terrestrial Pb. There is much evidence that many SNC meteorites, and certainly Dar-al-Gani 476, have been heavily contaminated by terrestrial Pb.

Our tactic to circumvent the effects of terrestrial contamination and superimposed younger (150 Ma to 1.3 Ga) disturbances of the SNC meteorites was to extrapolate the Pb isotopic composition to a zero U content on U-Pb isochron diagrams. In this way we sought to obtain initial Pb isotopic ratios, presumably representing the Pb composition of the source from which the actual meteorite was generated. Here we emphasize again that the cause of this young disturbance remains a mystery to us. While the Sm/Nd ratio has been changed drastically, the Lu/Hf ratio appears to be essentially unaffected. Likewise, while the U/Pb ratio was substantially increased, the Rb/Sr ratio was not significantly fractionated. We are unaware of any magmatic process that would result in such a geochemical modification, and consider those processes advocated so far as largely ad hoc.

Whatever their cause, Pb isotopic systematics seem to be the best way to look through these young disturbances. The maskelynite and pyroxenes of SNC meteorites have measured Pb isotopic compositions close to their calculated initial values because both of these minerals have a low U/Pb ratio. A major fraction of the U and Th in the SNCs is not a primary constituent but was introduced at the time of disturbance and resides in the phosphates. By contrast, the Pb in the silicate minerals seems to have remained essentially in isotopic equilibration with the U and Th in the mineral since the time of original crystallization. The main cause of any scatter in the determined initial composition is probably due to the addition of terrestrial Pb, although some minor *in situ* isotopic disturbance cannot be ruled out. Our best values for the initial isotopic ratios of Shergotty, Zagami, and Los Angeles are shown in Fig 2. Values for EETA and DaG are excluded because they show deviations in $^{208}Pb/^{204}Pb$, possibly caused by the addition of an external Pb component.

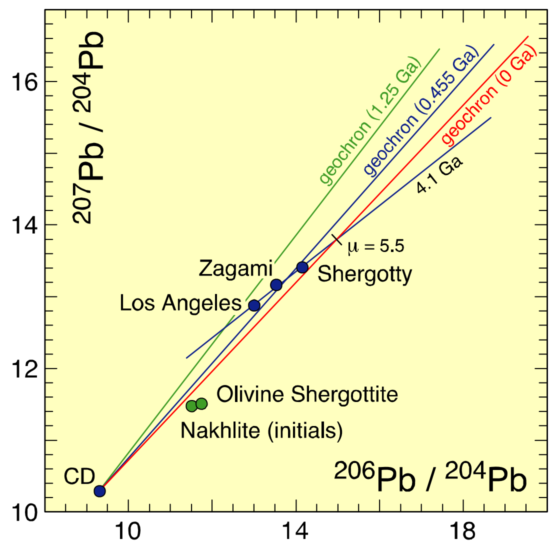

Fig. 2 Pb isotopic initial ratios of SNC - meteorites

Two different scenarios can be proposed to interpret the evolution of these meteorites: (1) The parent body formed and differentiated at 4.55 Ga, and the various meteorite source lithologies evolved isotopically undisturbed until 0.45 Ga (Los Angeles with a $\mu = {}^{238}U/{}^{204}Pb$ of ~4, Zagami with a μ of ~4.5, and Shergotty with a μ of ~5). At ~0.45 Ga the "young event" affected each of these meteorites and the initial Pb ratios, after being corrected for subsequent in situ growth of radiogenic Pb, are scattering on a fossilized 0.45 Ga geochron. (2) The parent body differentiated at 4.55 Ga and formed a single reservoir with a μ of ~5.5. At 4.1 Ga this reservoir further differentiated and formed the various lithologies from which the "young event' produced the meteorites in their present form.

While variants of the second scenario have received much attention, we do not see evidence for a differentiation at 4.1 Ga. The Rb-Sr system is susceptible to disturbance by shock mobilization of Rb and thus may provide only limited time resolution; even so, it gives no evidence of a differentiation event at 4.1 Ga. More persuasively, the U-Pb systematics, as illustrated by Concordia plots in [3], suggest an early differentiation at 4.55 Ga, but no indication of a differentiation at 4.1 Ga. Furthermore, the "crustal rock" ALHA 84001 is unequivocally older than 4.1 Ga.

Additional insight is gained from isotopic data for the Nakhlites, including several that have been newly found and analyzed. All Nakhlites appear to have been derived from an isotopic uniform reservoir, and share a well-defined "young event" age of 1.25 Ga. Of particular note is the fact that their initial Pb isotopic composition does not plot on the modern geochron, but instead to the right of it. If experiencing only a single stage evolution prior to 1.25 Ga, its initial Pb should actually plot on a fossilized 1.25 Ga geochron considerably to the left of the modern geochron. Only a relatively recent increase of the U/Pb ratio in the Nakhlite reservoir could explain the higher $^{206}Pb/^{204}Pb$ value. It is interesting to notice that the initial Pb from the olivine Shergottites, Sayh al Uhaymir 008 and Yamato 980459, plot close to that of the Nakhlites, although the petrographically similar Dar al Gani 476 is so altered and contaminated by terrestrial Pb that a meaningful initial Pb isotopic composition cannot be determined. Allowing for the different age for these olivine-bearing Shergottites, they might actually come from the same isotopic reservoir. Furthermore, the ^{142}Nd and ^{82}W anomalies appear to be restricted to meteorites coming from this Nakhla source. Sr, Nd, and Pb isotopes also indicate that this reservoir was strongly depleted in large ion lithophile elements (LIL), such as U, Rb, Nd, and W, over most of its lifetime. Because the initial Pb isotopic composition has evolved to the right of the geochron, an increase of the U/Pb ratio, possibly accompanying magmatic activity, must have occurred at some intermediate time before the "young event" produced the Nakhlites at 1.25 Ga.

Accepting Mars as the source of SNC meteorites, we may speculate on what was the surface expression of the isotopically-manifested petrogenetic processes. Shergotty, Zagami, and Los Angeles might be typical Martian crustal rocks, and the "young event" could be impact related and have no further surface expression. Hence, that crust could be ancient and possibly even 4.55 Ga old.

Nakhlites, with their unique exposure age and isotopic uniformity, may well all have come from a single, homogeneous mantle source. Olivine Shergottites, showing a similar isotopic composition to Nakhlites, although with different exposure ages, appear to have sampled basalts from the same widespread mantle source at a number of different places. These basalts are likely to be low viscosity surface lava flows of picritic composition, and in some cases those lavas might have assimilated crustal rocks (EETA 79001 [A], Dar al Gani 476). The age of such flows could be between 0.5 and 2 Ga with maximum volcanic activity occurring at about 0.8 Ga.

References: [1] Bouvier A. et al. (2005) EPSL **240**, 221-233; [2] Jagoutz E. (1991) Space. Science Rev. **56**, 13-22; [3] J. H. Chen and G. J. Wasserburg (1985) GCA **50**, 955-968;