**THE AGE OF TISSINT: Sm-Nd & Rb-Sr ISOTOPE SYSTEMATICS OF A MARTIAN METEORITE FALL.**

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**Introduction:** The recently acquired meteorite Tissint is the first recognized fall of a depleted shergottite. Other such shergottites were found in the hot deserts (e.g., NWA 1195, Dhofar 019, DAG 476) or in the Antarctic cold desert (e.g., QUE 94201, Y980459) and, in many cases, have disturbed isotopic systematics due to terrestrial contamination [1-4]. Tissint represents the freshest sample of this important group of martian meteorites and thus provides an unprecedented opportunity to study pristine material derived from the depleted martian mantle. This work investigates the $^{87}$Rb-$^{87}$Sr, $^{147}$Sm-$^{143}$Nd and $^{146}$Sm-$^{142}$Nd systematics of Tissint to determine its crystallization age and to assess the nature of its source regions by comparison to other known martian meteorites.

**Samples and Methods:** Multiple whole-rock samples, their leaches and residues, and mineral separates from Tissint were used in this study, with the specifics of each fraction given below. Samples were digested, spiked with $^{149}$Sm-$^{150}$Nd and $^{87}$Rb-$^{84}$Sr tracers and analyzed for Rb-Sr and Sm-Nd isotope systematics following previously established procedures [5].

*Mineral separates.* Approximately 1.8 grams of fresh interior material was rinsed in ultrapure $H_2O$ then gently crushed and sieved. Mineral separation was performed employing a combination of magnetic separation, followed by extensive hand picking for further purification to remove the significant melt glass component and isolate individual mineral phases of Tissint. The resulting fractions: Non-Mag (56 mg), Mag-1 (214 mg), Mag-2 (309 mg), Mag-3 (311 mg), Olivine Macrocrysts (63 mg), and Melt Glass (117 mg) were leached in 0.5N HCl for 5 minutes prior to dissolution and chemistry.

*Whole-rock aliquots.* Three true whole-rock aliquots: WR-1 (531 mg), WR-2 (245 mg), and WR-3 (460 mg), as well as the fine powder collected after crushing and sieving for mineral separation, designated "Fines" (508 mg), represent various samples of bulk Tissint. All bulk samples of Tissint were washed with ultrapure $H_2O$ to remove any surface contamination and then were crushed into a powder. The Fines fraction and WR-1 were leached for 5 minutes with 0.5N HCl. The leachates (Fines-L, WR-1L) and the remaining residues (Fines-R, WR-1R), along with the unleached whole-rock samples WR-2 and WR-3 were then completely dissolved prior to chemistry.

**Results and Discussion:**

*Sm-Nd Isotopics*. The WR-1L, WR-1R, and WR-2 fractions lie on a tie-line, which we interpret to represent an isochron with a preliminary $^{147}$Sm-$^{144}$Nd age of 596±23 Ma (Fig. 1). Additionally, an initial $\varepsilon^{143}$Nd=+41.9±0.53 is calculated from the whole rock tie-line, indicating a close relationship between Tissint and QUE 94201. These samples are derived from sources with nearly identical $^{147}$Sm/$^{144}$Nd ratios (0.279 for Tissint versus 0.284 for QUE 94201 [6]). Whereas the age of Tissint is most similar to that reported for Dhofar 019 (586±9 Ma; $\varepsilon^{143}$Nd=+34.6±0.6 [2]), the initial $\varepsilon^{143}$Nd values indicate that the source regions for these two meteorites are similar, but isotopically distinct. Data collection from Tissint mineral separates is currently in process.

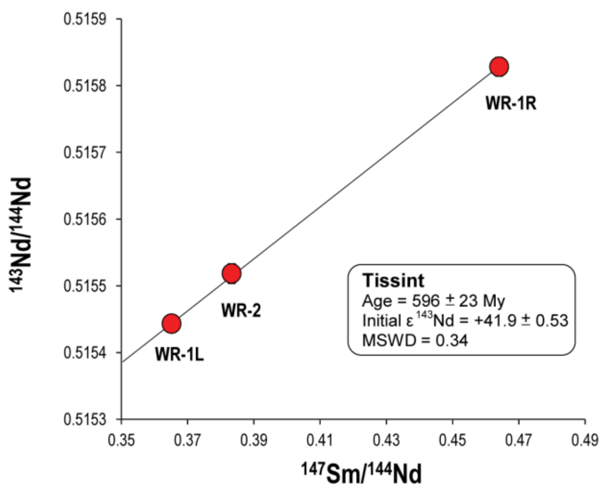


Fig. 1 – The $^{147}$Sm-$^{143}$Nd isochron showing the completed samples of this study, producing a preliminary age of 596±23 Ma.

Initial $\varepsilon^{142}$Nd values have currently been obtained for WR-1L (+0.82±0.07) and WR2 (+0.90±0.49) and are in agreement with previous work on depleted shergottites that demonstrate resolvable $^{142}$Nd excesses in whole-rock samples indicative of source region formation at ~4525 Ma [3, 6]. Combined $^{142}$Nd data from enriched, intermediate, and depleted shergottites produces a whole-rock isochron that provides additional constraints on the age of basalt source regions, as shown in Fig. 2. This age is slightly younger (~10 Ma) than previous estimates [3, 6], because it is defined by more high precision data points analyzed as part of this study. These include Tissint, Los Angeles, NWA 4468, and NWA 1066.

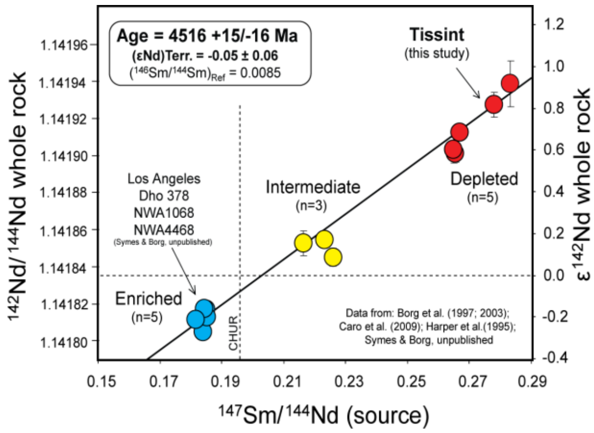


Fig. 2 – A whole-rock isochron plotting the various shergottite subgroups. Data from [3, 6-9] and this study.

It has been argued that the young internal isochrons determined on the shergottites are disturbed and that the ancient (~4.3 Ga) Pb-Pb ages determined on these samples represent their true crystallization ages [e.g. 10]. Although we are skeptical of this interpretation, the $^{146}$Sm-$^{142}$Nd system may provide an unequivocal test of this hypothesis. An ancient age would be supported by a positive correlation between $^{142}$Nd/$^{144}$Nd and $^{147}$Sm/$^{144}$Nd in the Tissint mineral and whole rock fractions due to the decay of extant $^{146}$Sm to $^{142}$Nd. If such a correlation is found, the data will indicate the sample crystallized at a time when the short-lived $^{146}$Sm was extant ($\gtrsim$4250 Ma). If no positive correlation is present, this data will not support the possibility that Tissint is derived from material that crystalized at a time when a quantifiable amount of extant $^{146}$Sm was present. Thus, it would be in agreement with the Rb-Sr and $^{147}$Sm-$^{143}$Nd systems of other shergottites.

*Rb-Sr Isotopics*. The Rb-Sr isotope system does not yield an isochron for the Tissint samples measured so far (Fig. 3). We suspect that this reflects disturbance of the Rb-Sr system by secondary processes occurring on Mars. The sample, and fractions we analyzed, are particularly susceptible to disturbances due to the low abundances of high Sr igneous phases (plagioclase) and the high abundances of impact melt in the whole rock. However, using the Rb-Sr systematics of WR-1R and the preliminary Sm-Nd isochron age, we calculate an initial $^{87}$Sr/$^{86}$Sr = 0.700739±10. This initial $^{87}$Sr/$^{86}$Sr ratio is resolvably lower than for other depleted shergottites (Fig. 4). This suggests that the Tissint parent melt was derived from a distinct martian mantle source characterized by the lowest Rb/Sr, and by inference, the lowest incompatible lithophile element abundances, of any martian meteorite analyzed so far. Data collection from mineral separates with the melt glass portion removed is currently in process.

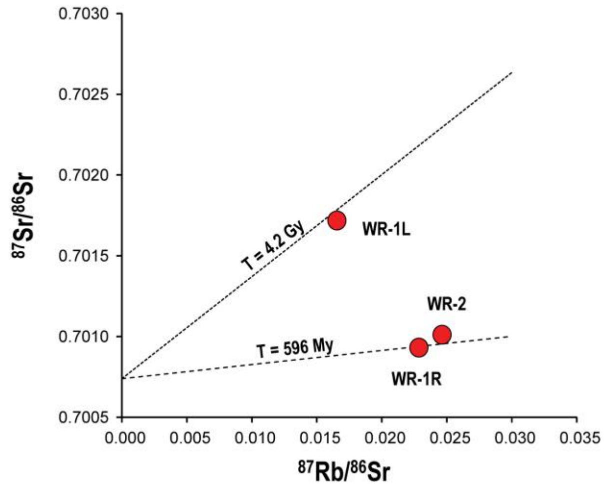


Fig. 3 – The Rb-Sr isotopics of Tissint, showing the Sm-Nd reference isochron of 596 My and a 4.2 Gy reference isochron. The Rb-Sr system does not provide meaningful age information for the samples that have been measured at present.

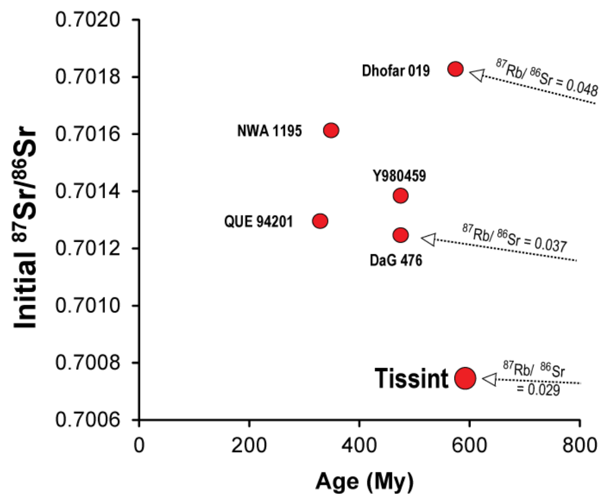


Fig. 4 – The initial $^{87}$Sr/$^{86}$Sr ratios of multiple depleted shergottites plotted against the age of each sample. Plotted evolution lines indicate the calculated starting composition of the parent melt of each meteorite and its relationship to each sample, where closely related samples lie on the same evolution line. Literature data are taken from [1-4, 6].

**References:** [1] Symes et al. (2008) *GCA* 72:1696–1710. [2] Borg et al. (2001) *LPSC* Abstract #1144. [3] Borg et al. (2003) *GCA* 67:3519–3536. [4 ]Shih et al. (2004) *LPSC* Abstract #1814. [5] Borg et al. (2011) *Nature* 477:70–72. [6] Borg et al. (1997) *GCA* 61: 4915-4931. [7] Harper et al. (1995) *Science*, **267**:213–217. [8] Caro et al. (2008) *Nature* **452**: 336–339. [9] Symes and Borg, unpublished. [10] Bouvier et al. (2009). *EPSL* **280**: 285–295. This work was performed under the auspices of the US Department of Energy by Lawrence Livermore National Laboratory under contract number DE-AC52-07NA27344.