KEEPING UP WITH THE MARTIAN METEORITES AND CONSTRAINING THE NUMBER OF SEPARATE LAUNCH SITES ON MARS. A. J. Irving[1], S. M. Kuehner[1], T. J. Lapen[2], M. Righter[2], H. Busemann[3], R. Wieler[3] and K. Nishiizumi[4] [1]Dept. of Earth & Space Sciences, University of Washington, Seattle, WA (irvingaj@uw.edu), [2]Dept. of Earth & Atmospheric Sciences, University of Houston, TX, [3]Inst. für Geochemie & Petrologie, ETH Zürich, Switzerland, [4]Space Sciences Laboratory, University of California, Berkeley, CA.

Introduction: Since our last summary of the diversity of Martian meteorites in 2015 [1], many more specimens (almost all from Morocco and elsewhere in northwestern Africa) have been studied and classified, bringing the total of evidently unpaired specimens to 101. The term "unpaired" refers here to single meteorites (or groups of stones from a single find site) with distinct petrologic and/or chemical characteristics, or which are judged to not be part of the same fall as others based on measured terrestrial residence ages. Among those specimens with shared characteristics, evidence from cosmogenic nuclides implies, however, that members of some groups of stones that are launch-paired fell to Earth at very different times [e.g., 2-4]. Based on current finds we infer that the number of separate ejection events from Mars could be as few as 20.

Nomenclature Issues: As more diverse types of Martian meteorites have been recovered, inevitably it has become necessary to revise the nomenclature used to describe them. Whereas the classic terms chassignite, nakhlite and shergottite remain in use, the subdivisions within the shergottites (by far the largest group with now some 87 members) has required modification. The nomenclature for shergottites adopted here is the tripartite scheme of [5, 6] based on textures (determined largely by cooling rates), ITE/isotopes (signifying distinct mantle sources) and major elements (specifically *mg* versus CaO, signifying degree of magmatic evolution). Although the unique specimen Allan Hills 84001 is reasonably described as an orthopyroxenite, it has become apparent that another unique group of stones including NWA 7034 from Rabt Sbayta, Morocco represents a Martian polymict regolith breccia.

Principles for Assessing Different Launch Sites on Mars: In attempting to constrain the number of separate launch sites for the 101 Martian meteorites, we have been guided by the following principles:

(1) It seems implausible that specimens with very different incompatible trace element (ITE) and/or related daughter isotopic compositions could have been emplaced above a common mantle reservoir, and thus should not be present together in a single launch volume. Since 2000 (when the total number of known Martian meteorites was only 24!), the vast majority of shergottite specimens has still been assignable to just three robustly separate ITE/isotopic groups (depleted, intermediate, enriched), and only NWA 4480 has been found to possess a different isotopic signature [7].

(2) Specimens with different ejection ages (sum of 4π exposure age+terrestrial residence age) obviously cannot have been launched from Mars in the same event. However, it is also true that specimens with the same ejection age were not necessarily launched together.

(3) Among shergottites with common ITE signatures and/or ejection ages, it may be possible to distinguish separate target rock volumes on the basis of very different igneous rock textures (e.g., olivine-phyric versus poikilitic). Yet, since the textures are predominantly a function of magmatic cooling rate, assignments based on them are necessarily more subjective.

(4) Crystallization age may seem like a reasonable criterion for discriminating among some launch sites, but the apparent longevity of igneous activity at some locations on Mars (e.g., the Tharsis volcanoes) diminishes the utility of crystallization age alone as a criterion.

We arrived at the launch groupings proposed below by *combined* application of these principles based on current data (which are incomplete for some specimens). Some of these assignments may require change as new information (and new specimens) become available.

Nakhlites and chassignites: The nine nakhlites (including NWA 10153 [8] and several pairings) and three chassignites (including NWA 8694 [9]) appear to constitute a single group based on petrologic features, crystallization ages and ejection ages, although perhaps NWA 5790/6148 was launched independently [see 3].

Allan Hills 84001 orthopyroxenite: A unique specimen in terms of petrologic and multiple age criteria.

Regolith breccia from Rabt Sbayta: NWA 7034, NWA 7475, NWA 7533 and paired stones are distinctive in many ways, and their 4.4 Ga zircons may signify a southern hemisphere launch site [10].

Depleted shergottites launched 1.1 Myr ago: At least 18 unpaired specimens (dominantly olivine-phyric and including Tissint, NWA 7635, NWA 8159, NWA

10416, NWA 10693) evidently were launched together [2-4], potentially from a site on Tharsis [see 11].

Dhofar 019: The long cosmic ray exposure (CRE) age (20 Myr) of this depleted, olivine-phyric shergottite is unique, as are some of its petrologic features [12].

QUE 94201, NWA 5990 and NWA 7032/7272: These three depleted specimens share many chemical and age characteristics (e.g., ~3.3 Myr CRE ages [3] and 325-400 Ma crystallization ages), although texturally they range from diabasic to microgabbroic [6, 13, 14].

NWA 4480: The only known shergottite with entirely unshocked plagioclase instead of maskelynite, plus a unique ITE signature and CRE age (~16 Myr) [7].

Intermediate poikilitic shergottites: At least 14 unpaired specimens broadly similar to ALHA 77005 are now known and share similar young crystallization ages and older ejection ages. Most are truly ultramafic, but some (NWA 1950 [15], NWA 2646) are permafic with >10% maskelynite. More recent members include NWA 10697, ?NWA 10808 and NWA 10961 [16].

EETA 79001: This intermediate shergottite stone containing both olivine-phyric and aphyric lithologies in contact has a unique ejection age (0.6-0.7 Myr [17]).

NWA 10567: Two stones found together have a microgabbroic texture (see below), intermediate ITE signature (sample #66.1 [1]), and a CRE age of ~4.5 Myr.

Polished slice of NWA 10567 (photo by A. Habibi)

NWA 480/1460 and NWA 5029: Intermediate olivine-free diabasic shergottites [18, 19] with a moderately old crystallization age of 340 Ma for NWA 1460 [18].

NWA 7042: A possibly unique intermediate olivine-bearing shergottite with intersertal texture [14] and a 2.9 Myr ejection age [3].

NWA 8705: Probably a unique intermediate olivine-phyric shergottite [1] with a 1.7 Myr CRE age.

Intermediate gabbroic shergottite NWA 10761: A coarse grained, relatively ferroan specimen with a CRE age of ~3.7 Myr.

Enriched olivine-free mafic shergottites: At least 26 specimens including Shergotty, Zagami, NWA 8656, Yamato 002192/002712 [20], NWA 10134 [21], NWA 10281, ?NWA 10299 [22], NWA 10414 [23] and NWA 10558. Textures range from fine-grained aphyric to pigeonite-phyric to diabasic to microgabbroic (NWA 8637 [1]). Those already dated have young crystallization ages, but the range in ejection ages from ~2-5 Myr implies that multiple launches were involved. Different Hf isotopic compositions for Los Angeles, NWA 856 and NWA 7320 also may set those apart.

Enriched olivine-phyric shergottite NWA 1068/1110: This meteorite [24] may be a primitive member of the main enriched group, with similar crystallization and CRE ages, but it is texturally unique.

Enriched poikilitic shergottites NWA 4468, RBT 04261/62, NWA 7397 and NWA 10618: Poikilitic textures [25, 26, 27] and long CRE ages (3-4 Myr) may serve to distinguish these olivine-bearing specimens.

References: [1] Irving A. et al. (2015) *LPS* **XLVI**, #2290 [2] Nishiizumi K. et al. (2011) *LPS* **XLII**, #2371 [3] Wieler R. et al. (2016) *MaPS* **51**, 407-428 [4] Lapen T. et al. (2017) *Science Advances* (in press) [5] Irving A. et al. (2010a) *LPS* **XLI**, #1547 [6] Irving A. et al. (2010b) *LPS* **XLI**, #1833 [7] Irving A. et al. (2016) *LPS* **XLVII**, #2330 [8] Irving A. et al. (2015) *78th Meteorit. Soc. Mtg.*, #5251; Mikouchi T. et al. (2016) *79th Meteorit. Soc. Mtg.*, #6396 [9] Hewins R. et al. (2015) *LPS* **XLVI**, #1365 [10] Agee C. et al. (2013) *Science* **339**, 780-785; Humayun M. et al. (2013) *Nature* **503**, 513-516; Wittmann A. et al. (2015) *MaPS* **50**, 326-352 [11] Irving A. & Lapen T. (2016) *79th Meteorit. Soc. Mtg.*, #6454 [12] Taylor L. et al. (2002) *MaPS* **37**, 1107–1128 [13] McSween H. et al. (1996) *GCA* **60**, 4593-4569; Warren P. et al. (1999) *GCA* **63**, 2105-2122 [14] Irving A. et al. (2012) *LPS* **XLIII**, #2496 [15] Gillet P. et al. (2005) *MaPS* **40**, 1175-1184 [16] Irving A. et al. (2017) *LPS* **XLIX**, this conf. [17] Herzog G. & Caffee M. (2014) *Treatise on Geochem., 2nd Ed* [18] Nyquist L. et al. (2009) *GCA* **73**, 4288-4309 [19] Mikouchi T. & Barrat J.-A. (2009) *72nd Meteorit. Soc. Mtg.*, #5344 [20] Mikouchi T. & Takenouchi A. (2016) *LPS* **XLVII**, #2456 [21] Tait K. et al. (2015) *78th Meteorit. Soc. Mtg.*, #5303 [22] Jean M. et al. (2016) *LPS* **XLVII**, #2698 [23] Hewins R. et al. (2016) *LPS* **XLVII**, #1898 [24] Barrat J.-A. et al. (2002) *GCA* **66**, 3505-3518; Shih C.-Y. et al. (2003) *LPS* **XXXIV**, #1439 [25] Irving A. et al. (2007) *LPS* **XXXVIII**, #1526 [26] Usui T. et al. (2010) *GCA* **74**, 7283-7306 [27] Huber L. et al. (2013) *LPS* **XLIV**, #1534.