THE EJECTION SITE OF NORTHWEST AFRICA 7034 REVEALED BY 90 MILLION IMPACT CRATERS. A. Lagain[1*], S. Bouley[2], B. Zanda[3], K. Miljković[1], A. Rajšić[1], D. Baratoux[4], V. Payré[5], L. S. Doucet[6], N. E. Timms[1] R. Hewins[3], G. K. Benedix[1], V. Malarewic[3], K. Servis[7], P. A. Bland[1]. [1]Space Science and Technology Centre, School of Earth and Planetary Science, Curtin University: Perth, Australia. [2]Université Paris-Saclay, CNRS, GEOPS: 91405, Orsay, France, [3]Institut de Minéralogie, de Physique des Matériaux et de Cosmochimie (IMPMC), Muséum national d'Histoire naturelle, Paris, France, [4]University Félix Houphouët-Boigny, UFR Sciences de la Terre et des Ressources Minières: Abidjan-Cocody, Côte d'Ivoire. [5]Department of Astronomy and Planetary Science, Northern Arizona University: Flagstaff, Arizona, USA, [6]Earth Dynamics Research Group, TIGeR, School of Earth and Planetary Sciences, Curtin University: Perth, Australia, [7]Pawsey Supercomputing Centre, CSIRO: Kensington, WA, Australia. *anthony.lagain@curtin.edu.au

Introduction: The geological record of the formation and differentiation of our planet has been destroyed by its subsequent evolution, but extremely rare clues may be obtained from other terrestrial planets. Mars provides a unique and accessible example of an early evolutionary path corresponding to that, inaccessible, of our own world. We can investigate it with spacecraft, and samples are available for in-depth analysis on Earth in the form of martian meteorites. So far, the only available martian samples that appear to have recorded the early conditions and the evolution of the planet until the present time are Northwest Africa (NWA) 7034 and its paired stones, nicknamed "Black Beauty".

This regolith breccia has been ejected a few million years ago by the formation of a large impact crater, and contains the oldest martian igneous material ever dated: ~4.5 Ga old [1-4]. However, its source and geological context have so far remained unknown. and with it, a region where the earliest geological records of the planet [1-4] are exposed on the surface. Knowing this source region would provide insights into early Mars geological history and crustal extraction [1-4]. This source region may therefore become a high-priority target for detailed orbital analyses and in-situ exploration [5].

Constraints on the meteorite launch site: Following a hypervelocity impact, ejecta materials moving faster than the escape velocity (5 km/s) may get through the martian atmosphere and continue their course into interplanetary space to become martian meteorites [6]. Slower debris fall back on the surface in a radial pattern or ray around the primary crater, forming secondary craters. The presence of 100 meter-size secondaries attests to the freshness of their associated primary craters [7]. Using the size and spatial distribution of more than 90 million impact craters >50 m (both primaries and secondaries) detected using a Crater Detection Algorithm (CDA) [7-8] on the whole surface of Mars from the global Context Camera (CTX) mosaic [9], our previous work [7] identified ray systems of secondary craters <150 m associated with 19 large primary craters, potential source of the ejection of martian meteorites.

Here we compare the abundance of K and Th [10-11] as well as the magnetic field intensity and the magnetization of the surface of Mars derived from orbital measurements [12] at the immediate vicinity of each crater candidate with those of the breccia. We also compare the geological context of each of the crater candidates with the chronology and the lithology of the meteorite [e.g. 1-3, 13-14].

Specifically, this meteorite contains a variety of igneous, sedimentary, and impact melt clasts, including the most evolved and oldest igneous clasts and zircons (4.44 – 4.48 Ga) [e.g., 2]. These old evolved clasts have most likely been excavated by an impact event during the Early Amazonian period, ~1.5 Ga ago, before being lithified and ejected ~5 Ma ago [e.g., 1,3]. Moreover, this meteorite is characterized by elevated concentrations in potassium and thorium as well as an unique magnetic signature compared to any other martian meteorite. These unique characteristics allows to define the following criteria to constrain the impact crater responsible for its ejection: (1) high magnetic field intensity and remanent magnetization at the surface, (2) high elemental Th and K concentrations of the areas surrounding each crater candidate, (3) superposition on a Noachian geological unit, and (4) connection with material from an Early Amazonian impact.

The ejection site of NWA 7034: Among the 19 crater candidates investigated, we found that only one match with the characteristics of the meteorite. The oldest clasts of NWA 7034 and paired stones were excavated ~1.5 Ga ago by an impact that has formed a 40 km crater (Khujirt, in blue on Fig.1) located in the north-east of the Terra Cimeria – Sirenum (TCTS) region, between Hesperia Planum and the Tharsis bulge. The ejecta material of this crater were subsequently ejected by a second impact occurring ~30 km away from the rim of Khujirt crater, a few million years ago, which led to the formation of a 10 km crater, Karratha (156°W, 16°S, in orange on Fig.1).

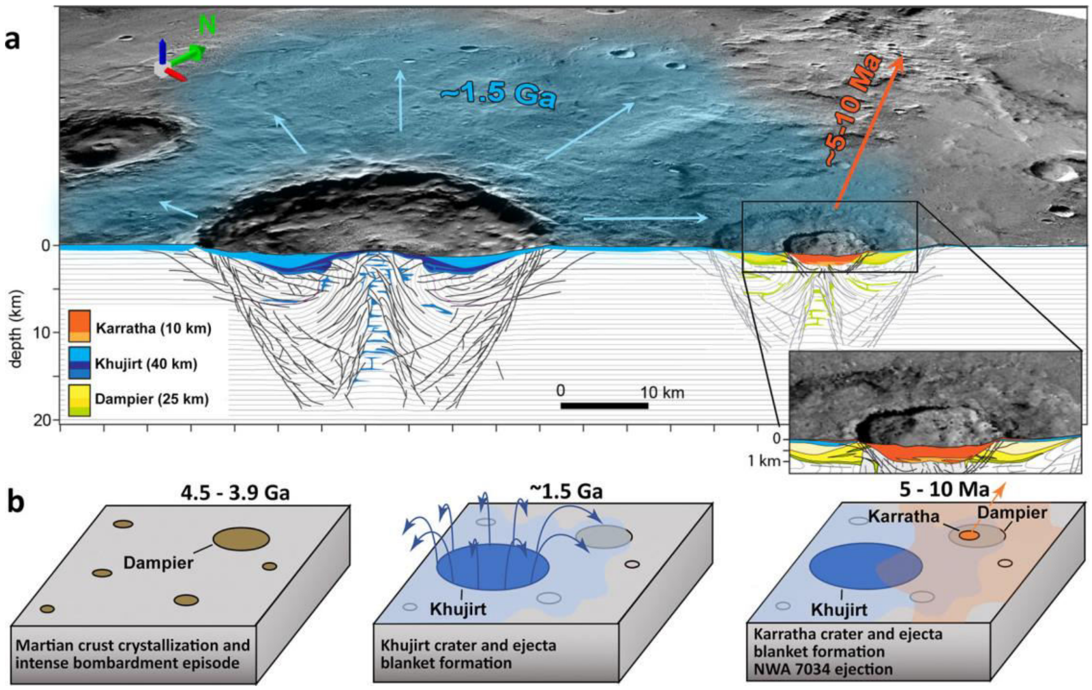

Fig.1 The NWA 7034 launch site geological context. a Perspective view (Context Camera mosaic [9]) and cross-section through Karratha along a SW-NE axis as interpreted from numerical modelling simulations [16]. Shades of colors denote impactites (impact melt and in situ breccia; ejecta and fall-back breccia). b Schematic of chronological events experienced by the host terrain of the regolith breccia.

Conclusion: Our work suggests that clasts contained in the regolith breccia are representative of the TCTS province, making this region a relic of the early crustal processes on Mars [e.g., 15], and thus, a region of high interest for future missions. This province covers about 10% of the planet and has been interpreted as a crustal block characterized by a geochemically evolved component [15]. Its distinct formation and evolution possibly reflect the first stage of differentiation occurring very early in the history of Mars.

The study of TCTS would help us unravel the conditions of formation and the first evolution stage of Mars, and by extension of all terrestrial planets, considering the fact that, in light of these findings, early crustal processes appear uniquely preserved and accessible on Mars. The flanks and central peaks of large and preserved craters within this region might constitute outcrops of high interest, containing the missing geological clues to the early-stage evolution of the planet.

Details on the identification of the crater source of this unique meteorite, as well as its geological context and broader implications for early crustal processes on Mars [16] will be presented at the conference.

Acknowledgments: This research was funded by the Australian Research Council grants DP170102972, DP210100336, DP180100661, DE180100584, and FT210100063, Curtin University, the Western Australian Government, and the Australian Government.

References: [1] Udry, A. et al. (2020) *Journal of Geophysical Research: Planets,* 125, e2020JE006523. [2] Bouvier, L. C. et al. (2018), *Nature* 558, 586–589. [3] Goodwin, A. et al. (2022) *Astrobiology*, ahead of print. [4] Costa, M. M. et al. (2020), *Proceedings of the National Academy of Sciences* 117, 30973-30979. [5] Rapin, W. et al. (2021) *Bulletin of the AAS*, 53(4). [6] Artemieva, N. & Ivanov, B. (2004), *Icarus* 171, 84-101. [7] Lagain, A. et al. (2021), *Nature Communications* 12, 6352. [8] Benedix, G. K. et al. (2020) *Earth and Space Sciences*, 7, e2019EA001005. [9] Dickson, J. L. et al. (2018) *49th Lunar and Planetary Science Conference*, Abstract #2480. [10] Boynton, W. V. et al. (2009), *Journal of Geophysical Research* 112, 12-99. [11] Taylor, G. J. et al. (2007) *Journal of Geophysical Research* 112, 03–10. 27. [12] Langlais, B., et al. (2019), *Journal of Geophysical Research: Planets* 124, 1542-1569. [13] Humayun, M. et al. (2013), *Nature* 503, 513-516. [14] McCubbin, F. M. et al. (2016), *Journal of Geophysical Research: Planets* 121, 2120-2149. [15] Bouley, S. et al. (2020), *Nature Geoscience* 13, 105-109. [16] Lagain, A. et al. (2022), *Nature Communications* 13, 3782.