A LATE MARTIAN DYNAMO CESSATION TIME 3.77 GY AGO. B. Langlais[1], E. Thébault[2], É. Ostanciaux[3] and N. Mangold[1], [1]Laboratoire Planétologie Géodynamique Nantes, CNRS/Université Nantes, 2 rue de la Houssinière, 44322 Nantes, France, benoit.langlais@univ-nantes.fr; [2] Équipe Géomagnétisme, CNRS/Institut de Physique du Globe de Paris, 75252 Paris, France; cedex 5, France; [3] Géosciences Rennes, CNRS/Université de Rennes 1, 35042 Rennes, France

Introduction: Several global models ([1] and references therein) of the martian lithospheric magnetic field and/or of its associated magnetization depict similar first-order characteristics. Intense, localized magnetic anomalies are found in the southern hemisphere, while the northern lowlands, as well as the giant basins and the largest volcanic provinces are devoid of significant anomalies [2]. It was concluded that these structures were formed while the dynamo was not active. A cluster of giant basins, similar in age [3], was found with very different magnetic signature, and interpreted as an evidence that the Martian dynamo cessation occurred during the early Noachian between 4.115 and 4.13 Gy [4]. This timing is however incompatible with the magnetic signatures recorded over younger and smaller impact and younger structures.

In this study we reconsider the problem of timing the cessation of the dynamo by characterizing the magnetic field (at MGS altitude) inside and outside craters larger than 200-km in diameter. We use the results of theoretical computations [5], which predict that 200-km diameter demagnetized impact basins possess magnetic signatures of the order of 1 nT at 400-km altitude. This implies that such craters can be characterized provided that the magnetic measurements are carefully selected. Our crater database is mainly based on the planetary nomenclature and on the Barlow's catalog [6]. We complete our study with six Noachian volcanoes. We then compare our results to a time line for these structures.

Data and method: Magnetic measurements acquired during the MGS Mapping Orbit cycles are used. We restrict our study to the last martian year of the MGS mission because this epoch is closer to the last solar minimum that occurred in 2008-2009. Only night side measurements are considered. Our selected measurement data set is further subdivided into four groups, each one representing one season of the martian year. Each crater is therefore characterized using three independent data sets which are used to infer the error associated with the statistics we derived.

Magnetic measurements (Fig. 1a) are selected inside and outside (up to one radius) rims for each crater and for each of the four martian seasons. Measurements are then averaged onto 0.25°x0.25°bins to minimize small spatial scale variations. Three values are finally computed, the mean intensity inside (B_{in}) and outside (B_{out}) the crater rim, and the ratio of these two quantities (B_{in}/B_{out}).

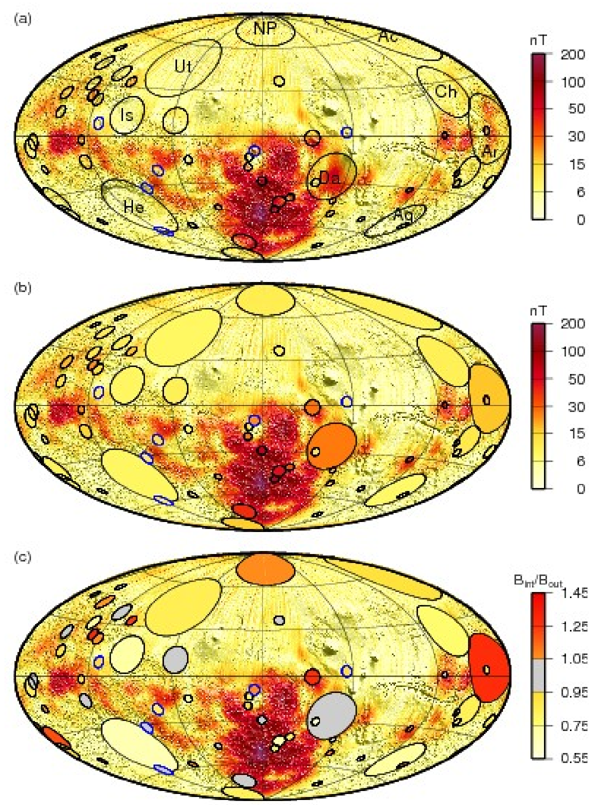

Fig. 1 (a) Magnetic field intensity as measured by MGS around 400-km altitude. Crater rims of the 55 largest basins are shown in black, and 6 volcanoes in blue. (b) Same as (a), but each crater (volcano) is associated with the mean magnetic field intensity inside its rim (within 200 km of its summit). (c) Same as (a) but each crater (volcano) is now associated with the ratio between the mean magnetic field inside its rim (within 200 km of its summit) and the mean magnetic field outside its rim up to one radius (200 km) away.

Results: We first compute B_{in} the mean magnetic field inside the crater rim (Fig.1b). With the exception of Ares and Daedalia as well as the two craters close to the South pole, none of the basins larger than 800 km have a mean magnetic signature exceeding 12 nT. Such craters and associated impact processes are however very likely to have excavated the entire pre-existing magnetized layer (if any), which was at that epoch between 20 and 40 km [7]. Currently the crust may be as thin as 7 km inside Hellas basins [8], possibly resulting from the alteration of exposed mantle rocks or from later filling of the basin interior. This layer may be too thin to produce a strong signature at spacecraft altitude. Null or weak magnetic signatures over basins larger than 800 km may thus be explained by the absence (or the limited presence) of magnetic material, rather than by the absence of magnetization due to the absence of a dynamo.

Most of the smaller basins located in the northern hemisphere, as well as those located between Argyre and Hellas display similar weak signatures. The mean field observed during the three independent time periods is very stable except for those polar craters. associated with weak magnetic fields. Only the craters located inside the highly magnetized regions of Terra Sirenum and Terra Cimmeria in the southern hemisphere are associated with a mean magnetic field larger than 30 nT.

We show in Fig.1c B_{in}/B_{out}. Most of the craters larger than 800 km in diameter display ratio lower than 1.0, except for Ares. The ratio associated which craters smaller than 800 km ranges between 0.64 (Koval'sky) and 1.30 (unnamed crater), with a limited number of craters associated with ratio larger than 1. All the craters located inside Terra Cimmeria and Terra Sirenum have magnetic fields weaker inside their rims than outside. Craters displaying more intense magnetic fields inside their rims are mostly located in Terra Sabaea and Arabia Terra. Comparison of the magnetic ratios with respect to the estimated and available surface ages of some basins [9] are shown in Fig. 2. Cassini (4.03 Gy), Newcomb (4.00 Gy), Schiaparelli (3.92 Gy) and Antoniadi (3.79 Gy) are the only dated basins with more intense magnetic field inside their rims. Based on these crater observations the dynamo did not stop before 3.79 Ga.

We now turn to volcanic structures. Apollinaris Patera is the only structure associated with a comparatively strong magnetic field and a B_{in}/B_{out} ratio significantly larger than 1. Amphitrites is associated with a very weak magnetic signal, and a ratio nearly equal to one. Close to Hellas basin, Hadriaca Patera has a similar magnetic field and ratio close to one. Tyrrhena Patera has a stronger signature (14 nT), but a weaker B_{in}/B_{out}, at 0.84. In the northern hemisphere, Syrtis Major and Biblis Patera have similar weak magnetic field values and B_{in}/B_{out} ratio close to 0.93. Only Apollinaris Patera (3.75 Gy [10]) is therefore positively magnetized. To the north-east, the formation of Lucus Planum was also identified as possessing a significant magnetic anomaly [11,12].

Conclusions: The analysis of the volcanic structures is very complementary to the results from the crater analysis. Both the magnetic signatures of the 250-to-800-km craters and volcanoes concur in a new magnetic time line on Mars. The dynamo was active when Apollinaris Patera was constructed and when Antoniadi was formed. The cessation of the dynamo very likely occurred before Syrtis Major and Biblis Patera were fully built and Lowell was formed. This narrows the timing of the dynamo cessation between 3.79 and 3.75 Gy model age.

Recent results based on impact crater morphology show that the regime of crater degradation by fluvial activity changed suddenly at 3.7 Gy [13]. This late timing is much more consistent with geological observations and a global climate change during the Early Hesperian than a dynamo cessation earlier than 4 Gy. This later-than-thought dynamo extinction provides an important constraint for the evolution of Mars. The new timing of the dynamo collapse, resulting in a shorter sputtering and atmosphere erosion period, has to be taken into account in hybrid simulations [14].

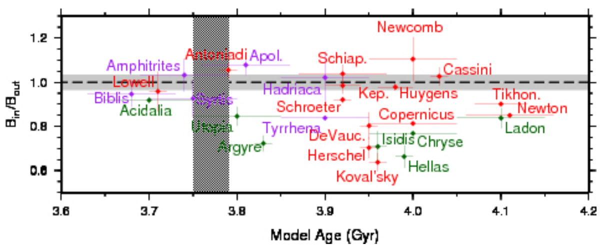

Fig. 2 Ratio of the mean magnetic field inside the rim to the mean magnetic field between 1 and 2 crater radii for those craters and volcanoes which were dated [9,10]. Green labels denote craters larger than 800 km. Purple labels denote volcanoes. Vertical gray area shows the dynamo cessation period.

References: [1] Langlais B. et al. (2010) *Space Sci. Rev.*, 152. [2] Acuña M. et al. (1999) *Science*, 284. [3] Frey H. (2008) *Geophys. Res. Lett.*, 35. [4] Lilis R. et al. (2008) *Geophys. Res. Lett.*, 35. [5] Langlais B. and Thébault E. (2011) *Icarus*, 212. [6] Barlow N. (1988) *Icarus*, 75. [7] McGovern P. et al (2004) *J. Geophys. Res.*, 109. [8] Neumann G. et al. (2004) *J. Geophys. Res.*, 109. [9] Werner S. (2008) *Icarus*, 195. [10] Werner S. (2009) *Icarus*, 201. [11] Langlais B. and Purucker M. (2007) *Planet. Spa. Sci.*, 55. [12] Hood L. et al. (2010) *Icarus*, 208. [13] Mangold N et al. (2012) *LPSC 43rd*. [14] Boesswetter A. et al. (2010) Planet. Spa. Sci. 58.

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