Improved understanding of magnetic signatures of basaltic lava flows and cones with implication for extraterrestrial exploration

PS 2.3

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Introduction

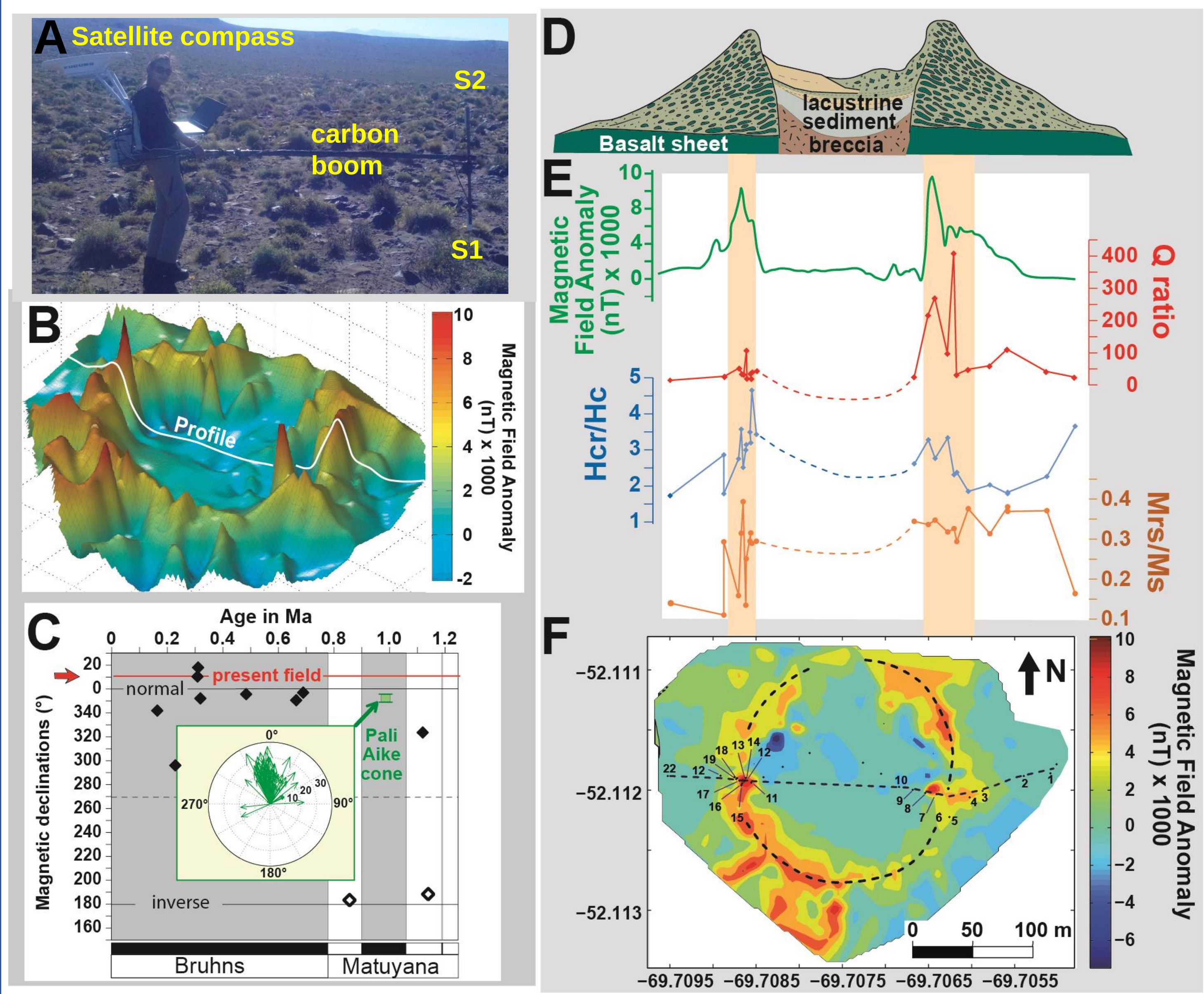
This work intends to understand the extremely variable and partly very pronounced magnetic anomalies of a basaltic cone as a terrestrial analogue of Mars, where very high remanent anomalies have been observed.

Basaltic rocks often show a very large range in magnetic intensities leading to regional anomalies associated to their mineralogical and chemical composition, cooling history and redox state during crystallization as well as exolution processes or oxide formations (e.g. olivine oxidation).

Such processes play an important role for crustal magnetic signatures on Earth and other planetary surfaces, like Mars or the Moon (e.g. Gunnlaugsson et al. 2006, Rasmussen et al. 2014, Filiberto et al. 2016).

The case of study concerns an agglutinated sputter cone from the Pali Aike Volcanic Field in Southernmost Chile. The selected crater is characterized by magnetic anomalies ranging from -6,000 to +8,000 nT. Highest values occur along the crater rim, while the crater floor, the outer flanks of the cone and the underlying and/or surrounding basalt sheets have weaker or negative anomalies (Diaz-Michelena et al. 2016).

1. Magnetic Surveys



A) Vector magnetometer and inertial system for oriented measurements; B) Magnetic anomalies of the crater and investigated profile; C) In situ measured paleo-orientations in its stratigraphic context (Diaz-Michelena et al. 2016); D) Idealized cross section with crater structure; E) Analyzed paleomagnetic data of the cross-section showing Q-ratio values (signature predominated by remanence), coercivity and magnetization of the remanence; F) Magnetic anomaly map with and localization of the samples.

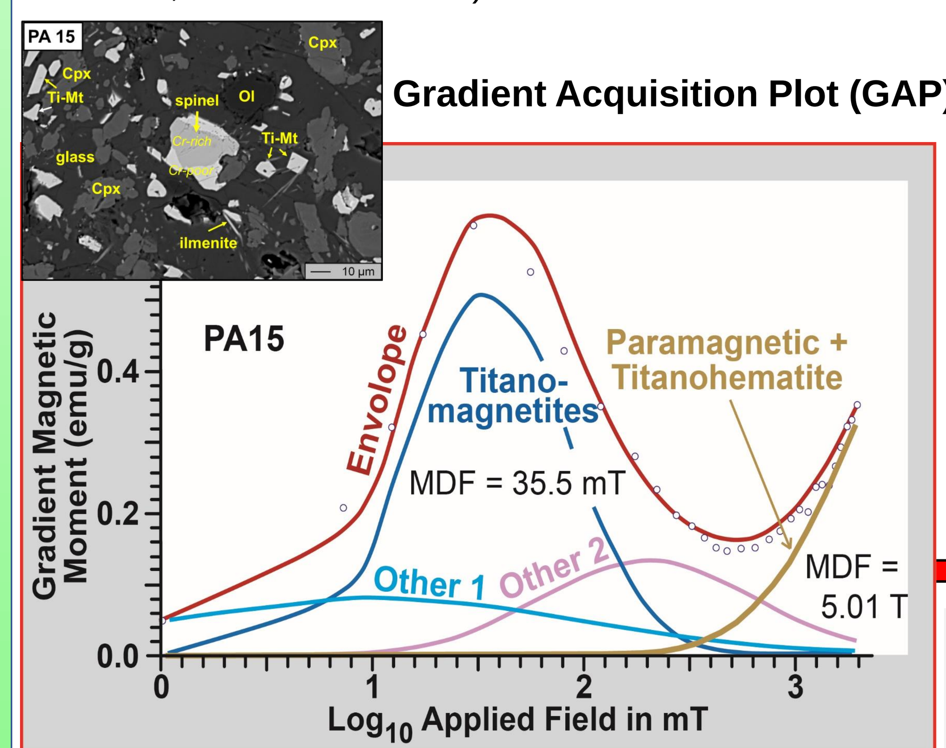
Objectives and methodology

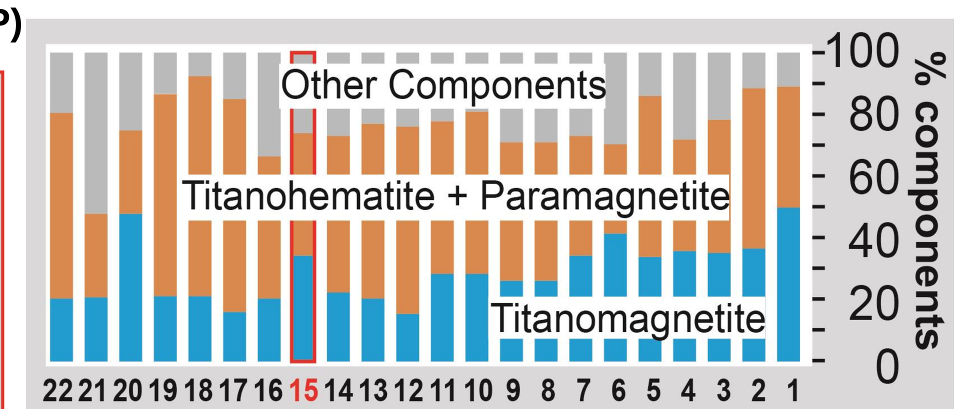
The main objective is to develop a methodology to achieve a better interpretation of future on ground geophysical characterization on - board planetary vehicles. The methodology is structured as follows:

1) In situ vector magnetic surveys and sample collection. This investigation allows having a preliminary magnetic signature of the crater. (Figures left below)
2) Laboratory analyses to improve the interpretation. These analyses involve two disciplines:
   a. Paleomagnetic analysis of collected samples performed at INTA and in the Complutense University of Madrid. (Figures below)
   b. Petrographical analysis performed at Göttingen University. (Figures on the right)
3) The experimental results are complemented with magnetic models which simulate the magnetic signature of the crater as a whole.

2. Paleomagnetic analysis

- NRM and susceptibility to calculate the Köningsberger ratios which show a predominant remanent magnetization of the rocks.
- Hysteresis loops for the Day plots to ascertain the grain size and the domain structure information.
- Coercivity spectrum based on Isothermal Remanent magnetization (IRM) to identify magnetic carriers (Tauxe, 2010, Kruvier et al. 2001).





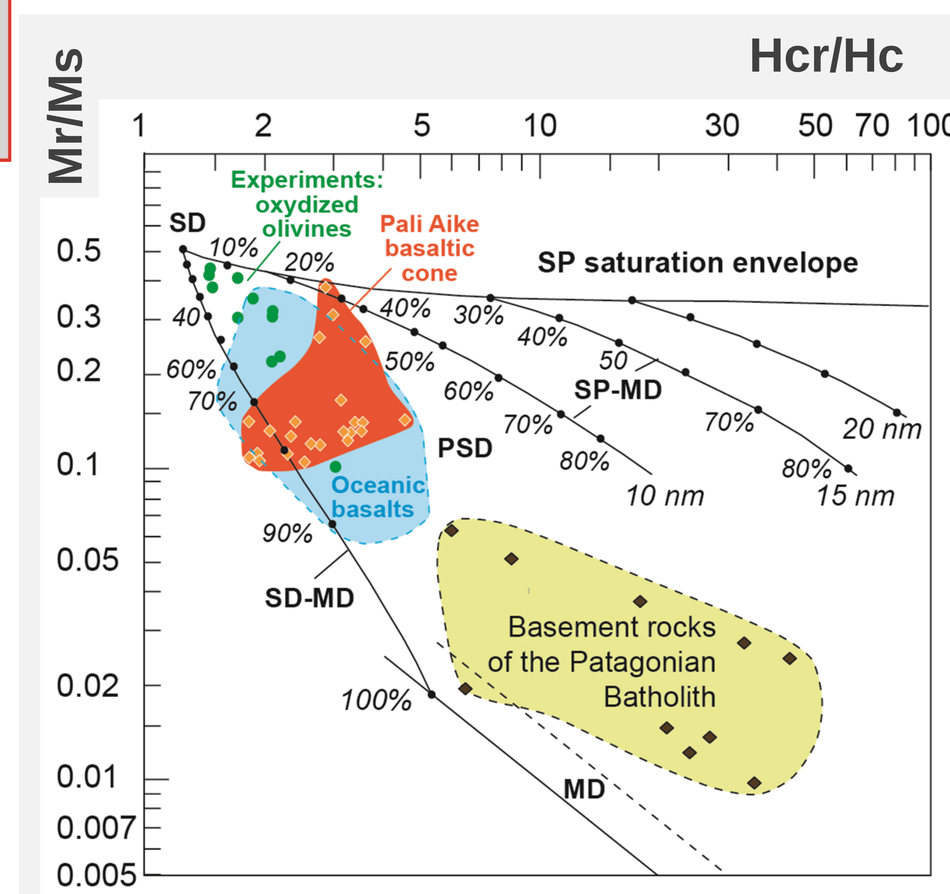
Example of IRM analysis (Sample PA 15) is shown in the figure above. All the studied samples have at least 4 magnetic carriers.

First component identified is titanomagnetite (Ti-Mt).

The second component represents probably a combination of a paramagnetic phase and titano-hematite, based on the trend of the curve and supported by the petrographic analysis (SEM photo in the upper left corner and the petrographic analysis, which show a significant amount of ilmenites and hematites).

The other components correspond to a minority composition and low magnetic moment (< 0.2 emu/g).

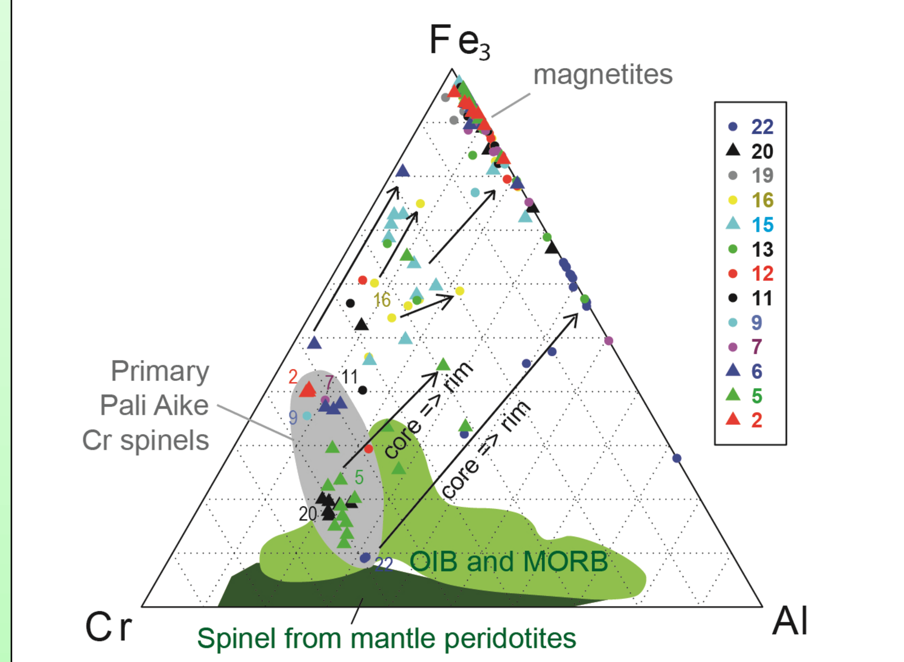
In the upper right figure the percentages of contribution of the different magnetic components are calculated for all investigated samples along the transect of the crater.



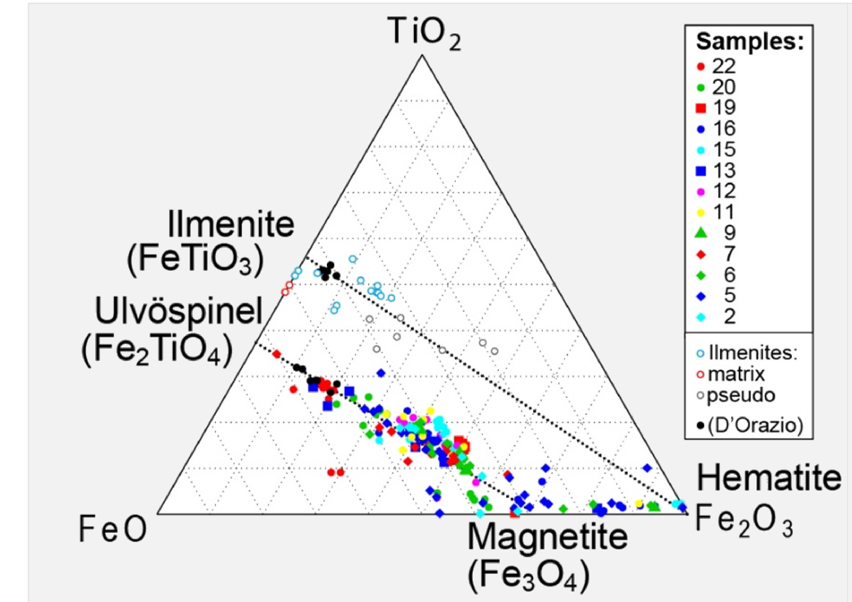
Day plot (Day et al. 1977) with the analyzed rock samples in between Single and Multidomain (SD and MD) and Pseudo Single Domain (PSD) areas. This is compatible with a content in MD Ti-Mt and some SD ones as an alteration product of the olivines. Green dots show experimental measurements of oxidized olivines forming nanoscale hematites (Filiberto et al. 2016). Basement rocks (Diaz-Michelena & Kilian 2015) and oceanic basalts (Dunlop 2002) are plotted for comparison.

3. Petrographical analysis

- Microprobe
- Back scatter electron image



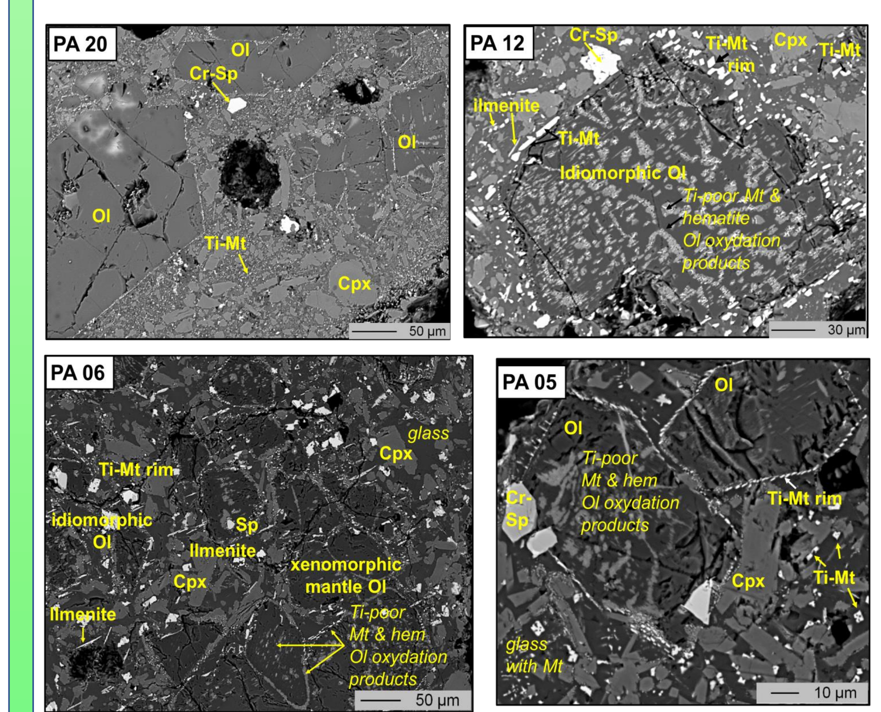
Fe^{3+}-Cr-Al ternary diagram for classification of the spinels measured in the samples of the PA crater:



Ternary FeO-Fe_2O_3-TiO_2 plot for classification of the investigated oxide phases. Black dots show Ilmenite-magnetite pairs with groundmass crystalization temperatures from 870 to 1090°C with oxygen fugacity ranging from −1.7 to −0.3 QFM log units (D'Orazio et al. 2000).

Primary Cr spinels and their chemical development from the crystal cores towards the crystal rims are illustrated (zoned Cr spinel). Spinels from other Ocean Island Basalts (OIB) and Mid Ocean Ridge Basalts (MORB; Roeder 1994) as well as spinel from mantle peridotites are shown for comparison (Moskowitz et al. 1998).

Back scatter electron images of the groundmass of basalt samples:



PA 20: Located westward from the crater rim (low magnetic anomaly). It contains partly unaltered (fresh) idiomorphic olivine (Ol) and sometimes only shows few Ti-poor Fe-oxidation products. The groundmass contains clinopyroxene (Cpx), chromium-spinel (Cr-Sp) and titanomagnetites (Ti-Mt) with sizes of 1 to 10 µm.

PA 12: Next to the highest magnetic anomaly. The idiomorphic Ol shows frequent micrometer to nanoscale Ti-poor Fe-oxidation products and it is rimmed by Ti-Mt. It also contains ilmenite in a low extent, as well as Cpx and Cr-Sp.

PA 06: Idiomorphic Ol with nanoscale Fe oxidation products as well as Cpx, Ti-Mt, Cr-Sp and glass. Also, needle-like and more frequent ilmenites show a common WSW to ENE orientation formed in a nearly solidified groundmass.

PA 05: Same composition as PA 06 except the xenomorphic Ol and ilmenite, with the idiomorphic Ol oxidation products.

Conclusions

The crater at the Pali Aike volcanic field has been proven as a very good analogue of Mars due to its highly variable and predominant remanent signature. The performed analysis including in situ oriented vector measurements, paleomagnetic and petrographic analyses provide a complete characterization. From these analyses it can be concluded that the magnetic signature is in particular sourced by nano-scale magnetites, an alteration products of the olivine, which seem to present a single domain structure with a relevant remanent magnetic moment as it has been considered to be important also on Mars (see references). Further magnetic carriers, like the ground mass titanomagnetites, contribute to the magnetic signature with an induced magnetization but this contribution is significantly lower.

The results obtained are a very good input for models which we are going to evolve.

Acknowledgements:

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