MAGMATIC INTRUSIONS BENEATH MARTIAN HIGHLAND VOLCANOES: CLUES FROM ERUPTIVE HISTORY, THERMAL-MAGNETIC-GRAVITY MODELING AND ELECTRON REFLECTOMETRY. R. J. Lillis[1], J. Dufek[2], W.S. Kiefer[3], L. Karlstrom[4], J.E. Bleacher[5],M. Manga[4], [1]UC Berkeley space sciences laboratory (rlillis@ssl.Berkeley.edu), [2]Georgia Tech Department of Earth and Space sciences, [3]Lunar and Planetary Science Institute, [4]UC Berkeley Department of Earth and Planetary Sciences, [5]NASA Goddard Space Flight Center

Introduction: Magmatic activity on Mars, just as on Earth, alters the magnetic properties of the crust. If a substantial enough volume of crust is magnetically altered to a sufficient degree, the magnetic field signature of the alteration should be visible even at orbital altitudes. As magnetic minerals are heated above their blocking temperatures, any prior magnetization is erased. As the crust cools, it acquires a magnetization proportional to the strength of the ambient magnetic field and the magnetic susceptibility of the mineral.

Martian crust which has been demagnetized by magmatic intrusion in the last ~4 Ga cannot have subsequently acquired, upon cooling, any substantial thermoremanent magnetization (TRM), due to the probable lack of a global magnetic field since then [1, 2]. Therefore when we examine orbital maps of crustal magnetic field, magmatic activity <4 Ga ago significant enough to cause thermal demagnetization on scales larger than the altitude of measurement, will result in reduced field amplitudes (without the terrestrial complications of induced magnetization, TRM or subtracting a global field).

Here we use magma intrusion modeling and stochastic magnetization modeling along with crustal magnetic field data at 185 km altitude from the Mars Global Surveyor Electron Reflectometer [3].

Modeling thermal demagnetization. We intrude magma stochastically as dikes and sills over 500 Ma into a half space using a 2-D finite volume method [4]. Intrusion is accommodated by extension or crustal thickening, and we record the maximum temperature ever reached at each location in the crust. We then allow the heat to conduct for a further 500 Ma. We then define a stochastic magnetization pattern with a characteristic vertical and horizontal coherence length [5] and a direction parallel/anti-parallel to the vertical, consistent with global field reversals (the direction is found not to be important for our purposes). We set to zero the magnetization of all areas where $T > T_{blocking}$ for a particular mineral (pyrrhotite, hematite, magnetite), then calculate the predicted values of *B185*, averaged over 20 such random magnetization patterns, as demonstrated in figure 1c,

Highland volcanoes showing evidence of thermal demagnetization.

Tyrrhena Patera. Tyrrhena Patera is 215 by 350 km across, with a summit relief of 1.5 km. The caldera complex is ~50 km across and 0.6 km deep [6]. Much of its erosional morphology suggests that surface deposits consist primarily of friable material emplaced by explosive eruptions [7, 8]. The bulk of the visible surface flows were emplaced at model crater ages between 3.7 and 4.0 Ga, with some minor volcanism at later times [9]. It's gravity anomaly can be modeled by a disk of olivine of radius 275 km and thickness 2.9 km [10]. Figure 1a,b show the topography and magnetic field signature of Tyrrhena.

Although the lowest magnetic field in the region are to the southeast of Tyrrhena, the volcano itself and the aforementioned disk are co-located the idea with an apparent partial 'break' in a region of otherwise strong crustal magnetic field running Southwest-Northeast. We find that the profile running northwest ~450 km from the center of the disk is well-fitted by a model run assuming a Curie temperature of 325°C (pyrrhotite), a cylindrical source diameter of 200 km at the base of the crust, a magma emplacement rate of 20 cubic meters per square meter per million years, emplaced stochastically over 500 Ma. Although this is not a unique result (for magnetite, an emplacement rate ~8 times higher gave an inferior but still reasonable fit). See figure 1c,d,e.

Syrtis Major is a large shield volcano, with a base diameter of 1100 km and a caldera 150-250 km across. It is basaltic in composition [11-13] and most likely Hesperian in age [14]. Kiefer et al. [15] showed that it's gravity anomaly can be explained by two cylinders of radius ~150 km of dense cumulate minerals (primarily pyroxene) over and just to the south of the caldera (shown by circles in figure 2), which also correspond to regions of very weak crustal magnetic field, implying almost total thermal demagnetization compared with the relatively strongly magnetized crust to the immediate east of the caldera complex.

Conclusions: The total volume of magma erupted on the surface is far greater for Syrtis Major than for Tyrrhena Patera. It is thus not surprising that Syrtis likely had an accompanying volume of intruded magma that was also far greater, large enough to completely demagnetize several tens of thousands of square kilometers of Martian crust, whereas Tyrrhena's magmatism was insufficient to completely demagnetize the crust beneath it. In future work, we shall apply the same modeling framework to Syrtis as we did to Tyrrhena.

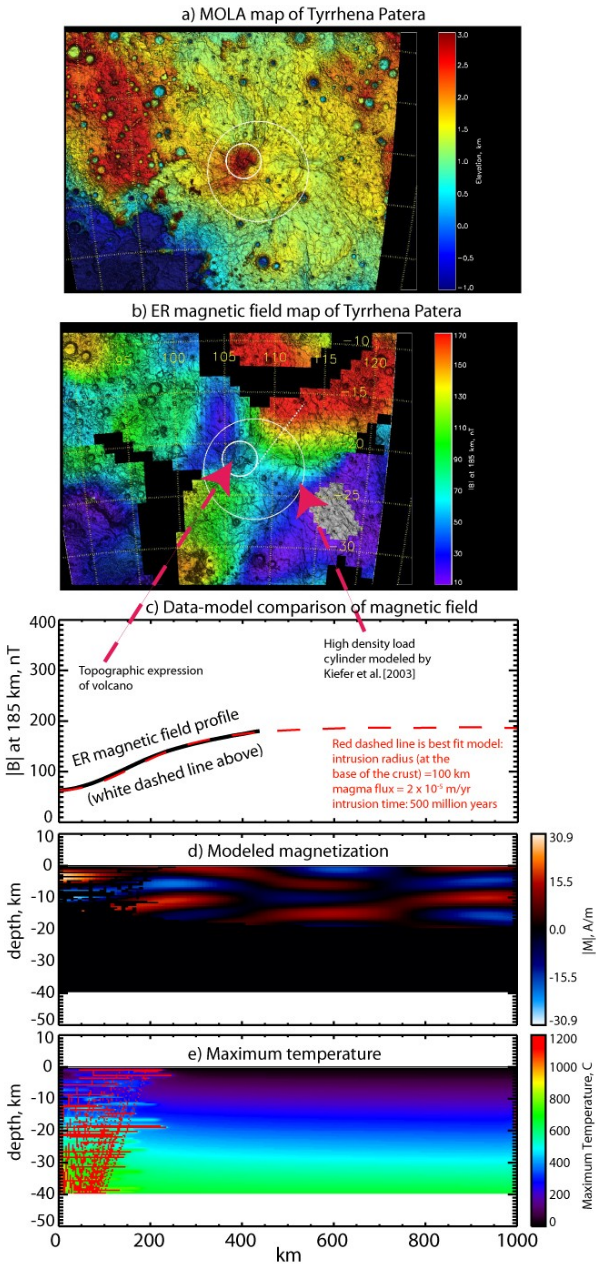

Figure 1: panels a), b) show topographic and crustal magnetic field maps of Terra Tyrrhena. The Tyrrhena Patera volcanic edifice is shown by the small white circle, while the modeled high-density load [10] is shown by the large white circle. Panel c) shows a comparison of the measured crustal magnetic field at 185 km [3] and the best-fit modeled magnetic field caused by thermal demagnetization. Panels d), e) show one example of the modeled magnetization pattern and the maximum temperature distribution (from a flux of 20 m³ per square meter per Ma) that produces the red dashed line in panel c).

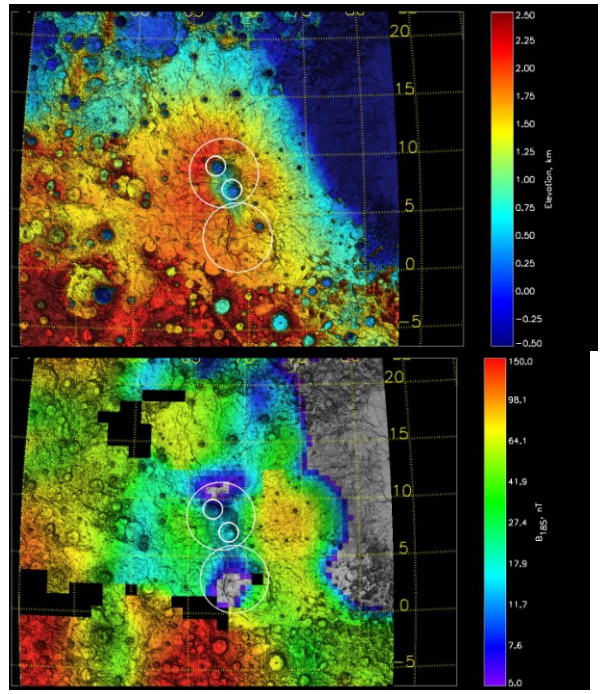

Figure 2: topographic and crustal magnetic field maps of the Syrtis Major shield volcano and surrounds. The modeled high-density cylindrical loads consistent with gravity data [15] are shown with large white circles, while the calderas of Nili and Meroe Paterae are shown with small white circles.

References: [1] RJ Lillis et al., GRL, 2008 [2] W. Kuang et al., GRL, 2008. [3] R. J. Lillis et al., *Icarus* (2008), [4] Dufek and Bergantz, *J. of Petrology,* (2005), [5] R.J. Lillis et al., *JGR Planets*, 2010 [6] Plescia et al., JGR, 2002. [7] Greeley and Crown, JGR 95, 7133-7149, 1990. [8] Gregg and Farley, JVGR 155, 81-89, 2006. [9] Williams et al., JGR 113, 2008JE003104, 2008. [10] Kiefer, 7th Int. Mars Conference, 2003. [11] G.G. Schaber, JGR, 1982. [12] C.A. Hodges, H.J. Moore, USGS professional paper, 1994. [13] D.E. Smith, et al., JGR, 2001. [14] Hiesenger & Head, JGR, 2004. [15] Kiefer, EPSL, 2004.