How Oxidized is the Martian Mantle? Insights from Gusev and Gale Craters

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The oxidation state of the Martian interior can be constrained by investigation of the oxygen fugacities (fO_2) of basaltic rocks, including the SNC meteorites and ones examined by landed Mars missions. The Spirit Mars Exploration Rover in Gusev Crater encountered an array of basalts, ranging from the K-poor Adirondack class (~0.02 wt% K_2O) to the K-rich Backstay class (up to 1.2 wt% K_2O determined by Alpha Particle X-ray Spectrometer, APXS), and exhibiting substantially more variation than observed in martian basaltic meteorites. The ratios of ferric to total iron (Fe^{3+}/Fe_T) measured by the Mössbauer spectrometer (MB) are high (equivalent to -0.76 to +2.98 ΔQFM; quartz-fayalite-magnetite buffer), reflecting secondary ferric oxides. By combining the Fe^{3+}/Fe_T of the igneous minerals determined by MB, we estimate primary fO_2 for the Gusev basalts to be -3.6 to 0 ΔQFM. Estimating fO_2 as a function of the dependence of the CIPW normative fayalite/magnetite ratios on Fe^{3+}/Fe_T yields a slightly smaller range of -2.58 to +0.57 ΔQFM. General similarity between the Gusev and shergottite fO_2 estimates (-3.8 to 0.2 ΔQFM; Herd, 2003; Goodrich et al., 2003) suggests that the overall range of fO_2 for the martian igneous rocks and mantle is relatively restricted. Like the shergottites (Herd, 2003), fO_2 estimates of three Gusev classes (Adirondack, Barnhill and Irvine) correlate with a proxy for LREE enrichment (0.2 to 0.6 K_2O/TiO_2). This suggests mixing of melts or fluids derived from reservoirs with contrasting fO_2 and incompatible element characteristics and limited tectonic processing of the Martian mantle.

If the K_2O/TiO_2 ratio is a robust indicator of oxidation state for Mars, then we can apply it to igneous rocks encountered by the Mars Science Laboratory (MSL) rover, even though it does not carry a MB. The Gale suite includes the mugearitic Jake M class rocks (K_2O/TiO_2 up to 4.4) and alkali basaltic volcaniclastic Bathurst_Inlet class (K_2O/TiO_2 2.0-2.8). Concentration of incompatible elements possibly by metasomatic processes into discrete domains may imply that portions of the Martian interior are significantly more oxidized than the Gusev or meteorite data imply.