Wishstone to Watchtower: Amorphous alteration of plagioclase-rich rocks in Gusev crater, Mars

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ABSTRACT

Previous observations by the Spirit rover in Gusev crater revealed a suite of rocks dubbed Wishstone and Watchtower Class in which the parent lithology and daughter products of a distinctive style of aqueous alteration are evident. Results from Spirit’s Miniature Thermal Emission Spectrometer (Mini-TES; ~2000–340 cm⁻¹) were compromised by dust contamination of one of the instrument’s mirrors, for which a correction has since been developed. Now we have documented nearly 200 examples of rocks encompassing the span of alteration from Wishstone Class, which spectrally resemble minimally altered plagioclase-phyric basalt, to the most altered Watchtower Class. Among them is a rock dubbed Bruce that may be a previously unrecognized alteration spectral end-member. We employed factor analysis/target transformation and linear least-squares modeling to investigate the spectral characteristics and mineralogy of these rocks. Our results amplify those of a prior preliminary analysis showing that alteration produced a material resembling basaltic glass that masks the spectral features of plagioclase. The association of this amorphous silicate component with a ferric iron nanophase oxide phase identified via Spirit’s Mössbauer spectrometer is now clearly shown by our data, further characterizing the distinctive mineralogic expression of the alteration. These components and the absence of any recognizable secondary silicates or opaline silica may be an expression of alteration in the extreme aridity and cold of the martian environment. Similar mineralogic characteristics of soil measured with the CheMin X-ray diffraction instrument on the Curiosity rover in Gale crater may be an indication that this alteration process is widespread on Mars.

Keywords: Mars, alteration, thermal infrared, spectroscopy, plagioclase, amorphous materials

INTRODUCTION

The Mars Exploration Rover Spirit encountered a remarkable diversity of rock types during its traverse of the Columbia Hills in Gusev crater, manifested both as variations in primary mineralogy and in secondary alteration (e.g., Arvidson et al. 2008). The classification of all rocks and soils observed by Spirit is based on elemental chemistry measured by the Alpha Particle X-ray Spectrometer (APXS), with subclasses defined where warranted by sufficiently large variations in Fe mineralogy measured by the Mössbauer spectrometer (MB) (e.g., Ming et al. 2006; Morris et al. 2006; Squyres et al. 2006). Both APXS and MB are contact instruments mounted on the rover’s instrument deployment device (IDD) that allowed for interrogation of small (<3 cm) spots on rocks. Many of these spots were cleared of dust by the brush on the rock abrasion tool (RAT), and in more limited cases, abraded by the RAT grind heads to expose fresh surfaces.

Wishstone and Watchtower Class were recognized as members of an alteration series identified by variations in geochemistry and Fe-bearing mineral phases (Hurowitz et al. 2006; Ming et al. 2006; Morris et al. 2006; Squyres et al. 2006). Work by Hurowitz et al. (2006) demonstrated a geochemical relationship consistent with two-component mixing between the less altered high Al₂O₃, TiO₂, CaO, Na₂O, P₂O₅ Wishstone Class end-member and an unidentified more altered end-member enriched in MgO, Zn, S, Br, and Cl. Watchtower Class is intermediate between these two end-members (Hurowitz et al. 2006). The alteration evident in the MB-derived Fe mineralogy is manifested as increasing values of nanophase ferric oxide (npOx), ferric to total iron ratio (Fe³⁺/Fe₄⁺), and mineralogical alteration index (MAI; the sum of npOx, hematite, goethite, and sulfate abundance) (Morris et al. 2008). The rocks of Watchtower Class display sufficient variations among these parameters that it was subdivided into three subclasses in order of increasing alteration: Keystone, Keel, and Watchtower.

A preliminary assessment of the bulk mineralogy of these rock classes using thermal infrared (TIR) spectra from Spirit’s Mini-TES revealed a dominant plagioclase component in Wishstone rock, and in Watchtower rock, up to 50% abundance of an amorphous component resembling basaltic glass (Ruff et al. 2006). These results were based on spectra from only a single rock for each class in part because most of the other examples were compromised by a sudden accumulation of dust on the Mini-TES elevation mirror on sol 420 of the mission, due to an aeolian event. Many tens of additional examples of Wishstone Class rocks were recognized following sol 420 despite the dust spectral artifacts, demonstrating it to be the most common rock type on the north side of Husband Hill (Ruff et al. 2006; Fig. 1). A robust correction for mirror-dust contamination has since been developed (Smith et al. 2006) and verified for surface observations (Ruff et al. 2011), allowing for more in-depth analyses of a suite...