

## PRIMARY MARTIAN BASALTS AT GUSEV CRATER: EXPERIMENTAL CONSTRAINTS.

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**Introduction:** Until recently the only information on Martian magmatic processes came from SNC meteorites [1], young magmatic rocks thought to have been ejected through meteoritic impact from the volcanic areas of Tharsis or Elysium. Most of these rocks, however, contain accumulated crystals, and all have suffered various extents of fractional crystallization and crustal assimilation, making it difficult to characterize their source regions. Lavas were also analyzed by the Mars Pathfinder mission, but the analyzed compositions are andesitic and represent differentiated magmas as well [2].

Basaltic rocks have recently been described from the Spirit landing site at Gusev Crater [3]. They are dark, fine-grained vesicular rocks, containing <25% phenocrysts. Chemical analyses of abraded samples by Alpha-Particle X-Ray Spectrometer are consistent with primitive basalts, with up to 12% MgO. Gusev Crater is located in the northernmost region of the highly cratered Southern Highlands; rocks with spectral characteristic similar to Gusev Crater basalts have also been documented in the cliffs surrounding Isidis Planitia [4], suggesting that the Gusev basalts may represent an important component of the ancient Noachian Martian crust. These are the first available data on primitive Martian basalts.

High-pressure, high-temperature phase relations of the Gusev basalts have been investigated in order to understand their formation conditions. The inverse experimental approach has been used to explore the processes of mantle melting and crust formation on Mars.

**Experimental results:** High-pressure, high-temperature liquidus experiments have been performed on a composition averaged from the unaltered Gusev basalts (Table 1) [3]. This composition has been calculated as the low-S extension of the Mg vs S alteration trend defined by the Gusev analysis [3].

The phase relations have been investigated between 1 atm and 1.5 GPa at temperatures of 1175 to 1400 °C. One atmosphere experiments were performed using the FePt wire-loop technique at an fO<sub>2</sub> of QFM; high-pressure experiments were performed in a ½-inch piston cylinder, using Pt-graphite capsules.

Spinel is present in nearly all experiments and is the liquidus phase at low pressure (Figure 1). Olivine (Mg# 78.7) is the second phase to crystallize below about 1.1 GPa and is replaced by orthopyroxene at higher pressure. Liquidus temperatures range from 1280 at 1-atm to around 1400 °C at 1.5 GPa. The

Gusev Crater basalt composition is multiply saturated with olivine + orthopyroxene + spinel near the liquidus at 1.1 GPa and 1360 °C (Figure 2).

Microscopic images of Gusev Crater basalts show an aphanitic groundmass with dark megacrysts that have been argued to be olivine [3]. The experimental observation of olivine as an abundant, early crystallizing phase strongly supports this identification. Spectral analyses of the basalts suggest the presence of olivine and magnetite crystals, in agreement with the experimentally determined low-pressure crystallization path.

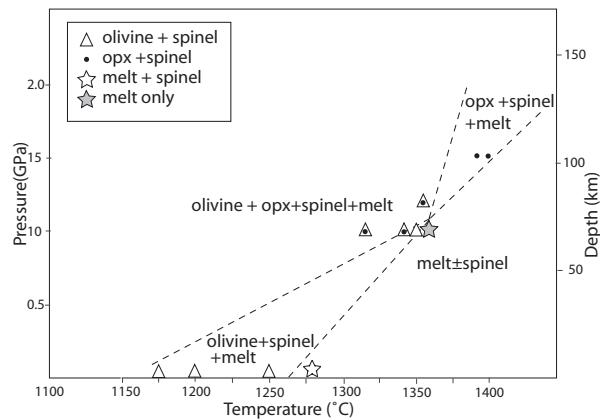


Figure 1. Experimental phase diagram for Gusev Crater basalt. An olivine + orthopyroxene + spinel multiple saturation point was found to be near 1.1 GPa and 1360 °C.

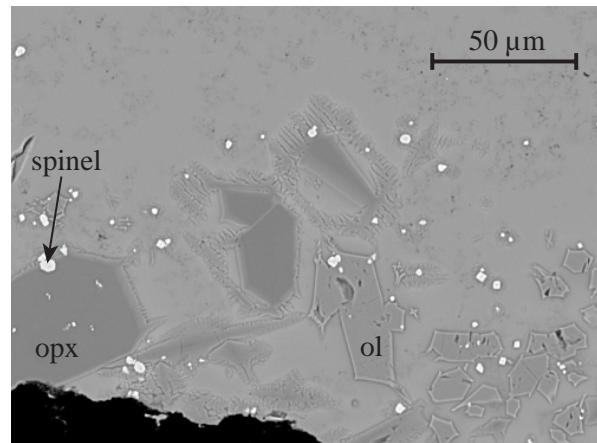


Figure 2. Backscattered electron image of a near liquidus olivine+orthopyroxene+spinel saturated experiment at 1.2 GPa and 1355 °C.

The Al/Si and Ca/Al ratios of the Gusev basalts do not follow the trend of Martian meteorites [3]. Low-pressure differentiation of the Gusev Crater basalts only slightly modifies their Ca/Al and Si/Al ratios, indicating that the shergottite basalts cannot be related to the Gusev basalt by fractional crystallization. This suggests a different mantle source and/or different genetic processes. The Spirit Rover has thus sampled a new kind of Martian magma, unrelated to the other known samples.

**Discussion:** The existence of a three-phase multiple saturation indicates that Gusev Crater basalt is a primary Martian mantle magma. The pressure of multiple saturation (1.1 GPa - 75 km) suggests that the Gusev basalts have been generated just below the ~50 km thick Martian crust [5] or that they result from a polybaric melting process, with melt segregating at 1.1 GPa. The results are consistent with mantle melting processes that extend to shallow depths in the Martian mantle. In addition, the multiple saturation depth places an upper limit on the thickness of the Martian lithosphere below Gusev Crater.

The temperature of multiple saturation is high, within the range that exists at Earth's modern mid-ocean ridges (1270 to 1425 °C, e.g. [6] and [7]), indicating that such basalts would have been generated at a high mantle potential temperature environment. Two possibilities seem compatible with the geological evolution of Mars: (1) Generation above a mantle plume related to the Elysium volcanic area. (2) Generation early in Mars' history, when the planet was not yet cooled from early impact heating and short-lived radiogenic isotope disintegration. The strong contrasts with SNC meteorites, and the absence of young volcanic features around Gusev Crater, however, make this first option improbable. In the second case, Gusev Crater basalts would be part of a primary basaltic crust, and their strong geochemical differences from SNC meteorites would be explained by the sampling of a different, primitive, undifferentiated mantle. The composition of the primitive Martian mantle has been estimated by using elemental correlation in SNC meteorites and composition of chondrites [8]. The composition of Gusev basalts is consistent with experimental melts of this calculated primitive Martian mantle (Figure 3) [9], supporting the conclusion that the Gusev basalts form part of a primary basaltic crust. Based on experimental results, the melt fraction necessary to produce the Gusev basalts would be about 20 percent.

Gusev basalts, which originated by high-degree shallow melting of a primitive Martian mantle, are probably part of the primitive Martian crust that forms most of the Southern Highlands.

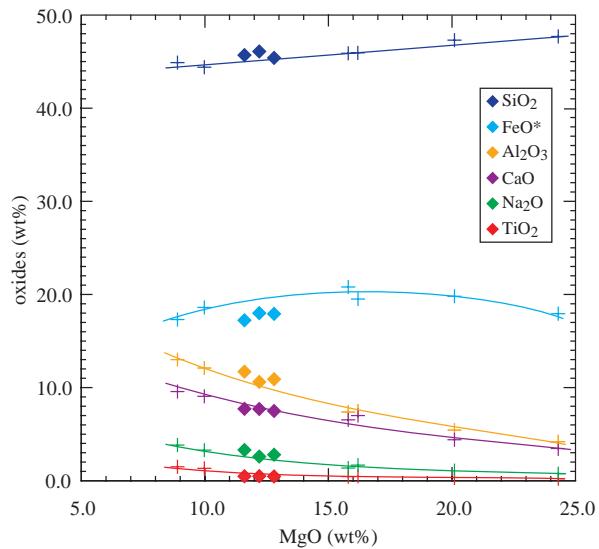


Figure 3. Comparison between Gusev basalts (diamonds) and experimental melting curve for calculated Martian mantle (crosses) [9].

| Oxide                          | wt %  |
|--------------------------------|-------|
| SiO <sub>2</sub>               | 46.04 |
| TiO <sub>2</sub>               | 0.49  |
| Al <sub>2</sub> O <sub>3</sub> | 11.14 |
| Cr <sub>2</sub> O <sub>3</sub> | 0.59  |
| FeO*                           | 17.82 |
| MnO                            | 0.39  |
| MgO                            | 12.28 |
| CaO                            | 7.68  |
| Na <sub>2</sub> O              | 2.91  |
| K <sub>2</sub> O               | 0.06  |
| P <sub>2</sub> O <sub>5</sub>  | 0.60  |

Table 1. Composition used in the Gusev experiments.

- References**
- [1] McSween H. Y. Jr. (2002) *Meteoritics*, 37, 7-25
  - [2] Miniti M.M. and Rutherford M.J. (2000) *GCA*, 64, 2535-2547
  - [3] McSween H.Y.Jr. et al. (2004) *Science*, 305, 842-845
  - [4] Hoefen T.M. et al. (2003) *Science*, 302, 627-630
  - [5] Zuber M.T. et al. (2000) *Science*, 287, 1788-1793
  - [6] Kinzler R.T. and Grove T.L. (1992) *JGR*, 97, 6907-6926
  - [7] McKenzie D. and Bickle M.J. (1988) *J.Pet.*, 29, 625-679
  - [8] Dreibus G. and Wänke H. (1985) *Meteoritics*, 20, 367-381.
  - [9] Bertka C.M. and Holloway J.R. (1994) *CMP*, 115, 323-338.