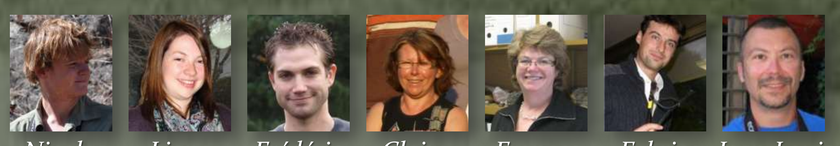
Synthesis of Gusev crater analogue basalts, Mars : interest for astrobiology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Introduction

The elemental composition of Martian basalts differs from that of terrestrial basalts; they are richer in Fe and Mg as indicated by *in situ* measurements on Mars. This enrichment shows up both in the altered surface rinds of the basalts, as indicated by the Pathfinder APXS analyses of the rock surfaces [1], as well as in the surfaces cleaned using the Rock Abrasion Tool (RAT) of the MER mission, for example at Gusev Crater [2] (Fig. 1). Thus, in order to have relevant analogues for studying martian basalts, a number of experiments have been undertaken to produce artificial martian basalts. Previous studies have synthesized Martian basalts by reference to compositions of Pathfinder mission and/or meteorite geochemical datasets [2,3]. In our experiment, we used the geochemical data set from surfaces cleaned by the RAT at Gusev crater to produce primitive Martian basalt analogues.

These synthetic basalts form part of the International Space Analogue Rockstore (ISAR), a collection of analogue rocks and minerals used to test and prepare instruments for *in situ* space missions(***see poster #1397***).


Fig. 1: Panoramic View of the "Columbia Hills" and Gusev Crater by Spirit (NASA)

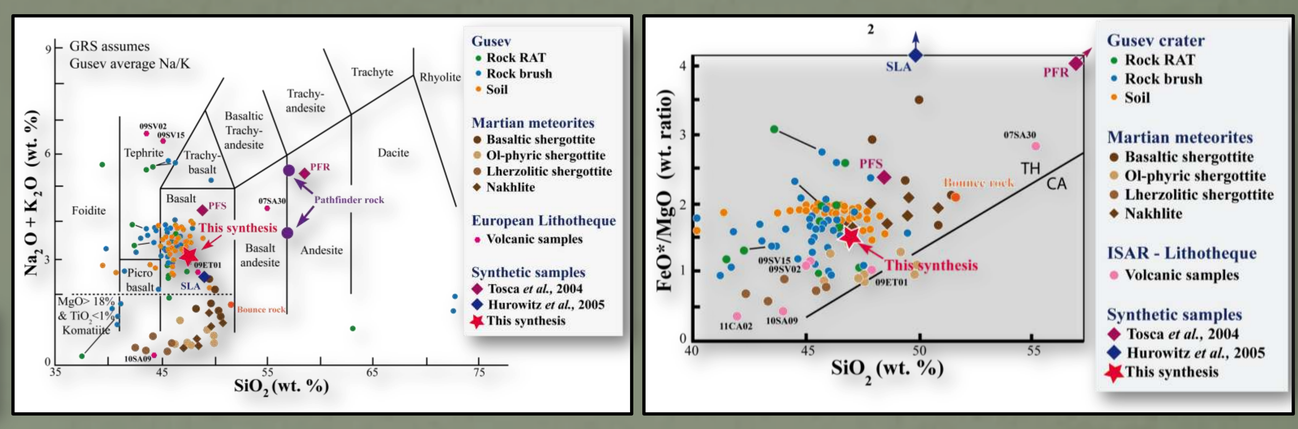


Fig. 2: Chemical compositions of Martian rocks (in situ analyses), meteorites, and previous synthetic basalts. Red star is from this study.

Synthetic basalt composition

We based our synthetic composition on the analyses of cleaned basalt surfaces in Gusev Crater [4], assuming that the basalt was totally degassed (i.e., no Cl, SO_3 or H_2O). We included corrections for the chemical weathering on the Martian surface [2], as shown in Fig.3.

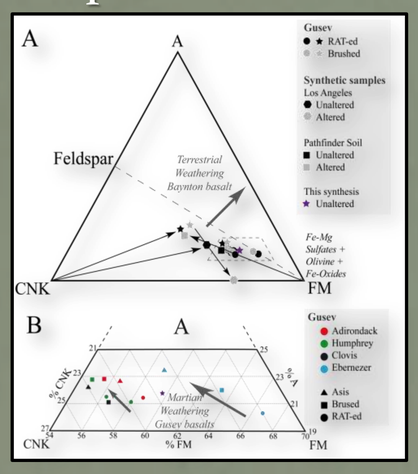


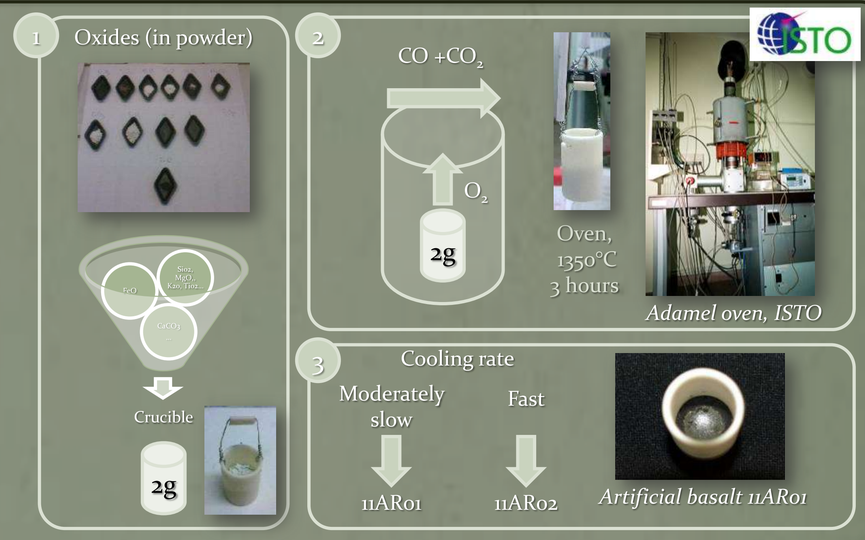
Fig. 3: Chemical weathering diagram with A Al), CNK(Ca, Na, K), and FM (Fe, Mg). Modified after [2]

First synthesis experiment

We placed 2g of well mixed oxide and carbonate powders (SiO_2, TiO_2, P_2O_5, Al_2O_3, Cr_2O_3, MnO, FeO, MgO, $CaCO_3$, Na_2CO_3, K_2CO_3, and NiO) into an open alumina crucible. The crucibles were heated in an oven at atmospheric pressure (10^5 Pa) to 1350°C for 3 hours under reducing conditions (80%CO_2 – 20%CO gas mixture).

Two different cooling rates were used:
- a relatively slow rate (~110°C/h), corresponding to 1 day in the cooling oven → ***11AR01****
- a faster rate (>> 1400°C/h), corresponding to less than 1 hour quenched in air →***11AR02****

** sample codes refer to their identifiers in the ISAR collection, http://isar.cnrs-orleans.fr/isar/*



Results

Two synthetic basalt samples were made with identical geochemical compositions. As a result of the different cooling rates they exhibited different textures.

-The slowly cooled basalt (11AR01) is characterized by spinifex-like textures (Fig. 4, [5,6]) formed by the dendritic texture exhibited by large pyroxene and smaller forsterite crystals. These textures are distinct from hopper or swallow-tail-like textures of olivines observed in MORBs and resemble more the spinifex textures observed in komatiites (Fig. 5). Associated with the major mineralogical phases are minor phases of well crystallized oxides (e.g., spinels). Despite the relatively slow cooling rate, the material contains small areas of augitic glass associated with the two types of elongated crystals.

-The rapidly cooled sample (11AR02) contains large areas of augitic glass and has the same mineralogical composition as the slowly cooled material, including anhedral (globular) olivine phases (Fig. 4). Sample 11AR02 is more vesiscular than sample 11AR01 because the faster air-quenching prevents outgassing of carbonate-derived CO2.

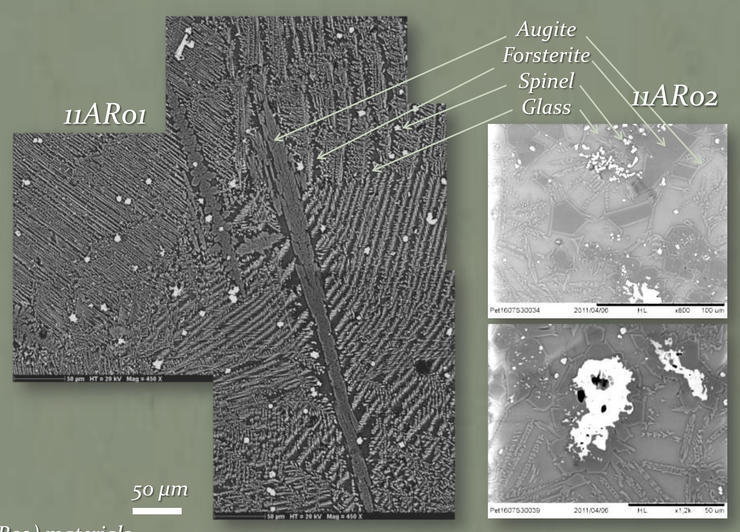


Fig. 4: Backscatter SEM images of the textures in the slowly (11AR01) and rapidly cooled (11AR02) materials.

Discussion

- Spinifex-like texture similar to komatiites (Fig. 5),
- Komatiites on Mars ? [7]

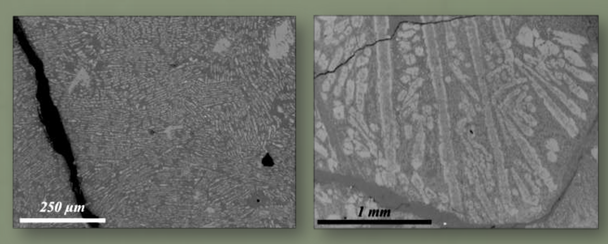


Fig. 5: Natural komatiite from Dundonald, Ontario, Canada

Second experiment: large volume basalt synthesis

A second experiment was carried out to prepare a larger quantity of synthetic material using 200g of oxide powders (SiO_2, TiO_2, P_2O_5, Al_2O_3, Cr_2O_3, MnO, FeO, MgO, CaO, Na_2O, K_2O, and NiO) that were placed into larger, open alumina crucibles (Fig. 8) and heated in an oven at atmospheric pressure (10^5 Pa) to 1480°C under reducing conditions (80%CO_2 – 20%CO gas mixture).

Two faster cooling rates were used (Fig. 8):
- one at ~400°C/h, corresponding the cooling rate of the oven → ***12AR01***
- one quenched in water → ***12AR02***.

Fig. 8: Larger samples (~200 g) of artificial basalts.

Preliminary results

Optical observation shows that there is a vertical and radial graduation in the texture (Fig. 9) caused by the differential cooling rates between the core and surface of the samples.

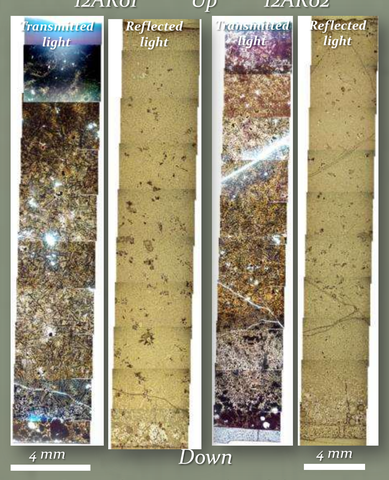


Fig. 9: Optical micrographs of thin sections.

Radial texture

SEM and Raman analyses

Synthesis of a larger volume results in the crystallization of pyroxene (augite) instead of olivine (forsterite) (Fig. 10) due to retrograde reaction.
Forsterite only occurs at the bottom of 12AR02 where the crucible had been plunged into water.

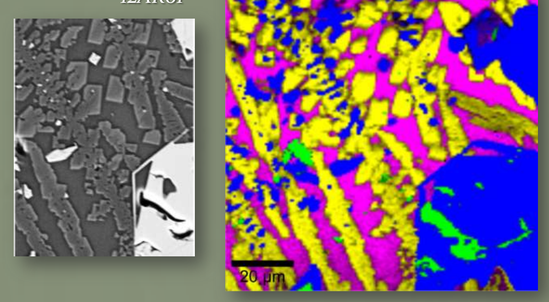


Fig. 10: SEM image and associated Raman compositional map of the sample 12AR01 : yellow = augite (pyroxene), pink = glass, blue = magnetite (spinel group) and green = carbon.

Astrobiological implications

Komatiites and their spinifex textures were common on the early Earth because of the higher mantle temperatures and possibly on early Mars [7]. Basaltic materials are ideal habitats for chemolithotrophic types of microorganisms that obtain their energy from redox reactions at the surfaces of the reactive volcanic material, as well as their nutrients through dissolution of the basalts [8-10] (Figs. 6,7). Microbially-derived organic compounds could be preserved in the aqueous alteration products basalts, including phyllosilicates [11], thus making these kinds of rock and minerals interesting targets for astrobiological investigations.

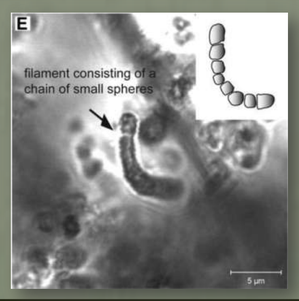


Fig. 6: Optical transmitted-light images of putative microfossils (short chains of small spheres) embedded in the K-phillipsite–filled vesicles in pillow basalt [9]).

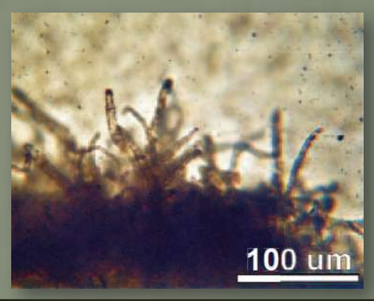


Fig. 7: Optical transmitted-light images of tubular structures of microbial origin protruding in fresh basaltic glass from the Troodos ophiolite [10].

References

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Conclusion & perspectives

- Synthetic Martian basalts are included in the ISAR collection to provide an analogue of basaltic material with a realistic Martian composition to test and calibrate instrumentation for *in situ* missions;
- Slight variations in cooling conditions produce significant mineralogical and textural variations in compositionally homogeneous materials;
- Martian synthetic basalts are astrobiologically interesting since they represent a source of energy and nutrients for chemolithotrophic microorganisms. These rocks and their alteration products are potential targets to search for organic molecules on the Martian surface.