IV-Martian silica

The presence of silica in its amorphous form on Mars has been proposed based on geochemical arguments (McLennan, 2003) and evidence of past hydrothermal activity (Farmer, 1996). In 2008, the presence of silica on Mars was confirmed by its infrared signature via instruments on orbital probes and rovers (Milliken et al., 2008; Squyres et al., 2008). However, the exact nature of this silica (opal, chalcedony...) remains unknown, which is why it is frequently encountered the term "opaline silica" to designate the hydrated amorphous silica detected.

1°) Detection methods

Silica identifications on the surface of Mars are mainly made using spectro-imagers. These instruments aim to acquire an image of the planetary surface in addition to spectroscopic properties. Indeed, for each pixel of the image, a spectrum is measured. This makes it possible to acquirewhat is called a cube (a spectral dimension in addition to the two dimensions of an image). There are two main types of spectral imaging, multispectral imaging, which uses wideband, non-contiguous spectral band sensors, and hyperspectral, which uses contiguous narrowband sensors. Thanks to these instruments, it is possible to have the spectroscopic signature (especially in the infrared) of the surface. The comparison of the spectra acquired by the spectro-imagers with the spectral libr airies of known minerals (the most used for silica being RELAB and that of the USGS; Clark et al. 2007; Pieters 2010), is used to determine which mineral constitutes the surface (Figure I-15). Knowing that mineralogical identification is mainly based on the infrared signatures of the surface, we speak of detections.

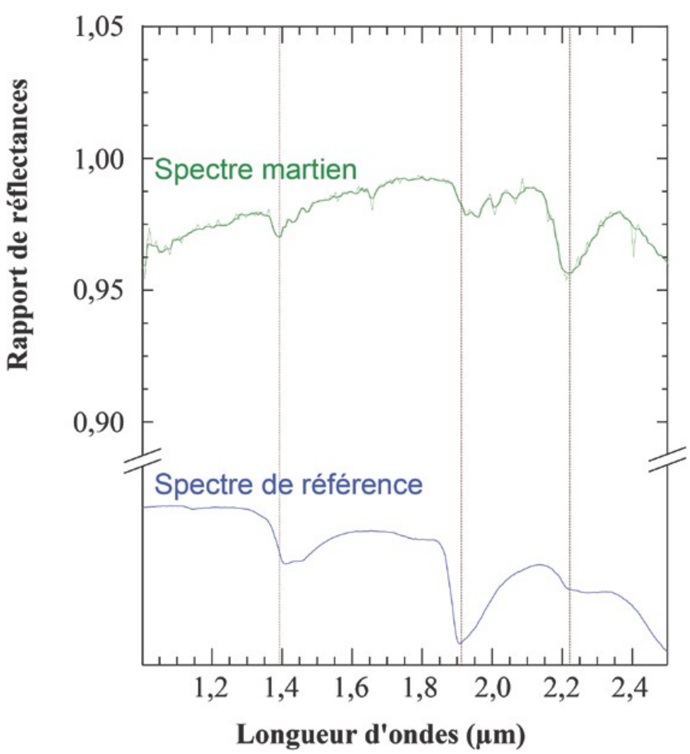

Figure I-15: Spectrum acquired by CRISM on the *Melas Chasma region (cube HRL44ac from Le Deit et al. 2010) compared with a reference spectrum from the RELAB library.*

These analyses can be coupled with other mineralogical characterization methods (such as X-ray diffraction or X-ray microanalysis) on board rovers . This coupling makes it possible to better identify the silica phase, as well as its chemistry.

2°) Martian silica deposits

Martian silica has been identified on the surface of Mars in several areas of the planet, but mainly in craters or close to the boundary drawn by the Martian dichotomy* (Figure I-16). The first silica detections on Mars were made in 2008. In May of this year, Squyres et al. (2008) published an *in-situ* detection using the Spirit rover in Gusev crater. This silica, present in a whitish soil exposed thanks to the wheel trace, is ≈ 98% pure. It was also observed in a nodular outcrop. Infrared spectroscopy analyses confirm the presence of hydrated amorphous silica interpreted as hydrothermal (Squyres et al., 2008; Rice et al., 2010a; Ruff et al., 2011).

In November, Milliken et al. (2008) detected the presence of silica when analyzing the data acquired by the CRISM (Compact Reconnaissance Spectrometer on the Mars Reconnaissance-Orbiter) plateaus adjacent to the Melas and Juvante Chasmal canyons . In this case, silica, associated with metrically stratified iron sulphates overlying lava flows, is interpreted as opal from basalt weathering under acidic conditions at low temperatures (Milliken et al., 2008). However, Rice et al. (2013) question the nature of this silica. Indeed, this study, which takes into account a large sampling of silica, suggests that the one detected by Milliken et al. (2008) is more likely hydrated glass. Strata rich in silica are also found all around Valles Marineras (Noctis Labyrinths, Ius, Melas, Condor, Ganges, and Juvante Chiasmata, Bishop et al. 2009; Le Deit et al. 2010; Roach et al. 2010; Weitz et al. 2010, 2011, 2013, 2015).

Subsequently, various silica detections were made on the surface of Mars (153 detections according to Carter et al. 2013). In Mawrth Valli's, silica indices are associated with the detection of montmorillonite (a smectite) and kaolinite. This silice appears to be a hydrated volcanic glass (McKeown et al., 2008, 2011). Its presence is attributed to the alteration of volcanic ash (deposited in an aqueous medium) by groundwater (McKeown et al., 2009).

In the north of Syrtis Major, several silica-rich areas have been detected. In Nili Fossae craters, these silica indices (interpreted as opal) are associated with minerals indicating weathering at temperatures between 200°C and 350°C (Ehmann et al., 2009). Studies have also shown deposits of quartz and amorphous silica in the low-lying areas of Antoniadi crater. These deposits are interpreted as aeolian and from rocks that have undergone extensive diagenesis (Smith and Banfield, 2012).

A peu further east, in Toro Crater, the detections of silica (interpreted as mostly amorphous) and hydrated minerals, as well as the morphologies observed, suggest a hydrothermal system associated with the impact (Marzo et al., 2010).

Further south in the Syrtis Major plains, in the Nili Patera caldera, silica detections are restricted to areas interpreted as manifestations of hydrothermal activity (including mayfly fumaroles) associated with volcanism (Skok et al., 2010; Smith et al., 2013).

In Terra Sirenum, south of Columbus Crater, a mound composed of silica associated with ferro-magnesium phyllosilicates is interpreted as the product of weathering by groundwater, implying acidic conditions (Wray et al., 2011; Smith et al., 2013).

In western Hellas Basin, extensive silica deposition has been detected (Bandfield, 2008). This silica is not associated with any other mineral or particular texture. This deposit is likely the result of a reworking of ancient silica-rich rocks, which does not allow a certain genetic origin of this silica to be inferred (Bandfield, 2008; Bandfield et al., 2013).

* Clear contrast between the northern hemisphere made of vast plains at low altitude and the southern hemisphere characterized by heavily cratered plateaus.

In view of all these Martian deposits, silica seems, as on Earth, associated with various geological processes ranging from underground weathering to hydrothermalism. In addition, the processes of formation of these silica are mainly identified thanks to the minerals associated with it. A study of geological environments associated with the formation of silica on Earth could provide clues to identify the processes leading to its genesis. It is also possible that its infrared signature (the main mineral identification tool on Mars) records formation conditions.