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SIMILARITY BETWEEN VISCOSITY AND MARTIAN VOLCANOES GEOMORPHOLOGY INFERRED FROMSNC METEORITES

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Abstract

The geomorphic features on theplanetary surface of Mars suggest that both effusive and explosive eruptive behaviour occurred. We studied magma viscosity through an extrapolation from 41 Martian SNC (Shergottite, Chassignite, Nakhlite) meteorites, by using data available from the NASA Martian Meteorites Compendium. Viscosity was used to characterize how eruptive style changed in different volcanic regions of Mars, according to the volcano geomorphology of the planet. Source regions for the studied meteorites were based both from Mars Global Surveyor Thermal Emission Spectrometer (MGS TES) and literature data.We found the magma source depth by using a relationship with the heights of the volcanic edifices, then using this data and geochemistry as input for thermodynamic simulations. The subsolidus equilibration temperature were used to find viscosity. Results indicate a crystallization temperature in a range from 1,120°C to 843°C, and a variation in viscosity from 101,43 to 105,97 Pa s. Viscosity seems to be higher in Tharsis, Elysium, Amazonis, and Syrtis Major regions than the other studied areas. According to past experimental studies about magma viscosity, we classified the eruptive style into effusive (101-103,5 Pa s), intermediate (103,5-104,5 Pa s), and explosive (104,5-106 Pa s).The Hellas Basin, Argyre Basin, Ganges Chasma, Eos Chasma, and Nili Fossae regions suggest an eruptive behaviour between effusive and intermediate, while the Tharsis, Elysium, Amazonis, Syrtis Major, and Terra Tyrrhena regions probably had a more explosive eruptive style during Mars geological history, even if were also likely affected by effusive/intermediate activity. Our results seems to be in accord with the actual Martian geomorphology of the studied areas.

Key words: Diverse Eruptive style, Mars volcanism, magma viscosity, SNC meteorites,

planetary geomorphology

1 - Introduction and background

The Martian meteorites, called SNC (short for Shergottite, Nakhlite, and Chassignite), consists of mafic and ultramafic rocks, with a relative young crystallization age and an elemental distribution that distinguish them from the other types of meteorites (McSween, 1994; Clayton & Mayeda, 1996).

From isotopic analyses on gases trapped in fluid inclusions of these meteorites and a comparison between the Martian atmosphere composition (through Viking lander data), was possible to enstablish as their source is planet Mars (Bogard and Johnson, 1983; Becker and Pepin, 1984). In particular, Nakhla and Shergotty crystallization ages is very young compared with the usual asteroidal meteorites: Nakhla has a Rb-Sr model age in a range of 2.5-3.6 Gy (compared with the primitive $^{87}Sr/^{86}Sr$ content of the Solar System), while the Shergotty Rb-Sr model ages are ≈ 4.5 Gy, matching the period of chemical differentiation of the planet (Papanastassiou and Wasserburg, 1974; Gale et al., 1975). Shergottites also have young cosmic ray exposure (CRE) ages. The calculated young ages (down to ≈ 165 My) about the SNCs meteorites leads to a relative recent volcanic activity on Mars (Nyquist et al., 2001).

We investigated whether planet Mars had change in style of volcanic activity on different areas of the surface by basing on available geochemical data about a great number of Martian meteorites actually known.

We used data about composition and crystallinity of 41 SNCmeteorites that came from the Martian Meteorites Compendium, compiled by NASA (Charles Meyer), and made properly calculations and thermodynamicmodelingby using petrologic softwares in order to obtain a likely scenarioabout magmatic processes for a certain area of the planet. In this work we avoid meteorites with poor/incomplete database. We assume the following: Mars never had moving plate tectonics and exist as a one-plate planet(Breuer & Spohn, 2003); no magma-water interactions;the H_2O wt% is equal to 0 for almost all the meteorites (except for Lafayette that have a significant H_2O wt% ≈ 0.3(Boctor et al., 1976)).

The physics of volcanism on Mars, as well as on each known extraterrestrial body, is different from that of Earth (Wilson & Head, 1983; Frankel, 1996; Frankel, 2005), in fact because of the lower gravity a great number of bubbles nucleate also in mafic magmas and this would generate plinian basaltic eruptions (Wilson & Head, 1983). On Earth, about 3 to 4 wt% of volatiles in the magma are needed to the bubbles to grow large enough to generate an explosive eruption; on Mars, only 0.03 and 0.2 wt% of volatiles are needed in order to have an explosive behaviour (Frankel, 2005). The depth (and pressure) of the magmatic source would be highly relevant for the resultant style of the eruption (Gudmundsson, 2012). For these reasons, the provenance locations were combined with a surface temperature map of the entire planetin order to locate a likely depth of the magma chamber or magma source for each sample, thus obtaining the pressure.At the end of the simulations, we based on viscosity of each sample to established our ideas about eruptive style for different areas on Mars at some point in the past, by presenting the data in a map and by comparing them with the known geomorphic features of the planet.

2 - Sample selection and provenance

2.1 - Sample selection

For this work we selected samples of all the typologies of martian meteorites fallen on Earth and whereas their database is clearly filled of the relevant geochemical/petrographic data. Data were obtained from the NASA Martian Meteorites Compendium, a complete database of all known Martian meteorites.

Almost all SNC meteorites were chose and classified (Tab. 1) in orderto show the official name, the type (Shergottite, Nakhlite, and Chassignite, that are also petrologically divided into basalt, lherzolite, clinopyroxenite, orthopyroxenite, and dunite), crystallization age, and degree of crystallinity. This last is well noticed to be very high for igneous Martian rocks (Nyquist et al., 2001).Geochemistry for each sample used here could be found in Fig. 1.

All the samples could be considered anhydrous with the exception of Lafayette meteorite with H_2O wt% ≈ 0.387, while the fO_2 could be considered as QFM (Bridges & Warren, 2006).

2.2 - Possible provenance

Strongly evidences suggest that all the rocks presented in Tab. 1 came from Mars (Treiman et al., 2000; Nyquist et al., 2001). Many authors described the source regions of SNC meteorites by studying their ages related to the Martian crust (Nyquist et al., 1998), the CRE (Nyquist et al., 2001), and the crater formation dynamics (O'Keef & Ahrens, 1986). Some authors suggested that the majority of the Martian meteorites came from small craters with ≈ 3 Km in diameter (Head & Melosh, 2000). The planetary source for each sample was obtained by basing on previous literature data (Nyquist et al., 2001; Hamilton et al., 2003; Mouginis-Mark et al., 1992; McSween, 2002; Werner et al., 2014).

Through data derived from the Mars Global Surveyor Thermal Emission Spectrometer (MGS TES) the source location of almost all the Martian meteorite lithologies has been identified (Hamilton et al., 2003). An high concentration of olivine and orthopyroxene, corresponding to a geochemistry of ALH77005 (lherzolitic shergottite), Chassigny (dunite), and ALH84001 (orthopyroxenite) was noticed overall in Nili Fossae, in Ganges Chasma, in the Argyre and Hellas basin rims, and in Eos Chasma. Since that the Nili Fossae is a great distance from the other locations (Hamilton et al., 2003; see especially Fig. 2), we can consider that Nili Fossae could be the sorce location for one of the only two known Martian dunite (Chassighy), while we consider as source location for lherzolitic shergottite (e.g. ALH77005) both Ganges Chasma and the two Argyre and Hellas basins. For the orthopyroxenite (e.g. ALH84001) the source location seems to be the Eos Chasma zone, the eastern part of Valles Marineris.

Name	Type	Crystallization Age	Cristallinity %
ALH77005	Lherzolitic Shergottite	175 My	100
ALH84001	Orthopyroxenite	4.5 to 4.0 By	100
Chassigny	Dunite	1.36 By	100
DaG476	Shergottite	474 My	100
DHO019	Basaltic Shergottite	575 My	100
DHO378	Basaltic Shergottite	157 My	97.2
EETA79001	Shergottite	170 My	100
GoWal	Nakhlite	1.37 By	99.1
GRV020090	Shergottite	196 My	100
GRV99027	Shergottite	177 My	100
Lafayette	Nakhlite	1.32 By	91
LAR06319	Shergottite	190 My	99.9
LEW88516	Lherzolitic Shergottite	183 My	93.3
LosAngeles	Basaltic Shergottite	172 My	100
MIL03346	Nakhlite	1.3 to 1.4 By	81.0
Nakhla	Clinopyroxenite	1.38 By	90.6
NWA480	Basaltic Shergottite	346 My	99.0
NWA817	Nakhlite	1.35 By	80.0
NWA856	Basaltic Shergottite	186 My	98.0
NWA998	Nakhlite	1.3 By	100
NWA1068	Shergottite	185 My	99.0
NWA1950	Shergottite	382 My	98.2
NWA2737	Dunite	1.4 By	100
NWA2990	Shergottite	N.Y.	100
NWA4480	Basaltic Shergottite	N.Y.	100
NWA4797	Shergottite	N.Y.	86.8
NWA4925	Shergottite	N.Y.	100
NWA5298	Basaltic Shergottite	209 My	99
NWA5789	Shergottite	N.Y.	59
NWA5790	Nakhlite	1.38 By	60
NWA5990	Shergottite	400 My	95
NWA6162	Shergottite	N.Y.	100
NWA6342	Shergottite	N.Y.	100
QUE94201	Basaltic Shergottite	327 My	96
RBT04261	Shergottite	170 My	100
SAU005	Shergottite	445 My	88
Shergotty	Basaltic Shergottite	165 My	97.2
Y000593	Nakhlite	1.3 By	95
Y793605	Shergottite	185 My	100
Y980459	Shergottite	472 My	75
Zagami	Basaltic Shergottite	170 My	97

Tab I - Name, type, crystallization age, and degree of cristallinity for each Martian meteorite taken into account for the proposed study; N.Y. = Not Yet Calculated.

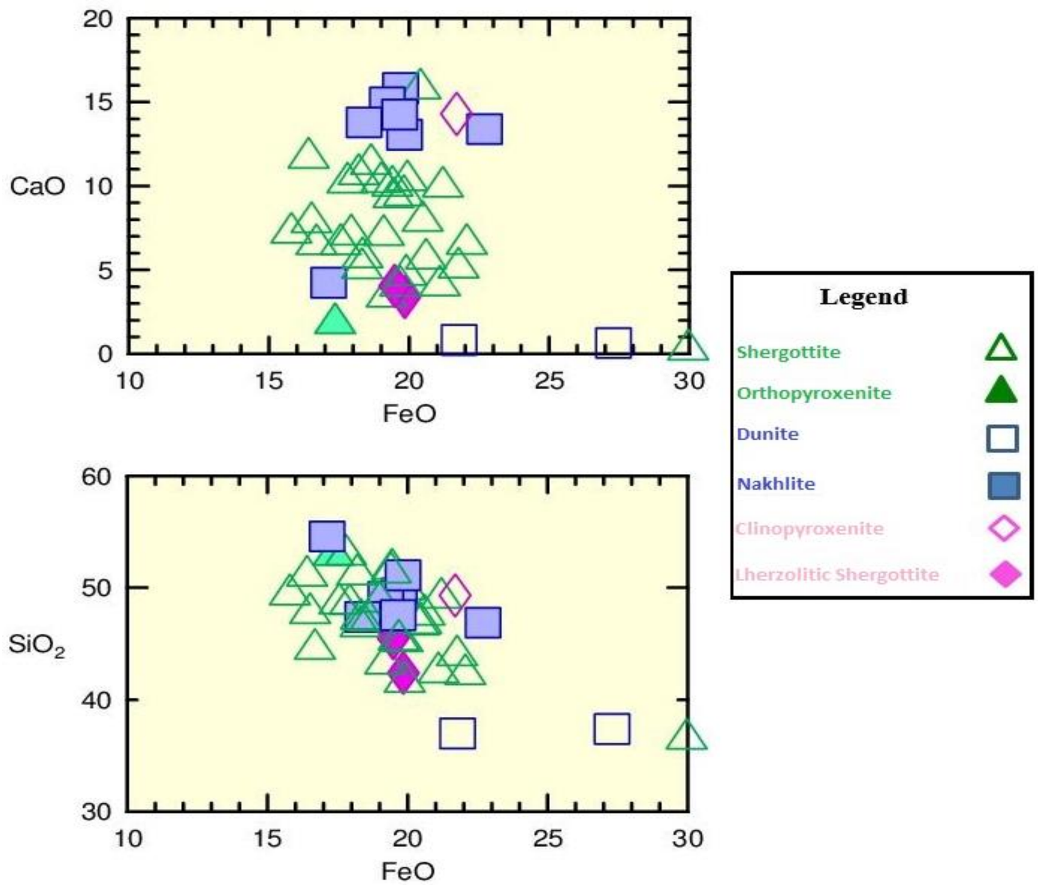

Fig. 1 - SiO_2/FeO and CaO/FeO geochemistry for each meteorites used for the proposed study based on published data (Jarosewich, 1990; Warren & Kallemeyen, 1997; Lodders, 1998; Folco et al., 2000; Terada et al., 2002; Ikeda et al., 2006; McSween & Jarosewich, 1983; Burragato et al., 1975; Lin et al., 2008; Boctor et al., 1976; Basu Sarbadhikari, 2009; Dreibus & Wanke, 1992; Rubin et al., 2000; Anand et al., 2005; Dreibus & Wanke, 1982; Barrat et al., 2002; Sautter et al., 2002; Jambon et al., 2002; Treiman & Irving, 2008; Barrat et al., 2002; Gillet et al., 2005; Beck et al., 2006; Bunch et al., 2009; Walton et al., 2009; Irving et al., 2010a, 2010b, 2010c; Irving et al., 2011; Jambon et al., 2010; Warren et al., 1996; Anand et al., 2008; Dreibus et al., 2000; Dreibus et al., 1982; Shirai et al., 2002; Warren et al., 1999; Greshake et al., 2004; McCoy et al., 1992)

Materials similar to Nakhla meteorites were detected near the eastern part of the Valles Marineris region and a part of Syrtis Major (Hamilton et al., 2003). Thus, we consider these two areas as source for clinopyroxenite (a nahklite). A similar mineralogy for the Zagami basaltic shergottite was detected within the Terra Tyrrhena region (Hamilton et al., 2003), even if there is not a spatially significant evidence.
In general, all the other known shergottites have a very young age compared with all the remnant Martian meteorites and their possible provenance have been chose as Tharsis, Elysium and/or Amazonis region mainly for this reason (Mouginis-Mark et al., 1992; Nyquist et al., 2001; McSween, 2002).For Tharsis and Cerberus Palus volcanoes (Elysium) young ages have been reported (Shumacher & Breuer, 2007; Hauber et al.,

2011) and Tharsis was already completely shaped at the end of the Noachian (Phillips et al., 2001). In particular, a great number of low-shield volcanoes clusters have ages of only a few My, suggesting that effusive volcanism was active also during the Amazonian (Hauber et al., 2011).
Recent studies (Werner et al., 2014) located the source of the majority of shergottites at the Mojave Crater, even if the formation of this crater is 4.3 billion years old. Thus, we take into account all these regions as possible sources for shergottites and basaltic shergottites.In Fig. 2 are resumed all the source locations for the SNC type of meteorites analyzed in this study.

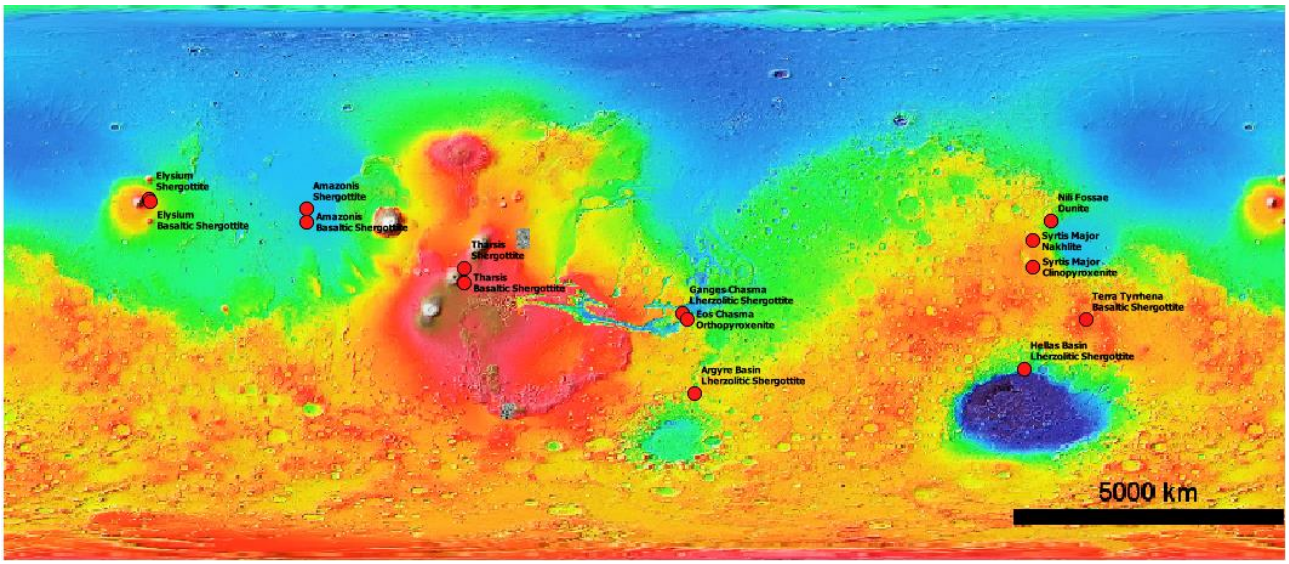

Fig. 2 - Hypothesized source locations on Mars for all the typologies of Martian meteorites studied in the present work.

3 - Methodology

3.1 - Depth and pressure of the magmatic sources

We used the Petrolog software (Danyushevsky & Plechov, 2011) for petrological simulations. In order to havethe correct input data for the simulations we needed to knowan average value for the depth (and pressure) of the magmatic source for each meteorite sample. Data about thermal anomalies and average temperature of the Mars surfaces are availablefrom the THEMIS instrument (Thermal Emission Imaging System, http://global-data.mars.asu.edu/bin/themis.pl), part of the 2001 Mars Odyssey mission. We used the average temperature of the areas in Fig. 2 in order to enstablish whether a magmatic source is shallow or deep(Gudmundsson, 2012).
Surface average temperaturesare -22,334° C, -44,126° C, and 1,362° C for Ganges Chasma, Argyre Basin, and Hellas Basinrespectively, while temperature is -7,529° C for Eos Chasma and -51,31° C for Nili Fossae. Temperature decrease in the more volcanic regions and is -43,225° C, -57,628° C, and -58,938° C, for Tharsis, Elysium, and Amazonis respectively. The Syrtis Major area has an average surface T of -21,361° C, while the average surface T in the Terra Tyrrhenaregion would be -45,142° C.
Past studies suggests that in all the terrestrial planets there is a relationship between the heights of the volcanic edifice and depth of their magma source zones (Eaton and Murata, 1960; Vogt, 1974; Epp, 1984). There are 3 assumption for this: (1) there is a continuous

pressure connection via a Newtonian fluid in the volcanic edifice; (2) the lithostatic pressure is the only pressure that appear in the country rocks sourrounding the melt source; 3) the melt that erupt at the volcano summit has a positive buoyancy. We used this equations (Wilson et al., 1992) to find the depth of the magma chambers beneath the Tharsis and Elysium volcanoes:

$$\rho l\ g\ Hs = \rho m\ g\ (Hs + Hv)$$

and thus, to find *Hs*

$$Hs = Hv\ [\frac{\rho m}{\rho l - \rho m}]$$

Where *Hs*is the depth between the surface and the melt source and*Hv*is the height of the volcano above the surface, *ρm* is the density of the magma, and *ρl* is the density of the lithosphere near the volcano; *g* is the acceleration due to gravity. In the case of the Tharsis and Elysium regions on Mars we have that *(ρl - ρm)* is positive and *Hv* is also positive and this can generate the volcanic morphologies (Wilson et al., 1992). We used *ρm* ≈ 2.86 g/cm^{3}and a *ρl* ≈ 3.93 g/cm^{3}according to the average density of the basaltic shergottites on Mars (Bridges & Warren, 2006) and the density of the planetary lithosphere.

Magma chambers on Mars needs to be at a greater depth than Earth in order to remain "neutral bouyancy zones", in fact, the lower gravity (and atmospheric pressure) would exsolve all the gases/melts if an opposite case exist (Wilson and Head, 1983). In fact, by finding *Hv* on the Tharsis volcanoes (Olympus Mons, 21.230 m; Arsia Mons,16.000 m; Pavonis Mons, 14.000 m; Ascraeus Mons, 18.225 m)and Elysium volcanoes (Hecates Tholus, 4.800 m; Elysium Mons, 13.900 m; Albor Tholus, 4.500 m) it is possible to reconstruct, theoretically, how the likely depth of the magma source would be 46.359 mfor the Tharsis region and 20.647 m for the Elysium region.The source depths are average estimates of the entire areas, other studies suggests, for example, a magma chamber depth of ≈ 16.000 m beneath Olympus Mons volcano (Zuber and Mouginis-Mark, 1992). By considering that on Mars we have an increase in pressure of 134 bars for 1 km (El Maarry, 2007; Zuber and Mouginis-Mark, 1992) the magma source pressure could be extrapolated as 6.2 Kbar and 2.7 Kbar for Tharsis and Elysium respectively.

Since that we have the surface temperature of the other regions of the planet that interested this work, we use a relationship/proportion between the Tharsis and Elysium zones and the remnants in order to obtain the average depths. The Amazonis region is similar to Elysium and we consider a magma source pressure of ≈ 2.7 Kbar, while regions as Ganges Chasma, Eos Chasma, Hellas Basin and Syrtis Major have higher surface temperature and their source depth could be approximated to ≈ 800 bars. Argyre Basin, Nili Fossae and Terra Tyrrhena are almost similar to the volcanic regions of Tharsis and Elysium and their pressure of magmatic source could be considered as ≈ 3.5 Kbar.

Successively, these data(geochemistry, pressure of magma chamber, fO_2) were used as input into Petrolog software for thermodynamic modeling of each meteorite. The degree of crystallinity was helpful to find the crystallization temperatures of the samples and the resultant temperature was used to obtain the viscosity for each magma.

3.2 - Subsolidus equilibration temperature and viscosity

By using the Petrolog softwarewas possible to obtain the crystallization T or eruptive T for each sample. In order todo this we inserted likely value of pressure for the depth of the magma chamber, taking into account the difference in gravity of planet Mars (3,711 m/s^2).

Initial condition chosen for the Petrolog runs were P equal to what previous described for each sample (see Chapter 3.1) with a gradient dP/dT = 0, an $fO_2$of QFM as buffer, and an H_2O wt% = 0 for all the samples.For the majority of the samples calculations were stopped when the melts reached 100% of fractionation, in order to chose an eruptive/crystallization temperature close to the value of crystallinity of that sample.

Estimates of the viscosity for each sample have been made basing on geochemical data and on the eruptive/crystallization temperature. In order to model viscosity to be temperature dependence (η) we used the Tammann-Vogel-Fulcher (TVF) equation (Giordano et al., 2008):

$$\text{Log } \eta = A + B/T(K)-C$$

where A is considered constant for all types of melts(A = -4.55±0.21), meaning that for a high-T all melts are at the same value of viscosity; B and C are related to compositional effects.

4 - Discussion

4.1 - Magma viscosity properties on Mars

Results that came from our petrologic modeling indicate a crystallization temperature in a range from 1,120°C to 843°C, while the viscosity vary from $10^{1,43}$ to $10^{5,97}$Pa s (Tab 2). Viscosity seems to be higher in Tharsis, Elysium, Amazonis, and Syrtis Major regions than the other discussed areas.

The Tharsis and Elysium regions on Mars are considered low-viscosity regions in order to generate the large shield volcanoes that characterize these areas (Hiesinger et al., 2007; Vaucher et al., 2009). This should be true for lava flows but, even if the majority of the samples analyzed here have high-viscosity properties (10^4-10^5 Pa s), we also detected some samples from Tharsis and Elysium that have low-viscosity (10^2-10^3 Pa s): this could be explained because of the totally random impacts that occurred on the Martian surface, so that a few of these samples derived from lava flows (low-viscosity) and the remnants from crystallized magma of the crust (relatively high-viscosity).

Name	Type	Crystallization T	Viscosity (log Pa s)	Eruptive style
ALH77005	Lherzolitic Shergottite	1.051,5°C	2,2	effusive
ALH84001	Orthopyroxenite	1.016,5°C	3,04	effusive
Chassigny	Dunite	1.174,8°C	1,43	effusive
DaG476	Shergottite	936.9°C	3,78	effusive
DHO019	Basaltic Shergottite	859.2°C	4,95	explosive
DHO378	Basaltic Shergottite	961.6°C	3,93	intermediate
EETA79001	Shergottite	939.3°C	3,78	intermediate
GoVal	Nakhlite	867.3°C	5,38	explosive
GRV020090	Shergottite	920°C	4,34	intermediate
GRV99027	Shergottite	914°C	3,96	intermediate
Lafayette	Nakhlite	950°C	3,18	effusive
LAR06319	Shergottite	864.9°C	5,33	explosive
LEW88516	Lherzolitic Shergottite	932.4°C	3,64	intermediate
LosAngeles	Basaltic Shergottite	843.3°C	5,97	explosive
MIL03346	Nakhlite	977.8°C	2,94	effusive
Nakhla	Clinopyroxenite	882.1°C	5,07	explosive
NWA480	Basaltic Shergottite	930.1°C	4,59	explosive
NWA817	Nakhlite	965°C	4	intermediate
NWA856	Basaltic Shergottite	934.1°C	4,53	explosive
NWA998	Nakhlite	865.7°C	3,89	intermediate
NWA1068	Shergottite	926.2°C	3,74	intermediate
NWA1950	Shergottite	910.1°C	3,87	intermediate
NWA2737	Dunite	933°C	4,11	intermediate
NWA2990	Shergottite	929.3°C	4,41	intermediate
NWA4480	Basaltic Shergottite	858°C	5,12	explosive
NWA4797	Shergottite	949.2°C	3,27	effusive
NWA4925	Shergottite	912.2°C	4,16	intermediate
NWA5298	Basaltic Shergottite	886.4°C	5,09	explosive
NWA5789	Shergottite	1.092,2°C	2,02	effusive
NWA5790	Nakhlite	929.6°C	5,23	explosive
NWA5990	Shergottite	881.4°C	4,14	intermediate
NWA6162	Shergottite	960.5°C	3,31	effusive
NWA6342	Shergottite	905.4°C	3,92	intermediate
QUE94201	Basaltic Shergottite	886.9°C	5,21	explosive
RBT04261	Shergottite	949°C	3,5	intermediate
SAU005	Shergottite	987.8°C	3,09	effusive
Shergotty	Basaltic Shergottite	1120 C°	2,29	effusive
Y000593	Nakhlite	875.4°C	5,29	explosive
Y793605	Shergottite	913°C	3,98	intermediate
Y980459	Shergottite	1.013,5°C	2,86	effusive
Zagami	Basaltic Shergottite	918.3°C	4,56	explosive

Tab II - Crystallization/eruptive temperature, viscosity, and eruptive style for each sample defined by petrological calculations. Crystallization T for sample GRV020090, Lafayette, and Shergotty was precisely previous calculated by other authors (Jiang & Hsu, 2012; Harvey & McSween, 1992; Dann et al., 2001).

The geomorphological characteristics of the Martian surface suggests that both eruptive behaviour, effusive and explosive, occurred (Baratoux et al., 2009; Vaucher et al., 2009). Shield volcano edifices as well as the impressive length of lava flows are linked with effusive volcanism indicating very fluid lavas (Greelay et al., 2005; Hiesinger et al., 2007), on the other hand, evidences of pyroclastic deposits underlined explosive volcanic activity (Hynek et al., 2003).
Experimental studies (Tomiya et al., 2014) shows as eruptive magmas are divided into low-viscosity type and high-viscosity type with the boundary at about 10^4 Pa s. Thus, according to the differences in viscosity, we classified the eruptive style into effusive (10^1-$10^{3,5}$ Pa s), intermediate ($10^{3,5}$-$10^{4,5}$ Pa s), and explosive ($10^{4,5}$-10^6Pa s).

4.2 - Eruptive style areas and Martian geomorphology

Eruptive style of some volcanic areas of Mars, extrapolated from this study, can be found in Fig. 3 and in a map showing the studied locations in Fig. 4. The general Martian geomorphology of the studied areas seems to be in accord with our results in almost all the cases.

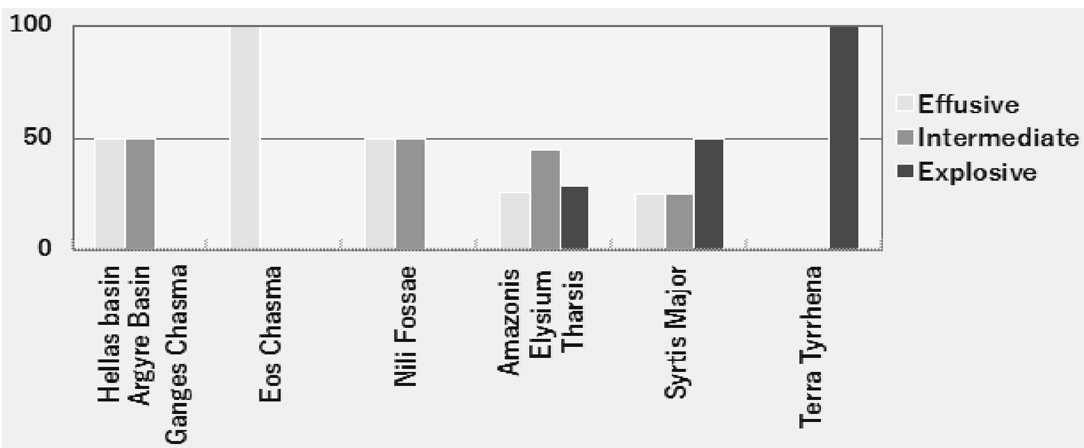

Fig. 3 - Hystogram showing the percentage of likely eruptive behaviour on the Martian surface by basing on the number of meteorites that came from a certain location on Mars.

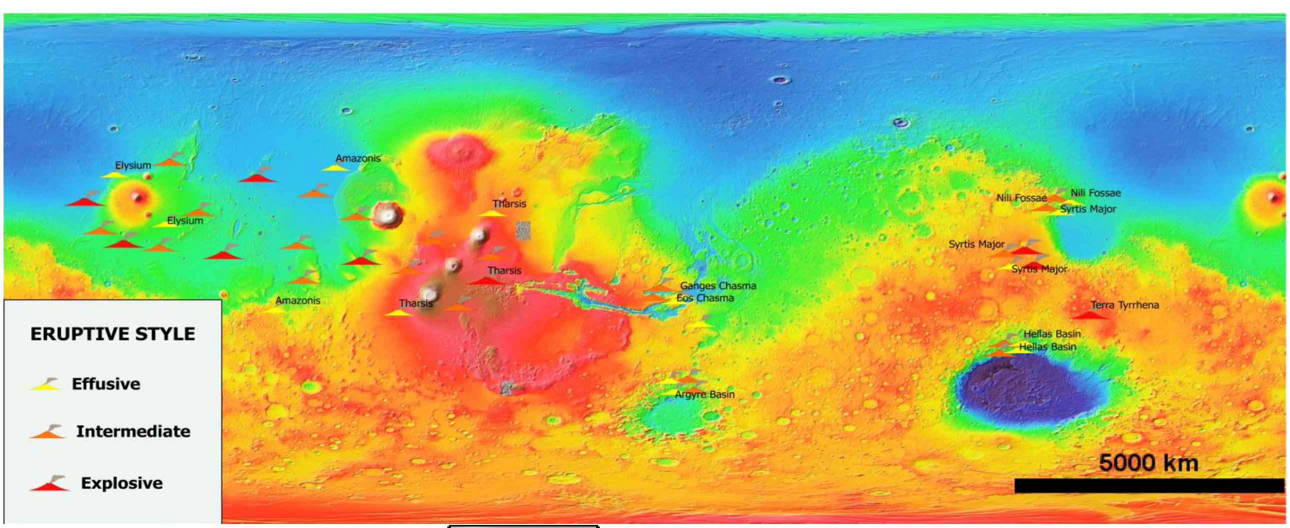

Fig. 4 - Map of planet Mars with representations of the different types of eruptive styles (effusive, intermediate, explosive) for each volcanic areas as analyzed in the present study, by basing on geochemistry of Martian meteorites.

Amazonis, Elysium and Tharsis, that preserve the highest volcanic structures are possibly linked with relatively more viscous lava than the remnant volcanic provinces of Mars, even if in this case the high growth rate of volatiles in the magma due to the lower gravity plays an important role on the eruptive behaviour (Frankel, 2005). Olympus Mons morphology suggest an explosive type of series of eruption in order to form (Hynek et al., 2003), also evidenced from the 6 pit crater formations on his summit, and Hecates Tholus volcano has the unique evidence of a plinian eruption on Mars, while volcanoes as Alba Patera seems to be related to effusive activity, evidenced by numerous pahoehoe lava flows on his flank (Frankel, 2005). In fact, our analysis suggests that these areas are characterized by all the type of eruptive styles (explosive, intermediate, effusive). This would appear also for the Syrtis Major and Nili Fossae regions even if there are no high volcanic structures on that area.

We noticed an effusive/intermediate behaviour for the areas of Hellas Basin, Argyre Basin, Eos Chasma, and Ganges Chasma. As we know from Martian geomorphology, all these areas are impact crater basins (Frankel, 1996) and this likely suggest that magma was erupted on the surface with an effusive behaviour, not linked with the impact (as a lunar mare) but instead by generating fracturization on the planetary crust in that point in order to have plain basaltic effusive volcanism. For the Terra Tyrrhena region we extrapolated an explosive eruptive behaviour, this could be confirmed by ash deposits that derive from the Tyrrhena Patera volcano (Carr, 2006), even if these ashes could derive by magma-ice interaction, althrough we have no much data (only a single meteorite sample) that could derive form this region in order to make a likely hypothesis.

An important thing that a volcano could have during its geological history is a switching in the eruptive behaviour due to changing in chemical/physical/tectonic parameters (Tomiya et al., 2014). Since that we assumed no moving tectonic plates in the planet we only based our study on chemical data obtained by meteorites, and these are also not representative of a whole volcanic region of Mars but they can only approximate the possible behaviour that a volcano had during its history in relation to a specific area.

5 - Conclusion

In this work data about 41 SNC meteorites, derived from the NASA Martian Meteorite Compendium, were used in order to identify whether the Martian surface had different eruptive behaviourson different areas of Mars.Viscosity was used as the main parameter to characterize how eruptive style could differ for each area.

Collected data from the MGS TESand previous studies identified the source regions for almost all the studied SNC meteorites. The depth and the relative pressure of the magmatic sources for each studied region of Mars was extrapolated by using THEMIS data and a relationship with the heights of the volcanic edifices. Successively, the pressure of the magmatic source was used as input into the Petrolog software to find the subsolidus equilibration temperature and, consequently, to enstablish a degree of viscosity for each meteorite sample.

Results indicate a crystallization temperature in a range from 1,120°C to 843°C, follow by a variation in viscosity from $10^{1,43}$ to $10^{5,97}$ Pa s. Viscosity seems to be higher in Tharsis, Elysium, Amazonis, and Syrtis Major regions than the remnant areas. According to past experimental studies about magma viscosity, we classified the eruptive style into effusive (10^{1}-$10^{3,5}$ Pa s), intermediate ($10^{3,5}$-$10^{4,5}$ Pa s), and explosive ($10^{4,5}$-10^{6} Pa s).

The Hellas Basin, Argyre Basin, Ganges Chasma, Eos Chasma, and Nili Fossae regions show an eruptive behaviour between effusive and intermediate, while the Tharsis, Elysium, Amazonis, Syrtis Major, and Terra Tyrrhena regions have a more explosive eruptive style, even if effusive/intermediate activity also occur. Our results seems to be in accord with the Martian geomorphology of the cited areas.

The present analysis is highly approximate because of some petrological and geochemical assumptions that we considered. Althrough, the studied meteorites are not representative of the whole characterization of a certain area of Mars. Future sample return missions and/or data from the Martian surface are essential in order to improve the understanding of the eruptive style in different regions of the planet.

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