Dipartimento
di Scienze della Terra
Sapienza
Università di Roma

Dottorato di Ricerca
in Scienze della Terra

1. Research activity:

Objective

Determination of viscosity and atomic structure of volatile-bearing magmas at high pressure and temperature with implications for their migration in the mantle and the deep cycle of volatile elements throughout the Earth's interior.

Rationale and state of the art

Rheology is a key parameter controlling the dynamics of magmas from the mantle source rock up to volcanic vents and it is strongly dependent on the atomic arrangement. Since rheology exerts a tremendous effect on the eruptive mechanism of volcanoes, the investigation of properties such as viscosity, density and atomic structure of lavas has been a great matter of interest to better assess volcanic hazard. Conversely, very little is known for magmas produced by partial melting at depths of the Earth's mantle, characterized by large amounts of volatiles (CO_2, H_2O). In fact, mantle magmas can contain CO_2 amount as high as 40 wt% decreasing to a few wt% as more SiO_2 is dissolved for higher degrees of partial melting (e.g. Gudfinsson and Presnall 2005) and H_2O up to 4 wt% as testified by mineral-hosted melt inclusions. These magmas can either stagnate at depth or sustain the feeding system of active volcanoes. Therefore, the knowledge of their viscosity and density at conditions of their formation is crucial to determine their mobility and ascent rate. The atomic structure of volatile-bearing melts largely remained uninvestigated, especially if compared to the considerable amount of data available for natural-occurring silicate and industrial/technological glasses (e.g. Rossano and Mysen 2012; Yadav and Singh 2015). Studies aimed to probe the structure of volatile-bearing glasses where either conducted on compositions not representative of mantle magmas (e.g. Genge et al. 1995) or performed ex-situ (e.g. Moussallam et al. 2016). Extrapolation of data collected at ambient pressure to mantle conditions might be misleading as some structural features might not be preserved upon decompression, as highlighted by in-situ studies where extreme HP-T conditions showed a strong influence on the atomic structure, at least in compositions ranging from volatile-free basalt to amorphous silica (Hemley et al. 1986, Williams and Jeanloz 1988, Sanloup et al. 2013). Therefore this study aims to provide insights on the atomic structure of volatile-bearing melts at mantle conditions and investigate its effect on viscosity.

Work plan

The starting materials I will employ are glasses representative of the most primitive compositions of magmas erupted in the active volcanic districts of interest (Mt. Etna, Alban Hills). Glassy samples will be prepared melting either natural powdered rocks or synthetic oxide-carbonate mixtures in the furnace. Volatiles (H_2O and/or CO_2) will be then added to the glass through HP-HT synthesis using either the piston cylinder or the multi anvil press.

In order to achieve the goal of my project I will conduct:

1) Viscosity measurements

In-situ viscosity measurements will be performed using the *falling sphere* technique at 16 BM-B HPCAT beamline of the Advanced Photon Source (Lemont, IL, USA) equipped with the Paris-Edinburgh press at pressures of 0.4-6 GPa and temperatures up to 1700°C. The fall of the sphere in the molten sample will be tracked by ultrafast X-ray radiography using a high-speed camera with a 500 frames per second (fps) recording rate.
Viscosity will then be calculated from the probing sphere terminal velocity using the Stokes' equation including correction factors for the effect of the wall and the end effect.

2) Structural measurements

The structural investigation will be conducted using both X-ray diffraction and vibrational spectroscopy. Melt structure measurements will be conducted using multi-angle energy dispersive X-ray diffraction (EDXD) at high pressure and temperature at the Advanced Photon Source soon after viscosity experiments. The diffraction patterns will be collected for ten fixed diffraction angles (2θ from 3° to 35°). This will allow to determine the structure factor and interatomic distances of T-O (T=Si, Al); M-O (M=Mg, Ca, Fe); M-M; T-T.
Glasses from quenched run products will be investigated using both micro-FTIR and micro-Raman spectroscopy at ambient pressure and high pressure. High pressure will be achieved by means of a diamond anvil cell (DAC). Micro-FTIR measurements will be conducted both at the Department of Physics, Sapienza University of Rome and Elettra Sincrotrone Trieste, whereas micro-Raman measurements will be carried out at the Experimental Volcanology and Petrology Laboratory (EVPLab), Department of Science, Roma Tre University.
Importantly, since for my master's thesis project I investigated viscosity of carbonatite-kimberlite-melilitite melts at HP-T and structural measurements for these compositions have

already been carried out at APS, I will also elaborate these data to obtain a complete range of investigation which allows linking rheology and structure of melts of mantle origin.

I will determine pressure-induced structural transformations of glasses and melts by combining EDXD with micro-Raman and micro-FTIR measurements, elucidating structural properties of deep magmas and major configurational changes that occur upon compression, allowing a quantitative correlation between structural and rheological properties of mantle magmas.

3) Element partitioning measurements

Viscosity experiments allow also measurements of element partitioning as function of pressure, temperature and determined viscosity between the quenched melt and a liquidus phase that have been observed to form during the 3hours of melt structure measurements. Trace elements will be measured using Laser-Ablation ICP-MS. Because few viscosity data are available at high P-T using the falling sphere technique, I like to point out that the effect of viscosity on the element partitioning have not been proposed so far. Such a study would imply the use of trace elements on olivine and/or cpx as *rheological markers*.

Experimental run products will be analysed by FE-SEM and EPMA for textural and chemical analysis and FTIR for volatile content determination.

References

Genge et al. 1995, Geochim. Cosmochim. Acta 59, 927-937
Gudfinnsson and Presnall 2005, J Petrol 46, 8, 1654-1659
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Moussalam et al. 2016, Earth. Planet. Sci. Lett. 434, 129-140
Rossano and Mysen 2012, EMU Notes in Mineralogy, 12, xvii + 504 pp., Chapter
Sanloup et al. 2013 Nature 503, 104–107.
Williams and Jeanloz 1988, Science 239, 902-906.
Yadav and Singh 2015, RSC Advances 5(83), 67583-67609

2. Research products

a) Publications (ISI journals)

- Stagno, V., **Stopponi, V.,** Kono, Y., D’Arco, A., Lupi, S., Romano, C., Poe, B.T. Poe, Foustoukos, D., Scarlato, P., Manning, Craig E. (2020). *The viscosity and atomic structure of volatile-bearing melilititic melts at high pressure and temperature and the transport of deep carbon.* Minerals, 10(3), 267.
- Stagno, V., Kono, Y., **Stopponi, V.**, Masotta, M., Scarlato, P., Manning, C.E. *(2020). The viscosity of carbonate- silicate transitional melts at Earth’s upper mantle P-T*

conditions by in-situ falling-sphere technique. In Manning, C.E., Lin, J-F., Mao, W. (Eds) Carbon in Earth's Interior, Geophysical Monograph 249, 223-236.

- Stagno V., **Stopponi V**., Kono Y., Manning C.E., Irifune T. (2018). *Experimental determination of the viscosity of Na_2CO_3 melt between 1.7 and 4.6 GPa at ~1200-~1700 °C: Implications for the rheology of carbonatite magmas in the Earth's upper mantle.* Chemical Geology 501, 19-25

b) Publications (NON ISI journals)

c) Abstracts

- **Stopponi V**., Stagno V., Kono Y., Hrubiak R., Misiti V., Scarlato P., Gaeta M. (2020). *Experimental constraints on mobility of volatile-bearing magmas and timing of melt-rock interaction in the Earth's upper mantle. Session S7.* Conferenza Rittmann, Catania, Italy.
- Stagno V., **Stopponi V.**, Kono Y., Romano C., Poe B.T., Lupi S., D'Arco A., Hrubiak R., Scarlato P. Bonechi B., Perinelli C., Gaeta M., Manning C.E. (2019). *Viscosity and atomic structure of CO_2-bearing magmas in the Earth's interior.* Goldschmidt Abstracts, 2019 3193.
- **Stopponi V**., Stagno V., Kono Y., Manning C., Scarlato P., Irifune T. (2018). *Experimental measurements of viscosity and melt structure of CO_2-bearing melts at high pressure and temperature*. Session S20 Congresso congiunto SGI-SIMP Catania, Italy.
- **Stopponi V**., Stagno V., Kono Y., Scarlato P., Irifune T. (2018). *Viscosity and melt structure of CO_2-bearing melts in the Earth's upper mantle: implications for the mobilization, ascent rate and emplacement of carbonatite rocks over time.* Geophysical Research Abstracts Vol. 20 EGU2018-1109-1, 2018. Session GMPV3.2/GD2.5/TS2.7 EGU General Assembly 2018, Vienna, Austria.
- **Stopponi V**., Stagno V., Kono Y. (2017). *Experimental viscosity measurements of carbonatitic magmas at pressures and temperatures of the Earth's upper mantle.* Third DCO Early Career Scientist Workshop to study Mt. Etna, Nicolosi, Italy.
- Stagno V., Kono Y., Greaux S., Kebukawa Y., **Stopponi V**., Scarlato P., Lustrino M., Irifune T. (2017). *From carbon in meteorites to carbonatite rocks on the Earth's surface (keynote lecture)* Session 05g Goldschmidt Conference, Paris, France.
- Stagno V., Kono Y., **Stopponi V.**, Scarlato P., Lustrino M., Irifune T. (2017). *An experimental study on the origin and emplacement of carbonate-rich melts through time.* Third DCO International Science Meeting, St. Andrews, Scotland.