High temperature in-situ emissivity study of basaltic dry magmas

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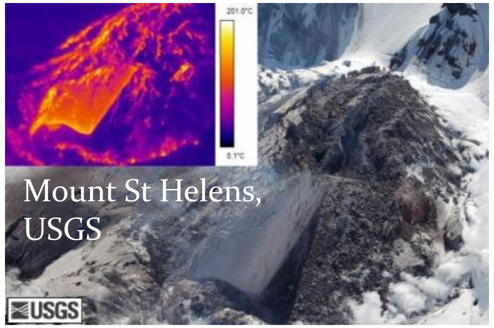
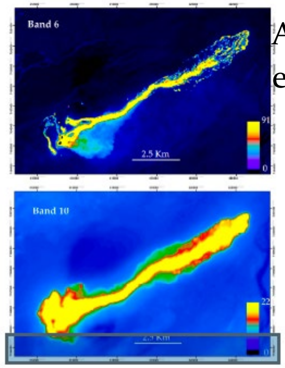
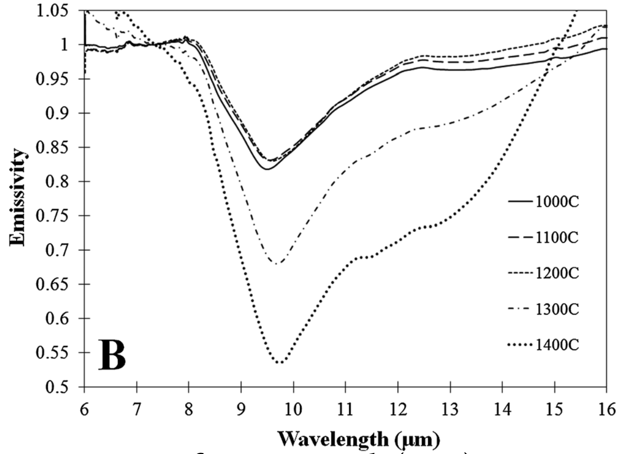
Context





Aufaristama et al. (2018)

- Volcanic eruptions are regularly monitored by remote sensing (RS).
- The accuracy of these RS techniques depends on crucial parameters such as spectral emissivity (ε).
- In litterature, ε is mostly considered constant for a given rock family or is estimated indirectly from Reflectance data (Harris 2013); for example ε = 1 or 0.95 in the case of basalts.
- To date, only a few studies have measured laboratory in-situ ε at relevant magmatic T: Lee et al. (2013), Rogic et al. (2019a, b), Ramsey et al. (2019), and Thompson and Ramsey (2020)
  - ε is measured in limited spectral range: 5-16 μm (2000-625 cm^{-1}).
  - Most data are acquired in limited temperature range: i.e. at T≤ glass transition. Only in Lee et al. (2013), T reaches 1400 °C.
  - Results show that ε decreases with T in TIR range (8-14 μm)
    - → Emissivity of melt (ε_{hot}) < Emissivity of crystallised lava (ε_{crust}). ⟶



Ex from Lee et al. (2013):
ε decreases with T in TIR range.

- These determined ε values do not allow to obtain reliable modeling results → overestimation of radiant flux measured by RS and modelled distance-to-run of lava.

To solve this issue: high temperature and broad spectral range ε data are necessary!

This work is aimed at determining the in-situ Emissivity response of three basalts over a range of magmatic temperatures (up to 1300 K) in the TIR-MIR-SWIR spectral regions (500-8 000 cm^{-1}).

In-situ emissivity measurements (De Sousa Meneses et al. 2015)

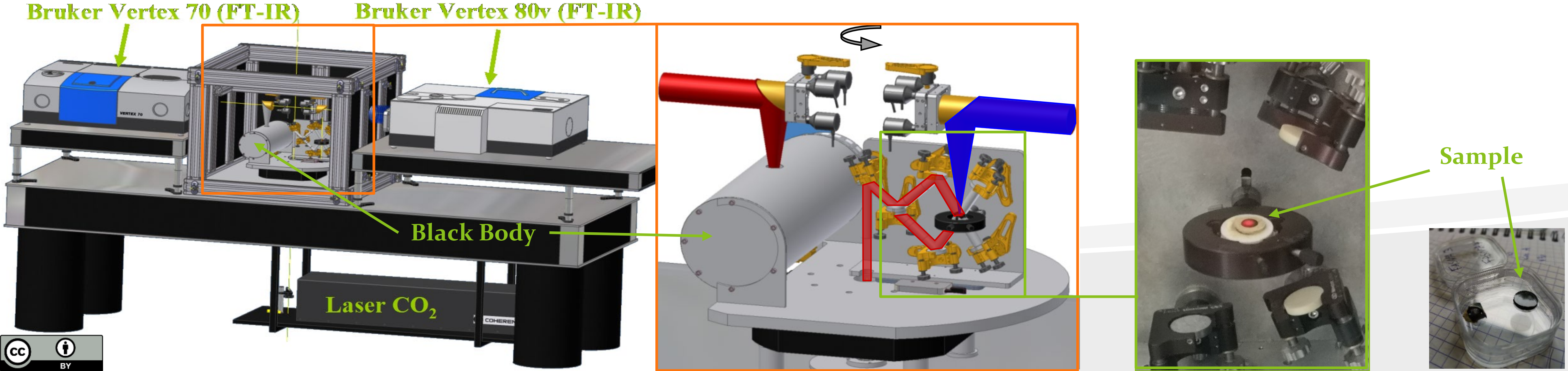
- Apparatus developped at CEMHTI (Orléans, France):
  - two FTIR spectrometers (Bruker 80v and 70) + CO_2 Coherent K500 laser + sample chamber
    - Sample chamber: turntable with sample holder + Black Body furnace (Pyrox PY8)
  - Wide spectral range 20-18 000 cm^{-1}, NIR-MIR-TIR →
  - High Temperature range from ambient to 2000 °C
  - Solid cylindrical glass samples of 1.5 x 10 ϕ mm

Spectrometer	Spectral range (cm^{-1})	Beam splitter	Detector
Vertex 80v	[20, 600]	Multilayer	Bolometer
Vertex 80v	[380, 5000]	Ge/KBr	DLaTGS/KBr
Vertex 70	[380, 5000]	Ge/KBr	DLaTGS/KBr
Vertex 70	[3800, 10,000]	Vis/CaF_2	InGaAs
Vertex 70	[9000, 18,000]	Vis/CaF_2	Si-diode

$$E(\sigma, T, \theta) = \frac{L(\sigma, T, \theta)}{L^0(\sigma, T)}$$

- Emissivity is determined using direct method (see Eq. enclosed), method validated for phonolites in Li PhD thesis (2018).

- Temperature is calculated via the Christiansen wavenumber (i.e. where ε =1) with uncertainty ~1 %).

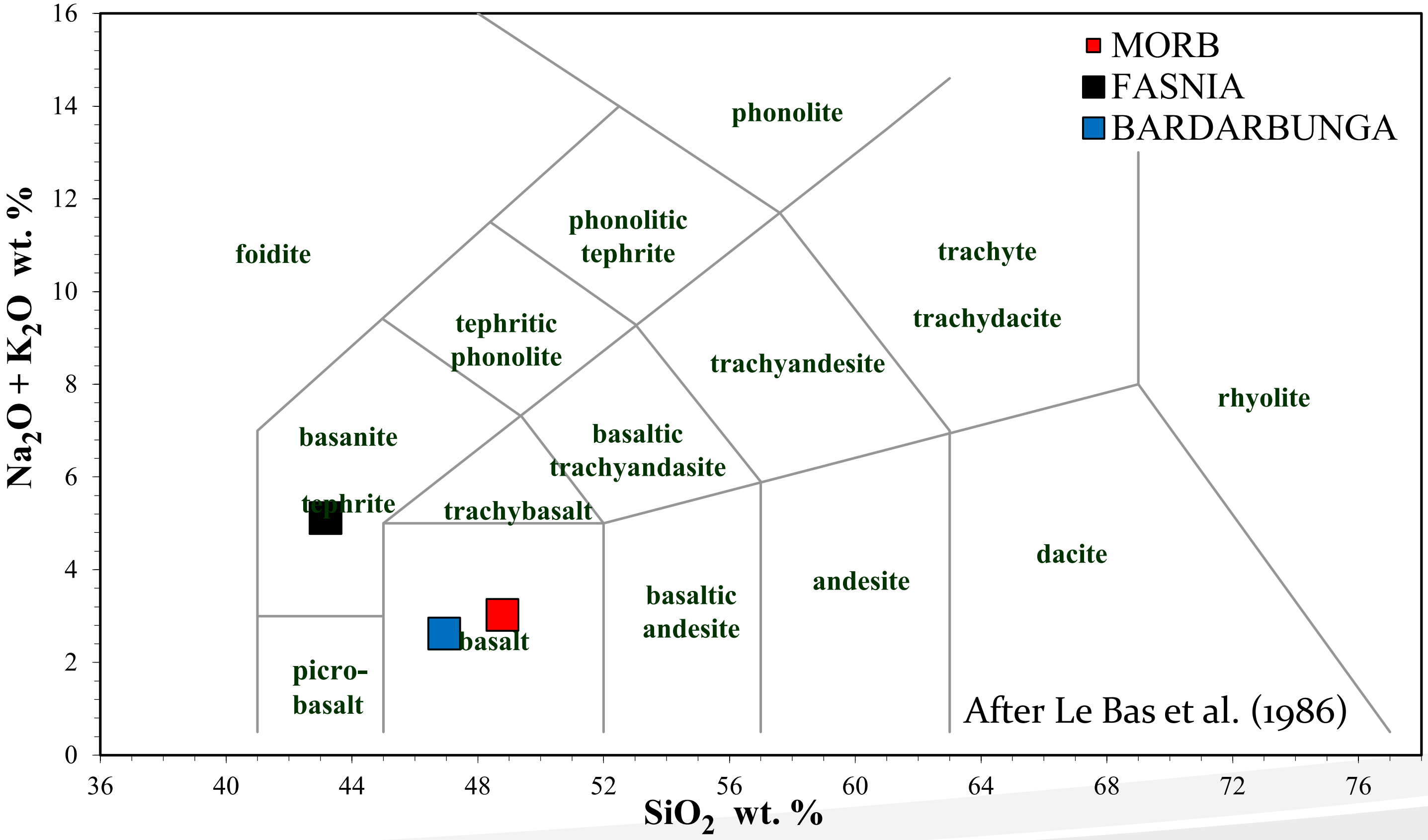


Glass Samples

Holuhraun 2014-2015, Bardarbunga volcano (Iceland)

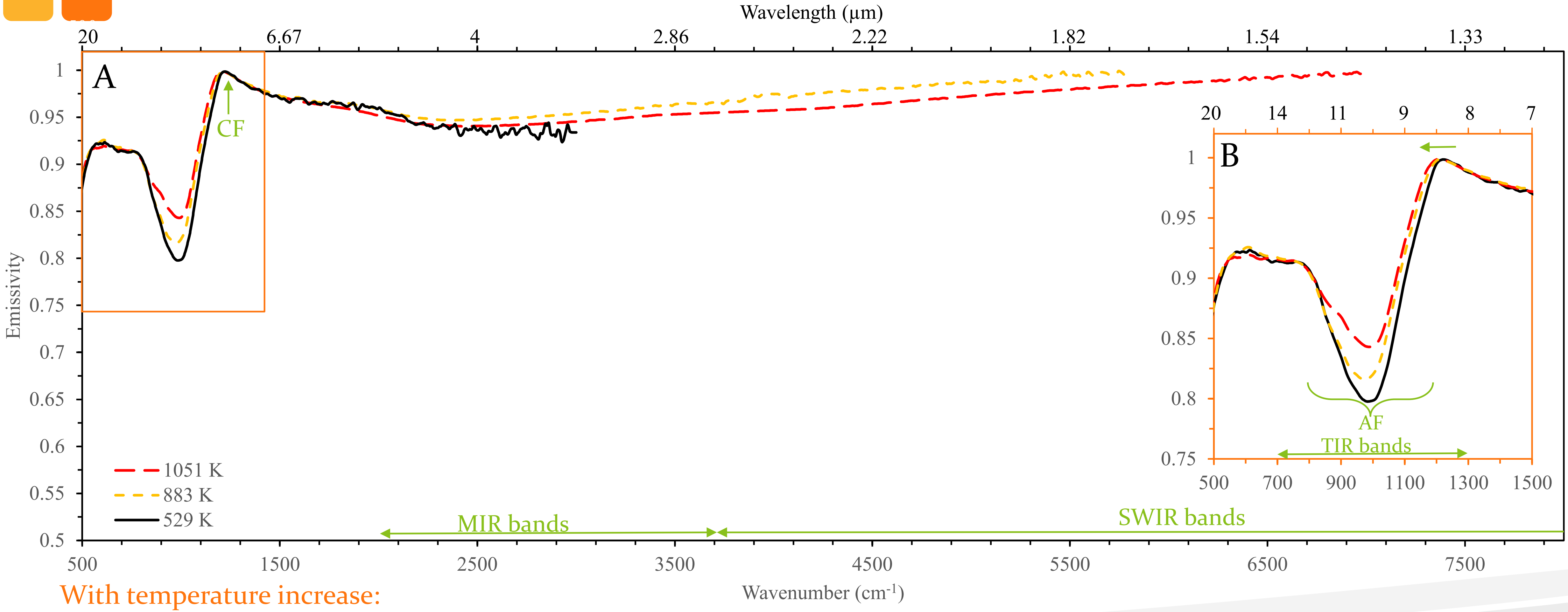
El Teide (Teneriffe, Canary Island) (credit: M. Jimenez)

- **Basalt: MORB** (Juan de Fuca, provided by Prouteau et al. 2001)
  - 48.8 wt. % SiO2 + 3.0 wt. % Alkali
- **Basalt: 2014-2015 Holuhraun** (Bardarbunga, provided by U. Iceland-A. Hoskuldson)
  - 46.9 wt. % SiO2 + 2.6 wt. % Alkali
- **Basanite: 1704-1705 Fasnia** (Tenerife Canary Island)
  - 43.2 wt. % SiO2 + 5.1 wt. % Alkali



Textural, chemical and structural characterisation before and after IR measurement: SEM, EMPA and µRaman spectroscopy.

Results – Thermal emissivity of MORB (Juan de Fuca)

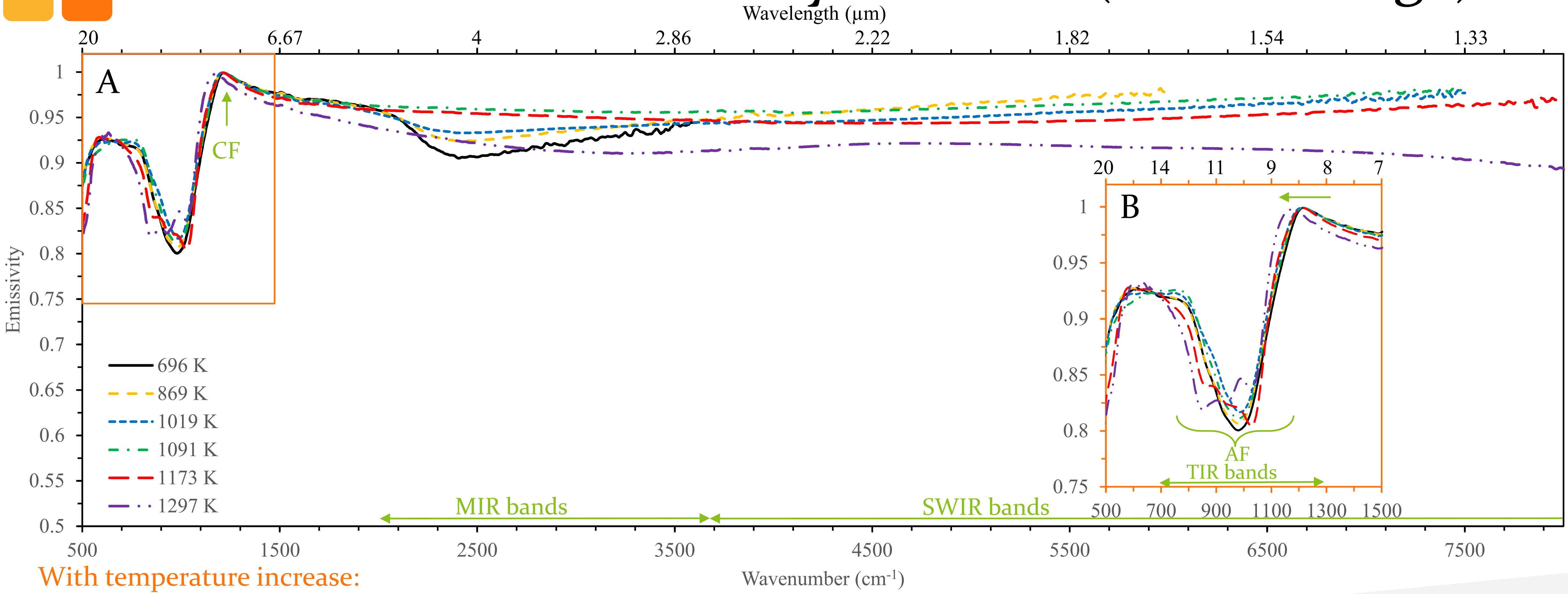


With temperature increase:

- ε increases in TIR range from 0.80 to 0.85 at 10 µm.
- In MIR and SWIR; ε shows very high, constant values (~0.95), close to a black body behavior.
- Absorption feature (AF) → vibrations of silicate network.
- The Christiansen feature (CF, around 1230 cm^{-1}) shifts towards lower wavenumber.

Holuhraun 2014-2015,
Bardarbunga volcano
(Iceland)

Results –thermal emissivity of Basalt (Bardarbunga)

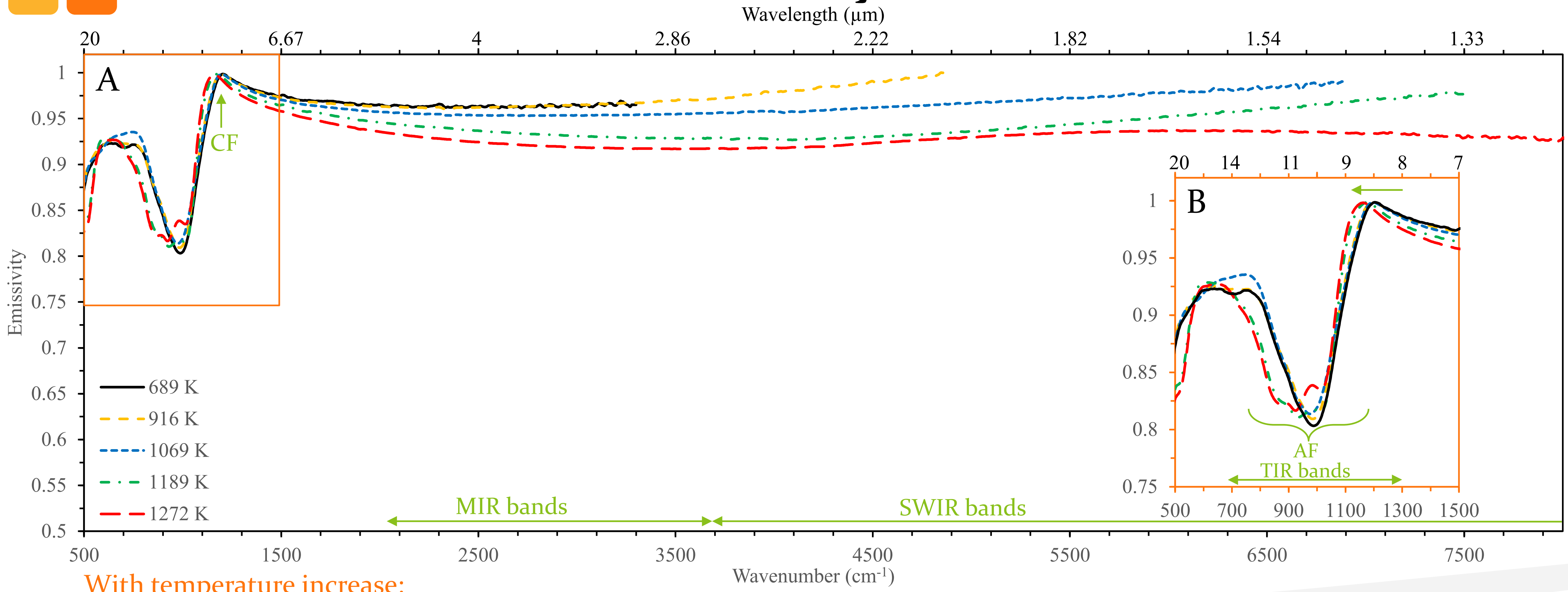


With temperature increase:

- ε increases in TIR range from 0.80 to 0.84 at 10 µm.
- ε almost constant (~0.95) in MIR and SWIR until 1173 K. With further T increase, ε slightly decreases to 0.90.
- Modifications of Absorption feature (AF) at T> 1173 K and shift of Christiansen feature (CF, around 1215 cm^{-1}) to lower wavenumber. → structural reorganization of glass network.

El Teide
(Teneriffe,
Canary Island)

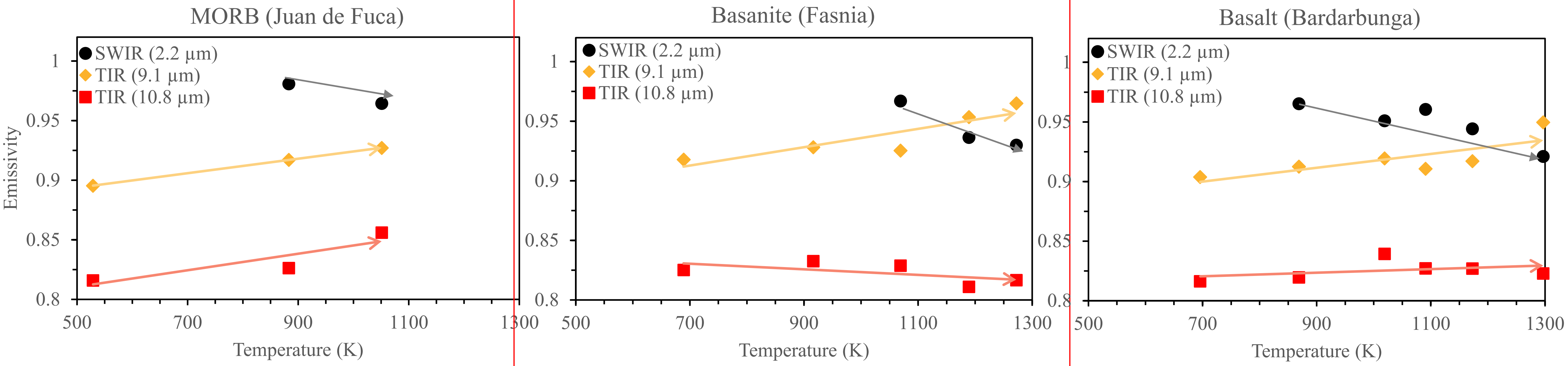
Results – Thermal emissivity of Basanite (Fasnia)

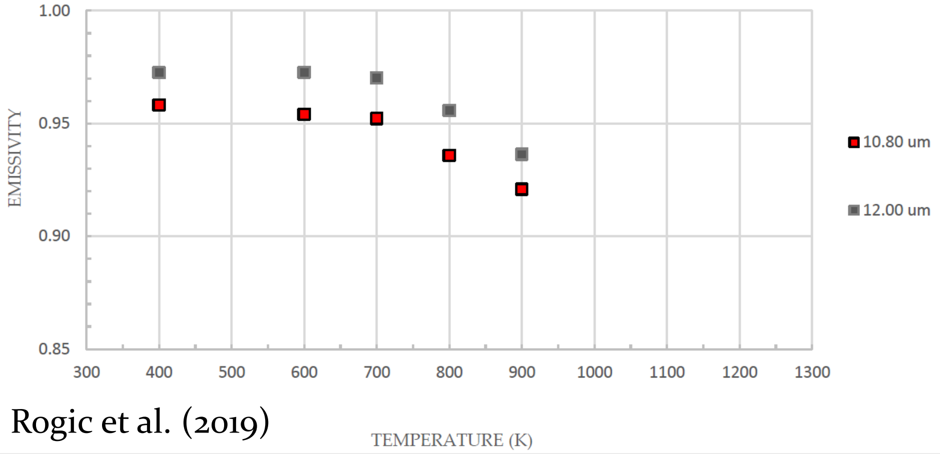


With temperature increase:

- ε increases in TIR range from 0.80 to 0.84 at 10 µm.
- ε almost constant (~0.95) in MIR and SWIR until 1069 K, With further T increase, ε slightly decreases to 0.91.
- Modifications of Absorption feature (AF) at T> 1069 K and shift of Christiansen feature (CF, around 1210 cm^{-1}) to lower wavenumber → structural reorganization of glass network.

Application – Emissivity for SWIR/TIR bands





Rogic et al. (2019)

- $\varepsilon_{10.8\mu m} < \varepsilon_{9.1\mu m} < \varepsilon_{2.2\mu m}$, except at >1190 K.
- Similar behavior between basalts and basanite.
- ε_{SWIR} decreases with T (from 0.97 at ~1100 K to 0.92 at ~1300 K).
- ε values remain high (>0.8) and slightly increases with T (light green arrows).
- MORB composition approaches Etna composition (Rogic et al. 2019).
  - $\varepsilon_{MORB} < \varepsilon_{Etna}$ at 600, 700 and 900 K.
  - at 10.8 µm: ε increases or remains constant with T (this study) VS ε decreases with T (Rogic et al. 2019).

Discussion

Our study	Litterature
Overall ε increase with T in TIR in all basalt samples.	**Overall ε decrease with T in TIR in all studies** **(Lee et al. (2013), Rogic et al. (2019a, b), Ramsey et al. (2019), and Thompson and Ramsey (2020)).**
ε shows almost a blackbody behavior in MIR and SWIR.	No data in MIR and SWIR.
Absorption feature (8.5-12 μm): vibration variations of Si/Al/Fe silicate tetrahedra in Restsrahlen bands = Rearrangement in the disordered glass structure at highest T.	Absorption feature between 8.5-12 μm.
Overall ε values remains above 0.80 within all conditions applied. In TIR: Emissivity of melt (ε_{hot}) > Emissivity of crystallised lava (ε_{crust}).	ε values are variable: - Ramsey et al. (2019): $\varepsilon_{hot}(0.60) < \varepsilon_{crust}(0.95)$ - Lee et al. (2013): ε from 0.50 to anomalous values >1 between 6-16 μm. - Rogic et al. (2019a, b): ε above 0.90
Basalts and basanite present similar ε behavior.	Rogic et al. (2019a, b): ε behavior of Etna basalts differs from the basalts presented here.
	Lee et al. (2013): large ε variations at T>1200 K.

Conclusion

- Emissivity is dependent of:
  - Composition
  - Wavelength
  - Temperature
- Emissivity increases with temperature in TIR, and remains constant, close to blackbody behavior, in MIR and SWIR until 1069 K for Fasnia and 1091 K for Bardarbunga. Then decreases in T range where structural modifications were detected.
- Basanite and basalts have similar emission behaviours, similar to Fe-rich phonolites (Li PhD (2018), Li et al. in prep).
- In-situ Laboratory ε must be compared to field data.

Improvements on E uncertainty will enhance our capacity to better constrain kinetic T and surface radiance from RS and accurately model lava flows with appropriate rheological evolution; information that are crucial to improve hazard assessment in volcanic systems.

Thank you for reading me...

25/10/19 Piton de la Fournaise (credit: R. Bouhet)

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