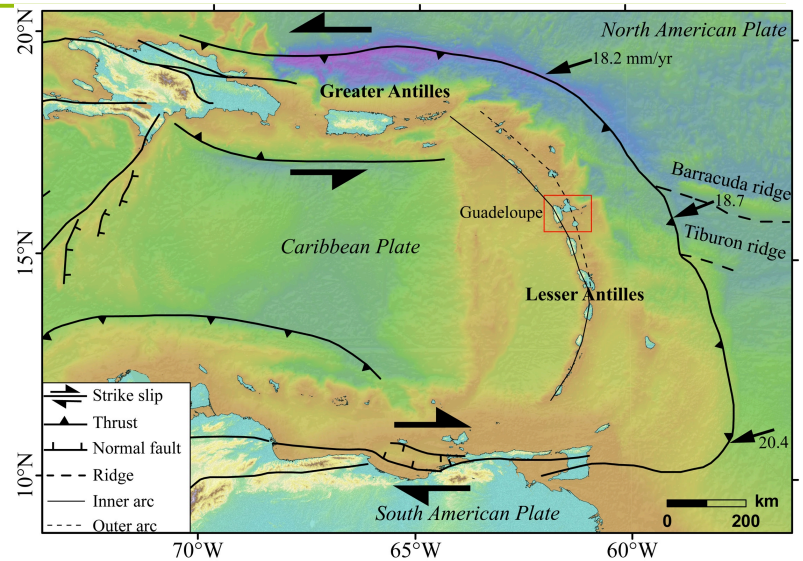
Thermo-physical properties of volcanic rocks and impact of hydrothermal alteration

Vivien NAVELOT[1], Alexiane FAVIER[3], Yves GERAUD[1], Marc DIRAISON[2], Michel CORSINI[3], Jeanne MERCIER DE LEPINAY[2] and GEOTREF Team

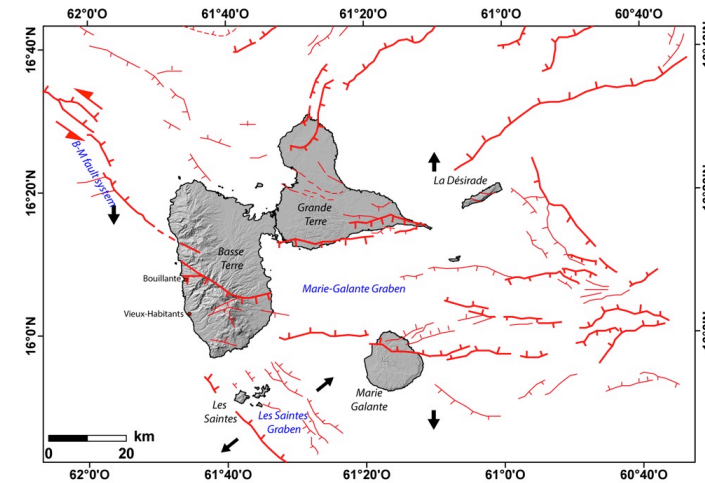
[1]GeoRessources Lab, ENSG-Université de Lorraine, Nancy, France.
[2]IPGS, Université de Strasbourg, Strasbourg, France.
[3]Geoazur, Université de Nice, France

General context

- The **Caribbean** volcanic active Islands offer a favorable environment to develop **high enthalpy geothermal energy**
- Many geothermal projects aim at creating electrical power plants:
  - Martinique
  - Dominica
  - St Kitts (*see Diraison et al. poster*)
  - **Guadeloupe** (Bouillante geothermal plant since 1980's and recently the multidisciplinary **GEOTREF** project) (*see GEOTREF TEAM poster*)



Modified from Bouysse et al., 1990, Feuillet et al., 2002 and Symithe et al., 2015

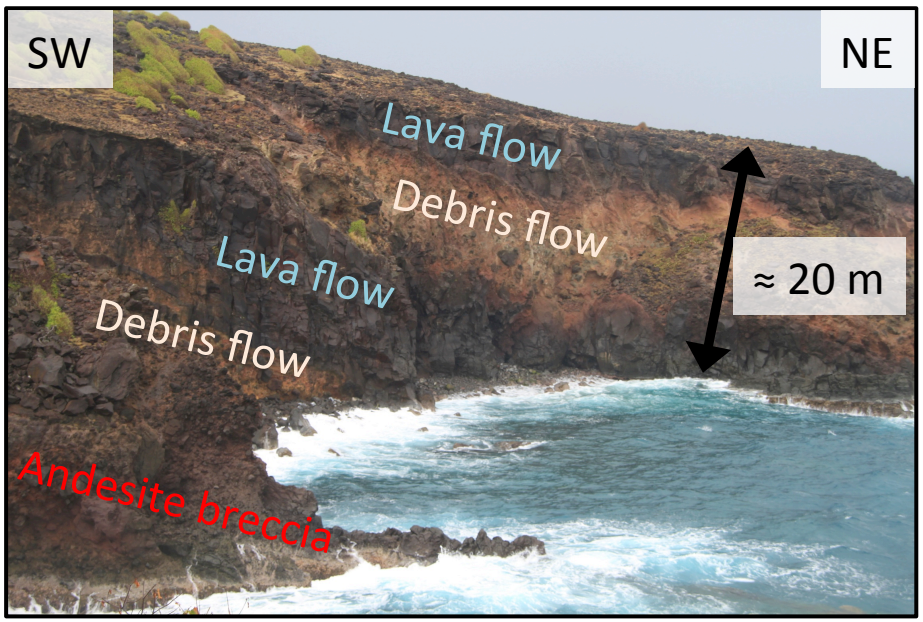


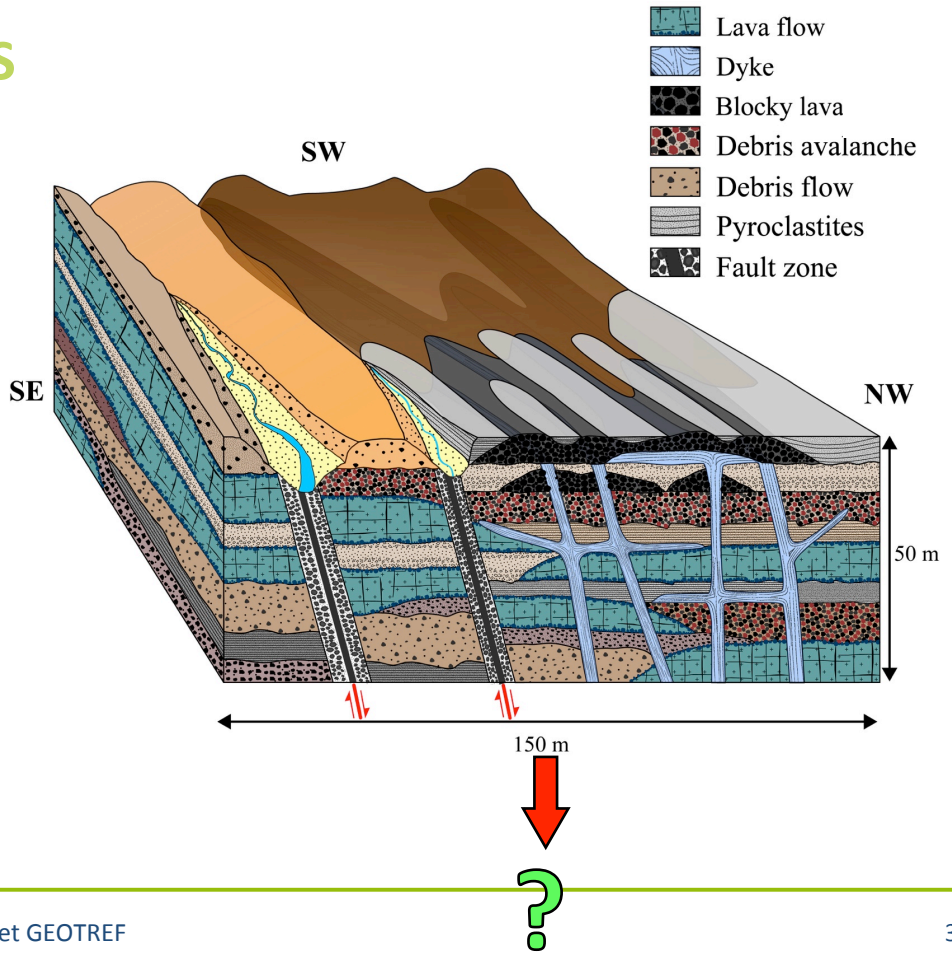
Modified from Feuillet et al., 2010, Leclerc et al., 2014

The issues to study geothermal system

- The **geometry** of deposits are highly **heterogeneous** (volume, extension…)
- Fresh rock-types are hetrogeneous + advancing **hydrothermal alteration**
- **Few drilling data** in the Caribbean Islands

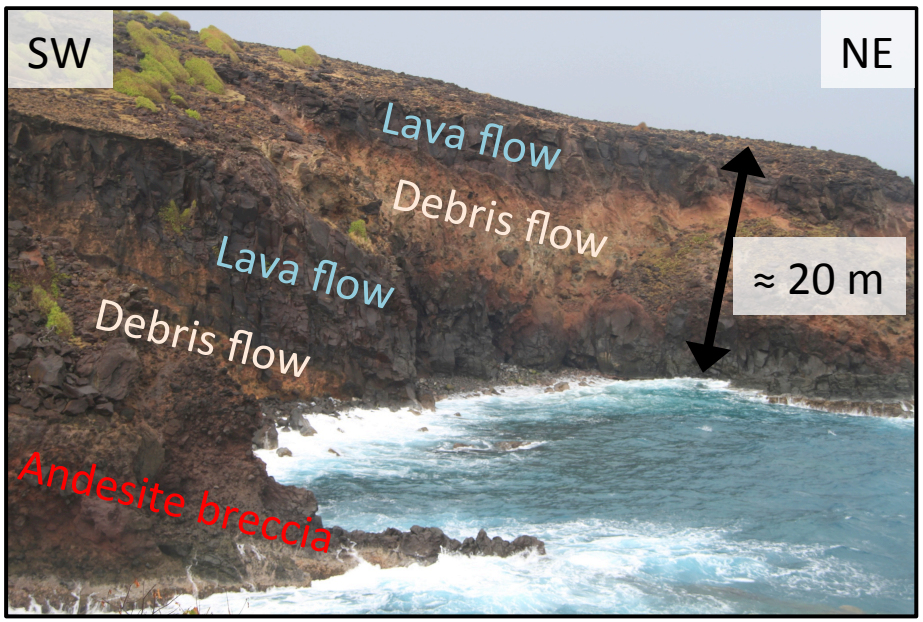
➔ **NEED TO FIND SURFACE ANALOGS**

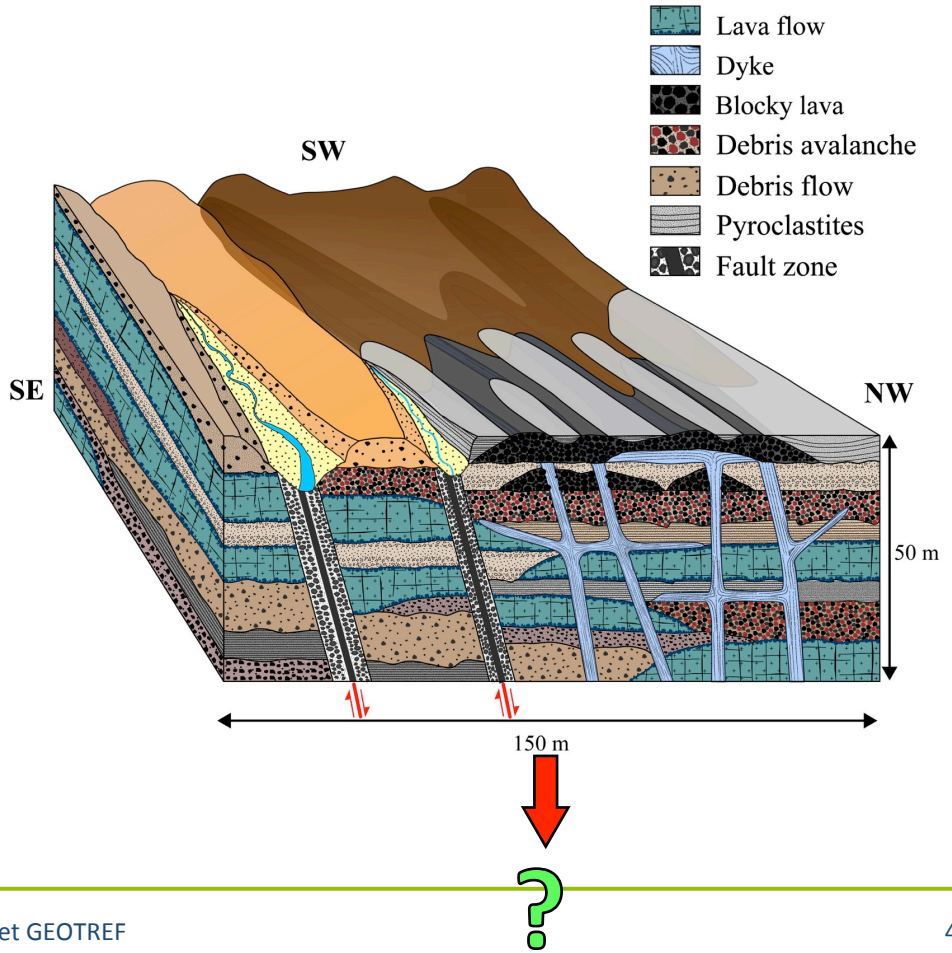




What we propose

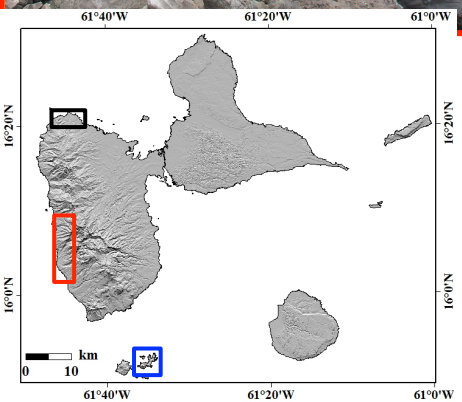
- Characterize **physical properties** of outcropping rocks
- Identify preferential rock-types for fluids flows and/or heat transfer
- Propose a **model** to explain a **geothermal system** in this volcanic environment





Outcrops

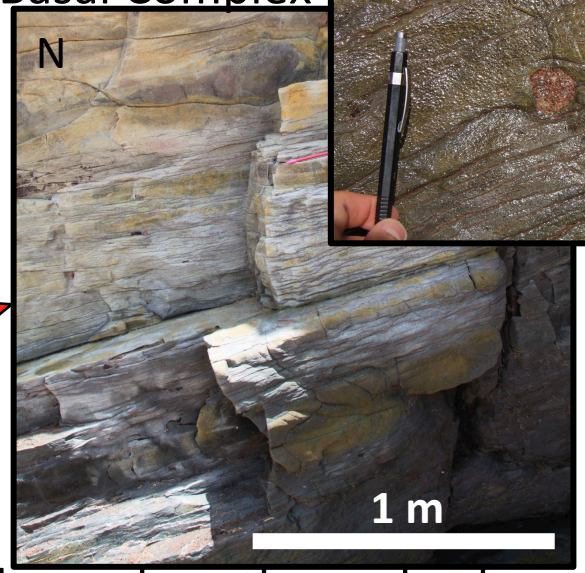
SURFACE: Fresh andesites
Vieux-Habitants area



BELOW VIEUX HABITANTS AREA ???

OR

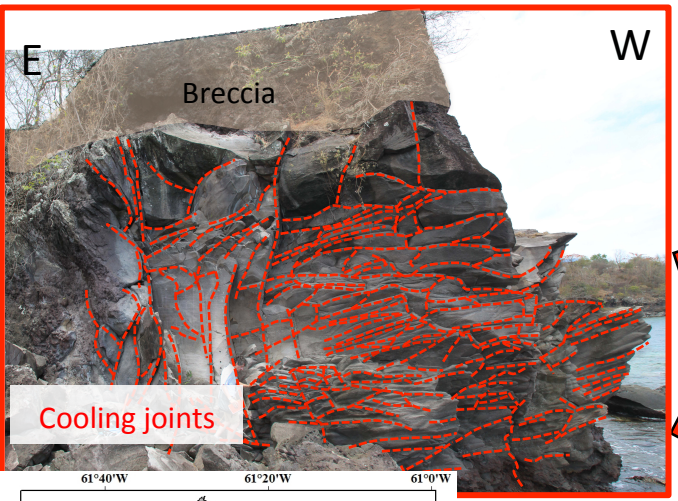
Meta-andesite
Basal Complex

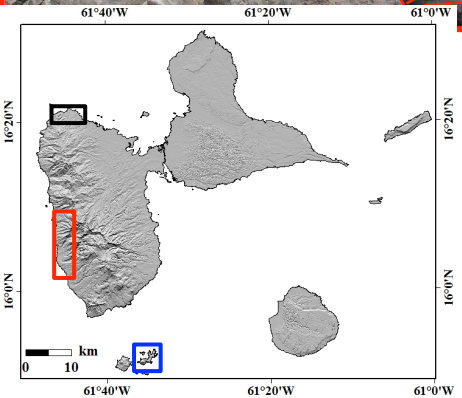


Exhumed geothermal paleosystem
Terre-de-Haut

Outcrops

SURFACE: Fresh andesites
Vieux-Habitants area





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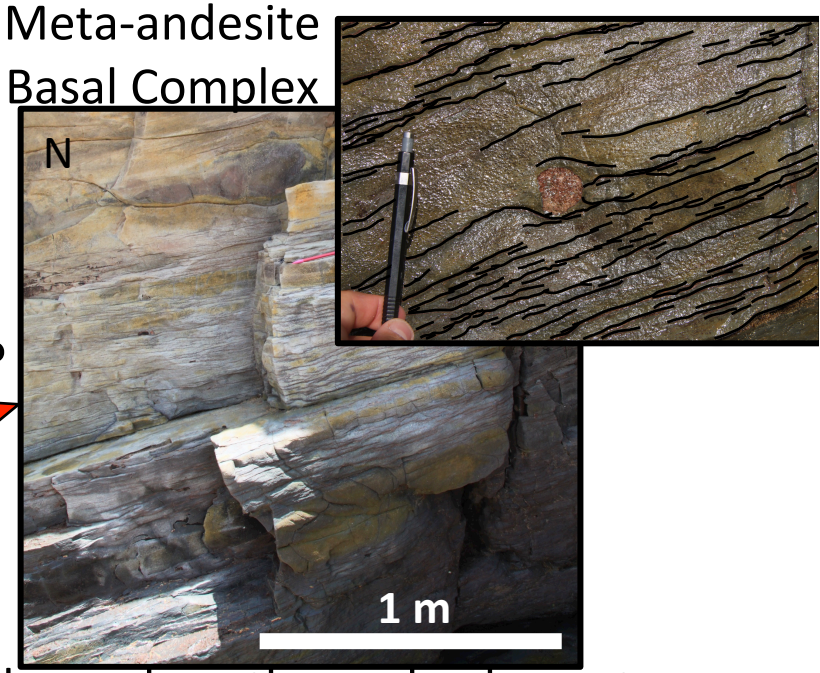
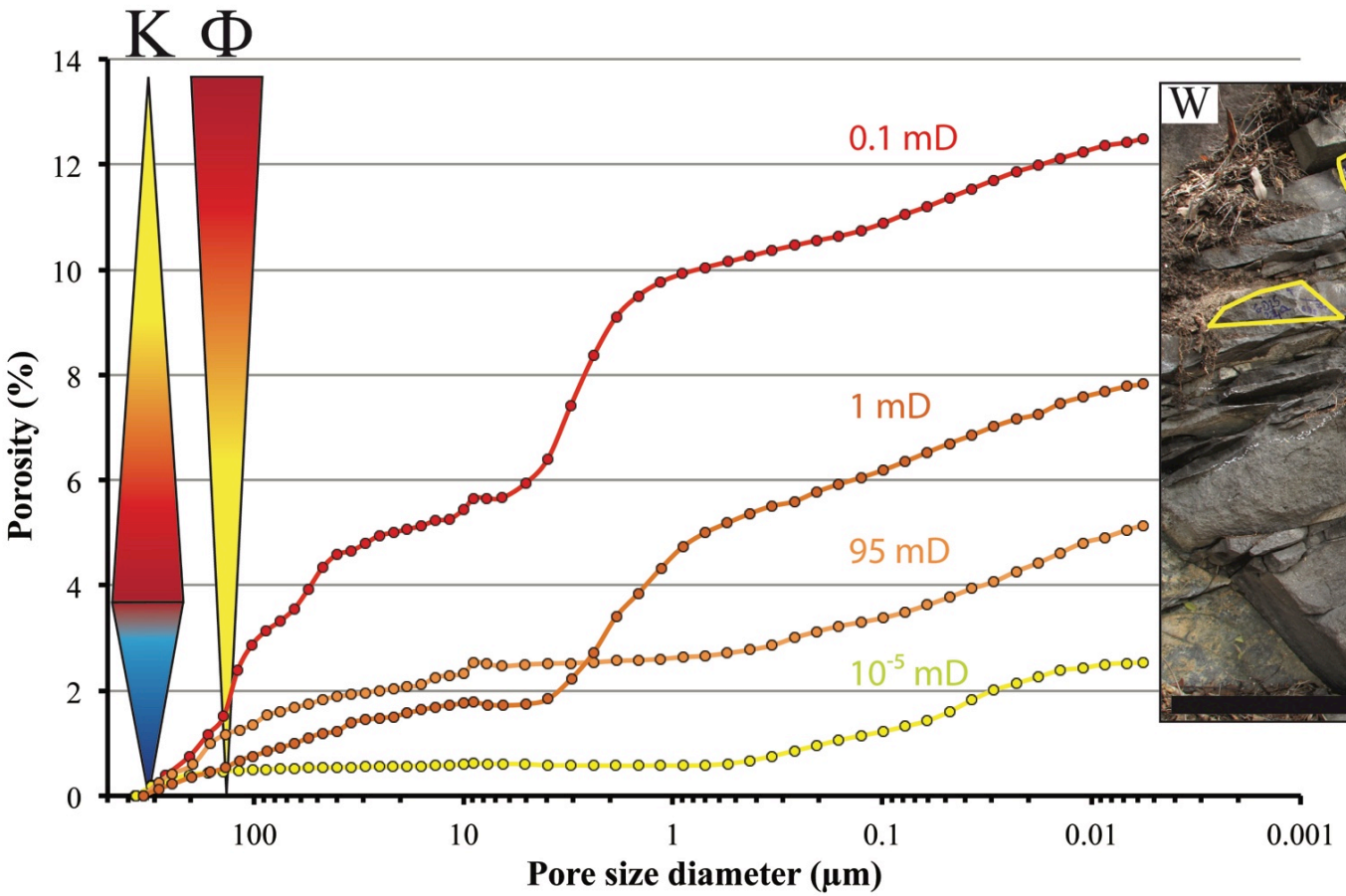
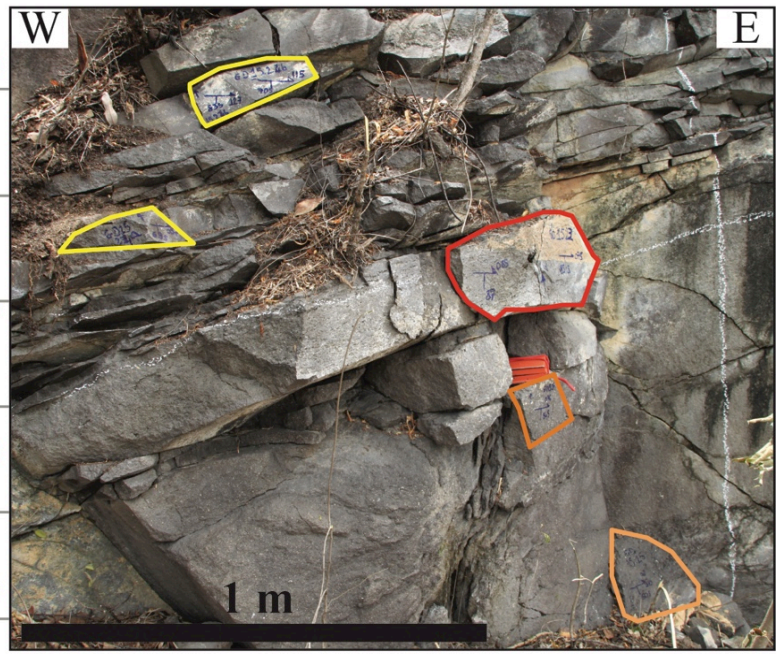


Exhumed geothermal paleosystem
Terre-de-Haut

Heterogeneities in fresh andesites lava flows

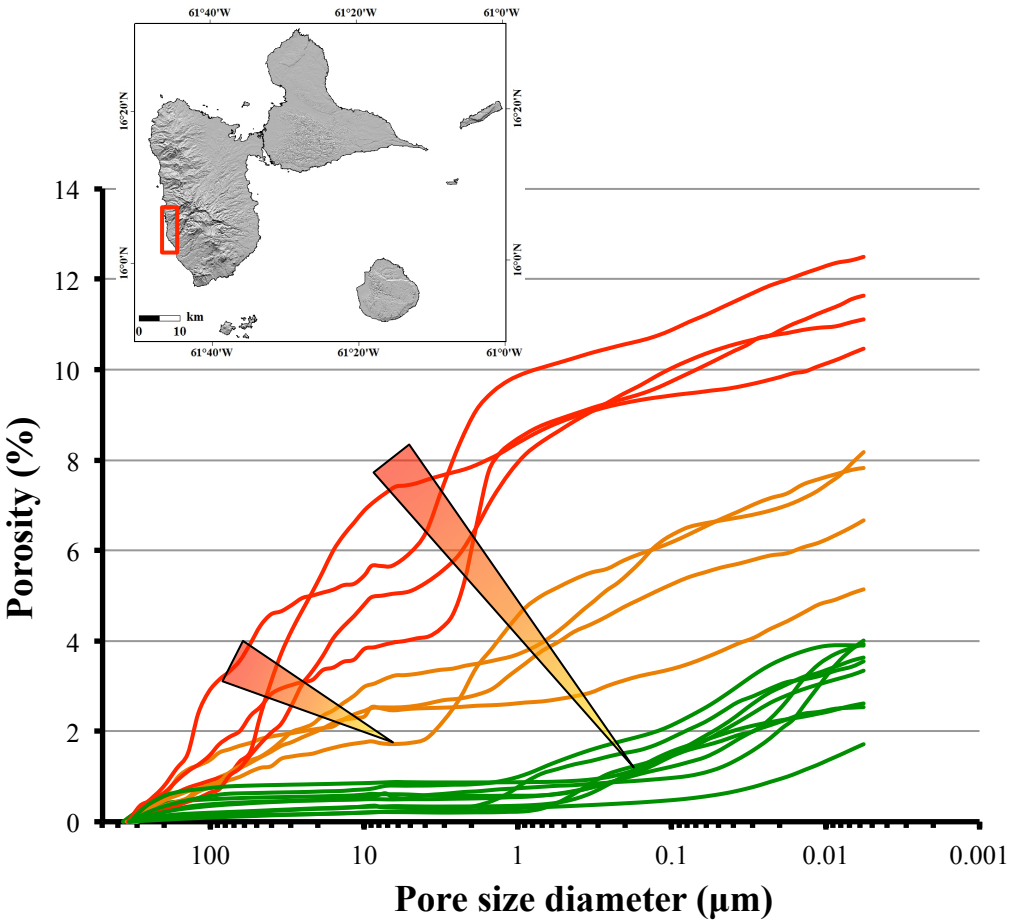
- 4 samples in the same lava flow
- Matrix porosity and permeability display large range of values

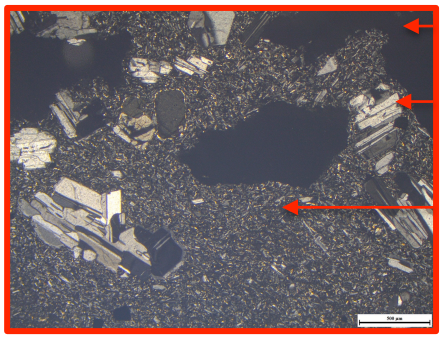




Porosity of fresh andesites

- Bouillante / Vieux-Habitants area (≈ 1 – 0.4 Myr): 3 major rock-types depending on the value of connected porosity and the pore size diameter



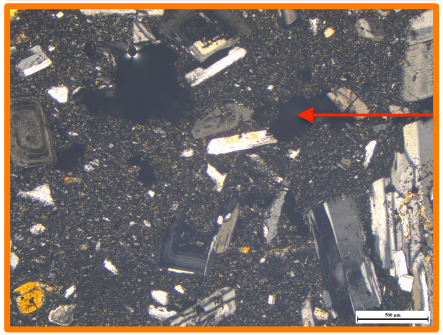


Large open pore

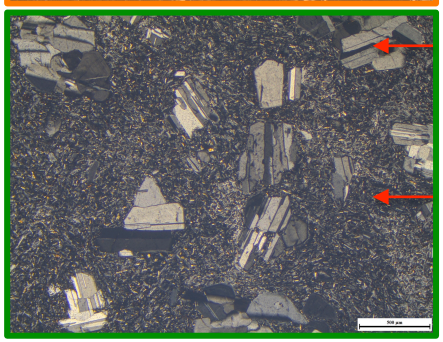
Phenocrysts

Matrix:

- Plagioclases
- Pyroxenes
- Amphibole
- Opaque minerals



Small and large open vesicles



Phenocrysts of constant size

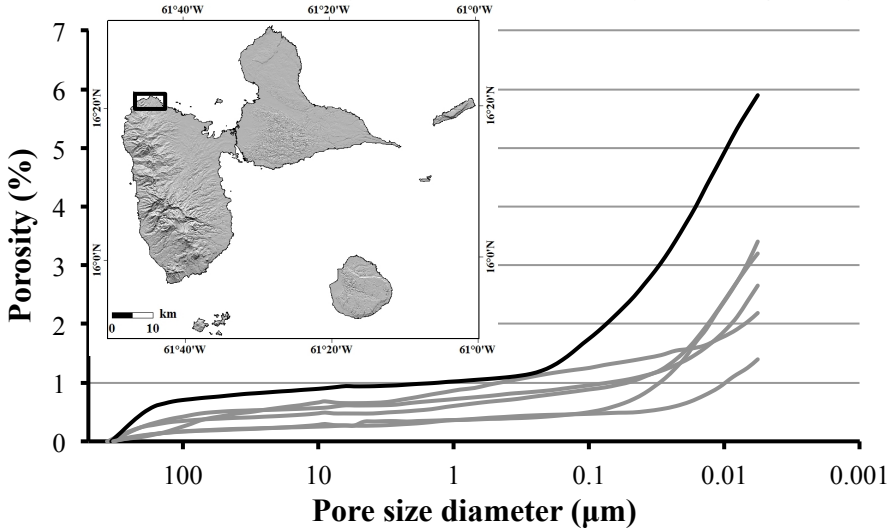
Matrix:

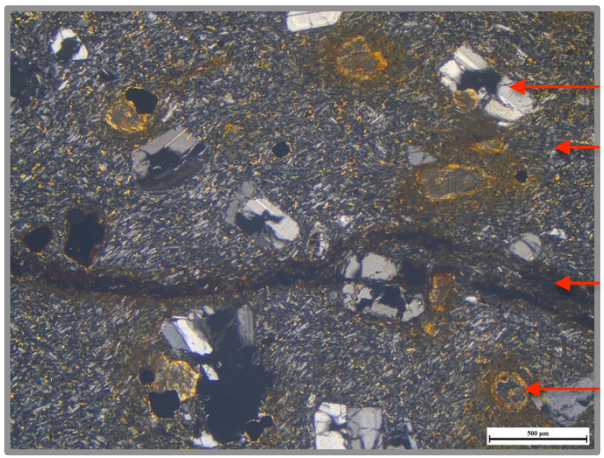
- No visible pore

➔ Thin and homogeneous porous network

Porosity of hydrothermalized andesites

- Basal Complex (≈ 2.7 Myr): slightly hydrothermalized





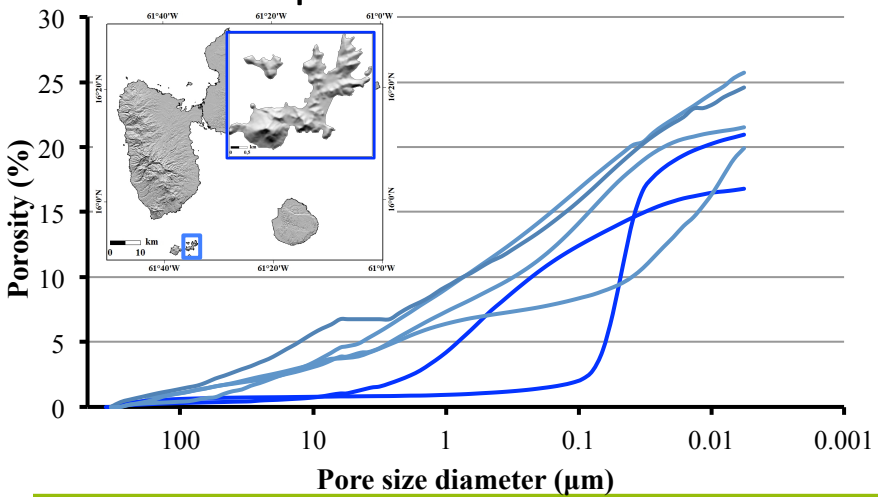
Dissolution in a **Plagioclase**

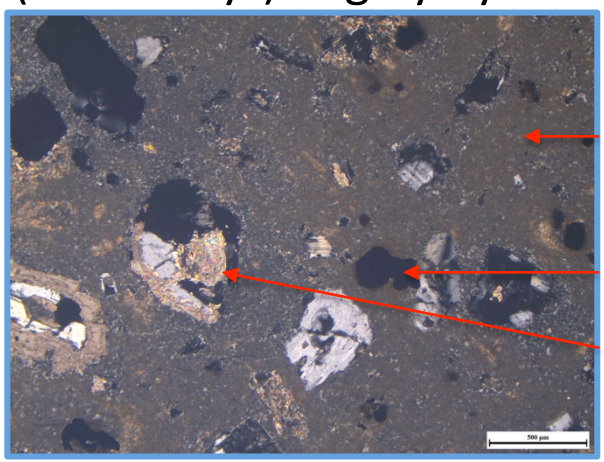
Matrix:
- Quartz
- Pyroxenes

Cleavage plane underlined by oxides

Pyroxene transformation: dissolution + oxides appearance

- Central part of Terre-de-Haut Island (≈ 3 - 2 Myr): highly hydrothermalized





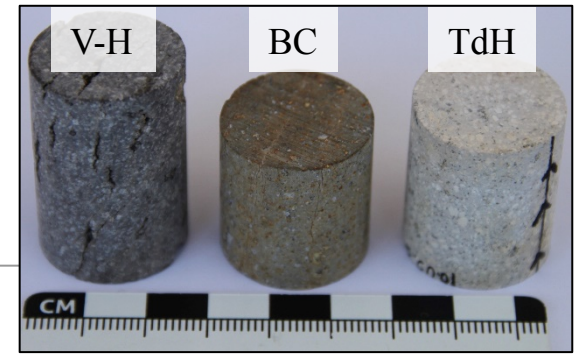
Matrix:
- Argiles
- Quartz

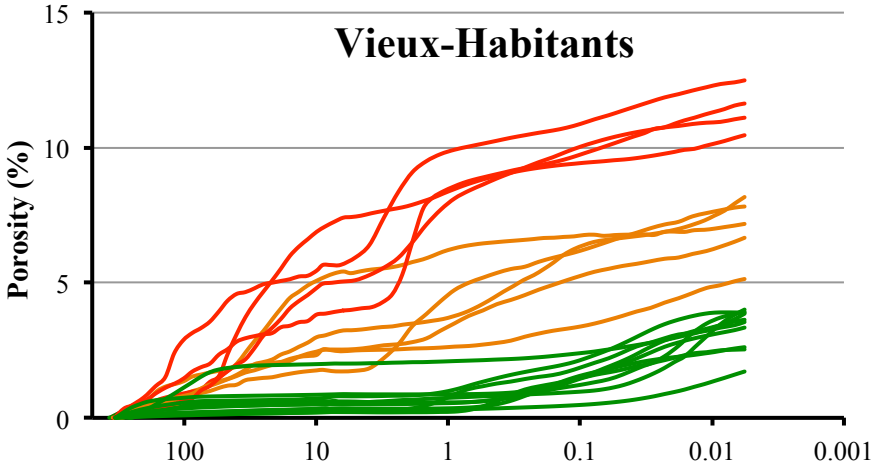
Pyrite

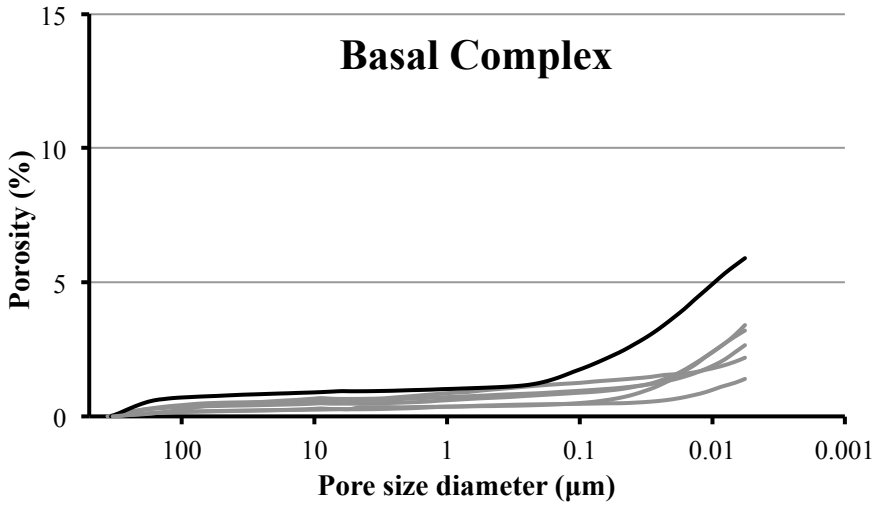
Transformation and dissolution of plagioclase Formation of calcite and large pores

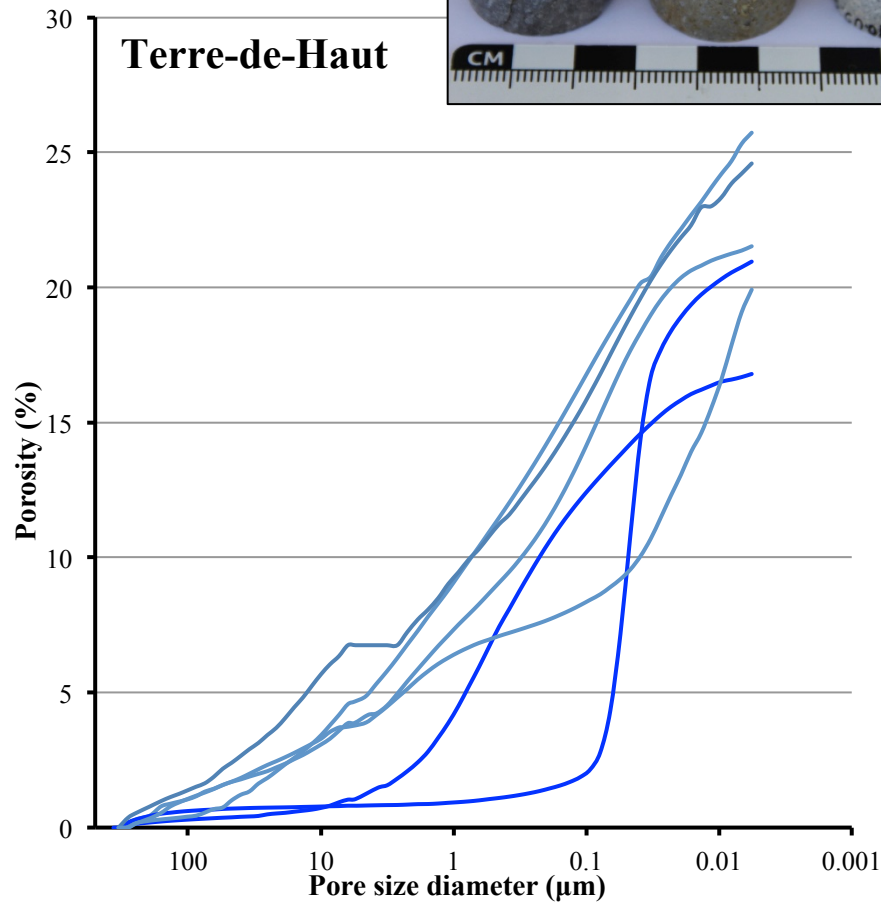
Comparison of porosity in the 3 study zones

- High **hydrothermal alteration deeply change the porous network** of fresh andesites









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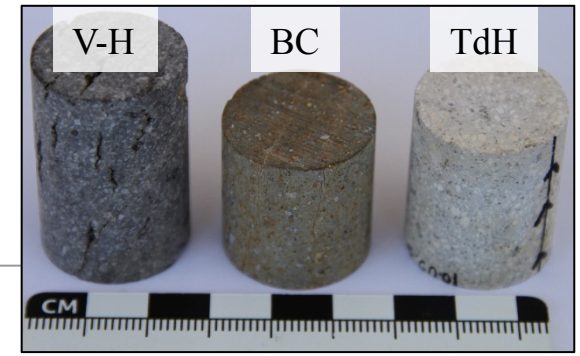
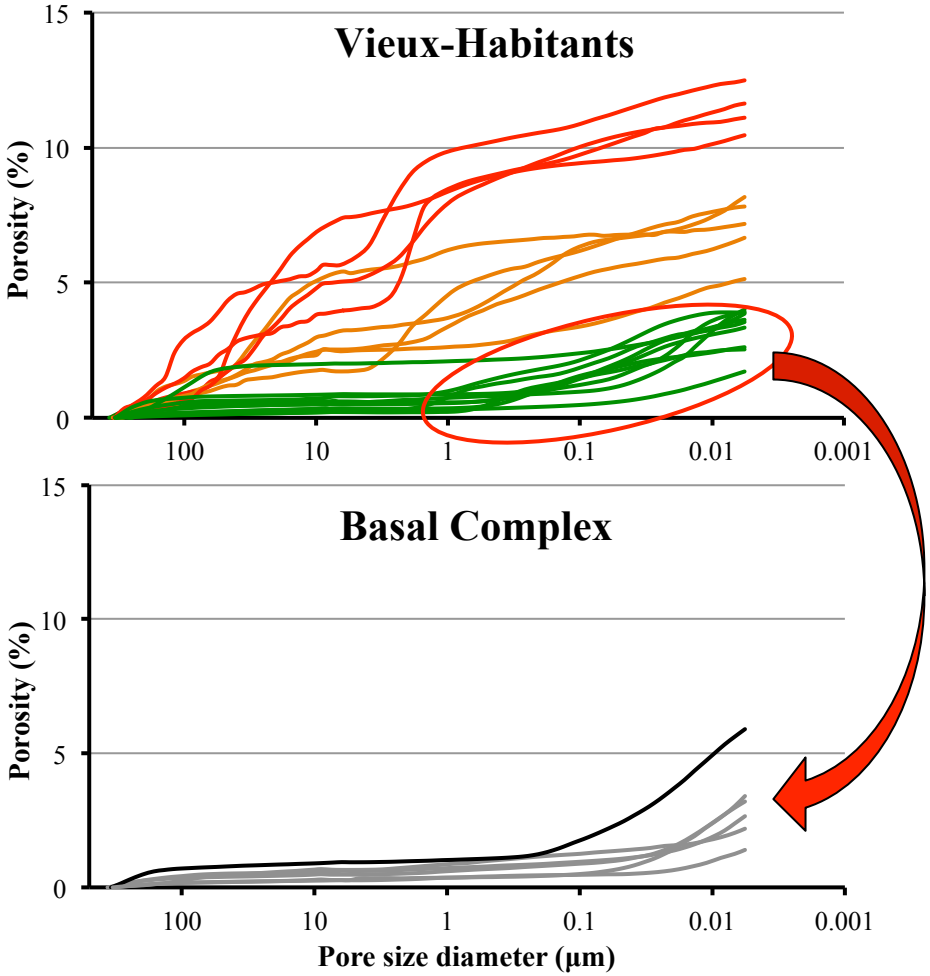
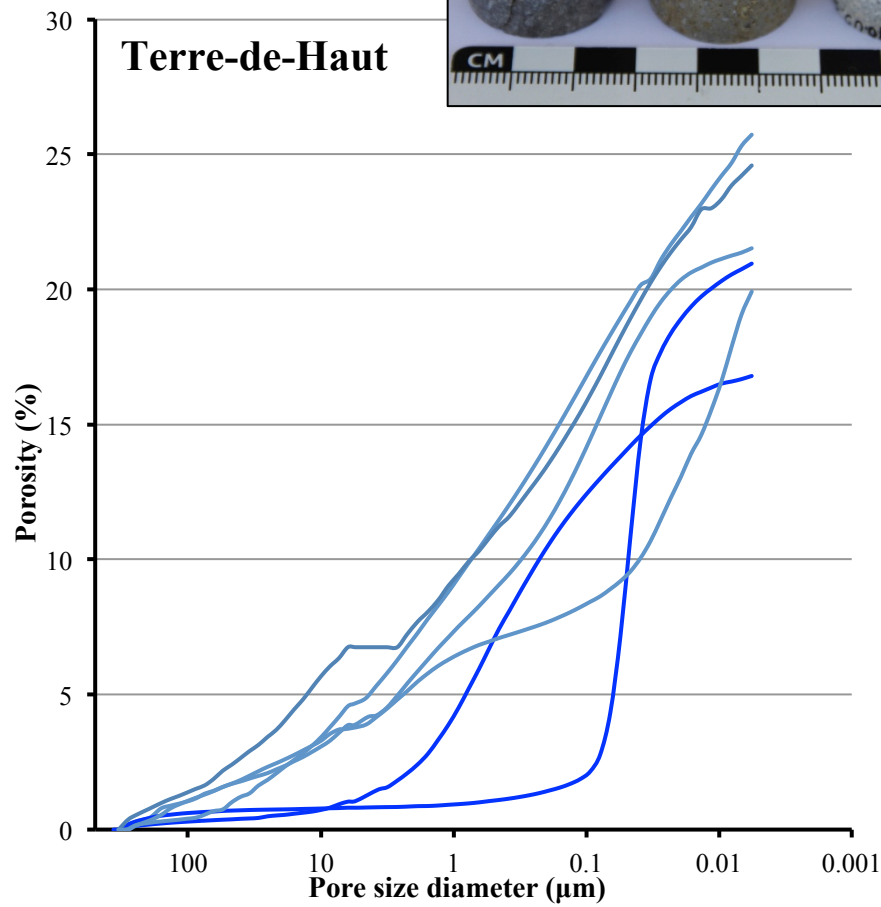
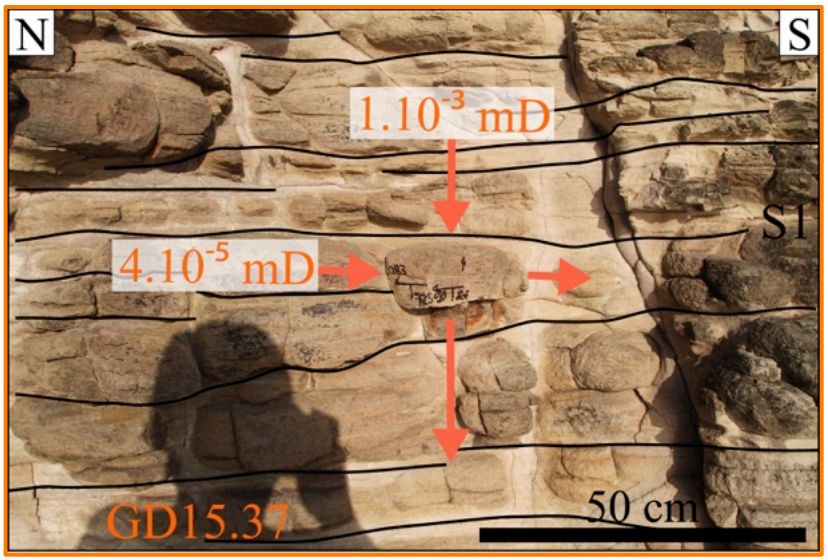


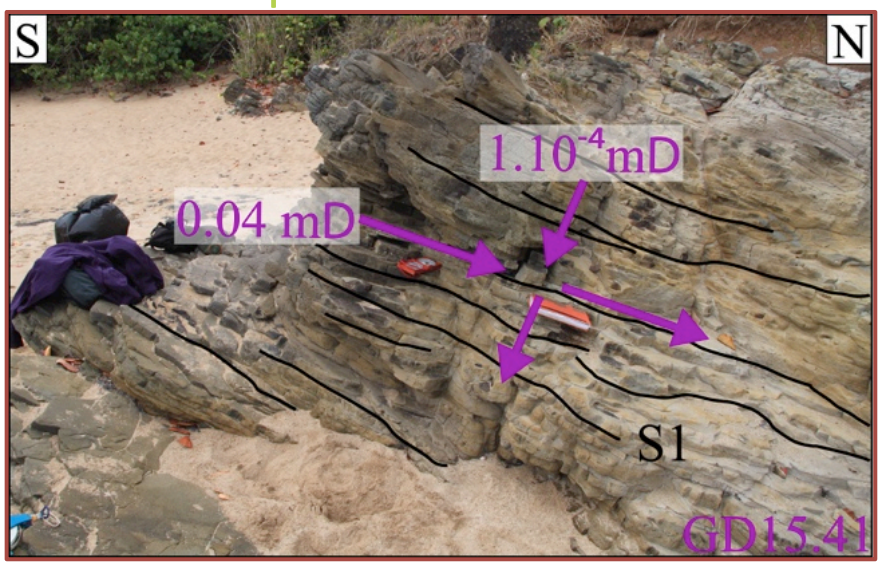


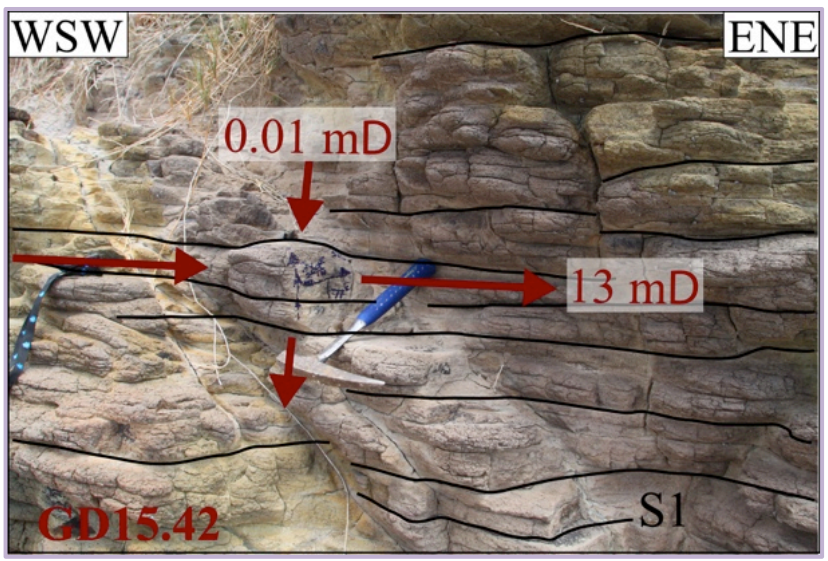


Anisotropy of permeability in meta-andesite

- **Permeability** of meta-andesites is **controlled by cleavage planes**
- Cleavage planes are not always preferential pathways for fluids (open or sealed)
- Same results in vesicles planes of fresh andesites ➔ Cleavage planes develop in vesicle planes

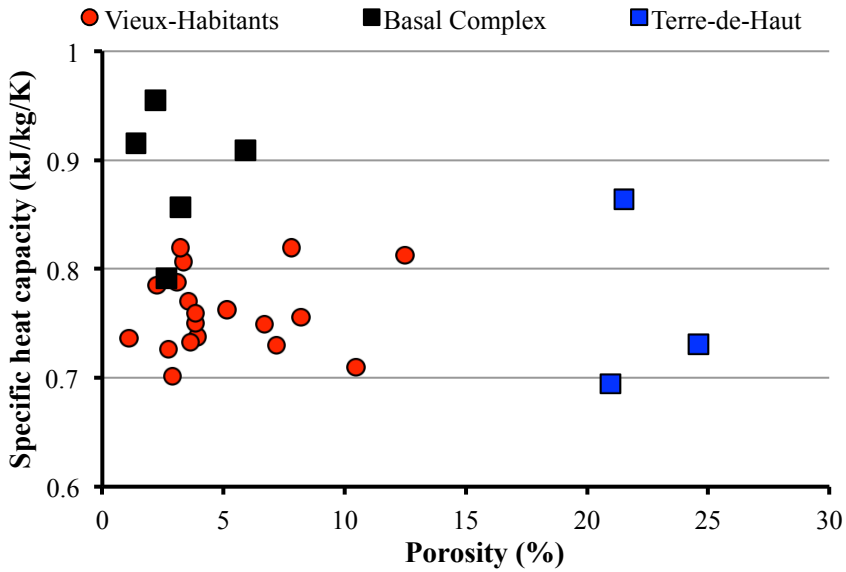


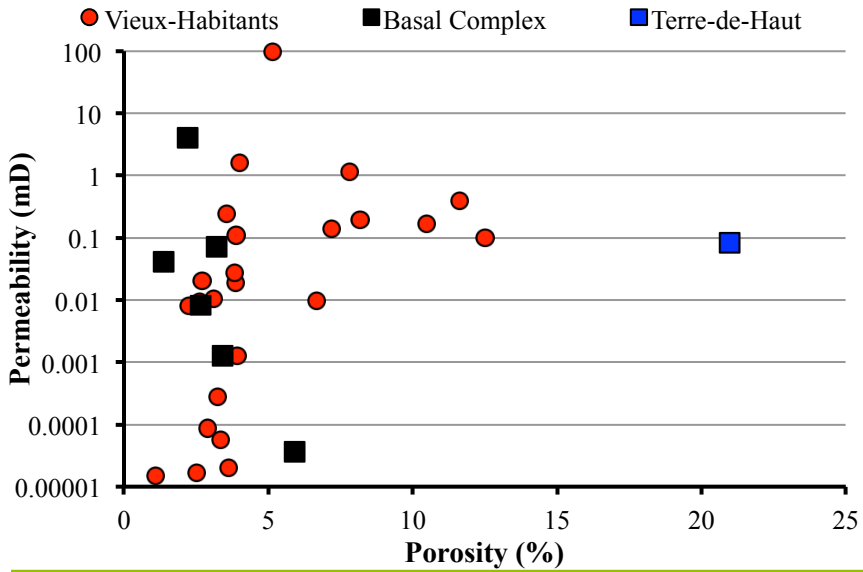


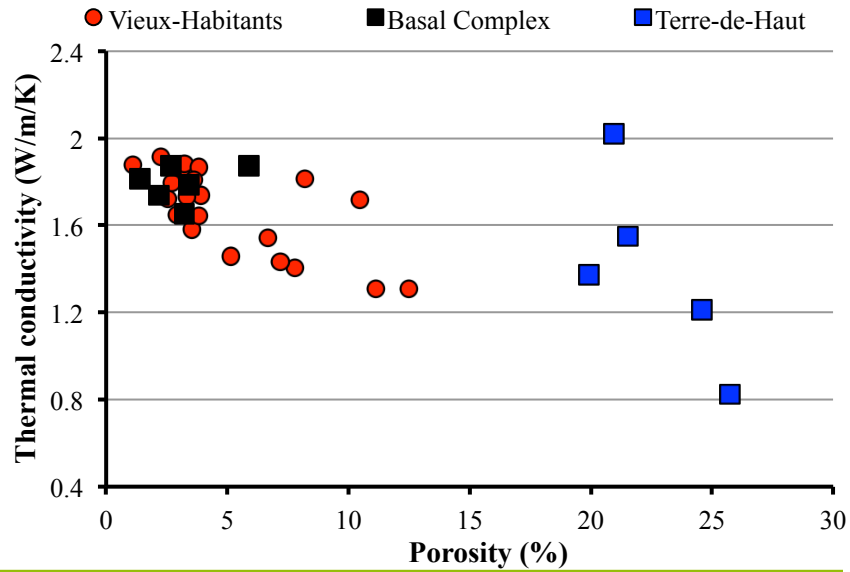


Evolution of physical properties of andesites

- 4 parameters are mesured :
  - Porosity
  - Permeability
  - Specific Heat capacity
  - Thermal conductivity

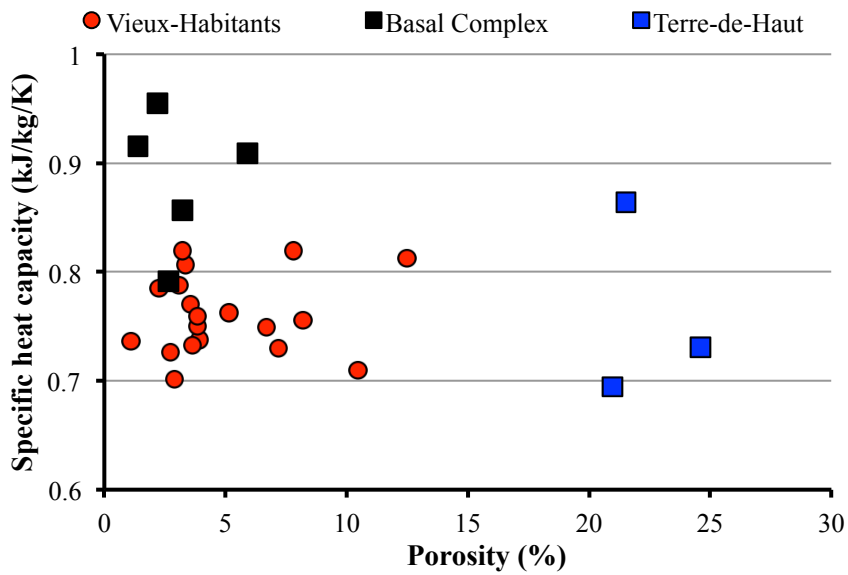


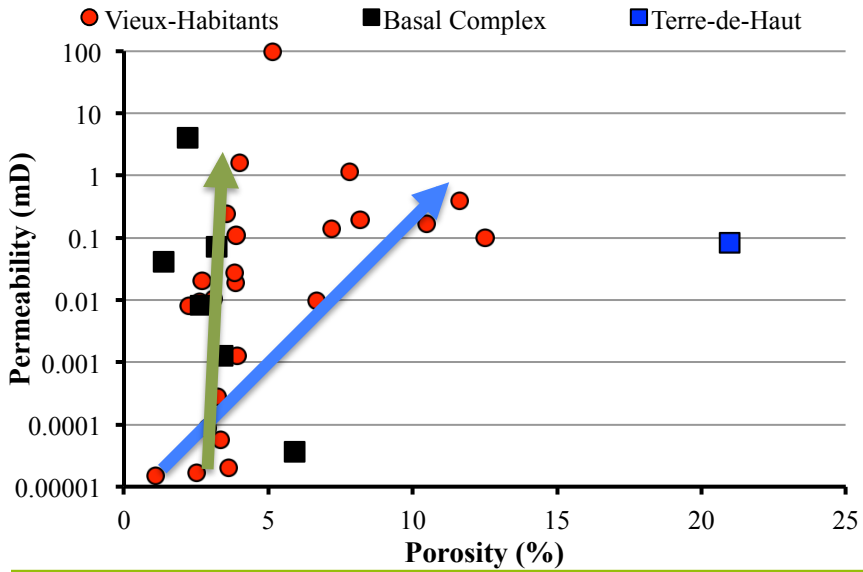


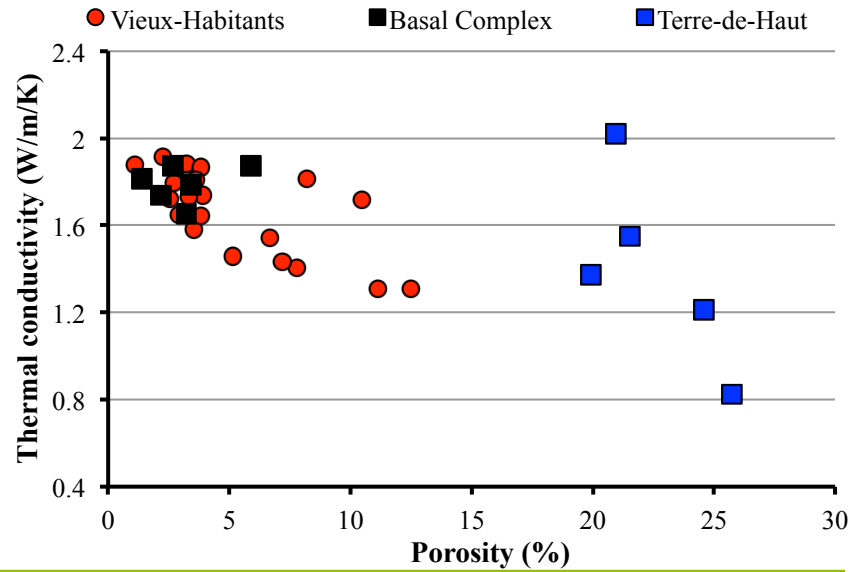


Evolution of physical properties of andesites

- Permeability:
  - Does not depend on the total connected porosity
  - Is a **fonction of pore shape and connectivity**

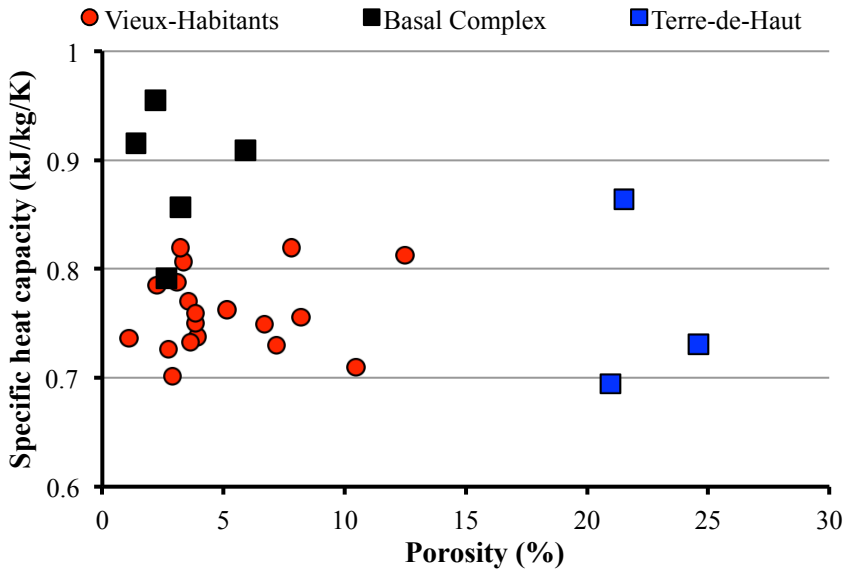


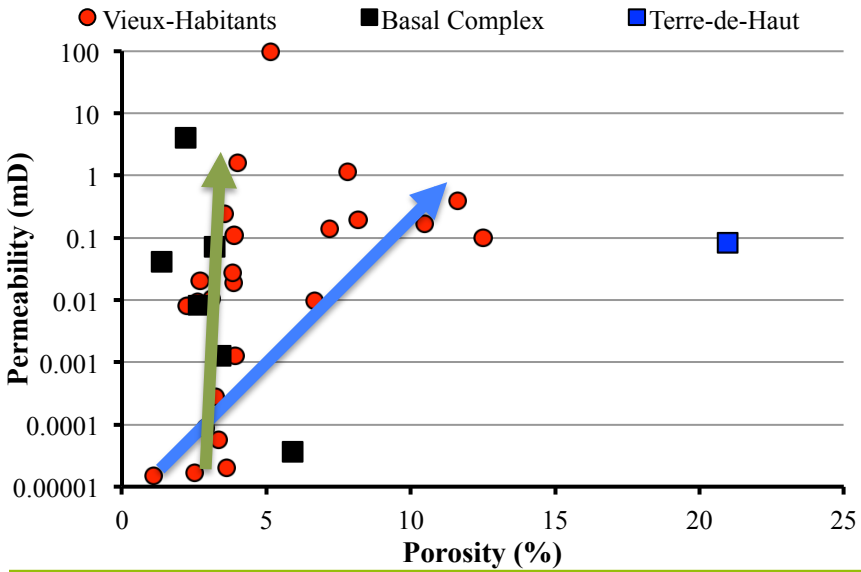


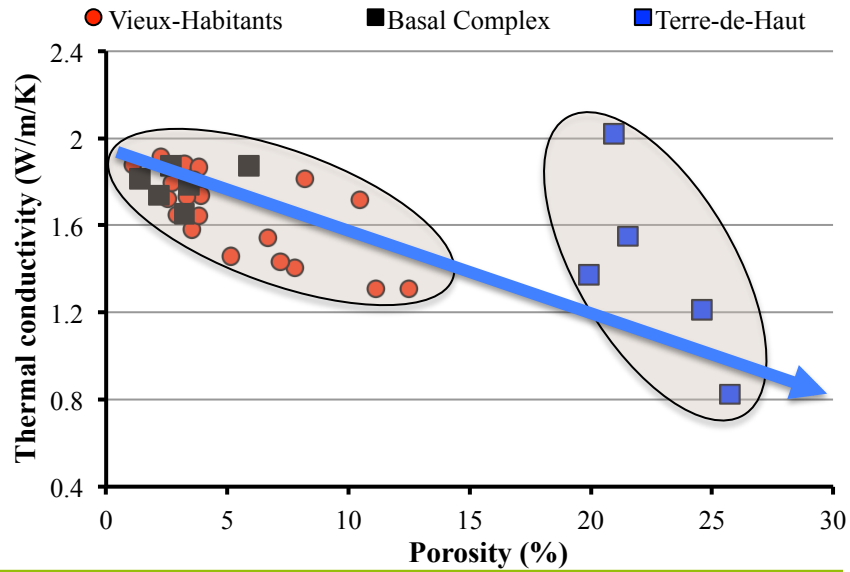


Evolution of physical properties of andesites

- Hydrothermal **alteration** creates **dispersion** in thermal conductivity

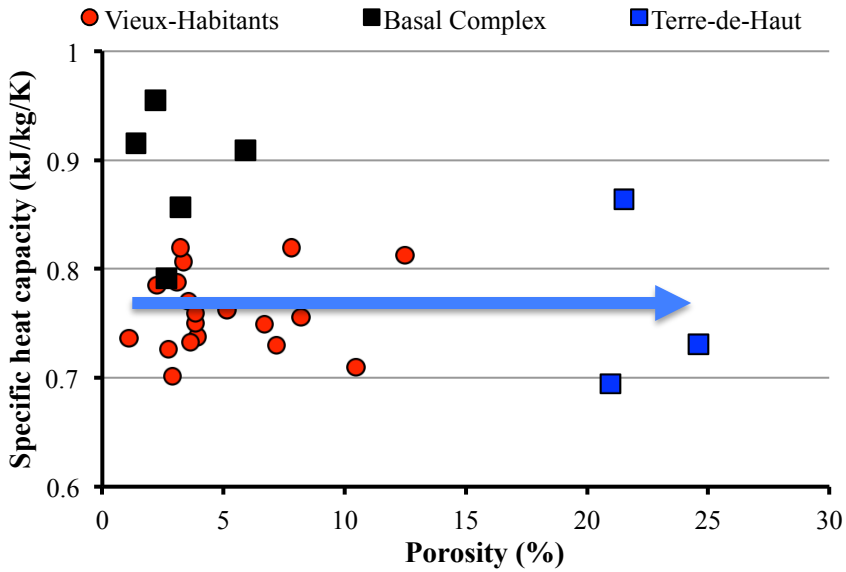


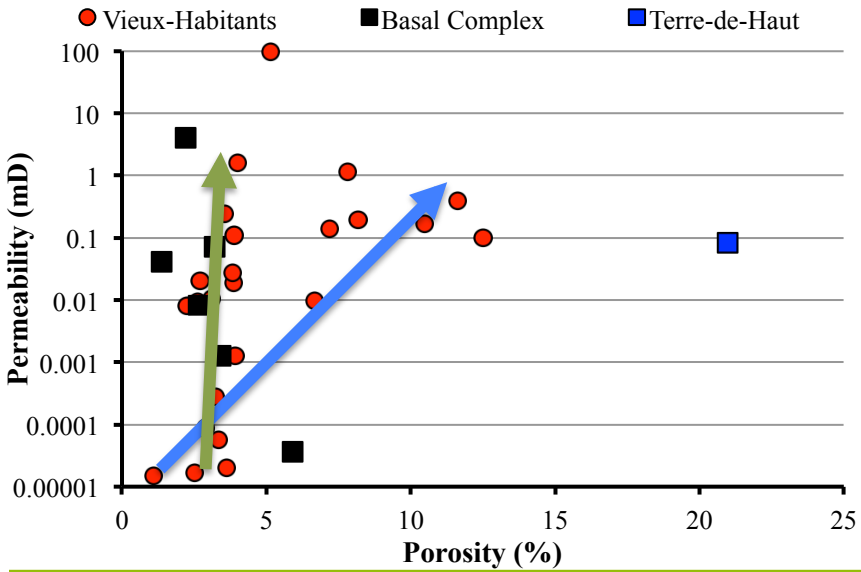


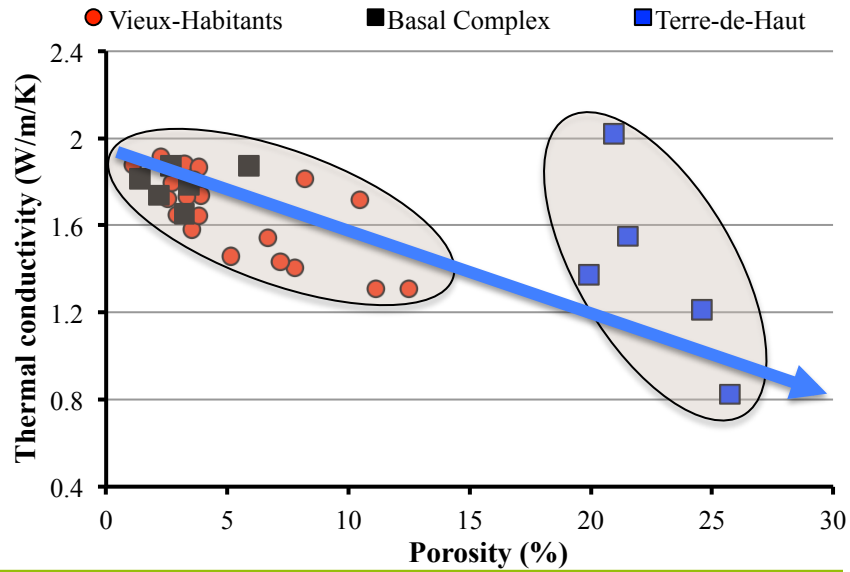


Evolution of physical properties of andesites

- **Heat capacity** is **not affected** by high hydrothermal alteration

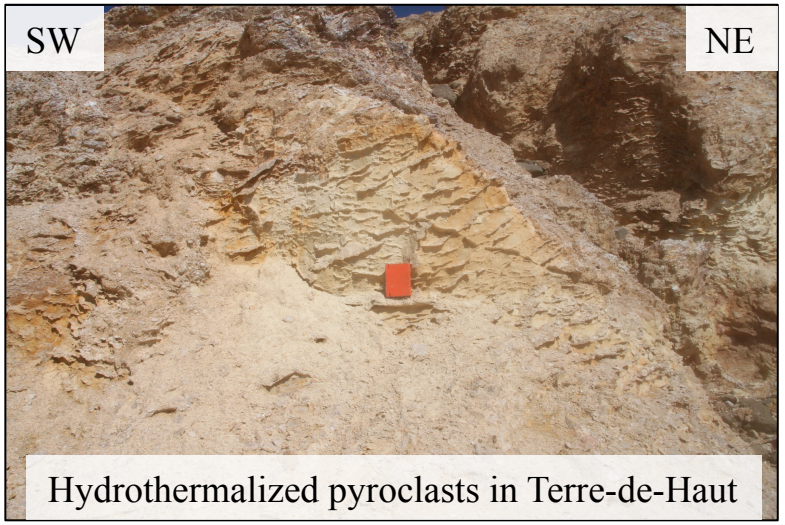






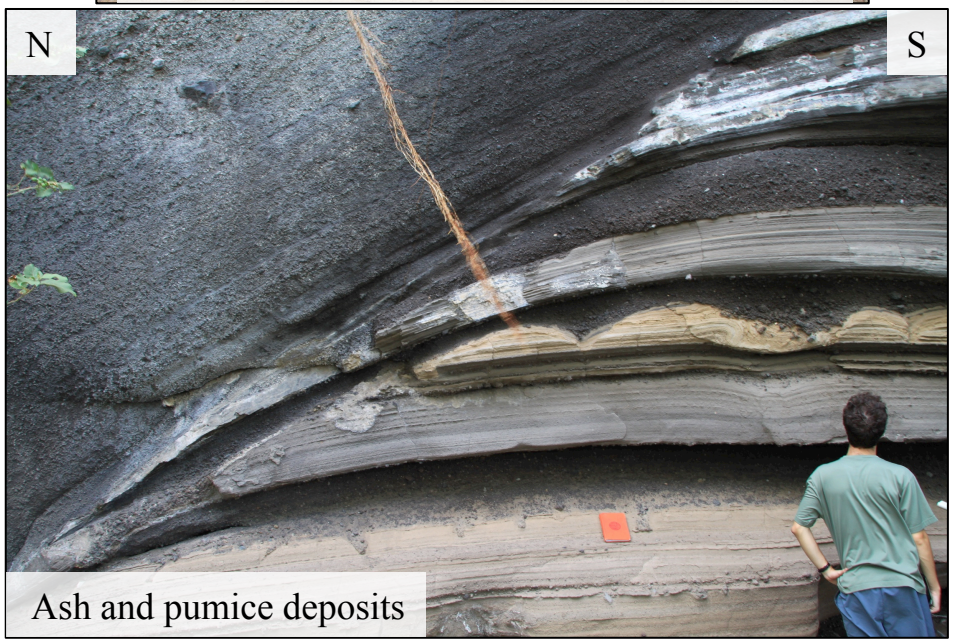
Volcano-sedimentary deposits

- Several types:
  - **Coarse**: debris flows and debris avalanches
  - **Thin**: pumice and ash flows / falls
- Fresh or Hydrothermalized



Hydrothermalized pyroclasts in Terre-de-Haut

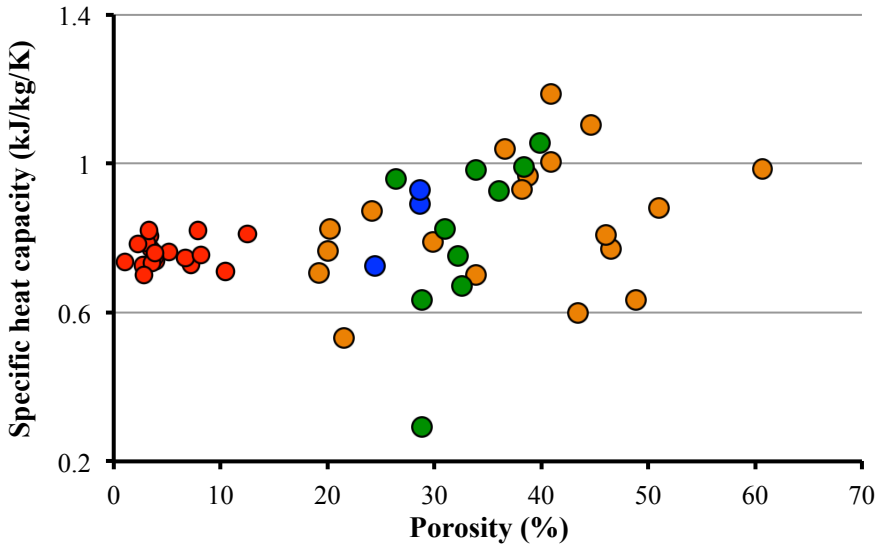
Debris flow

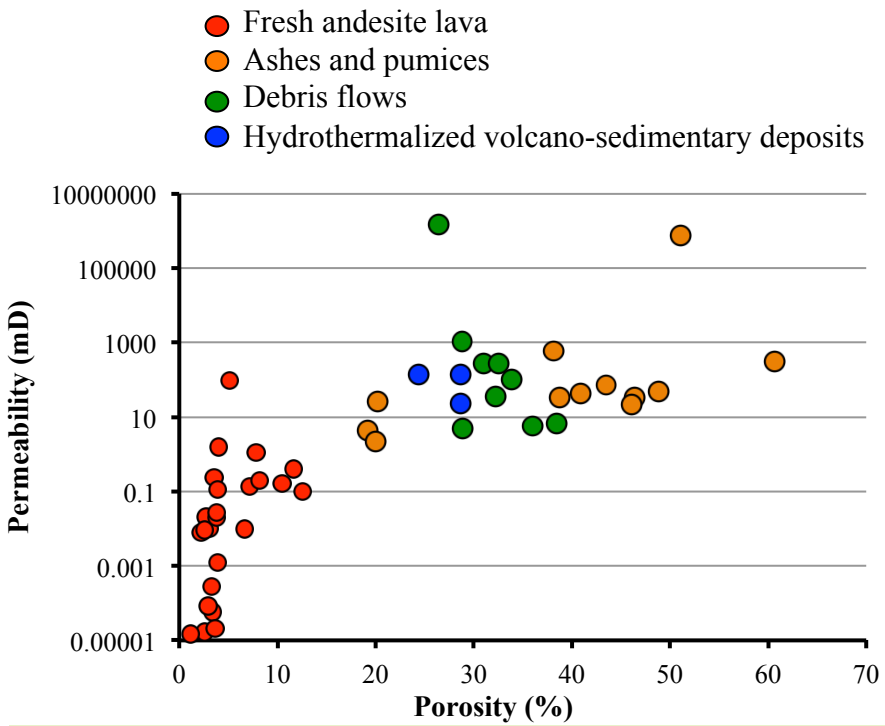


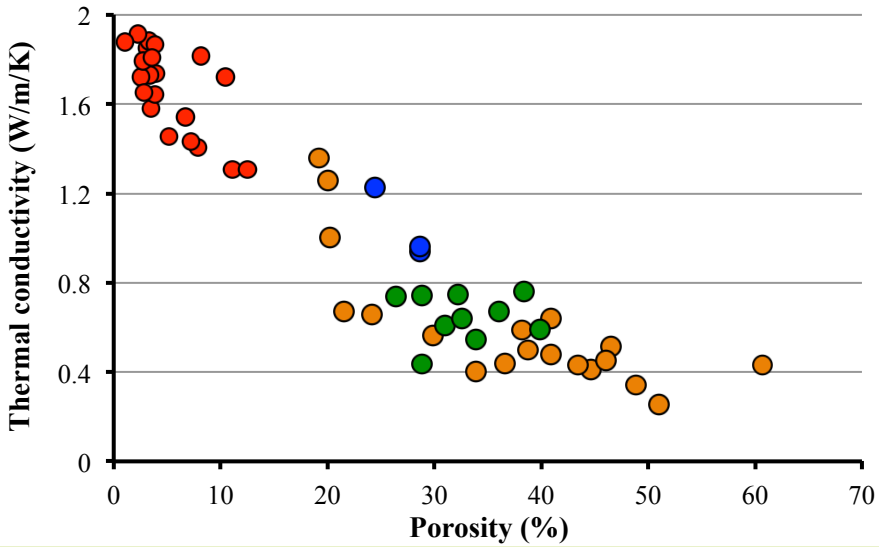
Ash and pumice deposits

Physical properties of volcano-sedimentary rocks

- Compared to andesites, volcano-sedimentary deposits have:







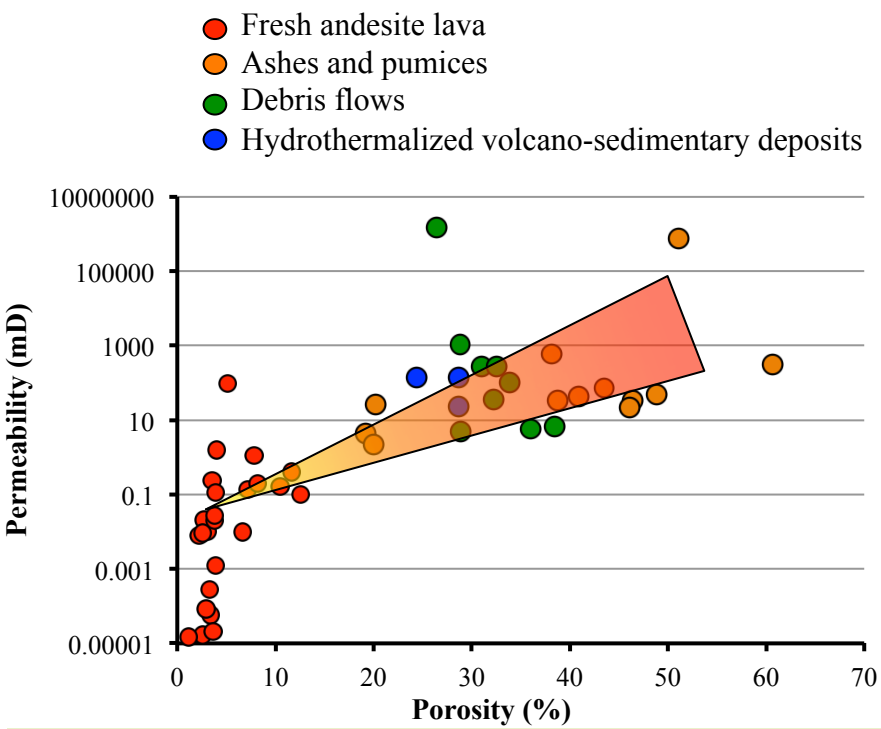
Physical properties of volcano-sedimentary rocks

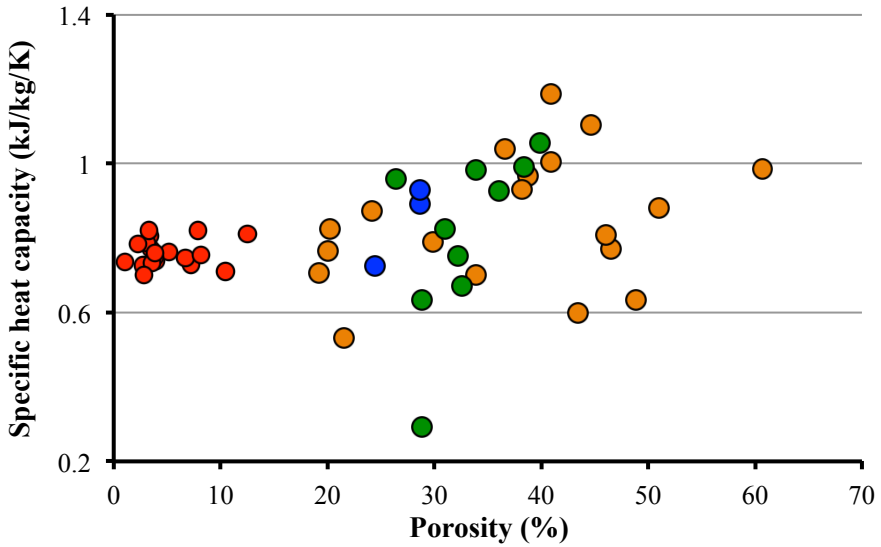
- Better porosity and permeability

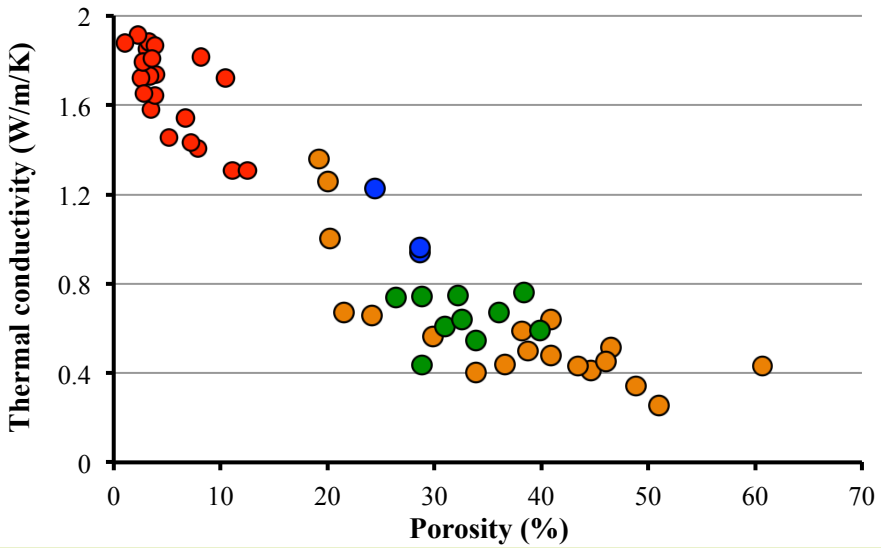
➔ Good storage capacity

➔ Preferential pathways for fluids

- Andesites are low permeable





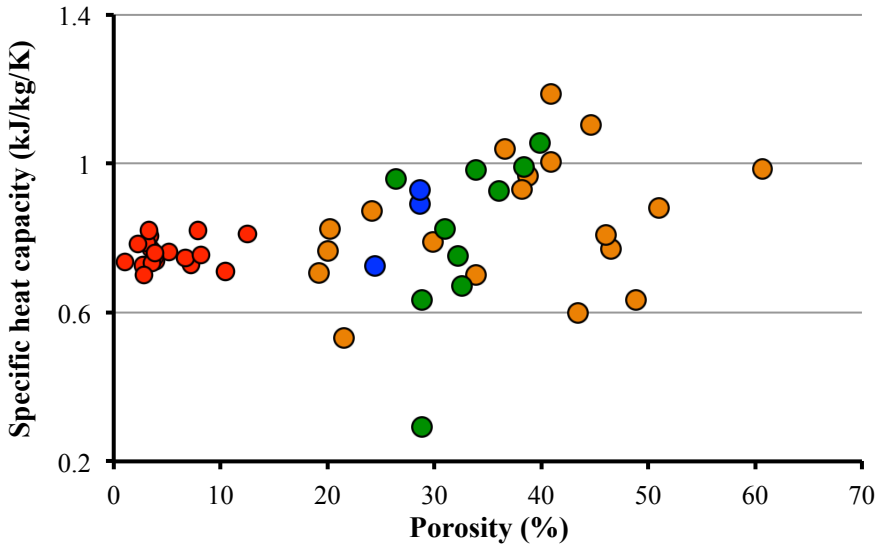


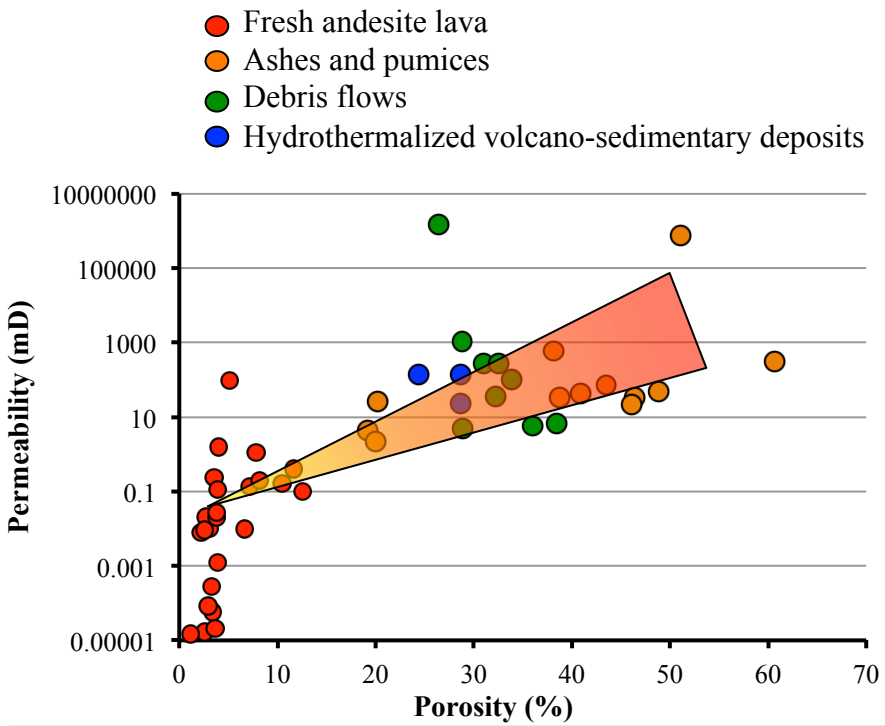
Physical properties of volcano-sedimentary rocks

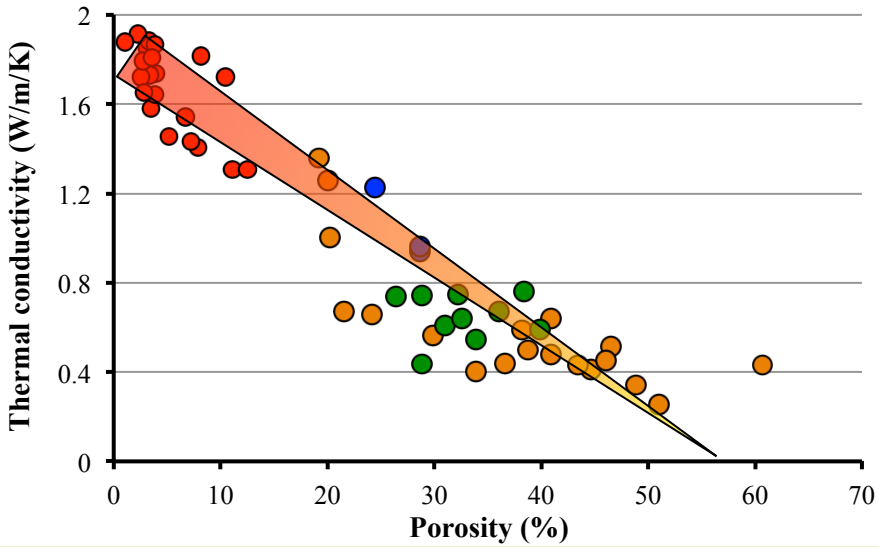
- Lower thermal conductivity

➔ Heat insulation

- Andesites are high conductive materials

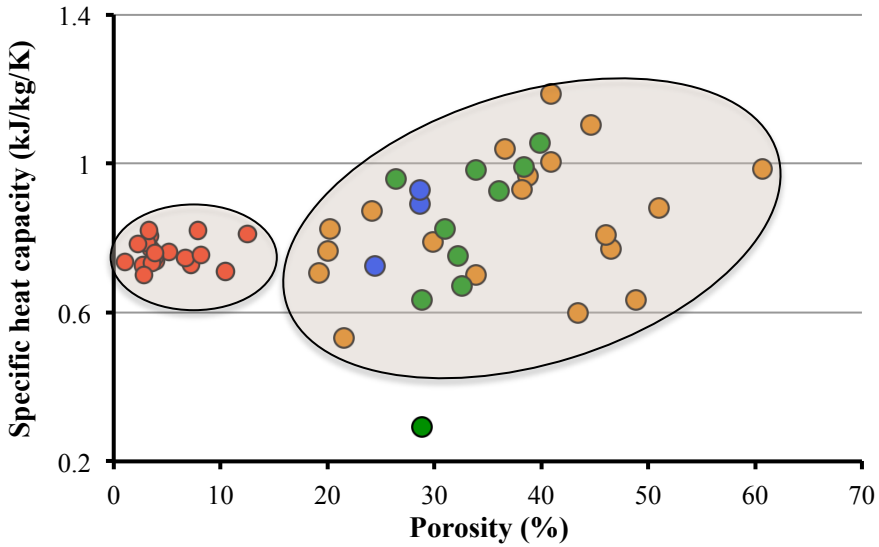


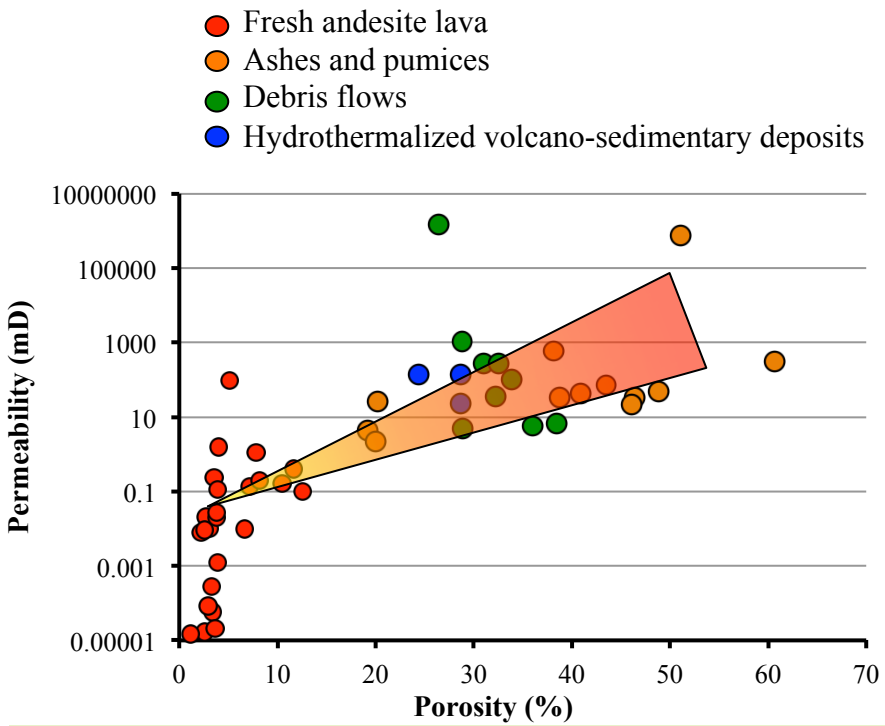


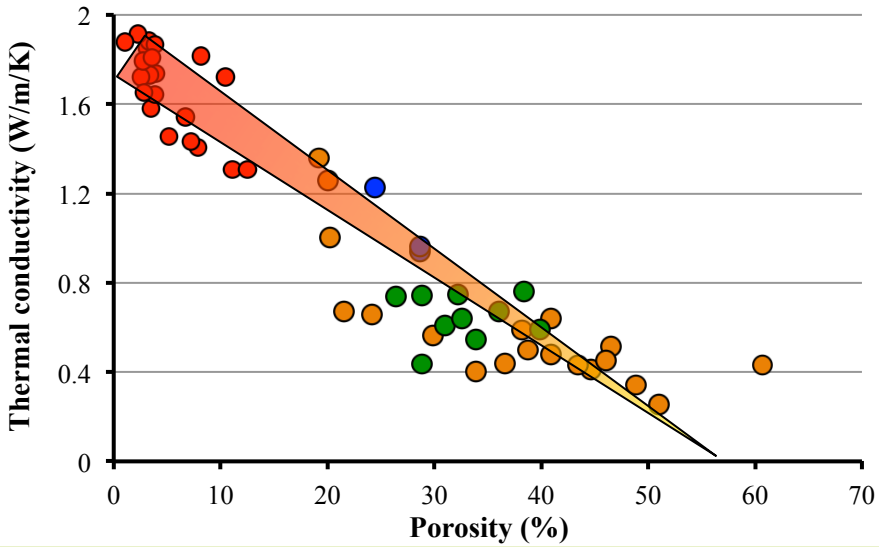


Physical properties of volcano-sedimentary rocks

- Higher specific heat capacity dispersion

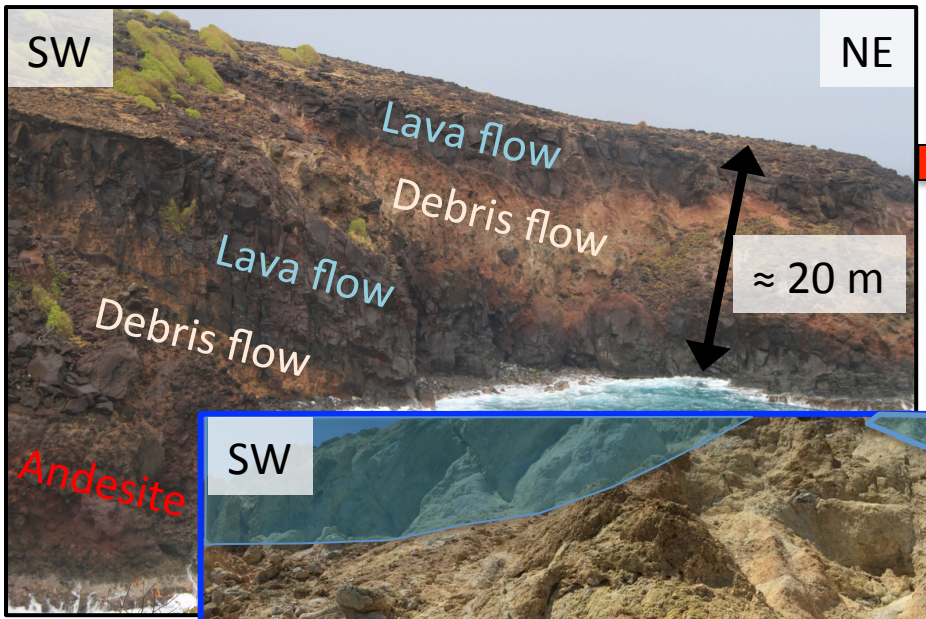




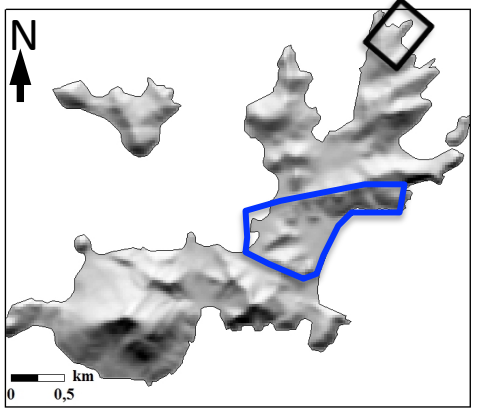


So… let's go back to the geothermal system

- How to intergrate these physical measurements in the geological model?

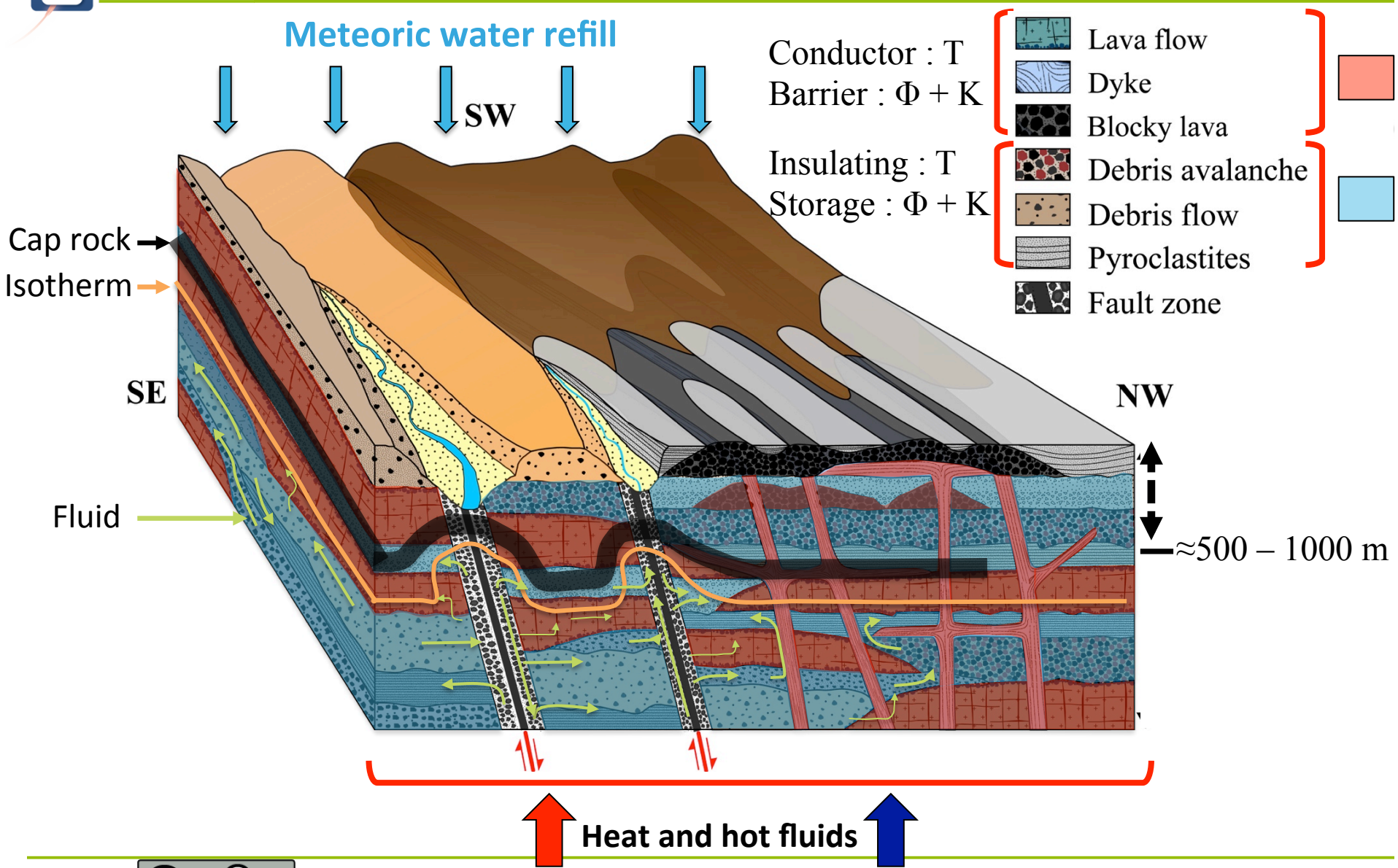


FRESH



HYDROTHERMALLY TRANSFORMED

Preliminary geological model for future 3D modelling



Conclusion

- **Volcanic environment** creates **complex geometry** deposits with heterogeneous physical and thermal properties
- **Anisotropies** are strong
- Impossible to create a geothermal reservoir when you have only lava flows

- But…
  - The serie **lava flows / pyroclasts /** … close to fault zones create **a channelized reservoir**
  - **Faults and debris flows** act as **thermal insulation** and preferential **pathways for fluids**
  - Fresh **lava flows** act as **heat conductor and barrier for fluid** flows
  - Fluids contribute to totally transform the rock matrix which improve initial physical properties