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Quartz Chemico-structural characterization: a tool for sediment source tracing

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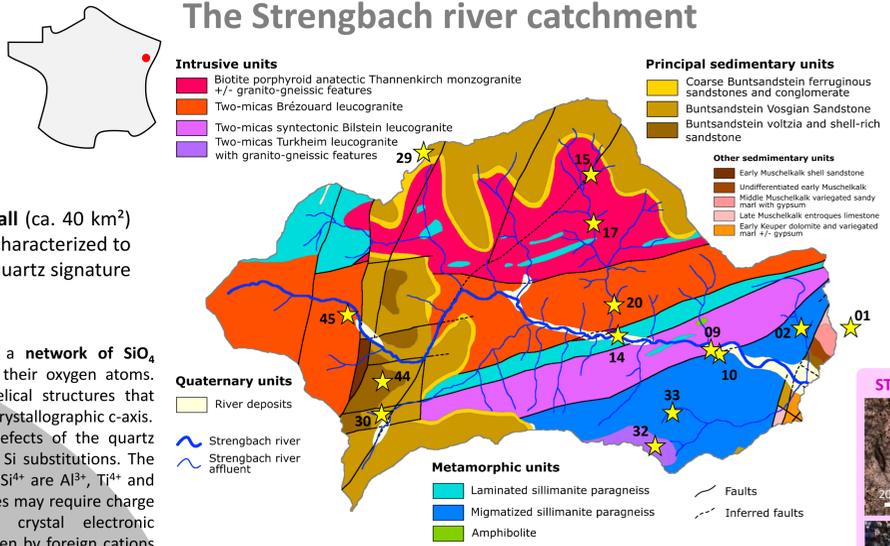
Claire AUPART¹, Catherine LEROUGE¹, Philippe LACH¹, Damien Desvisme², Florian TRICHARD², Manon BOULAY³, Magali RIZZA³, Pierre VALLA⁴, Pierre VOINCHET⁵, Gilles RIXHON⁶, and Hélène TISSOUX^{1,5}
¹ Bureau de Recherches Géologiques et Minières (BRGM), Orléans, France; ² Ablatom S.A.S, Villeurbanne, France; ³ Aix Marseille Univ, Centre Européen de Recherche et d'Enseignement en Géosciences de l'Environnement (CEREGE), Aix-en-Provence, France; ⁴ Université Grenoble Alpes, Institut des Sciences de la Terre (ISTerre), Gières, France; ⁵ Histoire Naturelle de l'Homme Préhistorique (HNHP), Paris, France; ⁶ Laboratoire Image Ville Environnement (LIVE), Faculté de géographie et d'aménagement, Strasbourg, France

Corresponding author : c.aupart@brgm.fr

Quartz is ubiquitous within continental crust and can virtually be found within all rock types (plutonic, metamorphic and sedimentary). During erosion, weathering and sedimentation processes, it has a very high preservation potential and is therefore a good candidate to **trace sediment production and transport dynamics**. One of the aims of the Quartz ANR project is to develop a multi-method protocol for quartz characterization that can be used to trace the origin of river sediments.

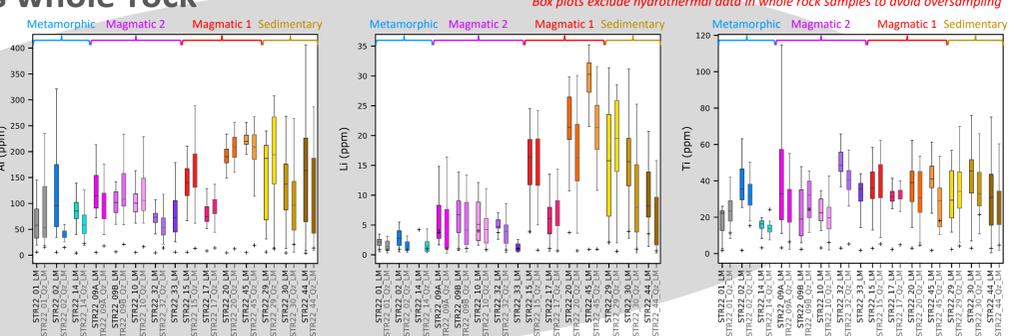
The Strengbach catchment, selected to develop the method, is relatively **small** (ca. 40 km²) with a relatively **simple lithology**. As a first step, **bedrock samples** have been characterized to establish their quartz signature that will be compared in a second step to the quartz signature within river sediments.

The Strengbach river catchment

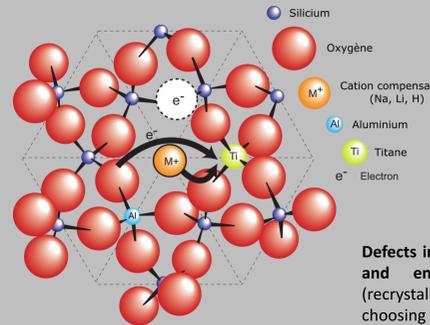


LA-ICP-MS: Grains vs whole-rock

- LA-ICP-MS analyses carried out both in whole rock samples and purified quartz grains
- Analyzed elements: Li, Be, B, Na, Mg, Al, K, Ca, Sc, Ti, V, Cr, Mn, Fe, Co, Ni, Ge, As, Rb, Sr, Sb, Cs, Pb, Th, U, REE
- Main elements detected: Al, Ti, Li
- No main effect of quartz purification
- Exception: STR22-02 due to selective quartz type sampling



Quartz structure defects

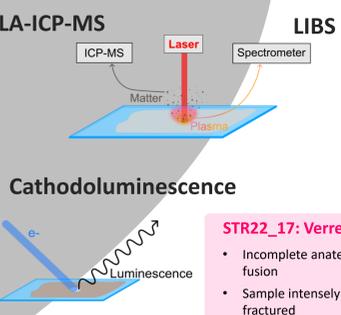


The ideal quartz structure is a network of SiO₄ tetrahedra linked together by their oxygen atoms. Tetrahedra are arranged in helical structures that create channels parallel to the crystallographic c-axis. Some of the most common defects of the quartz lattice are atom vacancies and Si substitutions. The most common substitutions to Si⁴⁺ are Al³⁺, Ti⁴⁺ and Ge⁴⁺. Substitutions and vacancies may require charge compensation to keep the crystal electronic neutrality. This role is often taken by foreign cations such as H⁺, Li⁺, Na⁺ or K⁺ that can circulate within c-axis channels.

Defects in the quartz structure are intricately linked to quartz conditions and environment of crystallization and consecutive history (recrystallization, metamorphism, alteration, etc.). It implies that, by choosing complementary analytic methods, it is possible to establish a signature common to quartz with a similar history.

LA-ICP-MS (Laser Ablation coupled to Inductively Coupled Plasma Mass Spectrometry) and **LIBS** (Laser Induced Breakdown Spectroscopy) are complementary methods for **trace elements** quantification. LA-ICP-MS tends to have the best sensitivity for heavy elements while LIBS has best results for light elements.

Cathodoluminescence, **OSL** (Optically Stimulated Luminescence) and **ESR** (Electron Spin Resonance) are techniques relying on electronic traps that are a direct consequence of the **mineral structure and its defects**. Not only chemistry affects the analyses, but also purely structural defects (vacancies, extra O or Si, dislocations, etc.). Cathodoluminescence is mostly used to image mineral structure variations in minerals or for mineral identification. OSL and ESR are more commonly used as dosimetric methods for dating. These two methods require pure quartz grain samples. Analyses thus return bulk results in opposition with other techniques punctual analyses. **All these techniques have shown their interest for source tracing.**



Quartz signatures

STR22_15 & 17: Thannenkirch granite

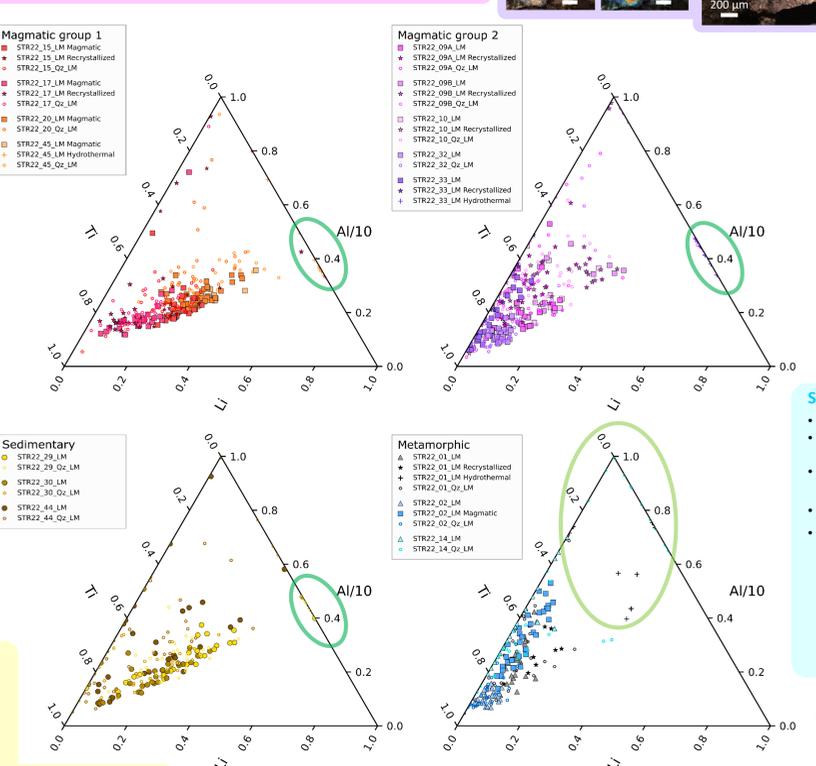
- Formed from paragneiss fusion
- Patchy, interstitial quartz
- Magmatic recrystallized quartz
- Dominant type: magmatic
- Bulging recrystallization
- No distinctive chemistry difference between quartz types

STR22_17: Verreries facies

- Incomplete anatectic fusion
- Sample intensely fractured
- Chemistry closer to magmatic group 2

STR22_20 & 45: Brézouard granite

- Mostly magmatic grains
- Some bulging recrystallization
- Very high fluid inclusions density
- Slight orange CL where inclusion density is high



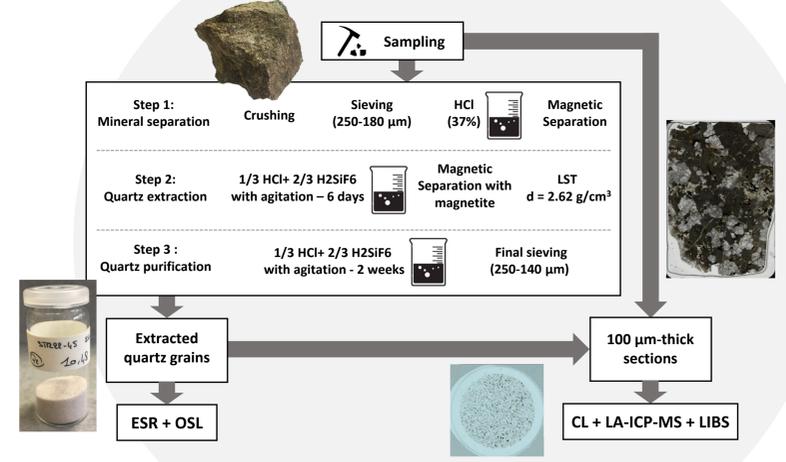
STR22_02: gneiss

- Magmatic and metamorphic quartz
- Dominant type: metamorphic
- Magmatic relics in inclusion in pseudomorphs
- Metamorphic quartz recrystallized by subgrain rotation, $\phi > 200 \mu\text{m}$
- Magmatic quartz significantly richer in Al
- Purified quartz grains include almost exclusively metamorphic grains
- Slight CL colors differences of individual grains

STR22_14: Gneiss

- Mostly metamorphic quartz
- Undulose extinction + some bulging on grain borders
- High fluid inclusion density (planes parallel undulose deformation)
- Lowest trace element concentrations
- CL signal stronger where inclusions

Sample preparation



Hydrothermal veins

- Most samples show signs of water circulation
- Hydrothermal veins observed only in a few samples
- Chemical signature identified in more
- At least two generations:

Al + Li poor in metamorphic

- Same crystallographic orientation than surrounding metamorphic quartz
- Mixed with feldspar
- Similar CL signal than metamorphic quartz

Al + Li rich in granites and sandstones

- Crystallized
- CL tends to be darker than magmatic quartz

STR22_29, 30 & 44: Buntsandstein sandstones

- Sedimentary quartz
- Sub-rounded to well-rounded grains
- Syntaxial overgrowth
- Grains imbrication
- Similar chemical signature as magmatic group 1

STR22_01: Metamorphic quartz vein

- Metamorphic and recrystallized quartz
- Undulose extinction in metamorphic grains
- Recrystallization by subgrain rotation, $\phi > 200 \mu\text{m}$ + bulging
- Recrystallized grains slightly depleted in Al and Ti
- Similar CL colors

Comparison to ESR and OSL

ESR data:

- Similar quartz signatures extracted from ESR signal
- Granite STR22-32 (granite-gneiss) grouped with metamorphic quartz
- Quartz metamorphic vein (STR22-01) separated from other metamorphic quartz

OSL data:

- Low OSL signal: metamorphic or magmatic group 2 quartz
- High OSL signal: magmatic group 1 or sandstone quartz
- Granite-gneiss signature of STR22-17 (Verreries facies) not visible

References: Ackerson et al., 2015; Augustsson & Reker, 2012; Baele et al., 2016; Baggs et al., 2002; Dutine et al., 2002; Götze et al., 2021; Minelli et al., 2021; Shimada et al., 2013; Tissoux et al., 2015