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# Use of $^{87}\text{Sr}/^{86}\text{Sr}$ ratio as indicator of flowpaths on a large-scale instability : the Séchilienne landslide (Isère, France)

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## STUDY SITE



FIG 1 : VIEWS OF THE SÉCHILIENNE LANDSLIDE (PHOTO CREDIT : SÉBASTIEN GOMMET, INSTITUT DES RISQUES MAJEURS)

Regarding the hydrogeology, water plays a significant role in the massif destabilisation.

Vallet et al (2015) as evidenced 4 water types which flow through the slope and which are different regarding to their location (figure 3).

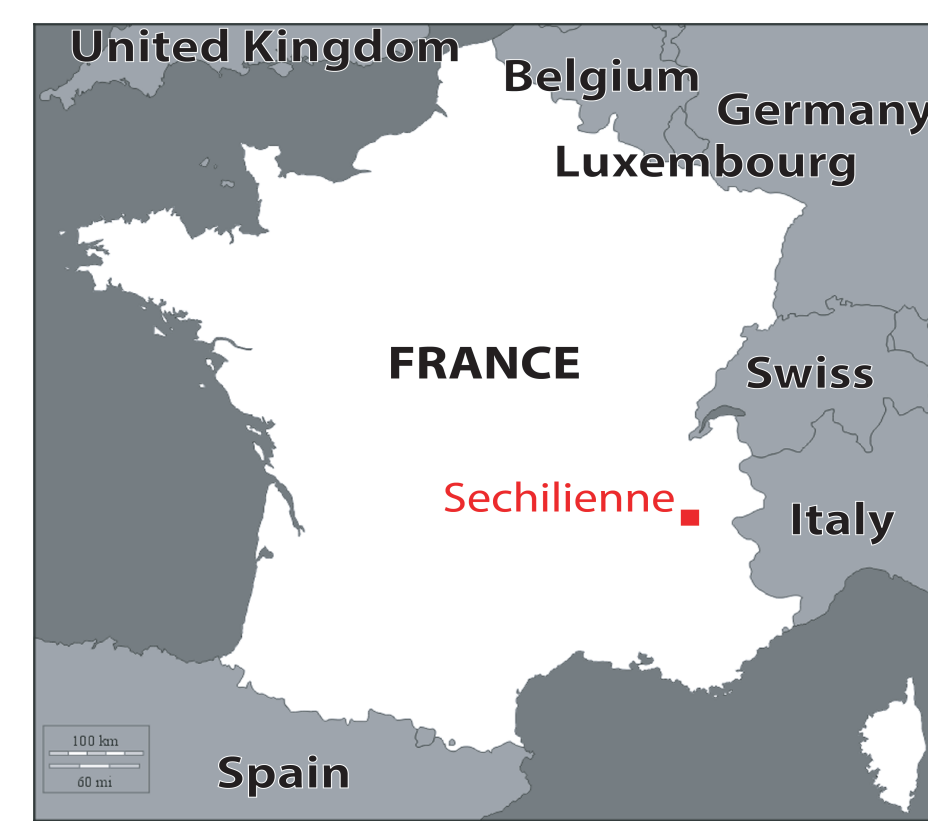


FIG 2 : LOCATION OF SÉCHILIENNE (ISÈRE, AUVERGNE RHÔNE-ALPES, FRANCE)

The Séchilienne landslide is located on the right bank of the Romanche River, South East of Grenoble (Isère, France). The active zone of the gravitational instability involves several millions of cubic meters.

The geology consists of fractured hard rocks (micaschists : external crystalline massif) with double permeability and strong spatial heterogeneities, covered by carbonates (Trias - Lias) deposits at the top of the slope (in purple in fig 3) . The slope is affected by major faults as the N20° Sabot and Sechilienne Faults.

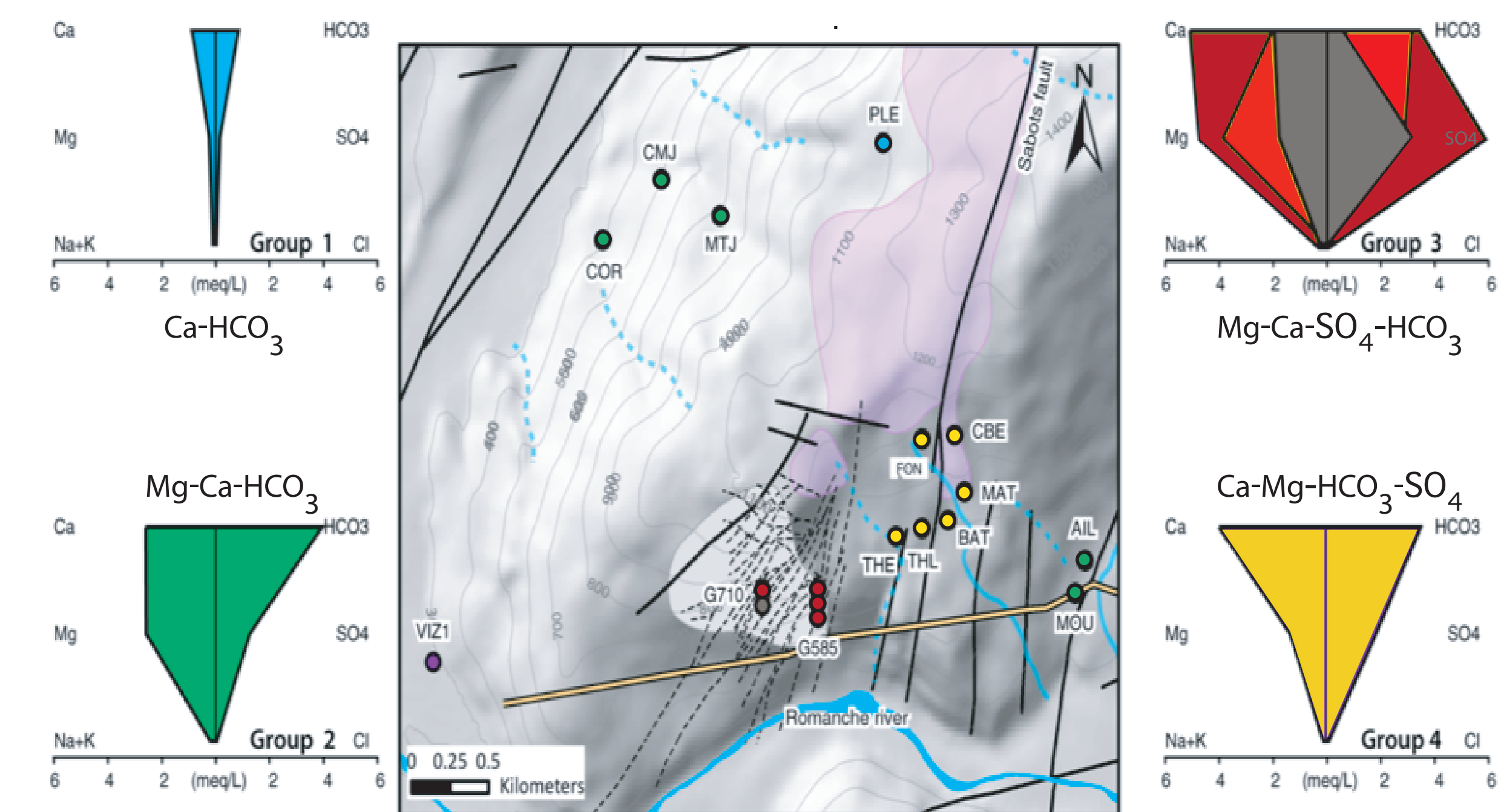


FIG 3 : SIMPLIFIED MAPS OF THE SÉCHILIENNE SLOPE WITH GEOLOGICAL ON HYDROGEOLOGICAL INFORMATIONS ; THE PURPLE LAYER REPRESENT THE CARBONATES COVER - STIFF DIAGRAMS ILLUSTRATE THE CHEMISTRY OF THE WATER

## METHODS

Major elements chemistry and Sr isotopes were measured in different outflows draining both the stable and instable part of the Séchilienne instability (fig1 & 4).

Springs were sampled at 4 different periods in June 2014 - Novembre 2015 - Mai 2016 - August 2017.

Cations were analysed by Atomic Absorption Spectroscopy (AA 100 Perkin-Elmer), anions by Ionic Chromatography (Dionex DX100) and Isotopic ratios were obtained using Multicollector Inductively Coupled Plasma Mass Spectrometer (MC-ICPMS).



FIG 4 : SATELLITE VIEW OF THE STUDY SITE WITH SAMPLING POINTS (OUTFLOWS)

**AIMS** THE CHEMISTRY OF THE WATER ONLY, CANNOT PROVIDES INFORMATIONS ABOUT THE ORIGIN OF THE CHEMISTRY OF THE WATERS WITH INSURANCE AS THE GEOLOGICAL CONTEXT IS COMPLEX AND MIXING PROBLEMS CAN OCCURS. THIS IS WHY WE USE SR ISOTOPES IN THIS STUDY IN ORDER TO IDENTIFY THE ORIGIN AND FLOWPATHS OF THE WATER AS SR ISOTOPIC VARIATIONS PROVIDE NATURAL FINGERPRINTS OF ROCK-WATER INTERACTIONS AND HAVE BEEN LARGELY USED IN STUDIES OF WEATHERING AND HYDROGEOLOGY.

## RESULTS & DISCUSSION

Ca/Sr ratio vs  $^{87}\text{Sr}/^{86}\text{Sr}$  allows to identify if the sampled waters had a silicate a carbonate origin (fig 5).

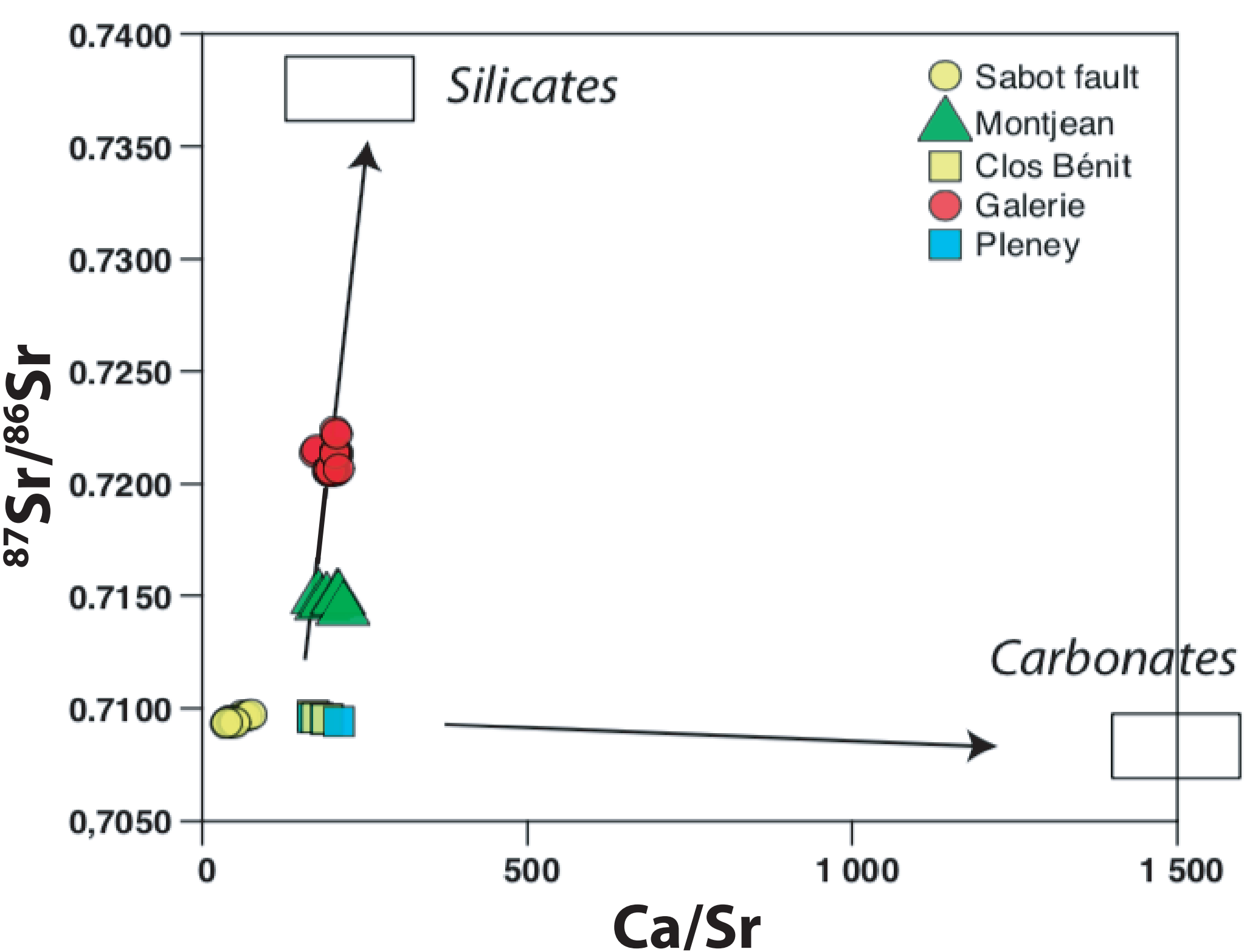


FIG 5: Ca/Sr VS  $^{87}\text{Sr}/^{86}\text{Sr}$  - FOR THE DIFFERENT SAMPLED SOURCES : GALERIE = G710 + C79 ; SABOT FAULT = FONAFFREY + BATHIE + THIEBAUDS + MATHIEUX ; PLENEY ; CLOS BENIT (CLOSE TO SABOT FAULT SOURCES)

Thus we distinguish waters with low Ca/Sr and with Sr isotopic ratios which are increasing toward the silicates pole. This waters corresponds to the Mt Jean sources and the gallery sources which present the highest isotopic ratio. The other sources present a low Ca/Sr and isotopic ratio close to the ratio of carbonates. These points correspond to Pléney, Clos Benit, and the Sabot fault sources.

Pléney outflow is typical of a water which as a rapid flow through to carbonate cover (fig 5 & 6).

The use of  $\text{SO}_4/\text{Na}$  permit to highlight other trends in the distribution of the sources (fig 6). Two trends are visible : the first one corresponding to an enrichment in sulfates and in  $^{87}\text{Sr}/^{86}\text{Sr}$  for the galerie and Mt Jean sources. The other trend is an enrichment in  $\text{SO}_4$  without any variation in  $^{87}\text{Sr}/^{86}\text{Sr}$  for the remaining sources.

For the enrichment in sulfates and in  $^{87}\text{Sr}/^{86}\text{Sr}$  both: the increase of the  $^{87}\text{Sr}/^{86}\text{Sr}$  ratio shows that silicate rocks are weathered whereas the increase in  $\text{SO}_4$  is provided by the weathering of Pyrite present in the fracture. This is the alteration of Pyrite which increase the silicate rocks weathering as it release acids.

High values of  $^{87}\text{Sr}/^{86}\text{Sr}$  ratios and  $\text{SO}_4$  in the gallery contrary to Mt Jean sources are explained by the high fracturation of the rocks of the unstable zone where the gallery is. The intermediate values corresponding to Mt Jean are due to a more stable context, with less fracturation.

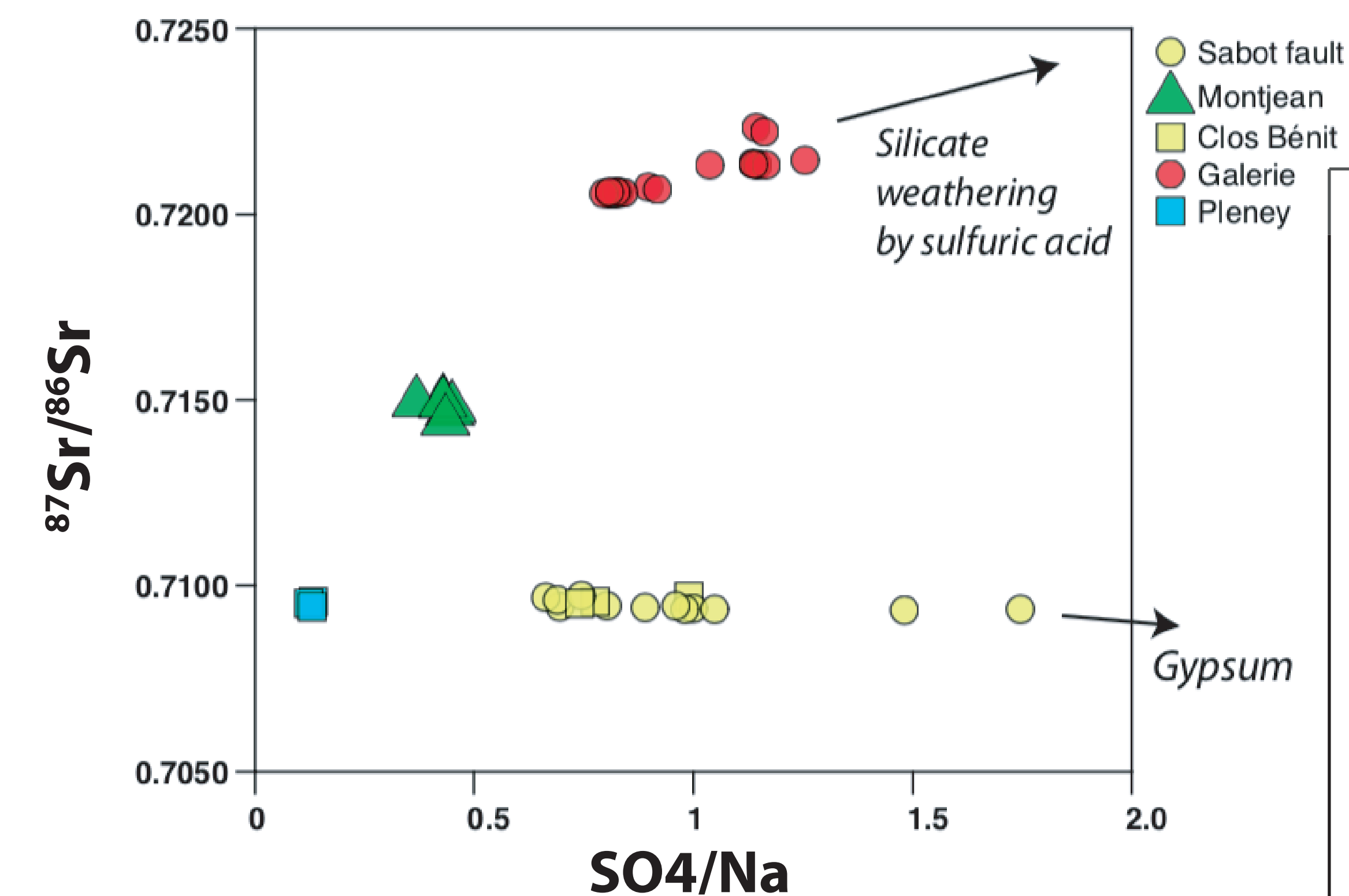


FIG 6 :  $\text{SO}_4/\text{Na}$  VS  $^{87}\text{Sr}/^{86}\text{Sr}$  - FOR THE DIFFERENT SAMPLED SOURCES : GALERIE = G710 + C79 ; SABOT FAULT = FONAFFREY + BATHIE + THIEBAUDS + MATHIEUX ; PLENEY ; CLOS BENIT (WHICH IS CLOSE TO SABOT FAULT SOURCES)

Increase of  $\text{SO}_4$  content observed in figure 6 for the Sabot et Clos Benit sources cannot be explained by the alteration of pyrite and silicate as explained before. Here the source of sulfates might explained by evidences of gypsum along the fractures draining the waters (gypsum occurrences on the geological map).

## CONCLUSION

This study allowed us to refine the hydrochemical model proposed by Vallet et al, 2015. We were able to bring precisions about the chemistry of the water by identifying the main contribution for the waters composition. Indeed, we first identified 2 main influences known as carbonates & silicates. Then, another contribution has been evidenced : occurrences of  $\text{SO}_4$  linked on one hand with alteration of Pyrite first and silicates, on the other hand the sulfates ( $\text{SO}_4$ ) are due to Trias occurrences in the water that wasn't evidenced before.

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