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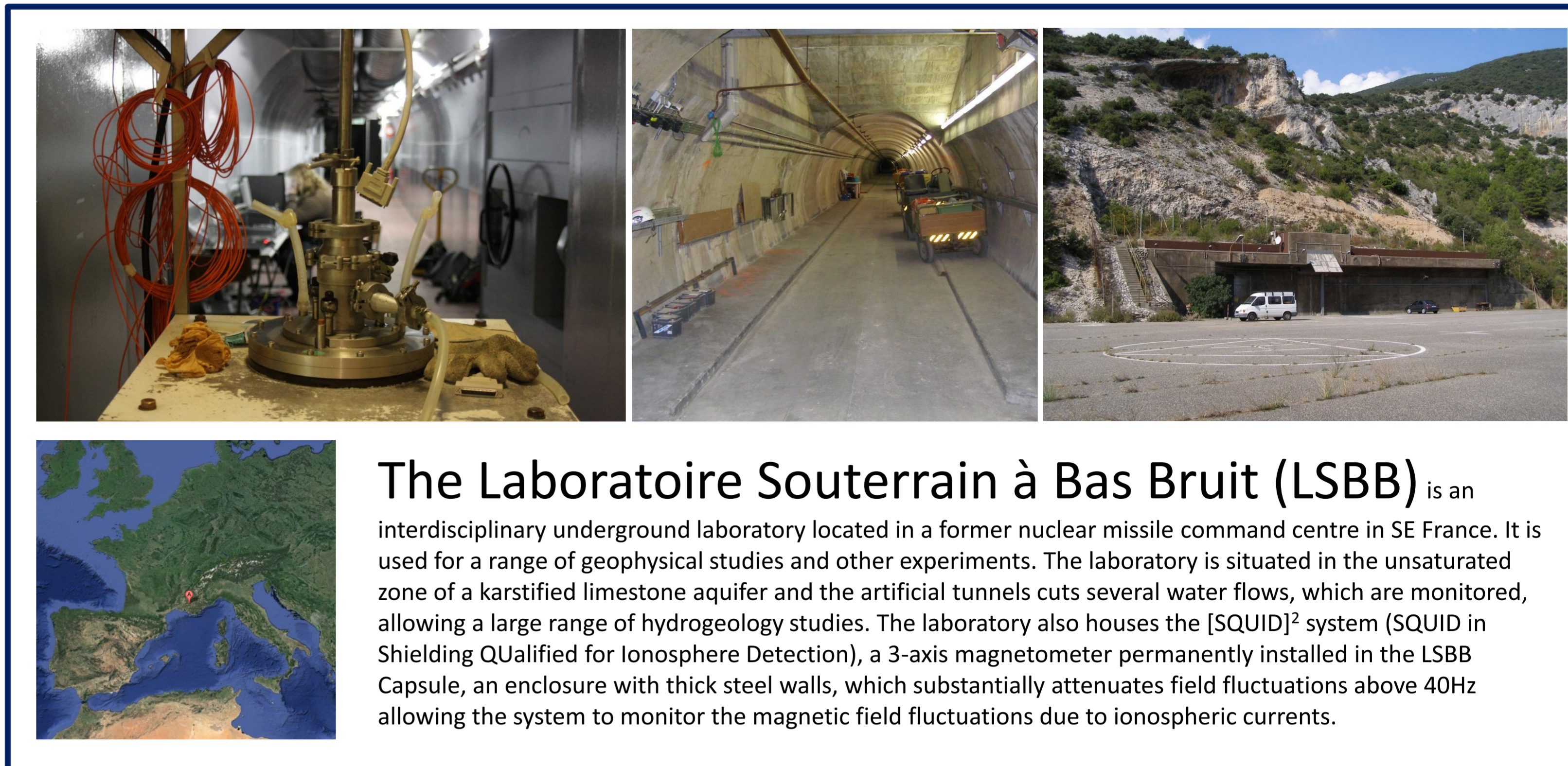
Monitoring magnetotelluric signals with multiple underground SQUID magnetometers

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The LSBB low noise underground laboratory in SE France is an ideal site to study the propagation of geomagnetic signals underground (www.lsbb.eu). We have monitored magnetic signals using two SQUID magnetometers at different depths. Precision magnetometry has the potential to allow passive studies of groundwater dynamics in complex systems such as karst. By measuring the magnetic signals generated by ionospheric currents and telluric currents, we can infer the electrical conductivity of the rock by the magnetotelluric method. The flow of water through rock is known to produce a small magnetic signal of unknown magnitude due to the electrokinetic effect. Our measurements have shown that the magnitude of this electrokinetic signal is below 0.2nT. We are now taking further measurements using three SQUID systems, as well as fluxgate sensors, to better study fluctuations in the gradient of the magnetic field across the underground medium.



The Laboratoire Souterrain à Bas Bruit (LSBB) is an interdisciplinary underground laboratory located in a former nuclear missile command centre in SE France. It is used for a range of geophysical studies and other experiments. The laboratory is situated in the unsaturated zone of a karstified limestone aquifer and the artificial tunnels cuts several water flows, which are monitored, allowing a large range of hydrogeology studies. The laboratory also houses the [SQUID]² system (SQUID in Shielding QUalified for Ionosphere Detection), a 3-axis magnetometer permanently installed in the LSBB Capsule, an enclosure with thick steel walls, which substantially attenuates field fluctuations above 40Hz allowing the system to monitor the magnetic field fluctuations due to ionospheric currents.

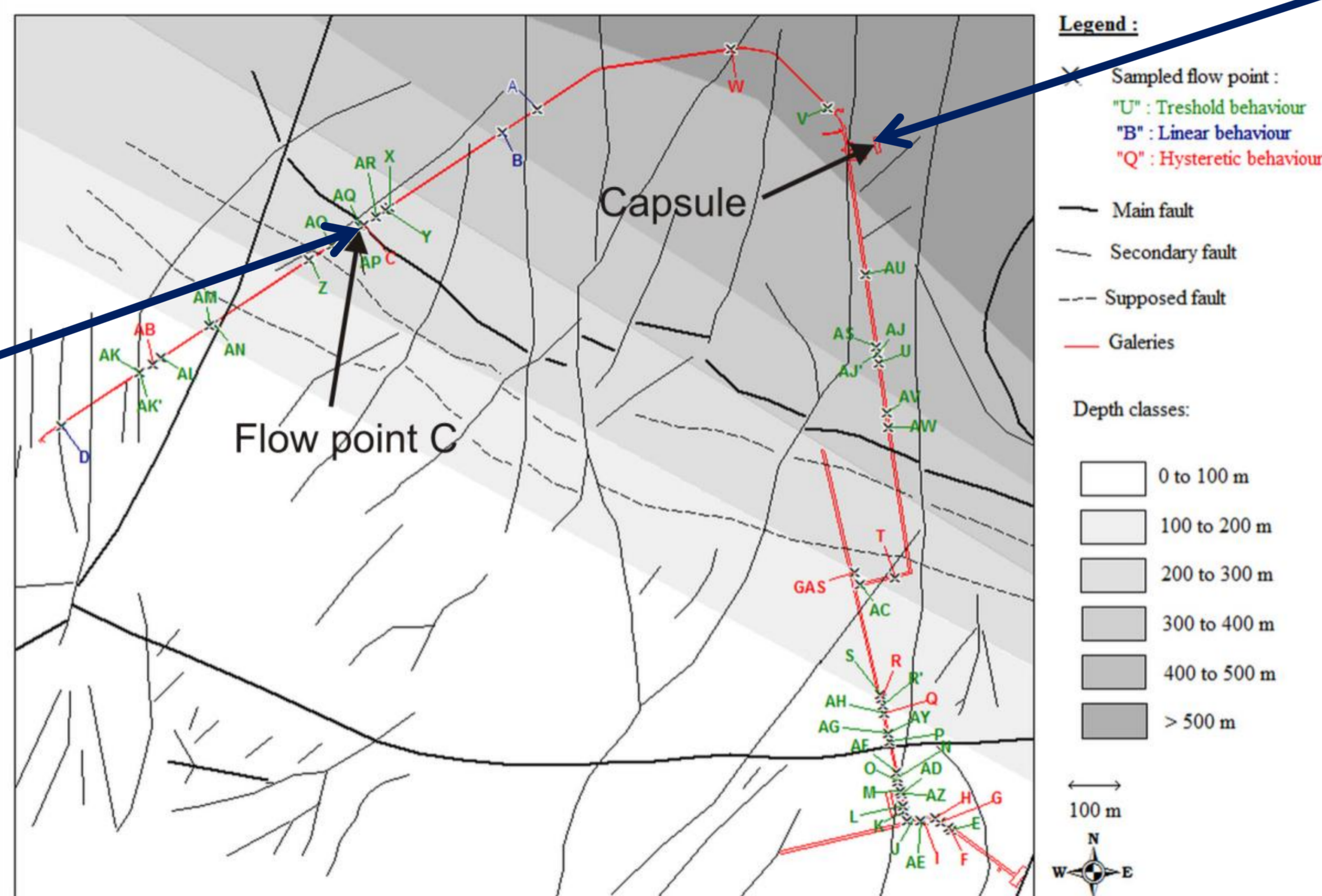
SQUID (Superconducting Quantum Interference Device) magnetometers are sensitive instruments which can track magnetic fields at a level of $fT/Hz^{1/2}$, far beyond the sensitivity of fluxgate sensors, over a bandwidth of quasi dc – 10kHz. There are not sensitive to the absolute magnetic field, but just track changes. The length of time for which they track the field is limited by interference glitches. Periods of several days are usual in quiet conditions in a low noise environment.

We carried out a measurement of the magnetic field gradient and a first search for a magnetic signals correlated with the change in groundwater flow at LSBB. The [SQUID]² magnetometer was used as a reference to track the ionospheric background. A second SQUID magnetometer was supplied by the precision measurements group at Oxford University. This was installed next to a point of monitored water flow. We examine the difference between the two signals.



Oxford system

The Oxford magnetometer was adapted from a system built for the cryoEDM neutron experiment, it uses a STAR Cryoelectronics PFL800 preamplifier and custom built electronics controlled by a laptop computer through a USB interface.



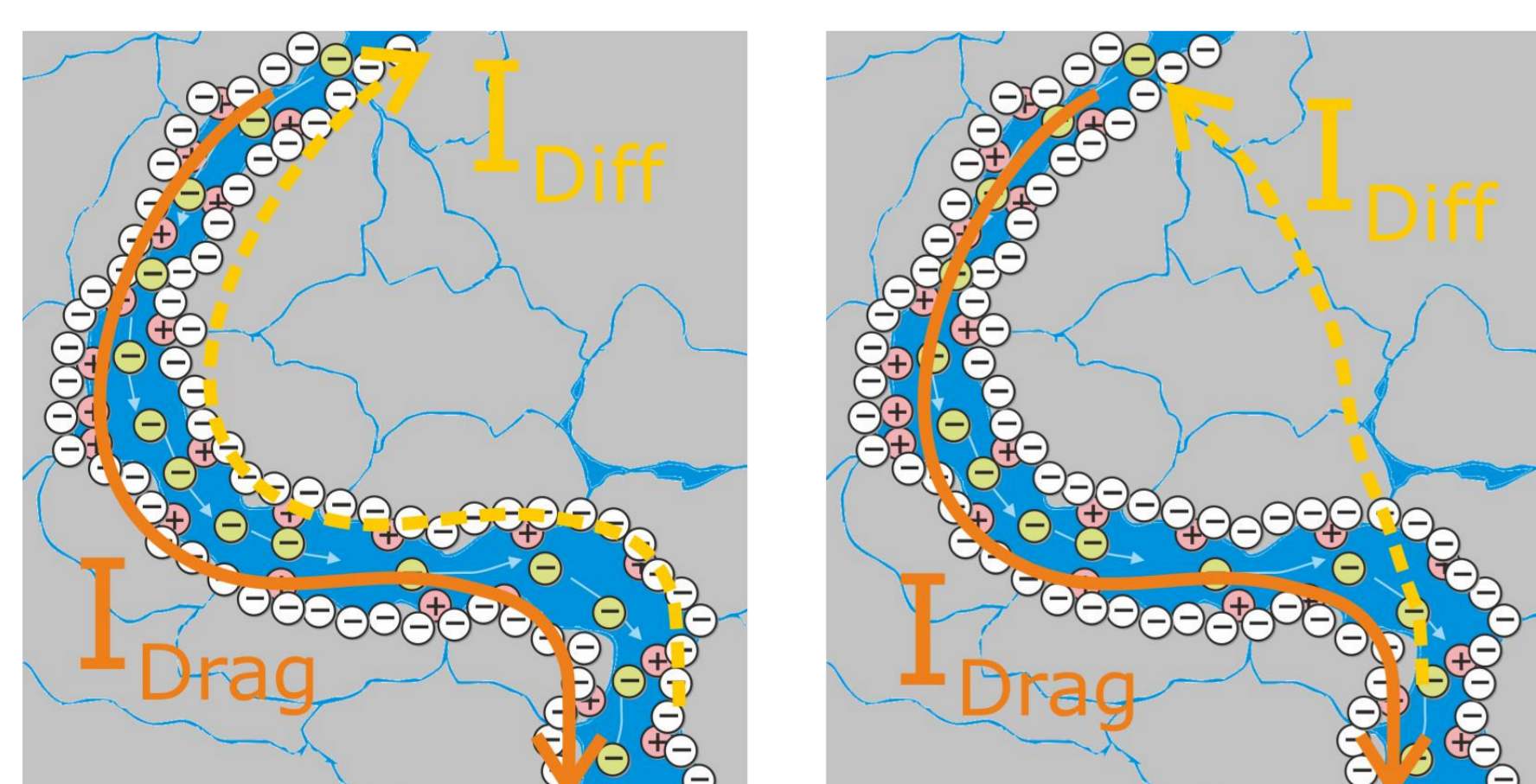
[SQUID]²

The [SQUID]² system is a permanent low temperature SQUID system at LSBB. The instrument has been used to reveal new results in fields such as ULF magnetic signals, magnetic storms, transient luminous events (sprites), Schumann modes, and magnetic signals induced by seismic waves.



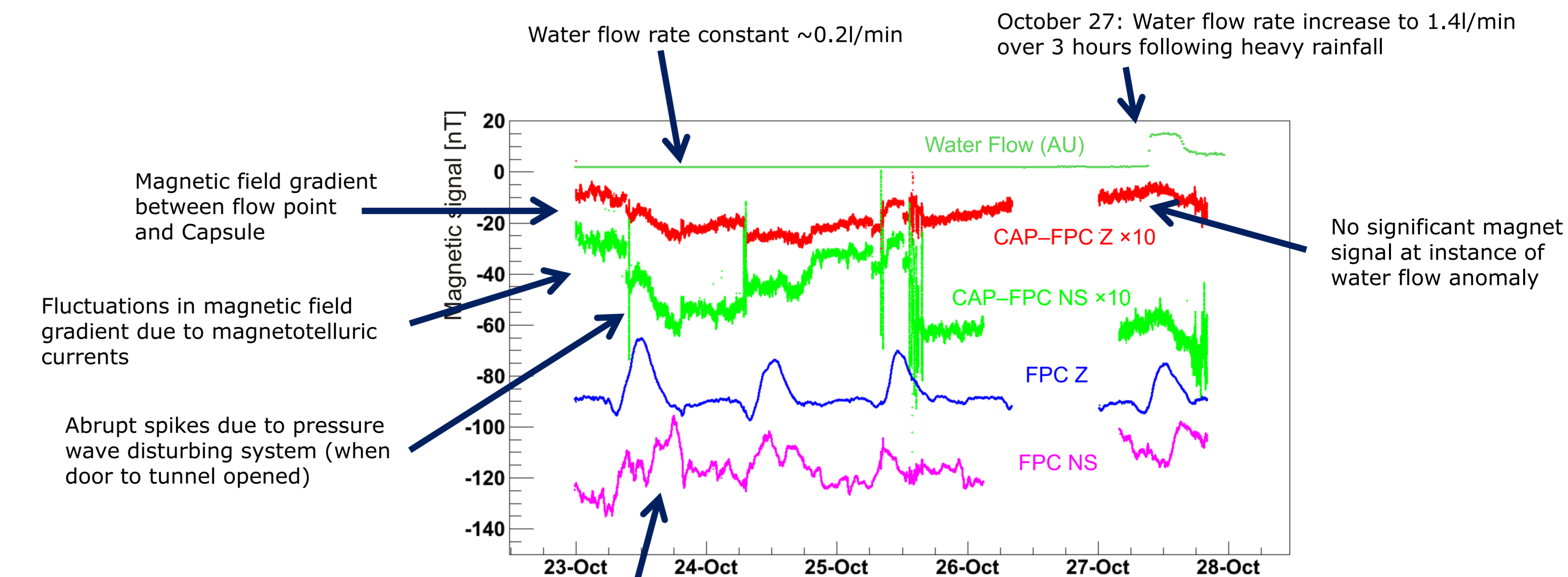
Magnetokinetic Effect?

We expect a small magnetic signal to be produced by the flow of the water through the rock by the electrokinetic effect. Due to the potential difference across the rock-water interface (the zeta potential), positive ions in groundwater are drawn to the surface, whereas negative ions are dragged along with the flow. The resulting drag current is balanced by the diffusion current to ensure charge conservation. If these two currents follow the same path (with opposite directions), then there is no net current or magnetic field. However in a realistic medium, the diffusion current will follow a different path as the path of lowest electrical resistance will vary from the path of minimum hydraulic resistance. This produces a current loop, and a resulting magnetic field. We believe the magnitude of this effect is <1nT, but without detailed information about the surrounding rock, it is not possible to calculate to any accuracy.



Currents produced by the electrokinetic effect due to the flow of water through rock. If the drag and diffusion current are balanced there will be no net magnetic field. If the diffusion current returns along a different path this will produce a magnetic field.

October 2012: Magnetic signals recorded by SQUIDs at the time of a water flow anomaly:



Component	Magnetic field change across water flow rise	Standard deviation of magnetic field over measurement period
Vertical	0.010	0.13nT
Horizontal (NS)	0.18	0.26nT