Introduction

The Bedretto Underground Laboratory for Geoenergies is an URL (Underground Research Laboratory) developed and managed by ETH Zurich since 2017. It is located in the Bedretto tunnel at about 2 km from the southern entrance, in a 100 m-long enlarged section (niche). The southern entrance of the tunnel is located in the Bedretto Valley, near the town of Ronco in the Ticino Canton, Switzerland. The tunnel runs in a straight line over 5 km with an azimuth of N317 until it intersects the Furka railway tunnel.

Here, we present succinctly the current state of the geological conceptual model built around the Bedretto laboratory. This work is built upon observations and measurements made by different partners involved in the different research projects mentioned above. Descriptions of the tunnel walls and borehole cores, including the characterisation of structures, fracture counts and structural analyses, in addition to image logging, have been used to build a coherent picture. In addition, preliminary observations from downhole radar measurements and hydraulic tests have been incorporated.

The model presented herein, as any other geological model, is still subject to changes, modifications and refinements as new data and more observations are constantly being acquired.

Geological Setting of the Bedretto Lab

The Bedretto Lab is located inside a granitic body known as the Rotondo granite, a magmatic body within the Gotthard massif. In the context of the Alps, the Gotthard massif, together with other massifs in Switzerland, France and Italy, form what is known as the External Massifs. The External Massifs represent the "old" basement that was already in place when important tectonic events took place during the Mesozoic (e.g. the breakup of Pangea) and the Tertiary (e.g. the Alpine orogeny). The Gotthard massif is composed of Precambrian and Paleozioc rocks, (mainly gneisses but also granitoids, migmatites, amphibolites, serpentinites, metagabros and metasedimentary and volcaniclastic rocks) (Berger et al., 2017).

The Rotondo granite is composed of more or less equal amounts of Quartz, Potassium Feldspar and Plagioclase (Hafner, 1958). The intrusion of the Rotondo granite took place between 295-293 Ma (Sergeev & Steiger 1995) in the late stages of the Variscan orogeny. The Rotondo granite has witnessed 3 major tectonic events: 1)The latest stages of the Variscan orogeny (the event responsible for the emplacement of the granite itself), 2)The Mesozoic break-up of Pangea, a crustal thinning event that led eventually to a lithospheric breakup and the creation of oceanic crust, and 3)The Alpine orogeny. It is widely accepted and reported in the literature that the structures observed in the Rotondo granite formed during the Alpine orogeny first in ductile conditions and later, as the massif was progressively uplifted, transitioned to the brittle domain (Lützenkirchen and Loew, 2011 and references there in). The influence of inheritance processes from the Variscan orogeny and/or Mesozoic rifting in the Rotondo granite has, to our knowledge, never been addressed. That matter is out of the scope of the present work but should be kept in mind when analysing the structure.

Methodology

The Bedretto Lab is located in a 100 m-long enlarged section of the tunnel. Six short boreholes (30 to 40 m long, referred to as SB boreholes) were drilled in and around the laboratory to gather data on the stress state and the rock in the proximity of the tunnel (Ma et al, 2019). Subsequently, three longer boreholes (300m, 220m and 190m, CB boreholes) were drilled on the SW side of the tunnel. These boreholes are oriented perpendicular to tunnel axes at approx. 45° inclination.

The present work integrates different data gathered in and around the Bedretto Lab:

- Detailed descriptions and structural logging of borehole cores of the CB1, CB2 and CB3 boreholes.
- An extensive structural logging of the tunnel walls (Jordan, 2019).
• Structural interpretations of image logging in the short and long boreholes.

Results

Three main structural directions have been identified, namely (in descending order of frequency) (Figure 1):

1. NE-SW dipping north.
2. N-S (N0°±15°)
3. E-W
4. NW-SE.

The NE-SW direction is parallel to the main foliation observed elsewhere in the Gotthard Massif and attributed to the Alpine Orogeny (Loew et al., 2007). This is also the orientation of the main lithological and tectonic boundaries of both the Gotthard and the Aar Massif (Berger et al., 2017).

The detailed borehole cores description allowed us to establish a typology of structures. The orientations of these structures were measured using image logs (optical and acoustic televiewers). The integration of orientations and typology is shown in Figure 2.

Shear fractures (Fossen, 2010) are the most common type of structures described in both the borehole cores and the tunnel walls. These are fracture planes that show evidence of shear movement (e.g. slickensides, mica smearing) but which offsets are too small to be considered as faults. All 3 main orientations described in figure 1 are represented in this subset of structures.

Figure 1 Main structural directions

All veins and dykes are oriented either NE-SW or NW-SE. A small number of biotite alignments (magmatic structure?) is oriented N-S to NNE-SSW.

The bottom row stereoplots in Figure 2 correspond to 1st order structures in terms of both strain and potential effect on fluid flow. These structures show, with very few exceptions, a preferential NE-SW strike and dip to the north.

Figure 2 Structure types identified in borehole cores with their respective orientations as measured on image logs.
Fault zones were defined in borehole cores based on the occurrence of several of the following criteria:

- A significant increase of fracture occurrence from a background level.
- The presence of breccias and/or fracture cleavage.
- The presence of mylonites.
- A decrease in the quality of the recovered core (excluding factors linked to drilling)

Based on the criteria listed above, a number of fault zones were defined in each borehole. Figure 3 shows these fault zones and their correlation across boreholes. Stereoplots of all structures inside each fault zone (purple) confirm the dominant NE-SW orientation mentioned above.

**Figure 3** Structural logs of CB boreholes.

**Conclusions**

Based on the integration of borehole and tunnel wall observations we have developed a preliminary conceptual model of the Bedretto Underground Laboratory for Geoenergies (Figure 4).

A hierarchy of structures has been established were all "major" fault zones are oriented NE-SW (perpendicular to the tunnel). The continuity of some of these structures between the CB boreholes (long) and the tunnel has been established thanks to borehole radar acquisitions. Structures oriented N-S (±15°) and NW-SE (parallel to the tunnel) are less common and generally associated to 2nd order structures.
Figure 4 Schematic 3D structural model of the Bedretto Underground Laboratory for Geoenergies

References


