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A mineralogical re-use classification model of molasse rock mass in the Geneva Basin

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Abstract

The Future Circular Collider (FCC) aims to become the largest and most powerful particle accelerator in the world located in parts of France and Switzerland. In order to host such an ambitious machine, a tunnel with a length of 97.75 km is currently under feasibility study at the European Organization for Nuclear Research (CERN). One of the study's main challenge is the handling of more than 9.1 million m^3 of tunnel excavation material. As a matter of fact, this requires a sophisticated geo-scientific and technical classification of FCC's proposed excavated geological units, respectively the molasse rock mass, in terms of re-use and disposal scenarios and to generally considerate its environmental and economic impact. The paper casts a glance at the arising scientific opportunity to classify the excavated tunnel material in future using a mineralogical approach from macroscopic to microscopic scale.

Analyses show nickel and chromium minerals within the upper and anhydrite in the upper and lower molasse parts. Nickel and chromium concentrations pollute the molasse rock mass but could imply potential mining as a re-use scenario. Anhydrite likely causes tunnel construction issues when in contact with water. The proposed classification model serves as a link to French and Swiss legislation as well as an European technical guideline concerning re-use of tunnel excavation material on any international construction site. It simplifies and delivers the basis for future contractual models from a client's and contractor's perspective under conditions and protection of national, international and European Union legislation.

Keywords

Classification, mineralogical, re-use, soft rock

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1 Introduction

Within the last decade, the European Organization for Nuclear Research (CERN) initiated several feasibility studies to build a future collider facing the physical challenges of the 21st century (Zimmermann 2015). A new collider should aim to supersede the current 27 km Large Hadron Collider (LHC) in terms of energy and luminosity. Currently, the High-Luminosity Large Hadron Collider (HL-LHC) project is upgraded to prepare for the next collider (Acar et al. 2017). However, looking beyond the next decade, a more powerful machine will be required. Hence, study efforts resulted in the final outcome named the Future Circular Collider (FCC) located in the canton Geneva, Switzerland and the French region Auvergne-Rhône-Alpes as depicted in Fig. 1. Its scope has been extensively examined with the intent to start physical measurements by 2040 (Abada et al. 2019a, b, c). The remaining time gap tends to investigate the subsurface being part of the geological Western Alpine Molasse Basin in terms of environmental, civil engineering and geological considerations and feasibility.

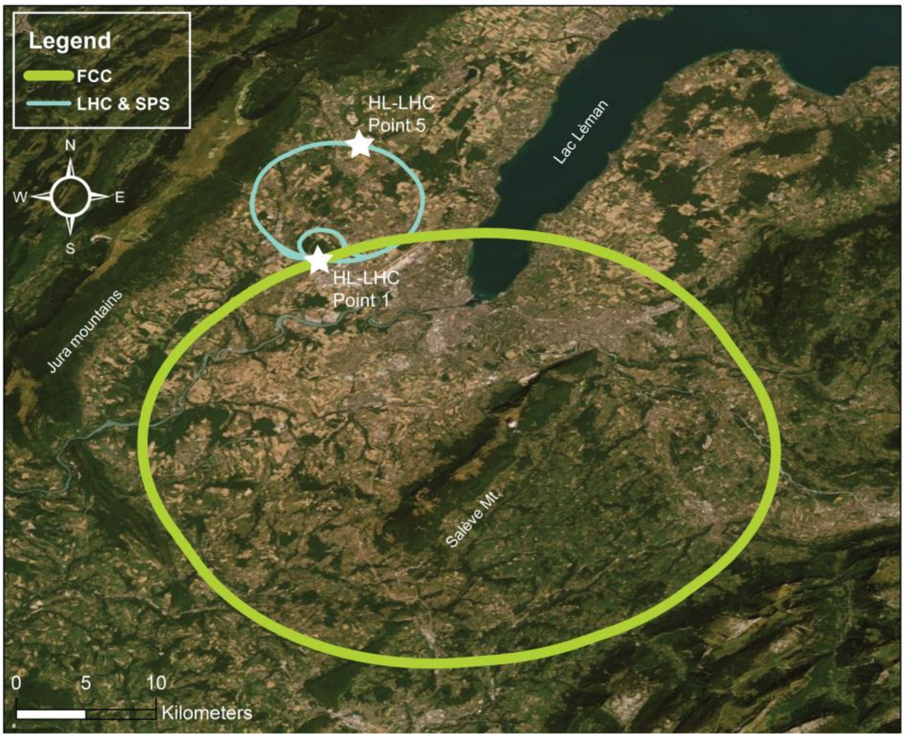

Fig. 1 The FCC ring layout in green with the LHC (large) and its predecessors (small) both in blue.

Social impact and environmental issues driven by civil engineering and geological constraints oblige to answer the question of how to handle 9.1 million m^3 of a 97.75 km tunnel in circumference. Potential re-use and disposal options on future construction sites are essential and legally mandatory to preserve sustainability. A set of multi-disciplinary approaches such as mineralogy, geophysics, geomechanics and geology associated to stratigraphy is available to classify the material accordingly. Classification turns out to be essential for further analyses and treatment and to derive re-use and disposal scenarios for the material when compared to other projects. Several researchers have developed methods to characterise excavated material using different approaches. Specifically, on-line systems were installed for construction sites to clarify for potential re-use scenarios (Erben 2016; Michel et al. 2016; INDU et al. 2014; Tokgöz 2013; Resch et al. 2009) and the Gotthard Base tunnel successfully re-used 22 % analysing the excavated material in terms of chemistry for concrete aggregates, which seemed to be the ideal individual re-use case (Fabbri 2004). That being said, each tunnelling project requires specific re-use investigations that might be adaptable to other construction sites in terms of concept and planning, but not in terms of its underlying geology and technical feasibility. Classification is impeded by geological heterogeneity and this requires an adequate choice of reasonable parameters within a vast set of geo-scientific domains for potential re-use.

This paper addresses a mineralogical approach to characterise the molasse rock mass constituting more than 90 volume-% of FCC's proposed excavated material. Potential obstacles predicted by polluted material are introduced to imply first insights and suggestions to re-use scenarios and to cast a first glance at geological and civil engineering uncertainties. Moreover, a first investigation is presented for the proposed polluted material containing heavy metal ions that might hamper re-use and construction.

2 Geological setting

The Western Alpine Molasse Basin (WAMB) as depicted in Fig. 2, often referred to as the Geneva Basin in Western Switzerland, is part of the Swiss Plateau and limited by the Salève Mountain to the SE and the Jura mountains to the NW. These distinctive, geological elevations were influenced by tectonic deformation during the Alpine foreland emplacement, the associated glaciations of Pleistocene age and post-glacial processes (Moscariello 2018). The WAMB is divided into the Alpine foreland consisting of the Jura plateau and the Haute Chaine as well as the Alpine units represented by the pre-alps (Penninic), the subalpine and Helvetic nappes, the external Crystalline massifs and the Penninic nappes (Chelle-Michou et al. 2017). The molasse rock units present in the basin crop out along the Salève, the Vuache and the Jura mountains, which consist of Mesozoic sedimentary rocks. The Mesozoic succession starts with evaporites at the base, followed by a succession of limestones and marls belonging to the southern margin of the European continent dated back to the Tethys Ocean. The Mesozoic sequence was deposited on top of the Palaeozoic crystalline basement. This shows graben-like structures filled with continental siliciclastic sediments during the Permian and Carboniferous, following the Variscan orogeny (Moscariello et al. 2020). The top of the Mesozoic sequence indicates an extensive erosive surface formed during the uplift of the foreland basin as the Alpine belt was compressed. Above the erosional surface, Oligocene heterogeneous siliciclastic Molasse are overlain by Quaternary glacial to fluvial deposits. These molasse packages were deposited as detrital formations during the Alpine orogeny (Trümpy et al. 1980) and represent FCC's targeted construction depth of 100 to 500 m.

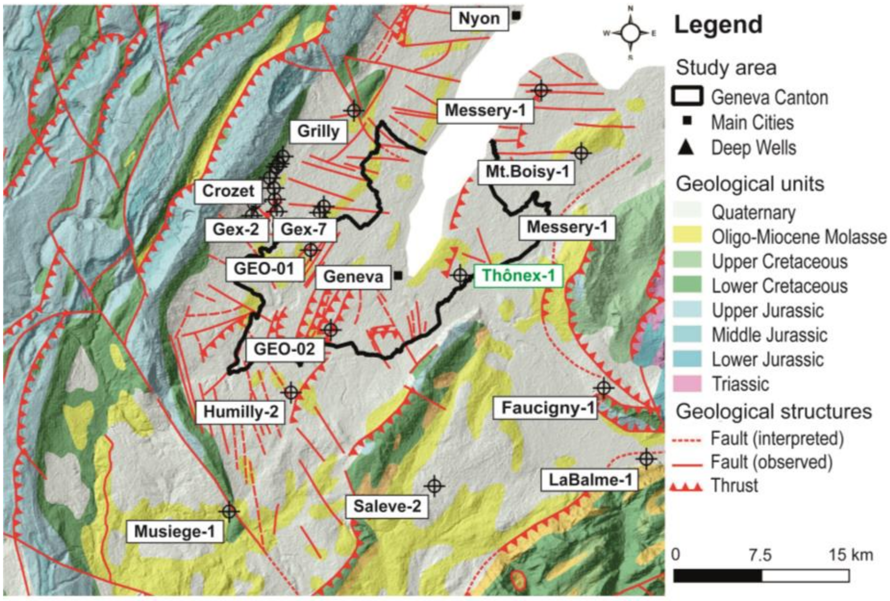

Fig. 2 Geological units with associated boreholes in the Geneva Basin. The well of Thônex chosen for this study is depicted in green. Modified after (Moscariello et al. 2020).

Two prominent classification models of its marl and sandstone components exist based on stratigraphy and the analyses of physical parameters. A stratigraphic classification of the molasse is given by Trümpy (1980) according to: Lower Marine Molasse (UMM), Lower Freshwater Molasse (USM), Upper Marine Molasse (OMM) and Upper Freshwater Molasse (OSM). In literature, molasse abbreviations usually refer to German terms. Data sets outsourced and gathered by CERN within the last 70 years served for a second and more recent geotechnical classification given by Fern et al. (2018), who subdivide the molasse into: very weak marl, weak marl, medium-weak marl, weak sandstone, medium-strong sandstone and strong sandstone. These categories increase in uniaxial compressive strength (UCS) and are further based on differences in e.g. Young's moduli or Atterberg limits, merely taken from HL-LHC Point 1. Even though these classifications led to a better understanding of molasse properties, a potential re-use classification was neither investigated nor demanded.

3 Data methodology

The mineralogical classification approach is based on data taken from the well of Thônex as depicted in Fig. 2. The samples were taken from cuttings, which typically contain sandstone, limestone and mudstone. In total, 113 samples each weighing between 100 to 200 g were chosen along a total analysed borehole depth of 1323 m. 53 out of 113 samples were selected with an interval of 10 to 15 m to guarantee a regular profile resolution. X-ray fluorescence (XRF) and inductively-coupled plasma (ICP) analyses have been conducted to measure the elemental composition of molasse rock material. These results later served for oxide calculations. In addition, automated mineralogical scanning electron microscopy (QEMSCAN©) allowed calculation of grain density and modal mineralogical composition on polished thin sections. Lithotypes classification could be performed using mineralogical and textural information. Sample preparation included washing to remove drilling mud, hand-picking of coarse-grained particles and embedding in epoxy resin to create thin polished sections. QEMSCAN© measurements were performed using a beam voltage of 15 kV at 10 µA, as typically applied for sedimentary rock. A 15 kV beam allows for a smaller analysis point (< 3 µm) compared to 25 kV at the expense of a less accurate determination of heavy elements. The small analytical point is preferred for sedimentary rocks, which predominant clay and fine-grained mineral mixtures, to minimize the number of mixed signal pixels (measured at the boundary between two minerals). The scans were performed applying a 10 µm grid on a 1.5x1.5 cm area. Measurements were performed with two fast EDS collectors, and each pixel was defined by an accumulation of 1000 counts, sufficient to identify the main components.

4 Results

QEMSCAN©, XRF and ICP-MS measurements are presented below and a classification model, respectively lithotypes, are derived. A first look was taken at grain densities calculated from QEMSCAN© data as shown in Fig. 3.

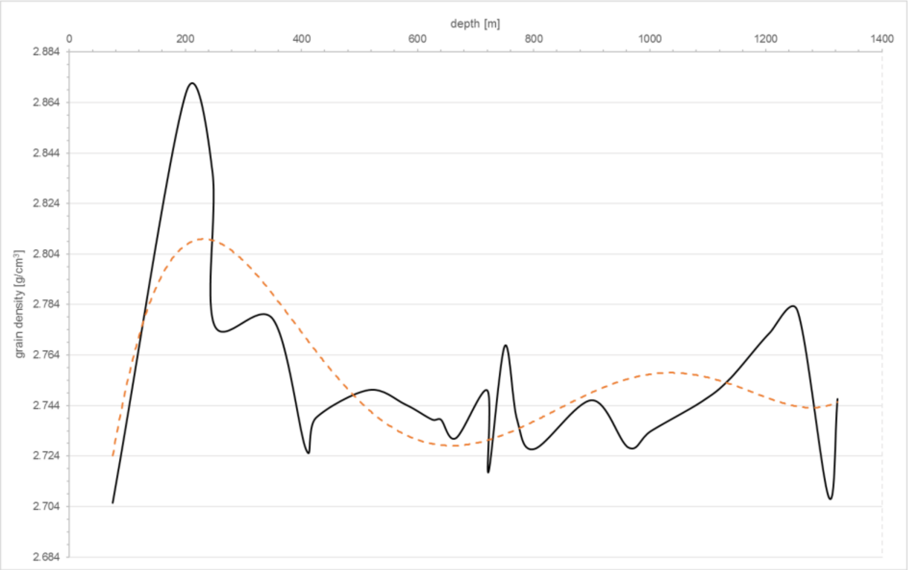

Fig. 3 Distribution of grain densities along borehole depth. Dashed line depicts a general trend.

After a first increase to around 2.87 g/cm^3 within the upper 240 m, the trend line shows density values dropping and stabilizing at around 2.73 g/cm^3. Zooming in at each depth level, Fig. 4 shows the area-% proportions of different lithotypes recognized in the cuttings particles. Lithotypes were created based on modal mineralogy and textural information. It can be seen that phosphatic rock type is not-existent. Pyritic rock type only occurs between depths of 1254 and 1323 m. Evaporitic rocks are defined by the abundance of anhydrite (identified as gypsum/anhydrite) and are found between depths of 201 and 516 m as well as 1089 and 1323 m. Sandstone, limestone and claystone occur from top to bottom, whereas the area-% of limestone decreases until approximately 650 m to continuously increase towards the bottom. A similar behaviour can be seen with evaporitic rocks. Claystone completely misses out between depths of 250 to 425 m, while sandstone shows the same pattern. However, little concentrations seem to be present at depth 408 m. Except for depth 75 m, the mixed rock category is present at all levels. Fig. 5 (A) shows the modal volume-% distribution of each mineral at different borehole depths and in (B) anhydrite cleavage can be seen under the polarizing microscope. Fig. 6 shows a final comparison of QEMSCAN©, XRF and ICP analyses. As proposed by lithotypes, gypsum/anhydrite (dark purple colour) is broadly distributed at certain borehole depths. QEMSCAN© data shows a fine-grained, compact texture with rather coarse-grained mineral compounds at depth 722 m. In XRF, SiO_2 (sandstone lithotype), CaO (limestone lithotype), Al_2O_3 and Cr_2O_3 are the most dominant oxides. ICP data shows element components such as nickel and chromium correlated to serpentinite and Cr-spinel. Magnesium shows rather constant values, whereas uranium and thorium values constantly differ from one another in all samples.

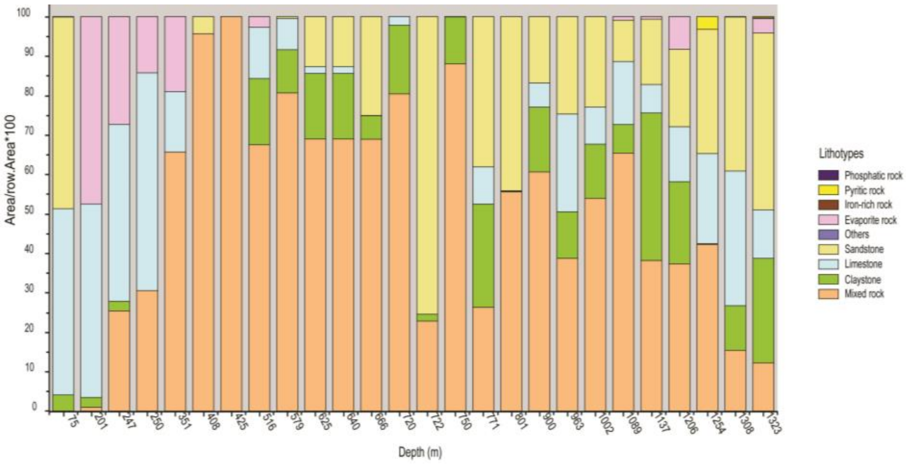

Fig. 4 Lithotypes derived from QEMSCAN© analyses at different borehole depths.

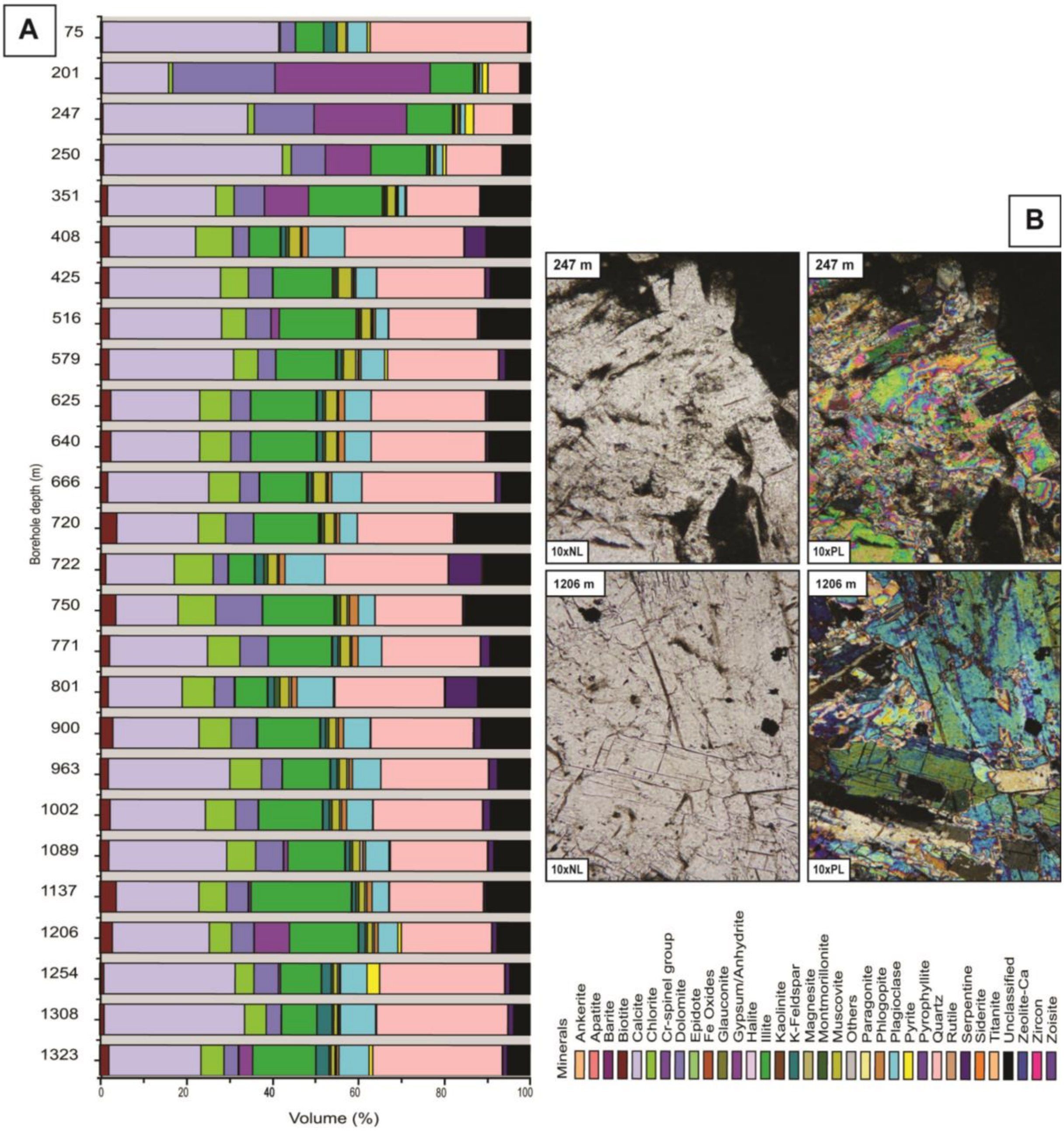

Fig. 5 A: Modal mineralogy at different borehole depths. B: Thin sections under polarizing microscope, in plane parallel (NL) and crossed polarized (PL) light. In contrast to QEMSCAN©, anhydrite is easily distinguished (birefringence, relief and cleavage) from gypsum under the polarizing microscope.

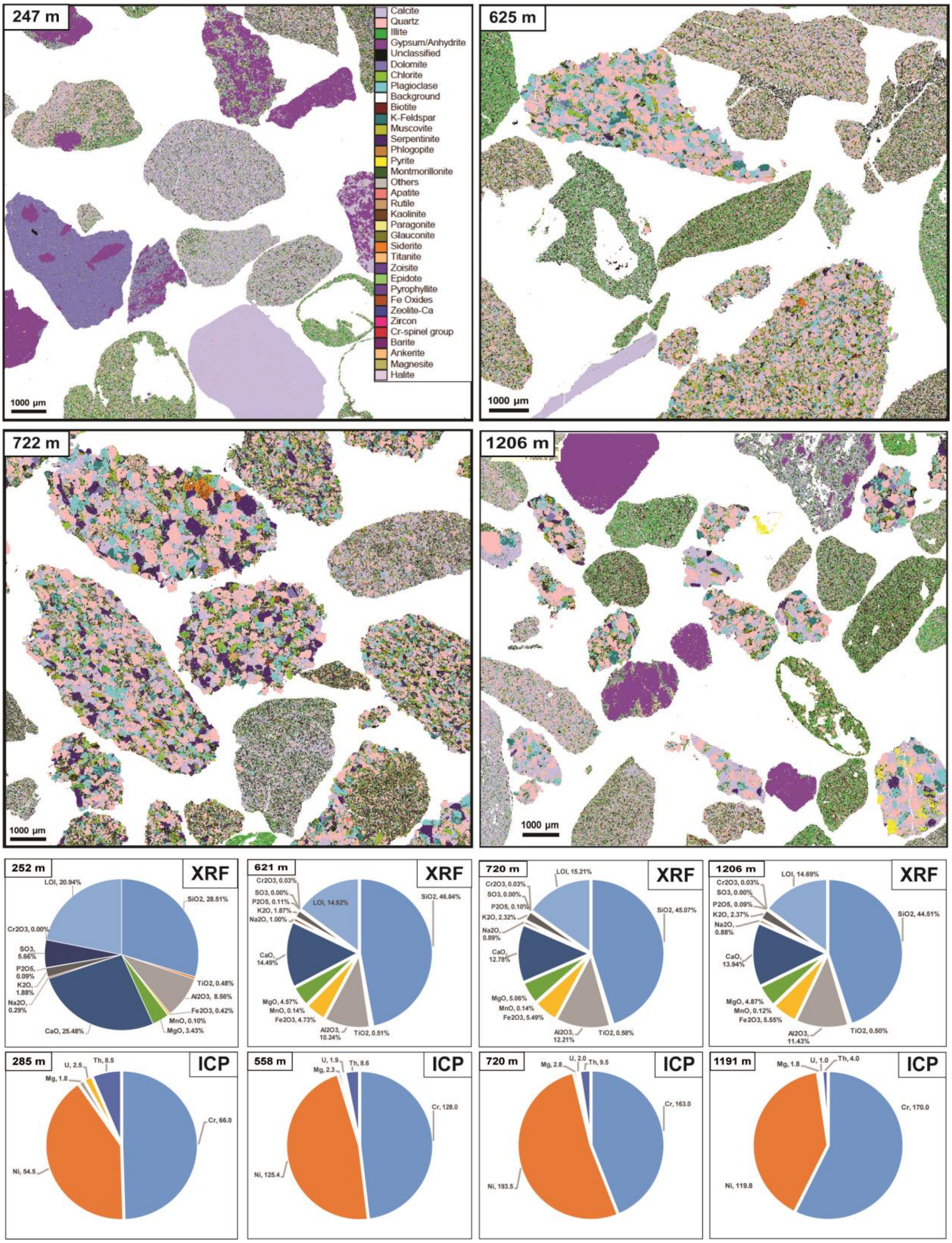

Fig. 6 QEMSCAN (top), XRF (middle) and ICP-MS (bottom) comparison at different borehole depths.

5 Discussion

Serried grain densities turned out to be not sufficient to derive a first classification model. They hardly allow a clear compositional classification. We created a few new definitions in the database (Cr-spinel, possibly also kaemmerrite) but left quite a significant amount of unclassified that may correspond to either picotite or mixtures. Unclassified pixels in QEMSCAN© data could be an unknown mineral (not included in the data base) or a mixture of various minerals that cannot be solved. Typical cleavage depicted in the polarized light under the microscope clearly concludes anhydrite as the predominating mineral for all depths. Especially for mechanized tunnelling including different TBM types such as Slurry-TBM or Earth-Pressure-Balanced TBM, this bears a lot of issues when in contact with water.

The hydration of anhydrite produces gypsum constituting lower density but higher volume. This dilation can break tunnel structures and requires expensive support. If possible, anhydrite must be avoided during tunnelling. The occurrence of anhydrite at the top and bottom of the borehole might be in close relationship to different molasse types. Beyond Salève Mt. marine molasse is predominant that proceeds towards the Thônex well becoming continentally influenced. A major problem is faced when considering Ni and Cr present in Cr-spinel and serpentinite. Serpentine grains (up to 14 % volume) contained in molasse sandstone are probably the main carriers of these polluting elements. It is not known if any mechanical or chemical process are able to separate the serpentine fraction so that a minor volume of higher-grade Cr-Ni sand could be produced for disposal.

Extracting the Cr and Ni of the serpentinite might not be economic under normal mining conditions when considering its concentrations but may be viable taking the very high cost of polluted disposal into account. This might require processing the excavated material technically and/or biologically for different French and Swiss disposal classes. Detailed clearance can be stated when investigating samples with QEMSCAN© at 25 kV voltage, which allows to detect heavy metal ions such as Ni and Cr with higher precision, even though this comes to the account of lower resolution. Differences in natural radioactivity elements like uranium and thorium relate to different ratios of marl and sandstone within the molasse and open up opportunities to classify them accordingly with a strong practical advantage when considering gamma spectrometry along a conveyer belt.

6 Conclusion & future perspectives

A first classification model of the molasse rock mass was presented using QEMSCAN©, XRF and ICP data analyses based on lithotypes and modal mineralogy. It could be shown that the presence of anhydrite in the molasse rock mass likely causes construction issues during tunnelling. Its geological heterogeneity, respectively of cuttings, was overcome by using elemental, mineralogical and lithological indications. Natural radioactivity given in U and Th are able to classify molasse material as a first quick-look method. The mixed rock lithotype corresponds to a fine-grained, marly sandstone lithotype that implies sub-lithotype classifications among sandstone and marls within the molasse units bearing Cr-spinel and serpentinite. Ni and Cr concentrations tend to increase with depth and may be suited for a re-use scenario as mineral resources. This re-use scenario overcomes the legal issue of French and Swiss disposal classes since these elements significantly pollute the excavated molasse material and hence, requires purification. The classification proposes a first mineralogical link to a unified European, technical guideline concerning re-use of tunnel excavation material.

Since these preliminary results showed a mineralogical classification approach, future studies foresee further boreholes being taken into account along FCC's full quasi-elliptical layout considering all mineralogical data in different boreholes. Contextually, this data will be linked to existing geotechnical values as well as new measurements within the same survey area. Currently measured multi-disciplinary, especially geotechnical laboratory data as well as old archive data to be digitized is going to compare with geophysical borehole logs (e.g. sonic, resistivity, gamma-ray and induction log) to derive testing geotechnical parameters. These parameters are in preparation and will be presented in a forthcoming paper. Gamma-ray logs will be used to detect natural radioactive occurrences, compare them with laboratory measurements and calculate shale volumes prior to FCC site investigations and construction phases to establish a general prediction model. These cross-correlations will have to prove its accuracy, credibility and liability within the next study efforts.

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