Sonic drilling coupled with on-line-on-mine-analyses: field tests at the Villeveyrac bauxite deposit (Southern France)

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Abstract. The field tests of the SOLSA expert system at the bauxite mine (SODICAPEI-VICAT, South France, 15th to 30th September 2018) aimed to evaluate the workflow and individual instrumental parameters, mechanics of the drill rig, the core scanner (RGB, profilometer, VNIR-SWIR (final with XRF)), the benchtop system XRD-XRF, data architecture, data transfer, software and interaction with the (open-) databases. The focus was on iron oxy-hydroxide and clay mineral rich lithologies, that is also present in Ni-laterite profiles. In total 65 m were drilled at two boreholes with a 90-100% core recovery on 52 m (80%). Core scanning recorded 40m/10h. The results on the undestroyed core surface are representative of the core. The XRD-XRF benchtop system is fast (5-7 min/sample) for validating and quantifying analyses on the regions of interest, defined by the core scanner. It will be installed at the drill site for immediate environmental analyses. Data connection was successful from drill to core-scanner. The hyperspectral database is performant for the lithologies present at this bauxite deposits. The sample database is operational based on international standards. Data superposition and fusion, and GUIs are under development. (https://youtu.be/mUfS1b5xFZE).

1 Introduction

The SOLSA expert system is developed in the frame of the EU H2020 project 689868 (2/2016-1/2020 9,8 M€, www.solsa-mining.eu). X-ray detector developments are performed in the PAIRED-X (EIT-KIC) project (http://nanoair.dii.unitn.it:8080/paired-x/). The expert system is composed of: (1) a sonic drill rig and a wire-line-system (2) a core scanner (RGB camera, profilometer, X-Ray fluorescence-spectrometer (XRF), Visible-Near Infrared (VNIR) and Short-Wave Infrared (SWIR) hyperspectral cameras) and (3) a benchtop system (X-Ray Diffraction (XRD)-XRF-Raman spectroscopy). SOLSA develops and extends existing open databases. Data from drill-rig and mineralogical and chemical data from the two sensor systems will be coupled to enhance the information at the exploration stage. The expert system will drill and analyze 80 m sonic drilled core per day, define regions of interests for the mining companies in real time through dedicated software and interaction with special designed databases. The prototype is designed for nickel laterites (SLN Mines, in New Caledonia). The final goal is to speed up exploration and optimize processing.

As bauxites have similar characteristics as Ni-laterites (grain size, material contrasts, clay mineralogy, iron-(aluminum) oxy hydroxides), the tests were performed at a bauxite mine in France, allowing short travel times and rapid material implementation. SOLSA was tested under field conditions in the on-line-on-mine-real-time workflow with variable drill bits, monitoring while drilling, the split liner prototype, different types of core-catchers. The different instruments of the core scanner and the XRD-XRF system were evaluated. The data architecture, data transfer from drill to core scanner, the software and interaction with the databases was established. The focus was on the (swelling-) clay mineral-rich marls, which resemble lithologies within in nickel laterites.

2 Geological characteristics

The bauxite deposit at Villeveyrac belongs to a synclinorium dipping SW. Bauxite is present to up to 800 m depth. It is a Karst-type bauxite, reaching thicknesses of 2 and 8 m (Fig. 1). The Karst is composed of dolomitized limestone. Bauxite is overlain by multicolored marls with variable iron oxy hydroxide contents and carbonate concretions with sandstone intercalations and limestone reaching up 700 m thickness in the center of the basin.

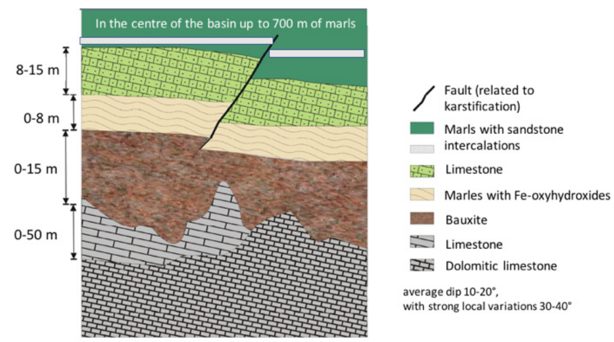

Figure 1. Schematic lithological profile at the bauxite deposit (Villeveyrac, France) (modified from Giroud et al. 2009).

3 Field test preparation

Drilling was done in collaboration with SODICAPEI-VICAT. Physical and mechanical rock parameters known from previous drilling were used for drill tool choice and definition. For calibration of the individual instruments of the core scanner and the XRD-XRF benchtop instrument, major lithologies were sampled and analyzed by laboratory XRF and XRD, portable XRF and pIR prior to field tests. A hyperspectral mineralogical database was established for the major minerals (quartz, rutile, illite, kaolinite, calcite, dolomite, montmorillonite, hematite, goethite, diaspore, boehmite; Prudhomme 2017, 2018). The SOLSA core scanner was tested on previously drilled core samples at the Thermofisher R&D laboratory (Artenay, France) to recognize the textures and minerals during the SOLSA field tests.

4 SOLSA Drill

Drilling was performed on two bore holes at the eastern boarder of the lac d'Olivet (Fig. 2). Two boreholes at about 200 m distance were drilled at 30 m and 35 m depths. At the first locality, only variegated marls were sampled. At the second location, 1-3 m thick sandstone is intercalated in the marls. The marls contain variable contents of iron oxy hydroxides and carbonate micro concretions (Fig. 3). Drill fluids (water, polymer, air) were tested in variable proportions. Spherical and ballistic drill bits of different geometries were tested. Sonic wireline and conventional sonic drilling was used. The SOLSA split liner prototype was tested, but revealed not being adapted to the clay-rich materials.

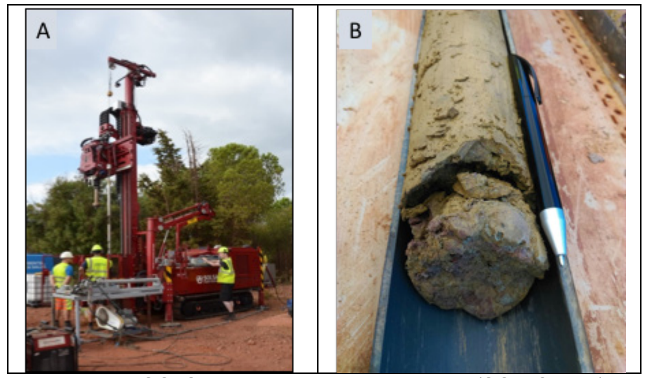

Figure 2. A. SOLSA Drill at the bauxite mine (SODICAPEI), B. variegated marls.

At the two borehole locations, 80% of the core gave 90-110 % core recovery. The clay-rich marls gave recovery rates of 101-110 %, related to the swelling clay mineral presence and interstitial water. This might be related to decompression and/or drill fluid addition. The drill core surface is covered by mud cakes (2-5 mm thick).

5 SOLSA Core Scanner

For the tests, The SOLSA core scanner was in a rented minivan to evaluate "in-field performance" at ~ 30 m distance from the SOLSA Drill (Fig. 4). The SOLSA software consists of data acquisition, data registration and data processing parts. In order to produce mineralogical maps, we implemented sparse unmixing techniques with the incorporation of spatial information using superpixel algorithms. The major mineralogy defined by laboratory studies and portable IR (Prudhomme, 2018), and by measurements performed by SOLSA core scanner at the Thermofisher R&D lab, could be confirmed under field conditions by the SOLSA core scanner (Fig. 5, 6). However, unlike the punctual analyses of the pIR, the core scanner and SOLSA software allows producing a mineralogical map of the undestroyed drill core surface.

Figure 3. A. split liner showing bursting of rubber band, a result of swelling pressure due to clay minerals in marls, B. Calcite concretion-hosting marls.

Figure 4: SOLSA core-scanner in a minivan (note that the XRF spectrometer was not mounted for security reasons).

A composite drill core was recorded and a mineralogical map was produced based on the SOLSA software using SWIR hyperspectral data (Fig. 5). During the tests, 1 m of core was scanned in 15 minutes (40 m/10 h shift). Data interpretation was not yet in real time, as the data fusion software is still under development.

6 SOLSA Benchtop combined XRD-XRF-Raman spectroscopy

The benchtop system is designed for analyzing the samples previously defined as regions of interests. For this SOLSA test, the EQUINOX XRD-XRF (Thermofisher) was used in a minivan. For this instrument, a special X - ray detector is developed in the frame of the PAIRED-X projects (KIC-EIT). The Raman spectrometer was not yet added to the XRD-XRF at the time of the field tests. The software XRF-XRD data interpretation has been developed on the basis of the MAUD open software for testing XRD-XRF combined analysis and calibration of clay structure. Software for Raman data acquisition and automatic analysis is being developed and integrated into the combined XRD-XRF software to make an ultimate software for combined XRD-XRF and Raman spectroscopy for SOLSA benchtop system. While the core scanner analyses drill core surfaces with a limited accuracy due to the selected instrumental configuration to achieve fast scanning, the combined XRD-XRF analyses will be performed on sample powders. After crushing and sieving, the < 200 µm fraction is milled in a micronizer (Fig. 6). During the field tests, the sample preparation protocol was established to reach a homogenous sample powder of ~10 µm at ~ 3-5 min milling time. The micronizer, operating beside the core scanner during the field tests, generated vibrations which impacted the results of the core scanner. In total 18 samples from drill cores, drill mud and stock piles were analyzed (5-7min/sample) giving satisfactory results for the mineralogy. Comparative analyses of the material from the inner core part and outer mud cake gave identical results for the mineralogy. The core scanner analyses are thus reliable. Figure 7 shows 3 examples of bauxites (red-white and an Fe oxyhydroxide-rich pisolite), analyzed by the XRD-XRF system.

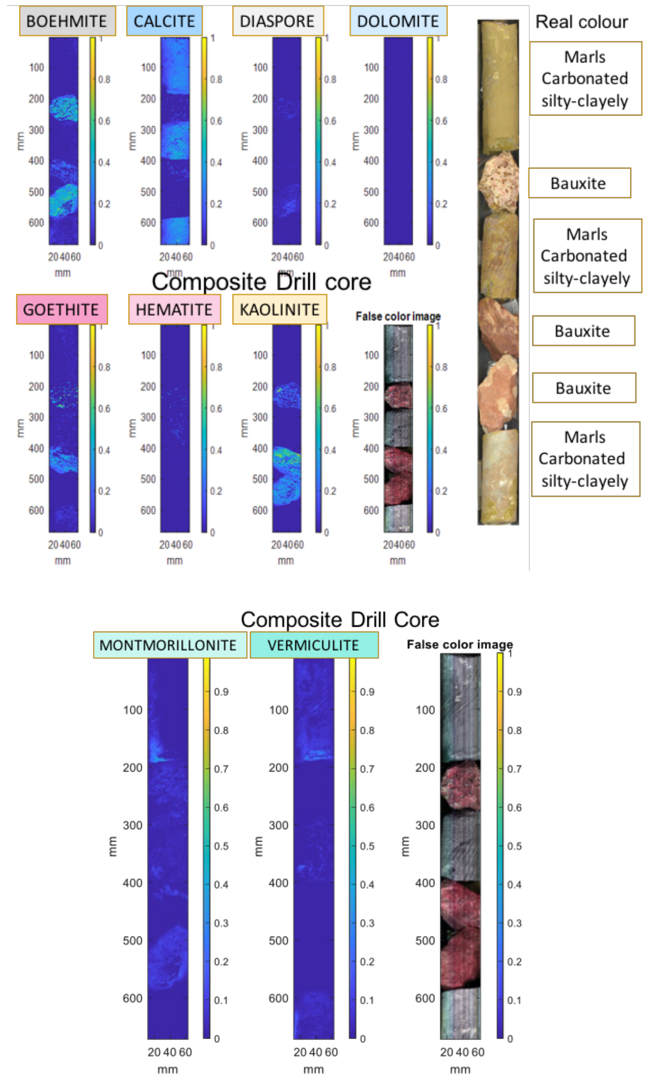

Figure 5. Artificial composite drill core of the major facies of the bauxite mine, showing the major mineralogy mapped by SOLSA software using SWIR hyperspectral data. Marls is sonic drilled.

Figure 6. Micronizer, Retsch (BRGM) for fast milling of homogenous powders from the region of interest, drill muds & dusts.

7 SOLSA databases

To provide on-line accessibility to the confidential generated data and to all open data, 4 SOLSA databases have been built: (1) The Raman Open Database (ROD) to store Raman spectra of pure mineral phases. (2) The Spectral Open Database (SOD), to store separate spectra (extracted from hyperspectral image) of pure mineral phases. (3) The Hyperspectral Open Database (HOD) to store hyperspectral images, which are 2D images (each pixel is a spectrum). (4) The Open Sample Database (OSD) relies on international standards (ISO14688-1/14689:2017). This architecture is operational for entering petrographical and mineralogical descriptions, for its use by mining companies. All SOLSA samples have a unique persistent identifier. The SOLSA sample database is implemented as a RESTful layer on top of a standard SQL database (currently, a MySQL back-end is used); the RESTful layer, implemented as a set of Perl CGI scripts, provides access to the data over the HTTPS protocol.

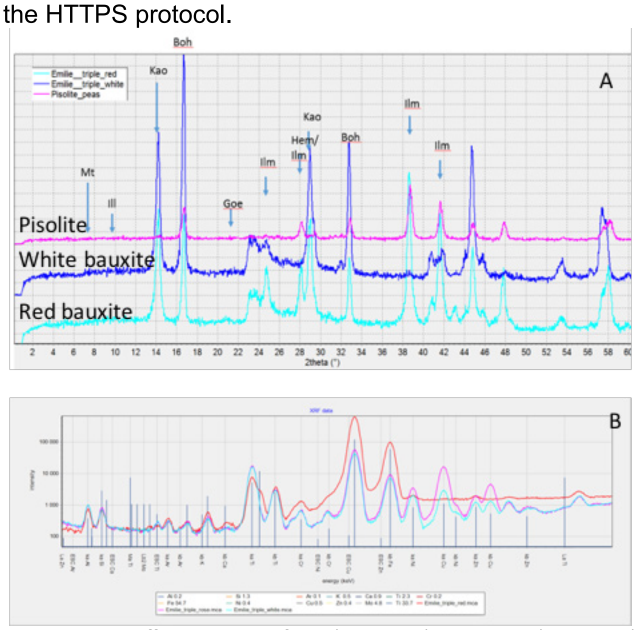

Figure 7. A. Diffractograms of red (light blue) and white (dark blue) bauxite and pisolite (red). B. XRF spectra of the same sample.

8 Discussion and Conclusions

During these real mine conditions, many parameters were tested on the expert system. Two weeks were too short to obtain sufficient data for statistical validation. For drilling, more precise geotechnical data are needed. A systematical drilling with small spatial off-sets is required. A spare wire line system should be available in the field to ensure continuous core flow. The split liner burst at high amounts of clay minerals and the presence of water. It thus cannot be used in wet marls. While swelling clay minerals were detected (Fig. 6), kaolinite and illite (Prudhomme, 2018), were not found by SWIR. Swelling clay minerals, but also interstitial water may have induced the increase of ~10 vol.% expansion. Phase quantification by coupled XRF-XRD-Raman is thus important. During the field tests, the core scanner reached ~ 40 m/10h shift (50 % of the target: 70-80m/10h shift drill+scan). During the field tests, data superposition and data fusion software were adapted. The minivan used for the tests was a rented car, temporary equipped for the field tests. The definite SOLSA minivan will be equipped with anti-vibration technologies to avoid the effect of the drill rig and micronizer, and to achieve reliable data superposition and fusion from the individual instruments. It was decided to install the benchtop XRF-XRD-(±Raman) in the minivan, as useful environmental data can be acquired simultaneously to drilling (e.g. drill mud, atmospheric dust). For OSD database, entry tests are ongoing to optimize interactivity and interconnectivity with the Crystallographic (COD), Hyperspectral (HOD) and Raman (ROD) Open databases (Grazulis et al. 2009, 2018; Bui et al. 2018; El Mendili et al. in press). Graphical user interfaces (GUI) are under development to facilitate operator's work. The final system will have CLOUD data and interacting software to reach almost real-time decision making. The overall workflow was tested in the field and for the first time, the data transfer from SOLSA drill to the core scanner operated via a RFTID system on split liners. The data transfer was already performed to the core scanner system. Drill specific data which will allow conclusions on physical and mechanical parameters of the rocks will be available in future. Our results are evaluated and the next drilling test is scheduled for the beginning of April 2019 for 2 weeks at the bauxite mine. This time we will focus on the interface between marls and bauxite. The SOLSA test is on schedule and will be performed in October-November 2019 at the SLN Nickel mine in New Caledonia

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