

Mineralogical mapping of ore samples and the implementation of Pd and Pt measurements using Laser-Induced Breakdown Spectroscopy and μ -XRF

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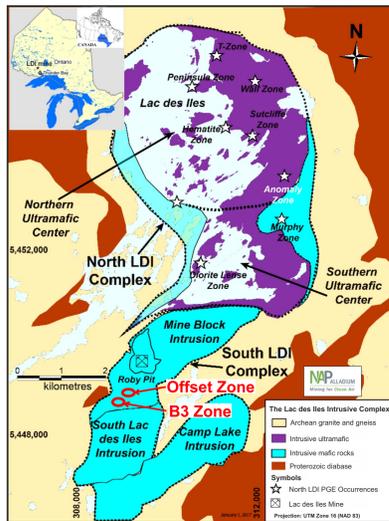
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INTRODUCTION

Thorough characterization of the geochemistry and mineralogy of ore samples is crucial to assess the economic potential of ore deposits. Such assessment requires fast and efficient techniques to reduce the time and therefore the costs related to decision-making in mineral exploration and processing. This study demonstrates the potential of Laser-Induced Breakdown Spectroscopy (LIBS) in the rapid characterization of the chemical and mineralogical content of Platinum Group Elements (PGEs) ore samples from the Lac des Îles mine (LDI) (Ontario, Canada). Micro X-Ray Fluorescence (μ -XRF) mapping, optical microscopy, Electron Probe Micro-Analysis (EPMA) and Scanning Electron Microscopy (SEM) contributed to corroborate the LIBS analyses. This work also demonstrates the potential of μ -XRF chemical mapping in identifying areas of interest for Platinum Group Minerals (PGMs).

GEOLOGICAL SETTING & STUDY AREA



Core samples characterized in this study are PGEs ores from the LDI mine. The mine is located 106 km northwest of Thunder Bay, Ontario (Figure 1). The LDI complex is characterized by mafic to ultramafic intrusions and it hosts a significant Pd deposit, from which 201,592 oz of Pd was produced in 2017 (Decharte et al. 2018). Three distinct intrusive bodies (Figure 1) have been distinguished in the LDI complex (Buss et al. 2017), namely the North-LDI intrusion, the Mine Block Intrusion (MBI) from which Pd is extracted, and the South-LDI intrusion. The samples covered by this study were collected from two different orebodies (Figure 1) within the MBI: the Offset Zone orebody, the host rock being named pyroxenite, and the B3 Zone orebody, the host rock being gabbro-norite.

Figure 1. Simplified geology of the Lac des Îles igneous complex (Buss et al., 2017). The red circles show the approximate locations of the studied orebodies.

MINERALOGY (silicates & PGMs)

Lac des Îles ore samples & LIBS database

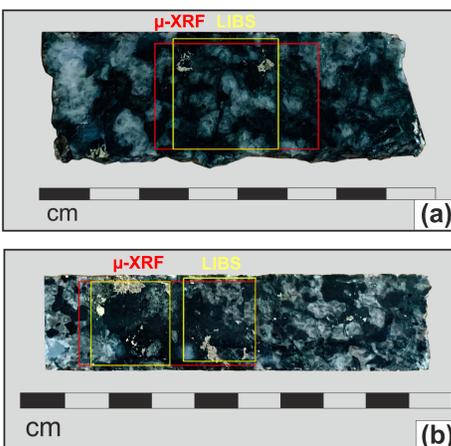
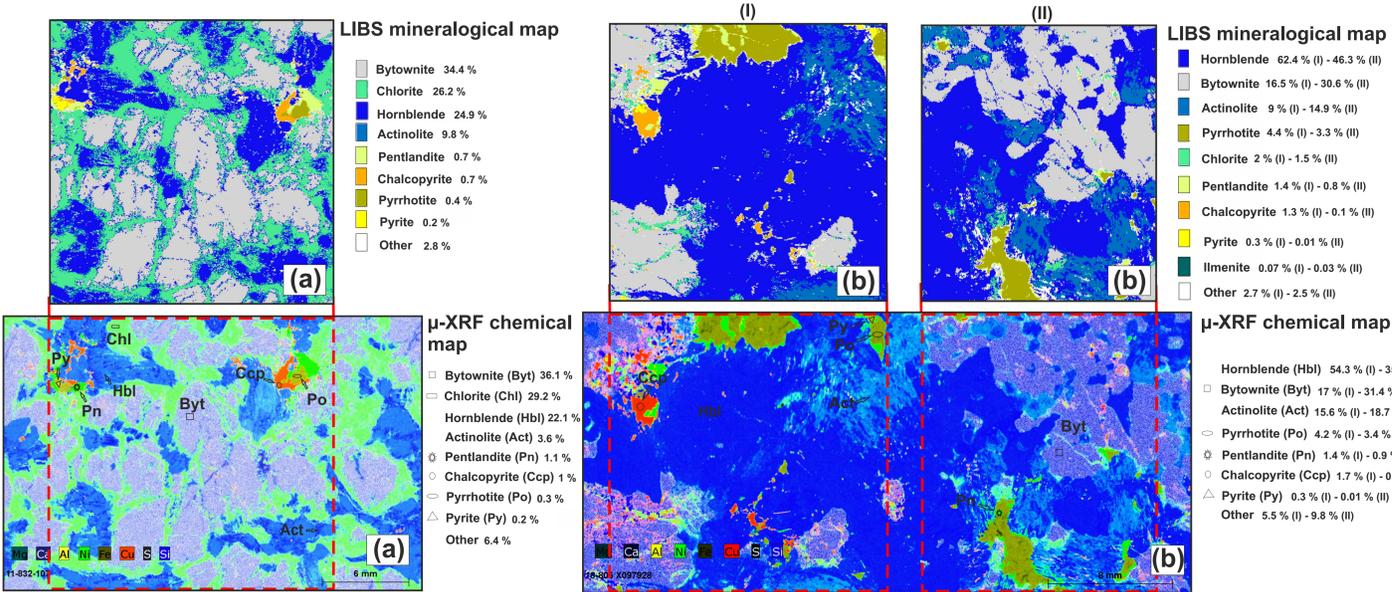


Figure 2. Photographs of (a) the pyroxenite core sample and (b) the gabbro-norite core sample. The red frames outline the areas scanned by μ -XRF. The yellow frames outline the areas scanned by LIBS.

Two LDI-rock types were studied for their mineralogical and chemical characterization: Plagioclase-bearing pyroxenite (Figure 2-a) and gabbro-norite (Figure 2-b). LIBS mapping was achieved to identify the major minerals of both PGEs core samples (Figure 3). μ -XRF mapping was performed to independently evaluate the LIBS mapping results (Figure 3). As part of this research, the potential of μ -XRF in the identification of areas of interest for PGMs was also investigated. Further, optical microscopy and EPMA studies were carried out to expand the LIBS database which was previously built on the basis of a TESCAN Integrated Mineral Analysis (TIMA). The TIMA database is composed of 14 mineral phases namely bytownite, pigeonite, diopside-hedenbergite, chlorite, talc, pentlandite, pyrite, pyrrhotite, chalcocopyrite, hematite-goethite, quartz, ilmenite, lizardite-antigorite and braggite. Two mineral species (magnesio-hornblende and actinolite) have been identified after investigating polished thin sections of LDI samples using a polarized light microscope and by EPMA (Figure 4). Therefore, these two mineral species were added to the LIBS database.

LIBS & μ -XRF mineralogical and chemical mapping



LIBS mineralogical mapping allowed the identification of four major silicate phases (chlorite, plagioclase, actinolite and hornblende) and five minor sulfide and oxide phases (Pd-bearing pentlandite, chalcocopyrite, pyrrhotite, pyrite and ilmenite). Interestingly, the LIBS mineralogical maps display not only the distribution of the identified mineral phases but also their abundances over the scanned surfaces of samples. Mineral phase standardless classification based on EDS μ -XRF spectra allowed the recognition of most of the phases identified by LIBS. LIBS mapping revealed that Pd is distributed over the pentlandite zones.

Figure 3. LIBS and μ -XRF mineralogical distribution maps for (a) the plagioclase-bearing pyroxenite and (b) the gabbro-norite samples. The μ -XRF maps include Mg, Ca, Al, Ni, Fe, Cu, S, and Si. For the μ -XRF maps, the symbols indicate the location of the spectra involved in the standardless mineral phase analysis. The red frames show the equivalent scanned areas by LIBS.

Optical Microscopy and EPMA

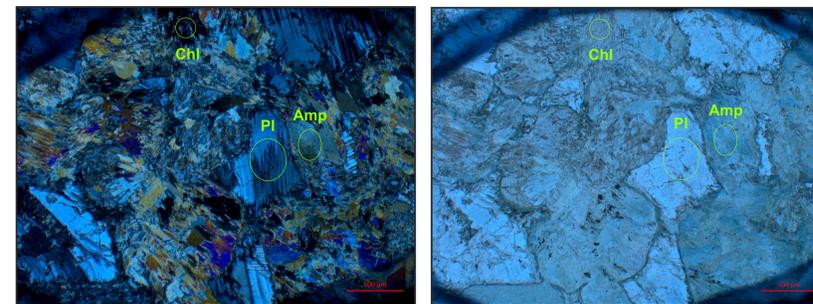


Figure 4. Microphotographs under cross-polarized light (left) and plane-polarized light (right) of the gabbro-norite sample showing the selected zones for EPMA including amphibole (Amp), plagioclase (Pl) and chlorite (Chl).

μ -XRF allows the identification of areas of interest for PGMs

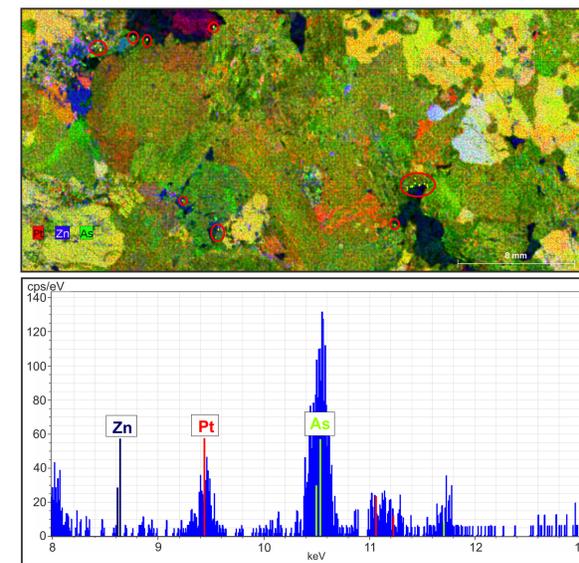


Figure 5. μ -XRF combined (Pt, Zn and As) distribution map for the gabbro-norite sample. Also shown are the selected zones (red circles) for SEM analysis as well as their EDS μ -XRF spectra showing Pt, As and Zn lines.

For LDI ores, PGEs are mainly hosted by sulfides. PGEs rather form PGMs. To identify areas of interest for PGMs from μ -XRF maps, zones at the proximity of sulfide phases were investigated. For each of the studied samples, Pt distribution map was displayed and minute areas showing strong Pt contrast were selected in order to evaluate their spectrum. Results revealed that L α line of Pt is overlapped by the K β line of Zn. Pt and Zn distribution maps were combined, expecting to discriminate areas containing only Pt. EDS μ -XRF spectra of the selected areas from this combined map showed significant signals for Pt (Figure 5). From the same spectra it was also possible to discriminate significant signals for As (an element with which Pt is frequently in combination for LDI-PGMs). Arsenic distribution map was combined with the Pt+Zn map, expecting to identify more regions containing Pt. The identified areas were considered as areas of interest for subsequent SEM analysis.

SEM analysis in areas of interest for PGMs

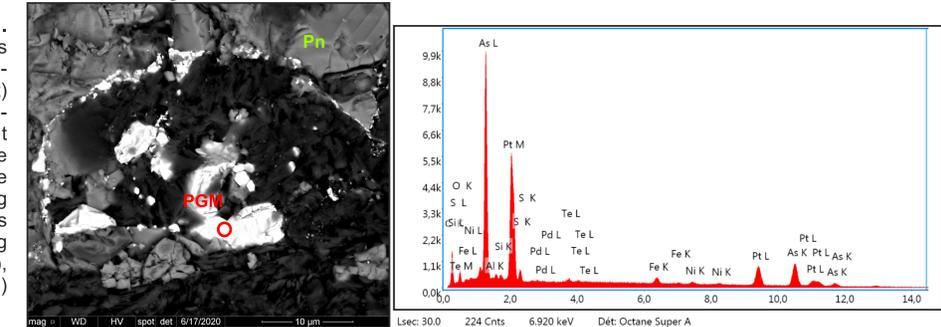


Figure 6. Back Scattered Electrons (BSE) image of the selected PGMs areas of interest from the gabbro-norite sample. Also shown is EDS spectra of the selected PGM grain (red circle). Pn: pentlandite.

BSE image in Figure 6 show bright zones corresponding to phases of higher average atomic number, these phases are presumably PGMs. EDS analysis achieved on these phases showed significant signals for Pt, As and in some cases for Te (which is commonly found in PGMs). According to SEM analysis the majority of the identified PGMs are sperrylite.

CONCLUSIONS AND FUTURE WORK

- LIBS mapping allowed the identification of 9 mineral phases from PGEs ore samples. The main mineral phases identified by LIBS were corroborated by μ -XRF. Further, LIBS mapping made it possible to display the spatial distribution of Pd inside the scanned areas of the samples. Pd appears to be essentially found within the pentlandite areas.
- This study showed the potential of LIBS for the fast chemical and mineralogical characterization of ore samples (LIBS acquisition speed is 1000 spectra per second compared to 160 spectra per second for μ -XRF). Accordingly, LIBS can provide a faster alternative to the standard methods currently in use in the mining industry. Also, it can provide accurate measurements for elements with low atomic number.
- μ -XRF mapping allowed the identification of areas of interest for PGMs. Therefore, μ -XRF is suitable to target specific areas for higher resolution analyses (SEM, EPMA, etc.).
- The potential of LIBS for Pd and Pt quantitative analysis from PGEs ore samples is currently under investigation. Preliminary results show that the measurement of Pd and Pt contents can reach low concentrations (in the sub-ppm and even ppb order).

References

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