Scanning laserspectroscopes for geological analysis, ore exploration and mining

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Research plan

Briefly

Topic of the research is applying new type of scanning laser spectroscopy devices for geological analysis. This documents presents my personal research plan on this topic. This plan was written originally late 2020 and updated in 2022.

In Aalto University department of Civil Engineering we have built completely new type of large area high resolution scanning laser-induced breakdown spectroscopy(LIBS) instruments that has potential to transform the workflow of geologists with very fine detail geochemical and mineralogical information from all types of geological samples. A project at Aalto University to commercialize this technology finished at 2021 creating a spin-off company (Lumo Analytics) and my research focus is to present this technology academically.

Purpose and Significance (a)

Sustainable development requires technologies, such as batteries, fuel cells and electrical motors, require growing amounts of production of raw materials such as lithium, cobalt and graphite. The continue of rising standards of living and urbanization require more and more of metal and mineral resources in the future. Because easily recoverable ore resources have mostly already been mined out, the ore resources of future will be progressively of worse quality, in more difficult to reach locations and deeper underground(Theo Murphy High Flyers Think Tank 2010).

The environmental effects of mining are considerable in every part of lifecycle of a mine. Mining activity destroys environment both directly, with mine wastewaters and acid mine drainage, excavated side rock and reshaping of the ground and indirectly with the massive energy use of mining. Only the comminution of rock materials for mining is estimated to be 4% of electricity consumption globally (Jeswiet and Szekeres 2016). Even small optimization to the comminution processes made possible by monitoring and selecting the incoming rock material could reach significant savings of energy and wearable parts of the machinery. Even larger impact could be gained with better targeted mining and stoping around the orebody. As an example, in Finland in recent years the amount of gangue extracted has grown significantly and faster than the amount of ore extraction (image 1). Turning the direction of this graph would be especially important.

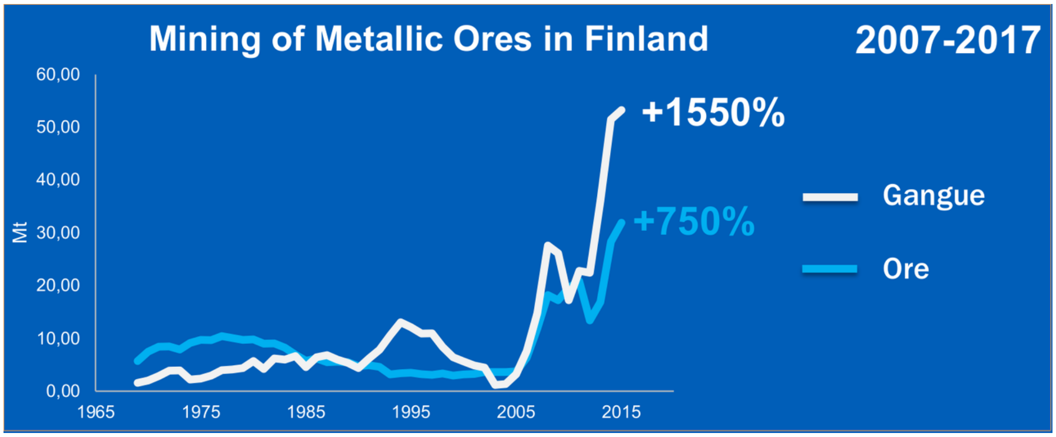

Figure 1: Amout of metal ore and gangue extraction in Finland, Tukes

The purpose of this study is to develop scanning LIBS analysis methods into a working toolset for geologists. This study supports the ore exploration and mining activities and geological research in Finland , in minor scale by supporting the selected pilot projects sites and most significantly by offering new tools to ore exploration and mining companies, geolology researchers and other actors such as GTK(Geologian tutkimuslaitos, Geological Survey of Finland). The research questions are presented in the next paragraph and also along the publication plan as hypotheses on the utility of LIBS technology.

Scanning LIBS with selected spectral analysis methods providing immeadiate analysis results is an efficient tool for geological analysis. Better geological information helps in every part of mine's life cycle: to improve ore exploration, help mine and stoping planning and facilitate more selective mining, help optimizing comminution processes and control refining processes, and to evaluate environmental effects of tailings. LIBS scanner fits especially also for the following purposes:

1. Geotechnical analysis by analysling fracture fillings.
2. Environmental mineralogy to evaluate the environmental effects and risks of mining prospect in advance by measuring the acid generation potential among others factors.
3. Measuring adversarial factors of refining processes, such as measuring the amount of graphite present.
4. Rock material hardness and required comminution energy estimation and with those optimizing the comminution circuit (our patent application is related to this).
5. Enhancing geologist's work and improving their skills by making visible previously invisible features of rock

Summary of previous research on LIBS for geological analysis(b)

LIBS is a form of emission spectroscopy, where with a short-time laserpulse a small amount of matter is ablated and heated up into plasma spark which when cooling emits light in wavelengths characteristic to the elements and some molecules present in the plasma. Research for LIBS for geological analysis has increased strogly during the last decade during which one of the major contributors to this has been the development of Mars rover CHEMCAM(Maurice et al. 2012) and the research related to its LIBS module(Fabre 2020). Use of LIBS to analyse drill core samples have been studied by among others (Bolger 2000), (Haavisto, Kauppinen, and Häkkänen 2013), (Khajehzadeh and Kauppinen 2015), (Kuhn et al. 2016) and (Streubel et al. 2016)

Advantages of LIBS to other techniques are its suitability for all materials, fit for real-time measurement, sensitivity to light elements(where X-ray fluorescence is not applicable)(Body and Chadwick 2001), high resolution imaging(Cáceres et al. 2017), and miniaturizing potential of LIBS instruments(Harmon et al. 2009).

Our research group was previously focused on Business Finland funded Research to Business(TutL, Tutkimuksesta Liiketoimintaan) project TUTL-LASOLIBS, where LASOLIBS means Large Area Scanning Open-source Laser Induced Breakdown Spectrometer. During the project we developed our drill core scanner prototype device and did pilot projects together with mining and ore exploration companies to prove the technology. During the project it become clear that scanning LIBS is a very efficient tool for geological analysis. The business opportunities focused project ended in 2021. The project resulted in a spin-off company Lumo Analytics, that continues commercializing the tehnology. The research findings of the project are mostly still unpublished but examples are available for example in LASO-LIBS presentation site and slides available at slush portal at `https://web.archive.org/web/20211130095101/https://www.slush.org/aalto-booth/laso-libs/` (link to internet archive). My personal research work has since been focused on publishing these findings academically and making sure the research continues.

The publications of the project constitute of three master's thesis works, slush presentation website and a patent application. The master's thesis are about 1) commercialization possibilities for the technology(Xue 2020)(available from Aalto University library or from me), 2) making of LIBS reference samples(Millington 2020) and 3) using neural networks on LIBS data to for mineral classification(Henri Johansson, work not yet published). One patent has been granted on the patent application made in the project(patent application number 20205892).

I have myself worked at Aalto University from 2018 first as a master's thesis worker and research assistant and starting 2019 Autumn as a PhD candidate. My own publications on the topic so far include my master's thesis(Laine 2019) and one conference paper(Panu, Petri, and Tauno 2020).

Methods (c)

This research is made possible with three things: prototype equipment, reference mineral library and cooperating with geologists from mining companies and GTK.

We have during the previous research projects built at the Aalto University Department of Civil Engineering Laserlaboratory(LIBSLAB) built new type of scanning LIBS prototype devices, which can quickly measure large areas in very high detail. Our most important tool is the LASO-LIBS scanner, which is designed to measure drill cores one box at a time. The same device also is fit to measure other shape samples such as crushed rock, drill cuttings or hand samples. We have scanned with the device thousands of meters of drill core and many hundreds of other samples.

In Aalto University collections there are thousands of mineral-, ore- and other rock material samples. Furthermore we have received from our partners and sometimes bought mineral and pure elemental samples. We have gathered a large mineral and elemental library to work as the reference material for LIBS analysis. Our approach to LIBS analysis is based on spectral angle mapping and machine learning methods which require big amount of training or reference data.

Third we have in the previous few years projects been in close cooperation with mining companies and GTK(Geologian Tutkimuskeskus, Finnish Geological Survey). This has allowed us to get instant feedback from the geologists for whose use the devices and methods we developed are meant for.

In addition to these the methods include documentaion, literary reference collection, analysis of previously measured data, validation of the methods and comparisons to other alternative measurement techniques.

Publication plan and schedule

Below is the planned schedule for the research outputs in order of publication date.

2021-2022: Papers on already finished LIBS measurements from Kittilä Gold mine that give new kind of geological data.

1. LIBS tunnel scanner presentation and measurement results from Kittilä mine, *"Scanning LIBS-LiDAR for Underground Mining"*, target: Applied Spectroscopy

This is partly written. The device was presented before in my master's thesis and this article is a more compact presentation and imporantly includes results from a real operating mine in Kittilä. This is part of GAGS -research project.

Authors: Lasse Kangas, Ilkka Laine, Jussi Leveinen

2. Kittilä gold mine drill core analysis with LIBS drill core scanner and applying to stope design

We have measured 80 meters of Kittilä gold mine cores with our drill core scanner and made elemental and mineralogical analysis on the data using machine learning methods. As a part of GAGS-project we find out how LIBS analysis results can be applied to stope design.

Authors: Lasse Kangas, Ilkka Laine, Jussi Leveinen, (possible cooperation authors also Mateusz Janiszewski, Lauri Uotinen, Mikael Rinne)

2022-2023: LASO-LIBS drill core scanner building instructions and academic presentation

3. LASO-LIBS 1: LASO-LIBS building instructions, *Open-Source LIBS Drill Core Scanner*, target HardwareX

Free and Open Source Hardware(FOSH) article on our drill core scanner building instructions that enable anyone to build the device. The article has been under work for long time together with the device development but the text requires heavy revisioning. Goal is to enable academic use of LIBS-scanner with reasonable price and thus advance the research of LIBS methodology and applications.

Authors: Lasse Kangas, Ilkka Laine, Jussi Leveinen, Joshua Pearce

4. LASO-LIBS 2. *LASO-LIBS presenting and showcase results,* target HardwareX

Example results on what the device built using our instructions can achieve.

Authors: Lasse Kangas, Ilkka Laine, Jussi Leveinen, Joshua Pearce

5. LASO-LIBS 3: *LASO-LIBS high resolution scanning: micrometer accuracy and megapixel imaging*

In addition to large area scanning, our device is also capable of very high detail 25micrometer resolution measurements, that result in megapixel level of data in area in the size of square centimeters. Images produced this way are not only visually breathtaking, but can be used to distinguish single mineral grains in sample material. This article showcases this technique and its applications.

Authors: Ilkka Laine, Lasse Kangas, Jussi Leveinen.

2023-2024: Spectral databases supporting geological LIBS analysis and publishing our LIBS analysis methods and compiling my doctoral thesis.

6. Open dataset and presenting article for: *LIBS spectral library for minerals*

Aalto mineral library(of hundreds of samples) based LIBS spectral library and confirming data such as XRD and XRG analysis when available.

Authors: Ilkka Laine, Jussi Leveinen.

7. Open dataset and presenting article for: *LIBS spectral library for elements*

Like previous one but for elements. These two will likely be published together or this one first as the easier one.

Authors: Ilkka Laine, Jussi Leveinen.

8. *Geotechnical analysis with LIBS 3D point cloud*

We have developed ad method for automatic RQD(Rock Quality Designation) assessment point cloud data gathered during LIBS scanning measurements. LIBS also fits for measuring the type and quality of fractures and fracture fillings. Combining these methods a LIBS device can automate and improve geotechnical analysis of rock materials. Example site is likely to be a partner mine in Finland.

Authors: Ilkka Laine, Jussi Leveinen.

9. *Estimating rock material acid generation potential with scanning LIBS*

Spectral fingerprinting based mineral classifier with LIBS analysis can be used to estimate the acid generation potential of tailings. The acid mine drainage of mines a significant environmental problem. If the rock material acid generation and neutralization potential can be estimated in advance, the acidity can be controlled to be fitting for both the refining processes and most importantly to avoid the environmental damage caused by acid mine drainage. An example site would likely be a mine or a ore exploration site in Finland.

Authors: Ilkka Laine, Lasse Kangas, Jussi Leveinen

Budget (d)

Costs

-listed in Finnish version

Travel expenses (e)

None planned.

Other funding

See below in acknowledgements.

Acknowledgements

I am a minority shareholder and a part-time employee of ja LIBS-technology startup company Lumo Analytics(https://www.lumoanalytics.com/). My full time job is to be a researcher at Aalto University. I have part of a patent application and multiple innovation disclosures related to LIBS technology.

Major financial supporters for my work have been as part of bigger projects by Academy of Finland and Business Finland and personally by K.H. Renlund Foundation and Kaute foundation.

Nothing else to disclose.

Liite 1

Figure 1: Publication 1: LIBS tunnel scanning

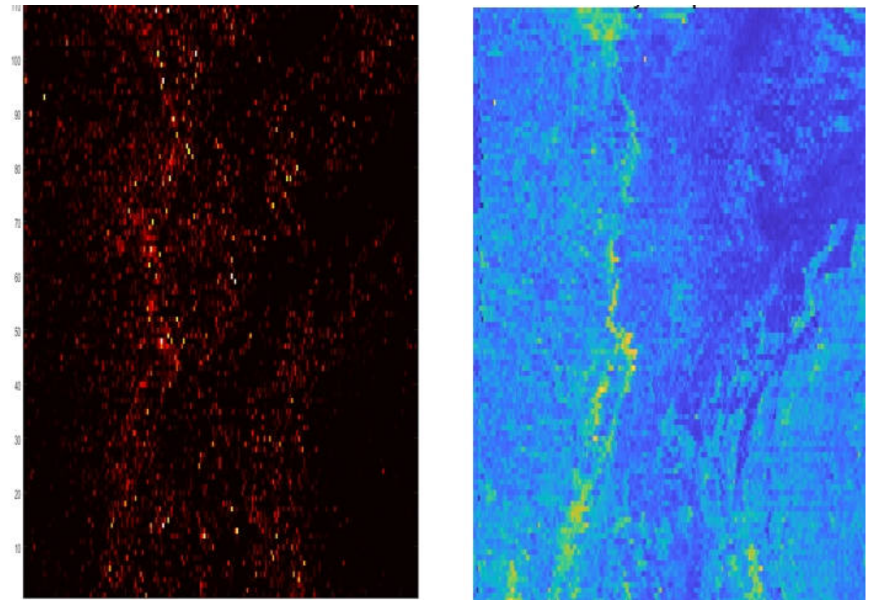

Figure 2: Publication 1: Tunnel scanning example, Kittilä gold mine left wall arsenic LIBS signal and laser-ablation sound intensity.

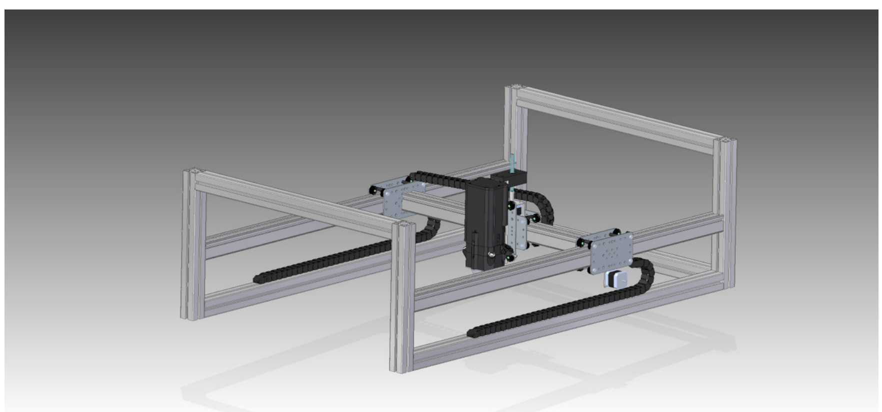

Figure 3: Publication 3: LASO-LIBS drill core scanner 3D-model

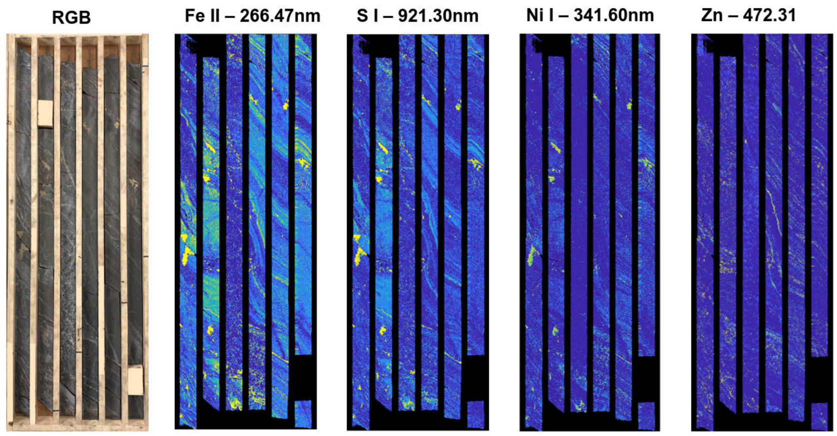

Figure 4: Publications 2 and 4: LASO-LIBS Drill core box scan. Iron, Sulphur, Nickel and Zinc

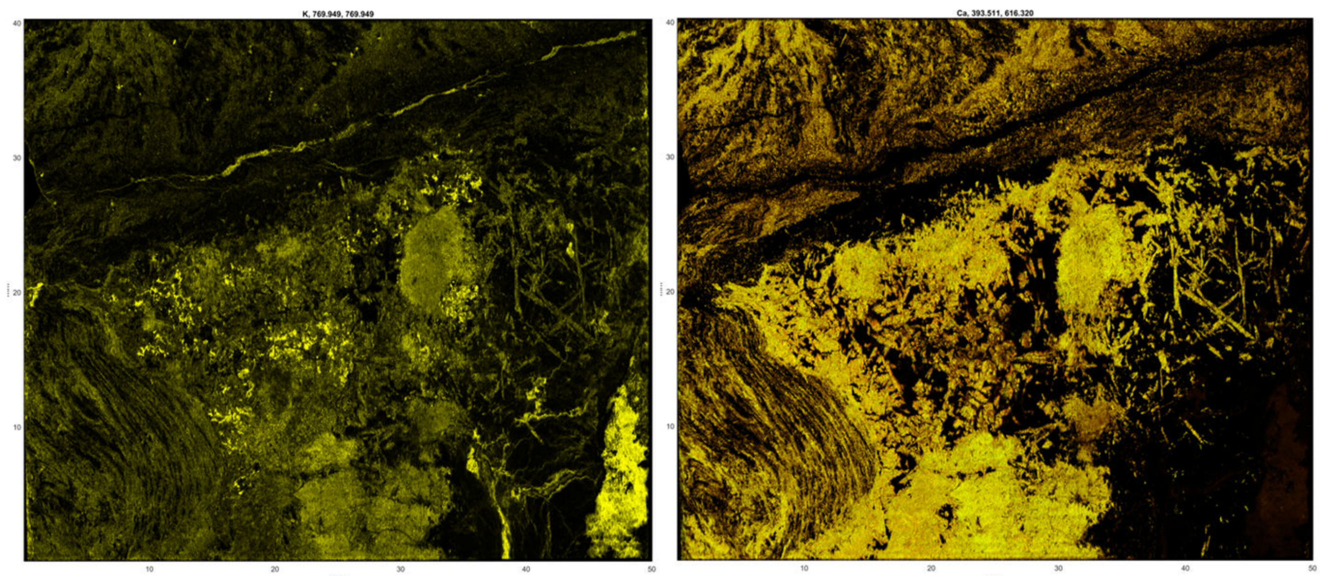

Figure 5: Publication 5: High resolution LASO-LIBS scan, 4x5cm surface. Potassium and Calcium

References

Theo Murphy High Flyers Think Tank. 2010. "Searching the Deep Earth : the Future of Australian Resource Discovery and Utilisation.". Edited by Australian Academy of Science, Theo Murphy(Australia) Fund,, and High Flyers Think Tank. Theo Murphy High Flyers Think Tank 2010 Proceedings. Canberra: Australian Academy of Science.

Jeswiet, Jack, and Alex Szekeres. 2016. "Energy Consumption in Mining Comminution". *Procedia CIRP* 48: 140–45. https://doi.org/10.1016/j.procir.2016.03.250.

Maurice, S., R. C. Wiens, M. Saccoccio, B. Barraclough, O. Gasnault, O. Forni, N. Mangold, et al. 2012. "The ChemCam Instrument Suite on the Mars Science Laboratory (MSL) Rover: Science Objectives and

Mast Unit Description". *Space Science Reviews* 170 (1-4): 95–166. https://doi.org/10.1007/s11214-012-9912-2.

Fabre, Cécile. 2020. "Advances in Laser-Induced Breakdown Spectroscopy Analysis for Geology: A Critical Review". *Spectrochimica Acta Part B: Atomic Spectroscopy* 166 (April): 105799. https://doi.org/10.1016/j.sab.2020.105799.

Bolger, J. A. 2000. "Semi-Quantitative Laser-Induced Breakdown Spectroscopy for Analysis of Mineral Drill Core". *Applied Spectroscopy* 54 (2): 181–89.

Haavisto, Olli, Tommi Kauppinen, and Heikki Häkkänen. 2013. "Laser-Induced Breakdown Spectroscopy for Rapid Elemental Analysis of Drillcore". *IFAC Proceedings Volumes* 46 (16): 87–91. https://doi.org/10.3182/20130825-4-US-2038.00047.

Khajehzadeh, Navid, and Tommi K. Kauppinen. 2015. "Fast Mineral Identification Using Elemental LIBS Technique". *IFAC-PapersOnLine* 48 (17): 119–24. https://doi.org/10.1016/j.ifacol.2015.10.089.

Kuhn, Kerstin, Jeannet A. Meima, Dieter Rammlmair, and Christian Ohlendorf. 2016. "Chemical Mapping of Mine Waste Drill Cores with Laser-Induced Breakdown Spectroscopy (LIBS) and Energy Dispersive X-Ray Fluorescence (EDXRF) for Mineral Resource Exploration". *Journal of Geochemical Exploration* 161: 72–84.

Streubel, Lukas, Lars Jacobsen, Sven Merk, Michael Thees, Dieter Rammlmair, Jeannet Meima, and David Mory. 2016. "Rapid Analysis of Geological Drill-Cores with LIBS". *Optik & Photonik* 11 (5): 23–27. https://doi.org/https://doi.org/10.1002/opph.201600035.

Body, D., and B. L. Chadwick. 2001. "Optimization of the Spectral Data Processing in a LIBS Simultaneous Elemental Analysis System". *Spectrochimica Acta Part B: Atomic Spectroscopy* 56 (6): 725–36.

Cáceres, J. O., F. Pelascini, V. Motto-Ros, S. Moncayo, F. Trichard, G. Panczer, A. Marín-Roldán, J. A. Cruz, I. Coronado, and J. Martín-Chivelet. 2017. "Megapixel Multi-Elemental Imaging by Laser-Induced Breakdown Spectroscopy a Technology with Considerable Potential for Paleoclimate Studies". *Scientific Reports* 7 (1). https://doi.org/10.1038/s41598-017-05437-3.

Harmon, Russell S., Jeremiah Remus, Nancy J. McMillan, Catherine McManus, Leslie Collins, Jennifer L. Gottfried, Frank C. DeLucia, and Andrzej W. Miziolek. 2009. "LIBS Analysis of Geomaterials: Geochemical Fingerprinting for the Rapid Analysis and Discrimination of Minerals". *Applied Geochemistry* 24 (6): 1125–41. https://doi.org/10.1016/j.apgeochem.2009.02.009.

Xue, Emilia. 2020. "A Service Vision for a Laser-Based Scanning Method". G2 pro gradu, diplomityö, Aalto University. http://urn.fi/URN:NBN:fi:aalto-202005173158.

Millington, Joseph. 2020. "Site Specific Calibration of Laser Induced Breakdown Spectroscopy for Rapid Elemental Analysis of Gold Ore Drill Core Samples". Master's thesis, Aalto University. School of Engineering. http://urn.fi/URN:NBN:fi:aalto-2020122056329.

Laine, Ilkka. 2019. "Scanning Laser-Induced Breakdown Spectrometer for Mine Walls". Master's thesis, Aalto university. https://doi.org/10.5281/zenodo.2620002.

Panu, Kiviluoma, Kuosmanen Petri, and Otto Tauno. 2020. "Newtonian Telescope Design for Stand-off Laser Induced Breakdown Spectroscopy". In *Proceedings of the 5th Baltic Mechatronics Symposium*, 58. Espoo, Finland. http://urn.fi/URN:ISBN:978-952-64-9603-0.