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Handheld LIBS for Precious Mineral Exploration: Prospecting for Gems, Conflict Minerals, and Diamond Kimberlites

Harmon, R.S.[1], Hark, R.R.[2], Wise, M.A.[3], Collins, L.M.[4], McGettigan, J.E.[2], Throckmorton, C.S[4]

[1] Department of Marine, Earth, & Atmospheric Sciences, North Carolina State University, Raleigh, NC 27695, USA

[2] Department of Chemistry, Juniata College, Huntingdon, PA 16652 USA

[3] Smithsonian Institution, National Museum of Natural History, Washington, DC 20560 USA

[4] Department of Electrical and Computer Engineering, Duke University, Durham, NC 27708 USA

Laser-Induced breakdown spectroscopy (LIBS) is Laser-induced breakdown spectroscopy (LIBS) is a straightforward and versatile spectroscopic technique based upon analysis of the spectral emission from laser-induced plasmas. In LIBS, a short-pulse-duration, low-energy pulsed laser light is tightly focused on a sample, causing 'breakdown', i.e. conversion of a minute amount of sample into vapor and particulate-bearing aerosol by laser energy absorption, and the formation of a high-temperature microplasma. With the advent of commercial handheld instruments that can be used in the field, LIBS now has the far-reaching capability to provide multi-element detection in any material - solid, liquid, or gas - *in-situ* in real time. Because LIBS is simultaneously sensitive to all elements, a single laser shot can be used to record the broadband emission spectra, which offers a means of rapidly distinguishing different geographic sources for a mineral because the LIBS plasma emission spectrum provides the complete chemical composition (i.e. 'chemical fingerprint') of any material in real-time.

Prospecting for mineral deposits often relies on the concept of geochemical fingerprinting. In some cases this may involve the recognition of a key chemical signature in minerals called 'pathfinders' that are important in the search for primary host rocks as they provide direct evidence of the presence of their source. For example, skarn, volcanogenic massive sulfide, and porphyry vein type deposits exhibit compositional differences that can be related to deposit types and their geochemical fingerprints can be used to separate different styles of mineralization. Arsenic variations in geothermal sinters (amorphous silica) can act as a guide to gold enrichment. Also, multi-element analysis of detrital and ore minerals can be used to discriminate different types of mineral deposits and to determine ore mineral provenance. This mineral study focused on three specific applications, using both a laboratory LIBS system (Applied Spectra Inc. RT100-HP) and a handheld LIBS instrument (SciAps, Inc. Z500) to acquire broadband LIBS spectra for the purpose of (i) Identifying and gemstones and determining their

provenance through an investigation to determine if the gem varieties of Li-bearing spodumene, hiddenite and kunzite, could readily discriminated by LIBS from other similarly colored minerals and if garnet could be distinguished by type and geographic setting; (ii) Examining the conflict mineral columbite/tantalite for provenance determination; and (iii) Determining if LIBS can be used to readily identify the Cr-enriched minerals (e.g., Cr-rich clinopyroxene and garnet) that are common pathfinder minerals for diamond-bearing kimberlites. Utilizing both preprocessing techniques to optimize the LIBS classification results, the multivariate statistical pattern recognition Principal Components Analysis (PCA) Partial Least Squares Discriminant Analysis (PLS-DA) led to a high level of discrimination and classification accuracy. Given that LIBS can be deployed as a man-portable analytical technology, these results suggest that LIBS has the potential to be utilized as an exploration tool for real-time analysis in the field.