NRC·CNRC

Advanced Laser-Induced Breakdown Spectroscopy Sensor for Fast Assessment of Gold Ore Samples

M. SABSABI, K Rifai, A. Harhira, P. Bouchard, A Blouin, M Laflamme (U Laval), M Constantin (U Laval) and F. Vidal (INRS-EMT)

National Research Council Canada
75 de Mortagne Blvd.
Boucherville, Québec
J4B 6Y4 Canada

Toronto, 25 October 2017

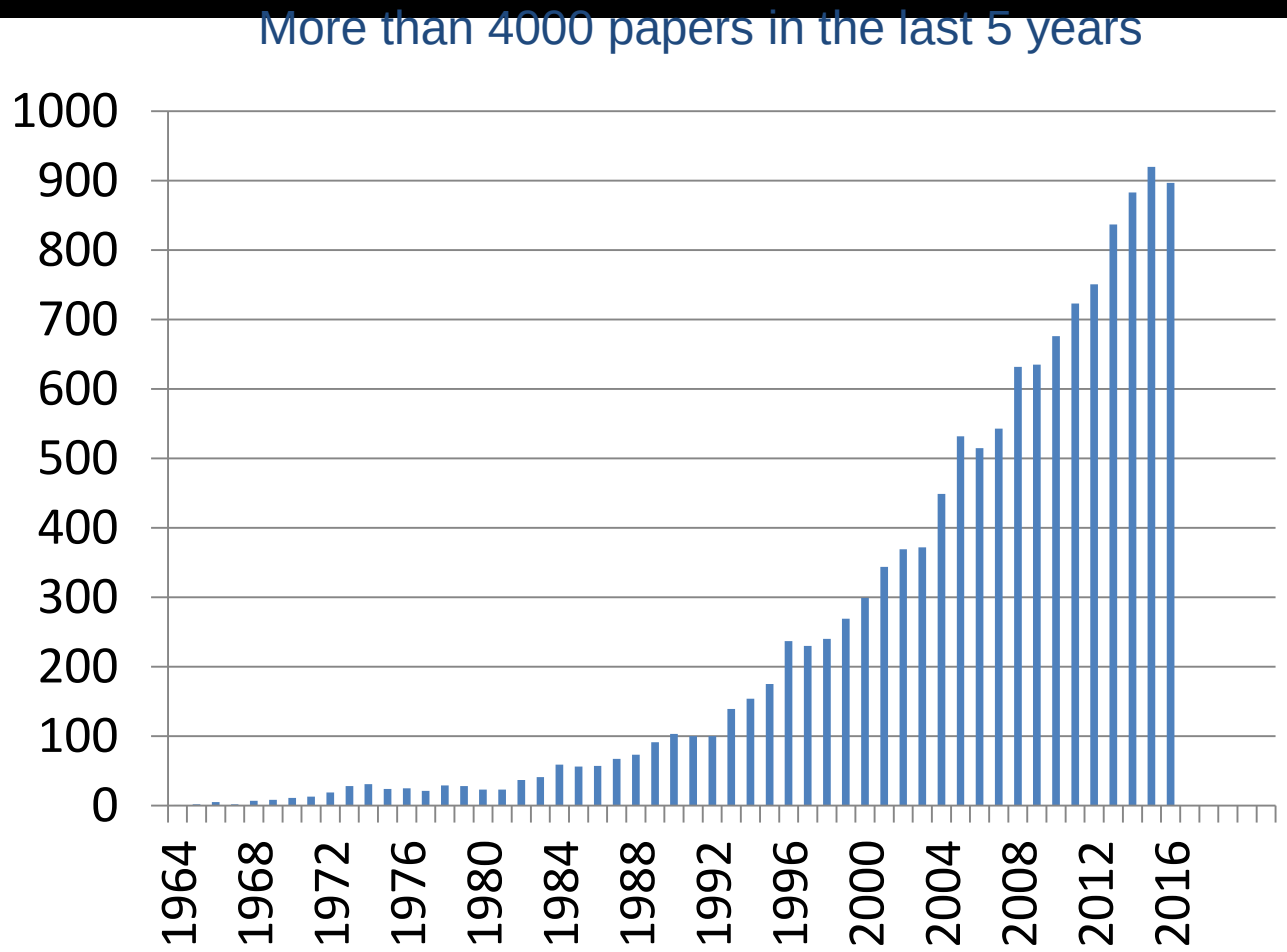
National Research Council Canada | Conseil national de recherches Canada

Canada

Outline

- Overview on the LIBS technique development
- Context of the analysis of mineral gold ore samples: challenges and issues
- LIBS analysis of mineral gold ore samples: application for gold ore grading
- Preliminary conclusions
- Perspective for applications of LIBS in mining industry.

LIBS papers evolution (13305 papers according to Scopus, May 2017)



LIBS companies

Handheld LIBS companies

OXFORD INSTRUMENTS
The Business of Science®

SciAps

BRUKER

B&WTEK
Your Spectroscopy Partner
SPECTROMETERS | LASERS | TOTAL SOLUTIONS

TSI
UNDERSTANDING, ACCELERATED

Rigaku

NRC·CNRC

LIBS companies for sorting

TOMRA

SHREDDERSORT

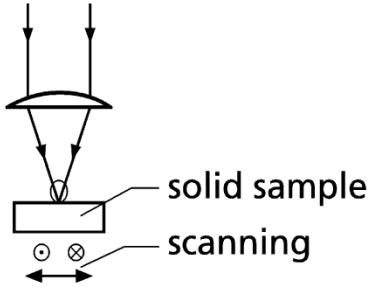
sense2sort
TORATECNICA

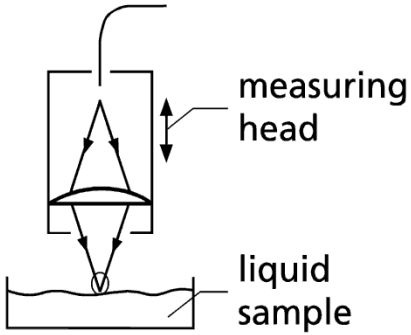
Austin AI
Automation & Instrumentation

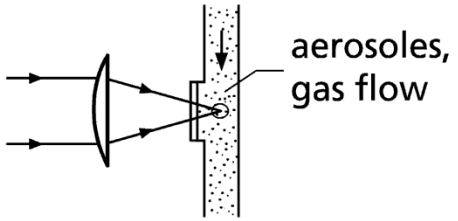
Eijkelkamp
SonicSampDrill

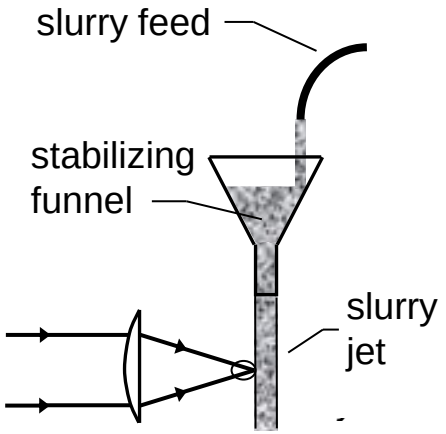
ima engineering
INNOVATIVE MINERAL ANALYSERS

LIBS: features and application potentials







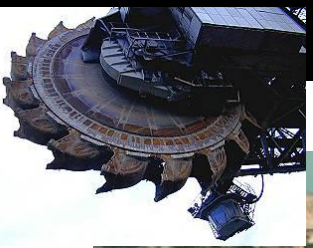


- stand off capabilities: 1 cm – 100 m
- static or moving samples: 0 – 20 m/s
- states of aggregation: solid, liquid, gaseous
- sample preparation: none
- analytes: all elements
- measuring frequency: 1 Hz – 100 kHz

→ **LIBS is well suited for on-line applications**

→ **LIBS is applicable at all stages of the production cycle**

Raw materials
Oil sands



Soil

Gold ore

Quality control

Molten metals

NRC LIBS activities

Context of analysing gold ore samples: Challenges and issues

- Techniques are sought for fast analysis of gold ore samples:
  - In all stages of the gold mining value chain, in particular for making decision to avoid processing non economic grade ore
- Conventional laboratory techniques are suffering from their offline character and time consuming process of sample preparation. They are not adapted for fast analysis.
- Faster techniques based on InfraRed Spectroscopy (IR) are good for mineralogy but not for elemental gold.
- Faster techniques based on of X-ray fluorescence (XRF) are excellent for elemental but not sensitive for low Z element and generaly suffers from interference with iron for the detection of gold in the sub ppm range.

➢ LIBS appears a good candidate for the application in terms of speed of analysis, stand off capabilities and no need for sample preparation

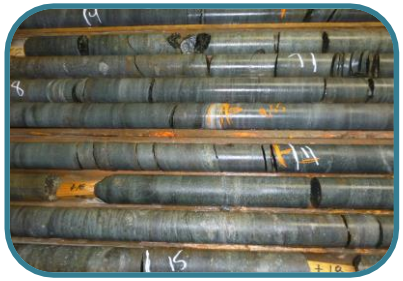
Needs identified by industry

Open pit mines – Drilling chips

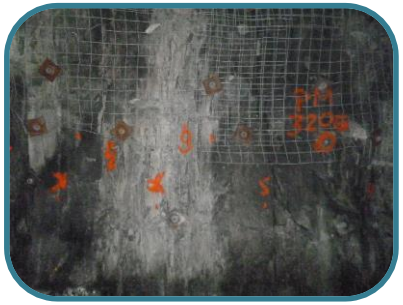
Drill

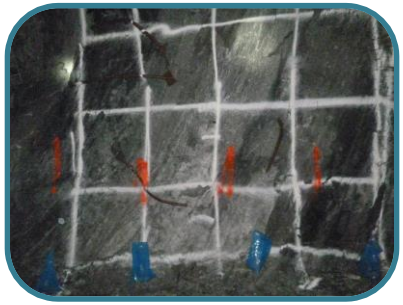
Drilling chips

Lithological sequence



- **Underground mine**

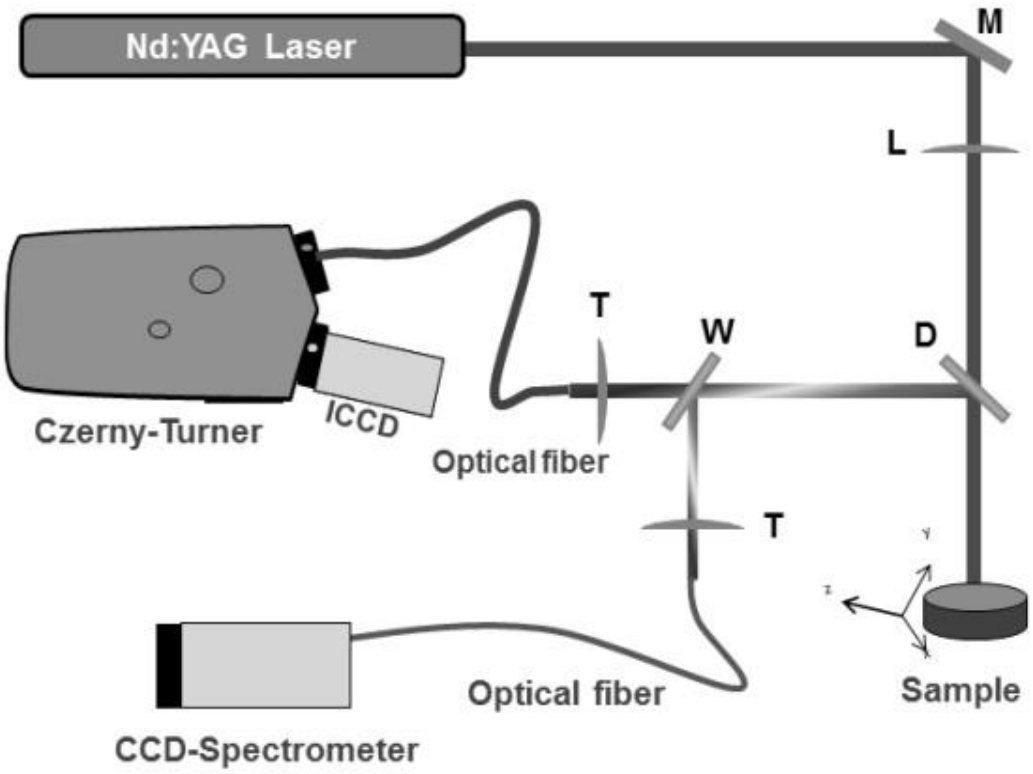




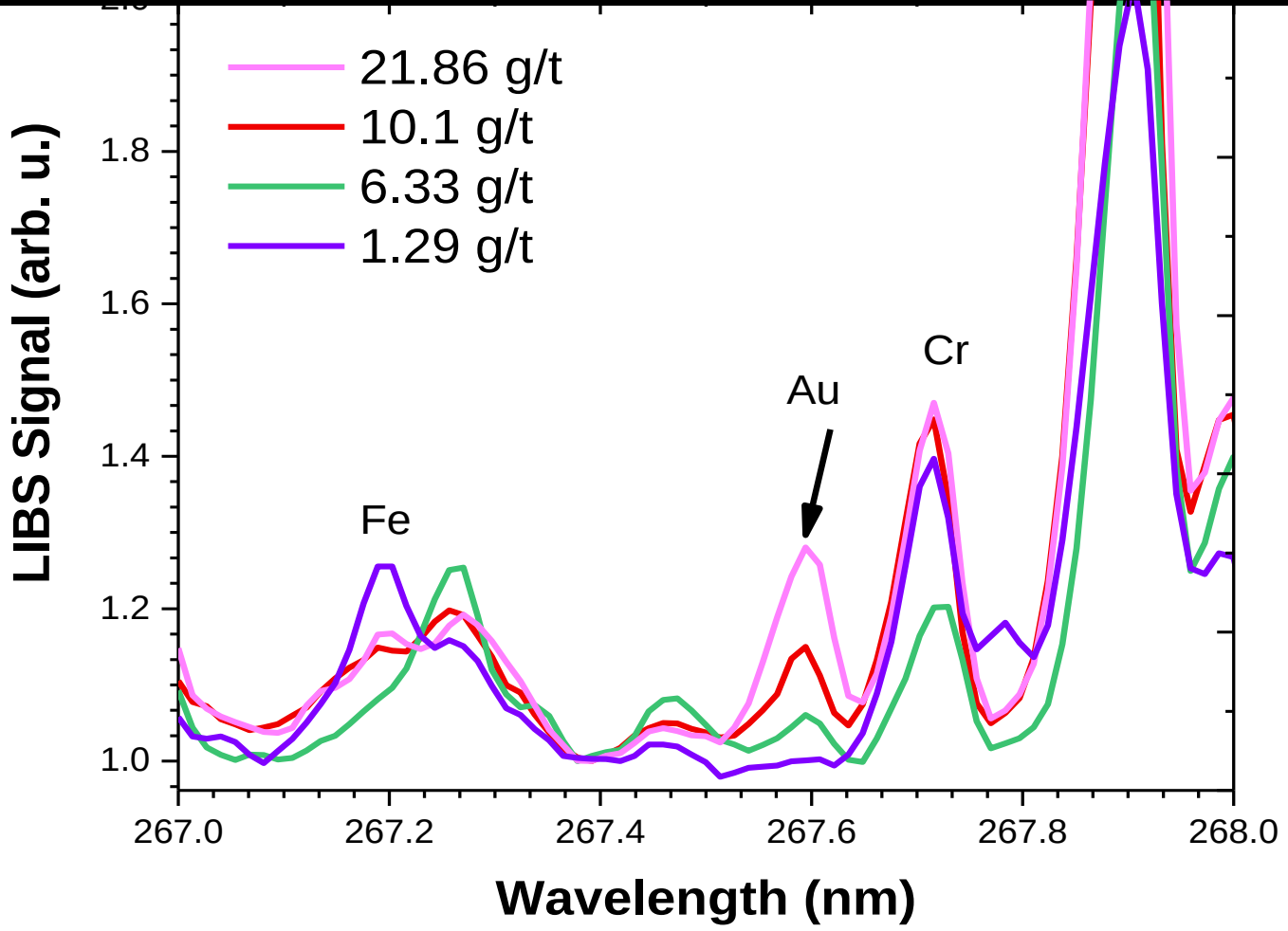
Analytical challenges

- Gold is embedded in several matrices: silica, quartz-chlorite, pyrite, etc.
  - ➢*Matrix effects*
- Particle size of gold varies from sub µm up to few tens of µm and laser spot size is in the mm range or less
  - ➢*Absence of standards for calibration in particular for higher concentrations (100 ppm above)*
- Distribution of gold in ore is mostly non homogenous
  - ➢*Strategic representative sampling is required*
- Sensitivity to the sub-ppm level of gold concentration
  - ➢*Optimised components and conditions for gold detection*
- Surface analysis versus bulk

Laboratory LIBS setup

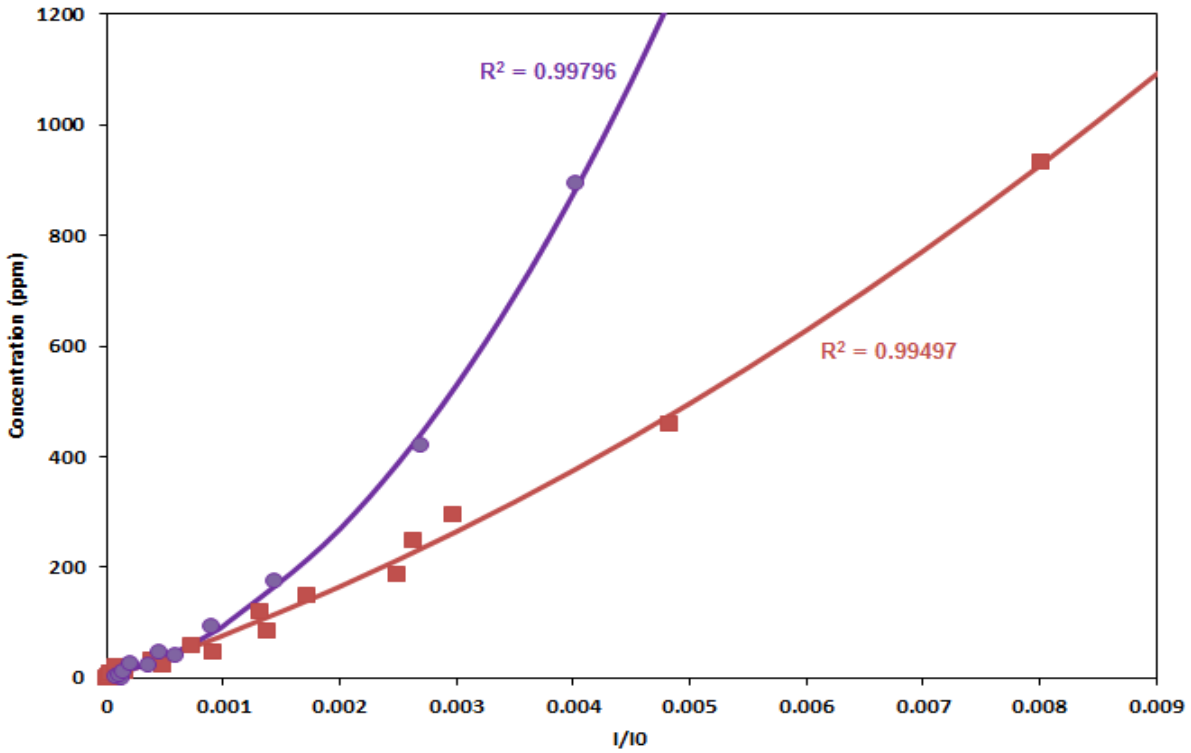


LIBS spectra obtained from several ore samples with different gold content varying from 1 to 22 ppm

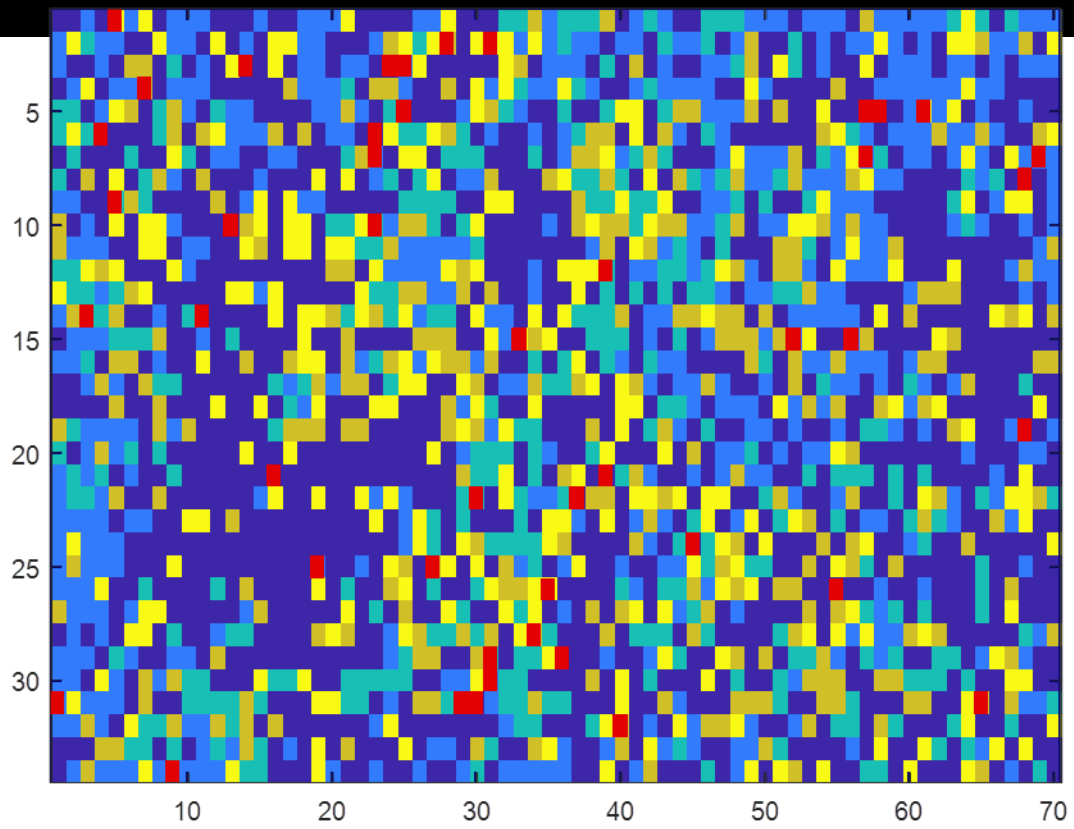


Calibration curves for gold in pyrite and quartz ore samples. Comparison of LIBS with laboratory analysis

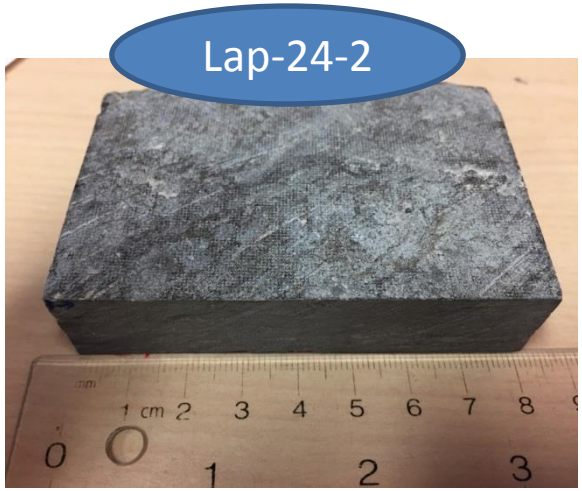
Lab assay gold concentration (ppm)	Gold concentration measured with LIBS (ppm)
4.2	4.9 ± 0.98
8.27	8.1 ± 2.04
9.6	9.3 ± 1.06
18.7	16.2 ± 4.36
23.9	19.9 ± 3.22
25	25.4 ± 1.38
119	122.9 ± 7.27
198	195.8 ± 12.59



LIBS mapping and gold distribution on rock sample. Example of sample heterogeneity



- Gold
- Iron-rich
- Silicates
- Calcium carbonates
- Carbonate-silicate mixtures
- Iron-carbonate-silicate mixtures



Comparison between Lab and LIBS results of analysis of LIBS obtained for the pulp, rejects and ¼ drill cores

Sample	Lab. [Au] ppm	LIBS		LIBS		LIBS	
		Pulp [Au] ppm	Number of shots	Reject [Au] ppm	Number of shots	¼ Drill core [Au] ppm	Number of shots
LAR-29	1.6 ± .08	1.6 ± 0.2	500	7 ±0.55	500	6.3 ± 1	9600
LAR-30	3.0 ± 0.2	2.6 ± 0.6	500	13.4 ± 3.2	500	11 ± 1.6	20055
Lap-33	54 ± 2.7	59± 5.5	500	49.5 ± 7.5	500	32 ± 4.8	20952

- Lab and LIBS analysis performed on different ¼ drill core.
- LIBS and labs measurements on pulp and reject from the same ¼ drill core.
- Pulp and reject have been analysed without being compressed
- Small number of laser shots for measurements on rejects

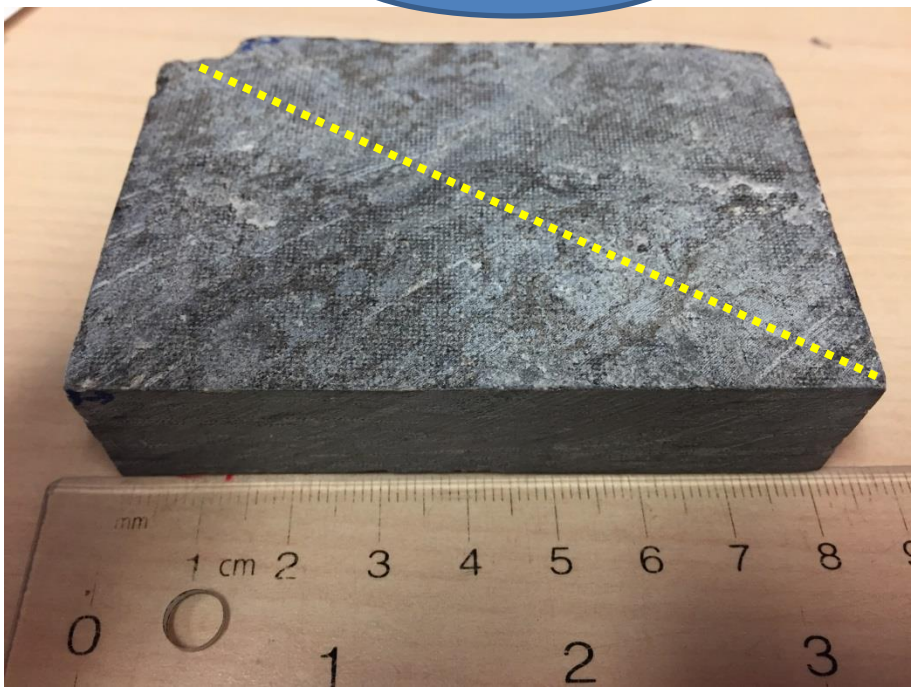
Gold content analysis: Lab VS Lab

- Mine Lab analysis have been performed on ½ of the drill core.
- ALS analysis have been performed on the ¼ of the other half.

		Gold Content (ppm)			
		Mine-Lab	ALS-Lab		
Nom	Lithologie	AA Or GRA	AA23	GRA21	Variation(%)
MAL-66B	Porphyre-MG	3.64	3.28		
MAL-65	Sédimentaire-HG	8.44	>10.0	12.45	
MAL-64a	Sédimentaire-MG	1.215	1.115		
MAL-67	Sédimentaire-MG	2.19	0.444		
MAL-69	Porphyre-HG	23.5		20.8	
LAR-21ca	Sulfure massif	3.56	2.77		
LAR-22ca	Sulfure semi-massif	2.76	3.41		
LAR-23ca	Sulfure semi-massif	5.37	4.9		
WEST-6	Balsalte avec veine de sulfures	9.54	>10.0	12.3	
WEST-3	Veine de quartz	2.022	1.41		
CASBER-4	Volcanique	31.42		3.65	
CASBER-6	Sédimentaire	4.82	5.13		
CASBER-7	Volcanique	23.66		24.1	
CASBER-11	Chert	15.08		33.1	
CASBER-14	Volcanique	13.4		1.62	
LAP-3	Sédimentaire	11.1		4.04	
LAP-4	Sédimentaire	38		3.42	
LAP-6	Volcanique	28.8		18.1	
LAP-7	Sédimentaire	5.23	4.82		
LAP-8	Volcanique	16.5		0.69	
GOL-31	Granodiorite	17.35		3.84	
GOL-32	Granodiorite	2.93	0.326		
GOL-34	Granodiorite	3.7	0.558		
GOL-35	Granodiorite	2.49	1.485		
GOL-36	Granodiorite	13.52		0.07	

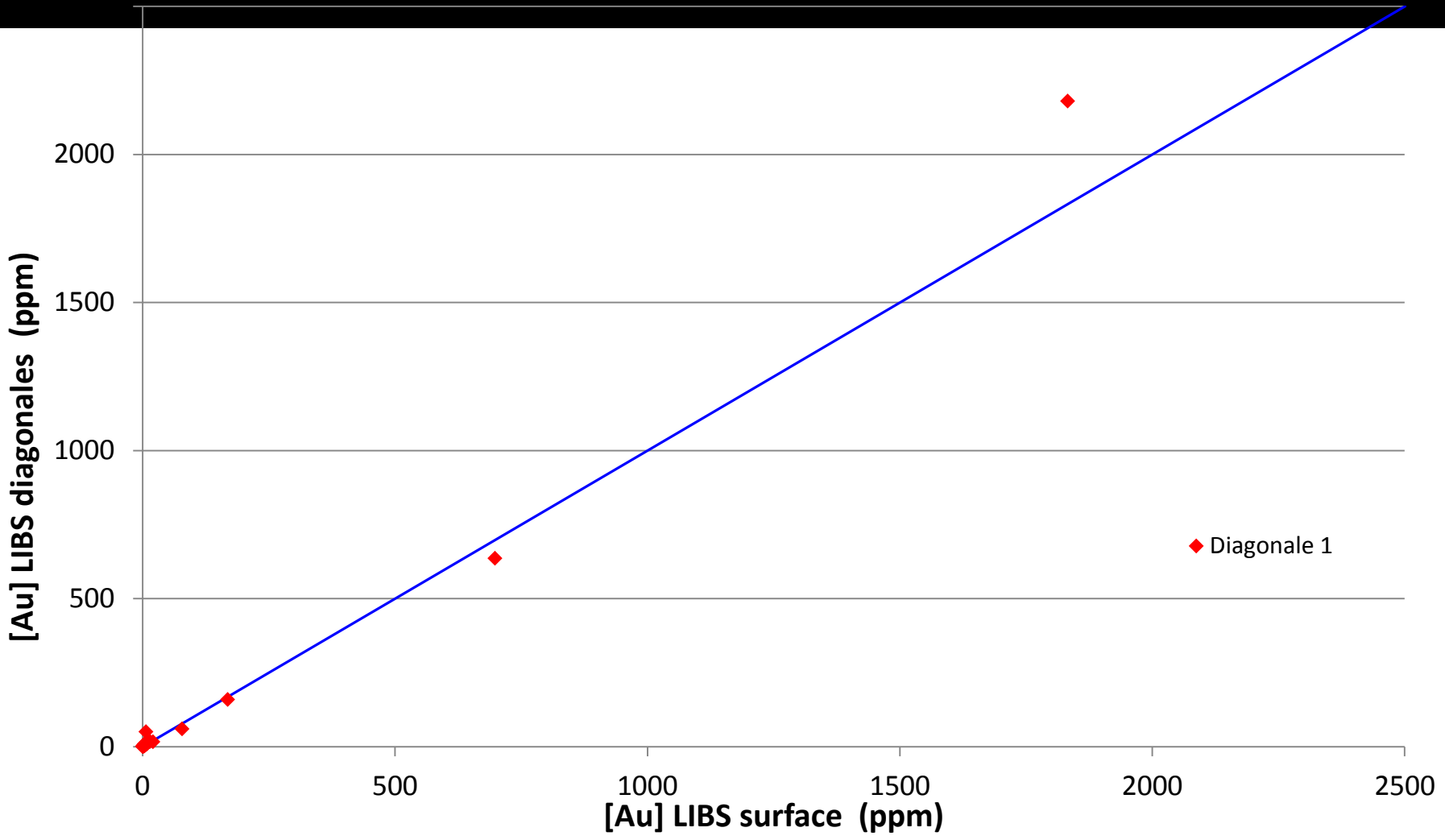
Lithology:
Comparison of concentration values obtained using all the LIBS points on Scanned surfaces and using only the points on the diagonal

Lap-24-2



West-10-2

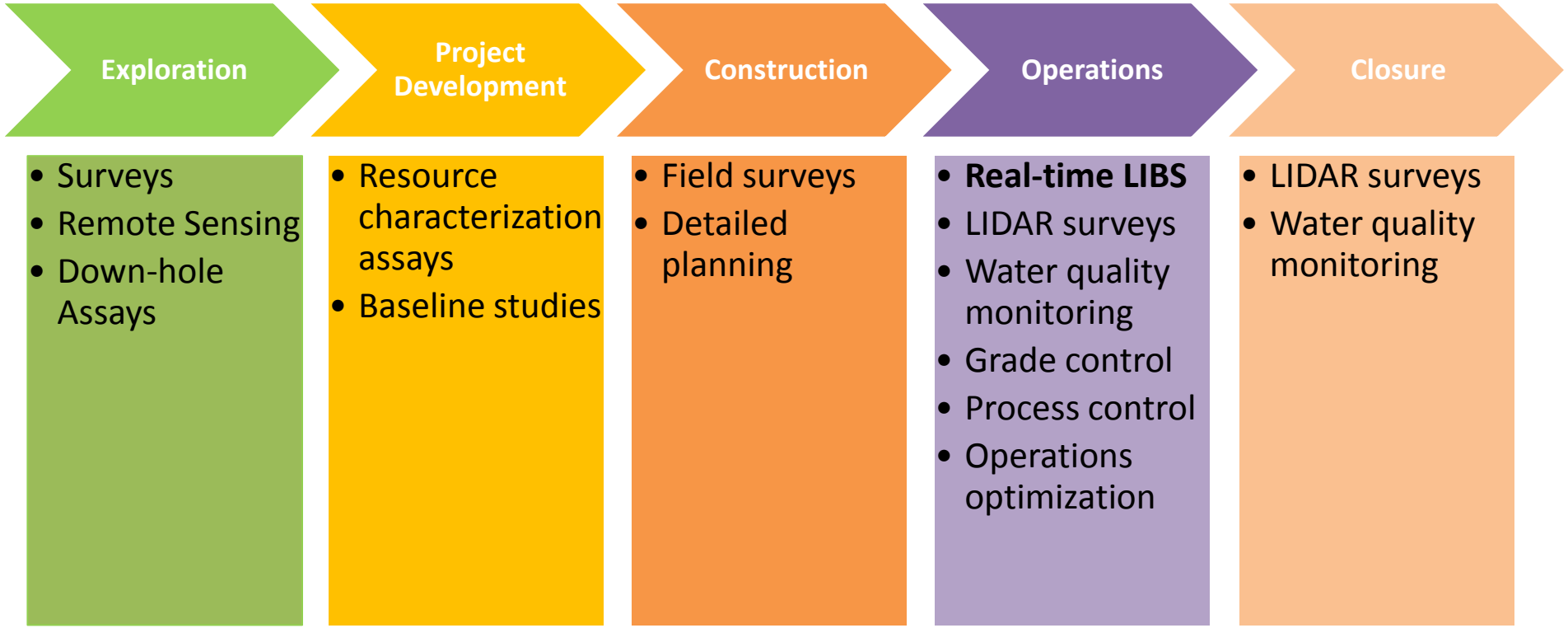
Comparison of concentration values obtained using all the LIBS points on Scanned surfaces and using only the points on the diagonal – encompassing the strats and representing the lithology



Analysis of gold ore samples by LIBS: Quick Facts

- LoD are below 0.4 ppm for Au in mineral ore samples (10 ppb for non homogenous samples).
- No sample preparation, (core, raw, powder, dust, particles, chips, rocks etc. can be analysed)
- Independent from surface roughness and morphology of the sample.
- Laser can clean sample from dust and has access to the bulk or clean rock
- Measurement is less affected to some extent by water layer on sample surface
- Fast measurements, up to 20000 measurements/s
- LIBS is validated with conventional laboratory techniques

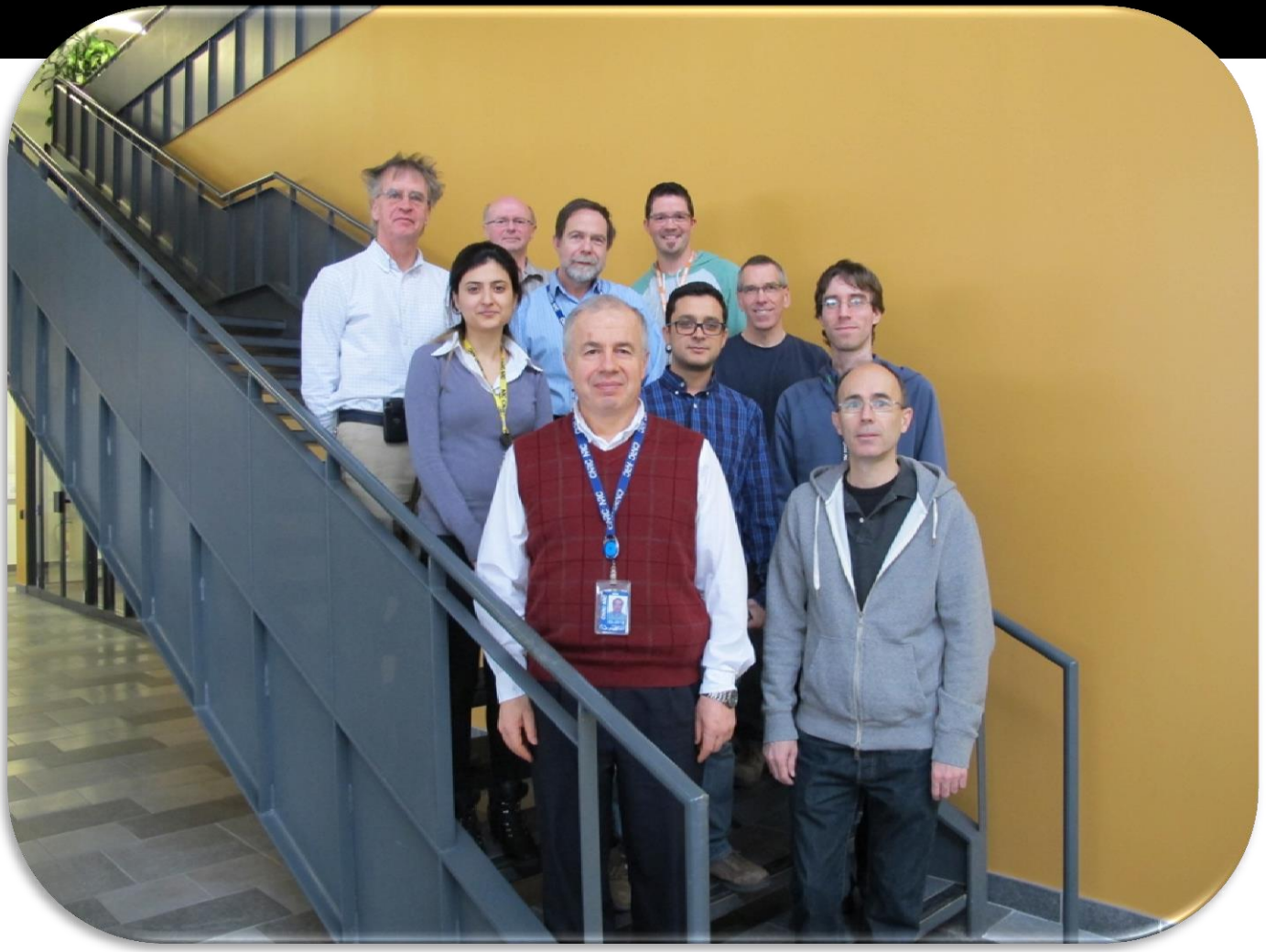
Perspective for applications of LIBS in mining industry
Photonics Sensor Applications for the Mining Value Chain



Conclusions

- LIBS opens new ways for fast and direct determination of chemical quantities for mining applications.
- LIBS can be applied and used for real time analysis at different stages of the mining cycle from exploration to finished products.
- The advent of new detectors, lasers and spectrometers open new opportunities for the LIBS in mining applications.
- The sampling and surface vs bulk analysis are issues but it can be resolved through different approaches that are currently under study.

The LIBS team at NRC



Mohamad Sabsabi
Christian Padioleau
Aissa Harhira
Maxime Rivard
André Hamel
Francis Boismenu
Paul Bouchard
Josette El Haddad
René Héon
Alain Blouin

André Moreau
Kheireddine Rifai
Francis Vanier
Daniel Gagnon
Elton Soares de Lima

Project Partners

- NRC, Université Laval et INRS
- FRQNT – Programme développement durable du secteur minier
- Mitacs Accélération
- Agnico Eagle - mines Goldex, Lapa and LaRonde
- Mine Canadian Malartic
- Hecla Québec - mine Casa Berardi
- Iamgold - mine Westwood

Thank you - Merci
Questions

Mohamad Sabsabi

Energy, Mining and Environment

Tel: 450 641 5113

Email: mohamad.sabsabi@nrc-cnrc.gc.ca

www.nrc-cnrc.gc.ca/eng/rd/eme