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Accurate mineralogical analysis for lithium ore processing
Analyse minéralogique pour le traitement du minerai de lithium

Marie-Ève Provencher & Dr. Uwe König

Topics

Mineralogical monitoring of lithium ores

Motivation & value

Lithium deposits and processing

What is X-ray diffraction (XRD)

Case study - Pegmatites

Case study - Brines

Conclusions

Motivation & value

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Motivation and value

Mineralogical monitoring of lithium ores

- Increased demand for lithium
- Efficiency of lithium ore processing depends on mineralogical properties (not only on chemistry)
- Increased complexity of mineralogy of new and existing deposits
  - Exact knowledge of ore domains needed for efficient ore sorting and blending
  - Recovery rates and profitability of downstream processing requires exact knowledge of mineralogical composition
    - Efficient use of reagents
    - Minimum downtime
    - …

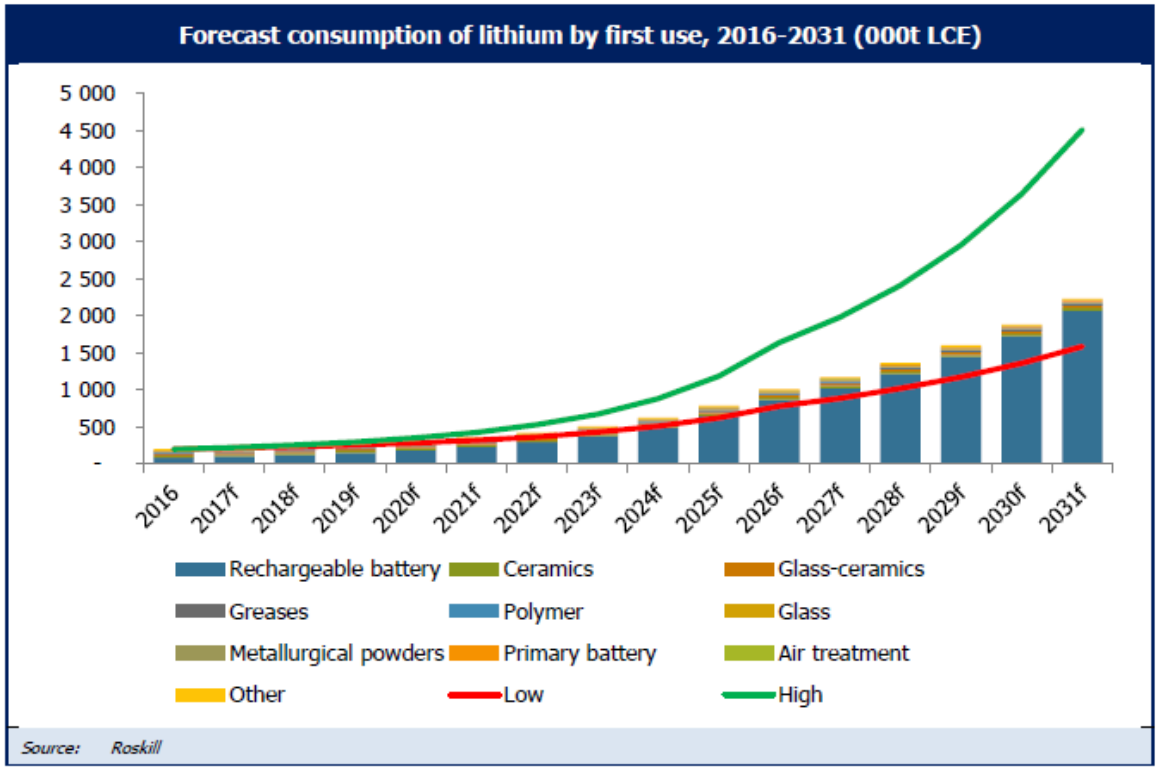
Increased demand for lithium

How much lithium is in everyday item ?

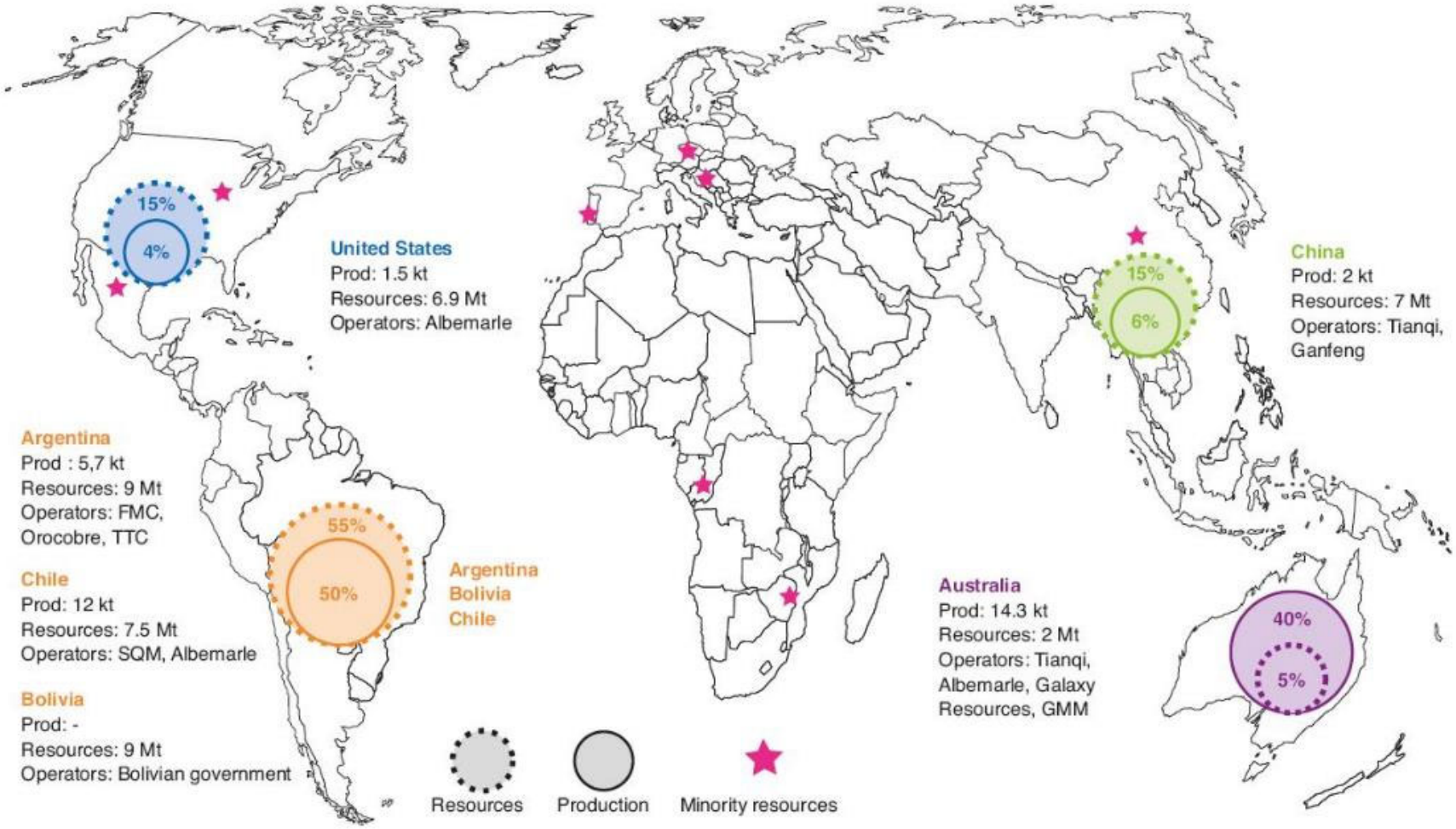
Source: www.visiualcapitalist.com

Increased demand for lithium

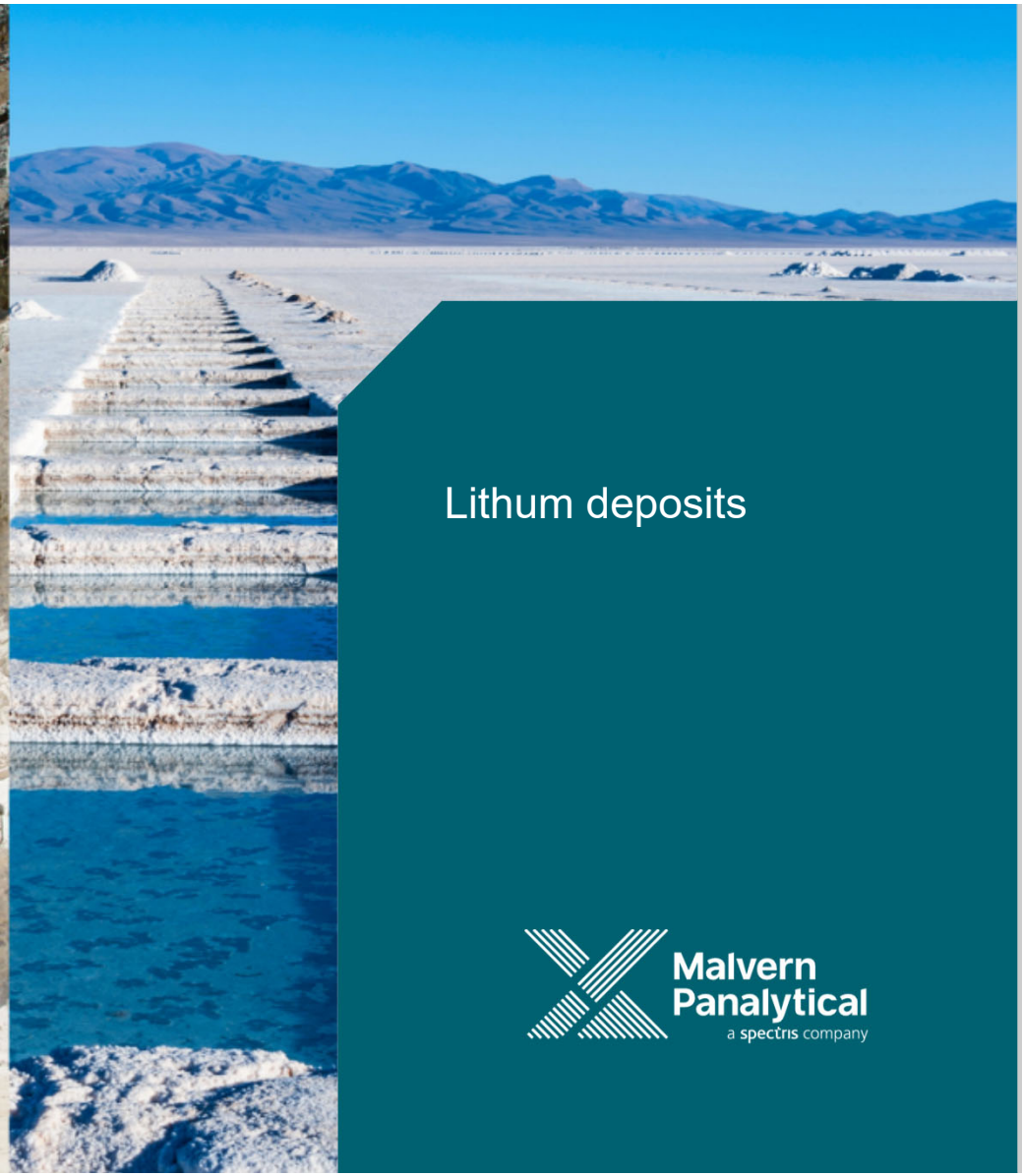
Forecast consumption



Source: Roskill Consulting Group Ltd, 2017



Sources: USGS (2017), producer announcements



Lithum deposits

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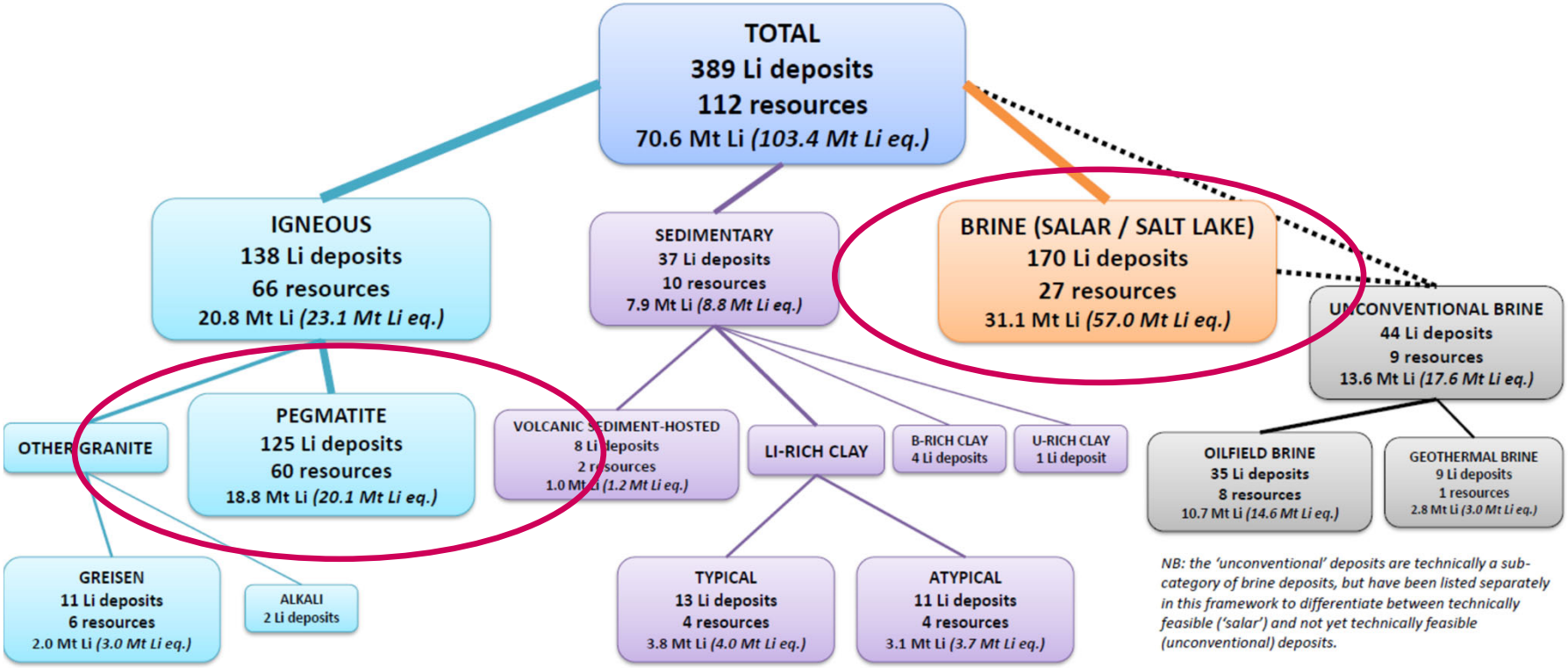
Lithium deposits

Overview



NB: the 'unconventional' deposits are technically a sub-category of brine deposits, but have been listed separately in this framework to differentiate between technically feasible ('salar') and not yet technically feasible (unconventional) deposits.

Sykes -MinExConsulting, 2019

Lithium deposits

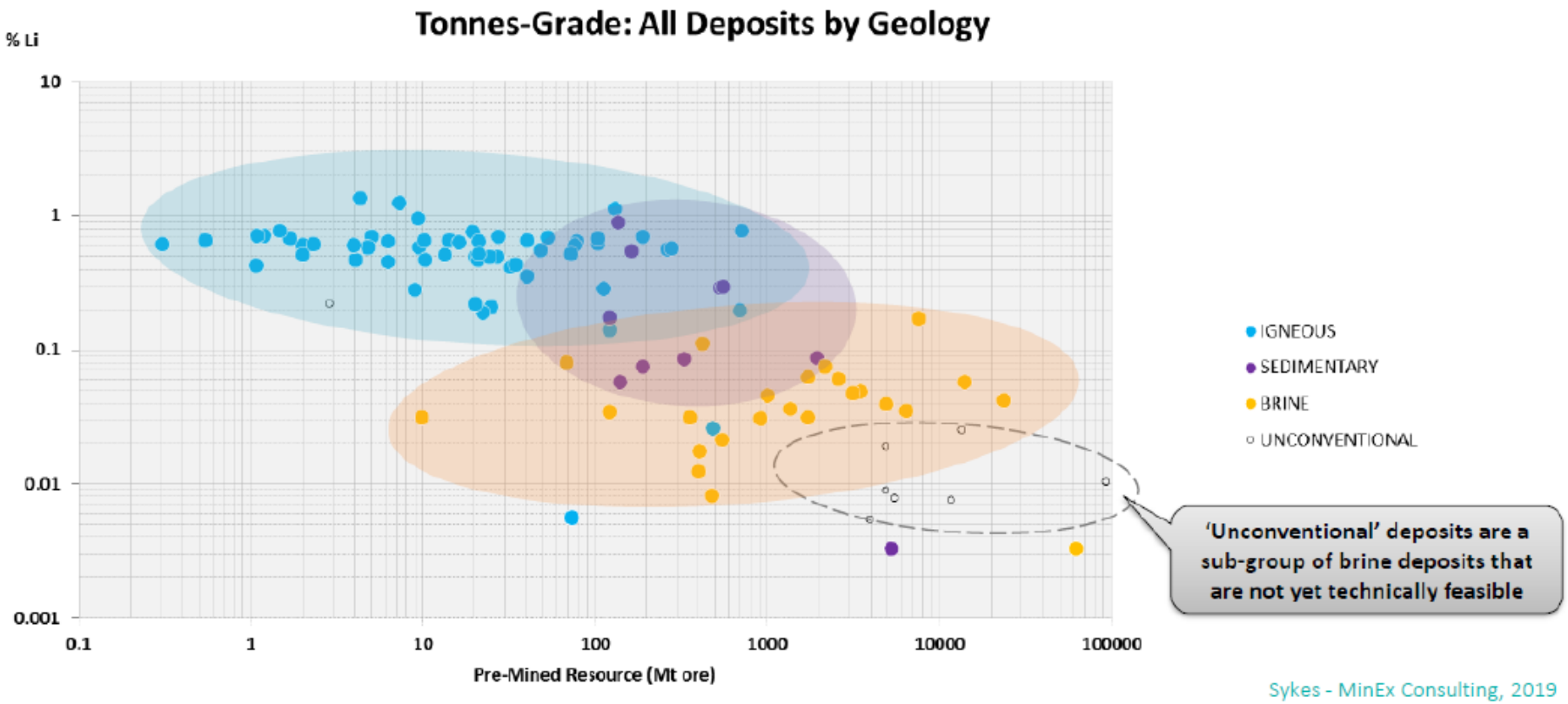
Brines versus pegmatites

- Formed by leaching of volcanic rocks in basin depositional environments
- **Large low-grade deposits**
- Extraction of Li involving the pumping of brine, concentration via evaporation, and purification through solvent extraction, end product mainly Li_2CO_3

- Lithium-bearing, aluminium silicate mineral which mostly occurs in lithium-rich pegmatites (granite-like igneous rock composed of quartz, feldspar and mica).
- **Complex high-grade deposits**
- Spodumene usually recovered through open pit mining
- Beneficiated via gravity techniques where the ore is concentrated from 1-2% Li_2O to a grade of ~6% Li_2O

Lithium deposits

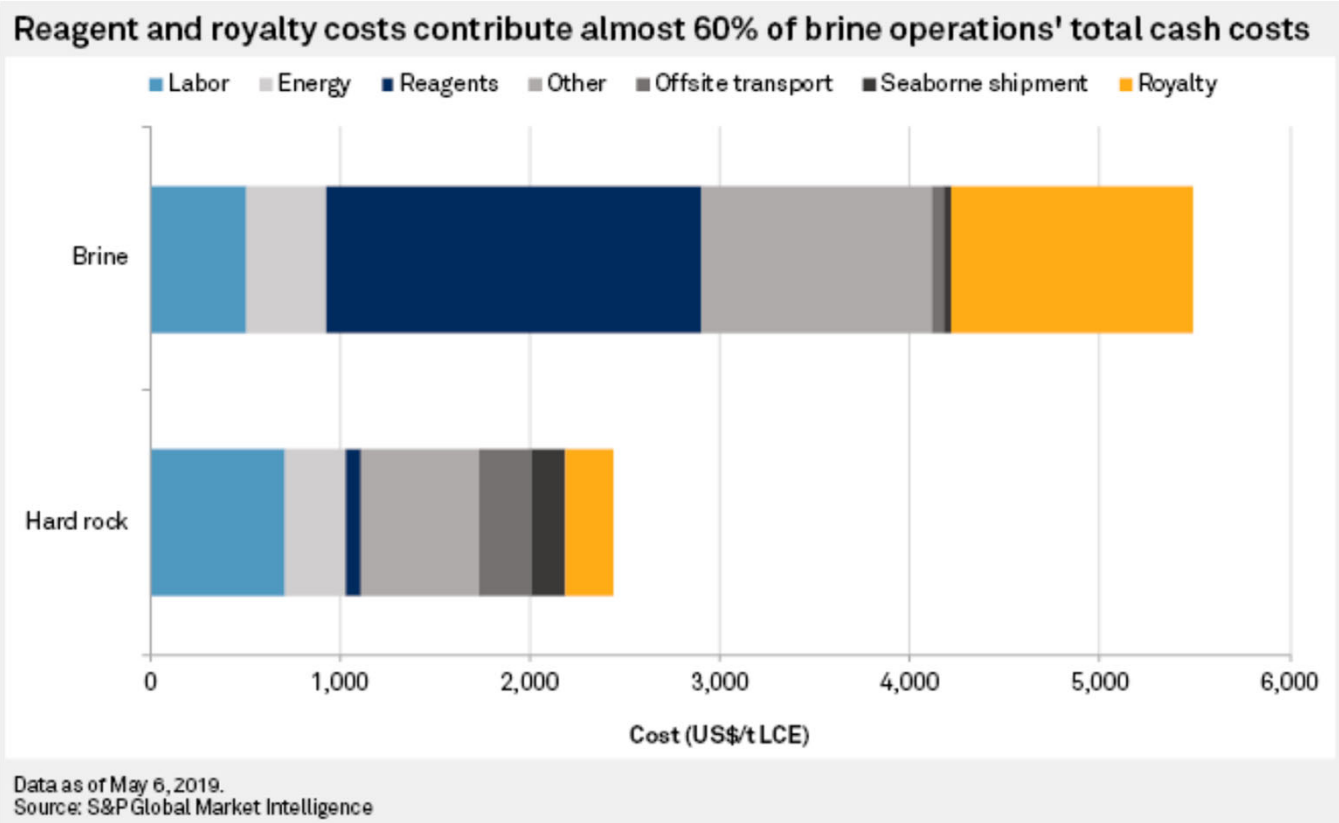
Brines versus pegmatites

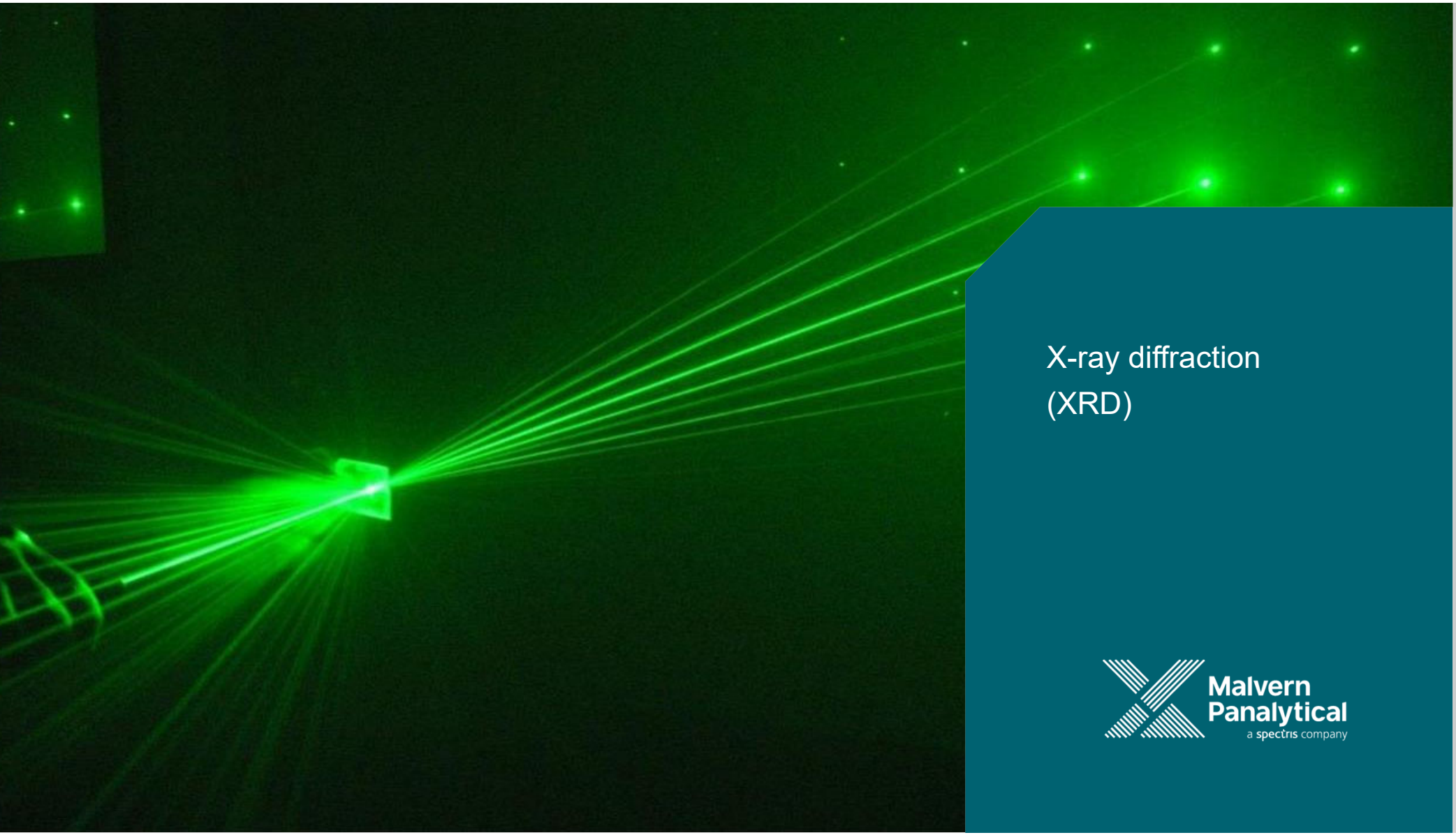


Sykes - MinEx Consulting, 2019

Lithium deposits

Costs





X-ray diffraction (XRD)

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Analytical techniques

Elements and minerals

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Wet chemistry

XRF

Neutron analysis

	Fe	SiO2	Al2O3	MgO	CaO	S
1	26.5	22.2	0.4	17.9	2.1	4.0
2	57.9	6.1	0.8	3.9	1.9	4.9
3	34.5	23.1	2.0	12.5	4.4	2.1

Elements

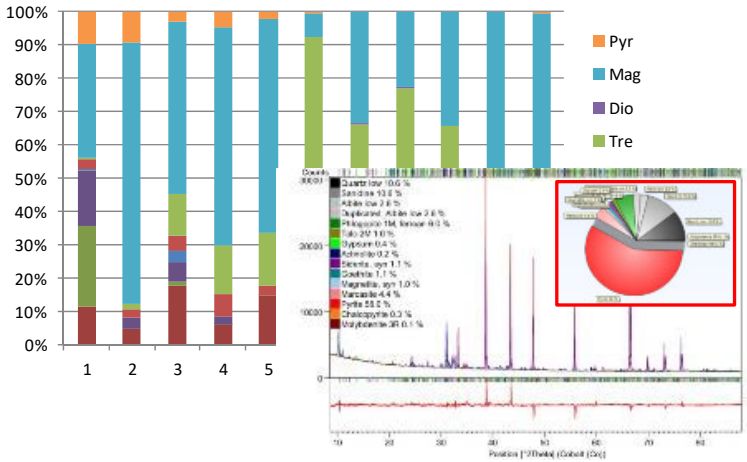
XRD

NIR

Electron microprobe

MLA, QEMSCAN

Microscopy



Minerals

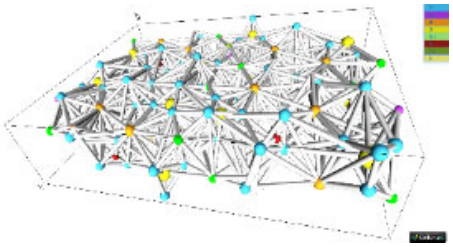
Process parameters

XRD in Geoscience

Usage

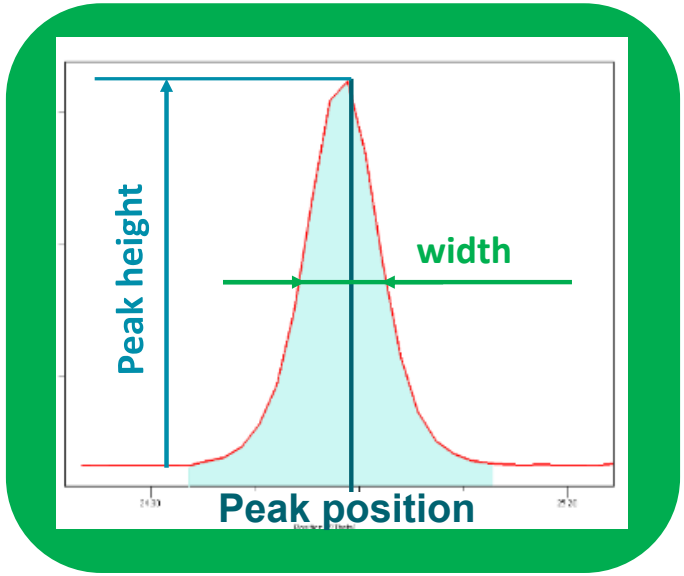
Main fields of applications:

- RESEARCH
- EXPLORATION
- PROCESSING
- ENVIRONMENT



XRD in Geoscience

What can we learn from XRD pattern?

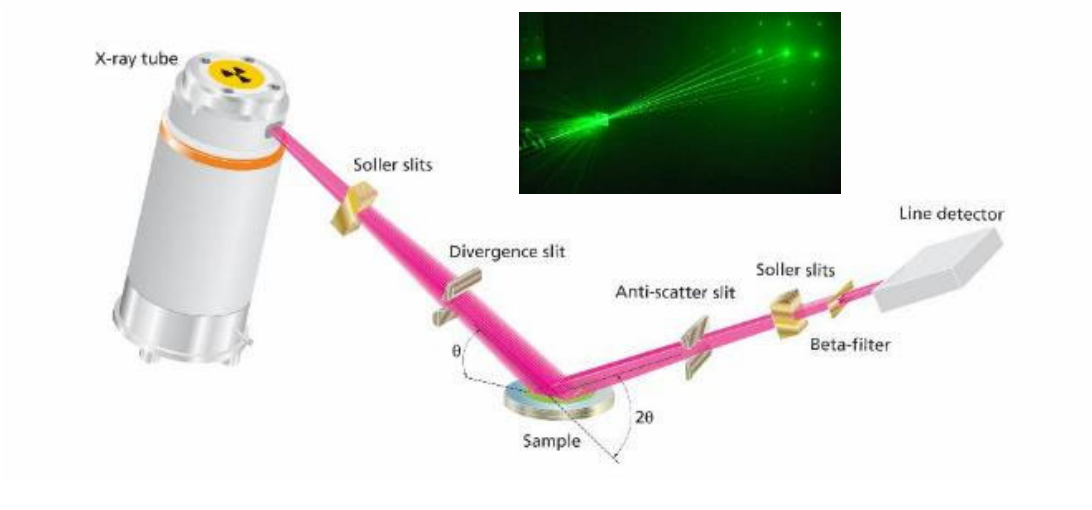


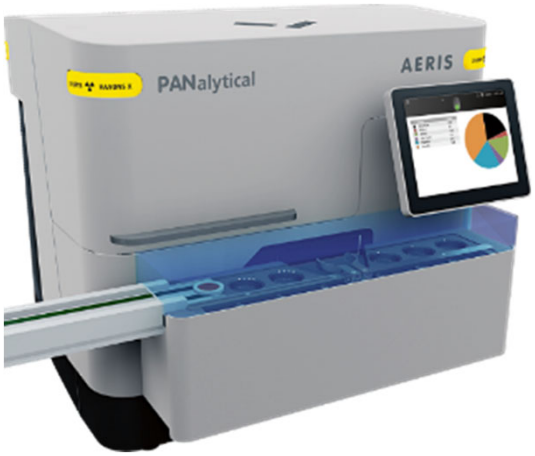
- Phase composition
- Amorphous content
- Crystallite size/microstrain
- Structural information
- Process parameters

X-ray diffraction

How does it work ?

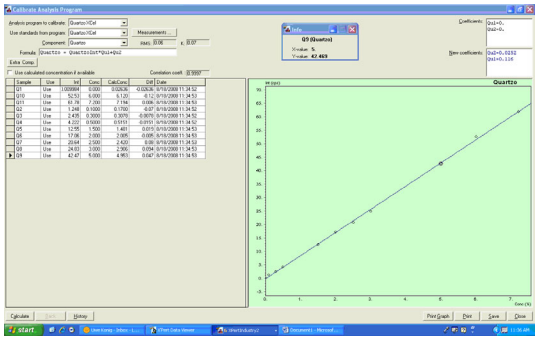
- Identification and quantification of crystalline phases and amorphous content
- Monitoring of process parameters



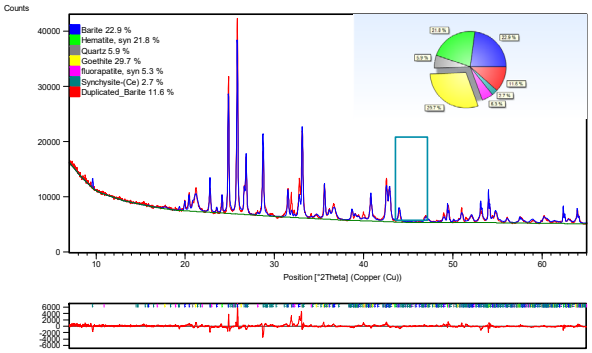


X-ray diffraction

Data evaluation



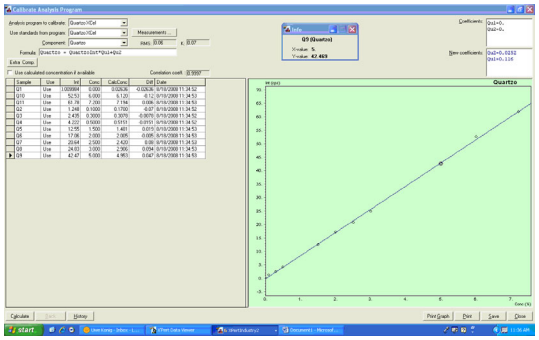
Calibration



Rietveld

X-ray diffraction

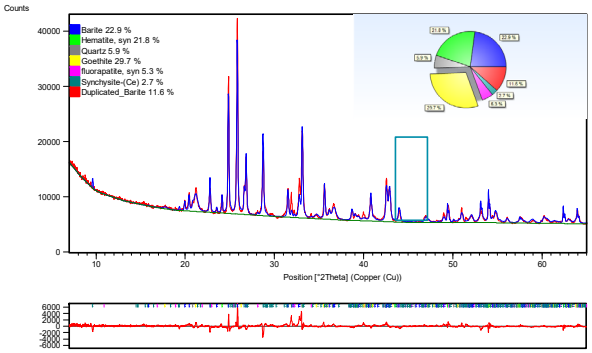
Data evaluation



Calibration

PLSR

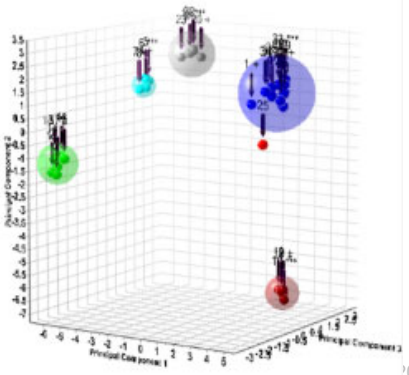
Partial Least Squares Regression



Rietveld

Clustering

Similarity analysis



Case study:
Pegmatites

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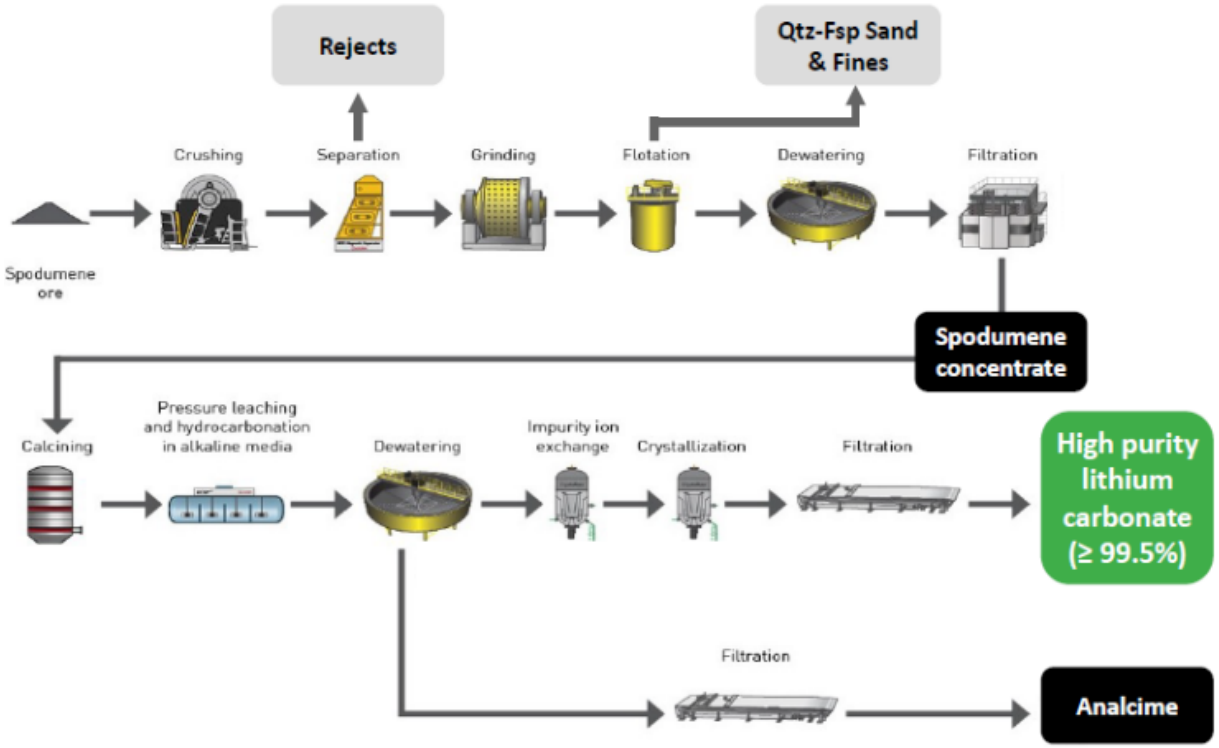
Process

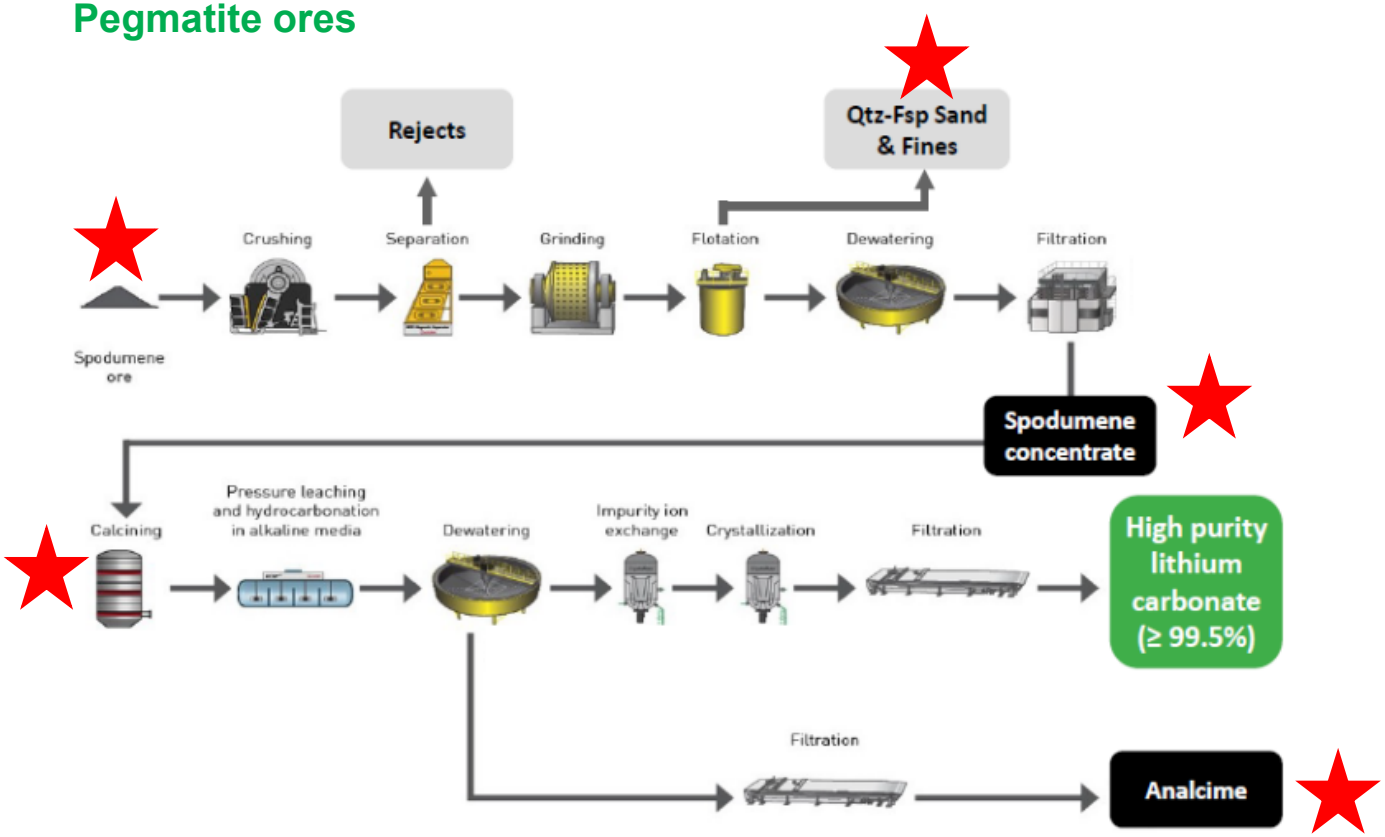
Pegmatite ores



Keliber BatterySupply Chain Europe /Düsseldorf, March13, 2018

Process

Pegmatite ores



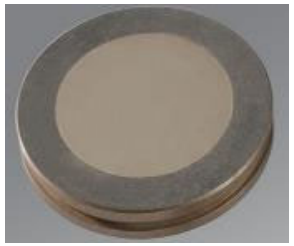
Samples case study

Keliber BatterySupply Chain Europe /Düsseldorf, March13, 2018

Mineralogical monitoring…

Exploration, mine planning, process monitoring

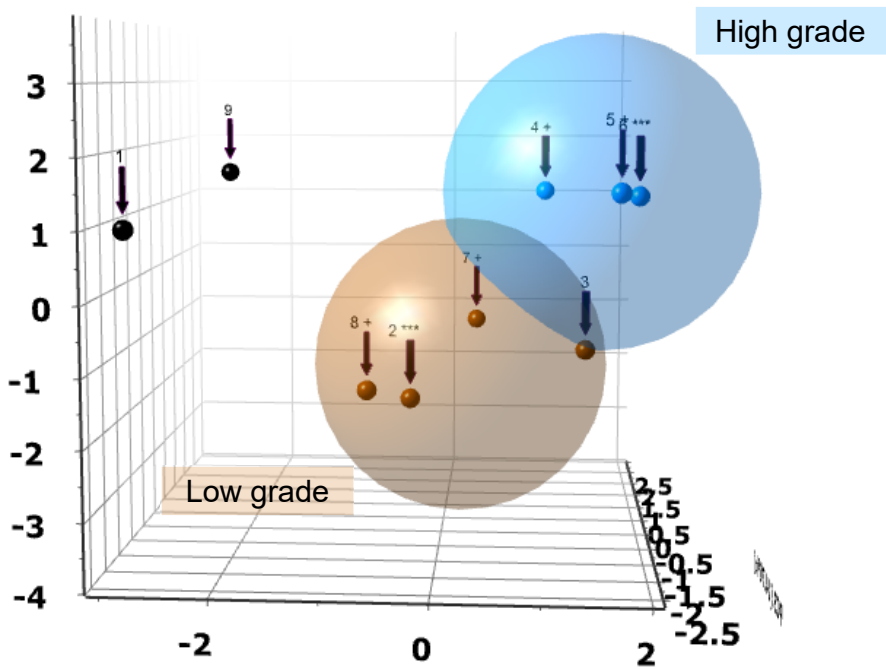
- Samples from several parts during mining and processing of lithium ores were analyzed
  - Lithium **ore** (raw material)
  - **Concentrate** (α – Spodumene)
  - Flotation **tailings**
  - **Calcination** product (β – Spodumene)
  - **Residue** (Analcime)


- Sample preparation
  - Automatic mill / press combination to ensure minimum sample preparation errors
- Measurement time per sample **8 min** (Aeris Minerals, benchtop XRD)

Cluster analysis

Lithium ores



- Prior to phase identification and quantification a **cluster analysis** was performed using all available ore samples
- 2 cluster (groups of similar samples) are identified
- 2 outliers (not belonging to any cluster)
- → fast check for different ore domains for greenfield or brownfield exploration

Lithium containing minerals

Pegmatites

Mineral	Formula	Theoretical Li Content (%)
Spodumene	$LiAlSi_2O_6$	3.73
Petalite	$LiAlSi_4O_{10}$	2.27
Eucryptite	$LiAlSiO_4$	5.51
Bikitaite	$LiAlSi_2O_6.H_2O$	3.40
Lepidolite	$KLi_2AlSi_3O_{10}(OH,F)_2$	~3.84
Zinnwaldite	$KLiFeAl_2Si_3O_{10}(F,OH)_2$	1.59
Amblygonite	$(Li,Na)AlPO_4(OH,F)$	4.73
Montebrasite	$LiAl(PO_4)(OH)$	1 to 4
Lithiophylite	$LiMnPO_4$	4.43
Triphylite	$LiFePO_4$	4.40
Hectorite	$Na_{0,3}(Mg,Li)_3Si_4O_{10}(OH)_2$	~1.93
Jadarite	$LiNaAlSiB_2O_7(OH)$	2.85
Zabuyelite	Li_2CO_3	18.79
Elbaite	$Na(Li_{1,5}Al_{1,5})Al_6Si_6B_3O_{27}(OH)_4$	1.11

- Spodumene theoretically contains 8.03% Li_2O

Lithium containing minerals

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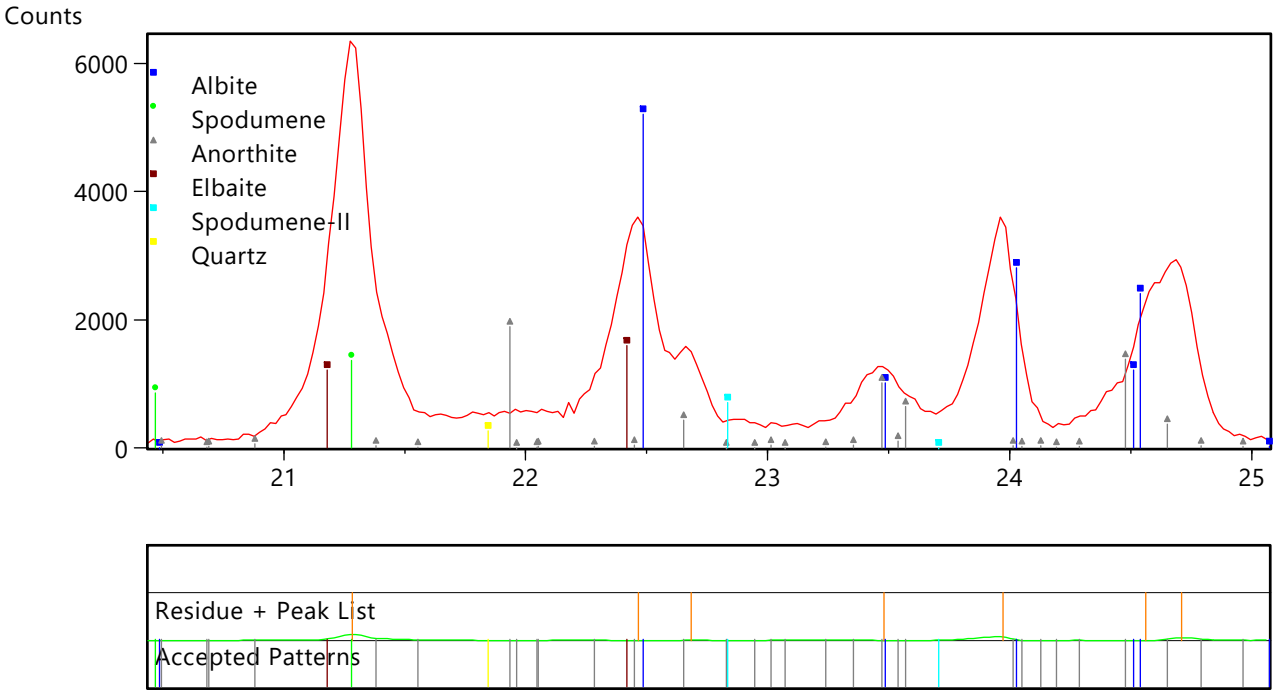
Mineralogy

Phase identification pegmatites



- Complex mineralogy
- 8 main and minor minerals identified in the lithium ores
- Additional mineral phases identifies in the processed ore
- XRD can distinguish between α- and β-spodumene !!!

Mineralogy

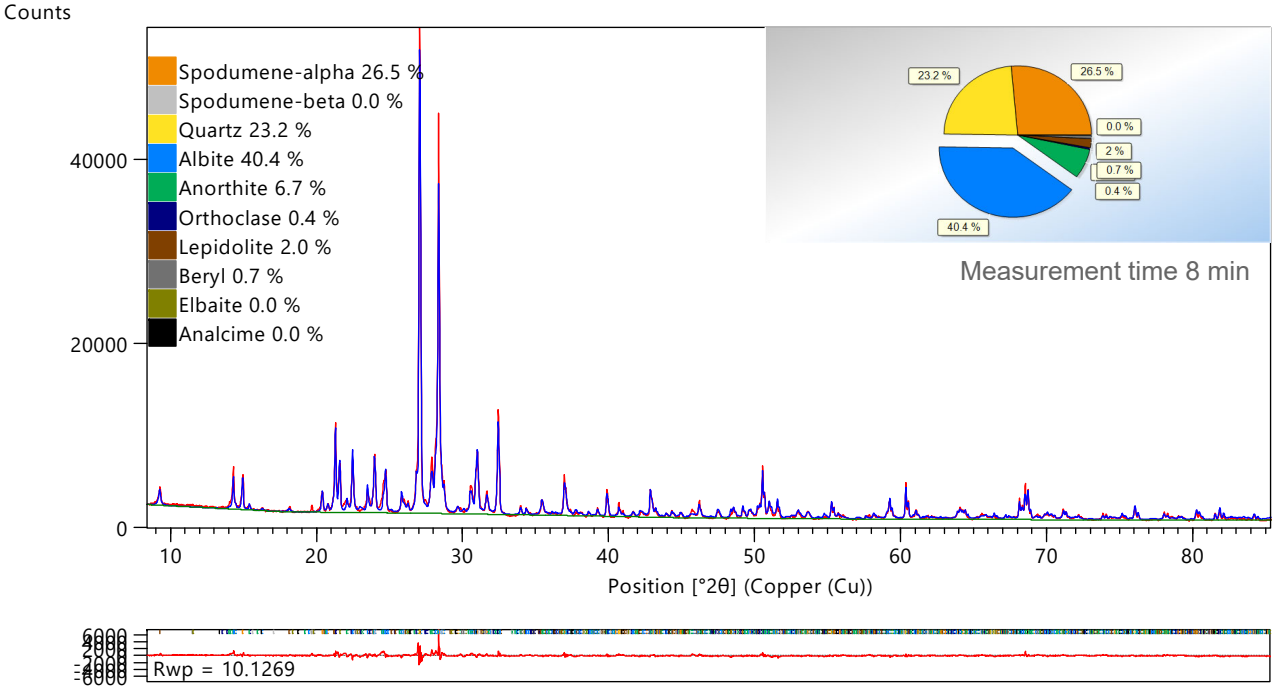
Phase identification

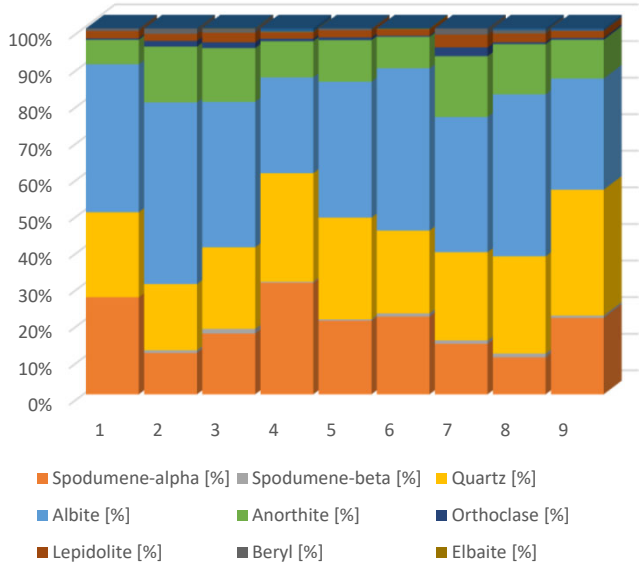
Mineral	Formula
Spodumene	$LiAl(SiO_3)_2$
Quartz	SiO_2
Albite	$NaAlSi_3O_8$
Anorthite	$CaAl_2Si_2O_8$
Lepidolite	$K(Li,Al)_3(Al,Si,Rb)_4O_{10}(F,OH)_2$
Orthoclase	$KAlSi_3O_8$
Tourmaline (Elbaite)	$Na(Li_{1.5}Al_{1.5})Al_6Si_6O_{18}(BO_3)_3(OH)_4$
Beryl	$Be_3Al_2(SiO_3)_6$

- Complex mineralogy
- 8 main and minor minerals identified in the lithium ores
- Additional mineral phases identifies in the processed ore
- XRD can distinguish between α- and β-spodumene !!!

Mineralogy (quantification)

Lithium ores

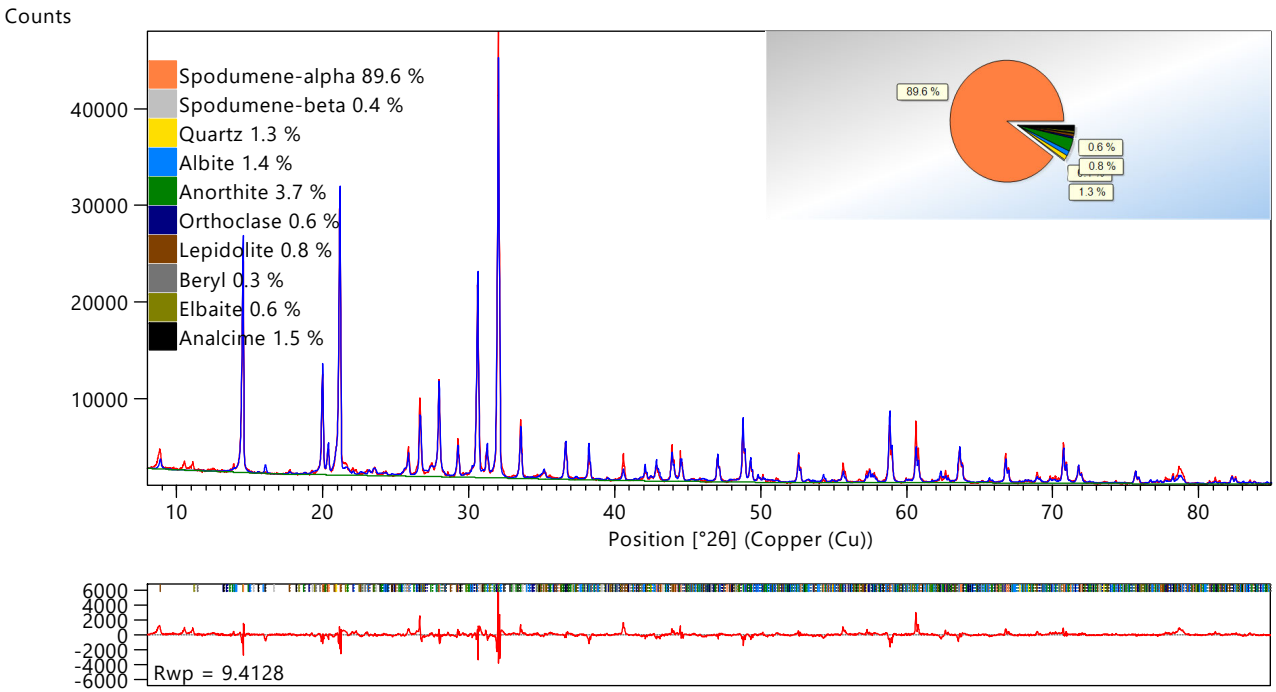


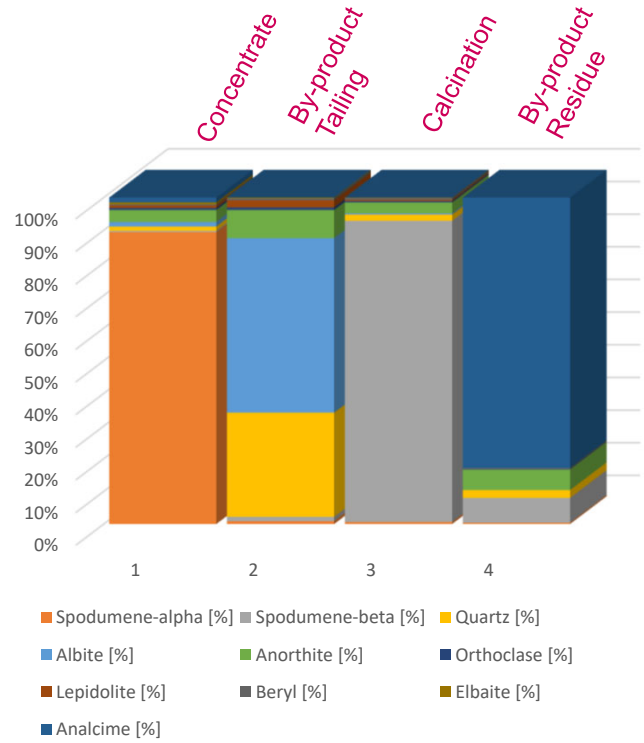


Example of a full-pattern Rietveld quantification of a hard-rock lithium ore

Mineralogy (quantification)

Processed lithium ore

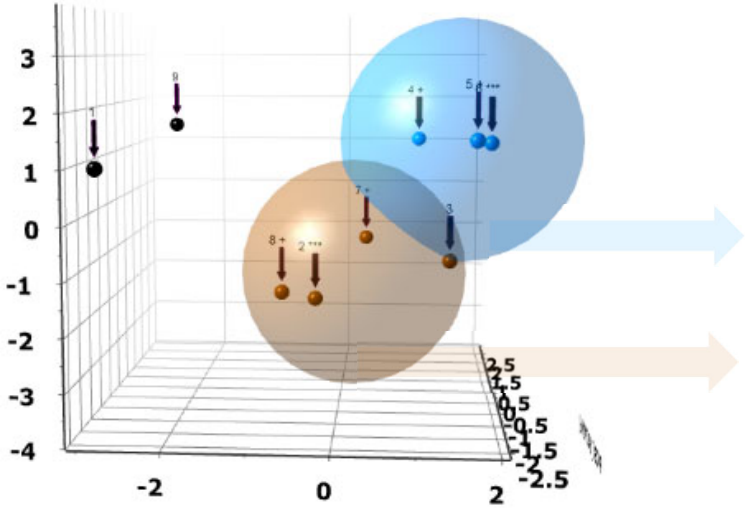




Example of a full-pattern Rietveld quantification of a spodumene concentrate

Results

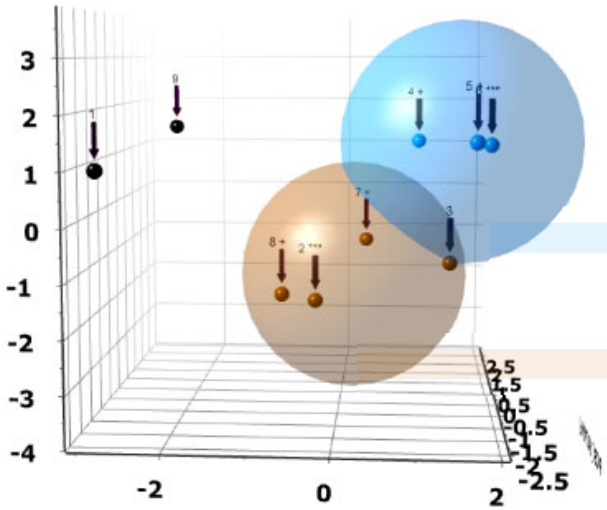
Mineralogical monitoring pegmatite processing



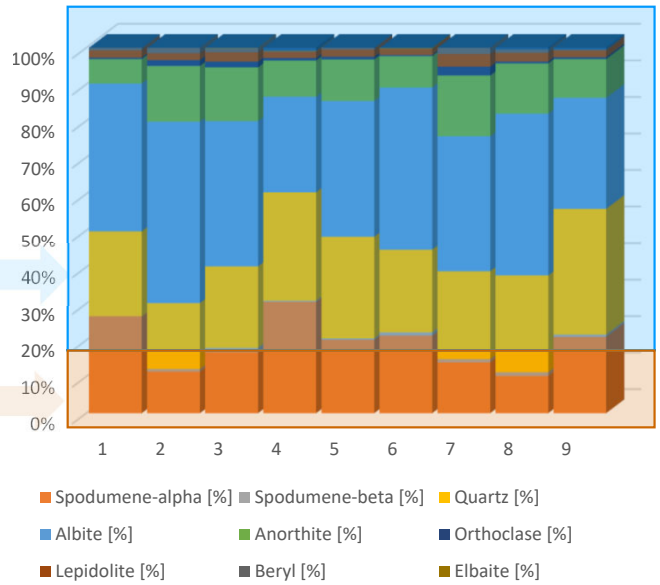
Clustering

Results

Mineralogical monitoring pegmatite processing



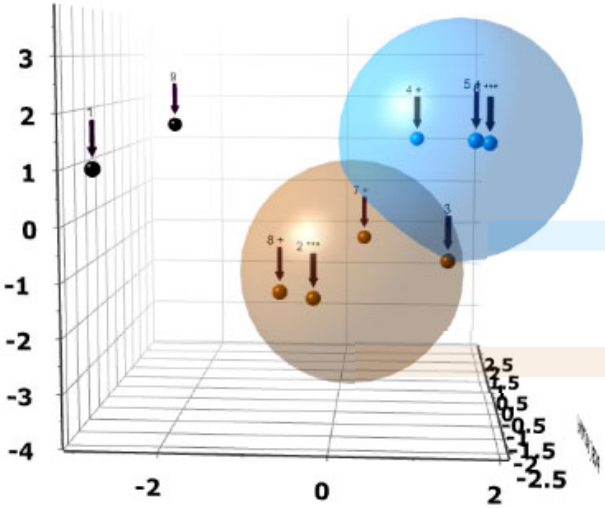
Clustering



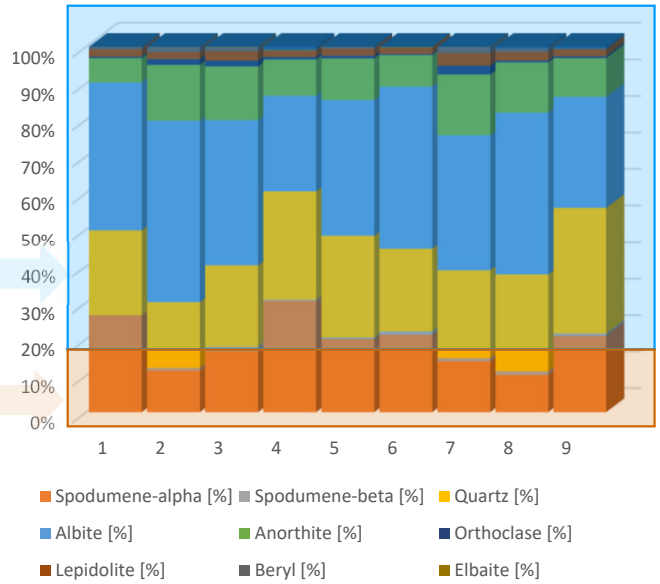
Mineral composition

Results

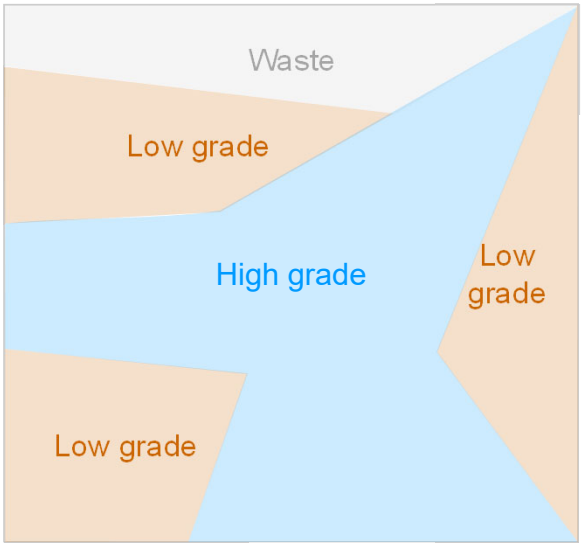
Mineralogical monitoring pegmatite processing



Clustering



Mineral composition



Grade blocks

Case study:
Brines

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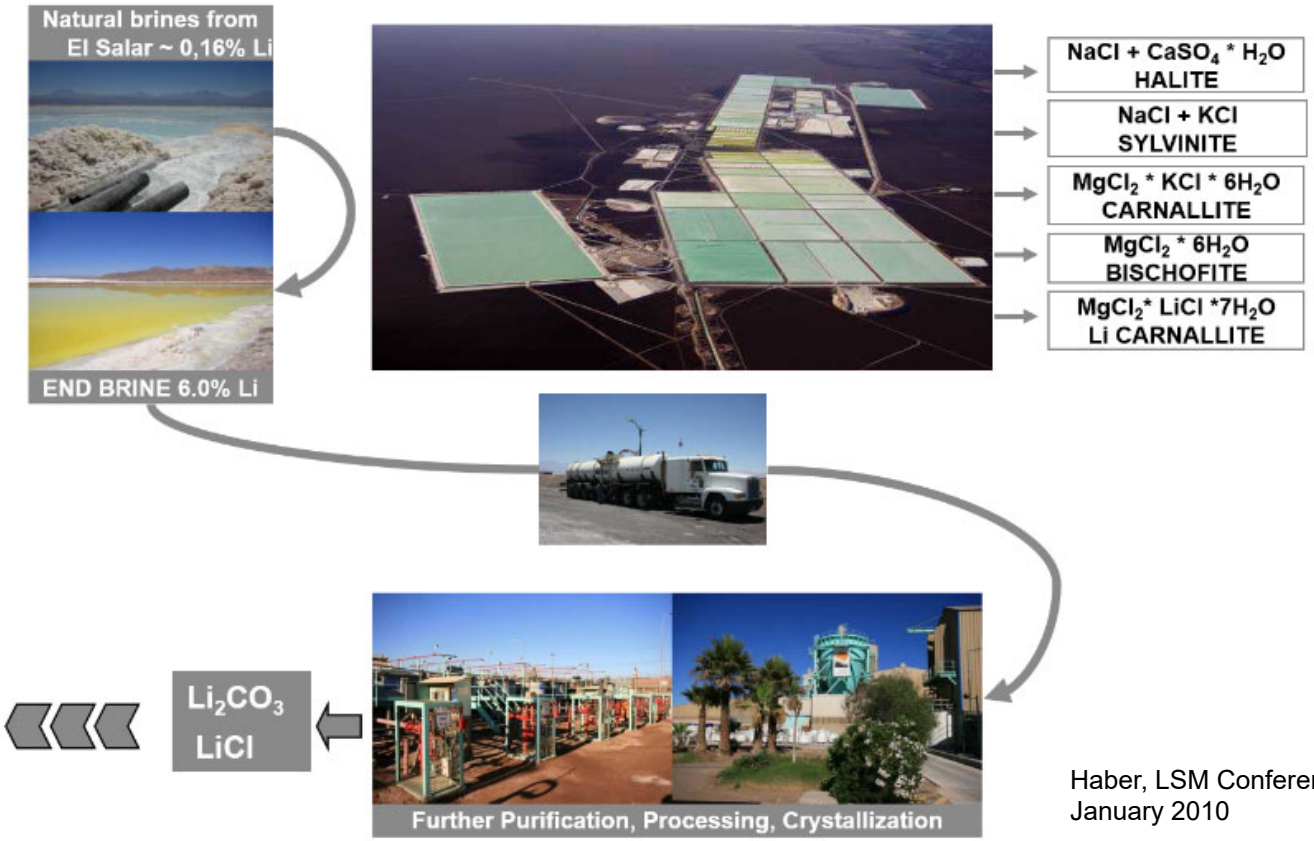
Process

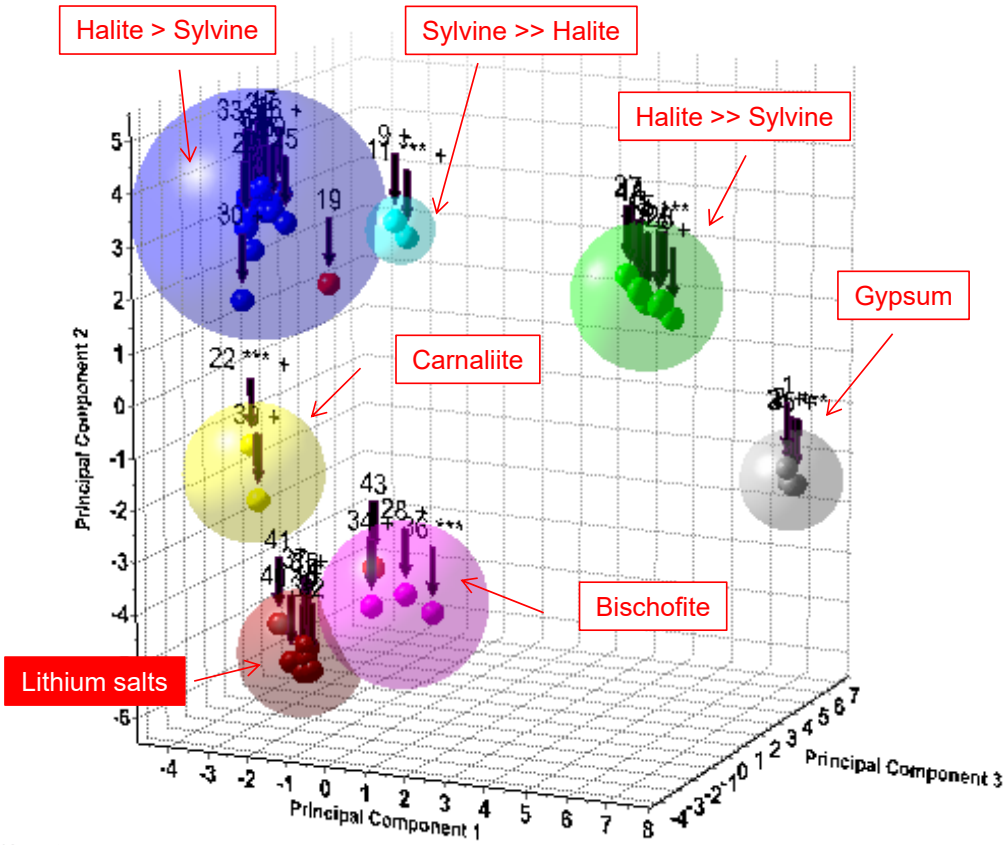
Brines

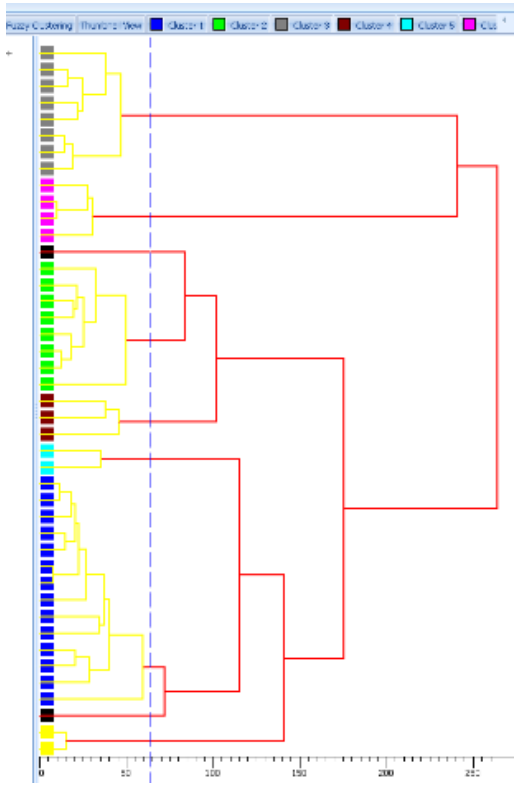


Haber, LSM Conference, Las Vegas, 26-28th January 2010

Cluster analysis

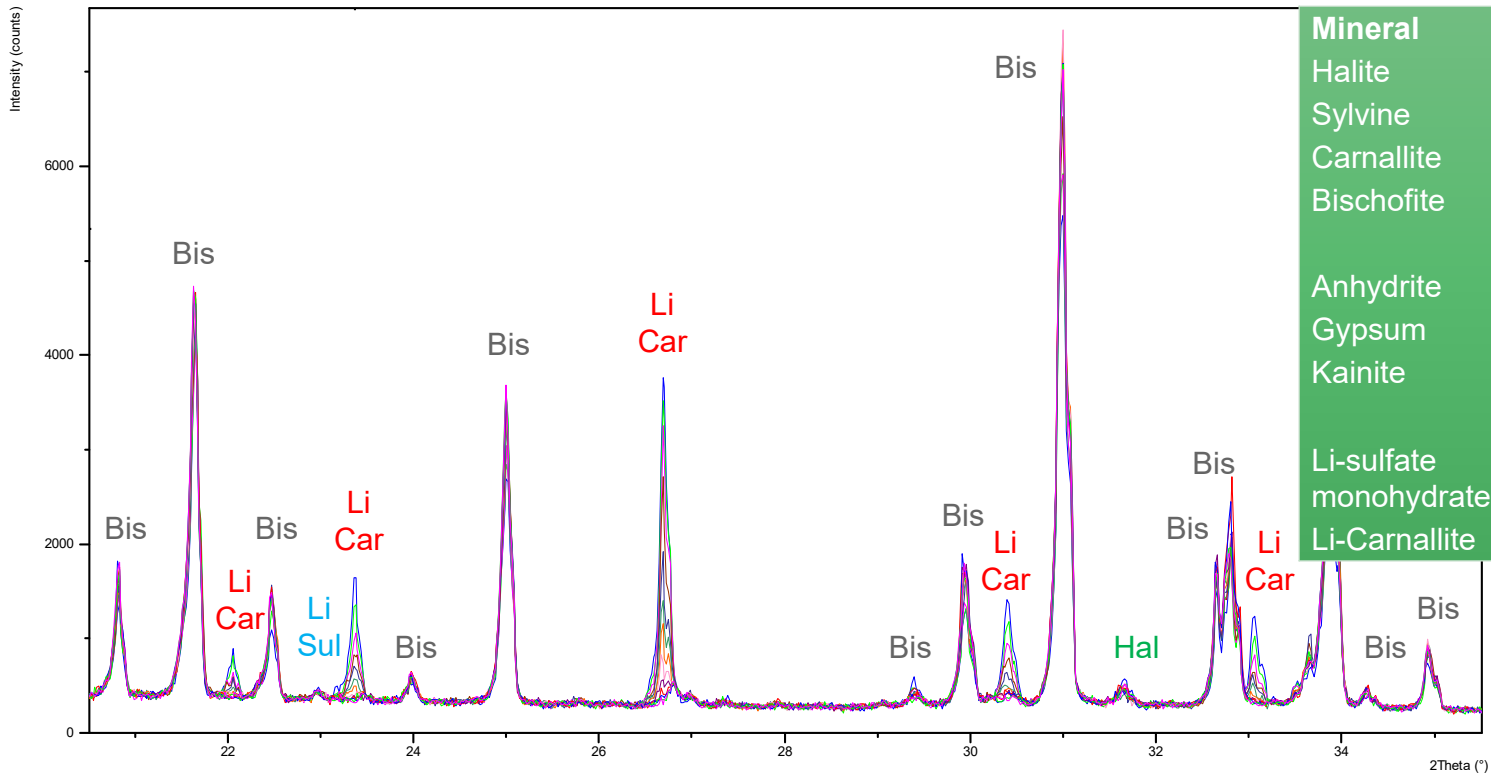
Brine samples





Mineralogy

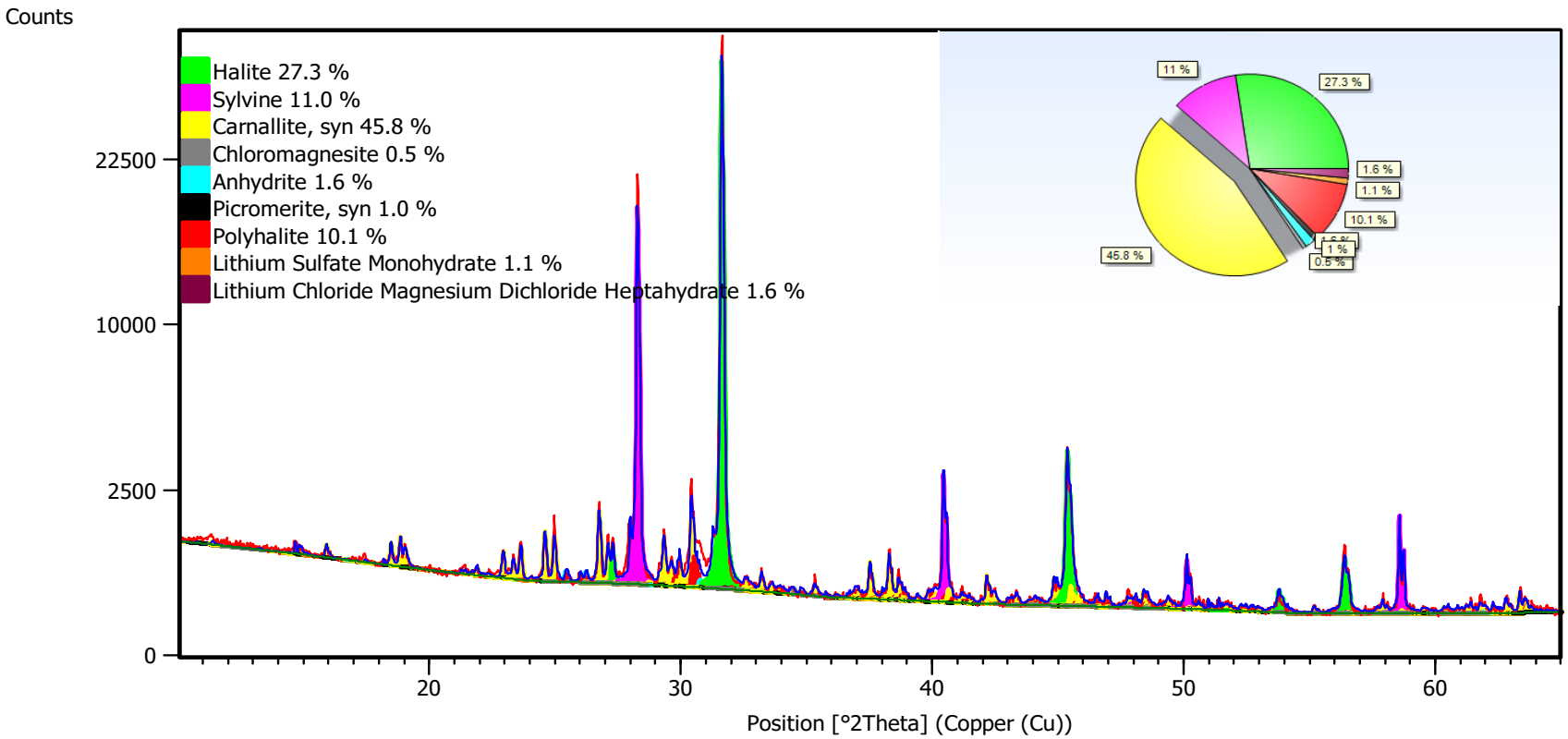
Phase identification brines

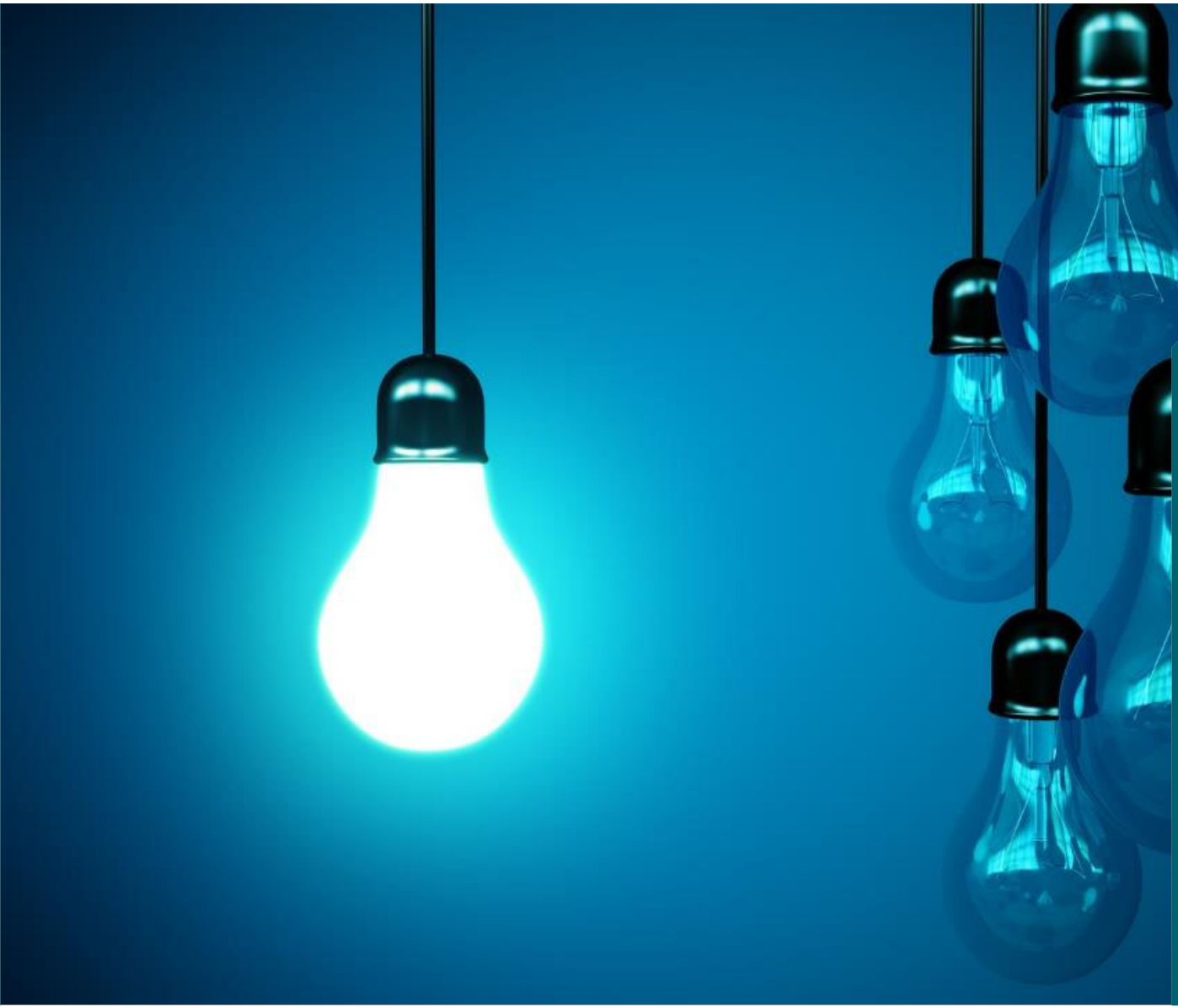


Mineral	Formula
Halite	NaCl
Sylvine	KCl
Carnallite	$KMgCl_3 \cdot 6H_2O$
Bischofite	$MgCl_2 \cdot 6H_2O$
Anhydrite	$CaSO_4$
Gypsum	$CaSO_4 \cdot 2H_2O$
Kainite	$KMg(Cl,SO_4) \cdot 2.75H_2O$
Li-sulfate monohydrate	$Li_2SO_4 \cdot H_2O$
Li-Carnallite	$LiMgCl_3 \cdot 7H_2O$

Mineralogy (quantification)

Lithium brines





Conclusions

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Conclusions

Mineralogical monitoring of lithium ores and brines

- **Fast tool to monitoring qualitative and quantitative mineral composition of lithium ore**
- **Fast detection of impurities or off-spec ore mineralogy**
- **BT XRD in laboratories or containers or an automated environment**

➢ **Fast decision making and counteractions on changing conditions, reduced operational costs**

➢ **Additional information for mine planning and downstream processing**

➢ **Higher degree of process automation with less manual testing, improved safety, lowest energy costs**

Questions ?

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