# Hard Rock Lithium Sources

## Particular Considerations for their Exploration and Mineral Resource Estimation

**Presenter:** Laura Donegan

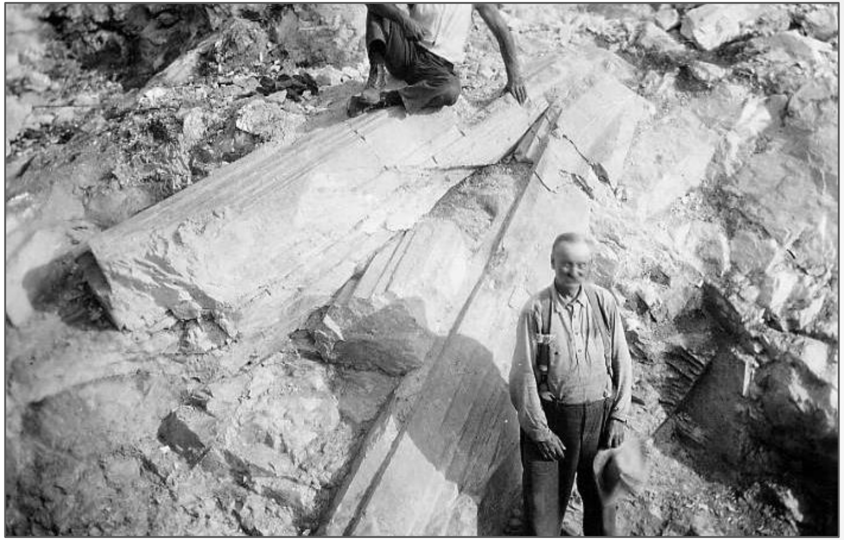
**Location:** Geological Society Lithium Conference

# Hard Rock Lithium Sources



**Pegmatites**

- LCT (Lithium-Caesium-Tantalum) Pegmatites account for a quarter of worlds Li production (USGS 2017)
- LCT pegmatites are peraluminous – high alumina content of micas
  - S-type granitic source – melting of mica schists
- Examples of deposits include:
  - Tanco, Canada
  - Greenbushes, Australia
  - Bikita, Zimbabwe
- Usually zoned on two scales
  - Regionally
  - Internally – mineralogical and textural
- Distinguishable by large crystal size
  - Crystallisation – flux rich incompatible elements – depress solidus temp, lower density, supress crystal nuclei (London, 1992)



**Giant crystals in pegmatite at the Bumpus Quarry in Albany** (maine.gov)

# Hard Rock Lithium Sources

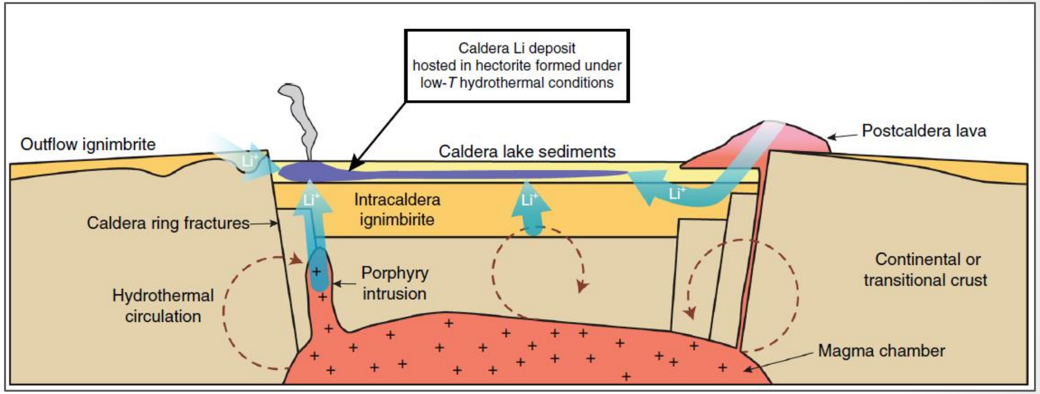
**Clays/Volcanic Tuffs**

- Form from lake sediments preserved within intracontinental rhyolite calderas
  - Lithium is leached from lavas and volcanic ash by meteroric and hydrothermal fluids (Benson, 2014)

- Examples of deposits include:
  - Kings Valley, Nevada USA
  - Clayton Valley, Nevada, USA
  - Sonora, Mexico

- Rhyolitic magmas are elevated in Li
  - Include continental crust material
  - >1,000 ppm Li
  - Associated brines adjacent to these magmas contain concentrated Li at higher grades

- Caldera collapse also acts as basin for accumulation of Li enriched runoff
  - Clays form from altered caldera lake sediments




**Schematic model for formation of caldera-hosted Li clay deposits** (Benson et al, 2014)

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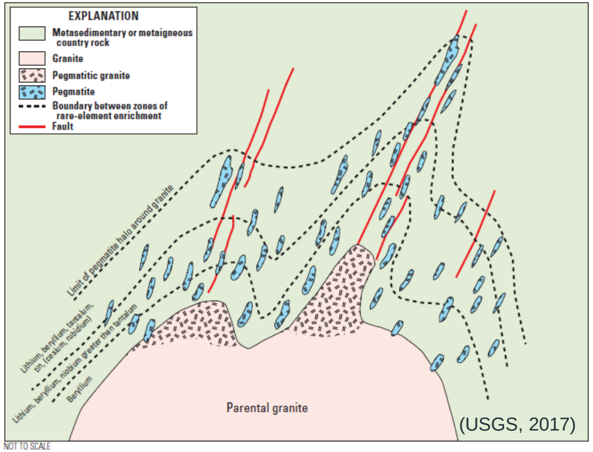
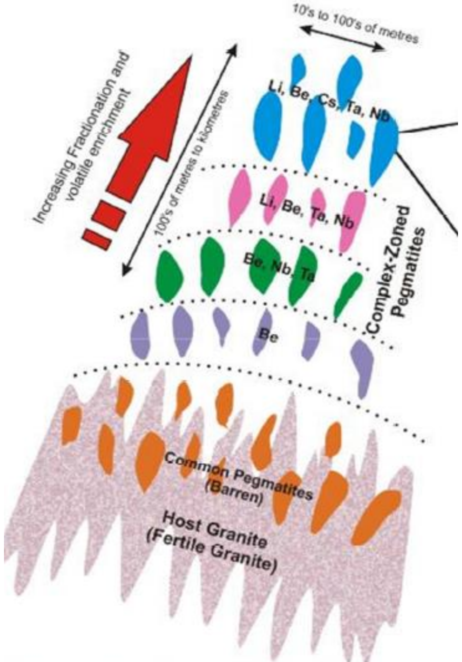
# Pegmatites – District Scale Zonation



- LCT pegmatites show broadly concentric zonation surrounding the source granite
- Most proximal = least evolved
  - Contain only standard rock-forming minerals of granite
- Greatest enrichment in incompatible elements in the most distal pegmatites




(USGS, 2017)



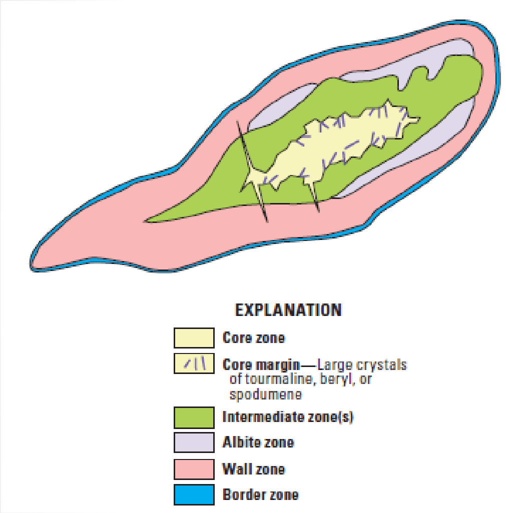

Chemical evolution through a Lithium-Rich Pegmatite Group
(Modified from Trueman and Černý, 1982)

**Typical concentric zonation may be affected by structural controls**
**Pegmatites can be found as far as 10 km from the source granite**

# Pegmatites – Internal Zonation



**Boarder Zone — Wall Zone — Intermediate Zone — Core Zone**

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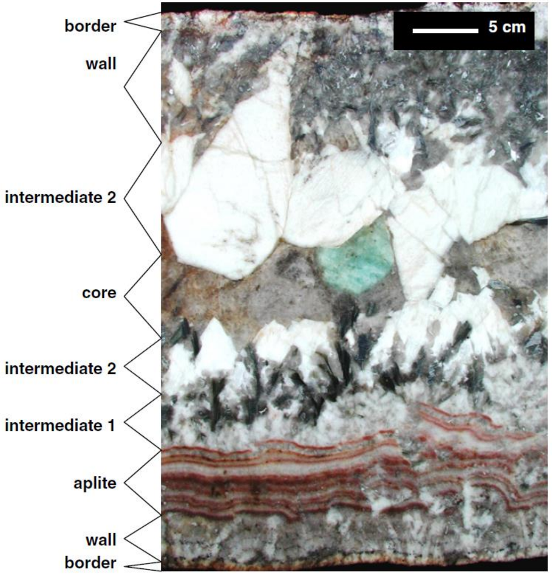
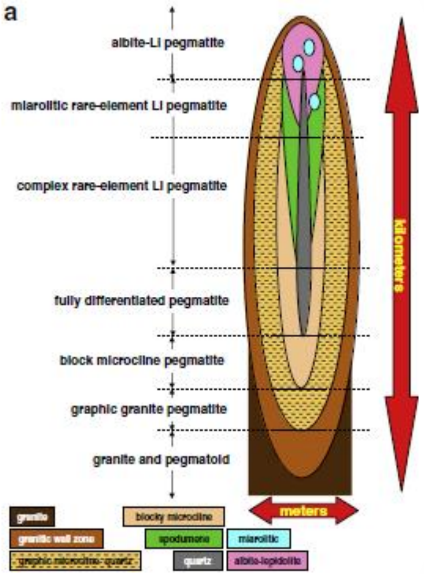



(London, 2014)




(London, 2014)

# Pegmatites – Internal Zonation

- Sharp boundaries to internal zones
  - Incompatible elements pile up at crystallisation front
  - Establishes boundary (London, 2014)

- In LCT pegmatites, the principal lithium ore minerals are:
  - Spodumene
  - Petalite
  - Lepidolite

- Individual crystals in LCT pegmatites can be enormous
  - Largest spodumene on record 14.3 m from Etta Mine, South Dakota

(London, 2014)

(Elements, 2012)

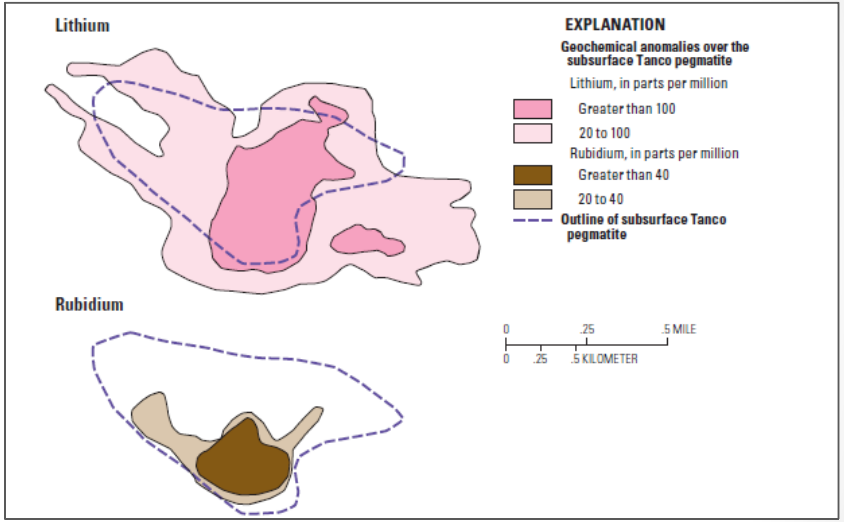
# Pegmatites – a challenge during exploration



- Challenging exploration
  - Do not have a strong geophysical signature
  - Low in iron so do not stand out in aeromagnetic surveys
  - Ground penetrating radar has been tried to identify gem pockets, but unsuccessful (USGS, 2017)

- Where to start?
  - Orogenic hinterland setting – evolved granites – regional zonation
  - In known pegmatite field gravity anomalies detect zonation within the pegmatite e.g. Tanco
  - Some rare-element pegmatites have elevated uranium which could be identified by radiometric surveys
  - Geochemical anomalies
  - Alteration haloes

**Presence of even a single LCT pegmatite suggests the existence of others nearby**




**Lithium and rubidium geochemical anomalies over the buried Tanco pegmatite** (USGS, 2017)

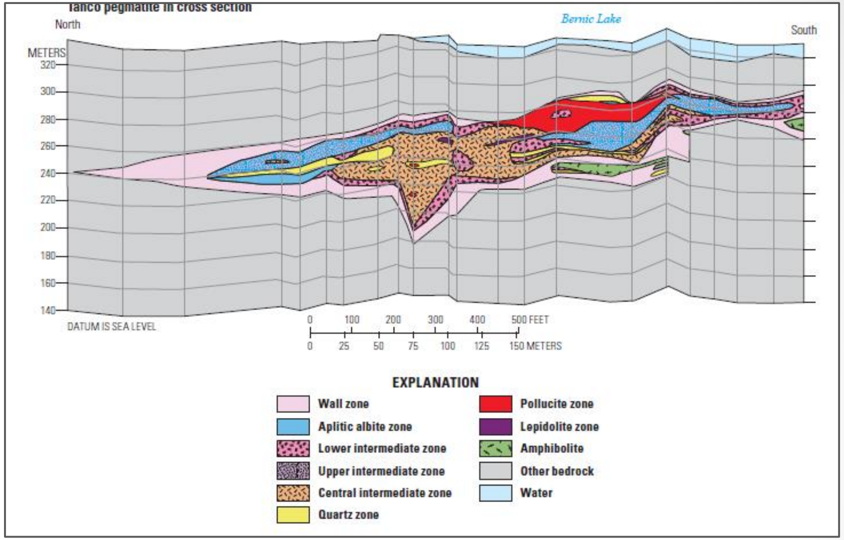
# Pegmatites - Geometries

- Various forms:
  - Tabular dykes
  - Tabular sills
  - Lenticular bodies
  - Irregular masses

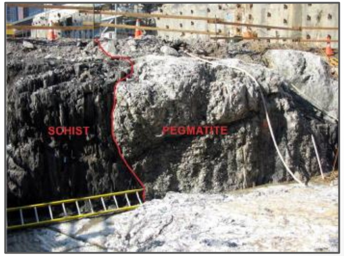
- Tanco, Canada – subhorizontal lenticular body

- Altai No.3, China – subhorizontal sheet that feeds upwards into a vertical stock

- Greenbushes, Australia – dyke swarm, dips of 40º-50º emplaced into a shear zone




**Cross section through the Tanco pegmatite** (USGS, 2017)

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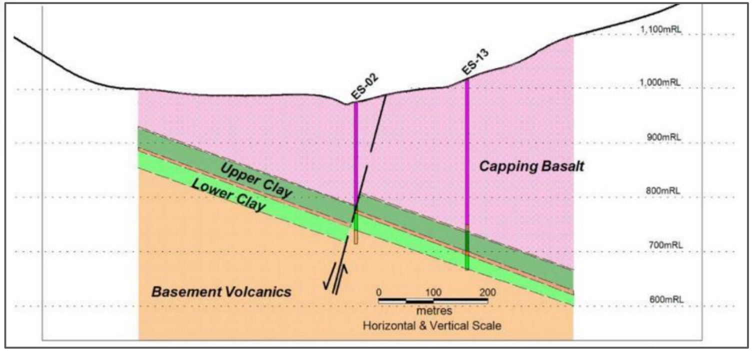
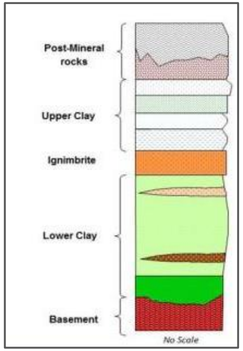
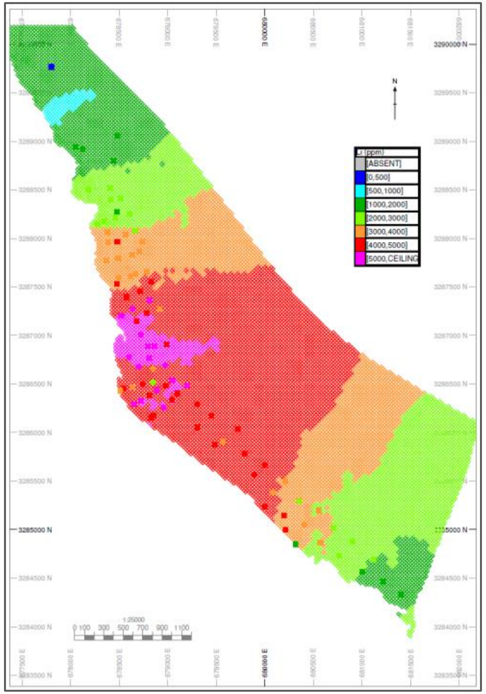
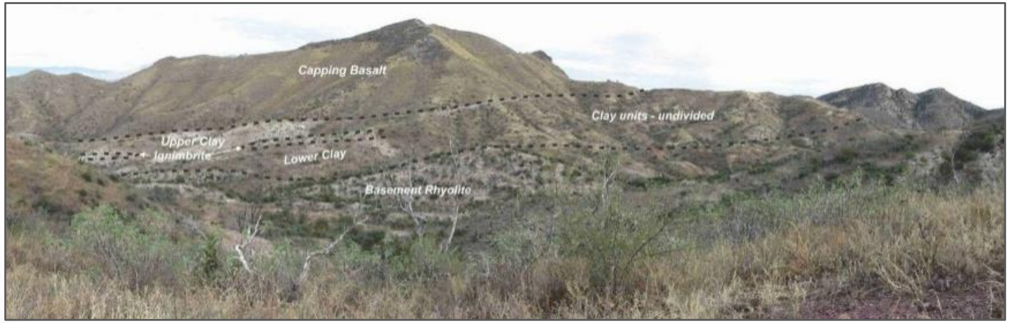
# Clays - Geometries



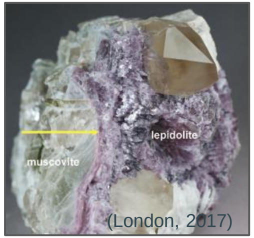



# Lithium Minerals



- Spodumene and petalite from LCT pegmatites were the main source of lithium metal and various lithium compounds historically
- More evolved pegmatites – micas evolve towards Fe-poor Mn-rich lepidolite and occasionally zinnwaldite
  - Lepidolite - colour of mica has no relationship to Li content
  - Zinnwaldite more common in NYF rather than LCT pegmatites
- Other lithium minerals can be present in some LCT pegmatites
- Clay deposits can host lithium in Montmorillonite
- Main lithium rich clay mineral is Hectorite (also Jadarite)

(London, 2017)




(London, 2017)

| Mineral | Formula |
|---|---|
| Amblygonite | $LiAlPO_4F$ |
| Bikitaite | $LiAlSi_2O_6.H_2O$ |
| Elbaite | $Na(Li_{1.5}Al_{1.5})Al_6(BO_3)Si_6O_{18}(OH)_3F$ |
| Eucryptite | $LiAlSiO_4$ |
| Holmsquistite | $Li_2(Mg,Fe)_3Al_2Si_8O_{22}(OH)_2$ |
| Lepidolite | $K(Li,Al)_3(Si,Al)_2O_{10}(F,OH)_2$ |
| Liddicoatite | $Ca(Li_2Al)Al_6(BO_3)_3Si_6O_{18}(OH)_3F$ |
| Lithiophilite | $LiMnPO_4$ |
| Montebrasite | $LiAlPO_4OH$ |
| Petalite | $LiAlSi_4O_{10}$ |
| Rossmanite | $(LiAl_2)Al_6(BO_3)_3Si_6O_{18}(OH)_4$ |
| Spodumene | $LiAlSi_2O_6$ |
| Triphylite | $LiFePO_4$ |
| Zinnwaldite | $K(Li,Al,Fe)_3AlSi_3O_{10}(F,OH)_2$ |
| Hectorite | $NaO_{.3}(Mg,Li)_3SiO_4O_{10}(OH)_2$ |
| Jadarite | $LiNaB_3SiO_7(OH)$ |
| Polylithionite | $KLi_2Al(Si_4O_{10})(F,OH)_2$ |

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# Competency changes and their challenges



- Hard/soft minerals – challenging for drilling in pegmatites and clays
  - Triple tube required
  - Experienced drillers are key – adjust the drilling as the material is being drilled to maximise recovery by experimenting with:
    - Short runs
    - Stabilising the hole with polymers
    - Minimising fluid flow
  - Ensure the driller is recovery focused rather than metres drilled focused

- Exposed soft spodumene/petalite are very prone to breaking down and losing Li
- Very weathered minerals may have no Li left – pseudomorphs
- Li can leach into surrounding country rocks

**Good recovery in difficult drilling conditions – clay alteration of lithium and feldspar minerals mixed with hard quartz**

# Assaying



- Pegmatite typical grade = 1.5 - 5% $Li_2O$
- Clays typical grade = 0.4 - 1.5% $Li_2O$ (BGS, 2016)
- Need to choose suitable assaying methods for the grade
  - Some trace element methods add lithium borate and therefore do not report lithium;
  - In lacustrine sediments, presence of organic matter can complicate ICP analysis.
- Direct analysis by XRF is not possible due to the low atomic number of the element
- 4 acid digest or sodium peroxide fusion with ICP-AES/ICP-MS recommended by ALS and SGS

## LITHIUM

SGS has the methodology to support exploration and production analysis of lithium. Multi-element packages are listed in the Exploration-Grade Analysis section of this guide for low grade lithium samples.

### LITHIUM PACKAGES FOR LOW GRADE MINERALIZATION

| CODE(S) | ELEMENTS/ LIMIT(S) | DESCRIPTION |
|---|---|---|
| GE ICP12B / GE ICP14B | Li (1 - 10000 ppm) | 2-Acid / aqua regia digest / ICP-AES |
| GE ICM12B / GE ICM14B | Li (1 - 10000 ppm) | 2-Acid / aqua regia digest / ICP-AES / ICP-MS |
| GE ICP40B | Li (1 - 10000 ppm) | 4-Acid digest / ICP-AES |
| GE ICM40B | Li (1 - 10000 ppm) | 4-Acid digest / ICP-AES / ICP-MS |
| GE ICP91A | Li (0.001 - 5%) | Sodium peroxide fusion / ICP-AES |
| GE ICM90A | Li (0.001 - 5%) | Sodium peroxide fusion / ICP-AES / ICP-MS |
| GE IMS90A | Li (0.0005 - 1%) | Sodium peroxide fusion / ICP-MS |

### LITHIUM PACKAGES FOR HIGHER GRADE MINERALIZATION

| CODE(S) | ELEMENTS/ LIMIT(S) | DESCRIPTION |
|---|---|---|
| GO AAS93B | Li (>0.001%) | Sodium peroxide fusion / AAS |
| GC ICP91A | Li (>0.001%) | Sodium peroxide fusion / ICP-AES |

# Resources vs. Recoveries



- It is important to record proportions of mineral species
  - Which minerals may contribute to a saleable product?

- More than 150 known minerals can host lithium as a major component - not all can be considered as having ore potential

- What is in resource vs. what is recoverable?
  - Reported Li resource does not reflect whether the Li can be extracted or indicate what form the Li is in
  - Don’t just rely in lithium assay – must to metallurgical testwork/detailed logging etc. to identify the mineral the lithium belongs to


(geology.com)

# Economic Lithium Minerals

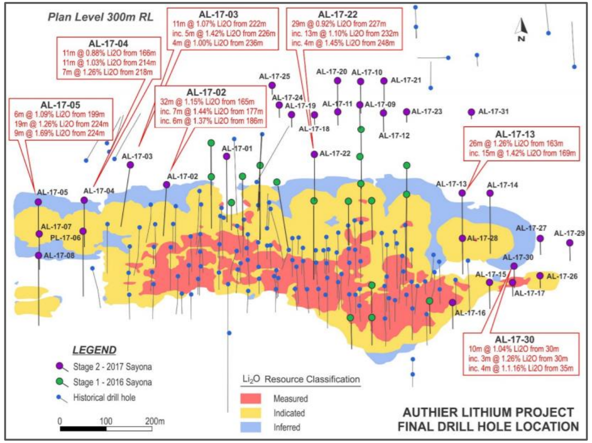


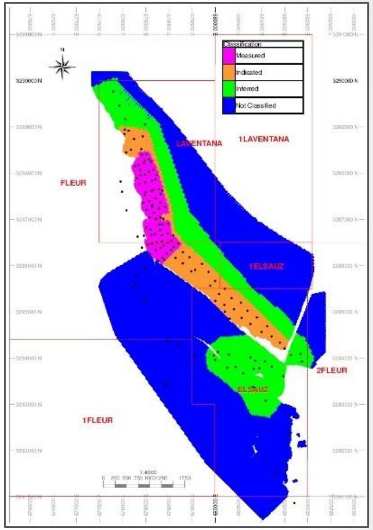
| Mineral | $Li_2O$% | Comment |
| --- | --- | --- |
| Spodumene | 6.9 | Major ore |
| Petalite | 4.73 | Common in African ores |
| Lepidolite | 4.19 | Widespread in low grade ores especially in Australia |
| Zinnwaldite | 2 - 5 | Common in European greisen ores |
| Amblygonite | 7.4 | Common in African ores e.g. Zimbabwe |
| Eucryptite | 9.7 | Common in African ores |
| Triphylite | 9.47 | Common in African ores |
| Jadarite | 7.3 | Only present at Jadar in Serbia |
| Hectorite | 1 - 3 | Main ore in volcanic tuff hosted ores |

(Evans, 2012)

# Classification – Pegmatites vs. Clays

- Geological and grade continuity
  - Extensive lateral continuity with consistent grade vs. Internal zonation, thickness variation with pockets of high grade
- Classification requires statistically defendable domains, demonstrable continuity and defendable geometry
- Authier pegmatite in Canada required close drill spacing of 35 x 35 m before applying measured classification
- Sonora lithium clay deposit in Mexico required less onerous drilling of 200 x 200 m before applying measured classification



# Summary



- Lithium is a relatively abundant but rare in economic concentrations
- Solid minerals –two deposit types
  - Pegmatite deposits
  - Clay deposits
- Large number of lithium minerals (>150) but only 9 dominate the commercial deposits
- Pegmatite deposits- complex geometry challenge for resource estimation
- Clay deposits- low grade, challenge for analysis and also resource estimation

**As lithium demand grows need to develop better understanding of the variation in these deposits to improve confidence in resource estimation and better understanding of occurrence to improve exploration success**

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