

TRACKING LITHIUM DEPOSITS WITH A REMOTE SENSING-BASED FRAMEWORK

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ENERGY TRANSITION

- Global energy sector's shift from fossil fuel-based systems to renewable energy sources like **wind** and **solar**
- Aim to reduce energy-related **greenhouse gas (GHG)** emissions through various forms of decarbonization → **Net-Zero**
- Increase in importance as investors prioritize **environmental, social and governance (ESG)** factors

MINERAL AND METAL NEED

- COP21 Paris agreement – **below 2°** by 2050
- **3bn tonnes** minerals/metals required
- Demand for battery metals
e.g. lithium: **500% rise** by 2050

Minerals FOR CLIMATE ACTION



LITHIUM

- Lithium is sourced from:

1. Hard-rock pegmatites
2. **Continental brines**
3. Hydrothermally altered clays

- The first three producers lie within the South American **Lithium Triangle**

1. Bolivia – 21 million tonnes resources
2. Argentina – 19.3 Mt
3. Chile – 9.6 Mt



1 Tanco, Canada	23 Salar de Pedernales, Chile	45 Zinnwald (and 4 others), Germany	67 Nuristan area, Afghanistan
2 Separation Rapids, Canada	24 Salar de Maricunga, Chile	46 Cinovec, Czech Republic	68 Zhabuye Salt Lake, China
3 James Bay, Canada	25 Salar de Olaroz, Argentina	47 Wolfsberg, Austria	69 Dangxiongcuo, China
4 Rose, Canada	26 Salar de Cauchari (2 projects), Argentina	48 Jadarr, Serbia	70 West Taiji Nai'er, China
5 Whabouchi, Canada	27 Salar del Rincón (3 projects), Argentina	49 Polokhovskoe (and 2 others), Ukraine	71 East Taiji Nai'er, China
6 Val-d'Or, Canada	28 Salar de Pozuelos, Argentina	50 Mina do Barroso (and 3 others), Portugal	72 Qinghai Salt Lake, China
7 McDermitt, USA	29 Salar de Pastos Grandes, Argentina	51 Aljô, Portugal	73 Sichuan Aba, China
8 Kings Valley, USA	30 Salar de Ratonos, Argentina	52 Valdefloréz/San José, Spain	74 Maerkang, China
9 Silver Peak, USA	31 Salar de Diablillos, Argentina	53 Alberta I, Spain	75 Jiakka, China
10 Bonnie Claire, USA	32 Salar del Hombre Muerto (3 projects), Argentina	54 Bougouni, Mali	76 Ningdu, China
11 Boron, USA	33 Mibra, Brazil	55 Goulimina, Mali	77 Finnis, Australia
12 Salton Sea, USA	34 Mina da Cachoeira, Brazil	56 Ewoyaa, Ghana	78 Pilgangoora, Australia
13 Clayton North, USA	35 Jequitinhonha, Brazil	57 Kenticha, Ethiopia	79 Wodgina, Australia
14 Magnolia, USA	36 Volta Grande, Brazil	58 Manono-Kitotolo, Democratic Republic of Congo	80 Kathleen Valley, Australia
15 Kings Mountain, USA	37 Länntä (and 5 others), Finland	59 Uis, Namibia	81 Mount Holland, Australia
16 Sonora, Mexico	38 Glenbuchat, United Kingdom	60 Karibib, Namibia	82 Greenbushes, Australia
17 Falchani, Peru	39 Aclare, Ireland	61 Orange River Area, South Africa	83 Mount Cattlin, Australia
18 Salar de Coipasa, Bolivia	40 United Downs, United Kingdom	62 Kamativi, Zimbabwe	84 Mount Marion, Australia
19 Salar de Uyuni, Bolivia	41 St Austell, United Kingdom	63 Zulu, Zimbabwe	85 Bald Hill, Australia
20 Salar de Pastos Grandes, Bolivia	42 Chédeville (and 4 others), France	64 Bikita, Zimbabwe	86 Buldana, Australia
21 Salar de Atacama (2 operators), Chile	43 Rittershoffen, France	65 Arcadia, Zimbabwe	87 Narraburra, Australia
22 Salar de Aguilera, Chile	44 Upper Rhine Valley, Germany	66 Parun area, Afghanistan	88 Ohaaki, New Zealand

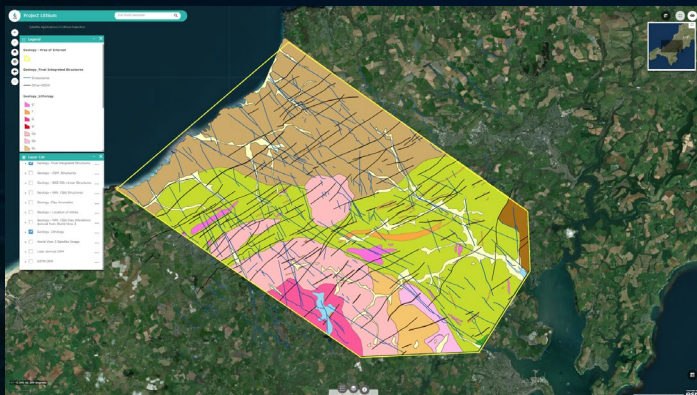
LITHIUM BRINES – CORNWALL AND THE LITHIUM TRIANGLE



- Recognised in 1864 within **warm brines** (51°C; 680 l/min) entering mines
- Derived from biotite **alteration** and **leaching** of granite
- Fluid flow influenced by **NW-SE fault** zones
- Can remote sensing map geothermal brines associated with lithium?
- What are the environmental constraints?

- Found in basins of **salt lakes**
- Water (rich in lithium) **flow** to the salars and then **evaporated**, concentrating the minerals
- Over long time periods (~Ma), high-density Li brines collect in a **nucleus**
- Can remote sensing be used to create a consistent and seamless methodology for tracking lithium mass?

CORNWALL – ALL ABOUT REMOTE SENSING PROXIES



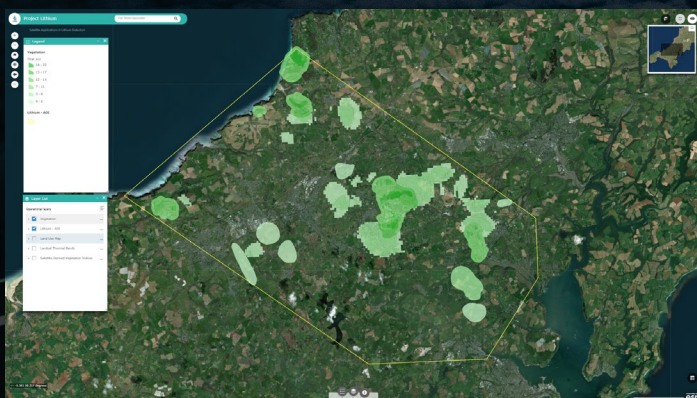
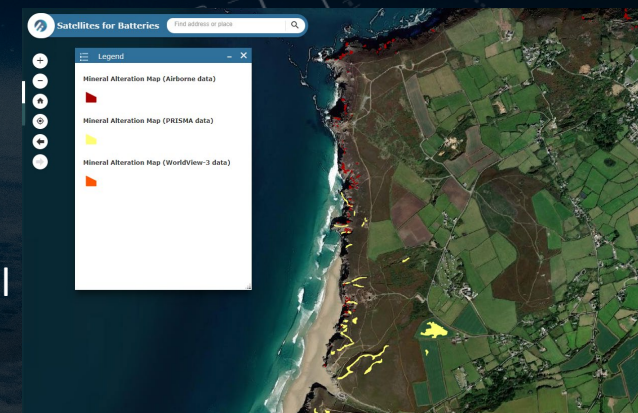
Faults

- Digitalisation existing maps
- Lineament mapping (SRTM, S2)
- OBIA (magnetic, radiometric)
- Experimental DL (SRTM, S2)

Mineral alterations

Clay-minerals & reference

- Hi-res WV3-SWIR
- ASTER
- PRISMA
- Airborne hyperspectral

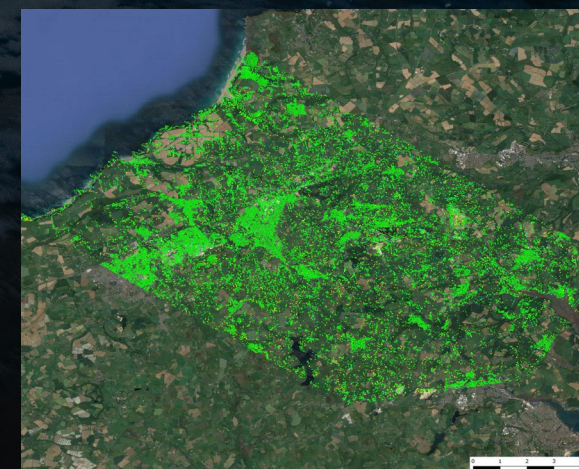


Vegetation anomalies

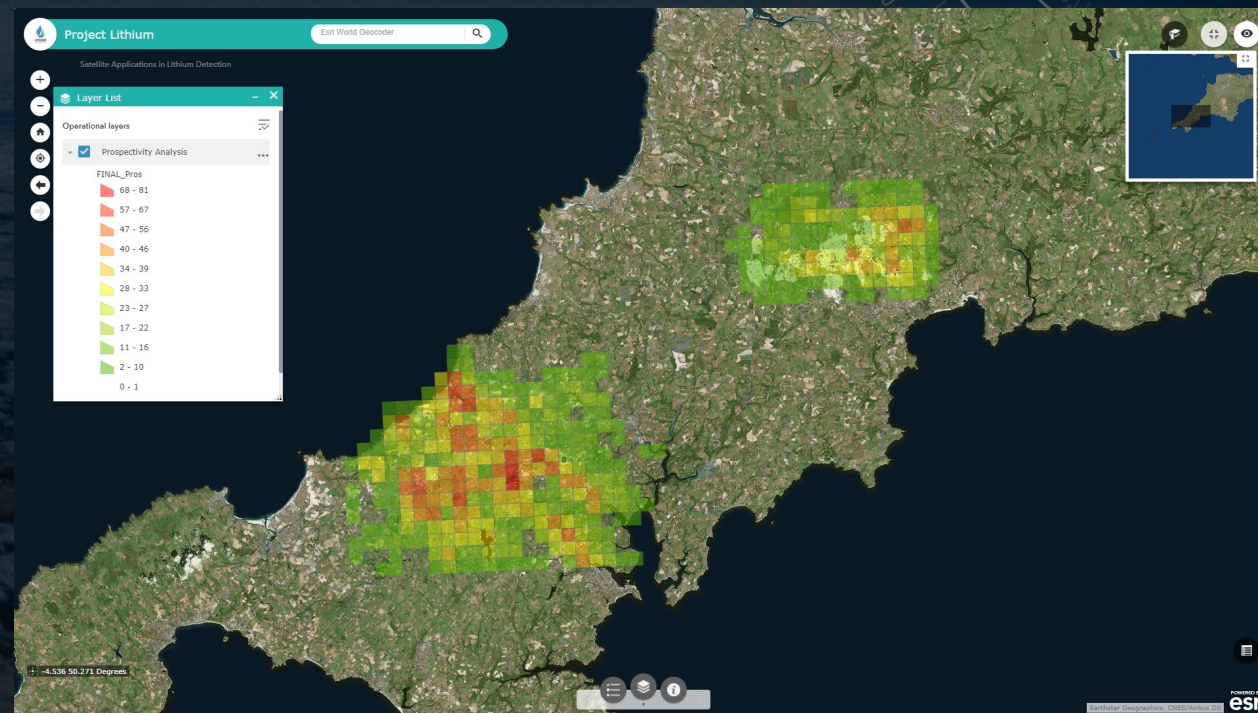
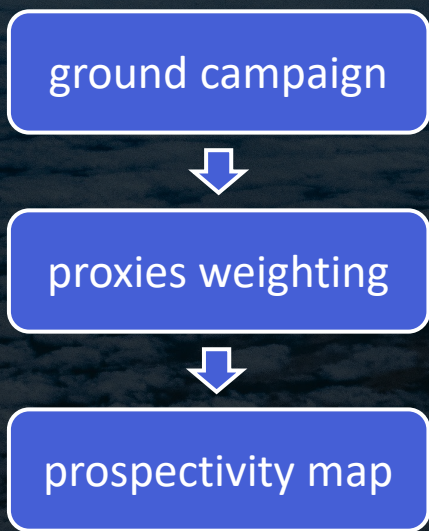
- Hi-res land cover classification (WV3)
- Land surface temperatures (L8)
- Vegetation indices (S2)

Surface displacements

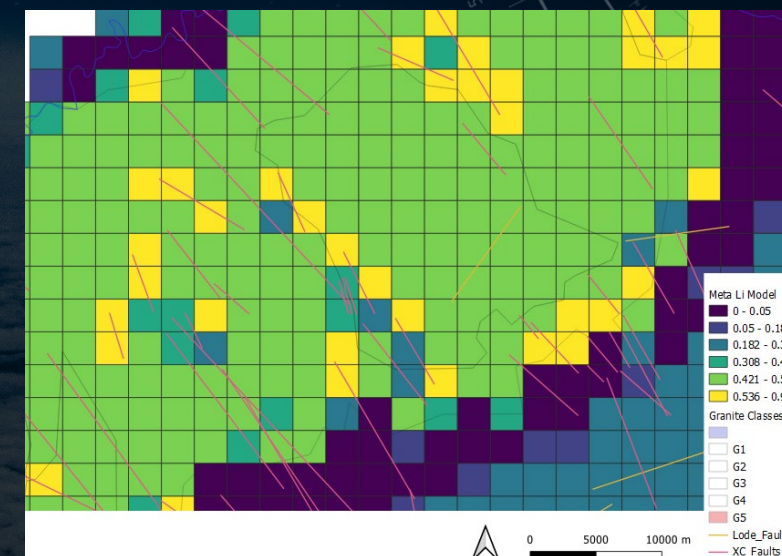
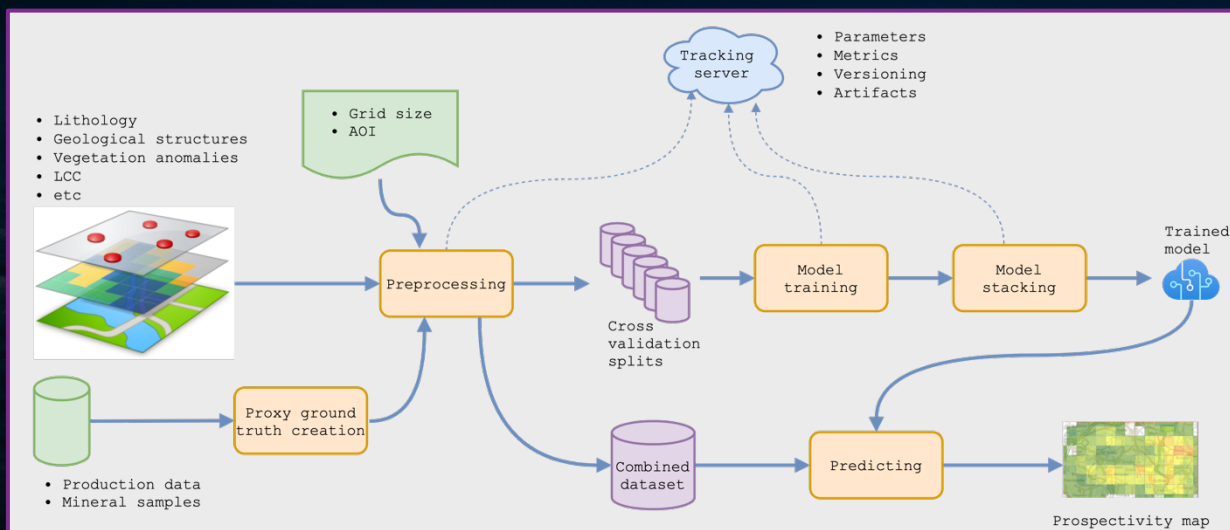
- C-band (S1)
- L-band (Palsar)



CORNWALL – EXPERT KNOWLEDGE (PHASE I)



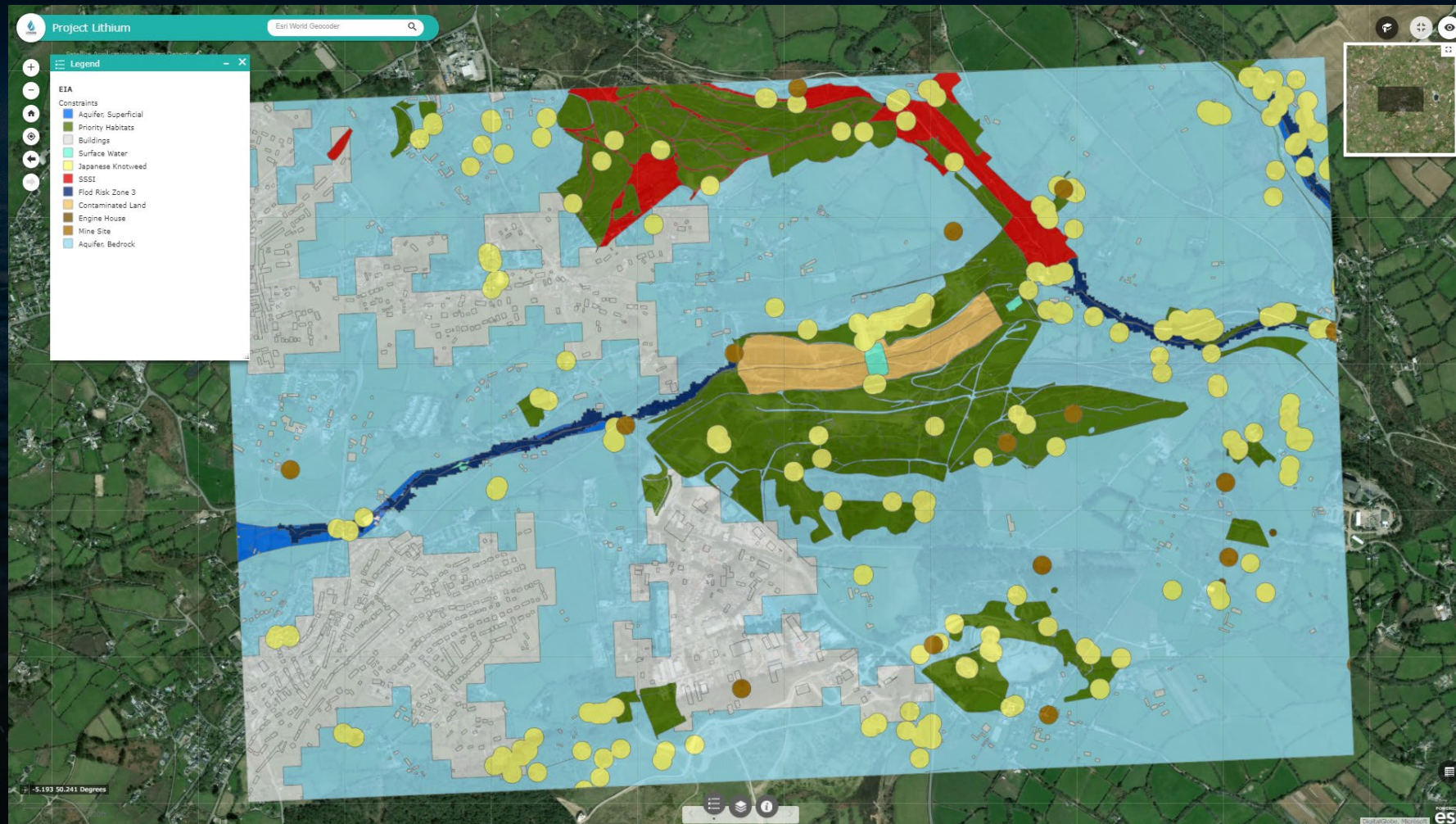
CORNWALL – MACHINE LEARNING (PHASE II)



- **Machine learning framework** to derive prospectivity – value of **AI4EO**
- Sparse ground truth – Li samples and historical mining data
- Shallow ML (*model ensembles*: aggregate predictions) to avoid overfitting

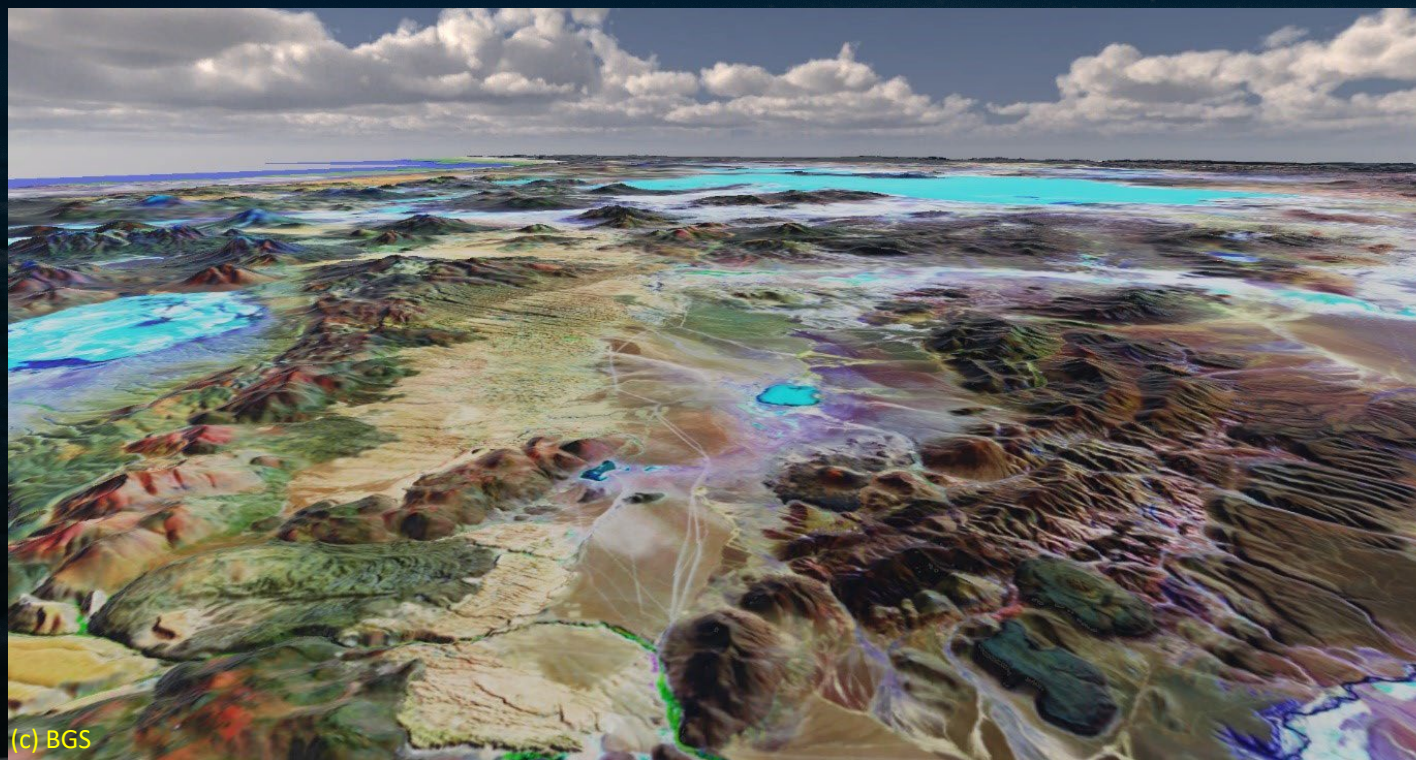
- Li resides in minerals known as **micas** - the more enriched micas are associated with granites of type G5
- Li identified in locations where G5 is known to outcrop and the model has recognised **inter-granite boundaries**
- Li mineralisation looks to coincide with **cross-course faulting**

CORNWALL – ENVIRONMENTAL CONSTRAINTS



- Land Cover
- Land Use
- Risk Maps
- Local Surveys

BOLIVIA – OVERALL FRAMEWORK

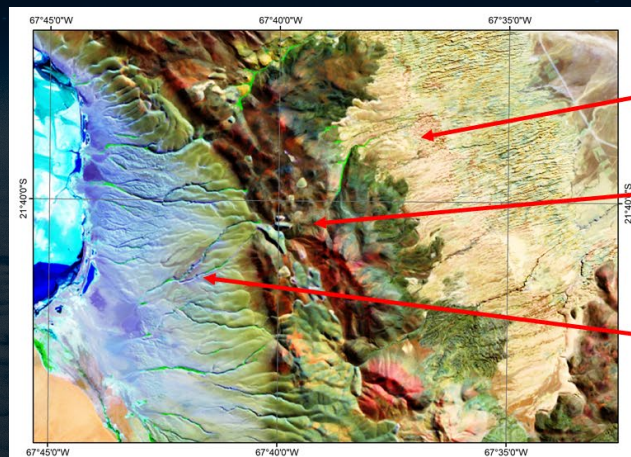


Virtual fieldwork with Geovisionary Software

- Evidence-based model and more general **hydrogeological framework** that employs **openly available satellite remotely sensed data** to describe the source of lithium and its movement in the environment
- Provide “fit for purpose” systems of **reporting** for Li brine resources

BOLIVIA – GEOLOGY

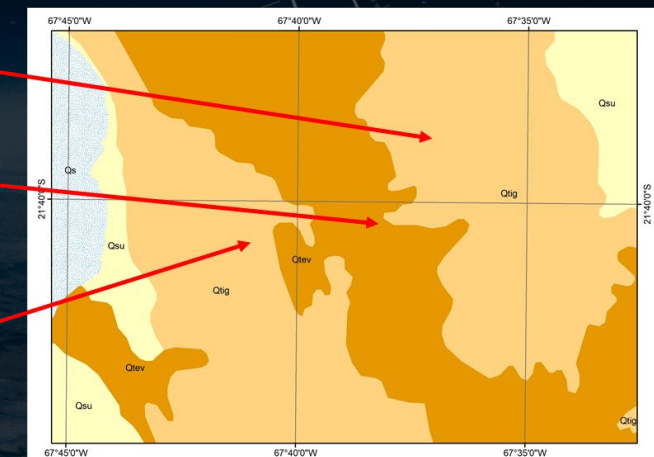
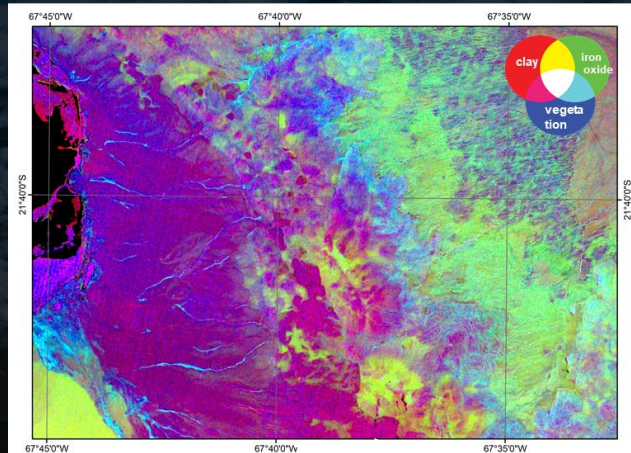
- Sources of lithium are the **recent volcanic rocks** and **derived unconsolidated sediments**
- **First stage:** derivation of the **3D geological model**
- Integration and interpretation of **optical remote sensing data** and **products** (e.g. ratios) with complementary input datasets



ignimbrites under the lavas

lavas

ignimbrites on top of the lavas: therefore not the same geological unit



Geology 1:250 000

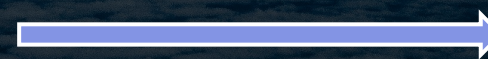
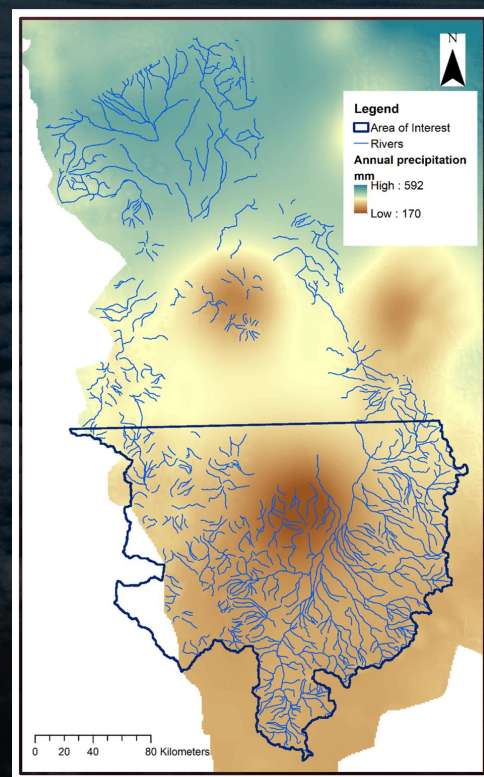
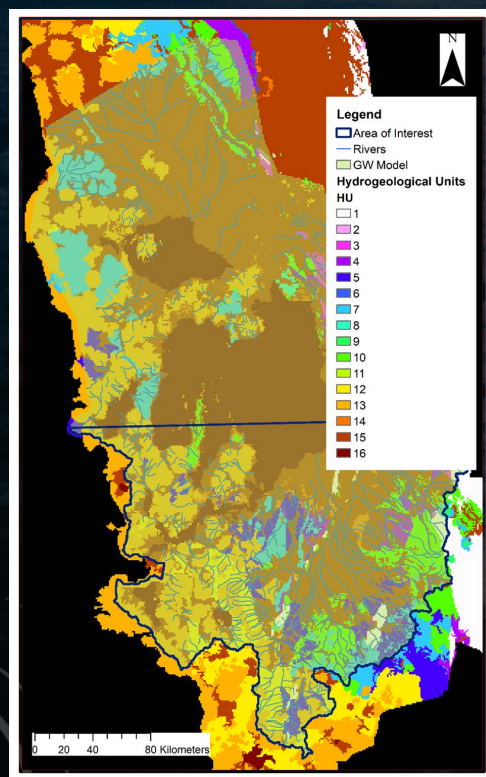
Qs	Salt deposits (Holocene and Pleistocene)
Ql	Lacustrine deposits (Holocene and Pleistocene)
Qtev	Stratovolcano deposits (Holocene to Miocene)
Qtig	Ignimbrite (Pleistocene to Miocene)

- **Output: enhanced geological map** → **Second stage:** translation into an **hydrogeological attribution map**

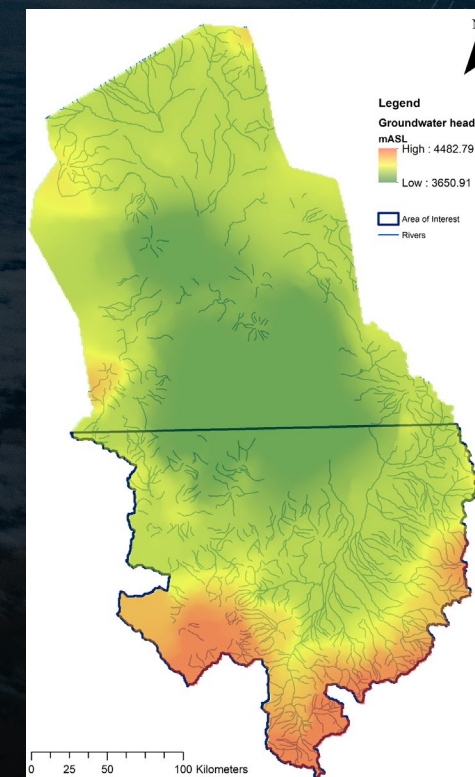
BOLIVIA – HYDROLOGY

- Quantification of the **amount of lithium reaching the salar** and **how long it takes to accumulate**
 → Third stage: **groundwater flow** and **particle tracking model** of the Uyuni watershed

- DEM
- River Network
- Land Cover Classification
- Soil Map
- Evaporation
- Rainfall

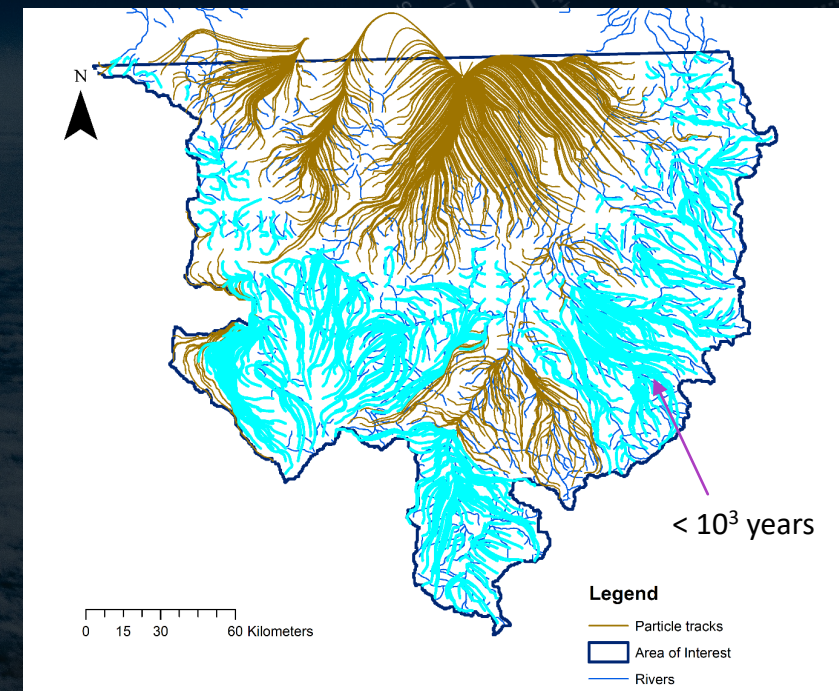
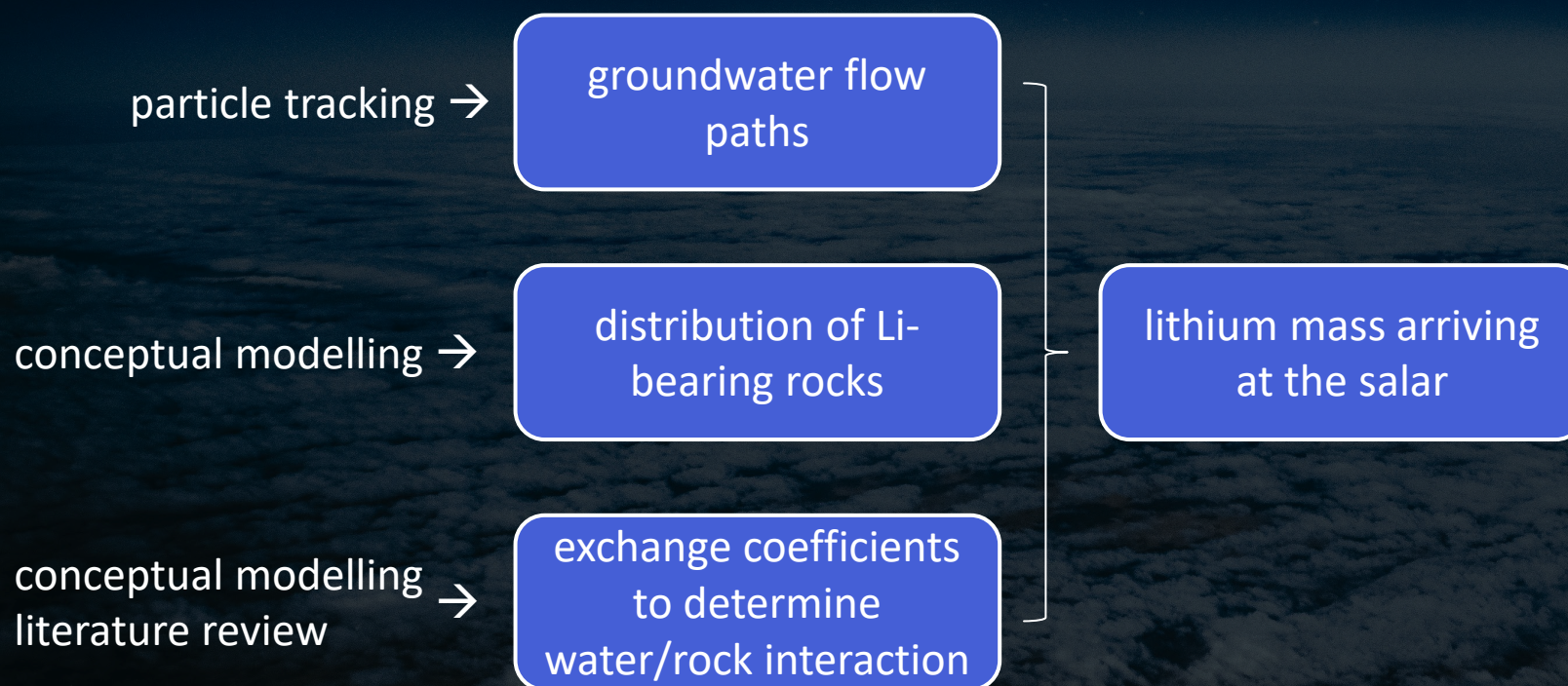


- Salars in the system act as **low points** attracting groundwater outflow



MODFLOW output

BOLIVIA – MASS BALANCE



➔ In the time of travel (**~10⁴ years**) sufficient lithium can be leached from the rock mass to provide the likely lithium concentrations in groundwaters of the order of **10 mg/L**

CONCLUSIONS

- Remote sensing is a powerful technology to support and complement existing frameworks linked to
 - Lithium-brine exploration
 - Intersection with **data science** and/or **geology**
 - Lithium-brine genesis
 - Intersection with **hydrology** and **geology**
- Pilot-plant testing currently ongoing in Cornwall to extract lithium from micas – Cornish Lithium
- Pilot-plant testing currently ongoing in Bolivia to extract lithium sustainably (Direct Lithium Extraction) – YLB

thank you for your attention!

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