Orléans University SEG-Student Chapter field trip report
Sn-W-Cu deposits related to Variscan granitoïds
- Cornwall (South-west England) -

Stronger of our previous experiences (the French Massif Central rare metal granites and pegmatites, 2015: the Carlin Trend province, 2016), members of the SEG-Student Chapter of the University of Orléans decided to focus, this year, on the Western Europe mining potential and especially on tin and tungsten (Sn-W) ore-deposits occurring in close relationship with Variscan granitoïds. This thematic was chosen for many reasons: (i) high-tech metals such as tin and tungsten is of growing strategic interest for EU, (ii) nature, origin and distribution of these deposits are still a matter of debate, (iii) the question of mine reopening arises in EU, especially in France where it's a burning topic.

At first, two successive fieldtrips were planned to illustrate our thematic; unfortunately for schedule reasons we had to choose between the two. Because of very good relationship with the SEG Student Chapter of the Camborne School of Mines (Exeter University), we decided to mainly focus our project on Cornwall.

The main scientific point of the fieldtrip in Cornwall was to have an overall view of Sn-W-Cu ore deposits occurring in the external part the Variscan belt in close relationship with the Cornubian batholith. A particular attention was also paid to the relationships between magmatic-hydrothermal transition, mineralization and deformation.

This was also a great opportunity to create relationships and develop future collaborations with the Camborne School of Mines experimented Student Chapter and Researchers of the Exeter University. By the way, without the invaluable help of the Student Chapter members Robert PELL and Christopher YEOMANS, the Academic advisor, Jens ANDERSEN, the researchers Robin SHAIL and Sam HUGHES, this project would not have been possible. All of them accompanied us both during the organization and on the field.

THE DAY OF TALKS

The first day in Cornwall was dedicated to scientific presentations at the Camborne School of Mines. This day was a success with 12 presentations including 5 presentations from the Orléans SEG-Student Chapter members. The program of the day was as follows:

- Dr. Robin SHAIL (Senior lecturer in Geology at the Camborne School of Mines) Overview of the tectonics, geology and resources of SW England.

- Christopher YEOMANS (Camborne School of Mines)
  Lineament detection from Airborne Geophysics: implications for geological structures and mineralization of SW England.

- Carlo ROBIATI (Camborne School of Mines)
  Application of UAV technology in geosciences.

- Zineb NABYL (Orléans University)
  Experimental characterization of alkaline magmatism rare metals enrichment.

- Eloïse BESSIERE (Orléans University)
  Geodynamical evolution of the Beltic-Rif Cordillera: some major events still in debate.

- Morgane RONDET (Orléans University)
  Behaviour of halogens (Cl,F) in silicate melts: experimental approach and thermodynamic modeling. Application to magma degassing.

- Alison COX (Camborne School of Mines)
  Insight into heap bioleaching at the agglomerate-scale.

- Laurens TIJSSELING (Camborne School of Mines)
  Geometallurgy of Carrollite: linking characterization to comminution.

- Luke PALMER (Camborne School of Mines)
  Spatial estimation and simulation of geometallurgical variables for enhanced process control.

- Florent CHEVAL-GARABEDIAN (Orléans University)
  Mineralogical characterization of the Au and Sb bearing veins in the Pierre Montlimart district (Variscan Armorican Massif, France).

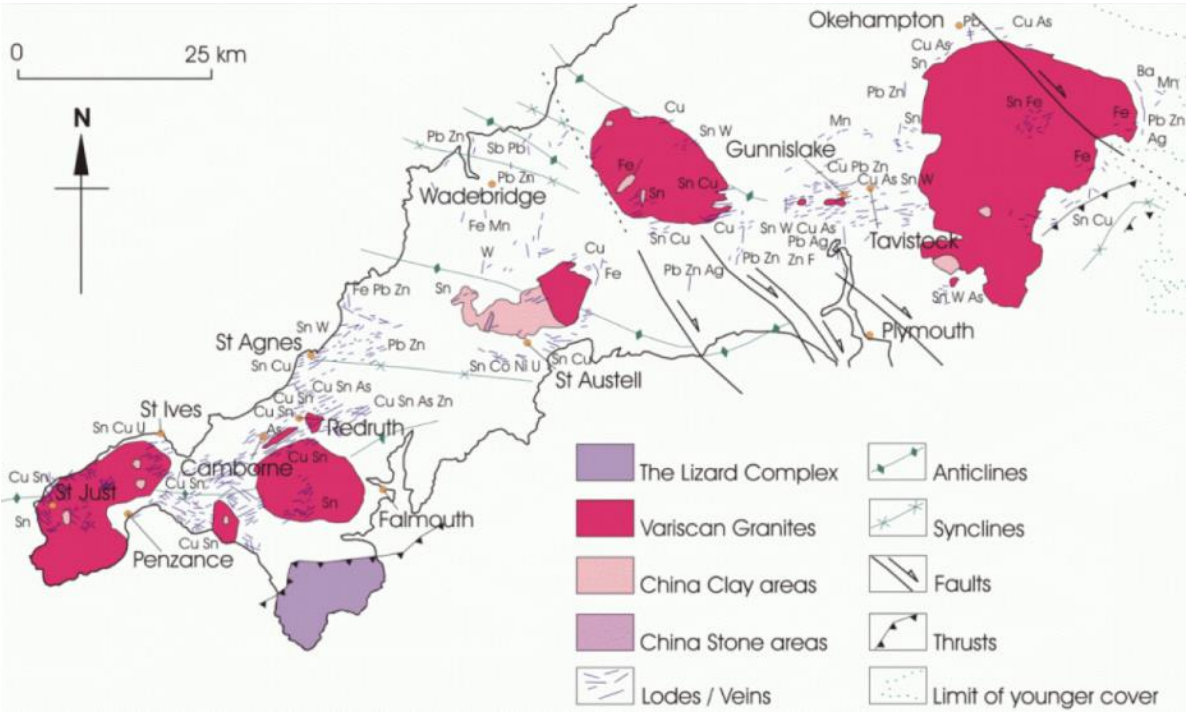
- Julie MICHAUD (Orléans University)
  From rare metal granite to Sn-W-Li-Nb-Ta mineralizations: results on Argemela (Central Portugal).

- Robert PELL (Camborne School of Mines)
  Rare earth elements, technology metal criticality and quantifying environmental performance.

Day of talks at Camborne School of Mines - Falmouth

The Academic advisor Jens ANDERSEN and students from Plymouth were also attending the presentations. At the end of the presentations, the Student Chapter members offered us a really nice appetizer with local products. This day was very rewarding and gave a good overview of our respective research thematics. The rest of the trip was dedicated to field work.

FIELDTRIP: THE CORNUBIAN BATHOLITH AND RELATED SN-W-CU DEPOSITS



Map of Cornwall (after Dunham et al., 1978) and location of the targeted mining districts.

Cornwall was taken into consideration for our fieldtrip because it fit very well our thematic. Indeed, it corresponds to the external part of the Western Europe Variscan belt and it is the most intensely mineralized belt in the British Isles which has been exploited for over 3000 years *(Penhallurick, 1986)*. Almost 3 MT of tin and 2 MT of copper were produced from this region from many types of deposits and most of the early tin was exploited from placers and exposed lodes. After a long period of closure, over 2500 mines were reopened during the 19th century. Copper and tin were the main mining products but a large amount of other metals and minerals were also produced. In 1866, metals prices declined quickly with the discovery of new deposits over the world leading to the closure of many Cornish mines. After this period and especially during World War I and World War II, Cornwall mining experienced highs and lows leading in 1998 to an end of some 3000 years of mining history. Nowadays, prospection is relaunched with the willing of Europe to reopen the mines.

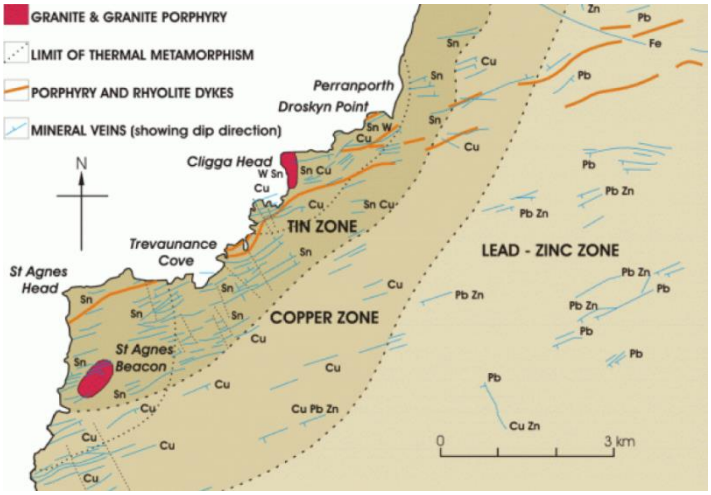
Apart from the mining history, the Cornubian batholith is exposed over a distance of about 200km in seven large plutons that are hosted by Devonian and Carboniferous sedimentary and igneous rocks *(Pownall et al. 2013)*. Most of the outcropping intrusions belong to S-type granite defined by *Chappell and White (1974)* indicating a crustal origin. S-type intrusions, that are thought to be the source of metals such as tin and tungsten, correspond to biotite and two-

micas granites but also lithium micas, tourmaline and topaz-fluorite granites showing enrichment in B, F, Li an P_2O_5.

In this formerly prosperous mining region, mineralizations occur in a variety of forms and can be divided into several mineralizing events, chronologically according to *Le Boutillier (2002)*: (i) pre-granite orebodies of sedimentary/sedimentary-exhalative type; (ii) syn-granite intrusion orebodies (skarns and pegmatites); (iii) early post-granite intrusion orebodies including greisens and sheeted veins complexes; (iv) main stage polymetallic orebodies with Sn-Cu-As-Zn-Pb lodes; (v) late post-granite mineralized Zn-Pb-Ag-Co fissure veins. Sn-W-As-Cu mineralizations, that interest us, occur mainly in high-angle fissure veins (lodes) in close spatial relationship with S-type granites *(Farmer, 1991)*.

In order to better apprehend the mechanisms of formation of the various type of ore deposits, we selected several districts presenting different interest.

DAY 1: ST AGNES MINING DISTRICT



Bromley and Holl, 1986

Leaded by Jens ANDERSEN, the first day on the field was dedicated to the St-Agnes mining district where the cliffs were mined for hundreds of years. This district includes many ancient mines along the coast. Orebodies were emplaced between the underlying St Agnes-Beacon granite and the metamorphosed country rocks. We begin with an introduction along the coast where we had a look on well-preserved ancient mining pumping engine houses and chimneys. This was followed by the visit of ancient exploration galleries in Chapel Porth and the W-E trending lodes in Trevaunance Cove.

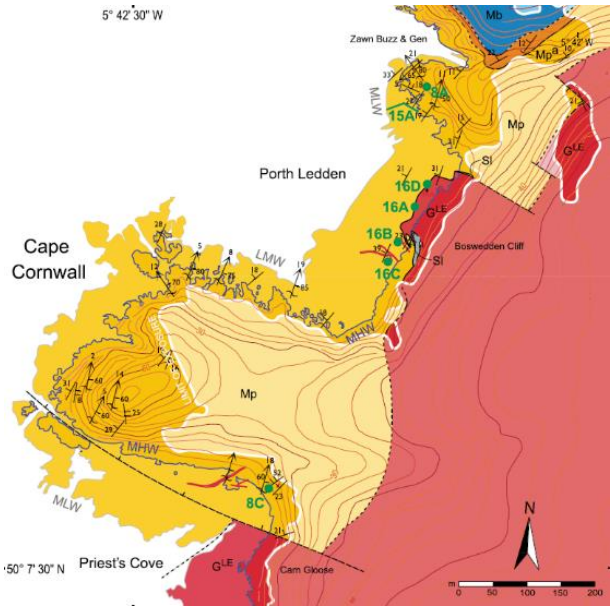
We finished our tour in his area around the Cligga Head granite, located between Perranporth and St Agnes. The small granitic stock, emplaced in the metasedimentary rocks during the Devonian period, is cut by a regular NE-trending greisen-bordered sheeted veins system. Such a regular system suggest a stable structural environment during the emplacement. These veins consist mainly of quartz with little tourmaline and can extend into the metasediments where tourmalinization is the main type of alteration. It is also common to find

wolframite, cassiterite, arsenopyrite, chalcopyrite and other sulphides. The origin of such veins has been strongly controversial and are generally considered as the expression of the magmatic-hydrothermal transition at the end of the granite crystallization. Nevertheless, greisen formation along the veins suggest a disequilibrium between the mineralizing fluid and the intrusion generally indicating a mixed origin of the fluids.

At the end of the day, we visited Roche Rock, which correspond to a tourmalinized granite outcrop in the middle of the China Clay district surmounted by an 15th century chapel. The origin of this tourmalinization is still a matter of debate with a central question on the origin of the fluids inducing this alteration.

First day on the field leaded by Jens ANDERSEN

DAY 2: ST JUST MINING DISTRICT



Pownall et al., 2013

Even if the weather was very bad, we still managed to go on the field. Thus, the second day of field work, leaded Sam HUGHES, began with the highly mineralized area of Cape Cornwall, at about 1.5km from St Just, and the surrounding bay of Porth Ledden. In the Porth Ledden bay, we had the occasion to see the well exposed contact between the roof of the Land's End biotite granite and the hornfels, and several granitic to aplitic dykes. The Land's End granite is coarse-grained and characterized by pluricentimetric zoned feldspar. It pass to a quartz-tourmaline rock (schorl) on the northern part of the bay, similar to the one at Roche Rock, that is interpreted by *Müller et al. (2006)* as being

Second day on the field leaded by Sam HUGHES

emplaced as a succession of sheets subparallel to the roof. After this really interesting morning we went back to the cars and by the way had a look on ancient mining buildings.

On the afternoon, as the weather was not improving, we decided to visit the Geevor mine museum. The Geevor mine was the last mine to work in Penwith closing in 1991. 50 000T of tin were extracted from the lodes. These steeply dipping structure have a complex banded appearance with infills ranging from high-temperature tourmaline-quartz-cassiterite to lower temperature chlorite-quartz-cassiterite and quartz-haematite-cassiterite according to *Le Boutillier (2002)*. Outside the geological aspects, the museum is a very interesting place to have an overview of exploitation methods and the largest preserved mine site of Great Britain. The museum told us about the long history of mining in Cornwall, how the ore was brought to the surface from undergrounds and processed in the mill to produce concentrate.

Finally, we took the time at the end of the day to walk toward the Botallack crown engine houses which represent a typical Cornish post-mining landscape.

DAY 3: BREAGE DISTRICT

During the third day of field work, which was leaded by Robin SHAIL and Jens ANDERSEN, we were very lucky with the weather and we drove toward Porthleven and the Tregonning granite. This day gave us the opportunity to have a great overlook of the deformation stages encountered in Cornwall through a visit of Megiliggar Rocks. The first deformation stage (D1) correspond to Variscan convergence associated with NNW-SSE shortening and characterized by isoclinal folds (difficult to observe) parallel to S1 cleavage. The D2 event is also associated to convergence and correspond to NNW-verging folding with the development of an axial plane S2 cleavage. Finally, the D3 event is categorized by NNW-SSE extension and correspond to SSE-verging folds and the development of a S3 axial planar cleavage at time associated with low-angle detachments. A late D3 can occur as a brittle event and as brittle normal faults.

The second part of the day was dedicated to Rinsey Cove and the Tregonning topaz granite. The Tregonning topaz granite is one of the most differentiated granite that occur in Cornwall. It is characterized by an equigranular texture with pegmatitic pockets in some places. We also observed unidirectional growth texture (more or less pegmatitic) normal the contact with the surrounding rocks and bedded aplites. Aplites and pegmatites are common in differenciated granites.

In this area, it was possible to observe the relationships between tectonics and granite. Indeed, granite and syn-granite intrusion bodies (pegmatite) are not affected by D3 event which means that D3 event predate granite emplacement. Emplacement of intrusions could be related to the latest extensional reactivation of Variscan thrusts *(Shail and Wilkinson, 1994)*. Also, we had proof, in this area and before, that tin-tungsten-bearing lodes are related to the D3 event. The Tregonning granite is also intersected by late Permian veins.

That very nice day was concluded by a discussion in front of the St Michael Mount.

Third day on the field leaded by Robin SHAIL

DAY 4: LAND'S END GRANITE

Fourth day on the field leaded by Sam HUGHES and Robin SHAIL

Day 4 was dedicated to the Land's End biotite granite and the famous tourmaline rocks of Cornwall. The walk, leaded by Robin SHAIL and Sam HUGHES, began between the cities of Morvah and Treen, and end in Porthmeor Cove. During the first stop we had the occasion to have a look on the coarse-grained texture with large feldspar megacrysts and the mineralogical assemblage of the granite. Feldspar megacrysts appeared to be strongly zoned indicating a disequilibrium with the granite groundmass (confirmed by trace elements). This zonation can be interpreted as the result of several batches of magma. When walking down to the bay, we had seen the contact between the coarse-grained facies and a second facies containing less megacrysts in a finer matrix. The following stop was another very good illustration of D3 folds intersected by the intrusion. Then all along the walk to Porthmeor Cove, we discovered the numerous tourmaline-bearing veins going from an echelon veins to massive tourmalinite pockets. We distinguished three types of veins: (i) Quartz-tourmaline veins with well crystallized tourmaline that appear to be more primary (more "magmatic"); (ii) massive to brecciated Tourmalinite which appears to be more hydrothermal; (iii) a generation of small tourmaline-bearing veins intersecting the previous ones. Then we reached Porthmeor Cove that is famous for its really well exposed granitic cupolas. It is, in fact, really rare to have such an occasion to have a look on these cupola systems generally hidden at depth. The contact between the cupolas and the surrounding rocks is in some places controlled by D3 brittle faults and the roof of the cupola is marked by a pegmatitic unit. At least three generations of differentiated dykes are observable in the area: (i) aplitic dykes; (ii) granitic dykes intersecting the aplitic dykes and inducing an offset; (iii) tourmaline-bearing dykes intersecting the two previous generations.

At the end of the day, we had the chance to visit Rosevale Mine with Tony from the Rosevale Historical Mining Society. It is a unique privately-run restoration project which aims to preserve industrial heritage of Cornwall restoring undergrounds as they were when the mine was working. So we had the occasion to see the orebody but overall to have a look on ancient underground working feeling like in 1910's. What emerges for it, is that it was a really hard work only illuminated with candles. We experienced the seven tiny ladders to go up and it was really something.

DAY 5: WHEAL MAID - CAMBORNE-REDRUTH DISTRICT

Our last field work day, accompanied by Jens ANDERSEN, was dedicated to Wheal Maid ancient mining area. The mine dates from about 1790 and was briefly reworked in the mid 80's. Only a small amount of ore was extracted with 230 T of tin. The point of this morning

was to talk about mining consequences, which can be really bad in some places. In the Wheal Maid area, many attempts has been made to contain the tailings like using waterproof materials, clay to absorb residual metals, keeping a reducing environment with water, using vegetation… but none of these trials really worked. The area is still full of arsenic, iron hydroxides, cadmium and sulphides; the pH of the water is 2.

After this really enriching morning on what should no longer be done, we had, unfortunately, to drive back to London to take our plane.

Last day on the field leaded by Jens ANDERSEN at Wheal Maid

CONCLUSIONS OF OUR CORNISH EXPERIENCE - PARTNERSHIP

All along this week we discovered a really nice country with very interesting geology. We reached our scientific objective of having a global view of tin and tungsten mineralizations related to S-type granites occurring in a special geodynamical context. We also had the occasion to apprehend the operating chain of mining from actual exploration in Cornwall to post mining operations. But overall, we had the great chance to meet and share with: the Student Chapter members especially Robert PELL and Christopher YEOMANS who accompanied us all along the trip; Jens ANDERSEN, Robin SHAIL and Sam HUGHES who take on their time also to share their knowledge of Cornwall with us. Finally, SEG-Student Chapters associations, in general, is a really nice organization allowing unique meetings like these.

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