# Topographic control on copper porphyry deposits: landscape modelling and predictive potential

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**Project Highlights:**

- Constrain landscape evolution across active parts of the Andes using data and numerical models
- Comparison with pressure-time paths from modern productive porphyry Cu deposits
- Establishment of geomorphic indices and protocols to predict potential porphyry Cu deposits

**Overview:**

The formation of porphyry copper deposits (PCDs) is associated with changes in stress, which drive metal-rich fluids to exsolve from cooling magmas in the upper crust. These stress changes are typically linked to tectonic processes and evolving tectonic regimes, e.g. post-orogenic relaxation of compressional stress. However, surface erosion also has the potential to change the stress field at depths down to a few kilometres, with important implications for the occurrence of deposits. For example, rapid changes in surface erosion might be driven by abrupt changes in climate [1] or through drainage piracy, when small rivers steal upstream drainage areas from larger catchments, thereby increasing overall discharge [2].

Drainage piracy can produce kilometre-deep valleys in less than a million years, causing rapid unloading of the crustal overburden and potentially triggering the exsolution of metal-rich fluids in the upper crust. Along the length of the Andes in South America, numerous flat surfaces are found at high elevations dissected by deep canyons, indicating drainage capture and piracy. In these locations, flat internally-drained catchments were captured by steep mountainous externally-drained catchments and the resulting unloading of the crust and release of stress may have driven PCD formation. The formation of this topography will also drive groundwater flow resulting in the interactions of meteoric water with magmatic fluids at depth. Both of these processes have important implications for PCD formation.

Productive PCDs along the Andes are currently at Earth's surface and the overlying topography that would have existed during their formation has been lost to erosion. Crucially, we can estimate what the topography looked like and how much has been eroded using thermochronometry. However, at other locations along the Andes the processes of orogenesis and active erosion are ongoing. For this reason, we will focus on coastal locations across Guatemala and Chile where there are active volcanic processes and efficient fluvial erosion. In this respect we will use these natural laboratories as analogues of past topographic evolution. Predicted pressure-time paths from data-constrained landscape evolution models can be compared to observations from modern deposits, providing a means to predict where shallow deposits may be found.

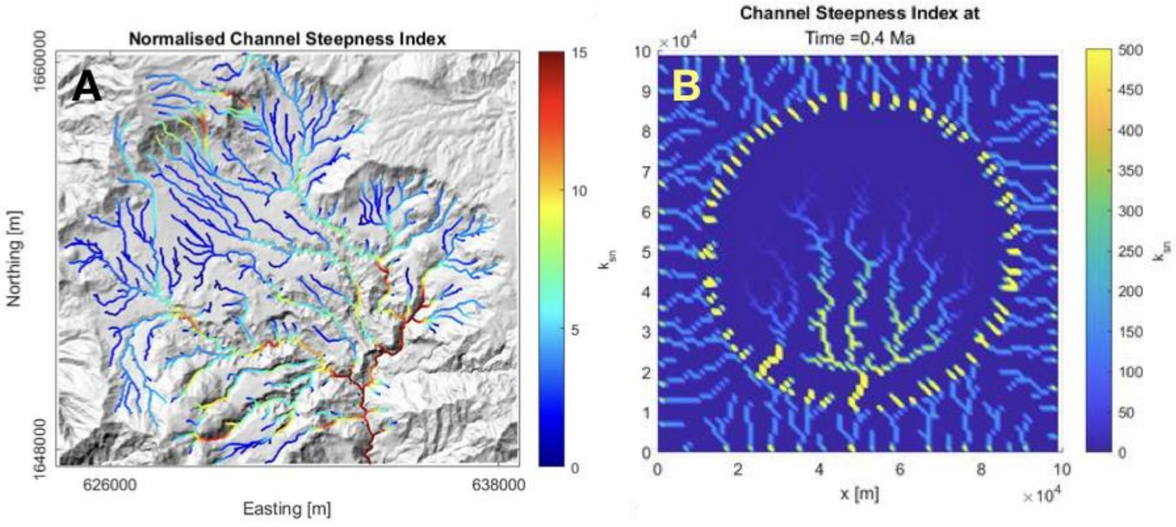


Figure 1. A) Digital elevation model of the San Marcos Caldera in Guatemala. The channel steepness ($K_{sn}$) is proportional to erosion rate but it must be scaled with geochronological constraints. High values are seen close to the edge of the caldera. A large canyon has formed downstream of this location. B) Landscape evolution model of an idealised circular caldera. Rivers show high channel steepness values close to where the caldera rim has been breached by erosion.

**Key research questions:**

This project aims to answer the following key research questions:

1) How quickly can erosional events produce the upper crustal changes in pressure required to trigger the formation of a porphyry copper deposit?

2) How did the landscape evolve above productive porphyry copper deposits?

3) Can landscape evolution modelling predict the locations of porphyry copper deposits?

**Methodology:**

The overlying topography that would have existed during the original formation of the deposits has been lost to erosion. However, we can measure the topographic evolution using thermochronometry, thermobarometry, and landscape evolution. Thermochronometry measures the thermal histories of rocks as they approach Earth's surface and can reveal topographic evolution [3], if carefully accounting for temperature changes due to magmatic processes. This approach can be carried out at the London Geochronology Centre using existing samples close to productive porphyry copper deposits. We have access to a large number of samples though project collaborators Katie McFall and Frances Cooper.

Coastal locations across Guatemala and Ecuador are areas of active volcanism and efficient fluvial erosion. However, the rates of erosion are poorly constrained. The goal of this project is to constrain landscape evolution and predict pressure-time paths associated with landscape evolution, as well as regional tectonic stress changes. Sedimentary terrace deposits will be rich in volcanic deposits which can be readily dated using the $^{40}Ar/^{39}Ar$ dating method. Samples will be collected during fieldwork to student-chosen site localities. Dating will be carried out at the London Geochronology Centre.

The resulting ages will be interpreted with the help of state-of-the art forward and inverse landscape evolution modelling [e.g., 4, 5]. This landscape evolution can be fed directly into new numerical models that calculate stress under evolving topography and tectonics [6]. The resulting pressure-time paths are directly comparable to pressure-time paths inferred from petrological analysis of productive deposits. Running the landscape evolution model forwards in time can also make predictions about how the landscapes evolve into the future. It is this predictive ability that will enable us to use geomorphology to predict where shallow deposits are most likely to be discovered.

**Possible timeline:**

Year 1: Numerical modelling of landscape evolution of selected site localities. In addition, thermochronometric work can be carried out on existing samples.

Year 2: Travel to selected site localities to target key locations revealed from the preliminary modelling. Invert thermochronometric data for landscape evolution above productive deposits. Prepare manuscripts for publication.

Year 3: Finalize landscape evolution models. Use landscape evolution to identify potential deposit localities. Present findings at international conference(s) and prepare thesis.

**Training and skills:**

TARGET researchers will participate in a minimum of 40 days training over the 3.5 years of study composed of:

- an annual one-week workshop dedicated to their year group, and tailored to that cohort's needs in terms of skills development – *for the first three years of their study*;
- an annual all-TARGET workshop with cross-year interactions, advanced training and opportunities to specialise in particular areas – *all years of study*;
- a number of one-day workshops;
- additional online events and in-person workshops attached to relevant conferences.

The student will be trained in thermochronometry lab work and numerical modelling. The lab work requires sample preparation, noble gas mass spectrometry and working in a clean lab. These skills are directly transferrable to wide range of exploration and environmental work. Numerical modelling will be carried out with Matlab, Python and Fortran. These languages are popular and very efficient. The student will learn to use these tools for datamining and numerical simulation. The student will also be trained in how to conduct fieldwork in remote locations. The student will join a 60+ cohort of PhD students in a vibrant department and will have access to UCL's doctoral training, including academic writing, entrepreneurship, teaching, and presentation skills. The student will join the UCL Earth Resources Centre and be encouraged to attend and contribute to group meetings, seminars and networking events.

**Partners and collaboration (including CASE):**

This project is in collaboration with Anglo-America and in particular, Dr. Christian Sellier. The student will benefit from extensive regional expertise, access to samples and sampling locations.

**Possible timeline:**

Year 1-3: Monthly meetings with Alex Whittaker will take place throughout the project. These meetings will be in person and it is straightforward to get between UCL and Imperial.

Meetings between Alex Whittaker, the PhD student and Matthew Fox, Frances Cooper and Katie McFall will proceed throughout the project. These meetings will be held in Imperial and UCL and travelling between these institutions is straightforward. The student will be fully intergrated into life at UCL and will be invited to seminars and student-led events at Imperial, as well.

**Requirements:** Applicants should ideally have an MSci or MSc degree in Earth Sciences, or a related subject, and an interest in geomorphology and natural resources.

**Further reading:**

[1] Cooper, F.J., Adams, B.A., Blundy, J.D., Farley, K.A., McKeon, R.E., Ruggiero, A., 2016, Aridity-induced Miocene canyon incision in the Central Andes. Geology.

[2] Han, X., Dai, J.G., Smith, A.G., Xu, S.Y., Liu, B.R., Wang, C.S. and Fox, M., 2024. Recent uplift of Chomolungma enhanced by river drainage piracy. Nature Geoscience, pp.1-7.

[3] Cuffey, K.M., Tripathy-Lang, A., Fox, M., Stock, G.M. and Shuster, D.L., 2023. Late Cenozoic deepening of Yosemite Valley, USA. GSA Bulletin, 135(5-6), pp.1547-1565.

[4] Fox, M., Carter, A. and Dai, J.G., 2020. How continuous are the “relict” landscapes of southeastern Tibet?. Frontiers in Earth Science, 8, p.587597.

[5] Quye-Sawyer, J., Whittaker, A.C., Roberts, G.G. and Rood, D.H., 2021. Fault throw and regional uplift histories from drainage analysis: evolution of Southern Italy. Tectonics, 40(4), p.e2020TC006076.

[6] Moon, S., Perron, J.T., Martel, S.J., Goodfellow, B.W., Mas Ivars, D., Hall, A., Heyman, J., Munier, R., Näslund, J.O., Simeonov, A. and Stroeven, A.P., 2020. Present-day stress field influences bedrock fracture openness deep into the subsurface. Geophysical Research Letters, 47(23), p.e2020GL090581.