Decoding tectonics and climate effects in incipient mountains: the Sierra Nevada (southern Spain) case study (Ref IAP2-18-39)

University of Glasgow, Geographical and Earth Sciences
In partnership with Durham University

Supervisory Team
- Dr Cristina Persano, Geographical and Earth Sciences, University of Glasgow
- Prof Alexander Densmore, Geography, Durham University
- Dr. Derek Fabel, SUERC, University of Glasgow
- Professor Trevor Hoey, Geographical and Earth Sciences, University of Glasgow

Key Words
1. Mountain building
2. Fluvial geomorphology
3. Burial dating using cosmogenic nuclides
4. Sierra Nevada

Overview

This project aims to constrain the evolving topography of incipient mountain belts and to ultimately understand how mountains grow. Although high mountain belts represent only c.5% of the surface area of the continents, they have been extensively studied as they influence both weather and climate, including present and past atmospheric circulation patterns, sediment budgets, ocean chemistry and climate change (e.g. Whipple, 2009). Constraining how elevation and width of mountains change with time, therefore, is crucial for understanding sediment delivery to the basins and changes in atmospheric circulation. Evidence of the early history of mountain belts is limited, both onshore because of poor preservation of the sediments and offshore where the sedimentary record may be incomplete and/or complicated by other processes, such as onshore temporary storage and sediment reworking.

The Sierra Nevada, in southern Spain, is a ~40x80 km long mountain belt that began to emerge above sea-level about 10 million years ago (Myr). The mountain front, especially on the western side, is defined by active normal faults that have generated river knickpoints that propagate upstream, deeply incising the mountain flank. Upstream of the knickpoints, erosion rates are two orders of magnitude lower than in the steep river valleys, creating stable, gently sloping headwaters and mountain tops (Reinhardt et al., 2007a). It has been suggested that this low-relief morphology represents a relict landscape that is not affected by rapid erosion, because the limited river discharge at high elevations provides insufficient energy for the knickpoints to propagate further (Reinhardt et al., 2007b). An important implication of this hypothesis is that the plateau-like morphology of the headwaters is a direct result of erosion efficiency and, therefore, of climate. The fact that this morphology is common to many non-glaciated mountains in arid environments (e.g. van der Beek et al., 2009) supports this hypothesis, which, however, has never been tested.

This project will test the above hypothesis by constraining the spatial variation of erosion rates as the mountain block of Sierra Nevada evolved through time. Specific questions to be answered are: 1. When did the slow-eroding plateau start to form?; and, 2. What effects have climate changes, such as the increase of aridity at 3.3-3.1 Myr ago (e.g. Jimenez-Moreno et al., 2013), had on the ability of the rivers to erode the mountain tops? The two questions will be answered by analysing the sediments of the Granada basin, which has developed on the hanging wall of the normal faults flanking the western section of the Sierra Nevada, and the deposits of one of the...
alluvial fans that overlies the Granada Basin (Clark and Dempster, 2009). Age of deposition of the sediments and the rates of erosion at the time of deposition will be reconstructed using the burial dating technique, by measuring the concentration of $^{10}$Be and $^{26}$Al cosmogenic isotopes from quartz-rich sediments (e.g. Ciampalini et al., 2015).

**Methodology**

Much of the sediment infill of the Granada basin is accessible on foot; some sections may be too steep and a drone will be used in these exceptional cases. The applied methods will include the following:

**Fieldwork:**
- (a) Sedimentary logging: grain-size; palaeo-currents;
- (b) Sampling for sediment analysis and microfossil biostratigraphy;
- (c) Drone flights to photograph the exposure, including inaccessible regions;
- (d) Sampling for cosmogenic dating.

**Laboratory techniques:**
- (e) SEM imaging of the sediments (equipment available at GU);
- (f) Preparation of targets for cosmogenic nuclide analysis. Measurements will be made at SUERC;

**Data analysis:**
- (g) Image processing and analysis (field images; SEM images);
- (h) Statistical analysis.
- (i) GIS analysis of the present morphometry of Sierra Nevada (focusing on the western sector); equipment, software and 5-m resolution DEM of Sierra Nevada are available at GU

Because the exposure is so extensive in this area, field sampling will be planned following an initial reconnaissance visit during which an overview of the site will be obtained. Initial samples from key parts of the sequence will be used to inform detailed sampling in two subsequent extended periods of fieldwork.

**Timeline**

**Year 1:**
- Training in key field and laboratory skills
- Literature review
- GIS analysis to quantify the landscape of Sierra Nevada
- Reconnaissance field visit and initial sampling (spring)
- Application to the CIAF facility for the cosmogenic isotopes ($^{10}$Be and $^{26}$Al) measurements

**Year 2:**
- Field work (2 x 4 week periods) – logging, drone photography, further sampling for cosmogenic analyses
- Laboratory sample preparation and SEM analysis
- Conference attendance to present poster of initial data

**Year 3:**
- Cosmogenic measurement and analysis
- Statistical analysis of all data
- International conference to present main results
- Final analysis and write-up (extended to 3.5 years as required)

**Training & Skills**

Specific training depends on the prior skills and experience of the student, but will include several of:
- fieldwork safety and first aid
- field survey using drone and dGPS
- field sedimentology (logging; sampling)
- sample preparation for SEM and SEM operation and analysis
- mineral separation for quartz extraction
- target preparation for cosmogenic nuclide dating
- principles of cosmogenic nuclide analysis, including error modelling
- GIS spatial analysis
- use of Matlab, Python and/or R for data analysis and presentation
- training in grant application (CIAF)

**References & Further Reading**

Ciampalini, Persano, Fabel & Firpo 2005 Dating Pleistocene deltaic deposits using in-situ $^{26}$Al and $^{20}$Be cosmogenic isotopes *Quaternary Geochronology*, 28; 71-79

Clark & Dempster 2009 The record of tectonic denudation and erosion in an emerging orogen: an apatite fission-track study of the Sierra Nevada, southern Spain *J. Geol.Soc.*, 166, 87-100.

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Further Information

For further information please contact the supervisory team:

Dr Cristina Persano ([Cristina.Persano@glasgow.ac.uk](mailto:Cristina.Persano@glasgow.ac.uk)) 0141 330 2290

Prof Alex Densmore ([a.l.densmore@durham.ac.uk](mailto:a.l.densmore@durham.ac.uk)) 0191 3341879

Dr Derek Fabel ([derek.fabel@glasgow.ac.uk](mailto:derek.fabel@glasgow.ac.uk)) 01355 223332

Prof Trevor Hoey ([Trevor.Hoey@glasgow.ac.uk](mailto:Trevor.Hoey@glasgow.ac.uk)) 0141 330 7736