Was the Austroalpine overthrust (Switzerland) reactivated as a normal fault?

Jason B. Price, Brian P. Wernicke, Kenneth A. Farley

Division of Geological and Planetary Sciences, California Institute of Technology

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Background

The Swiss Alps have been a crucible for geologic inquiry, particularly with regard to crustal shortening and attendant deformation. Despite the richness of this inquiry, some fundamental questions remain. In particular, ***what was the role of the Austroalpine overthrust during crustal shortening, and was it reactivated during the exhumation of the central Penninic core of the Alps as a normal fault?***

The Austroalpine overthrust is a major structural juxtaposition of rocks having African affinity in the hangingwall with rocks having European affinity in the footwall (Fig.1). It has been described as the "orogenic lid" that was imbricated during an Eoalpine period (latest Cretaceous) and then rode atop Penninic rocks during subsequent continental collision (Schmid et al., 2004). The Austroalpine domain usually occupies a somewhat passive position at the top of the nappe stack in the common "bulldozer" model of Alpine orogeny.

In the past 25 years, several important observations have demonstrated that some of the structural nappe contacts have a normal sense of slip. In particular, the Turba mylonite zone (Nievergelt et al., 1994) on the east side of the central Penninic core and the Simplone fault (Wawrzyniec et al., 2001) on the west side of the central Penninic core exhibit latest motion that is normal. In addition, recent Ar-Ar thermochronometry (Augenstein, 2012) dates normal movement on these faults to 34 Ma and 20-3 Ma, respectively. Such data suggest that the Alps were built primarily by crustal shortening but had important, probably repeat, periods of extension, particularly towards the end of its deformation history.

The Simplone fault occurs low in the structural stack at the Helvetic-Penninic boundary, while the Turba mylonite occurs in the middle of the stack, within Penninic rocks. We are investigating rocks at the top of stack at the Penninic-Austroalpine boundary. The nappes that we have sampled include, from structural bottom to top: Margna-Sella decke (most distal Briançonnais), Corvatsch teildecke, and Bernina decke, the latter two both basal Austroalpine.

Methodology

Over a three week period, we completed two vertical transects covering about 2500 m of structural section in southern Switzerland, near St. Moritz and Zermatt (Fig. 1). Along the transects we collected structural data (presumed S1 foliation strike/dip, mylonite "top" directions) and 104 metamorphic rock samples, many of which were mylonitic L-S tectonites.

Upon returning to the lab, we completed petrography on ~85 oriented thin sections to determine shear sense "top" directions based on rotated porphyroclasts and S-C fabric. Foliation was plotted on stereonets as poles to the plane, while shear top directions were plotted as plunge-trend of the associated stretching axes. Normal lower-hemisphere stretching directions are shown with diamonds. Upper-hemisphere stretching directions are reprojected down-axis to the lower hemisphere and shown with filled circles.

Based on the petrographic observations, we obtained mineral separates for 16 of the most prospective granitoid or granitoid-protolith samples on which to do U/Th-He (apatite, zircon) and Ar/Ar thermochronometry (muscovite, biotite). Apatite grains have been analyzed in Ken Farley's lab at Caltech according to the methodology outlined in Farley (2002) and Flowers et al. (2009).

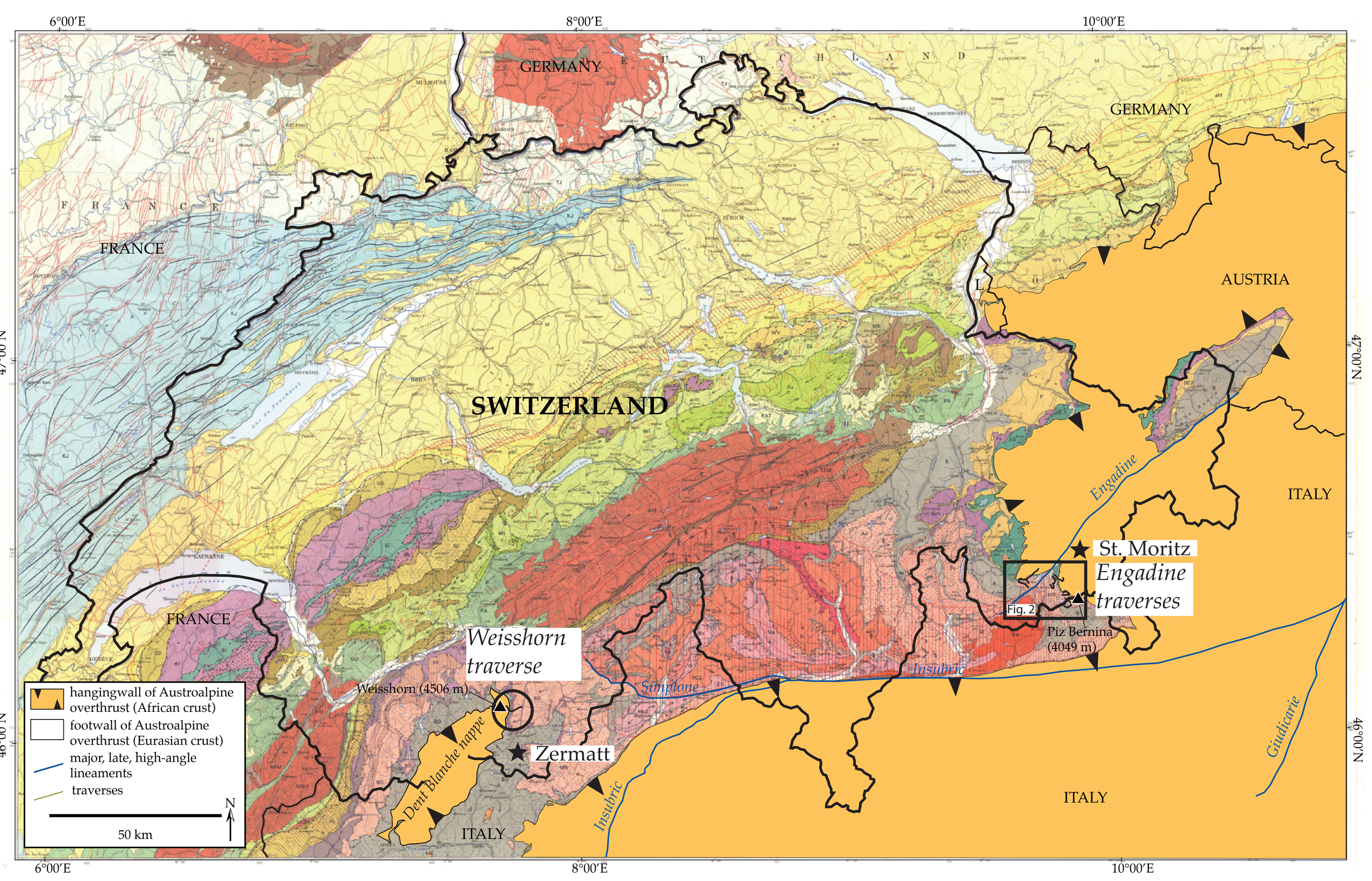

Fig. 1: Tectonic map of Switzerland and environs showing the Austroalpine overthrust (teeth on hangingwall) and the rocks believed to be associated with the African plate (in orange). The other rocks are believed to be Eurasian in origin. Major late faults are shown in blue and labeled. Traverse lines are shown in grey within the black circles.

Results

Field and petrographic observations have been compiled in maps and stereonets (Fig. 2). They are reported from NW (Maloja Pass, Margna-Sella decke) to SE (Piz Roseg, Bernina decke). At Maloja Pass, Margna-Sella schist, paragneiss, and minor orthogneiss are strongly foliated and mylonitized. Principal foliation (S1) measured in the field forms a broad fold with a plunge/trend of 29/040. The petrographic stretching lineations mostly cluster in the NE quadrant around the plunge/trend of the folded S1 cleavage and suggests co-axial deformation and stretching of rocks parallel to the down-plunge direction of the S1 fold. At Piz Corvatsch, Corvatsch teildecke schist and orthogneiss are strongly foliated and mylonitized. S1 foliation forms a broad, open fold with a plunge-trend of 10/081. Stretching directions mostly plunge shallowly E-W and again suggests stretching of rocks in the down-plunge direction. At Piz Roseg, however, Bernina decke quartz diorite is only locally mylonitized and in many places exhibits no preferential foliation. The paucity of S1 data plotted in Fig. 2 reflects this fact. Average S1 strikes E-W and dips gently N. Stretching lineations show no dominant orientation and trend E-W, N, NE, and NW.

To date, we have obtained U-Th/He apatite cooling ages for only two of the 16 samples that we ultimately plan to analyze (Fig. 3). The grains are highly radiogenic, and this may have some deleterious effect for this type of analysis. We do not yet know if samples from the other traverses are also excessively radiogenic (i.e., is this common in the Alps?) or if we just happened upon anomolous samples. There is concern about the poor correlation between stoichiometric and dimensional Ca. Stoiciometric Ca comes from the ICP-MS measurements while dimensional Ca is calculated from physical measurements of the apatite prior to analysis. There is no apparent correlation between effective U and corrected age, and in general the mean cooling ages for the two samples appears to be reasonable and probably meaningful.

In spite of some possible flaws in the data, we report here two new cooling ages for the Bernina decke: 19.1 ± 0.6 Ma for the base of the thrust sheet and 15.2 ± 0.6 Ma for the top of the mountain.

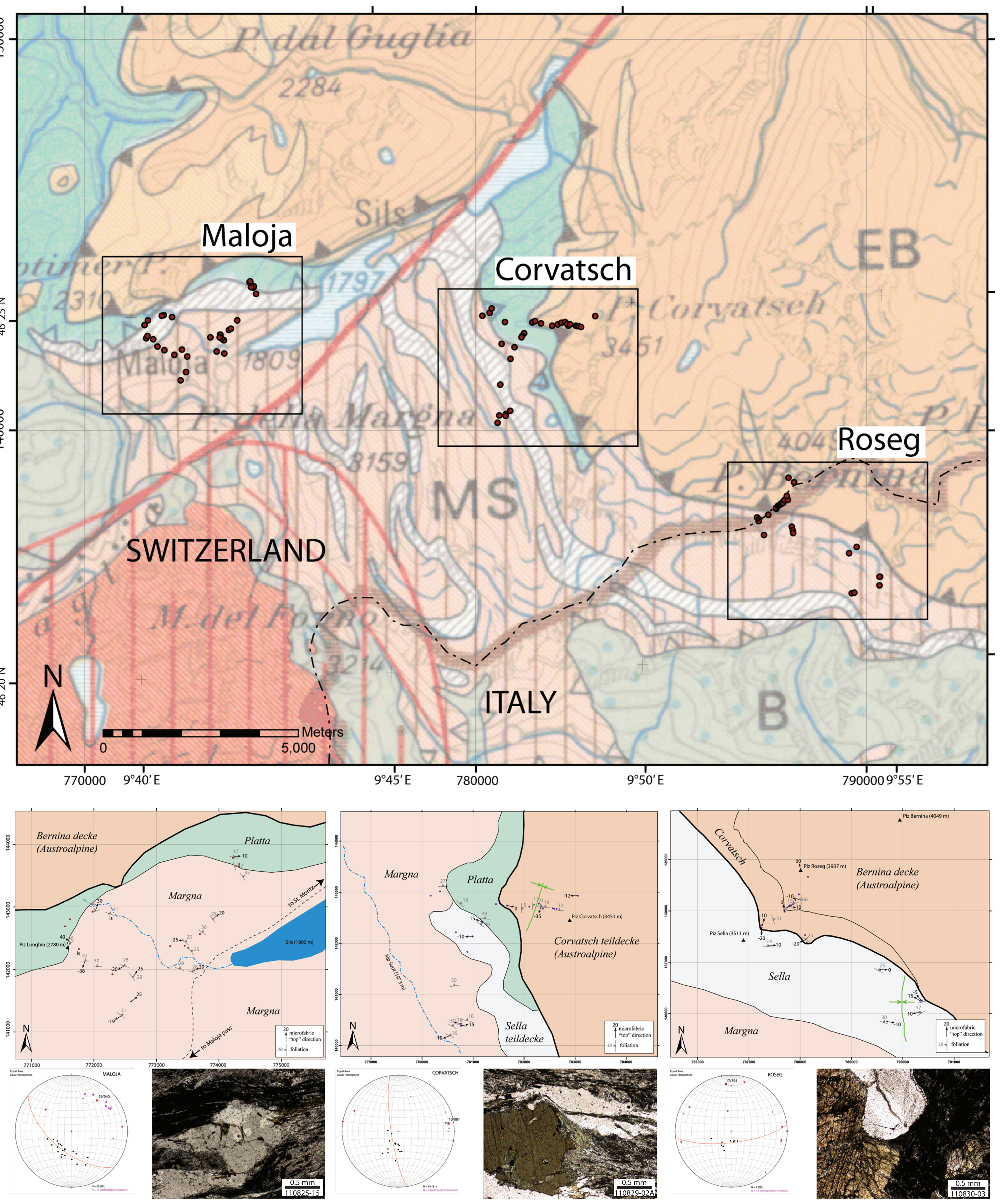

Fig. 2: Field maps of the Engadine traverses. Top map shows part of the Engadine and Bregaglia valleys with black inset boxes showing the locations of the sampling traverses. Second row: Corresponding field sheets showing folitation data (grey foliation symbol; measured in the field) and black petrographic stretching lineations. Nappe contacts are taken from the Tectonic map of Switzerland, 25000-scale sheets. Third row: Corresponding stereonets with a representative photomicrograph showing rotated porphyroblasts for Maloja and Corvatsch but directionless quartz diorite for Roseg. All photomicrographs are in plane-polarized light. v

These are the approximate ages at which these rocks passed through the ~70°C He-retention window for apatite. Generally, one would expect these ages to be reversed, with an older age at the top of the mountain. Nevertheless, these cooling ages are unusual and suggest that there may be a tectonic, rather than erosional, mechanism to account for them. Clearly, additional data is needed before a tectonic interpretation should be made.

Future Work

We plan to continue the thermochronology on apatite and zircon mineral separates at Caltech. The next samples will be from the Corvatsch, Sella, and Margna nappes below the Benina nappe in hopes of better understanding the strange results we have received to date. In addition, we plan to do Ar-Ar thermochronology on muscovite and biotite mineral separates at Australia National University in conjunction with Gordon Lister. The latter technique has a higher closure temperature (300-400°C) and will yield additional information about the early geologic events that affected these rocks. Lastly, there is some need of a 25,000 scale geologic map in the Maloja Pass area (not yet completed by the Swiss Geological Survey), and we may contribute some field mapping to this effort.

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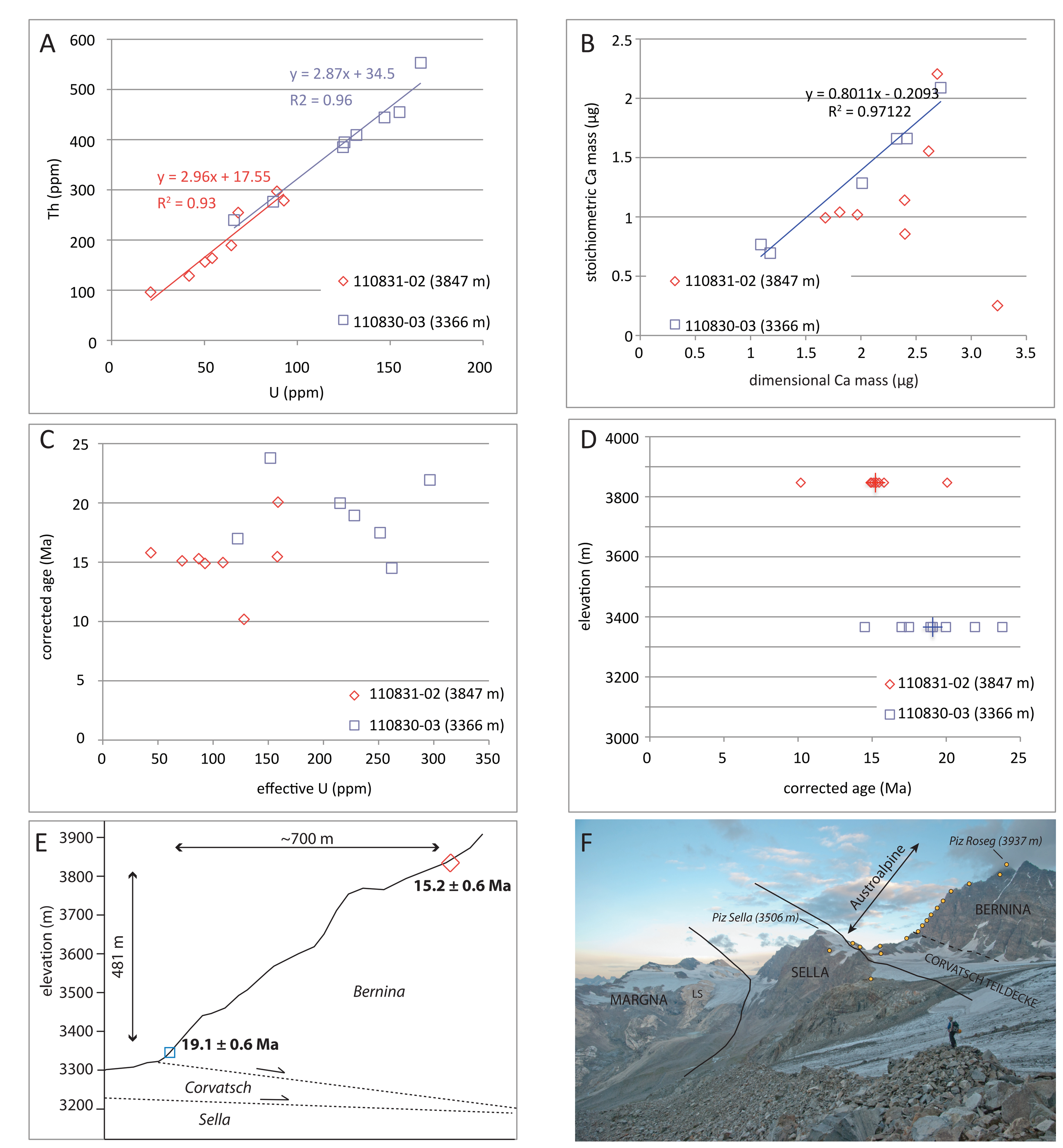

Fig. 3: Preliminary (U-Th)/He apatite thermochronologic data for the Roseg traverse (Bernina decke). Each point represents one measurement of one apatite grain. A) Concentration of U vs. Th. Both of these samples are highly radiogenic, but it is unknown how persistent this signal is and if it will be problematic for future analyses and data interpretation. B) Stoichiometric Ca in the apatite structure (measured on the ICP-MS) vs. dimensional Ca expected from measuring the length and width of the grains. The ideal case makes a 45° slope (1:1 correlation). By inspection, we see that both grains are off from the ideal correlation; 110830-03 moderately so; 110831-02 severely so. Some criterion may need to be applied to exclude some of the outliers. C) Corrected age (Ma) vs. effective U (ppm). Effective U ($[U_{eff}]$) is calculated by 0.235[Th]+[U] and allows "total radiogenecity" to be plotted against age. The age of sample 110831-02 is fairly insensitive to the $[U_{eff}]$ while there is some indication of an inverse correlation between age and $[U_{eff}]$ for sample 110830-03. D) Corrected ages vs. elevation for the two samples. Although the spread is large (~10 Ma for each sample), the mean are a reasonable estimate for the sample. E) The mean age shown on a topographic profile of Piz Roseg (Bernina decke) with its schematic structural position shown. The ages are the inverse of what one might expect for normal topography-driven cooling (i.e., via uplift and erosion). At this early stage in the study, it is unclear what these data signify with respect to the tectonic development of the Austroalpine overthrust. F) Field photo showing the layout of the Piz Roseg area. The samples reported here come from the foot of the mountain just above the Bernina-Corvatsch contact and high on the mountain at the second orange dot below the mist.