Pushing the limits of Electrical Resistivity Tomography Measurements: Success and Challenges

Geo-ecosystems in Transition on the Tibetan Plateau (TransTiP)

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How to successfully carry out ERT measurements on a rock glacier at 5500 m a.s.l. on the Tibetan plateau

Introduction

Why a rock glacier in Tibet?

Rock glaciers are a surficial expressions of **mountain permafrost**. They can be recognized by their steep front and lobe or tongue shaped body that consists mainly of debris and ice. As part of the mountain cryosphere they are of importance to the hydrosphere and climate. The included ice is protected by a thick debris cover, causing slow ice melt in warm seasons and therefore steady surface runoff. This makes them an **important hydrological component** under future warming conditions. Especially in semi-arid mountain ranges where flora and fauna rely on sustained water supply, their meltwater is of high importance in dry seasons (compare Brenning, 2005).

The **origin and evolution** of rock glaciers is still under debate (Knight et al. 2019). Furthermore only little data exists on rock glaciers in Asia (compare Gruber et al., 2017), where they are usually **remote** and harder to access than in better studied areas like the Andes or the Alps. Our aim was therefore to study the internal structure of a rock glacier in the semi-arid Nyainqêntanglha mountain range on the Tibetan plateau, China (location: see *Figure 1*).

The study was successful in detecting **internal structures** of the rock glacier by carrying out electrical resistivity tomography (ERT) measurements, but was also faced by challenges. The findings of this study contribute to a better understanding of the present state and evolution of the cryosphere on the Tibetan plateau.

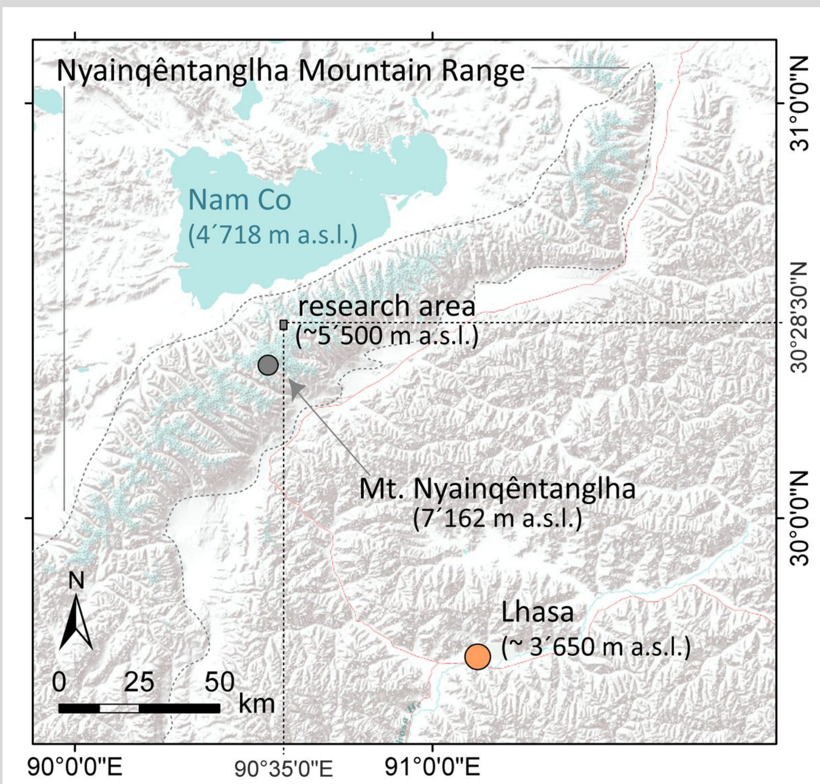

Figure 1: Location of the study area in context of adjacent landmarks, topography and elevation references. (terrain base map sources: Esri, USGS and NOAA)

Field situation

The local conditions (*Figure 2*) made ERT measurements challenging and required good preparation.

condition:	**requirement:**
high altitude and elevation changes	good physical adaptation
remoteness	good planning
coarse substrate	ERT setup adaptation

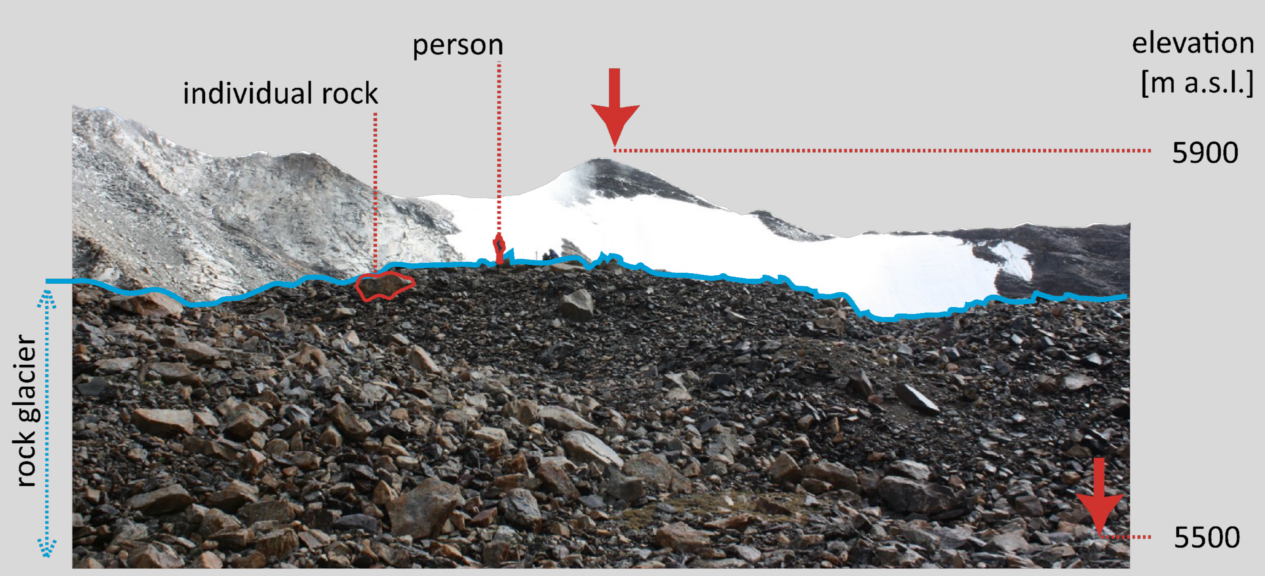

Figure 2: Picture of the investigated rock glacier in between the surrounding high mountain peaks. Note the large block size in comparison to the size of a person and the relatively big voids that are left in between the debris blocks. Also note the general high elevation of the study site.

Fieldwork

Overcoming setup challenges

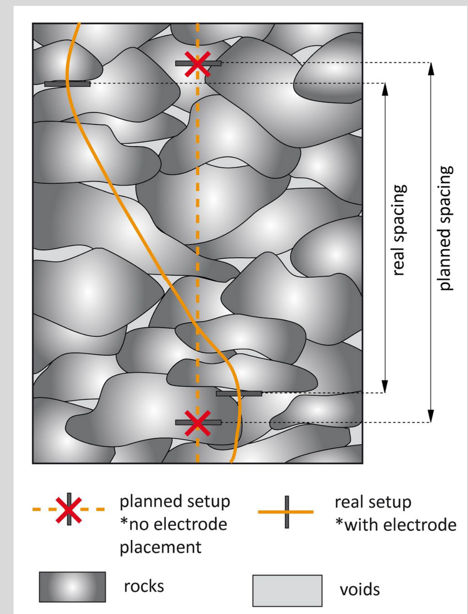

Figure 3: Electrode spacing: lateral displacement of electrodes leads to profile distortion and slight shortening.

The location of the ERT profiles can be planned in advance by analysing satellite imagery, but the suitability of the location can only be estimated by viewing the size and distribution of the surface cover in the field. On the investigated rock glacier the large block size was a general problem that called for compromises in the profile setup.

Exact **linear profile arrangement** and uniform electrode spacing is often disturbed by the local rock setting, impeding electrode placing in the planned location (*Figure 3*). Depending on the rock size, electrodes might be out of place by several decimeters. If the cable section length allows for it, electrodes should be preferably **relocated** in a direction **perpendicular** to the profile to minimize distortions and profile length shortening. Note that even with these measures a slight shortening of the profile is inevitable.

In order to obtain **continuous information** on the lower ice boundary, long profiles are required. These can be obtained by a "**roll along sequence**" (*Figure 4*). Note that at poor coupling the lower boundary might still not be reached.

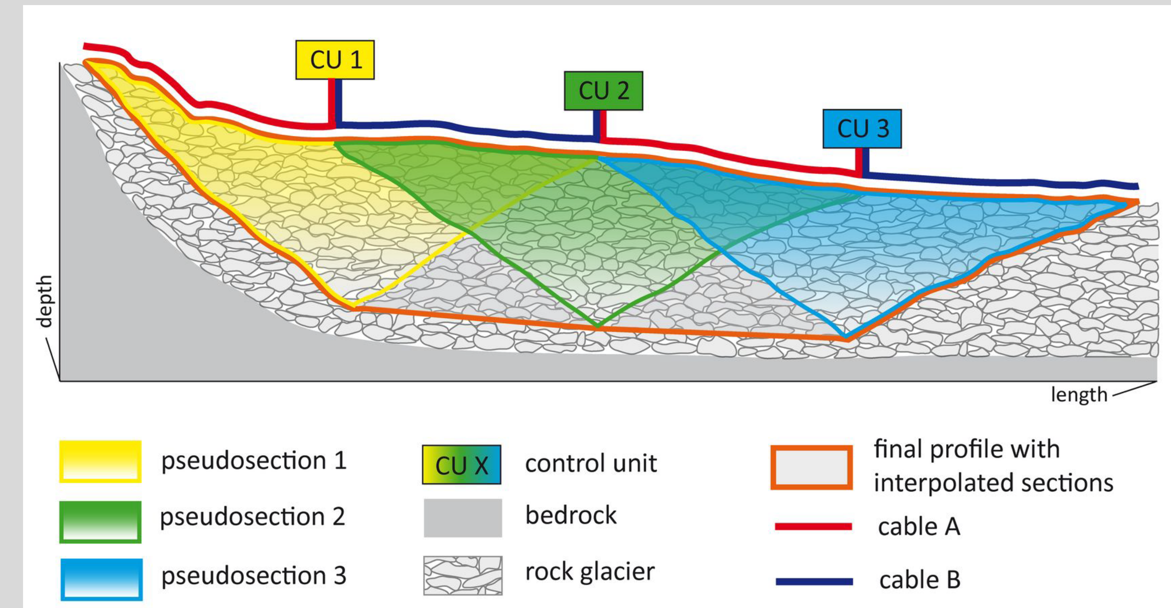

Figure 4: Illustration of a „roll along sequence" for long profile measurements. Individual pseudosection measurements are concatenated to form one continuous profile. For each successive measurement, only one cable and the control unit are displaced.

Overcoming substrate challenges

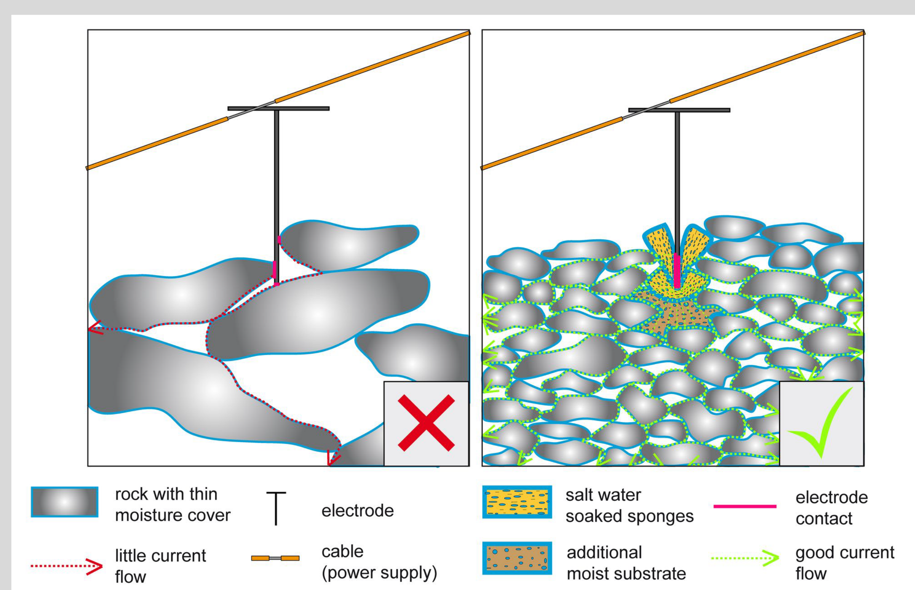

Figure 5: Comparison of poor (left) and good (right) electrode contact to the surficial rock glacier substrate. Contact resistances improve at smaller rock size and more conductive void fillings (like additional substrate and sponges).

As illustrated in *Figure 5* ERT measurements on rock glaciers are hampered by the abundance of **big boulders** and **voids**, resulting in few contact points. Measurements including poorly coupled electrodes result in outlying, **random apparent resistivity values** that need to be removed before the inversion (inverse modelling of real resistivity distribution). As visualized in the right panel electric conductivity can be improved by adding **fine grained substrate** and/or, **salt-water** soaked **sponges** to the electrodes. Note that the sponges might dry fast and thus a strong commitment is needed for watering up to 50 electrodes along a 196m long profile line.

Rock glaciers are expected to include a **rock, ice, water and air** phase (*Figure 6*). These phases cannot be disguished by ERT measurements, but their different resistivity results in lower or higher apparent resistivity values in the ERT profile.

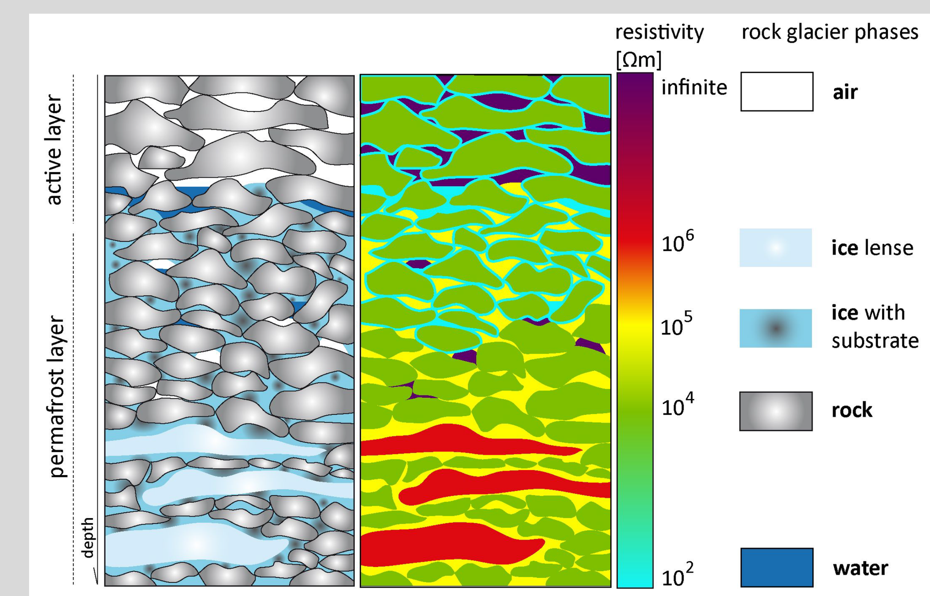

Figure 6: Illustration of the approximated resistivity of the supposed individual rock glacier components to electric current flow. Thin water coatings allow current flow, while ice causes high resistivity (resistivity: Telford et al., 1990 and Reynolds 1997).

Consequences for the data

Especially the challenging conditions that are created by the coarse substrate make it necessary to filter random resistivity values from the resultant pseudosections (*Figure 7*).

Two different effects that limit subsurface coverage can be distinguished.

One effect results from (partially) **disconnected electrodes**. The abnormally high contact resistances of single electrodes lead to erroneous high apparent resistivity values at all depths. In case of Wenner-type arrays this creates a radiant pattern.

If deep measurements are carried out, the **high overall contact resistance** inside the rock glacier reduces the signal-to-noise ratio and results in an additional loss of data at the bottom of the pseudosection.

All erroneous resistivity values need to be removed before the resistivity model is calculated from apparent resistivity pseudosection in the inversion.

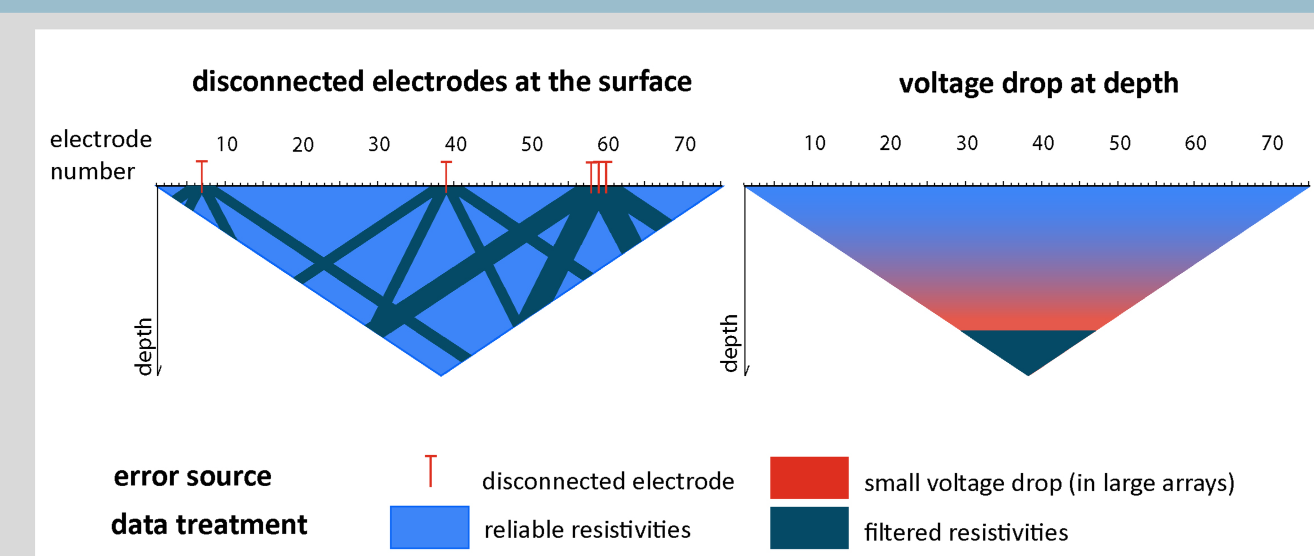

Figure 7: Schematic sketch of the error distributions in two ERT pseudosections resulting from two different error types. Disconnected electrodes (left) create a radiant pattern of random apparent resistivity values that needs to be removed, while limited current flow at depth (right) makes the removal of values in the lower part of the pseudosection necessary.

Outcome

Results and interpretation

The ERT measurements on the rock glacier that were carried out during field work in September 2019 show a heterogeneous subsurface. One profile section is shown and interpreted in *Figure 8*.

In the resistivity profile one can distinguish between a thin surficial layer of **low resistivity** (lower than 10´000 Ω m) and an underlying **high resistivity layer** (greater than 10´000 Ω m). The presence of abnormally high resistivity values within this layer (higher than 1´000´000 Ω m) suggests a further change in material properties or composition.

The top low resistivity layer is interpreted as the **active layer** (no ice present), where the presence of water ensures good current conduction. This layer is about 4 m deep. The subjacent high resistivity zone is interpreted as the **permafrost layer**, where the presence of ice increases electrical resistivity. The semi-circular zone of abnormally high resistivity might correspond to a particularly ice rich permafrost zone of about 10 m thickness.

At about 25 m below the surface the data starts to be less reliable (defining the depth of investigation), because of the low current density and should therefore be treated with caution. Since all included materials are known to result in a great range of possible resistivity values, the exact delineation of the interpreted features are subjects of discussion.

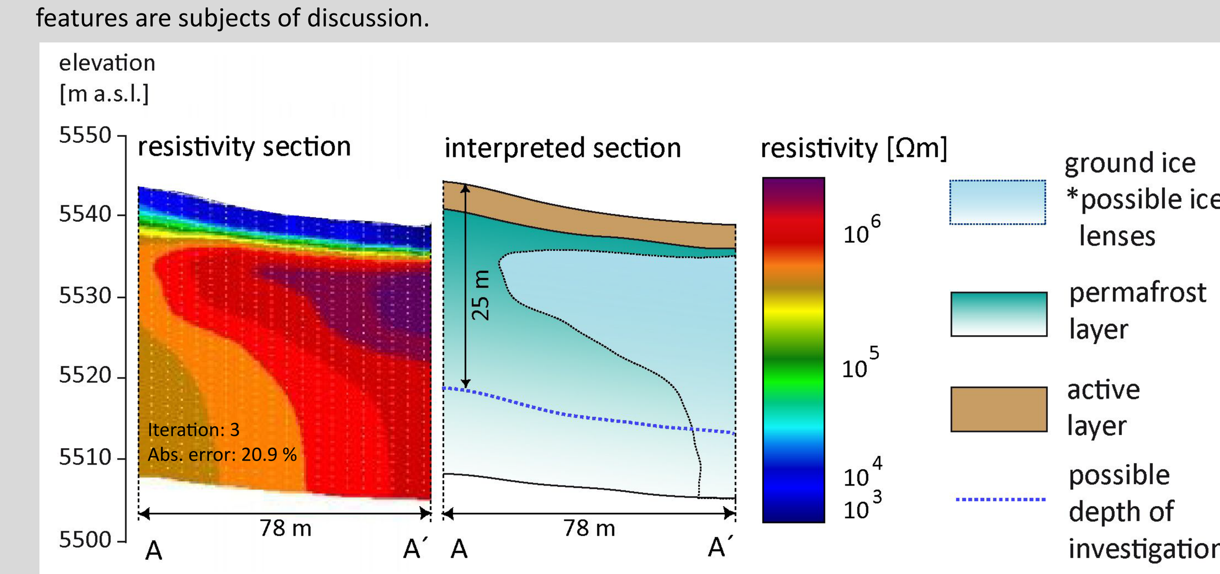

Figure 8: The left section shows a small part out of one of the ERT profiles that were measured on the investigated rock glacier on the Tibetan plateau (September, 2019). It is compared to a possible interpretation of the same section. The resistivity values within the resistivity profile suggest the presence of at least two distinct layers.

Check List

What to consider when preparing ERT measurements on top of a remote and blocky rock glacier at high altitude

(find a complete list and further application examples in Hauck and Kneisel, 2008)

- Set a goal for the minimum profile number, but keep challenging conditions at remote location and high altitude in mind.
- Choose the most suitable profile position (if the research question allows for it prefer small sized substrate and little elevation change over large rocks and hard terrain).
- Check electrode coupling before and during measurements!
- In case of big voids and high contact resistance, improve current flow by filling the voids around the affected electrodes with moist, fine substrate and/or salt-water soaked sponges.
- Consider combining the measurements with complementary geophysical methods for best result interpretation (e.g. ground-penetrating radar and/or seismic measurements).

Literature: Brenning, A., 2005. Geomorphological, hydrological and climatic significance of rock glaciers in the Andes of Central Chile (33–35 S). Permafrost and Periglacial Processes, 16(3), pp.231-240.
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