Magnetotelluric Study of the Southern Pamir, Tajikistan

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1. Introduction

Pamir is a high plateau which was formed by crustal shortening and thrusting during the India-Asia collision. The relative north-south motion between India and Eurasia is currently around 30mm/yr and mainly accomodated in two rather localized deforming zones (Ischuk et al., 2013):

- ~10-15mm/yr across Chitral Himalaya and Hindukush
- ~10-15mm/y across the Main-Pamir-Thrust

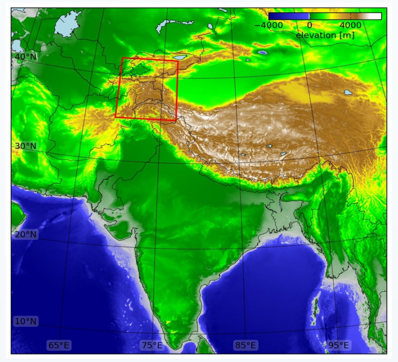


Fig. 1: Pamir region at the north-west tip of the Tibet-Himalaya orogen

- < 5mm/yr take place across the South Tien Shan
- negligible north-south shortening happens within the high Pamir.

An east-west extension of at most 10mm/yr (measured over the whole lateral Pamir extent) seems to be entirely at the cost of the Tajik Depression; the GPS velocities give no indication of shortening on the eastern edge of the Pamir where the Pamir meets the stable Tarim Basin.

Subduction

Beside the GPS measurements, there are other geophysical evidences that a slab of Asian lithosphere has been underthrust beneath Pamir:

- Vigorous intermediate-depth earthquakes witness the presence of cold, brittle material and describe an arc-shaped slab that bends from north-south strike to an east-west strike.
- Teleseismic tomography image shows a strong high velocity anomaly observed in 300 to 600km depth.
- Magnetotelluric measurements reveal a remarkable conductivity contrast between a hot, probably partly-melted middle crust in the south of Pamir and regions in the central and northern Pamir, which are much colder and composed of more brittle material.

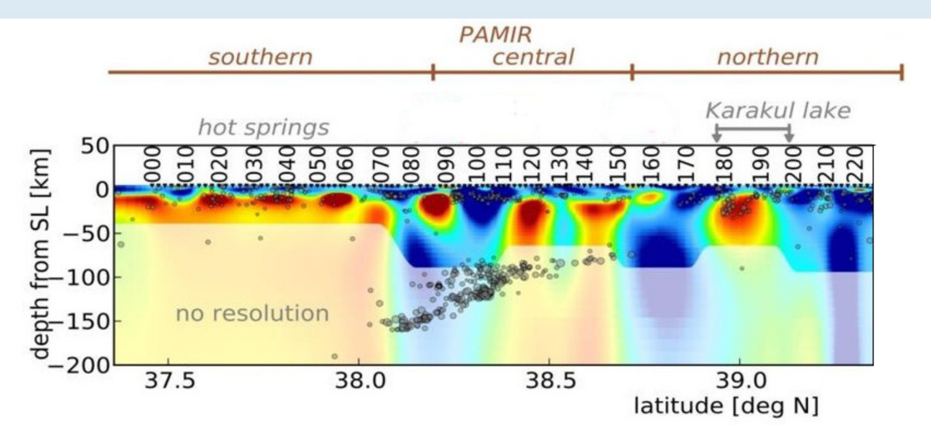


Fig. 2: 2 D electrical resistivity model of Pamir from Saß et al (2014). Circles mark earthquake locations, from Sippl et al. 2013

Subduction

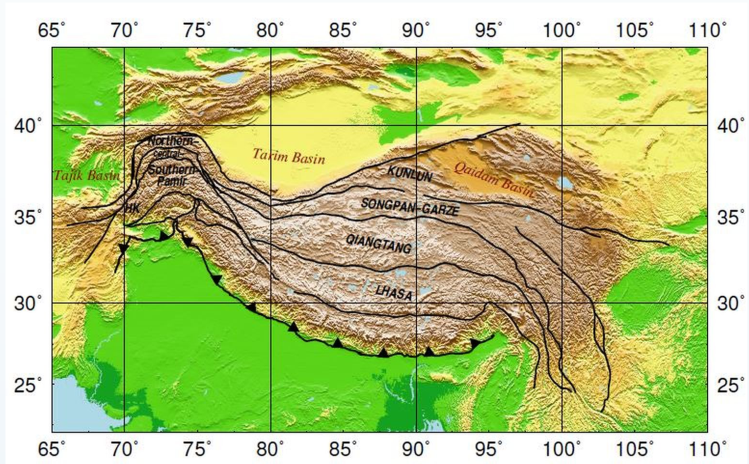


Fig. 3: East-West trending belts in Pamir and Tibet correspond to continental terranes which colided to Asia prior to India. The correlation of these belts and also suturs indicate that the Pamir has been displaced

The northern Pamir is a Palaeozoic arc and subduction-accretion complex like the Kunlun arc and the Songpan-Ganze terrane in northern Tibet. (Schwab et al. 2004)

The central Pamir comprises Palaeozoic-Jurassic platform rocks correlative with the Qiangtang terrane. The southern Pamir consists of Paleozoic-Mesozoic meta-sedimentary rocks, rare proterozoic gneisses, and voluminous Cretaceous-Paleogene granitoids, equivalent to the Lhasa terrane in Tibet.

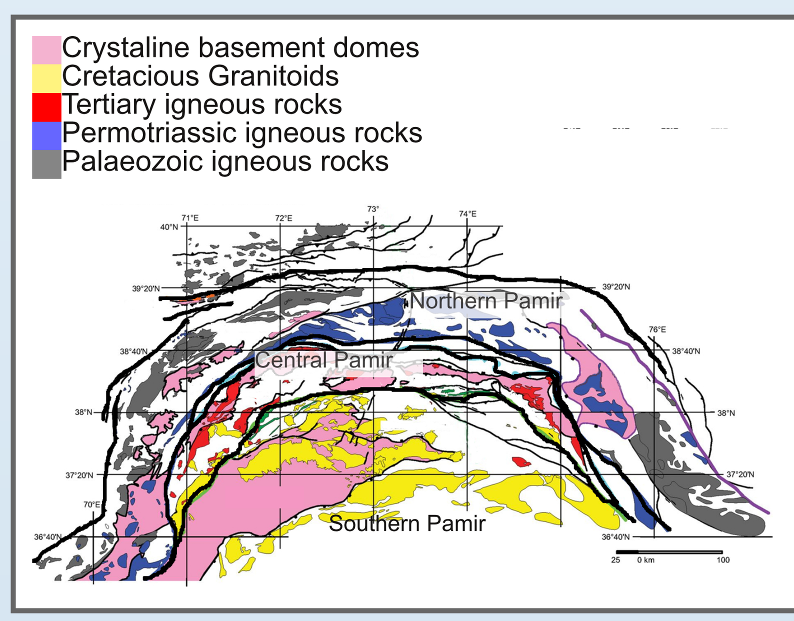


Fig. 4: Geological map of Pamir slightly modified from Mechie et al. (2012)

Method

In the experiment, we measure the natural electric and the magnetic fields E and B at the surface of the Earth for each site of the survey. In the frequency domain the fields are assumed to be linearly related by the impedance tensor Z:

$$\begin{pmatrix} E_x \\ E_y \end{pmatrix} = \begin{pmatrix} Z_{xx} & Z_{xy} \\ Z_{yx} & Z_{yy} \end{pmatrix} \begin{pmatrix} B_x \\ B_y \end{pmatrix}$$

The impedance tensor is the response of the Earth to electromagnetic induction and carries information about the conductivity distribution of the subsurface.

The complex impedances are often represented as apparent resistivity,

$$\rho_{ij} = \frac{\mu_0}{\omega} |Z_{ij}|^2$$

which is an averaged electrical resistivity within the induction volume of the electromagnetic fields, and phase

$$\phi_{ij} = tan^{-1}\left[\frac{\mathrm{Im}(Z_{ij})}{\mathrm{Re}(Z_{ij})}\right]$$

In nature, the electrical resistivity varies over many orders of magnitude. Low values of electrical resistivities (anomalies) are due to

- fluids
- melts
- ores
- graphite/sulfide

2. Field experiment

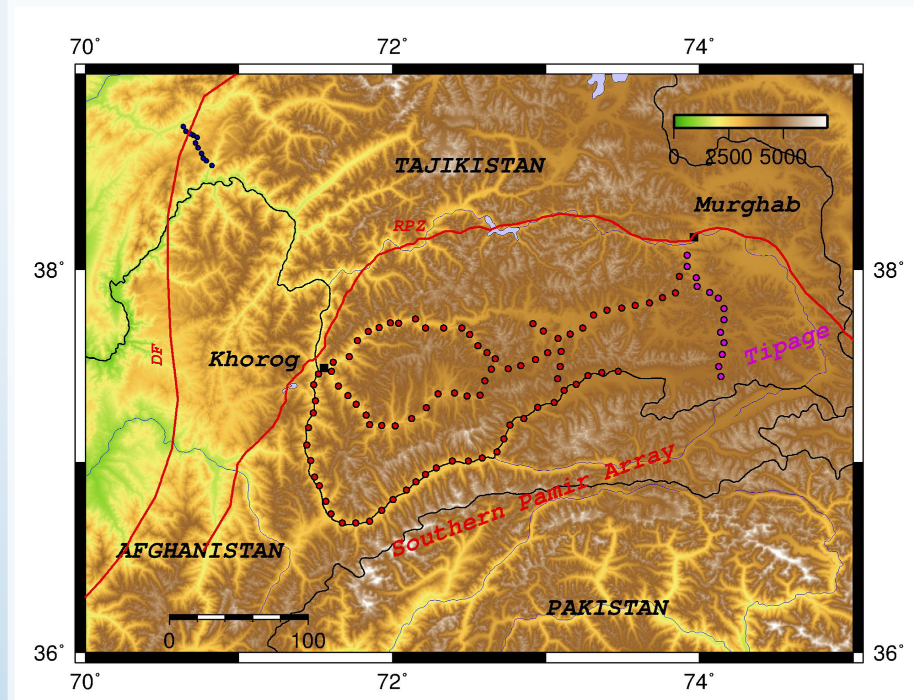


Fig 5: Southern Pamir Array

Southern Pamir Array:

- 85 magnetotelluric stations
- region between Murghab and Chorog, and between the Pamir Highway and the Panj-/Pamir-rivers (250km x 100km).
- site spacing ~8km
- installation duration 3days
- Used instruments: Metronix MFS05/06 induction-magnetometer, non polarizable Ag-AgCl electrodes, horizontal dipole length ~60m.

Motivation

In the Tipage experiment (Saß et al. 2014), a remarkable zone of high electrical conductivity (resistivities below 1 Ohmm) was found below the Pamir Plateau, starting at a depth ~10-15km (see Fig. 2). Saß explains this conductivity anomaly with felsic material containing interconnected melts and states that the ammount of melts in this region is likely above the reologically critical melt connectivity transition (7%) and may be related to a middle/lower crustal flow underneath the Southern Pamir.

With our MT measurements we investigate following questions:

- **How wide is the east-west extent of the conductive anomaly?**
- **Is there a crustal flow underneath the Southern**

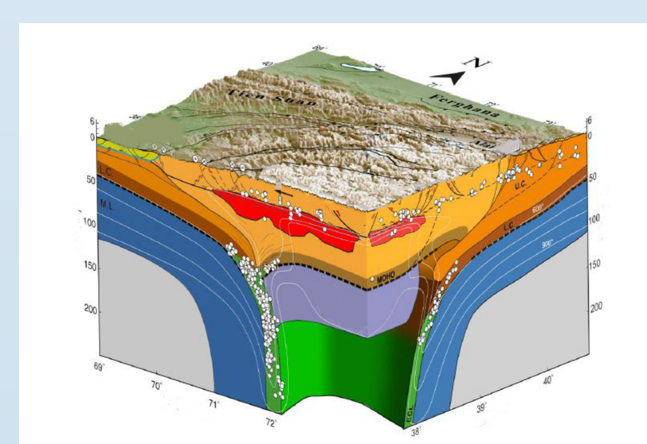


Fig 6: Cross section of the Pamir, showing a possible geodynamic model from (Saß, 2013). The subducting slabs of the Indian and Asian lithosphere are depicted in blue and area underneath Southern Pamir where crustal flow is possible is indicated as a red zone.

3. Results

3D Inversion

We run a series of 3D inversions using the "Modular Electromagnetic Inversion System" (ModEM, Meqbel 2009, Egbert and Kelbert 2012).

All components of the impedance tensor as well as vertical magnetic transfer functions were used. Not all sites from the TIPTIMON experiment were taken into acount, since the data processing has not been completed yet. While the data quality is excellent in the sparsely populated southeastern Pamir plateau, it is heterogeneous or disturbed by EM noise in the populated southwestern Pamir.

Additionally, the Southern Pamir data of the TIPAGE experiment (Saß 2014) were included.

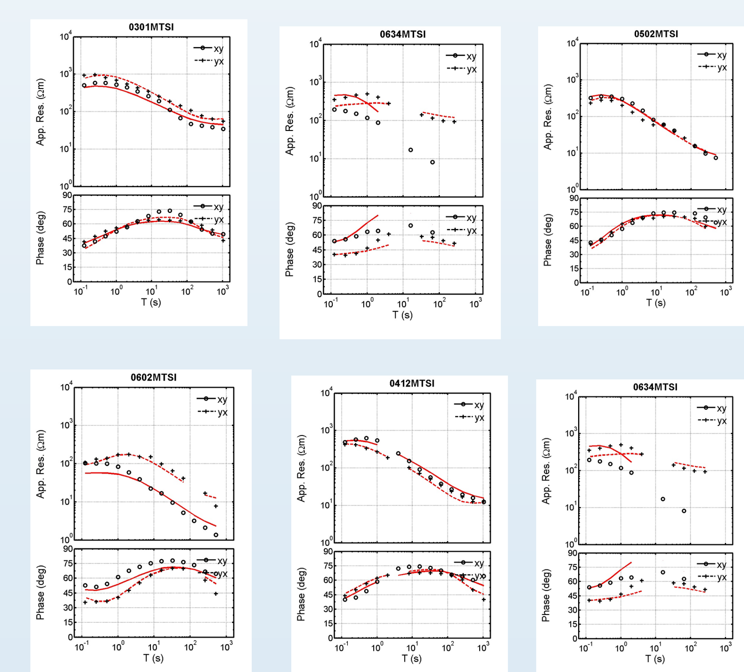
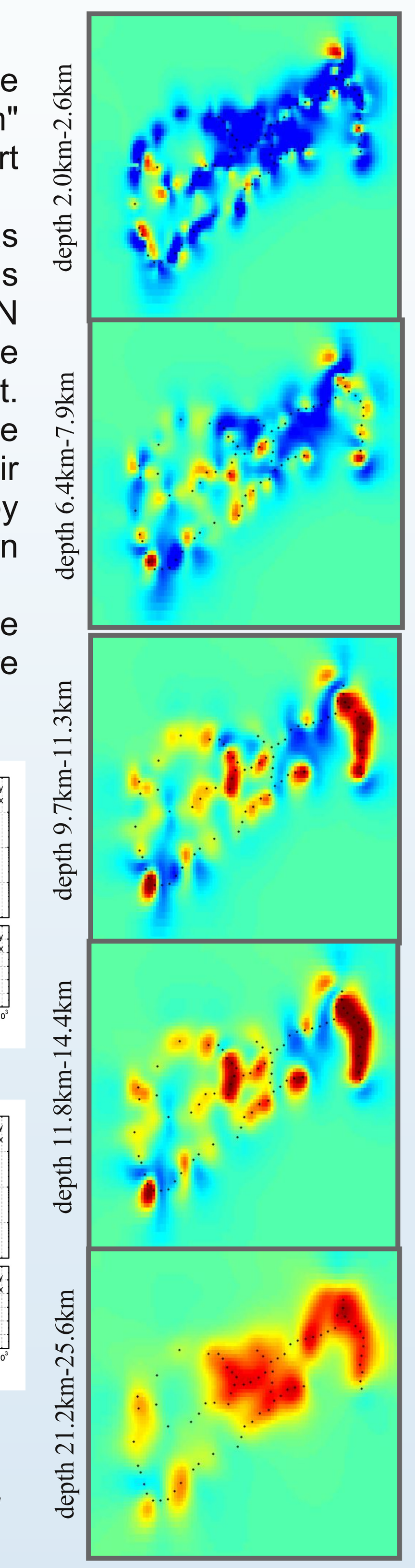


Fig 6: The data fit of the shown inversion was generelly good. The sites in the western part of Pamir were strongly affected by cultural noise and have therefore data gaps due to poor data quality.

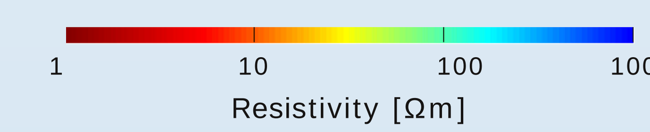


Interpretation

3D inversion reveals following features:

- At the shallow depths, the entire Pamir appears to be resistive reaching values around 1000 Ωm.
- There is a conductive anomaly, which starts in the most eastern part of the Pamir plateau at approximately 9 km, becomes larger with the depth and spreads over the entire eastern half of the plateau at the depths of 20 - 25 km. The conductivity anomaly is delimited to the west. This may be an indication against the crustal flow assumption (Saß et al. 2014).
- The limit of the conductivity zone is possibly the gigantic metamorphic Shakdara dome, which dominates the whole southwestern Pamir and is expected to be resistive. However, the data of the southwestern Pamir used in the inversion were incomplete, because processing of the noisy sites (western survay area) has not been finished yet.
- Future work will focus on a further improvement of the transfer function quality and probing of the inversion results. Interesting investigation issues would be the extension of the experiment to the east, or a longer recording time for the sites in southwestern Pamir, in order to test the possibility that the conductor starts at a greater depth in this part.

Fig 7: *3D inversion showing horizontal slices at different depths*



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