24th Electromagnetic Induction Workshop

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Abstracts

SESSIONS DESCRIPTION

Session 5. Marine EM

Marine EM encompasses both active and passive soundings of the sub-seafloor from the Arctic to the tropics and from mid-Ocean ridges to continental shelves. We invite contributions from authors working at all scales of marine EM, stretching from large arrays for offshore and amphibious exploration to borehole logging and monitoring. We welcome results of basic and applied research including the challenges inherent in running field campaigns, developing instruments, processing data, estimating errors, and implementing inversion algorithms. We encourage discussions on state-of-the art methods for marine magnetotelluric and controlled source electromagnetic data acquisition, inversion and interpretation as well as where active exploration is heading given recent emphasis in deep-sea mineral deposits, petroleum exploration and shallow water CO2 sequestration.

Conveners: Romina Gehrmann, Kim Senger, Yuguo Li

2D inverse modeling of Magnetotelluric data with standard and uniform grid Laplacian approaches and new insights into tectonics from Saurashtra, India

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SUMMARY

Saurashtra peninsula is situated at the northwest India, in which the area is mostly covered with the Deccan trap volcanics. This region is believed to have basement and sub-basement structures causing anomalous seismic events. The present study was carried out with 21 broadband magnetotelluric (MT) sites in a north-south profile which lies over recent sediments, Deccan trap, Cretaceous – Jurassic sediments and again recent sediments from south to north. The main objective of the study was to understand the tectonics and hidden structures (sub-basaltic) in the study area with the 2D inverse models resulted from the standard and uniform grid Laplacians. Frequencies from 100 Hz to 0.01 Hz were used for this study. Apparent resistivity and phase values of the off-diagonal components (XY and YX) were used to prepare pseudo sections and analyzed together with the geological information along the profile. Higher frequencies in the northern part of the section are observed as conductive. But except the southern site, the other sites in south exhibit comparatively high resistivity. Dimensionality analysis results from Swift skew, Bahr skew, and Phase tensor suggested the two-dimensional nature of the data set. The strike analysis carried out suggested a NS strike. We present here the results obtained from standard and uniform grid Laplacians. Though the data fit in the uniform grid is better, the standard grid is preferred for subsequent interpretation due to realistic structures obtained in the model. As the profile direction is parallel to the regional strike direction, we have carried out the TE, TM and TE + TM modes individually. Several interesting features came out from this study, which includes the signature of volcanic plugs identified in the southern segment of the Saurashtra peninsula. Basement faults are also identified from the modeling studies. One of these fault zone happens to be source of the earthquake. A detailed modeling results vis-a-vis the tectonics will be presented in the workshop.

Keywords: 2D inversion, Magnetotellurics, Saurashtra

3-D Electrical Resistivity Structure Beneath a Graben with a Focus on Aso Caldera, Southwest Japan Subduction Zone

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SUMMARY

We obtained a 3-D electrical resistivity structure model of the Beppu-Shimabara graben, in Southwest Japan subduction zone, by inverting network-magnetotelluric (network-MT) data with a period range from 640 to 10,240 s. Network-MT surveys for the electric field (the electric potential difference) were performed around the graben from 1993 to 1998 by using long metallic wires based on the commercial telephone company's networks [e.g., Uyeshima et al., 2002; Hata et al., 2015]. The graben is characterized by volcanically and seismically active regions owing to a tectonically active region comprising a N-S extensional stress field. Active Quaternary volcanoes, such as Aso with a caldera, Kuju, and Yufu, occur approximately from the center part of the graben toward the east with an interval of ~20 km in the graben. Our resistivity model indicates that the crust beneath the graben is a discontinuous electrically conductive belt that contains several significant conductive anomalies. Moreover, two specific anomalies of them are located at around the active Naka-dake cone (Aso volcano) in Aso caldera at depths of 0–17 km and in the Hohi volcanic zone centered on Kuju volcano at depths of 0–39 km. These conductive anomalies are considered to mainly reflect the effects of various fluids: melt, slab-derived hydrothermal fluid, volcanic thermal fluid, and aqueous fluid. In addition, the locations of the anomalies correspond with low seismicity areas in the graben, whereas resistive blocks of the model correspond with high seismicity areas, especially at the southwestern graben, the northeastern graben, and a border between Aso caldera and the Hohi volcanic zone. Our model suggests that the electrical resistivity structure of the graben can contribute to evaluating whether each part of the graben in the regional extensional stress field has a high potential for the earthquake occurrence.

Keywords: Aso caldera, graben, melt and fluid, seismicity, electrical resistivity structure

ACKNOWLEDGEMENTS

We thank the staff of Nippon Telegraph and Telephone Corporation for their assistance with network-MT observations in Kyushu district. This study was partly funded by the Program of Research and Observation for Prediction of Earthquake and Volcanic Eruption of the Ministry of Education, Culture, Sports, Science and Technology of Japan, and the Cooperative Research Program of the Earthquake Research Institute, University of Tokyo, Japan. This study was also partly supported by the Secretariat of the Nuclear Regulation Authority of Japan.

REFERENCES

Hata M, Oshiman N, Yoshimura R, Tanaka Y, Uyeshima M (2015) Three-dimensional electromagnetic imaging of upwelling fluids in the Kyushu subduction zone, Japan. J Geophys Res 120: 1–17. doi:10.1002/2014JB011336

Uyeshima M, Ichiki M, Fujii I, Utada H, Nishida Y, Satoh H, et al. (2002) Network-MT survey in Japan to determine nation-wide deep electrical conductivity structure. In: Fujinawa Y, Yoshida A (ed) Seismotectonics in Convergent Plate Boundary. TERRAPUB, Tokyo, pp 107–121

3D electrical resistivity model of Gran Canaria island (Spain)

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SUMMARY

The magnetotelluric method has been applied worldwide for the characterization of geothermal fields. During the summer of 2017, 100 broad band magnetotelluric stations were acquired on the Gran Canaria volcanic island to obtain a 3D electrical resistivity model. This study was performed in order to evaluate the geothermal resources of the island for both, hydrothermal and unconventional systems. Gran Canaria island belongs to the Canary archipelago. The island is circular in shape, with 45 km of diameter and rises to an altitude of 1949 m.a.s.l. The Gran Canaria island presents a combination of basaltic shield volcanism and caldera-forming felsic eruptions, with abundant intracaldera and extracaldera ignimbrites (Carracedo and Troll, 2016). Morphologically, the island is divided into two parts by an NE-SW Pliocene rift zone. The SW older part of the island is formed by the Miocene volcanic, whereas the younger NE contains the rejuvenation and recent Plio-Quaternary volcanism. The central part of the island is occupied by the most distinctive geological feature of the island, the Miocene Tejeda collapse caldera. All soundings displayed a 3D behavior at depth, so a 3D inversion has been performed. The 3D electrical resistivity model was obtained from the inversion of the full impedance tensor using the ModEM code (Kelbert et al., 2014), with periods ranging from 0.0005 to 1000 seconds, depending on stations quality. Topography and sea have been included in the inversion procedure. The overall rms of the model is 1.9, using an error floor of 5% and 10% for the off-diagonal and diagonal components of the impedance tensor respectively. The final model allows to interpret the first kilometers in depth of the Gran Canaria island. The most prominent feature of the final model is the imaging of the Tejeda caldera at depth, showing high resistivity values.

Kelbert, A., Meqbel, N., Egbert, G. D., & Tandon, K. ModEM: A Modular System for Inversion of Electromagnetic Geophysical Data. Computers & Geosciences. 2014
Troll, V. and Carracedo, J.C., The Geology of the Canary Islands, pp 636, Elsevier, 2016. ISBN: 9780128096635.

3D Electromagnetic Imaging of Fluid Distribution Below the Kii Peninsula, SW Japan Forearc: Implications for plate coupling, non-volcanic tremor and hot springs

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Summary

Although Kii peninsula is located in the forearc side of SW Japan subduction system, it has high temperature hot springs and fluids from mantle are inferred from the isotopic ratio of helium. Non-volcanic tremors underneath the Kii peninsula also suggest rising fluids from slab.

Previously, in the southern part of the Kii peninsula, wide band magnetotelluric measurements were carried out (Fuji-ta et al., 1997, Umeda et al., 2006). These studies could image the existence of the conductivity anomaly in the crust and upper mantle. Long period observation using network MT data showed low resistivity on wedge mantle (Yamaguchi et al., 2009). These studies, however, used two-dimensional inversions and three-dimensionality is not fully taken into consideration.

As part of the “Crustal Dynamics” projects, we measured 21 more stations so that the whole wide-band MT stations constitute grids to make three-dimensional modeling of the area. In total we have 52 wide-band magnetotelluric sites. 3D inverse modeling showed the following features.
(1) The high resistivity in the eastern Kii peninsula at depth of 5-40km. This may imply consolidated huge magma body of Kumano Acidic rocks underlain by Philippine Sea plate, which subducts with a low dip angle.
(2) Hot springs in Kii peninsula are located at the rim of the huge high resistivity. This may imply that fluids from slab rise along the rim of Kumano acidic rocks and appear on the ground as high temperature hot springs.
(3) The non-volcanic tremor is located at the edge of the resistive block, which in interpreted as Kumano Acidic Rocks at depth. This may suggest that the plate locking is strong beneath the root of the Kumano Acidic Rocks and is weakened towards deeper part of the plate interface.

Keywords:

3D MT inversion, Subduction, Forearc, Fluids, Plate coupling

3D inversion of MT data from the Mérida Andes, Venezuela

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Summary

The Mérida Andes form the main mountain range in western Venezuela. The mountain started to rise in the Miocene due to the convergence of the Caribbean and South American plates. While the Mérida Andes are associated nowadays with increased earthquake activity, the surrounding sedimentary basins are interesting in terms of oil deposits. Magnetotellurics (MT) can decipher and image regions of high fluid contents (rock water) which may be connected with dynamic processes associated with the subduction of the Caribbean plate beneath the Mérida Andes. Another application is related to the identification of the Boconó fault zone, the most prominent feature for seismic hazard in the Mérida Andes. While the MT method is applied world-wide for exploration purposes, this has not been the case in Venezuela.

The Venezuelan Magnetotelluric dataset consist of 72 broadband MT stations, recorded in March 2015. The MT sites are distributed along a 240 km long profile across the center of the Mérida Andes with a site spacing of 3 - 5 km. The MT transfer functions were estimated in a period range from 0.0001 s to more than 1000 s, using robust single site and remote reference processing of the EMERALD software package. Data quality could be improved by using a frequency domain selection scheme and a novel statistical approach to calculate transfer functions employing the concept of the Mahalanoubis distance and removing magnetically strongly polarized data.

A dimensionality and directionality analysis was carried out for the entire data set. A geo-electric strike analysis resulted in varying (regional) strike directions along the profile, which indicates overall three-dimensional (3D) structures for the deep subsurface. 3D forward modeling studies were used to investigate the influence of topography, the ocean, and other off-profile features. These studies set the ground for the inversion of the measured data as well as showing the limitations and challenges of working with 3D influences on a data set which was collected predominantly along a profile. The 3D inversions results suggest significant influence of off-profile features and generally good correspondence with the known tectonic structures from regional geology in the area.

Keywords: 3D inversion, magnetotellurics, geodynamics

A progress report on the subsurface electrical resistivity structure obtained from the Network-MT survey in the vicinity of area with a forthcoming slow slip event in the SW part of the Shikoku Island, SW Japan

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SUMMARY

In the Bungo channel region at the western margin of the Nankai megathrust rupture zones, the long-term slow slip events (SSE) repeatedly occurred about every 6 or 7 years and we expect the next event soon. The SSE also activate deeper episodic tremors and slips (ETS) on the plate interface.

In order to examine influence of interstitial fluids on occurrence of the SSE and/or ETS activities, we have started the Network-MT survey in the western part of the Shikoku Island facing the Bungo channel since April, 2016. We use metallic telephone line network of the Nippon Telegraph and Telephone Corp. to measure the electrical potential difference with long baselines of from several kilometers to 10 and several kilometers. We selected 17 areas in the western part of the Shikoku Island and installed 3 or 4 electrodes in the respective areas. The electrical potential differences measured in this way are known to be less affected by small scale near-surface lateral resistivity heterogeneities (e.g. Uyeshima, 2007). We also measure the geomagnetic field at two stations in the target region. With the aid of the BIRRP code (Chave and Thomson, 2004), we could estimate the frequency-domain response functions of good quality.

In this presentation we will show the 3-D electrical resistivity structure in the target region and compare with regional seismicity together with the ETS spatial distribution. In the inversion, we used the 3-D DASOCC inversion code (Siripunvaraporn et al., 2004), which directly invert the Network-MT response between the voltage difference and the magnetic field.

Keywords: Network-MT, 3-D resistivity structure, SW shikoku, slow slip events, episodic tremors and slips

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REFERENCES

Chave, A. D., and Thomson, D. J., Bounded influence magnetotelluric response function estimation, Geophys. J. Int., 157, 988–1006, 2004.
Siripunvaraporn, W., Uyeshima M. and Egbert, G., Three-dimensional inversion for Network-Magnetotelluric data, Earth Planets Space, 56, 893-902, 2004.
Uyeshima, M., EM monitoring of crustal processes including the use of the Network-MT observations, Surv. Geophys., 28, 199-237, 2007.

Advances in deep geoelectric modeling for SE Baltic shield with integrated geophysical and geological interpretation

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The Baltic (Fennoscandian) Shield is characterized by strongly inhomogeneous deep conductivity structure, with abundant crustal conductors which can serve as bright markers of the Precambrian crustal architecture. The results of last decade magnetotelluric experiments in the central part of the Shield have successfully underwent cross-verification with available CCP seismic materials and helped to fill up seismic structural patterns by material properties. While in the absence of high resolution seismic data in SE Fennoscandia, the progress in crustal structure imaging was achieved here mostly due to the magnetotellurics.

The geoelectric modeling for the area of Lake Ladoga conductivity anomaly - LLA, one of the strongest anomalies in EEC, studied already more then 3 decades - has proceeded to a new stage after recent magnetotelluric measurement campaigns. They have been started 5 years ago from synchronous MT/MV soundings at Vydorg-Suojarvi profile along the Northwestern bank of the lake, in strike to the main anomaly. The limitations of earlier MT data analyses have been generally overcome due to increased resolution of new LLA resistivity cross-section enable thoughtful geological interpretation. The latter has demonstrated that the anomaly is caused not by a single source, but is due to several objects of different geological and structural identity, most probably connected with graphite in highly metamorphosed granulites of South Finland Granulite-Shist Belt and graphitized sedimentary and volcanic rocks of lower metamorphic stages in Raahe-Ladoga pericratonic zone.

The paper presents recent advances in LLA area geophysical studies, including:

1). current results of 3D MT/MV inversion for Vyborg-Suojarvy profile data with incorporation of limited tipper array over adjacent Finnish territory into inverted data set, which have generally verified former 2D results and helped to recognise some 3D features of conductivity distribution out of profile;

2). 2D inversion of the MT/MV data set at the segment of 1-EU transect in SE Lake Ladoga area, completed to the North-East by new long-period measurements of 2016 year, to follow Eastern continuation of LLA conductors under the sedimentary cover of EEC;

3). correlation analyses of LLA forming material and structural crustal complexes with those causing anomalies in the potential fields: from classification of fields' spatial patterns over SE Fennoscandian and LLA regions to multi-component cluster analyses in the profile cross-sections with following interpretation of revealed significant clusters in petrologic terms on the base of the information on the physical properties of the rocks in the region;

4). demonstration of very low believability level for fluid LLA nature hypotheses (which is still discussed by some fraction of MT research community) on the base of integral conductivity estimates for crustal geoelectric models developed.

Keywords: crustal electrical conductivity, Eastern Fennoscandian shield, Lake Ladoga conductivity anomaly, integrated geophysical and tectonic interpretation

Acknowledgements: Colleagues from Finnish geomagnetic observatories Nurmijarvi and Mekkrijarvi, Geological Institutes of the Kola and Karelian science centers of RAS and "Nord-West" Ltd for assistance in the field work; RFBR grant 16-05-00543.

Amphibious MT investigations of melt storage beneath Okmok caldera, Alaska

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SUMMARY

Ash plumes erupted from volcanoes pose a significant hazard to aviation. Okmok volcano, located along the central Aleutian arc in Alaska, last erupted explosively in 2008 (VEI 4), accompanied by a 16-km high ash plume that impacted air traffic, and was preceded by at most a few hours of seismic unrest. Okmok is located at a pronounced along-arc transition in the depth to the subducting slab; the region is also characterized by unusual back-arc volcanism. Geophysically, Okmok presents an attractive target, as a pair of caldera-forming eruptions within the last 10,000 year have left relatively subdued topography and a shallow magmatic system. An amphibious MT survey in 2015, coupled with a yearlong broadband seismic deployment, are being analyzed to investigate the magmatic plumbing beneath Okmok from the slab to the surface. MT data include onshore stations both within and outside of the calderas, a ring of offshore stations surrounding the island, and a 300-km long offshore profile spanning from the trench, across the island, and into the backarc basin.

The MT data, particularly stations near the coast and within the forearc, exhibit strong 3D effects that challenge efforts to model the complete data set. Initial effort is focused on 3D modeling and inversion of the land data, and suggests a significant portion of the data variability is due solely to bathymetry. Coaxing anomalous structure out beneath the volcano is thus challenging, particularly at longer periods where larger skin depths give rise to a trade-off between offshore sub-ocean structure and onshore sub-volcanic structure. As evidence of this, models to date produce geologically reasonable structure in the upper ~5 km, but show little structure at greater depth.

Shallow structure includes a conductive apron that flanks the 2008 vent, attributed to fine-grained proximal ash deposits. At depths as shallow as 500 m, an arcuate conductor outlines the southern half of the caldera margin, interpreted to reflect hydrothermal circulation focused along the fractured caldera margin above the magmatic system. This feature soles at 2 km depth into a compact conductive zone centered upon the 2008 vent, yet above the zone of melt storage (3-4 km depth) inferred from seismic and geodetic data. A second conductive anomaly at ~1 km depth bisects the caldera, connecting to a satellite vent outside of it. Both of these conductors (1 S/m) could be attributed to partial melt, however the high conductivity would imply a significant volume of eruptible (>50%) melt at depths significantly shallower than supported by seismic modelling. We favor a hydrothermal explanation given the geometry and conductivity of these zones, with enhanced conductivity due to a combination of hydrothermal alteration, elevated fluid temperature and salinity, or both.

Ongoing efforts to image the magmatic system beneath Okmok involve incorporating the near-island offshore data; through constraining the offshore structure we hope to break the equivalence between offshore sub-ocean structure and onshore sub-volcanic structure. Other investigations include seeding the inversion based upon seismic modeling results and nesting the inversion model within a regional model derived from the offshore profile data.

Keywords: volcano, magnetotelluric, amphibious, seismic, Aleutian arc

Analysis of magnetotelluric array data from the Central Finnish Lapland

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Central Finnish Lapland is located in the Archaean part of the Fennoscandian shield. The Archaean basement outcrops to the south and to the east but is mostly covered by heavily reworked Palaeoproterozoic supracrustal volcano-sedimentary belts and granitoids. The belts bear significant base metal and gold potential and are under extensive exploration and mining activity. This has also resulted in a wealth of geological and geophysical research in the area and the intrinsic near-surface structure of the belts is reasonably well known. However, the complex regional crustal and lithospheric scale structure and tectonic evolution is still obscure.

In the context of the Magnetotellurics in the Scandes project, five-component electromagnetic data from total of 79 sites from the Central Finnish Lapland were acquired in 2014. High quality transfer functions (impedance tensor and tipper vector, 0.001-10000 s) were obtained. Aligned with the goals of the project, the data set is expected to provide constraints on the crustal and lithospheric structure and evolution. Naturally, previously acquired MT data (e.g. BEAR and EMMA projects) were also included in the analysis. Geologically, the site array is positioned in the Central Lapland granitoid complex bordered by the Central Lapland Greenstone belt in the north, the Peräpohja belt in the south and the Kuusamo belt in the southeast. Towards east and west the Kola and the Norrbotten cratons, respectively, are encountered. In general, the granitoid area is resistive and e.g. sulphide and graphite bearing conductive rocks are to be expected within the belts.

Geoelectric dimensionality and strike were addressed using the phase tensor analysis, which revealed a dominant E-W (N80^{o}E) strike direction. At the same time strong 3-D imprints, such as high skew values and out-of-quadrant phases, characterise the data set. Therefore, 3-D inversion was performed using the ModEM code. With reasonable data fit, a complex 3-D inverse model was obtained with strong (10000 S and more) crustal conductors in the vicinity of the belt areas. The tops of the major conductors lie at 15–20 km depth. For example in the north, a conductor seems to plunge well into the granitoid complex. Existence of this conductor is supported by tipper data and is also in agreement with seismic reflection data, which suggests that previously deformed units underlie the northern part of the granitoid complex. In the Peräpohja belt, it appears that the complexity of the geoelectric structure exceeds the resolving power of the current data set and no stable inversion results in that part of the model has been obtained. Nevertheless, high conductance areas in the belt clearly exist. The conductive belts in the south and in the north are divided by a resistor, coinciding with the granitoid complex. Together, these main characteristics lead to the observed highly anisotropic MT responses with E-W as the higher conducting direction. This may suggest the existence of previously unknown E-W striking concealed crustal boundary, although anisotropy in the mantle as a partial source cannot be excluded. Interpretation of the data set is complicated by the dominantly east pointing Wiese vectors. However, 3-D model from the combined impedance and tipper inversion can explain both data. This indicates enhanced conductivity in the west/southwest outside the site array. Although further investigations are needed, this is tentatively attributed to the assumption that the Proterozoic lithosphere in the southwest is generally more conductive than the Archaean lithosphere in the northeast.

Keywords: Fennoscandia, magnetotellurics, 3-D inversion, crust, lithosphere

Architecture across the Paleozoic collisional suture zone in the southeastern Central Asian Orogenic belt, northern China: revealed by magnetotelluric profile

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SUMMARY

The Central Asian Orogenic Belt (CAOB), located(lay) between the Siberian craton to the north and the North China-Tarim Cratons to the south, is one of the world's largest and complex accretionary collages. It was formed as a result of long-lived subduction and final closure of the Paleo-Asian Ocean (PAO), the amalgamation of micro-continental terranes, as well as the accretion of juvenile materials from the Neoproterozoic to Mesozoic. Different models have been proposed to elucidate the tectonic evolution of the CAOB, whereas some disagreements still remain, especially for the location of final closure and the final stage tectonic evolution of the PAO. The southeastern CAOB in Northern China is thought to have resulted from closure of PAO and occupies an important position as it records final closure of the PAO and the termination of subduction-accretionary activity. Thus, knowledge of the architecture of this region is of key importance to advance understanding the complex tectonic evolution of the CAOB.

Broadband magnetotelluric (MT) data were collected along a north-west to south-east trending profile that extended from the northern accretionary orogenic belt (NOB) in CAOB across the Solonker suture zone, the southern accretionary orogenic belt (SOB) to the northern margin of the North China Craton (NCC). Both two-dimensional (2D) and three-dimensional (3D) electrical resistivity models along the profile were generated by MT inversion modelling. Two models are similar and show some significant features. The resistivity structure varies systematically from the CAOB to the NCC. The crust and uppermost mantle structure in the CAOB is more resistive than that of the adjacent NCC. The northern NCC resistivity structure is characterized by thinner and conductive. The different resistivity feature could indicate existence of a tectonic boundary. A northwest-dipping high conductor from the surface down to the lower crust is detected within SOB which appears to be associate with the Solonker suture. The resistivity models provide new constrains on the tectonic evolution of this region.

Keywords: Central Asian Orogenic Belt, North China Craton, Solonker Suture Zone, Magnetotelluric, Electrical Resistivity

AusLAMP in Tasmania: The 3D geoelectric structure of Tasmania

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SUMMARY

Recent MT data acquisition in Tasmania as part of the ongoing Australian Lithospheric Architecture Magnetotelluric Project (AusLAMP) is yielding a unique dataset from geologically enigmatic terranes in south eastern Australia.

In this contribution, we outline the data collection efforts and 3D modelling results for this remote and challenging region. The dataset comprises 57 long period MT sites with periods ranging from 5 to 16000 seconds distributed across the island at a site spacing of ~35 km. Data collection took place in 4 phases throughout 2016 and involved multiple teams of field staff from multiple institutes. Numerous challenges were faced including difficult access, highly vegetated country, bush-fires, snowy conditions and helicopter access for some sites. This major field endeavor resulted in a unique dataset including both long-period data and broad-band data for some key locations in the west and northwest of Tasmania.

Three-dimensional resistivity modelling using High Performance Computing infrastructure has generated a complete picture of Tasmania's lithospheric geoelectric structure. The Tamar Conductivity Anomaly is confirmed in the context of the geoelectric structure of the state as a major feature in the upper crust and appears to separate the uniformly resistive East Tasmania Terrane from the more complex pre-Cambrian West Tasmania Terrane. Another upper-crustal anomaly separates the fault bounded Rocky Cape and Dundas-Fossey tectonic elements in Western Tasmania. Major upper crustal conductive regions appear to correlate with metamorphic complexes emplaced in the Cambrian suggesting a causal link between deep Earth processes and surface geological features.

Keywords: Magnetotelluric, AusLAMP, Tasmania, Australia

Bi-modal Magma Storage across the Main Ethiopian Rift Zone as imaged by 3-D Magnetotellurics

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SUMMARY

Active magmatism in the Main Ethiopian Rift (MER) is not limited to the well-developed volcanic centers located on the rift axis, i.e. the location of maximum extension. Instead, a number of off-axis volcanic fields characterizes both the eastern and the western parts of the Central MER. On-axis volcanoes mostly host post-caldera silicic eruptive products, whereas off-axis volcanism is fexpressed by a multitude of monogenetic vents with mostly basaltic output. The central volcanoes have been the focus of several recent studies related to their geothermal potential and associated volcanic hazard. The off-axis volcanic fields in turn have been largely neglected. Integrating models of electrical conductivity derived from magnetotelluric measurements (MT) with other geophysical data sets from gravity and seismics as well as petrological analysis of eruptive products (e.g. water content) allows for a more comprehensive picture of magmatic processes across the rift zone.

Our field area includes the silicic volcano Aluto situated in the lakes region (central MER), showing large surface deformation from satellite imagery, and the Butajira volcanic field, elongated for >100 km along the rift on the western shoulder and populated by multiple scoria cones. With MT we find no zone of enhanced electrical conductivity under Aluto, despite a high water content (up to 9 wt%) in eruptive materials, suggesting that melt is only present as a highly crystalline mush or in small unconnected lenses. Zones of higher electrical resistivity are imaged at mid-crustal level together with high density bodies and a zone of higher velocities. In contrast, under the off-axis volcanic field, there is a wide crustal zone of high electrical conductivity. High Poisson's ratio at Butajira indicates the presence of partial melt as do lower seismic velocities. MT helps to illuminate the complex and highly asymmetric structure of the rifting zone and its related magmatic processes.

Keywords: Magnetotellurics, continental rift zone, partial melt content

Complex structure of Piton de la Fournaise and its underlying lithosphere revealed by magnetotelluric 3D inversion

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SUMMARY

La Réunion is a large volcanic construction resting on Paleocene oceanic crust. More than one hundred magnetotelluric (MT) soundings acquired at the western part of Piton de la Fournaise volcano were inverted using the ModEM code and taking into account the rough topography and bathymetry. The resulting model reveals the resistivity structure down to the base of the volcano and upper lithosphere. An upper resistive layer corresponds to unsaturated and water-saturated lava flows. Below, the rest of the edifice is distinctly more conductive and shows highly conductive patches. The origin of the globally weak resistivity of the lower part of the construction can be tentatively attributed to a higher degree of alteration. The highly conductive patches of few ohm·m imply the presence of highly conductive fluids and/or minerals that are generally associated with hydrothermal phenomena. In the lower part of the edifice, a dome of moderate resistivity (>1 kohm·m) is wider than a dense intrusive complex inferred from gravity models. The present resolution of both MT and gravity models cannot exclude a same nature for both structures. Beneath 4 km b.s.l., an increase of the resistivity values underlines an interface in good agreement with the inferred location of the transition between the edifice and the oceanic crust at this depth. The upper lithosphere shows resistivity values above 250 ohm·m. This study therefore demonstrates the capability of the method to image major shallow structures such as the hydrothermally altered zones, and deeper ones such as the heterogeneity of the crust.

Keywords: Piton de la Fournaise, Magnetotelluric data, 3D inversion, Hydrothermal System, Oceanic lithosphere

Crustal heterogeneity beneath the seismogenic region of 1956, M6.0 Anjar earthquake, Kachchh, India— Magnetotellurics evidence for a fluid driven seismicity

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Abstract

The Kachchh rift basin in north-western part of India is one of the active intraplate seismic regions of the world. The basin had experienced two major events in the region that includes the Allahbund earthquake of 1819 (M 7.8) and Bhuj earthquake of 2001 (Mw7.7). In addition, the significant earthquake occurred on July 21, 1956 with Mw 6.0 (Focal depth: 15km) also caused considerable damage and casualties in the region. We present the results of magnetotelluric investigation carried out in the eastern part of the Kachchh intraplate region covering the seismogenic region of the 1956 Anjar earthquake. A total of 20 MT sites were acquired along a NE-SW profile that traverse across the major fault zones, e.g. South Wagad Fault (SWF), Kachchh Mainland Fault (KMF) and the Kathrol Hill Fault (KHF). The two dimensional geoelectrical model, after distortion and decomposition analyses of the processed data reveal the assemblage of conductive (at depth of 15-20km) and resistive zones in the upper and mid crustal depths in the close vanity of the major fault zones. The resistive zones (~1000 Ω.m) observed in the derived model might indicate the Alkali basalt intrusive rocks suggesting remnant signatures of earlier magmatic activities. Importantly, the study delineated a very high conducive zone (< 5 Ω.m) in the vicinity of the moho supporting the presence of upper mantel fluid reservoir as inferred by previous geophysical study in the eastern Kachchh. However, Unlike the SWF, the KMF and KHF does not breach the entire crust rather terminates at mid crustal depths. By comparison with the seismicity, we observed that the present seismicity including the 1956 Anjar earthquake is located at the transition of the conductor and the resistive zones signifying the strong crustal heterogeneity near the epicentral zone. We suggest that the trapped fluids, imaged as high conducive zones in the upper to mid crustal depths and their seepage to the resistive plutons might be a possible mechanism for trigger of the 1956 event as well current seismic activity in the region.

Deep electrical structure of Chuxiong Basin in southwest of China

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SUMMARY

The Chuxiong Basin in southwest China is near the southeastern margin of the Indo-Asia collision zone with highly complex and active tectonic features. The electric structures of this basin have been investigated by carrying out 2D inversion of magnetotelluric data of a large array of 1188 observation sites covering part of the basin. Preliminary interpretation of inverted resistivity sections has revealed the different patterns of deep electric structures below different part of the basin. Double in-crust conductive layers can be delineated below the western and central part of the basin, while only one conductive layer can be identified below northern and eastern part of the basin. It is also inferred that the in-crust conductive layers are dipping southward in large gradient according to the burying depth of the conductive layers for different traverses. 3D inversion of this set of data is underway and better resolution and reliability of inversion results can be expected.

Keywords: deep electrical structure, Chuxiong Basin, magnetotelluric sounding

INTRODUCTION

The Chuxiong Basin in the center of Yunnan Province is a relatively large Mesozoic tectonic sedimentary basin in southwest of China. Its location is near the southeastern margin of the Indo-Asia collision zone, and bordered by the Red River Fault belt to the west. This region is tectonically the mixed area of inner and edge of the plate, controlled by the uplift of the Qinghai-Tibet plateau. Its dynamic characteristics are very complicated (Kan et al.,1986) and is highly active with earthquake risk.

The basin was formed in late Triassic and subsequently experienced several violent tectonic movements (Wan et al.,1998). The northwest border of the basin is bounded by Chenghai Fault, and connected with the Yanyuan-Lijiang block of Songpan-Ganzi fold belt. The southwest is bounded by the Red River Fault and is adjacent to the famous Sanjiang fold system or the only Tethys tectonic region in China. The east border of the basin is defined by the Pudu River Fault and connected with the Kunming Fold belt of the Yangtze block. The Huaping Uplift is on the northern margin and separates this basin from the Shichuan Basin.

The development and application of magnetotelluric (MT) method have activated studies of electrical structures in Sanjiang fold system and its adjacent areas since 1980s. Some one-dimensional inversion results of MT data for the Nanhua-Tengchong and Menglian-Luoping profiles have indicated that there is a low resistivity layer in the upper crust of the region (Sun et al., 1989; Tang et al., 2012 and Li et al., 2014). Long period MT data of Yingjiang-Yaoan profile has revealed that there is indeed a low resistive layer in crust but with varying of depth and thickness along the profile, and also large scale of low resistive region has been illustrated in crust-mantle transition zone (Yu et al., 2017). These studies have given general knowledge of characteristics of deep electrical structures of Sanjiang fold zone and can be inferred to apply for neighbouring area indirectly. This work is trying to use a set of 3D MT data in Chuxiong Basin to obtain the detail information of its deep structural features and help to understand its dynamics mechanism.

DATA ANALYSES

This set of 3D MT data consists of 1188 observation sites compositing 14 survey traverses with average 2km of site separation and about 10km of traverse separation. The distribution of observation sites and tectonic background are as shown in Figure 1. The survey area covers approximately 20000 km^2 of the central section of Chuxiong Basin in north-south direction and crossover in east-west direction.

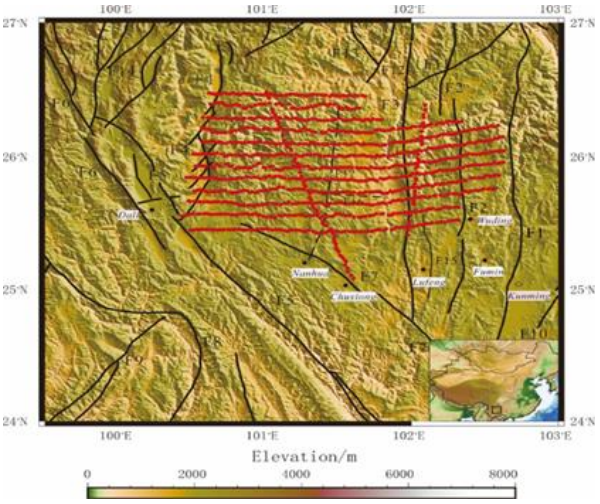

Figure 1. Distribution of MT sites and tectonic background of Chuxiong Basin

(F1 - Pudu Rriver Fault; F2 - Anning River Fault;
F3 - Mopanshan-Luzhijiang Fault; F4 - Yongsheng-Binchuan Fault;
F5 - Red River Fault; F6 - Weixi-Weishan Fault;
F7 - Nanhua-Chuxiong-Jianshui Fault;
F8 - Lancangjiang Fault; F9 - Nantinghexizhi Fault;
F10 - Xiaojiang Fault; F11 - Ninghui Fault;
F12 - Limingjiu Fault; F13 - Xifantian Fault;
F14 - Heqing-Eryuan Fault; F15 - Lufeng Fault;
F16 - Dayao-Yuanmou Fault; F17 - Dukou-Nanhua Fault.)

Parameters derived from observed MT time series are mainly apparent resistivities, impedance phases and tippers, etc. by running data processing software of the measuring system. The distortion factors of observed MT data in this area are mainly the topography effect, surface electrical inhomogeneity and cultural noises. The average elevation of the survey region is about 2000 m but heavy rolling of peak and valley, with highest peak of 3395 m in southwest. The famous Jinsha River also crosses this region from east to west. The rugged topography causes severe topographic distortion specially to apparent resistivity curves. The effect of near surface electric inhomogeneity is usually termed as static effect and is always a problem for MT data acquired at region of poor surface conditions. Besides topography, the Chuxiong Basin is also an area of intensive tectonic activities with complex changes of stratigraphic facies at surface, resulting of the static shift of the MT apparent resistivity curves. Although the area is not densely populated, several small hydropower stations, mining tunnels and a dense powerline grid exist in the survey area, and strong powerline interferences accompany with observed MT series. Besides to partially take into account of the effect of topography and near surface electric inhomogeneity in the inversion scheme, data reprocessing measures, mainly power spectrum re-editing, denoising and distortion correction (Karsten, 1990), have been applied to some identified poor quality data set at the data processing stage.

INVERSION

The observation data can be processed by 2D inversion after carefully reprocessing. The crucial procedures for inversion are the determination of the initial model and the selection of mode of apparent resistivity curves to be used for 2D inversion scheme (Zhang et al., 1999). Some commercially available softwares are tested and the non-linear conjugate gradient (NLCG) algorithm (Rodi, 2001) is used for the joint inversion of TE and TM mode curves. The regularization factor Tau value is an extremely important parameter for 2D inversion, and Tau = 3 is selected for this study after evaluating inversion results of various Tau values.

PRELIMINARY INTERPRETATION

2D inversion results of some traverses are presented here for preliminary discussion of deep electric structures of the studied region. The ultimate goal of this study is to make better understanding of deep structures by means of 3D inversion of this MT data set, but the results are not ready currently. .

Figure 2 shows the inverted resistivity section for traverse CX03. Notice that the parameter for vertical axis is elevation in km, and the maximum depth of the section goes to 100 km; the color scale for contours are blue for resistive and read for conductive formation. The traverse CX03 is located at the northern side of the study area which is adjacent to the Kangdian ancient land. There are four electric layers can be identified in general from the section plot and all strata tilt slightly eastwards. The surface is mainly covered with resistive stratum, and the thickness is gradually increased from about 1 km to about 5 km from west to east. Underlying is a continuous conductive layer with about 10 km in thickness and about 50 ΩM of

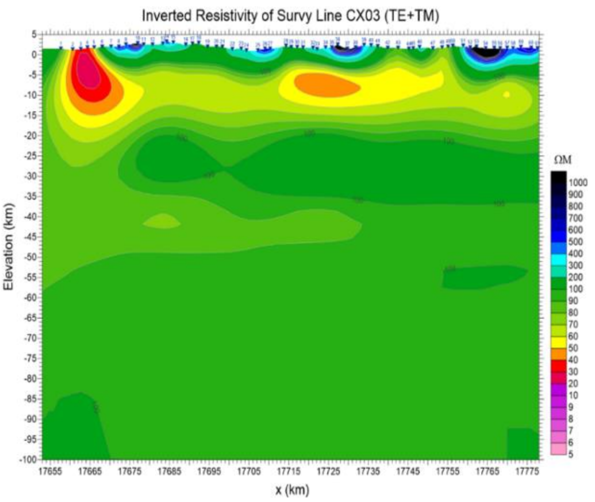

Figure 2. Inverted resistivity profile of CX03

resistivity. The Yongsheng-Binchuan (F4) and Dukou-Nanhua Fault (F17) can be recognized by the conductivity anomalies of first and second layer of this traverse. A relative uniform resistive (about 100 ΩM) layer of about 15 km in thickness is followed. The bottom layer below about 35 km is relative conductive with resistivity less than 100 ΩM, and more conductive at the west end of the traverse. The deep information given in this section is however less reliable since the periods of MT data not all long enough to well resolve the deep structure at maximum depth.

Figure 3 present the inverted resistivity profile of traverse CX07, which is located near the center of the survey area. The traverse is the longest, and not only crossing Chuxiong Basin from west to east but also extending eastward through Yuanmou uplift and Yunlong sag. Six electric layers can be identified in general from the resistivity section plot. The surface layer is not continuous in conductivity and depth, which may be a reflection of the surface stratigraphy. The underlying second layer is thick and mainly conductive for basin and sag area but intervened by two resistive uplifts which may be inferred as Dayao and Yuanmou Uplift. Four faults can be identified as F4, F17, F3 and F2 respectively from west to east according to conductive anomalies of this layer along traverse. The deep structure from here down for Chuxiong Basin area can be clearly divided into high - low - high - low resistive layer, namely the double low resistance structure, and the top boundary is at about 35 km for the first in-crust conductive layer and about 70 km for the second conductive layer. The deep structures below Yuanmou uplift to the Yunlong depression show somewhat different features from the basin region, only the first conductive layer can be well identified and the second conductive layer is not well resolved or diminished.

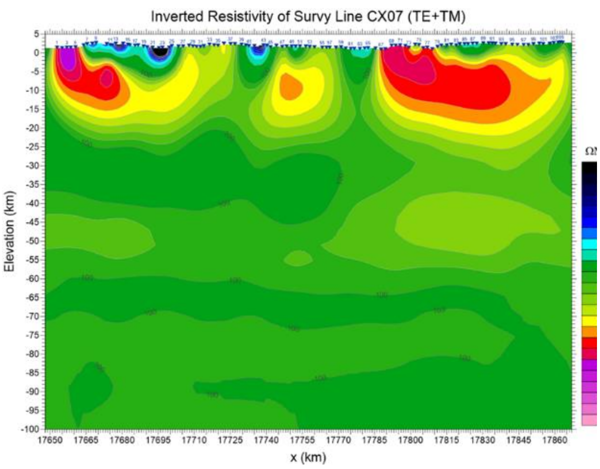

Figure 3. Inverted resistivity profile of CX07

The inverted resistivity profile of CX12 is shown in Figure 4. This traverse is located at the south end of the survey area which is more close to the center of the basin. The basic feature of electric strata is similar to that of traverse CX07, and six layers can be divided from the resistivity section. All layers show relatively simple structure and double conductive layers can be identified as well. The surface layer is thin (0~3 km) and resistive (100~1000 ΩM). The second conductive layer is relatively thick, with average resistivity 20ΩM and only Yuanmou uplift can be identified by the resistive anomaly of the profile plot. The double conductive structure in depth is well resolved, but with much deeper burying depth, about 50 km for the top boundary of the first conductive layer and about 90 km for the top boundary of the second conductive layer. The detection of burying depth and location of low resistivity layer is consistent with the results of MT exploration in the neighboring area (Li et al. 2014). The results and the existing geophysical data indicate that the western thrust belt and the central strike-slip thrust region have been characterized by thick low resistivity layer.

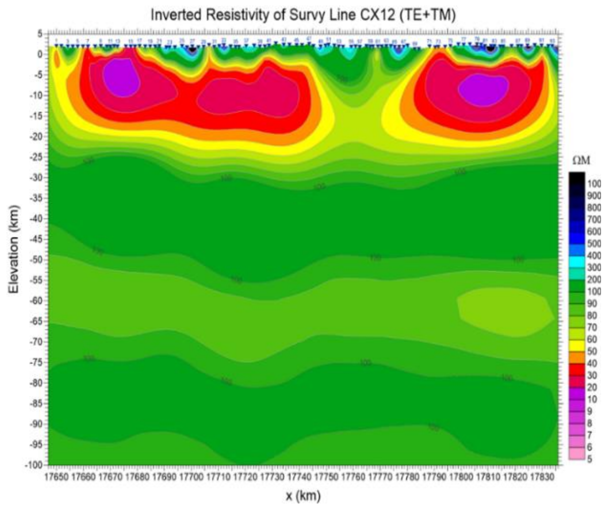

Figure 4. Inverted resistivity profile of CX12

Conclusions

From above preliminary 2D inversion results it can be concluded that (1) inverted resistivity sections for all profiles demonstrate somewhat similar pattern of electric strata, and is reasonably consistent with the known features of surface tectonics; (2) different features are identified for deep electric structures below different part of Chuxiong Basin, that is, double in-crust conductive layers can be delineated below the western and central part of the basin, and only one conductive layer can be inferred below the northern and eastern part (east of Yuanmou Uplift) of the basin; (3) the double conductive in-crust layers are quite uniform in thickness but dipping southward in large gradient; (4) 3D inversion for this large set of MT data is underway, better resolution and reliability of electric structures can be expected.

Acknowledgements

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References

Ji J Q, Zhong D L, Zhang L S. (2000) Kinematics and Dating of Cenozoic Strike-Slip Faults in the Tengchong Area, West Yunnan: Implications for the Block Movement in the Southeastern Tibet Plateau. Chinese J. Geol. (in Chinese) 35(3):336-349.

Jin S, Zhang L T, Wei W B, et al. (2010) Magnetotelluric Method for Deep Detection of Chinese Continent. ACTA GEOLOGICA SINICA. (in Chinese) 84(06):808-817.

Kan L J, Lin Z Y. (1986) A Preliminary Study on Crustal and Upper Mantle Structures in Yunnan. Earthquake Research In China. (in Chinese) 2(4):50-61.

Karsten B. 1990. Geological noise in magnetotelluric data: a classification of distortion types. Phys. Earth Planet., 66(1-2):24-38.

Rodi W, Mackie R L. 2001. Nonlinear conjugate gradients algorithm for 2D magnetotelluric inversion. Geophysics, 66(1): 174-187.

Sun J, Xu C F, Jiang Z, et al. (1989) The Electrical Structure of the Crust and Upper Mantle in the West Part of Yunnan Province and Its Relation to Crustal Tectonics. Seismology and Geology. (in Chinese) 11(01):35-45.

Tang J, Xiao Q B, Zhan Y, et al. (2012) Electrical Structural Characteristics and Regional Tectonic Studies in Southern Yunnan Province. Recent Developments in World Seismology. (in Chinese) (06):71.

Li R，Tang J, Dong Z Y, et al. (2014) Deep electrical conductivity structure of the southern area in Yunnan Province. Chinese J. Geophys. (in Chinese),57(4):1111-1122.

Wan L, Guo S P, Liu D L. (1998) Tectonic Evolution and Its Relationship with Hydrocarbon of Chuxiong Basin in the Middle of Yunnan Province. Journal of Nanjing University (Natural Sciences). (in Chinese) 34(3):322-329.

Wei W B, Jin S, Ye G F, et al. (2003) Methods to study electrical conductivity of continental lithosphere. Earth Science Frontiers. (in Chinese) 10(01):15-22.

Yu C Q, Zhang G, Wang X B, et al. (2017) Deep electrical resistivity structure of Sanjiang Area of west Yunnan and its significance. Chinese J. Geophys. (in Chinese),60(6):2385-2396.

Zhang X, Hu W B. (1999) Joint 2-D inversion of magnetotelluric sounding data having landform effect. OIL GEOPHYSICAL PROSPECTING. (in Chinese) 34(2):190-196.

Deep electrical structure of the transition zone between southeastern Tibetan Plateau and western Yangtze craton: implications for geodynamic evolution

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SUMMARY

We report on a recent magnetotelluric (MT) survey across the SE margin of the Tibetan Plateau, where crustal thickening and surface uplift have been widely attributed to outward flow of Tibetan crust toward the southeast. Three-dimensional inversion of the profile data reveals a horizontally extensive conductive layer beneath SE Tibet at a depth of ~20-60 km depth, which is consistent with ~2-5% partial melt in the mid-lower crust and with the development of topography-driven crustal flow. However, contrary to expectations, this flowable layer does not extend into the western Yangtze craton but is terminated ~30 km south of the Lijiang fault by a lithospheric-scale resistor. The south-dipping, crustal-scale conductivity contrast under the Lijiang fault is interpreted to be a significant rheological boundary between the weak, warm Tibetan crust and the rigid, cold Yangtze craton. These results do not support the notion that unimpeded crustal flow creates the gently dipping SE Tibetan margin.

Keywords: southeastern Tibet, western Yangtze craton, resistivity structure, crustal flow, magnetotellurics

INTRODUCTION

The SE margin of the Tibetan Plateau, situated between the eastern Himalayan syntaxis (EHS) and the Sichuan basin, is thought to have formed by unimpeded flow of weak Tibetan crust towards adjacent foreland (Clark and Royden, 2000). This flow requires a low-viscosity layer in the middle and lower crust that could be identified by geophysical measurements. However, although previous geophysical data from this area are consistent with the presence of weak crust capable of flow, it is still unclear whether widespread, continuous crustal flow is occurring. To help resolve this uncertainty, broad-band and long-period magnetotlluric (MT) data were collected across the margin to image the electrical resistivity of the crust and uppermost mantle (Figure 1). In contrast to previous MT data, which are generally deployed perpendicular to the NW-trending strike-slip faults, this profile is parallel to the inferred flow direction and thus provides an excellent opportunity to verify the crustal flow hypothesis.

MT DATA

As part of the Eastern Himalaya Syntaxis (EHS3D) project, 46 broad-band (0.003-1800 s) and 12 long-period (20 - 10, 000 s) MT stations were collected in 2014 along a ~400-km-long profile that extends from SE Tibet onto the Chuxiong basin in the western margin of the Yangtze craton (Figure 1). The broad-band and long-period MT data were recorded with using Phoenix MTU-5A and LVIV LEMI-417 instruments respectively.

3-D MODELING AND RESULTS

Input data consisted of the full impedance tensor from 46 MT stations at 25 periods from 0.01 s to 10,000 s. An error floor of $5\% \times \sqrt{|Z_{xy} \times Z_{yx}|}$ was applied independently to each impedance tensor element. All the inversions were started from a 100 Ω·m homogeneous half-space. The preferred inverse model fit the data to a normalized root-mean-square (RMS) misfit of 2.45, which represents a 92% reduction in RMS relative to the starting model. Comparison of the observed and predicted response for all tensor elements shows that this model could match the observation of most sites.

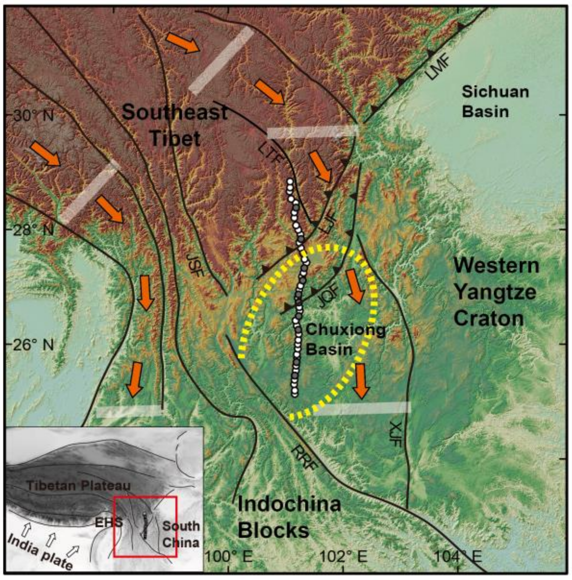

Figure 1. Tectonic settings of the study area and locations of the magnetotelluric (MT) sites. White and gray circles show the locations of the broad-band and long-period MT sites respectively. Black solid lines denote faults after Deng et al. (2003). LTF: Litang fault; LJF: Lijiang fault; JQF: = Jinhe-Qinghe fault; XJF: Xiaojiang fault; RRF: Red River fault; JSF: Jinshajiang fault; LMSF: Longmenshan fault. White bars show the location of elevated crustal conductivity observed by previous MT measurements, and the orange arrows denote the two inferred crustal flow channels (Bai et al., 2010). Yellow dashed line marks the outline of the inner zone of the Emeishan large igneous province (ELIP) (after He et al. (2003)).

The 3-D resistivity model in Figure 2c reveals three prominent features: (1) a moderately conductive layer (C1) at a depth of ~20-60 km beneath SE Tibet that extends from the northern edge of the profile to ~30 km south of the surface trace of the Lijiang fault; (2) a highly conductive zone (C2) in the mid-lower crust beneath the central Chuxiong basin; and (3) a lithosphere-scale resistive region (R1) situates between C1 and C2, with resistivity decreases from >1000 Ω·m at crustal depth to ~200 Ω·m in the uppermost mantle.

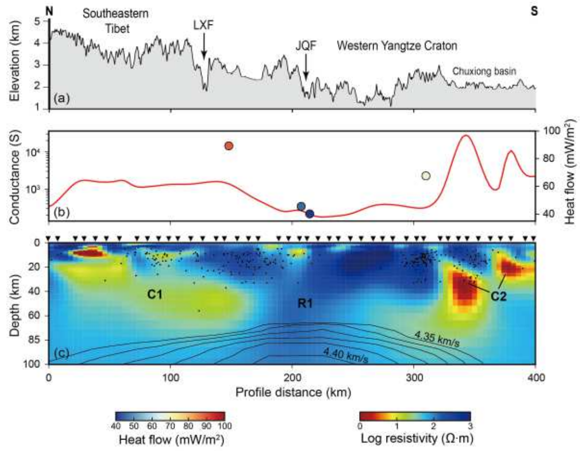

Figure 2. (a) Topography variation along the MT profile; (b) Depth-integrated conductance of the mid-lower crust (20-60 km) (red curve) and heat flow measurements (circles) along the profile; (c) Vertical section through the center of the 3-D resistivity model. Black dots mark earthquake hypocenter locations within 25 km of the profile line (provided by China Earthquake Network Center). Black contour lines outline a dome-shaped structure with high seismic speed of 4.35-4.40 km/s in the upper mantle (interpreted from Bao et al. (2015).

INTERPRETATION AND DISCUSSION

Both the conductors C1 and C2 are most likely fluid-based for several reasons. First, graphitic conductors can perhaps be excluded because interconnected graphite is unlikely to be preserved at such depths beneath high-temperature regions like SE Tibet and Chuxiong basin (Figure 2b). Second, the observed negative gravity and magnetic anomalies are difficult to reconcile with the existence of large-scale mineral deposits. Furthermore, low shear-wave speed (Bao et al., 2015), high Vp/Vs ratios (Sun et al., 2012) and high Lg-wave attenuation (Zhao et al., 2013) were found to coincide with their locations, consistent with the presence of fluids in these regions. Finally, the general absence of seismicity within these conductors implies that they are likely to be internally weakened by fluids (Figure 2c).

The surface location of R1 corresponds well with the inner zone of the Emeishan large igneous province (ELIP) in SW China (Figure 1), where the emplacement of the Late-Permian Emeishan basalts and the inferred kilometre-scale pre-volcanic doming have been widely attributed to the interaction of a mantle plume with the lithosphere (Xu et al., 2004; He et al., 2003). Previous seismic studies in this area have identified a plume-induced underplating interface at a depth of ~35 km within the thick, fast, high-Poisson's-ratio crust (Chen et al., 2015) and a dome-shaped, seismically fast structure in the upper mantle (Bao et al., 2015; Xu et al., 2004) (Figure 3c). These features, as well as high resistivities we observed, could be explained as cooled mafic/ultramafic rocks that was generated from the plume head and trapped at the base of, or within the crust during their rise to the surface. This interpretation is consistent with the anomalously low heat flow values (~40 mW/m^2) observed in the inner zone of the ELIP (Figure 3b).

The presence of a horizontally extensive fluid-bearing layer beneath SE Tibet is significant because it can be regarded as a thin low-viscosity channel that is being sandwiched between strong upper crust and lithospheric mantle. Geodynamic models suggest that such a layer may flow in response to lateral pressure gradients created by topography variations, i.e. Poiseuille flow (Clark and Royden, 2000; Royden et al., 1997). It was suggested that a melt fraction in excess of 5% and a conductance value in excess of 7,000 S would be required to facilitate crustal flow in southern and central Tibet respectively (Rippe and Unsworth, 2010; Unsworth et al., 2005). Given the relatively low conductance (~2000 S) and melt fraction (~2-5%) of C1 (Figure 3a), the key question becomes whether the mid-lower crust beneath SE Tibet is weak enough to permit lateral crustal flow under gravitational pressure.

As shown in Figure 2a, topography across the SE margin of the Tibetan Plateau decreases from ~4000 m to 2000 m over a horizontal distance less than 120 km. The resulting pressure gradient of 180 Pa/m is much higher than those for central and northern Tibet (~80-120 Pa/m) (Le Pape et al., 2015; Rippe and Unsworth, 2010). Under such a gravitational pressure, the minimum flow velocity of C1 can be calculated as 4 cm/a for granitic melts (Figure 3b), which is higher than the observed surface speed (< 2 cm/a). Thus, we speculate that conductor C1 may represent a southeastward branch of crustal flow from central Tibet into SE Tibet. However, contrary to expectations, such a flow does not propagate continuously into the Yangtze craton but is terminated ~30 km south of the Lijiang fault. The abrupt changes in resistivity and fluid distribution across the Lijiang fault suggest that this fault may defines a significant rheological boundary between the weak, warm Tibetan crust and the rigid, cold western Yangtze craton.

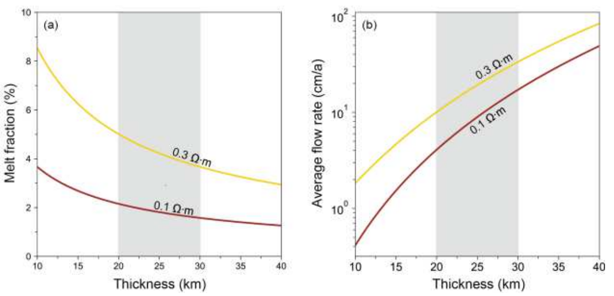

Figure 3. (a) Melt fractions as a function of layer thickness estimated from the modified Archie's law for a layer with a conductance of 2000 S. Assuming that conductor C1 is 20-30 km thick and melt resistivities ranging between 0.1 and 0.3 Ω·m, a melt fraction in the range ~2-5% is required to account for the observed conductance. The melt is assumed to be relatively well interconnected and the resistivity of the solid rock is set to 1000 Ω·m. (b) Average flow rates as function of layer thickness obtained by relating the conductance to laboratory results of granitic melt viscosity [Rippe and Unsworth, 2010]. Under a pressure gradient of 180 Pa/m, a 20-30 km thick layer with a conductance of 2000 S predicts a minimum flow rate between 4 and 10 cm/a for granitic melt.

CONCLUSIONS

The resistivity profile presented here reveals a moderately conductive layer at ~20-60 km depth beneath SE Tibet extending from the northern edge of the profile to ~30 km south of the Lijiang fault. This anomaly is associated with the presence of ~2-5% partial melt in the mid-lower crust and is interpreted to represent a southeastward flow of melt-weakened Tibetan crust. The inferred flow, however, does not protrude into the western Yangtze craton as expected but is being obstructed by a lithosphere-scale resistor under the inner zone of the ELIP. Although our MT data are consistent with the development of topography-driven crustal flow beneath SE Tibet, the notion that unimpeded crustal flow builds the SE margin of the Tibetan Plateau is unlikely. A 3-D inversion of regional MT array data is required to fully reveal the resistivity structure of this area and constrain the possible pattern of crustal flow.

ACKNOWLEDGEMENTS

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REFERENCES

Bai, D., et al. (2010), Crustal deformation of the eastern Tibetan plateau revealed by magnetotelluric imaging, Nat Geosci, 3(5), 358-362.

Bao, X., et al. (2015), Two crustal low-velocity channels beneath SE Tibet revealed by joint inversion of Rayleigh wave dispersion and receiver functions, Earth Planet Sc Lett, 415, 16-24.

Chen, Y., et al. (2015), Magmatic underplating and crustal growth in the Emeishan Large Igneous Province, SW China, revealed by a passive seismic experiment, Earth Planet Sc Lett, 432, 103-114.

Clark, M. K., and L. H. Royden (2000), Topographic ooze: Building the eastern margin of Tibet by lower crustal flow, Geology, 28(8), 703-706.

Deng, Q., P. Zhang, Y. Ran, X. Yang, W. Min, and Q. Chu (2003), Basic characteristics of active tectonics of China, Science in China Series D: Earth Sciences, 46(4), 356-372.

He, B., Y. G. Xu, S. L. Chung, L. Xiao, and Y. Wang (2003), Sedimentary evidence for a rapid, kilometer-scale crustal doming prior to the eruption of the Emeishan flood basalts, Earth Planet Sc Lett, 213(3-4), 391-405

Le Pape, F., A. G. Jones, M. J. Unsworth, J. Vozar, W. Wei, S. Jin, G. Ye, J. Jing, H. Dong, and L. Zhang (2015), Constraints on the evolution of crustal flow beneath Northern Tibet, Geochemistry, Geophysics, Geosystems.

Rippe, D., and Unsworth, M., 2010, Quantifying crustal flow in Tibet with magnetotelluric data: Physics of the Earth and Planetary Interiors, v. 179, no. 3-4, p. 107-121.

Royden, L. H., B. C. Burchfiel, R. W. King, E. Wang, Z. L. Chen, F. Shen, and Y. P. Liu (1997), Surface deformation and lower crustal flow in eastern Tibet, Science, 276(5313), 788-790.

Sun, Y., F. Niu, H. Liu, Y. Chen, and J. Liu (2012), Crustal structure and deformation of the SE Tibetan plateau revealed by receiver function data, Earth Planet Sc Lett, 349–350, 186-197.

Unsworth, M. J., A. G. Jones, W. Wei, G. Marquis, S. G. Gokarn, J. E. Spratt, and I.-M. Team (2005), Crustal rheology of the Himalaya and Southern Tibet inferred from magnetotelluric data, Nature, 438(7064), 78-81.

Xu, Y. G., He, B., Chung, S. L., Menzies, M. A., and Frey, F. A., 2004, Geologic, geochemical, and geophysical consequences of plume involvement in the Emeishan flood-basalt province: Geology, v. 32, no. 10, p. 917-920.

Zhao, L. F., X. B. Xie, J. K. He, X. B. Tian, and Z. X. Yao (2013), Crustal flow pattern beneath the Tibetan Plateau constrained by regional Lg-wave Q tomography, Earth Planet Sc Lett, 383, 113-122.

Deep lithospheric structure beneath Dolsk and Odra fault zones as a result of integrated Magnetotelluric 1-D, 2-D and 3-D data interpretation.

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ABSTRACT

The scientific aim of the project is identification of the crust and upper mantle structure around a part of the Fore-Sudetic Monocline. The new data obtained from the measurements and the data from the Pomerania studies and also from our previous research from eastern part of Fore-Sudetic Monocline, will be used to a better establishment of the boundaries of lithospheric blocks (terranes) as well as to recognize their origin. The magnetotelluric (MT) soundings were carried out to achieve this goal. The collected data allow to construct 3-D models of the conductivity distribution.

The research area is characterized by remarkably complex geological structure and unclear history of tectonic evolution. The area involves the region of the Dolsk fault and the Odra fault. These zones are important geologic borders of a regional nature and they pull apart the crust blocks which have different origins. The character of this geological structure is currently almost unknown. The area was covered with a relatively dense network of deep seismic profiles but the doubts about the fault zones are not settled. The Variscan basement between these two faults is not well-known as well, that is why it attracts interest a strong group of researchers. The previous geophysical results, mainly seismic, show that it is highly likely that the Dolsk fault zone mark out the polish, northern border of the Variscan crust. It is worth to admit that the Odra fault is a natural continuation of the Elbe fault in the eastern Germany. Taking into account the previous local logging and geological studies, the need for a thorough and large-scale magnetotelluric basic research, seems to be natural.

There were conducted 51 soundings on five parallel profiles. That allow to construct a regular mesh in the area of the Fore-Sudetic Monocline. Processing and preliminary data interpretation were conducted according to the progress of field work. There were created 1-D and 2-D models by using the inverse algorithms. The models were prepared for each profile separately. Finally, there were applied a parallel (ModEM) 3-D inversion codes. ModEM is an inversion code which employs MPI and which, besides impedances, includes tippers.

The results of our study shed additional light on the problems connected with the geology and geotectonic of this area. The obtained models of conductivity distribution document the existence of deep conductive faults and show the differences in resistivity structure of distinctive crust blocks. It allows a relevant supplement of foregoing knowledge, thereby to obtain more delighted recognition of the Dolsk and Odra fault zones This research project substantially permits for better reconstruction of the tectonic evolution of Baltika foredeep.

Keywords: Fore-SudeticMonocline, Odra Fault, Dolsk Fault, Magnetotellurics

Deep three-dimensional electric structure of Dabie orogen and southern section of Tan-Lu fault zone and its tectonic significance

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SUMMARY

The Dabie orogen is located in the transition zone between the north China plate and the south China plate. It is sinistrally offsetted from the Sulu orogen by the Tan-Lu fault zone. Some geophysical profile and three-dimensional structures with finite resolution played an important role in study of the two plates contact relations, but they are not sufficient for a study on detailed three-dimensional structural contact relations. Syn-collisional exhumation of Dabie ultrahigh pressure metamorphic rocks and post-orogenic magmatic activities played a significant role during the evolution of the orogen. In this work, we used 3-D inversion code in the electromagnetic inversion module ModEM to invert a data set that consisted of 449 broadband MT sites situated in Dabie orogeny and in southern of Tan-Lu fault zone. A three-dimensional impression and iterative reconstruction inversion technique and a multi-grid method was employed to reduce the effects of the initial model on inversion results. The three-dimensional electrical structure indicates: Tan-Lu fault zone is segmented. the section on the east side of the Dabie orogen separating the orogen (a resistance body) from the Qianshan basin (a conductive body). beneath the section to the north of Dabie orogen, there is a slender high resistive body along the fault zone, extend down to the depth of 25km, and corresponding to the surficial Zhangbaling uplift. In the eastern and northern of the Dabie orogen, the locations of those conductive bodies at the depth of 20-35km are in accordance with place of exposed early cretaceous granite and ultrahigh pressure metamorphic rocks. Below the depth of 75km, the resistivity values in north China pate are slightly lower than values in south China plate. More tectonic significance about the result need more comprehensive analysis of geological and geophysical data.

Keywords: Dabie orogen, Tan-Lu fault zone, electrical structure

Electrical conductivity distribution and its relation to types of magmatism beneath Hasandağ composite volcano, Central Anatolia, Turkey

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SUMMARY

Since mid-Miocene a series of volcanic activity took place in the vicinity of the polygenetic Hasandağ, Central Anatolia, Turkey, creating tholeiitic, alkaline and calc-alkaline magma series. While the ridge that derived the Neo-Tethyan ocean floor is responsible for generating the tholeiitic magma, the subduction of the ocean floor beneath Kırşehir block and the collision of Tauride-Anatolide to Kırşehir blocks along the Inner Tauride suture resulted in the calc-alkaline and alkaline magma series. The water content in the medium is considered as the key element for the development of calc-alkaline and alkaline magma series and iron (Fe) is a product of tholeiitic magma series. In this study, part of NSF-funded Continental Dynamics/Central Anatolian Tectonics Project, the signatures of these events and their results were traced by unveiling the electrical conductivity structure as both conduction mechanisms (either ionic and/or electronic) played crucial roles. The structure in the vicinity of Hasandağ, was imaged by means of three-dimensional numerical modeling of wide-band (320 Hz – 5000 sec.) magnetotelluric data collected at 40 sounding locations. Acting as barriers for fluid flow Hasandağ, Tuz Gölü and Keçiboyduran-Melendiz faults and cracks facilitated the transportation of volcanic material and were clearly traced on the resulting conductivity images. Induction arrows and phase tensor ellipses were benefited to examine the dimensionality of the magnetotellurics data.

Keywords: Hasandağı Composite Volcano, Fluids, Electrical conductivity,

Electrical Conductivity Structure beneath Mt. Erciyes Stratovolcano: Preliminary Results

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SUMMARY

Mt. Erciyes is the largest stratovolcano in Central Anatolian Volcanic Province of Turkey, which evolved in two distinct stages of the Quaternary. Since the trend of magmatism in a volcanic system determines the source type of igneous activity, tholeiitic to calc-alkaline series were produced during the Koçdağ and New Erciyes stages, respectively. There are several geochemical evidences present, claiming that fractional crystallization occurred during the formation of the volcano with minor crustal assimilation component. Moreover, there are proofs for magma mixing particularly on the samples gathered from the summit area. Imaging how the electrical conductivity structure is distributed in the vicinity of this stratovolcano may be used to resolve magmatism types, fractal crystallization, crustal assimilation and magma mixing processes. In this preliminary work, part of NSF-funded Continental Dynamics/Central Anatolian Tectonics Project, three-dimensional numerical modeling of profile based magnetotelluric data were used to develop electrical conductivity structure beneath the stratovolcano in the wide-band frequency ranges. Current models suggest that there is no clear sign of high conductivity anomaly beneath Mt.Erciyes as descending to a deeper source. However, in shallow portion, interconnected high conductivity zones are present and are bounded by local faults, which belong to Ecemiş Fault Zone within Erciyes pull-apart basin. Ongoing data acquisition will contribute to achieve enhanced models for comprehensive interpretations.

Keywords: Erciyes stratovolcano, magmatism, fluids, electrical conductivity, Central Anatolia

Crustal electrical constraints of the 4°50' shear zone (Hoggar-Southern Algeria)

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SUMMARY

The greatest 4°50' Hoggar (Southern Algeria) Shear zone also known in Nigeria as Kandi fault and in Brazil as Transbrasiliano lineament (TBL) has been described (Liégeois et al., 2003; Caby 2003) as a major suture zone between two domains, the metacraton LATEA and the Iskel bloc. The 4°50' shear zone played important roles during the different tectonic phases known in Hoggar from at least the Neoproterozoic until the present day.

In order to highlight the electrical behavior of this great lineament and its geodynamical evolution during the Neoproterozoic orogeny, the Magnetotelluric (MT) method has been used in a region where Neoproterozoic structures are widely manifested. 150 km Magnetotellurics NW-SE profile has been realized from LATEA (Central Hoggar) to In tedëini terrane (Western Hoggar).

The collected MT signals cover a wide frequency band from 100 to 0.001 Hz. The Phase tensor ellipses indicate a 2D structure until 100s. Up to 100s the regional structure is 3D. The strike varies from -15° (Crustal part) to +15° (Lithospheric mantle).

Two codes of inversion have been realized to deal with the limitations problems present in our case. 3D modeling is excepted for a suitable modeling and for a captive interpretation, for that, the acquisition of a second profile is already done. So, we expect to realize a 2D TM+Tipper inversion modeling for the two profiles using Mackie et al., 2001 algorithm code and realize afterwards 3D modeling of the entire data.

Figures, maps and more details will be discussed during this workshop.

Keywords: Hoggar, 4°50', Magnetotellurics, Phase tensor, 2D modeling.

Electrical resistivity models reveal mineralization and fault systems in the Valley of the Lakes, south-central Mongolia

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SUMMARY

The Valley of the Lakes, south-central Mongolia, is located between the uplifted Hangai Dome and the Gobi-Altai Mountains, within the Central Asian Orogenic Belt. It includes many interesting features, including the South Hangai fault system that represents an ancient suture zone and terrane boundary. This zone is possibly an extension of the Mongol–Okhotsk suture that resulted from the closure of the Mongol–Okhotsk Ocean. The adjacent obducted Bayankhongor Ophiolite Belt is possibly the longest continuous ophiolite belt in the world. This region is important because it is associated with the Bayankhongor Metallogenic Belt that is an economically significant zone for ore extraction in Mongolia, including important sources of gold and copper.

Electrical resistivity is a key parameter for mineral exploration. Because faults and suture zones are regions of fractured, weakened crust they often have circulating fluids that act to increase their electrical conductivity. Additionally, economic mineralization is commonly associated with a conductive signature from associated sulfide minerology. We present magnetotelluric data acquired in an array across central Mongolia (Comeau et al., 2018; Käufl et al., 2018; Becken et al., 2018; this abstract volume). The magnetotelluric data were used to generate 3-D electrical resistivity models of the shallow crustal structure, which was previously poorly understood.

Because the cratonic upper crust is highly resistive (>1000 ohm-m) the low-resistivity (<30 ohm-m) South Hangai fault system is easily detected. It is revealed to be a major crustal-scale structure. A clear transition in crustal electrical properties was observed across the suture zone and may reflect both the rheological and petrological differences across accreted terranes. Furthermore, anomalous, low-resistivity zones in the crust are spatially associated with the surface expressions of known mineralization and resource extraction projects. By combining our electrical resistivity results with other geological and petrological data we attempt to gain insights into the potential mineral resources of this unique region and their origin.

Keywords: Magnetotellurics, Mongolia, Valley of the Lakes, Hangai, fault zones, mineralization

Electrical resistivity models give evidence for crustal boundaries, a weak lower crust, and an asthenospheric upwelling beneath the Hangai Dome, Mongolia

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SUMMARY

The Hangai region in central Mongolia occupies a unique position in central Asia because it is a link between the Siberia craton and the actively deforming regions of northern China. It is believed to be a rigid pre-Cambrian crustal block, or micro-continent, and is bounded by large, seismically active, strike-slip faults that act to accommodate northwards compressional motion. Furthermore, it encompasses the Hangai Dome, an unusual high-elevation intra-continental plateau located far from tectonic plate boundaries and characterized by dispersed, low-volume, intraplate volcanism. The mechanism of uplift and support in the continental interior is an open and important question, as is the cause of intraplate volcanism. The processes responsible for developing this region remain largely unexplained, due in part to a lack of high resolution geophysical data.

Here we present newly acquired broadband and long period (0.008 – 10,000 s) magnetotelluric (MT) data collected in 2016 - 2017 across west-central Mongolia. This data set consists of a large regional array (610 km by 360 km), with a nominal site spacing of 50 km, and several long profiles, with 5 - 10 km site spacing, totaling 294 sites. This is the first study of its kind in Mongolia. For field efficiency, we installed both full MT sites and telluric-only sites, where inter-station transfer functions were computed. The profile MT data were used to generate electrical resistivity models of the crust and upper mantle below the Hangai Dome. 3-D modelling of the full array is described by Käufl et al. (2018; this abstract volume). Here we highlight the features of the electrical resistivity models, which offer new insights into the structure and origin of the Hangai Dome.

Although the upper crust is generally highly resistive (>1000 ohm-m), as expected for a cratonal block, it contains several anomalies that are coincident with surface features. These include: electrical signatures due to hydrothermal alteration from past magma ascent and eruption events, and large known fault zones including the Bogd fault system, the South Hangai fault system (Comeau et al., 2018; this abstract volume), and the northern Bulnay fault system (Becken et al., 2018; this abstract volume). Furthermore, south of the Hangai Dome a clear transition in crustal electrical properties is observed that may reflect the rheological differences across accreted terranes. Additionally the Bayankhongor Ophiolite Belt and the Bayankhongor Metallogenic Belt are identified. These mineralized zones, located adjacent to the South Hangai fault system that represents a major terrane suture, represent an important economic region for Mongolia.

The resistivity models show that the lower crust (25 – 50 km; below the brittle-ductile transition zone) beneath the Hangai Dome contains anomalous discrete pockets of low-resistivity (<30 ohm-m) material that indicate the presence of local accumulations of fluids. These anomalous regions appear to be spatially associated with the surface expressions of past intraplate volcanism, present-day hydrothermal activity, and known fault systems. They also correlate with observed crustal low-density and low-velocity anomalies. Critically, it provides compelling evidence that the crust beneath the Hangai region is not a homogeneous, strong, block, but rather contains a weak lower layer, which has important implications for lithospheric dynamics.

Petrological studies indicate a thin lithosphere below the Hangai region. The resistivity models show that the upper mantle (< 70 km) contains an anomalous low-resistivity zone directly below the Hangai Dome. This indicates a shallow, bulging asthenosphere and a zone of melt generation. The MT data require the presence of a small amount of partial melt (~6%) at this location, consistent with petrological data. We speculatively suggest that an upwelling asthenosphere could have been influenced by edge-driven convection from a substantial lithospheric step (>100 km) between central Mongolia and the Siberian craton. Overall, the results are consistent with a small-scale asthenospheric upwelling that supports uplift of the Hangai Dome and is responsible for intraplate volcanism due to decompression melting within the upwelling.

Keywords: Magnetotellurics, Mongolia, Hangai Dome, uplift, fault zones, mineralization, partial melt

Electrical Structure Beneath the Ordos Block and Its dynamic implication

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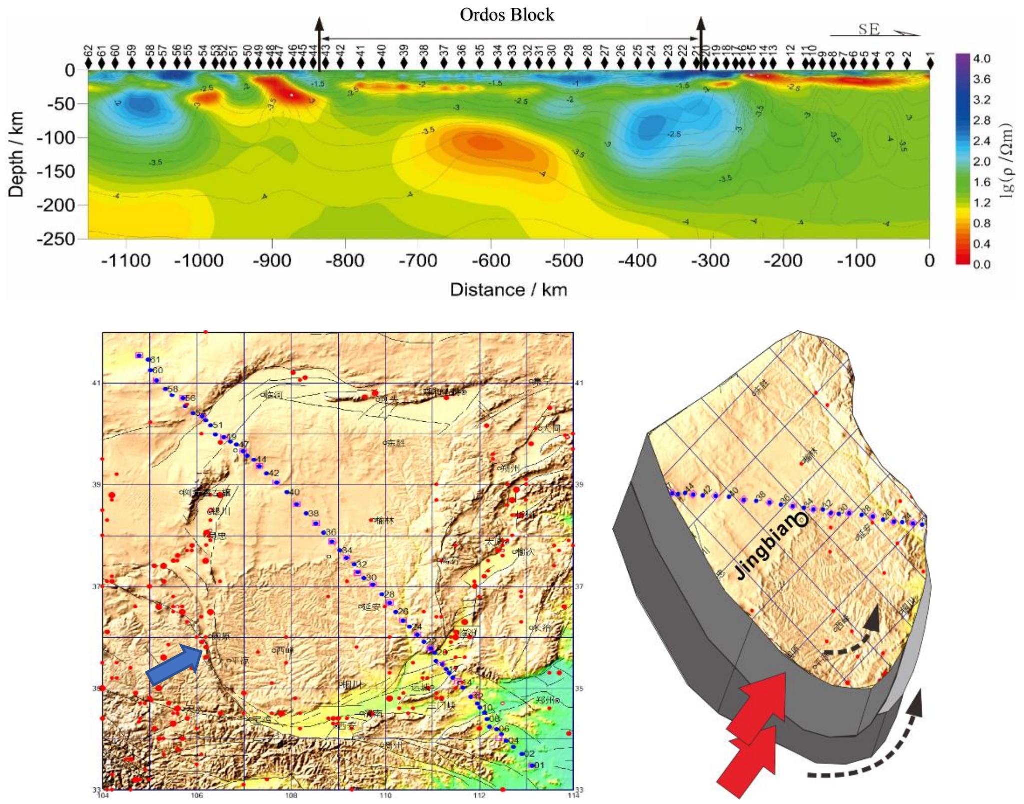
SUMMARY

The Ordos block is located in the western part of the North China Craton. Although the North China Craton has been destroyed since the Mesozoic, the damage was occurred mainly in the east part, the Ordos block is still very stable and there has never been an earthquake with magnitude great than 6. The velocity structure of the Ordos block given by seismic sounding is very simple and there is no low-velocity layer in the crust, further confirming that the Ordos block is a remnant stable craton. However, within the Ordos block, there are obvious differences between northwest and southeast landforms, and seismic activity is significantly different. The southeastern part is the Loess Plateau, which is tens of thousands of ravines, where have occurred tens of earthquakes with magnitude great than 5. In the northwestern part is the Maowusu Desert, which is a flat plain and there is no any earthquake occurred. This paper presents the detection results of a magnetotelluric profile crossing the entire Ordos block along NW. The total length of the profile is 1200 kilometers, including 62 broadband MT sites (effective frequency range is 320H-1/2000Hz) and 22 long-period MT sites (effective frequency range is 1/100-1/10000HZ). Through the impedance tensor imaging analysis, inversion result of electrical structure, and the result of numerical simulation of three-dimensional dynamics under the constraints of GPS velocity fields, we build up a dynamic model. In terms of the dynamic model, under the strong NE push of the Tibetan Plateau, decoupling movements along the middle-lower crust occurs in the southern part of the Ordos block. The conductive layer in the mid-crust of the Loess Plateau is enduring damage, and the fluid overflows, decreasing the electrical conductivity, increasing the deformation and seismic activity; while the northwestern crust has not yet been destroyed, and the original conductive layer is still preserved. The Ordos block is currently under destruction, and its stability depends on the fact that the southern part of the Ordos pushed by the Qinghai-Tibet Plateau is just a high-strength zone.

Keywords: Ordos Block, Magnetotellurics, dynamics



The upper is the resistivity model, the lower-left is the MT sites location, and the lower-right is the dynamic model based on the resistivity model and dynamic 3d modeling.

Evidence for crustal and mantle weak zones controlling intra-plate seismicity associated with the 2017 Botswana earthquake sequence

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Summary

Large earthquakes away from plate boundaries pose a significant threat to human lives and infrastructure, but such events typically occur on previously unknown faults. Most cases of intra-plate seismicity result from compression related to far-field plate boundary stresses. The recent Mw 6.5 earthquake in central Botswana, and subsequent events, occurred in a region with no previously known large earthquakes, occurred away from major present day tectonic activity, and, in contrast, accommodate extension rather than compression. The main event is near to the putative Okavango incipient rift, but is about 200 km off-axis, and on a fault that is roughly perpendicular to the rift trend. Here, we present results from an integrated geophysical study that suggests the recent earthquakes may be a sign of future activity, controlled by the collocation of a weak upper mantle and weak crustal structure, between otherwise strong Precambrian blocks. Magnetotelluric data highlights Proterozoic continent accretion structure within the region, and shows that recent extension and seismicity occurred along ancient thrust faults within the crust. Our seismic velocity and resistivity models suggest a weak zone in the uppermost mantle, that does not persist to greater depths, and is therefore unlikely to represent mantle upwelling. The Botswana events may therefore be indicative of top-down extension as a result of strain transfer from the incipient Okavango rift.

Keywords: magnetotellurics, intra-plate earthquakes, tectonics

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First results of new simultaneous MT/MV soundings in the Eastern Tibet and SE India

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SUMMARY

The first integrated results of simultaneous MT/MV soundings collected in 2010-18 in the frames of the EHS3D international project in the Eastern Tibet and SE India are presented and discussed. The data acquisition was held at and around several geotraverses in long-period (LMT) and broadband (BMT) period ranges simultaneously in groups of field sites and geomagnetic observatories. The multi-site data processing techniques were applied to get reliable impedance, tipper and horizontal MV data estimates using observations with different types of instruments. New data extend the array view at MT/MV transfer functions in the area from the Eastern Tibet across the Himalaya to the NE edge of the Indian Craton. The integrated data sets make possible to get 2D+ inversion solutions along joint profiles of ~2000 km length and to start 3D interpretation.

Keywords: Tibet, Himalaya, Indian Craton, simultaneous magnetotelluric soundings, conductivity anomalies

INTRODUCTION

The EHS3D international project was initiated by Prof. D. Bai and widely discussed in 2004 during the 17th EMIW in Hyderabad, India. First soundings were made in 2007 and 2009 by the Chinese team along EHS-2 and -3 profiles (Figure 1) in cooperation with Russian and Ukrainian scientists. LMT sites were collected with LEMI-417 and denser BMT sites with Phoenix instruments. 2D models based on BMT impedance data along EHS3D profiles were presented in (Bai et al. 2010). The model along the EHS-3 profile based on joint 2D+ inversion of long-period MT/MV data was described in (Varentsov et al. 2010). The constructed models justified the need to extend observations at profile edges at the Chinese side and to add soundings over the border in NE India. During the second EHS3D project phase since 2010 more soundings were made at EHS-2,3 profiles and a new EHS-4 profile was worked out between them. BMT and LMT data were collected as earlier. Finally, in 2016 at the third EHS3D phase the Indian-Russian subproject was started to make soundings along the EHS-IND profile in the Brahmaputra Valley. This time the KMS-820 instruments were used to get data in the joint BMT/LMT period range (Figure 2, red triangles). In addition, results from several tens of previous Phoenix BMT soundings (Figure 2, white diamonds) were integrated into the joint database.

This paper presents first results of the analysis of integrated data sets from all 3 project phases.

METHODS

The Russian multi-site data processing system (Varentsov 2015) was applied to estimate impedance, tipper and horizontal MV responses for all LMT sites (including resent Indian KMS-820 observations) and a part of BMT sites. 3-4 simultaneous remote sites were usually used in multi-RR estimation. Total numbers of processed LMT sites exceed 80 at the Chinese and 30 at the Indian sides. All Chinese and Indian BMT sites were processed with the Phoenix firmwere.

RESULTS

We mainly focus in this paper at the part of the EHS3D sounding array located south from the 30°E latitude (Figure 2). Figure 3 shows maps of extremal apparent resistivities (from Spitz decomposition) and phase tensor phases (from CBB decomposition) at the 2048 s period. These maps definitely indicate the highly resistive deep crustal structure below the Upper Brahmaputra Basin (UBB) comparing with strongly conducting adjacent Tibetan blocks and medium conducting zone (Gokarn et al. 2008) around the Shillong Plateau (SHP). The sedimentary conductance in the UBB reaches 400 S. The SW UBB edge seems to be the most contrast. Figure 4 presents the complex diagram of MV responses at the same period for the whole EHS3D area. The horizontal MV data are given there relative to the Shillong (SHL) observatory shown by the white star. These data are looking quite normal in NE India with minor inhomogeneity related to the currents within the UBB. The strongest anomaly in the maximal amplitude is seen north from the BNS line reaching 1.9 level. The strike of this zone changes from SE to SSE approaching the Yunnan province. Real induction arrows south from this zone naturally orients away from it. In NE India these arrows are small enough. The largest of them at the SW UBB edge have western orientation pointing away from deep conducting anomaly somewhere close to the Myanmar border.

CONCLUSIONS

The data collected in NE India looks quite consistent along the EHS-IND profile. However, they have medium to strong 3D distortions in almost all components. Their invariant analysis is to be continued in more details to properly select data sets for the joint 2D+ MT/MV inversion. At the same time, the achieved EHS3D array extension gives good grounds to start 3D data interpretation.

ACKNOWLEDGEMENTS

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REFERENCES

Bai D, Unsworth M, Meju M et al. (2010) Crustal deformation of the eastern Tibetan Plateau revealed by MT imaging. Nature Geoscience Let doi: 10.1038/NGEO830

Gokarn SG, Gupta G, Walia D et al. (2008) Deep geoelectric structure over the Lower Brahmaputra Valley and Shillong Plateau, NE India using magnetotellurics. Geophys J Int 173: 92-104

Varentsov IvM (2015) Arrays of simultaneous EM soundings: design, data processing, analysis, and inversion In: Spichak VV (ed) EM sounding of the Earth's interior: theory, modeling, practice. Elsevier, pp 271-299

Varentsov IvM, Bai D, Sokolova EYu (2010) Joint inversion of long-period MT/MV data at EHS3D transects (Eastern Tibet). 20th EMIW Ext. Abstracts. Egypt, Giza, S7-05

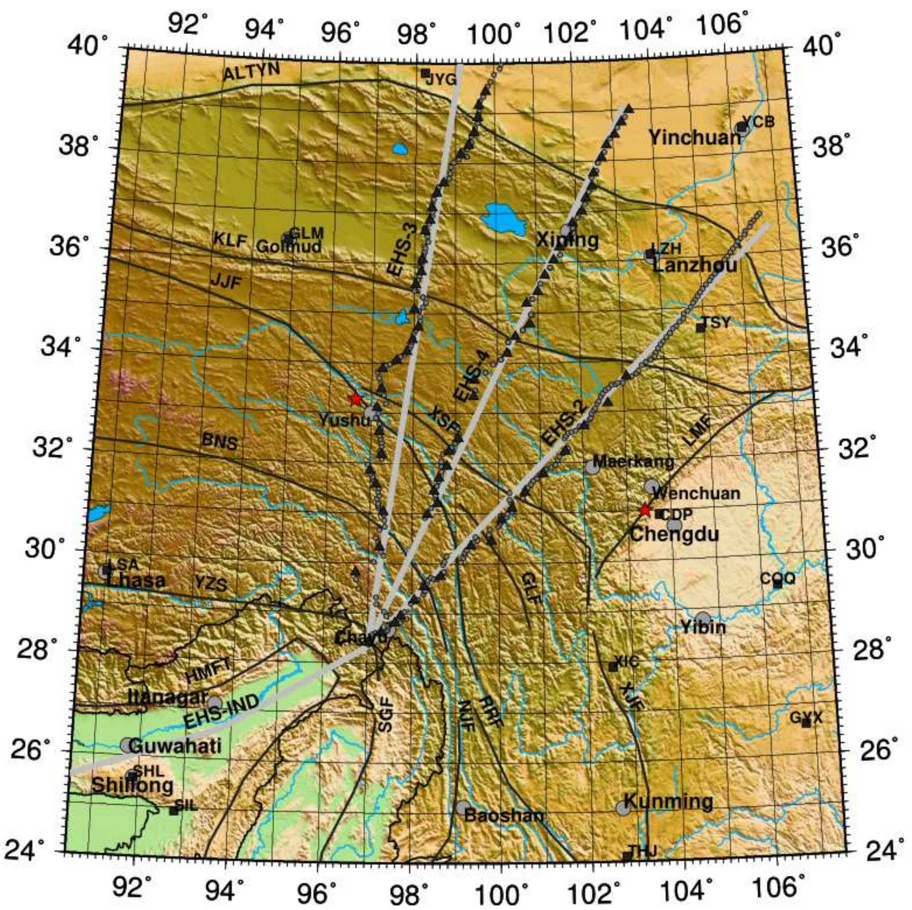

Figure 1. Simultaneous MT/MV sounding sites set up at EHS profiles in the Eastern Tibet: triangles – LMT, smaller circles – BMT, squares – geomagnetic observatories, tectonic lines – see (Bai et al. 2010).

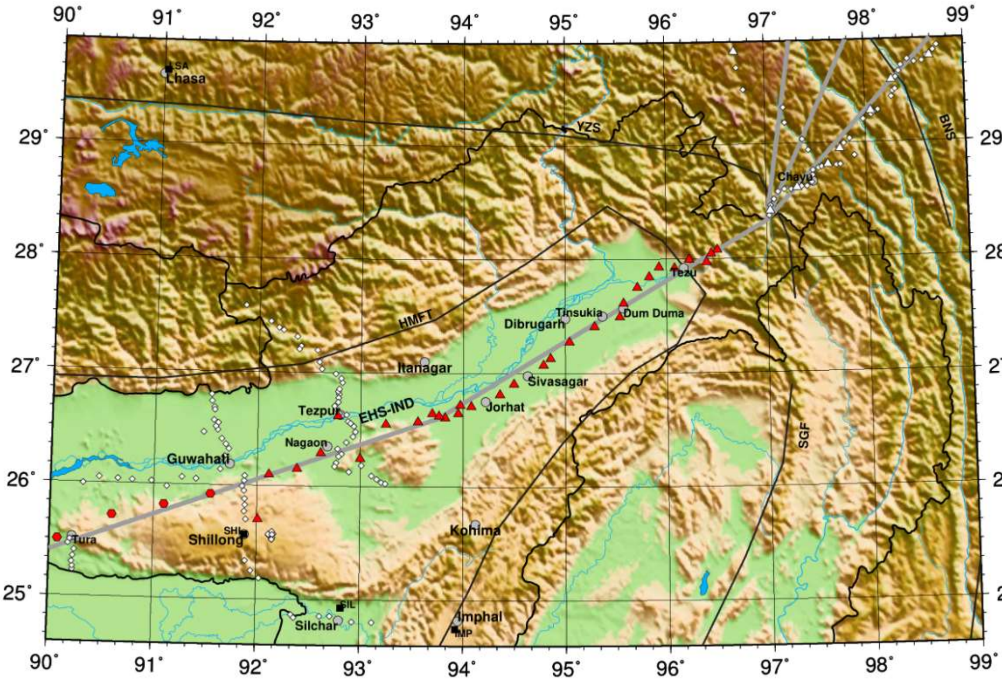

Figure 2. MT/MV sounding sites set up at and around the EHS-IND profile: triangles – LMT, smaller diamonds – BMT, hexagons – LMT sites to be collected, squares – observatories, tectonic lines – see (Bai et al. 2010).

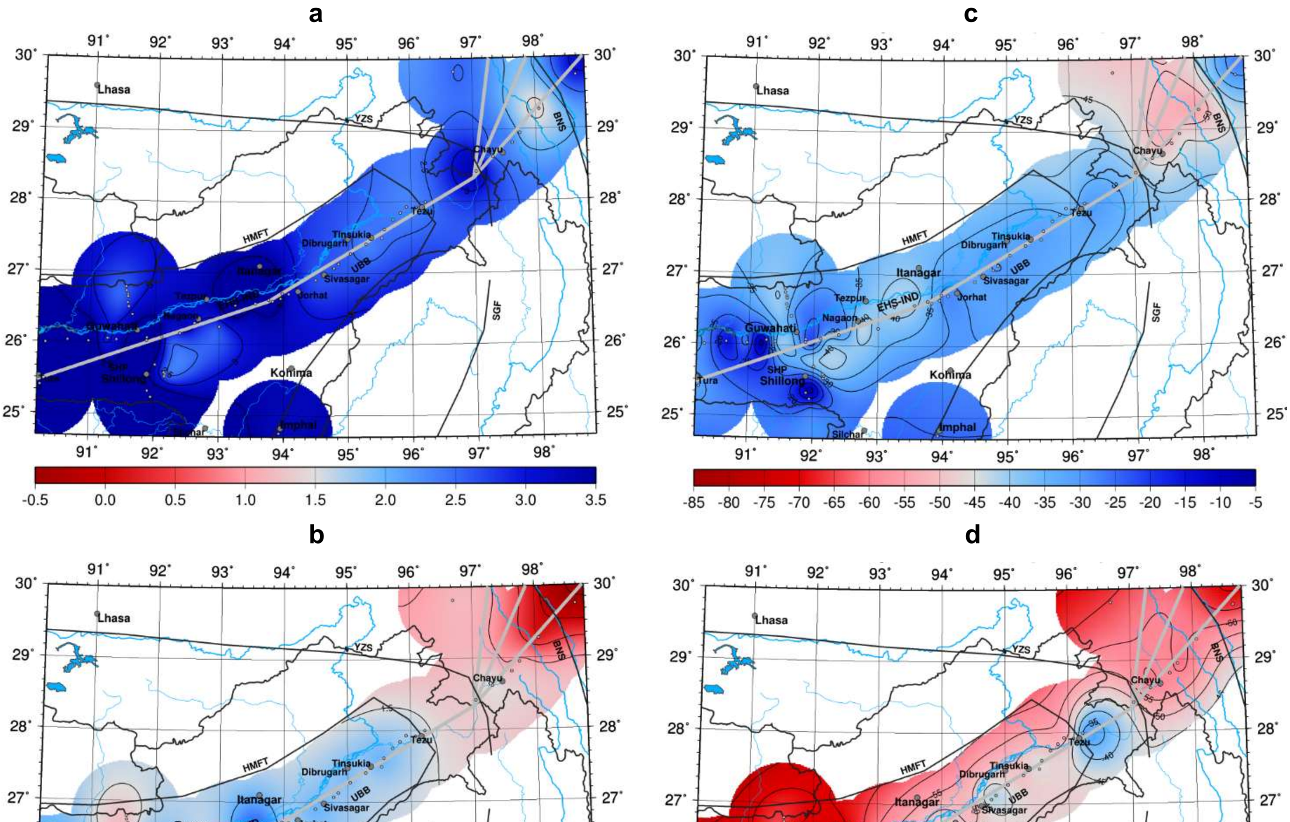

Figure 3. The impedance invariants at and around the EHS-IND profile: **a**, **b** – maximal and minimal apparent resistivities (Spitz decomposition, Ωm, lg-scale), **c**, **d** – maximal (closest to 0°) and minimal (closest to -90°) CBB phases (deg., convention with [-90, 0] 1D quadrant), respectively.

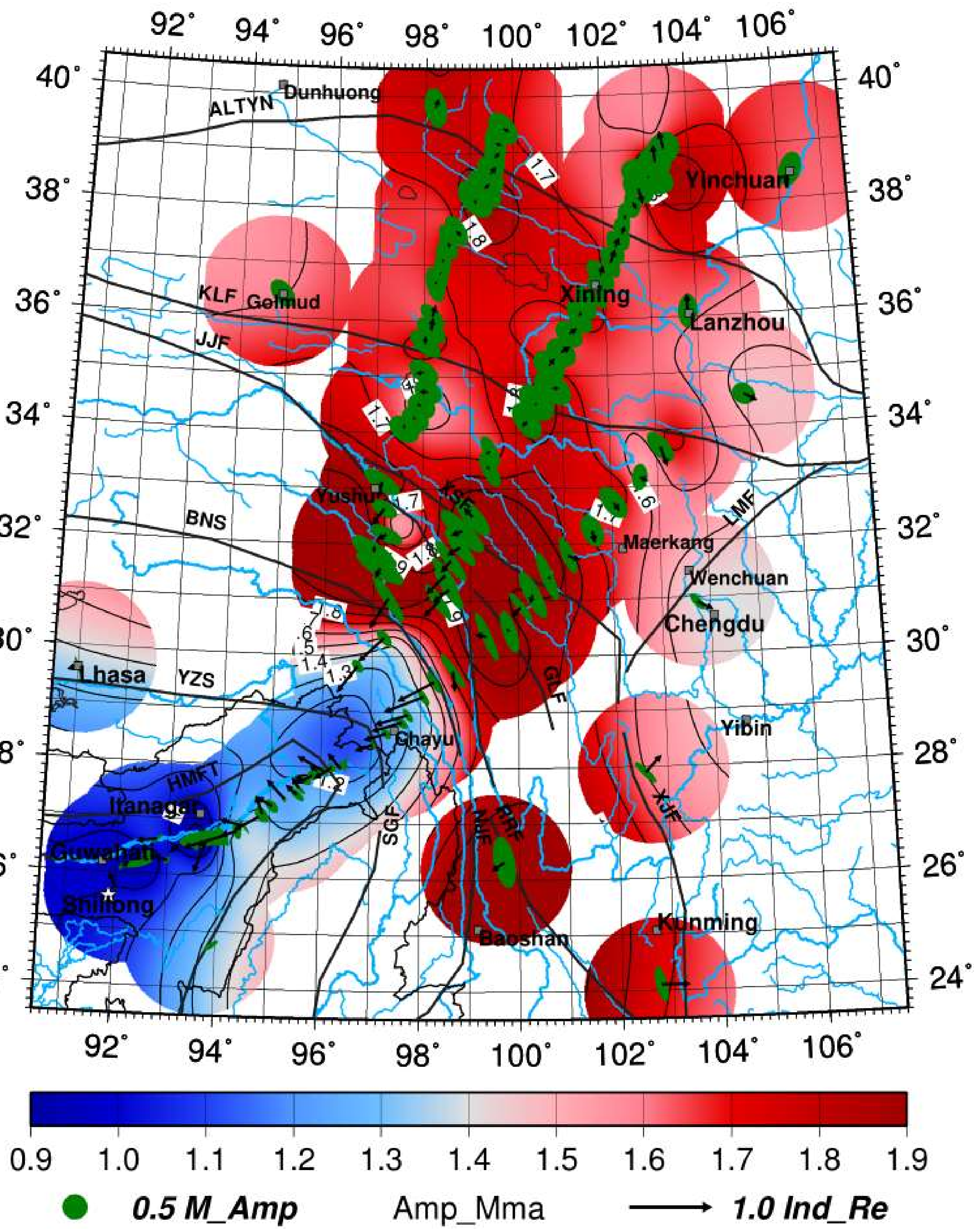

Figure 4. The diagram of MV data invariants for the EHS3D array at 2048 s period with the maximal amplitude map of the horizontal MV response (relative to the SHL site marked by the white star) overlapped with the extreme amplitude ellipses (green color, 90º-rotated) of its anomalous part and with black real induction arrows (Wiese convention); black solid tectonic lines – see legend in (Bai et al.2010).

Fluidized pockets in the lower crust beneath the Bulnay strike-slip fault system at the northern edge of the intra-continental Hangai high-plateau, Mongolia

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Summary

As part of the Hangai magnetotelluric array (cf. Comeau et al., 2018; Käufl et al., 2018; this abstract volume), we obtained magnetotelluric (MT) data along several profiles across the east-west oriented left-lateral Bulnay strike-slip fault system in Mongolia. The fault system is believed to accommodate clockwise rotation of the Hangai block at its northern edge. Compared to other major strike-slip fault systems, slip rate estimates of about 3 mm/yr are relatively small, but long earthquake recurrence intervals of thousands of years can account for accumulation of stresses eventually leading to large earthquakes. Two Mw>8 earthquakes with cumulative offsets of ~9 m ruptured the fault system over a length of 180 km and 375 km, respectively, in the twentieth century (Rizza et al., 2015). The driving forces for the uplift and rotation of the Hangai block and the deformation along the surrounding fault systems are yet poorly understood; both far field tectonic stresses or the interaction with dynamic mantle processes are discussed as the causes.

We discuss the MT data from four parallel profiles separated by ~50 km and with site spacings of 5-20 km. We carried out 2-D inversions as well as 3-D inversions of individual profiles and 3-D inversions of all four profiles simultaneously. 2-D inversions were justified by careful dimensionality and distortion analysis and the down-weighting of 3-D aspects in the data. Employing a two-stage inversion scheme, we down-weighted the TE apparent resistivities to reduce the effect of static shifts in a first stage, and in a second stage, resistivity structure and static shift factors at approximately 2/3 of the stations were jointly estimated. We used the Mare2DEM code by Key (2016) for this task. For 3-D inversions, which used ModEM (Egbert and Kelbert, 2012), the impedance data were inverted as is, but with error floors of 10% imposed on the data. Both 2-D and 3-D inversions could achieve excellent data fits and generated similar resistivities cross-sections. However, the 3-D inversion produced isolated structures beneath each of the profiles, which are separated by homogeneous regions close to the 300 ohm-m starting model. This suggests that 50 km profile separation is too large to obtain a coherent 3-D image of the crust by 3-D inversion without additional constraints. In turn, the 2-D inversions resulted in consistent images and revealed resistivity anomalies at comparable depths and at similar positions relative to the main fault strands. Our preliminary interpretation is therefore based on these 2-D inversions, leaving the task of improved 3-D inversion to future analysis (e.g. Käufl et al., 2018).

The MT data image the brittle-ductile transition zone (BDTZ) as a sharp resistivity boundary between a resistive upper crust (typically > 1000 ohm-m) and a less resistive lower crust (<300 ohm-m). The most intriguing features of the inversion models are distinct low-resistivity domains (between 5-25 ohm-m) embedded in the lower crust. These zones are separated by 40-60 km in the profile directions perpendicular to the fault and at remarkably similar profile positions relative to the Bulnay main fault strands. At least four such zones were imaged. It is important to note that these low-resistivity zones do not breach the BDTZ. Alternating resistive/ low-resistive zones in isotropic inversion models are often considered an indication for anisotropy. Therefore, we tested 2-D inversion with tri-axial anisotropy. This test excluded (tri-axial) anisotropy as the sole cause of these low-resistive zones, as the structural features were similar to those obtained with isotropic 2-D inversions. We consider therefore saline fluids as the likely explanation for the low resistivities in the lower crust. Fluid volumes of 5-8 %, assuming appropriate fluid resistivities, are sufficient to account for the observations. Under this premise, the MT images are in remarkable agreement with the conceptual model of fluid trapping in a depth of tectonically induced neutral buoyancy below the brittle BDTZ (Connolly and Podladchikov, 2004; Jiracek et al., 2013). Such fluidized zones behave as mechanically weak zones in a stronger crust and may significantly impact the deformation. We discuss our resistivity models in view of this conceptual model.

Keywords: Mongolia, intracontinental deformation, weak zones in the lower crust

Geoelectrical Signatures along the Satluj Valley, Northwest Himalaya, India

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Abstract

In order to understand the deep crustal structures and Geometry of Main Himalayan Thrust (MHT) beneath the Satluj valley, magnetotelluric (MT) investigation at 28 MT sites have been carried out by different field campaigns. The profile along the Satluj valley in North West Himalaya is important, as the southern end of the profile crosses Nahan salient and Northern part of the profile cut across Kaurik Chango Rift, a zone of concentrated seismicity. Collected MT time series data were robustly processed for an apparent resistivity curves using median as the robust estimators. At few stations, electric field recordings were very noisy perhaps due to ongoing hydro-electricity projects and unbalanced power network of the region reflecting larger error bars in estimated impedance tensors. The apparent resistivity curves were analyzed for dimensionality and decomposition. Swift skew and Bahr's phase sensitive skew indicate the complexity of geoelectrical structure, as none of site response of entire period band can be classified as strictly 2-D. Variation of skew parameters therefore suggest that dimensionality of the subsurface geoelectrical structure is band limited and varying depth wise. Modeling of the rotated impedances in the tectonic framework of the region is attempted and a shallow dipping mid crustal conductor is observed at an approximate depth of 5-10 km. The poster will present the subsurface resistivity variation along the profile obtained after rotating impedances in the tectonic framework of region and will briefly discuss the tectonic significance of major thrusts along the Satluj profile.

Geoscience Australia's Magnetotelluric program and data release

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SUMMARY

Geoscience Australia, in partnership with State and Territory Geological Surveys and research organisations, has applied the magnetotelluric (MT) method to image the resistivity structure of the Australian continent over the last decade. Data have been acquired at nearly 5000 stations through the collaborative national AusLAMP survey and regional MT surveys. The data provide valuable information for multi-disciplinary interpretations that incorporate various datasets. Most of these MT data have been released to the public.

To date, AusLAMP has been completed ~30% of the national coverage. Data have been acquired at nearly 1000 stations. This pre-competitive dataset will be an essential input to Geoscience Australia's Exploring for the Future program as well as a valuable resource for researchers to reconstruct the tectonic evolution of the Australian continent.

The regional MT surveys have been undertaken across potential mineral/energy provinces and greenfields areas in the Australia continent. A number of regional surveys have been completed recently. The MT data from the poorly understood Southern Thomson Orogen and Coompana region have improved understanding of cover thickness, sub-surface geology, and crustal architecture. The data reduce the uncertainty associated with intersecting the targeted stratigraphy for the pre-competitive stratigraphic drilling program. Comparison with drill-hole information indicates that the technique is capable of identifying major stratigraphic structures and providing cover thickness estimates with reasonable accuracy in regions where there is little surface outcrop and thick cover sequences.

The MT data from the Mount Isa inlier in northern Australia provide new insights into basement architecture, the crustal architecture and resource potential in this region. The data reveal some crustal-scale conductivity anomalies which correspond to known major crustal boundaries and faults. Those faults and boundaries are considered the primary factors in the partitioning of mineralisation in the region, with some conductors in the upper crust coinciding with known mineral deposits.

Keywords: Magnetotelluric, Regional, Cover-thickness, Architecture, Resource

Geothermal inferences drawn from 3D inversion of Magnetotelluric Data recorded from Chamoli region, Uttarakhand, India

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SUMMARY

Broadband Magnetotelluric (MT) data were recorded at 28 sites in Chamoli region, Uttarakhand, India to image the geoelectrical structure and its correlation with possible geothermal system in the area. MT data were processed using MAPROS software to obtain impedance tensor for each site. After processing, for 3D inversion, we have chosen impedance responses of 23 sites. MATLAB based 3D MT inversion code (AP3DMT 2017) has been used for the inversion of impedance tensor. Different inversion experiments were performed using initial guess model of homogeneous half space with varying resistivity values. Effect of regularization parameters was also studied by varying smoothness in x, y and z-direction. For the off diagonal impedance tensor a normalized Root mean square (nRMS) misfit of 2.3 was obtained; however, it was reduced to 1.7 after removing two sites having high nRMS values. The inverted geo-electrical model indicates an intra-crustal high conductive feature (< 10 ohm-m) around Chamoli region at a depth of 10-18 km. This conducting feature is moving upward and it seems to flow in multiple channels which reach upto the depth of one km from surface. These conductive channels appear to be correlated with the hot water spring in the area. The low resistivity (< 10 ohm-m) of this feature is an evidence of fluid-filled fractured rock with high concentrations of either aqueous fluids or melts or their combination. The meteoric water is flowing from the Higher Himalayan region reaching to these high conductivity zones and is transported to the surface in the form of hot water springs in the study area.

Keywords: 3D Magnetotelluric inversion, Hot springs, Main Central Thrust (MCT)

INTRODUCTION

The Himalaya is one of the youngest and highest mountain range, which originated from continental collision tectonics and under-thrusting of the Indian Plate beneath the Eurasian Plate. Regional N-S compression, resulting from horizontal movement of rock masses along the north dipping thrust planes, caused crustal shortening, horizontal extrusion and lithospheric delamination (Le Fort 1975; Molnar 1990). In this process, leading upper brittle portion of the subducting Indian crust has been sliced and stacked up southwards to form the Himalayan mountain belt. The various regional thrust systems in the area, namely, the Main Central Thrust (MCT), the Main Boundary Thrust (MBT) and the Main Frontal Thrust (MFT) are the elements of this geodynamical process. Magnetotelluric investigations were carried out in the Garhwal corridor along Roorkee to Gangotri (RKG) profile of the Uttarakhand Himalaya and Geoelectrical model presented earlier by Israil et al. (2008). In the present study we have recorded MT data at 28 sites in the east of the Roorkee-Gangotri profile in and around the Chamoli region. 3D inversion is performed from the processed MT responses using AP3DMT a MATLAB based inversion code (Singh et al. 2017).

GEOLOGICAL SETTING

The study area falls in MCT zone. The zone is characterized by dual strands. The upper and lower strands of the MCT are Vaikrita thrust (VT) and Munsiari thrust (MT) respectively (Valdiya 1980; Gupta et al. 2012). Together they form the MCT zone, a ductile zone where Higher Himalayan Crystalline (HHC) complex is placed over Lesser Himalayan Sequence (LHS). The metamorphic pressure and temperature across the MCT increase from 5 kbar and 550°C in the LHS to 14 kbar and 850°C in about 3 km zone of the MCT in the Higher Himalaya (Spencer et al. 2012). The zone is characterized as geothermally anomalous and high temperatures, high heat flow and hot springs (GSI 1991). The cluster of hot water springs are emerging in the area. The hot springs in the area have a temperature gradient of 60±20°C/km and the heat flow of 130±30mW/m^2 (GSI 1991). The hot springs in MCT zone shows high temperature in the range of 55°C to 94°C. Most of the thermal springs emerge through joints and are controlled by interface of lithological units.

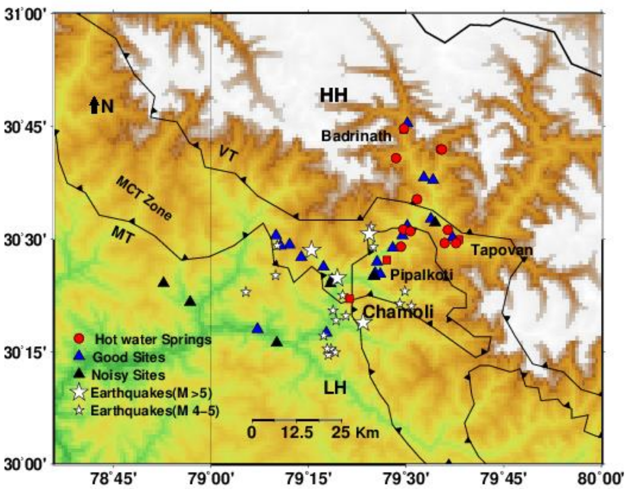

Figure 1. A simplified map, showing Garhwal Himalayan thrusts: MT: Munsiari thrust; VT: Vaikrita thrust; LH: Lesser Himalaya; HH: Higher Himalaya (complied from Valdiya 1980) and MT sites.

DATA ACQUISITION AND PROCESSING

Broadband MT data was acquired, at 28 sites, using Metronix ADU06 system in and around the Chamoli region. Locations of these sites are shown in Figure 1. MAPROS software (Friedrichs 2003) was used to estimate impedance tensor (Z) from the recorded time series. Out of 28 MT sites, 5 sites were discarded due to very high noise in the estimated MT response. Thus stable impedance tensor at 23 sites, derived in the period range 0.001-100s, are used in further processing and inversion. The response curves were smoothed using the numerical techniques and consistency test, a procedure available in WingLink, Geosystem code (WinGLink User's Guide). Smoothed responses, off diagonal impedance and full impedance tensor were used for 3D inversion.

3D INVERSION OF MT DATA

We used MATLAB based 3D inversion code, AP3DMT (Singh et al., 2017) for the inversion of MT data. This code uses non-linear conjugate (NLCG) gradient algorithm for minimization of penalty functional $\Psi = \Psi_d + \lambda\Psi_m$ composed of data misfit Ψ_d and model regularization term Ψ_m weighted by λ, the trade-off parameter. We have taken several inversion runs with different data selection, off-diagonal impedance tensor rotated in regional strike direction (N80^0W) and full impedance tensor. We also vary smoothness in x, y and z- direction keeping in view the regional geological strike. 3D geoelectrical model with robust features are presented in Figure 2 and 3. The prior and initial guess models were set as homogeneous half space of resistivity 100ohm-m. In the first inversion run all 28 sites were used for inversion of off-diagonal impedance tensor for 39 periods, logarithmically spaced between 0.001-100s. Data errors were set at 10 per cent of $|Zxy\ Zyx|^{1/2}$. For inversion, the model was discretized into 50×56×40 cells in X, Y and Z direction respectively. We also added seven cells (layers) in air. The inversion domain comprises a uniform mesh of 44×38x40 having a cell size of 1.7 km with 12 planes padded in each horizontal direction around the central domain. The vertical thickness of first layer is 50 m; the thickness of successively layers increases by a factor of 1.2. In 96 NLCG iterations, the normalized nRMS value reduced from 28.45 to 15.1. By analyzing the nRMS values for each site, we found that nRMS values at five sites were very high. It could be due to high noise level in the responses at these sites. We, therefore, removed these sites in the next stage of inversion run. Inversion was performed with 23 sites responses. In this inversion run we set the initial guess model as the output model obtained from the inversion of 28 sites. It is observed that the nRMS decreases from 5.13 to 3.44 in 73 iterations. Next, the inversion was done on 23 sites for full impedance with initial guess model of homogeneous half-space with resistivity of 100 ohm-m and the nRMS decrease from 20 to 3.4 in 85 iterations. In view of higher noise level, in the next inversion run, the data error floor was increased from 10% to 15%, keeping all the other inversion parameters same. In this inversion run the nRMS decreases from 13 to 2.34 in 68 iterations. In addition to the above, we have also carried out several inversion experiments by varying resistivity of homogeneous half space model used as initial guess model and found that the resistivity of 100 ohm-m is an optimum value. The off-diagonal elements were rotated by N80ºW (geological strike direction) and performed another inversion run with rotated off-diagonal elements. For this, the model was discretized into 60×63×44 cells in X, Y and Z direction respectively. The inversion domain comprises a uniform mesh of 42×45x44 having a cell size of 2.0 km with 18 planes padded in each horizontal direction around the central domain. For this the nRMS decreases from 9.4 to 1.83 in 67 iterations. The covariance was changed to study the effect of smoothness for both full impedance and rotated off-diagonal impedance tensor. We have found that, in general, broad features of the model are retained in the final inverted model. 3D inverted model and various depth slices are shown in Figures 2 and 3 respectively.

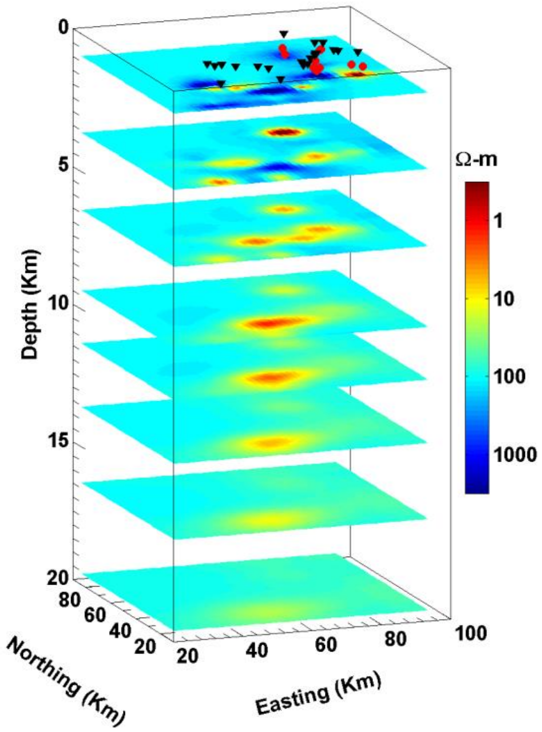

Figure 2. Model showing only the conductive features (less than 10 ohm-m) at various planes extending from z=0 to z=20 km. The black inverted triangles show the inverted sites and the red circles are known geothermal locations (GSI 1991).

DISCUSSION

A well planned MT survey is very crucial in mapping geothermal areas. In Himalayan tough terrain with limited accessibility, it is not possible to record MT data over a well defined grid. Therefore, MT site locations and their spacings are also guided by the accessibility and noise conditions. We conducted several inversion experiments by changing the control parameters, initial guess model and by choosing different data set. We observed that in general the prominent features of the inverse model obtained are common in most of the run with different final nRMS. The near surface is generally resistive (>500 ohm-m) except at few locations where the subsurface is fractured or influenced by the fluid filled zone Figures 2 and 3. Resistive near surface represents exposed lithology of quartzite rocks. The conducting (< 10 ohm-m) is located at a depth of 10-18 km around Chamoli region. This feature lies in the MCT zone and is an example of mid-crustal conductor. A similar conducting zone was also obtained by (Rawat et al., 2014) through 2D inversion of a profile extending from Bijnaur to Malari. Also, this high Conductive body is observed in MT profiles in various part of Himalayas like, Garhwal Himalaya (Israil et al. 2008), Nepal Himalaya (Lemonnier et al. 1999) located 50-70 km west and 500 east of Chamoli respectively and Sikkim Himalaya (Harinarayana 2009). As evident from Figure 2, the conducing zone appears emerging upward in the form of three channels from this main conducting body. One channel emerges around Chamoli region. In this region, the occurrence of moderate to high temperature springs have been reported (GSI 1991). The second limb terminates at a depth of 2.5-3.0 km while the third limb extends to the surface near the Tapovan hot spring.

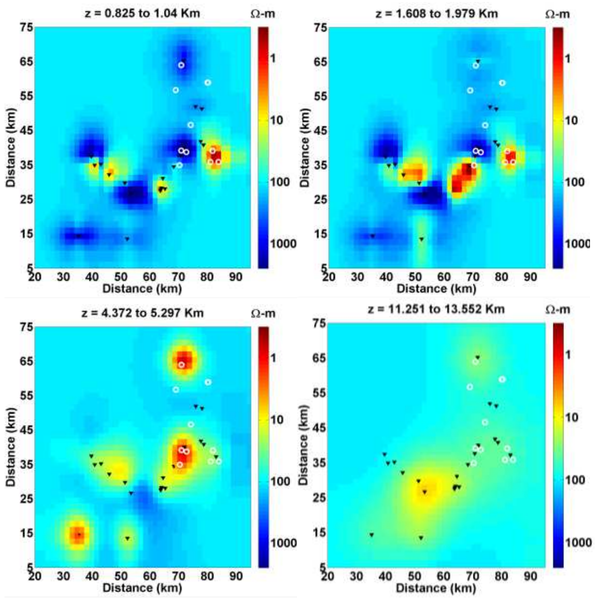

Figure 3. The depth slices at different depth for inverted model. The black inverted triangles show the inverted sites and the white circles are known geothermal locations (GSI 1991).

This high conductivity zones may owe their high conductivity to (i) fluids expelled from the underthrusted sediments (Arora et al. 2007) and (ii) fluids released by metamorphic reactions in the down-going plate slab (Hyndman 1988), although nature of fluids, still remains a subject of debate (see Li et al. 2003). At this depth, partial melt alone or in combination with free fluid may be contributing in high conductivity in the MCT zone. Most likely, the conductive phase is fluid, since under-thrusting of the Indian crust can ensure continuous recharge of the hanging wall by fluids released during dehydration reactions (Lemonnier et al. 1999). This zone is associated with high temperatures, high heat flow, and hot springs in the MCT zone.

CONCLUSION

The high conductive feature obtained in the MCT zone, from 3D inversion of MT data, is a coherent feature of MT profiles located to the west and east of study area. This feature is interpreted as inter-connected fluid filled rock system enhancing electrical conductivity. At a depth of 10-20 km, partial melt is the main contributor to the high conductance. However, the role of free fluids cannot be ruled out. These fluids move upwards through various weak faults and joints resulting in hot water springs in the vicinity of Chamoli. In some case they are trapped by overlaying crystalline rocks.

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REFERENCES

Arora, B. R., Unsworth, M. J., and Rawat, G. (2007). Deep resistivity structure of the northwest Indian Himalaya and its tectonic implications. Geophys. Res. Lett., 34(4).

Friedrichs, B. (2003). MAPROS: Magnetotelluric data processing software; Metronix GmbH; Braunschweig, Germany.

GEOSYSTEM SRL (2008) WinGLink User's Guide. Release 2.20.02.02. Italy.

GSI (1991). Geothermal Atlas of India, Geol. Surv. India Spec. Publ., 19, 143.

Gupta, S., Mahesh, P., Sivaram, K., and Rai, S. S. (2012). Active fault beneath the Tehri dam, Garhwal Himalaya- seismological evidence. Current Sci. (Bangalore), 103(11), 1343-1347.

Harinarayana, T. (2009). Geothermal energy scenario in India. In Proceedings of international seminar.

Hyndman, R. D. (1988). Dipping seismic reflectors, electrically conductive zones, and trapped water in the crust over a subducting plate, Journal of Geophysical Research: Solid Earth, 93(B11), 13391-13405.

Israil, M., Tyagi, D. K., Gupta, P. K., and Niwas, S. (2008). Magnetotelluric investigations for imaging electrical structure of Garhwal Himalayan corridor, Uttarakhand, India. Journal of Earth System Science, 117(3), 189.

Lemonnier, C., Marquis, G., Perrier, F., Avouac, J. P., Chitrakar, G., Kafle, B. and et al.,(1999). Electrical structure of the Himalaya of central Nepal: High conductivity around the mid-crustal ramp along the MHT. Geophysical Research Letters, 26(21), 3261-3264.

Le Fort, P. (1975). Himalayas: the collided range. Present knowledge of the continental arc. American Journal of Science. 275(1), 1-44.

Li, S., Unsworth, M. J., Booker, J. R., Wei, W., Tan, H., and Jones, A. G. (2003). Partial melt or aqueous fluid in the mid-crust of Southern Tibet? Constraints from INDEPTH magnetotelluric data. Geophysical Journal International, 153(2), 289-304.

Molnar, P. (1990). A review of seismicity and the rates of active underthrusting and deformation at the Himalaya. J. Himalayan Geol., 1,

Rawat, G., Arora, B. R., and Gupta, P. K. (2014). Electrical resistivity cross-section across the Garhwal Himalaya: Proxy to fluid-seismicity linkage. Tectonophysics, 637, 68-79.

Singh, A., Dehiya, R., Gupta, P. K., and Israil, M. (2017). A MATLAB based 3D modeling and inversion code for MT data. Computers & Geosciences, 104, 1-11.

Spencer, C. J., Harris, R. A., and Dorais, M. J. (2012). The metamorphism and exhumation of the Himalayan metamorphic core, eastern Garhwal region, India. Tectonics, 31(1).

Valdiya, K. S. (1980). Geology of the Kumaun Lesser Himalaya, Wadia Institute of Himalayan Geology, Dehradun. Google Scholar, 290-291.

Title: Imaging regional and local electrical structure in central Chile (35 – 36° S) using magnetotellurics: The Laguna del Maule Volcanic Field and its links to regional scale subduction processes

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Broadband and long-period magnetotelluric (MT) data were collected along an ENE profile in central Chile at 35° – 36°S in an effort to better understand the subduction processes at this latitude. In addition, an array of broadband MT data were collected at the Laguna del Maule Volcanic Field (LdMVF; 36°S, 70.5°W), which has been experiencing unprecedented upward ground deformation since 2007. These data were inverted to create a regional two-dimensional electrical resistivity model and a separate, local three-dimensional electrical resistivity model in an effort to better understand the links between shallow volcanic plumbing systems and the deeper regional structure.

In the local, 3D model, a large conductor is imaged to the north of the LdMVF at ~8 km depth and is interpreted as being a magma reservoir composed of hydrous rhyolitic-to-dacitic melt. It is hypothesized that this conductor is the primary shallow reservoir which is supplying heat and melt to the surface vents of the LdMVF via a dipping conduit which is also imaged. This suggests a lateral southward component of magma migration from depth to the surface vents.

The regional 2D inversion model images a conductive anomaly beneath the LdMVF which aligns with the location of the large conductor in the local 3D model. In addition, the 2D regional inversion model images a conductive zone beneath the modern volcanic arc at San Pedro-Tatara Volcano but no conductors are imaged west of the volcanic arc which precludes the possibility of continuous eastward arc migration. There are two conductors in the forearc above the slab interface at 35 - 50 km depth which are likely related to aqueous fluids released from dehydration of the down-going slab. No significant conductor is imaged at depths >50 km beneath the volcanic arc suggesting that zones of deep partial melting beneath modern edifices such as the LdMVF are neither large nor widespread.

Imaging the shallow structure of the El Tatio geothermal field, using Time Domain Electromagnetics

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SUMMARY

El Tatio geothermal field, located in the north of Chile, is the largest geothermal field in the southern hemisphere and the third largest in the world. It comprises more than one hundred active geothermal manifestations such as: geysers, perpetual spouter, fumaroles, hot spring pools and mudpots, including approximately 10% of the geysers in the world. Well known as a touristic attraction in north Chile, its structure and internal behavior have been briefly studied. Currently there are several key questions regarding the processes that control the different manifestations.

This study presents one of the first geophysical studies in the region with the objective to detect dominant subsurface structures and to understand there influence on the existence/development of the great variety of geothermal manifestations. The Upper Basin of the geothermal field is characterized by a lineament of several geysers in NE direction where a normal fault that bounds the El Tatio half-graben has been inferred, while the Middle Basin is characterized by a perpendicular lineament (NW direction) of perpetual spouters, where another fault has been inferred from geological studies. These evidences suggest a structural difference between these two zones that allows the lineaments of different shallow manifestations. In order to study these structures, TDEM data has been collected along several profiles crossing these zones to obtain an electrical resistivity model up to 100 meter depth and to (1) image the presence of fluids, (2) detect the inferred faults that could influence in the permeability of the rock and control the upflow of fluids.

At a starting stage, 1D inverse models have been calculated and a first idea of the resistivity distribution at depth has been obtained. Zones with very low electric resistivity (0.5 Ωm) were identified which are likely to be associated with fractured zones that allow the up-flow of hydrothermal fluids. However, in some of the profiles a lateral variation of the resistivity structure is evident, which enhances the necessity of 2D TDEM modeling tools. Therefore, 2D forward modeling studies are performed along the measured profiles, in order to estimate possible 2D effects.

Keywords: Time Domain Electromagnetic methods, Geothermal system, Electrical resistivity.

Imaging the transition from weakly to strongly coupled plate interface at the Hikurangi margin, New Zealand

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SUMMARY

Along the Hikurangi subduction-margin on New Zealand's east coast, plate-coupling changes from weakly coupled in the north to strongly coupled (or locked) in the south.

Previously, magnetotelluric (MT) measurements from the northernmost part of the margin (Raukumara peninsula) have shown a good correlation between resistivity variations and the pattern of areal strain rate derived from GPS data providing evidence that the fluid and sediment content of the interface shear-zone plays an important role in the degree of inter-plate coupling.

To further test this correlation, we have collected 160 new MT measurements in the Hawke's Bay region, across the transition from weak coupling in the north to locked in the south. 3-D inverse modelling of these data generally confirm the results from the Raukumara peninsula, showing an increase in resistivity in the upper plate from north to south. However, in contrast to Raukumara, a dipping conductor associated with the plate interface is not observed beneath Hawke's Bay, suggesting that less sediment is entrained in the subduction interface shear zone due to a smoother plate interface.

Our results show that in the weakly coupled part of the margin, lower resistivity in the crust of the overriding plate and the occurrence with seismicity shows that the plate interface is permeable and allows fluids sourced from dehydration in the subducting plate to migrate into the upper plate. In the locked southern part of the margin, the upper plate is resistive indicating that less fluids are available from the subducting slab and/or a less permeable plate boundary.

Keywords: Hikurangi subduction margin, plate coupling, magnetotellurics

Integrated interpretation of magnetotelluric sounding data for structural recognition of overthrust and folded orogeny, example from Sol area, Polish Western Carpathians

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SUMMARY

The flysch Carpathians represent a geological medium that is especially difficult for deep recognizing with use of geophysical methods. Complex geological structure of folded orogeny and connected with it distribution of physical parameters generates ambiguous and frequently unreadable seismic image. In the area of Sol, located in west part of polish outer Carpathians, magnetotelluric measurements were carried out along the selected fragments of seismic lines, crossing the outcrops of flysch formations, perpendicular to general strike of structures in the area of outer Carpathians. Within the framework of advanced data processing, next to the standard calculation of magnetotelluric parameters, including amplitude and phase sounding curves, static shift correction function was applied for elimination of effect caused as a result of near surface inhomogeneities. In this procedure results of vertical electrical soundings were used. It needs to be stressed, that lithological (and resistive) differentiation of flysch layers outcrops lying below thin layer of weathered material generates particularly strong effect of static shift, whose omission undermines the reliability of calculated resistivity distribution in geological medium.
Preliminary inversion of magnetotelluric soundings revealed a generalized distribution of resistivity in the flysch cover and its basement. The need of detailed recognition of flysch structures and potential identification of basement formations caused the execution of series of inverse modeling with taking into account so called constrains which are considered as limitations resulting from borehole data and results of processing and interpretation of seismic sections. Obtained resistivity cross-lines constitute the useful material used for support and verification of seismic data results and interpreted geological structure models

This paper was based on results of investigations carried out in the framework of the project of acronym „ShaleCarp” in “Blue Gas II " program financed by National Centre for Research and Development and co - financed by Polish Oil and Gas Company.

Keywords: *Western Carpathians, magnetotellurics, static shift, inversion, constrains.*

Integrated modeling of the lithospheric structures of Inner and Outer Western Carpathians in Slovakia

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SUMMARY

A multidimensional and multi-parametric geophysical modelling is presented in the area of contact zone between the Inner and Outer Western Carpathians. We used geophysical data collected during CELEBRATION 2000 project and project THERMES to perform magnetotelluric (MT), gravimetric and seismic studies of crustal and lithospheric structures. The integrated modelling with included MT and joint inversion is divided into two studied areas. The general model of the whole Central European area based on Tasarova et al., (2016) LitMod3D modeling is converted to the more detailed 3D model of eastern Slovakia and 2D/3D model of central Slovakia. The selected approach, where the regional bigger model is derived to the smaller models, secures removing of regional trends effects in small scale modelling. Almost 300 MT sites, gravity (Bouguer anomaly and Free Air data from global, national, and commercial databases), seismic data and models (CELEBRATION 2000 profiles, 2T deep seismic reflection profiles, Atlas of Slovak seismic profiles), and thermal data has been gathered and some of them reprocessed.

The central Slovakia 2T profile modelling was chosen for testing, because of the presence of several good quality geophysical data and previous studies in this area. The profile is crossing neovolcanic structures and other major Carpathian geological units. The ongoing 3D modelling of mostly 2D data already exhibits several features, which could not have been unveiled by previous simple 2D models. The modeling includes preliminary geophysical-petrological modeling of the investigated 2T profile area with thermaly-selfconsistent manner by LitMod3D code based on initial parameters and models from previous studies. The crustal part for LitMod modeling is prepared externally by joint inversion code and is imported with additional geophysical parameters.
Four basic segments can be identified in the crust structure of the central in central Slovakia part of the Western Carpathians: in the North there is a segment of the European Platform with overthrusted flysch nappes, further to South there is a segment of less dense mass with highly resistive parameters composed of mostly granitic and granitised hercynian complexes in the tectonic tatric unit, south of which there is another segment with mostly heavier and less resistive masses, represented by hercynian gneissic and mica-schist complexes (Alpine Veporic unit), and finally the southernmost physically distinctive segment with high full crust conductivity caused by young volcanic activity.

The eastern Slovakia MT modelling suggests more electrically conductive structures in the middle and lower crustal depths in comparison with Central Slovakia, where we observed structures dominated by resistive complexes overlaid by conductive sedimentary formations. The higher conductivities below the East Slovakian Basin restrict penetration depth of the geoelectrical images. The electrically conductive structures are connected with tectono-thermal development in Neogene and presence of volcanic activity. Another significant conductive anomaly is imaged along the contact zone between Inner and Outer Western Carpathians in depths of about 10 - 20km, which is known as the Carpathian Conductivity Anomaly (CCA).
A possible preliminary geological interpretation of the northern segment of investigated area suggests a resistive European platform below conductive flysch sediments. The boundary between Inner and Outer Western Carpthians represented by the Klippen Belt on the surface is changed to the CCA in higher depths. In the direction to the south, there are higher amount volcanic fluids in middle crustal depths. Our models are important to enable the understanding of the geodynamical and thermal processes during the collision of Carpathian block with the European platform and the connected development of the Pannonian Basin. There are still uncovered features in tectonic structures, which should be further investigated by integrated thermal geophysical modelling of available data.

Keywords: magnetotellurics, joint inversion, integrated modeling, Western Carpathians

Investigating crustal scale fault systems controlling volcanic and hydrothermal fluid processes, using regional scale magnetotelluric and gravimetric signatures in the South-Central Andes

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At convergent plate boundaries, volcanic orogeny is largely controlled by major thrust fault systems that act as magmatic and hydrothermal fluid conduits through the crust. In the south-central Chilean Andes, the volcanically and seismically active Tinguiririca and Planchon-Peteroa volcanoes are considered to be tectonically related to the major El Fierro thrust fault system due to their preferential orientation along the fault strike. These large scale reverse faults are characterized by 200 – 500m wide hydrothermally altered fault cores, which possess hydrothermally altered mineral haloes along the damage zone, and geothermally heated springs that occur along the outcropping fault plane. Another indicator of the link between the faulting and volcanism in this region are found in secondary order fault structures characterized by intrusive plutonic bodies , that possess geochemical alteration signatures related to copper-porphyry deposition. Few studies have been conducted in this study area, however a recent shear-wave and geochemical analysis of the Tinguiririca volcano concludes that a magmatic and hydrothermal system at 7- 10km depths is still active. This study contributes to a combined geological and geophysical survey of the study area, that aims to constrain the architecture of these tectono -magmatic features at depth, and their interaction with the active geothermal system. The primary method for this project is a combined magnetotelluric and gravimetric survey conducted on a 40km^2 grid within the selected study area. Long period Fluxgate magnetometers and broadband Metronix induction coil instruments were distributed along 30 sites with an average of 5km spacing in the selected field study region, and robust remote referencing techniques were performed using BIRRP to produce reliable impedance results.

The influence of local noise rendered the western sites and longer frequency ranges unusable, and therefore interest has shifted to shallow – mid crustal depths in the eastern limits of the surveyed area, where most geological features of interest occur. Preliminary results from resistivity pseudo-sections and 1D inversions indicate the presence of a conductive body at a 10km depth that migrates from east into west with increasing depth, the geometry of which will be determined with the 3D inversion. The gravity survey conducted in the same region show spatially coincident anomalies, where high density and high conductivity signatures occur at the base of the Tinguiririca Volcanic complex, and at an intersection of two structural features that converge at an exposed hydrothermally altered unit. Preliminary interpretation of the results conclude that these features occur as a result of fault interaction at depth, where intersecting fault planes act as fluid barriers within the crust, resulting in concentrated hydrothermal alteration of the host rock, therefore increased local conductivity and density properties. The continued 3D inversion of the magnetotelluric dataset will provide further constraints this hypothesis, insights into the conductive properties within the shallow crust, and a 3D model of the subsurface. This study will ultimately provide insight into the interaction of geothermal fluids with subterranean fault systems, and their influence on orogenic evolution of this region of the South Central Andes.

Joint 3D MT and GDS imaging beneath flood-basalts of central Paraná Basin, Brazil

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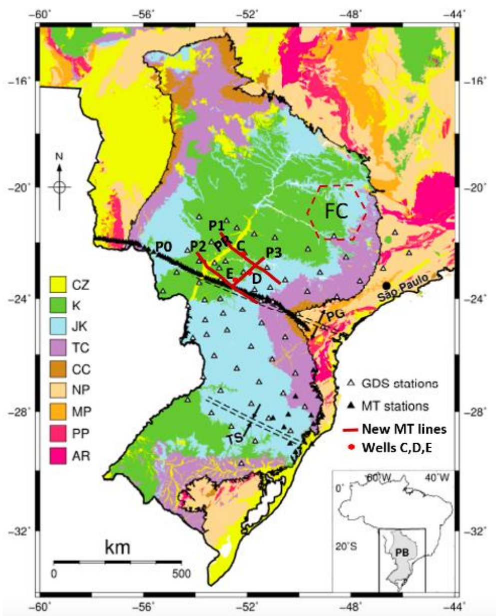
Summary

The deep crustal structure underneath the basalt-covered central part of Paraná basin is not clearly understood. We inverted three new Magnetotelluric (MT) profiles in 3D to reveal the local-scale resistivity structure of the central part of the basin. We validated our 3D modeling results with resistivity logs of three deep exploration wells. MT model maps the resistive (>100 Ωm) flood basalts, and post-volcanics cover layer, the underlying electrically conductive (~10 Ωm) sediments and the highly resistive (>1000 Ωm) crystalline basement. It also distinguishes highly resistive thick upper crust and conductive lower crust above a resistive mantle. Subsequently, joint MT and geomagnetic depth sounding (GDS) 3D inversion imaged two prominent sub-parallel bands of N-S and NNE-SSW trending steep conductors in the deep crust and upper mantle. One of the deep conductive zone lies beneath the present-day axis of thickest sedimentary sequences in the basin, whereas, other deep conductive zone lies near the coast boundary, where dolerite dyke swarms intrude the outcropping Precambrian basement. These two conductive zones bound a ~500 km wide resistive block dissected by NW-SE linear crustal conductors where deepened Moho and P-wave velocity and density anomalies in the upper mantle have been noted by previous workers. These linear conductive zones appear to delimit the Paraná magmatic province at depth and are interpreted as shear-zones in the lithosphere exploited by arc magmatism, which controlled the basin evolution and served as conduit paths for the voluminous Early Cretaceous magma within the region.

Keywords: MT, GDS, basalts, sediments, Paraná
Reference: Maurya, V.P., Meju, MA., Fontes SLF, Padilha AL, La Terra EF & Miquelutti LG (2018), Deep resistivity structure of basalt-covered central part of Parana basin, Brazil from joint 3D MT and GDS data imaging. *Geochemistry, Geophysics & Geosystems* (accepted).

Figure. 1



Joint interpretation of AMT and gravity data for clarification of Pasha-Ladoga Basin structure (NW Russia)

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SUMMARY

Clarification of the Pasha-Ladoga Basin structure was conducted using joint interpretation of audiomagnetotelluric (AMT) and gravity data. AMT investigations were performed along a regional profile with a length of 86 km, and three additional 10 km profiles within the south-eastern part of the basin. A four-layered geoelectrical model was obtained up to a depth of 2 km according to 2D inversion results of AMT data, and model interpretation enabled determination of the upper and lower boundaries of Riphean rocks in the Ladoga-Pasha Basin. Maximum thickness of the zone of the Riphean deposits was established at the central part of the regional profile. Joint AMT and gravity data interpretation results clarified a division of the Pasha-Ladoga Basin area and determined two fore deeps and a central linear zone with a trough structure, where the zone is characterized by a maximum thickness of Riphean deposits and corresponds to the linear positive anomaly of the gravity field in a north-western direction. Results of gravity field modeling show that this anomaly relates to heavy rocks, which are probably basalts and mafic volcanic rocks. The structure of this zone and its filling by mafic volcanic rocks can be interpreted as a rift structure, and based on gravity data the rift structure is found to extend to the Ladoga Lake area, with an observed length of about 140 km and a width of 17–25 km. The results obtained in this study allow better definition of the borders and specification of the Pasha structure's rift origin.

Keywords: Pasha-Ladoga Basin, Pasha Rift, audiomagnetotelluric sounding, gravity survey.

INTRODUCTION

The Pasha-Ladoga Basin is located on the border between the Russian Plate and the Fennoscandian Shield and is controlled by the Ladoga-Bothnia zone of deep long-living fractures at the joining zone of the Karelian and the Svekofennian geoblocks (Amantov 2014). The geological structure of the Pasha-Ladoga Basin and surrounding area has been considered in a number of studies (Amantov et al. 1996; Stupak and Leshchenko 2008; Kuptsova 2012; Amantov 2014). However, the interior structure of the basin has not yet been adequately researched. In the south-eastern part a separate structure, known as Pasha Graben, has been determined in the interior part of the basin using geophysical data (Amantov et al. 1996; Amantov 2014).

The aim of this study, therefore, is to determine the interior structure of the Pasha-Ladoga Basin according to a joint interpretation of available regional gravity data and audiomagnetotelluric soundings (AMT) along a regional profile with a length of 86 km and three additional profiles with a length of 10 km each.

Geological setting

The Pasha-Ladoga Basin is part of the widespread rift system lying under the sedimentary cover of the Russian Plate in the western part of the Fennoscandian Shield (Kuptsova 2012). The basin contains Riphean sedimentary and extrusive rocks and extends from the Ladoga Lake area to the south-east. Riphean sediments fill the northern part of the Ladoga Lake sub-bottom, and outcrop in the eastern and western parts of the lake's coast. In the southern and south-eastern parts of the study area, the Riphean rocks are covered by the Vendian-Paleozoic sediments of the East European Platform.

AMT data

Data were acquired from 121 stations; 87 of these stations belong to the regional profile in a north-east direction (Line A-B), 13 stations are situated along the cross profile (Line-1), and 21 stations are located along two parallel profiles (Line -2 and Line-3). Figure 1 shows the survey area. There is an average distance of 1 km between stations on each profile. AMT measurements were conducted using the ACF-4M system (Saraev et al. 2011), and the measurement array at each station provided a record of electric (E) and magnetic (H) horizontal electromagnetic field components in directions magnetic north (Ex and Hx) and east (Ey and Hy). Each station in the study area was remotely referenced using a station situated approximately 30 km away from it. Measurements at each station were conducted in 0.1-1000 Hz frequency range. AMT field data were processed using SM+ software, which is included in the ACF-4M set (Saraev et al. 2011).

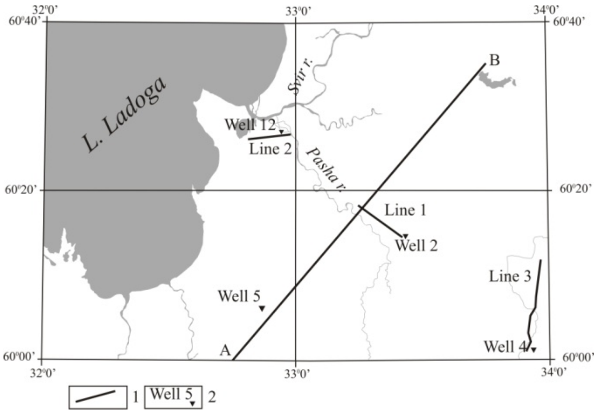

Figure 1. Location map of (1) AMT sounding lines, and (2) wells

After processing, AMT data analysis and inversion were then conducted using ZondMT software (www.zond-geo.com). The inversion procedure included two stages. In the first stage we used effective impedance values for 1D inversion using ZondMT software. Well data were also used in 1D inversions. The geoelecric model obtained has a positive correlation with well data. Vendian-Paleozoic deposits, which are composed mainly of clays, are characterised by resestivity values of about 10 Ω·m. A low thickness layer with resistivity values of about 100 Ω·m is observed in the upper part of the model, which corresponds to sandstones and limestones. Riphean sandstones with basalt interlayers are also characterised by resistivity values of about 100 Ω·m, and increasing resistivity of up to 1000 Ω·m is observed in the bottom part of the model, which corresponds to Arhean-Proterozoic rocks of the crystalline basement.

The geoelectric model obtained from 1D inversion for stations with a small RMS value (less than 8 %) was applied as the initial model in the 2D inversion. The Occam inversion (deGroot-Hedlin and Constable 1990) algorithm was used for 2D inversion. We applied the joint TE + TM inversion because it allowed inclusion of both polarization information, which is superior for medium with horizontal heterogeneities. The RMS error value of the resistivity model obtained was 2.8%.

The geoelectrical model along Line A-B was obtained according to a 2D inversion of AMT data (Figure 2a). Four layers are determined in a depth range of 50–2000 m. The first shallow layer (up to 100 m depth) is observed for only some parts of Line A-B, and a small increase in the resistivity value of up to 100 Ω·m is established for this layer. The second layer is characterized by low resistivity values (1–50 Ω·m) and a constant thickness along the investigated profile. The third layer has resistivity values of 50–500 Ω·m, which are observed from the south-western end of Line A-B to Station 68. The resistivity of the fourth layer exceeds 500 Ω·m. However, the geoelectric model is complicated by vertical heterogeneities of low resistivity values (less than 10 Ω·m) at Stations 20–24 and 75–83.

Well data and available geological information were used in interpretation of the geoelectric model. The second layer of low resistivity was found to correspond to Vendian-Paleozoic sedimentary rocks mainly consisting of clay stones. Lenticular high resistive zones in the upper part of this layer represent the Paleozoic sandstones and limestones. The Vendian-Paleozoic deposits overlay older rocks in the study area, and their thicknesses vary from 250 m in the north-western part of Line A-B, increasing in its central part to 450 m, and in the south-eastern part reaching 300 m. The third layer consists of Riphean sandstones, siltstones, and extrusive rocks of the Pasha-Ladoga Basin.

The data obtained in this study allowed us to determine the upper and lower boundaries of Riphean rocks and the geological features of both the Pasha-Ladoga Basin and the crystalline basement structure along Line A–B. Riphean deposits were observed at Station 68, where their lower boundary is located at 300 m. In a south-west direction towards Station 55, the lower boundary dips smoothly in small increments, and after reaching a depth of 600 m it then dips more steeply at Stations 38–55 up to a depth of 900 m. A trough structure with steep walls is observed at Stations 10–38, where the thickness of the central part of Riphean deposits is more than 2 km. In addition, a low resistive vertical zone connected with a fault is determined at Station 22.

The fourth layer corresponds to high resistive rocks of the Archean-Proterozoic crystalline basement; in this layer the conductive zone is observed at Stations 75–82 and is probably in relation to the flat dipping fault and graphitic zone in the Low-Proterozoic schists (as graphitic schists of the Low-Proterozoic Pitkaranta Suite are known in the northern and eastern Ladoga regions) (Stepanov et al. 2004, Kotova et al. 2011).

Technique used for density distribution modeling

Density distribution modeling was implemented using GM-SYS software (Geosoft Inc.) and the Bouguer gravity map 1:200000 from the Federal Database of gravity and magnetic data «GRAVIMAG» (VIRG «Rudgeophysica», Saint-Petersburg, Russia). Gravity field plots were obtained along investigated profiles from an area with a matrix of 200 x 200 m. The coincidence of observed and calculated gravity field curves was used as correctness criterion in the obtained density model.

Configuration of polygons was set based on AMT, well data, and geology. Density values were set for each of the model polygons according to a laboratory-based core study for neighboring areas. The following density values were specified for different rocks in the area investigated: Vendian-Paleozoic sediments 2.4 g/cm3; Riphean sandstones with a basalt interlayer 2.6–2.7 g/cm3; Riphean basalts and dolerites 2.9 g/cm3; Riphean rapakivi granites 2.6 g/cm3; gabbro 2.9 g/cm3; Low-Proterozoic shields and gneisses 2.75–2.78 g/cm3; Archean gneisses and migmatites 2.75 g/cm3; Archean amphibolites 2.83 g/cm3.

Joint geological interpretation results.

The geoelectrical model obtained along Line A-B was used for the gravity field modeling and geological model construction (Figure 2c). According to the results of modeling, gravity field anomalies at sites of the lower boundary of flat bedding Riphean deposits were determined by heterogeneities in the crystalline basement, and the trough structure allocated by AMT data corresponds to the gravity positive anomaly. The results of modeling have shown that this anomaly is caused by heavy rocks (density 2.9 g/cm3), and is thus probably represented by Riphean basalts and mafic volcanic rocks. The lower boundary of these rocks lies at a depth of 4 km. The positive gravity anomaly corresponding with the trough structure at the Line A-B has a linear behavior and extends to the Ladoga Lake area (Figure 3).

The results of joint interpretation allow us to divide the Pasha-Ladoga Basin area (Figure 3). Two fore deeps and a central linear zone with a trough structure are determined according to geological data and the behavior of geophysical fields. The upper and lower contacts of Riphean deposits in the north-eastern fore deep, obtained along the additional AMT profiles (Line-1, Line-2 and Line-3 in Figure 1), confirm the increasing thickness of these deposits in a south-westerly direction. The principal feature of the central linear zone is the gravity field, which is a linear positive anomaly in a north-westerly direction, and is crossed by Line A-B in its south-eastern part. The structure of this zone, and the fact that it is filled with mafic volcanic rocks, could allow it to be interpreted as a rift structure. This assumption is also inferred from gravity data. The zone extends to the Ladoga Lake area (Figure 3), has an observed length of about 140 km, and a width of 17–25 km.

The Pasha Graben boundaries determined during previous investigations using geophysical data (Amantov et al. 1996; Amantov 2014) join the rift structure in the north-east and have the same strike direction. However, previous researchers have noted that the borders are assumptive. AMT data, and the results of density modeling, show the maximum thickness of the Riphean deposits outside the Pasha Graben borders determined in previous investigations (Figure 3). Thus, it is confirmed that this study allows an accurate determination of borders, and the ability to specify the rift origin of the Pasha structure.

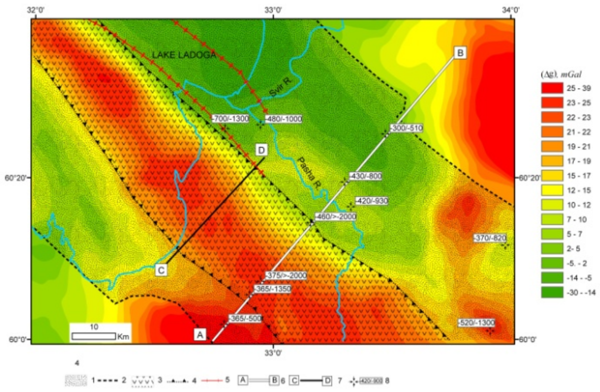

Figure 3. Bouguer gravity map and tectonic map of Pasha-Ladoga Basin. 1. Fore deeps; 2. Borders of Pasha-Ladoga Basin; 3 and 4. Pasha rift and boundaries; 5. Part of Pasha graben according to Amantov et al. 1996; 6. Line of AMT and density modeling; 7. Line of density modeling; 8. Depth values of upper and lower boundaries of Riphean deposits by AMT data.

CONCLUSIONS

New data pertaining to the south-western part of the Pasha-Ladoga Basin structure are obtained according to joint AMT and gravity data interpretation. The AMT results allow determination of the upper and lower boundaries of Riphean rocks and the distribution of a trough structure. The use of gravity field modeling determines this to be a structure lying in a north-westerly direction. The structure is composed of heavy rocks that are probably basalts and mafic volcanic rocks. The results obtained enable a more accurate definition of the borders of the Pasha structure, and allow us to specify its rift origin.

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REFERENCES

Amantov, A.V. (2014) The geology of the Pre-Quaternary deposits and the tectonic of the Ladoga Lake. Regional geology and metallogeny, 58, 22-23. (In Russian)

Amantov, A., Laitakari, I. and Ye. Poroshin (1996) Jotnian and Postjotnian: sandstones and diabases in the sorroundings of the Gulf of Finland. Explanation to the Map of Precambrian basement of the Gulf of Finland and sorrounding area 1:1 million, Geological survey of Finland, Special Paper 21, 99-114.

deGroot-Hedlin, C. and S. Constable (1990) Occam's inversion to generate smooth, two dimensional models from magnetotelluric data. Geophysics, Vol. 55, 12, 1613- 1624.

Kotova, I.K., Gordon, F.A. and S.R. Kotov (2011) Structure and composition of the Pitkaranta suite rocks in the area of stratiform sulfide-skarnoid mineralization (North-East frame of Impilachti dome, Northern Ladoga coast). Vestnik St. Petersburg University, Vol. 7, 4. 28–49. (In Russian)

Kuptsova, A.V. (2012) Geological setting and evolution of the Riphean uraniferous basins: Pasha-Ladoga, East Anabar and Atabaska. PhD thesis, Saint Petersburg State University, Saint Petersburg. (In Russian)

Saraev, A.K., Antashchuk, K.M., Pertel, M.I., Eremin, I.S., Golovenko, V.B. and K.A. Larionov (2011). The software-hardware system of audiomagnetotelluric sounding ACF-4M. The V Russian Workshop in the name M.N. Berdichevky and L.L. Vanian of the electromagnetic soundings of the Earth (EMS-2011), Saint-Petersburg. (In Russian)

Stepanov, K.I., Sanin, D.M. and G.N. Sanina (2004) Explanation to the State geological map of the Russian Federation 1:200000 sheets P-35-XXIV, P-36-XIX. The 2nd edition. Saint Petersburg. (In Russian)

Stupak, V.M. and N.V. Leshchenko (2008) Results of the joint interpretation of the earthquake converted waves and CDP seismic data in the south-eastern Fennoscandia, The seismic prospecting technologies, 2. 48-52. (In Russian)

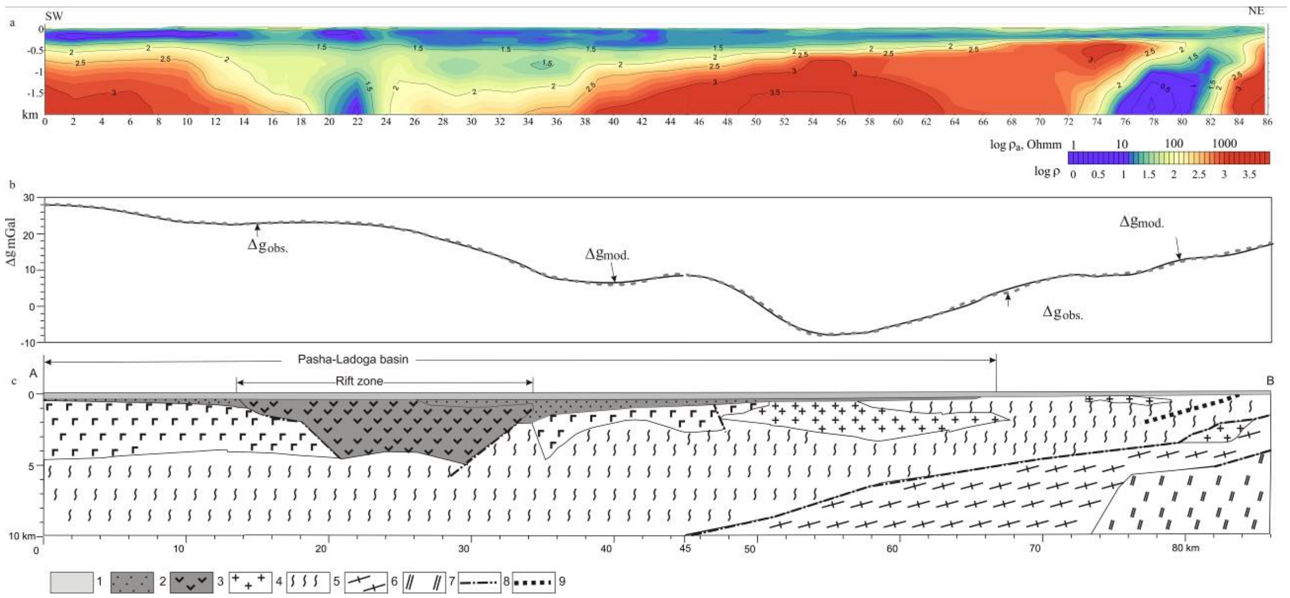

Figure 2. (a) Geoelectrical model; (b) plots of observed ($\Delta g_{obs.}$) and calculated ($\Delta g_{mod.}$) gravity fields; and (c) geological model (c) along Line A-B. Ratio of horizontal and vertical scales is 1:3 for geoelectrical model. 1. Vendian-Paleozoic sedimentary rocks; 2. Riphean sandstones with basalt interlayers; 3. Riphean basalts and dolerites; 4. Riphean rapakivi granites; 5. Gabbro; 6. Low-Proterozoic schists and gneisses; 7. Archean gneisses and migmatites; 8. Archean amphibolites; 9. Faults; 10. Faults marked by low resistive zones.

Joint inversion of MT and satellite gravity data in the North-Western USA

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SUMMARY

We investigate the lithospheric structure of the north-western USA using magnetotelluric (MT) data from the USArray in combination with the XGM2016 gravity model. This test area is characterized by a variety of geologic and tectonic settings such as the subduction of the Pacific plate in the west, hot-spot volcanism in Yellowstone and cratonic lithosphere in the eastern part of the study area. Previous inversions using the USArray MT dataset in this region reveal similar signatures of many of the tectonic features, but show diverging results in features such as the structure of a conductive anomaly beneath Yellowstone. We attempt to clarify these discrepancies by combining the MT and gravity data in a joint inversion.

Initially, we individually invert the gravity and MT data. While the resulting conductivity models show features similar to those observed by previous inversions, the density models show clear lateral variations mirroring the observed gravity signal but suffer from the lack of vertical resolution. Using different starting models and different subsets of the available MT data we assess the robustness of recovered features and the influence of station coverage as well as the ability of the gravity data to recover information in gaps of the MT data. By comparison with the individual inversion results we demonstrate the added value of a joint inversion.

Keywords: MT, Satellite gravity, Joint inversion

Joint MT and seismic imaging of Yellowstone supervolcano - connections between deeper mantle melt sources and shallow hydrothermal expressions from wideband MT array data collected in 2017

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SUMMARY

The Yellowstone (YS) volcanic system in the western US has produced three large caldera forming eruptions 2.1, 1.3, and 0.64 Ma. Smaller post-caldera eruptions with rhyolite and basaltic compositions followed until 70 ka. Previous seismic and magnetotelluric (MT) studies of the crust and upper mantle beneath YS have provided insight into the origin and migration of magmatic fluids into the YS crustal volcanic system. However, important questions remain concerning: 1) the origin and location of magmatic fluids at upper mantle/lower crustal depths 2) the preferred path of migration for these magmatic fluids into the mid- to upper-crust, 3) the resulting distribution of the magma reservoir, 4) the composition of the magma reservoir, 5) links between hydrothermal expressions and shallow melt distributions, and 5) implications for future volcanism at YS. To evaluate the above questions, we are carrying out a joint MT and seismic study of the YS region. In summer 2017, we installed 45 densely spaced, wideband MT sites across YS. We are currently inverting these, as well as previously collected EarthScope long-period MT data, to obtain a high resolution image of 3D resistivity structure at upper crustal through upper mantle scales at YS. Due to MT data's sensitivity to the presence of magmatic fluids, it is an ideal tool for constraining magma storage. In tandem with this work, we are carrying out a joint surface/body-wave velocity inversion of the region. Since body and surface waves are sensitive to different regions of the model space, joint inversion should allow us to obtain a more complete image of YS's velocity structure and inferred magma storage. Spatially coincident velocity and resistivity models from this work are being interpreted jointly in order to better constrain the structure, temperature, and composition of the YS volcanic system.

Keywords: magnetotelluric, Yellowstone, plume, seismic

Lithosphere-scale suture between the Yangtze and Cathaysia Blocks in South China: constrained from the 3-D magnetotelluric array data

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SUMMARY

We use a magnetotelluric array across the Jiangnan orogenic belt, which was formed by collision between the Yangtze block and Cathaysian Block belonging to the Southern China, to establish the regional lithosphere-scale three-dimensional resistivity model. The crust and upper mantle of the Yangtze and Cathaysian blocks show relatively high resistivity (>5000 Ωm), which may reflect the low porosity and water content as well as undeformed ancient lithospheric mantle. Below the high resistivity layer, a high conductivity (~10-100 Ωm) anomaly area appears. The interface between them may reflect the electrical characteristics of the lithosphere-asthenosphere boundary (LAB). The electrical LAB depth below the Yangtze block is ~100-120 km while ~80-90 km below the Cathaysian Block, which may indicate that the Cathaysian lithosphere has been deformed by the upwelling asthenosphere hot materials to a greater extent than the Yangtze block. A high-conductivity anomaly in the middle and lower crust and lithosphere mantle appears below the western margin of the Jiangnan orogenic belt, corresponding to the Chenzhou-Linwu Fault on the surface. The upper mantle part (~40-120km) is nearly upright, slightly west-dipping (~30-50 Ωm), and connected to the inferred asthenosphere beneath it. We suggest that this high-conductivity anomaly could be a lithosphere-scale weak zone and the suture between Yangtze and Cathaysian blocks, which could be formed by the westward subduction and collision events during the closure of ancient China South Ocean and reactivated as a result of the subduction and rollback of the Pacific plate.

Keywords: South China, Yangtze Block, Cathaysia Block, Suture, Magnetotelluric Array

Lithospheric deformation of the eastern Tibetan Plateau and its tectonic influences on eastern China — the EHS3D project updates

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SUMMARY

The collision of the Indian and Asian continents has formed the Tibetan Plateau, and the associated deformation extends across large parts of Asia. The eastern Tibetan Plateau is one of the most tectonically active regions on Earth and it is believed that regions of the lower crust are weak enough to flow (Unsworth et al., 2005). Geodynamic modeling studies suggest that the lithosphere beneath the Sichuan Basin (SB) may block the eastward crustal flow from central Tibet and split it into two branches beneath the eastern margin of the plateau. One branch passes through the northeast plateau margin into the Ordos Block(OB) (North China Craton), and the other branch flows southeast into the Yangtze Block (Clark and Royden, 2000). The EHS3D project was initiated to investigate the deep structure of this region in 3-D and improve understanding of the dynamics around the Eastern Himalayan Syntaxis (EHS). Currently, this project is mainly focusing on the geometry of possible channels of crustal flow with MT exploration. The first stage of the EHS3D project revealed two low resistivity features that could be zones of crustal flow around the EHS. However no low resistivity feature was found for the northeast branch (Bai et al., 2010). Since 2010, a large number of new broad-band and long-period MT measurements have been made over a larger area to fully image the resistivity structure of the region and constrain the nature of the crustal flow. By the end of 2017, over 2000 MT measurements have been made in an area of 1400×2000 km (Figure 1). Preliminary results show that the average conductance of the lithosphere of Tibetan plateau is much higher than the surrounding regions (North China craton and Yangtze block). In particular, 3-D inversion models of the two key regions (I and II in Figure 1) give new insights into the patterns of the crustal flows. Details of our results will be presented and discussed during the workshop.

Keywords: magnetotellurics, resistivity structure, Tibetan Plateau, lithospheric deformation, crustal flow

REFERENCES

Unsworth, M. J. et al. (2005). Crustal rheology of the Himalaya and southern Tibet inferred from magnetotelluric data. ***Nature*** 438: 78-81.

Clark M., and Leigh Handy Royden(2000). Topographic ooze: Building the eastern margin of Tibet by lower crustal flow. ***Geology***, 28: 703-706.

Denghai Bai et al. (2010). Crustal deformation of the eastern Tibetan plateau revealed by magnetotelluric imaging. ***Nature Geoscience***, 3: 358-362.

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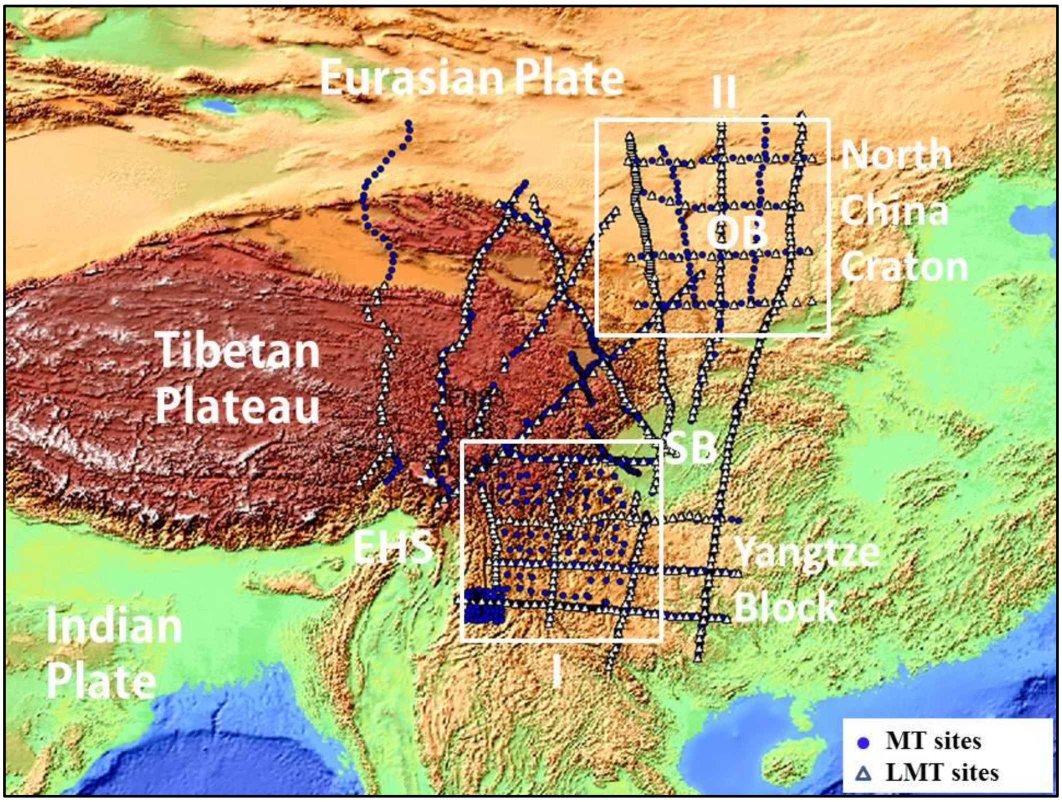

Figure 1. Topography of the study area and location of the EHS3D MT sites

SB：Sichuan Basin. OB：Ordos Block. EHS：Eastern Himalayan Syntaxis.

I and II are two key areas for 3D imaging of this work.

Lithospheric Deformation Mechanism of the Northern Tibetan Plateau as Revealed by a Magnetotelluric Transect across the Northern Qaidam Basin

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SUMMARY

As a unique geologic unit on the northern margin of the Tibetan Plateau, the Qaidam Basin plays a significant role in constraining the vertical uplift and horizontal expansion of the Tibetan Plateau. However, deformation mechanism of the lithosphere beneath the Qaidam Basin is still highly debated. To better understand the lithospheric electrical structure and deformation mechanism of the Qaidam Basin, A 250 km long, NE-SW directed Magnetotelluric (MT) profile was finished in the northern portion of the Basin. Original time series data is processed with regular robust routines. Dimensionality and regional strike direction are determined for the dataset through data analysis. 2D inversions were performed to produce a preferred model of the lithospheric electrical structure. Uncertainty analysis of the 2D inversion model was conducted based on a data resampling approach. The outcome 2D electrical model was further used to estimate the distribution of temperature and melt fraction in the upper mantle based on laboratory-determined relationships between the electrical conductivity and temperature of nominally anhydrous minerals and basaltic melt by using Hashin-Shtrikman's bounds. The results suggest that: (1) the crust-mantle boundary is imaged as a conductive layer beneath the western Qaidam Basin, with its temperature estimated to be 1100-1300 C and melt fraction 5-8%, indicating decoupling deformation of the crust and upper mantle. (2) A large-scale east-dipping conductor is imaged beneath the eastern Qaidam Basin. This conductor extends from the upper crust to the upper mantle, implying vertical coherent deformation of the lithosphere. Melt fraction of this conductive region is estimated to be as high as 10%, which might accommodates a major portion of the thrust deformation on the basin's eastern boundary. (3) The decoupling deformation and vertical coherent deformation are both active on the northern margin of the Tibetan Plateau, and both play significant roles in controlling the uplift and expansion of the northern Tibetan Plateau.

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Keywords: Northern Tibetan Plateau, Qaidam Basin, Deformation Mechanism, Magnetotellurics

Lithospheric Electrical Structure in Western Junggar and Its Implications

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The Western Junggar located in the western part of Junggar basin, which is a key component of Central Asian Orogenic Belt. This region has undergone complex ocean-continent transformation and multiple tectonic events, resulting in controversial interpretations about the origin and tectonic setting. Recently, voluminous geological, geochemical and limited geophysical data have reached a consensus that the Western Junggar has experienced oceanic-continental or oceanic-oceanic subductions in Late Paleozoic, and there may be some remnant of Paleozoic oceanic lithosphere preserved beneath this area (Xu et al., 2016; Zhang et al., 2017). Since the high-quality geophysical data are seriously insufficient, it is difficult to provide constrains on the tectonic formation and evolution of the lithosphere beneath Western Junggar. In our study, we obtained five broadband magnetotelluric (MT) profiles to image the electrical structure of the crust and lithospheric mantle. Combining the MT results with other geophysical and geological information, it offered important insights to understand the lithospheric dynamic processes during the Late Carboniferous in this region.

The induction vector (Parkinson, 1959, 1962) and phase tensor (Caldwell et al., 2004; Booker, 2013) have been calculated using the MT sounding data, the results show that the southern part of the Western Junggar can be seen as a two-dimensional structure at the shallow depth and a three-dimensional structure at the deep part; while the northern part is as a three-dimensional structure. Considering the direction of the survey line, and also the differences of dimensionality in the region caused by the tectonic strike and the resistivity change in different geomorphic cover zones, different strategies of inversion have been adopted for the survey data, where LINE1-LINE4 use the two-dimensional inversion (deGroot-Hedlin, 1990) of TE and TM modes, and LINE5 uses the two-dimensional inversion of impedance tensors (Szarka & Menvielle, 1997; Berdichevsky; 1998). In the mountain areas near to Karamay, the three-dimensional inversion is performed on all stations in the LINE1-LINE3 and some stations in the LINE5 of the Back Mountain area of Karamay. After analyzing all the results, we choose the two-dimensional joint inversion results of TE and TM modes for the LINE4, and two-dimensional inversion results of impedance tensors for the LINE5. Moreover, the result of the three-dimensional inversion (Egbert & Kelbert, 2012; Kelbert et al., 2014) constrained by spatial structural has been selected for all the stations in the Back Mountain area of Karamay.

Based on the electrical conductivity structure of five broadband MT profiles and combined with the geology, geochemistry and satellite gravity data of the study region, we conducted a preliminary comprehensive analysis of the lithosphere evolution process in this region. The results show that there is an intraoceanic subduction system of the Late Carboniferous in the Western Junggar. The Karamay-Urho fault approximately represents the location of the ancient trench. The area between the Darbut and Karamay-Urho faults represents the Paleozoic forearc basin and the accretionary wedge. The area north to the Darbut fault could be interpreted as the center of an immature intraarc extension.

The low resistivity zone represents a confluence of metasomatism, which is resulting from upwelling of the upper mantle due to its partial melting. There is a relative high resistivity layer beneath the Junggar Basin, which is inferred as a residual melange formed in the intraoceanic subduction system. The depth characteristics of the Darbut fault in LINE1-LINE4 are not obvious, implying that its extension depth is limited. The Karamay-Urho fault might be a suture zone after strong deformation during several stages of tectonic evolution, which is significance for the tectonic division. The formation of Miaoergou rock is related to a relamination process (Hacker et al., 2011). During the process, the differentiation of magma and the mechanical mixing in the crust cannot be ignored, which causes they have a complex component and their emplacement times are not precisely same as their crystallization ages.

Key words: Western Junggar; Magnetotelluric; Resistivity structure; Three-dimensional inversion; Intraoceanic subduction

REFERENCES

Berdichevsky M N, Dmitriev V I, Pozdnjakova E E. On two-dimensional interpretation of magnetotelluric soundings. Geophysical Journal International, 1998, 133(3): 585-606.

Booker J R. The magnetotelluric phase tensor: A critical review. Surveys in Geophysics, 2013, 35(1): 7-40.

Caldwell T G, Bibby H M, Brown C. The magnetotelluric phase tensor. Geophysical Journal International, 2004, 158(2): 457-469.

deGroot-Hedlin C, Constable S. Occam's inversion to generate smooth, two-dimensional models from magnetotelluric data. Geophysics, 1990, 55(12), 1613-1624.

Egbert G D, Kelbert A. Computational recipes for electromagnetic inverse problems. Geophysical Journal International, 2012, 189(1): 251-267.

Hacker B R, Kelemen P B, Behn M D. Differentiation of the continental crust by relamination. Earth and Planetary Science Letters, 2011, 307(3-4): 501-516.

Kelbert A, Meqbel N M, Egbert G D, et al. ModEM: A modular system for inversion of electromagnetic geophysical data. Computers and Geosciences, 2014, 66(3): 40-53.

Parkinson W D. Directions of rapid geomagnetic fluctuations. Geophysical Journal International, 1959, 2(1): 1-14.

Parkinson W D. The influence of continents and oceans on geomagnetic variations. Geophysical Journal International, 1962, 6(4): 411-449.

Szarka L, Menvielle M. Analysis of rotational invariants of the magnetotelluric impedance tensor. Geophysical Journal International, 1997, 129(1): 133-142.

Xu Y X, Yang B, Zhang S, et al. Magnetotelluric imaging of a fossil paleozoic intraoceanic subduction zone in western Junggar, NW China. Journal of Geophysical Research: Solid Earth, 2016, 121(6): 4103-4117.

Zhang S, Xu Y X, Jiang L, et al. Electrical structures in the northwest margin of the Junggar basin: Implications for its late Paleozoic geodynamics. Tectonophysics, 2017, 717: 473-483.

Lithospheric Rheology of the Great Basin Tectonic Province Derived from Magnetotelluric Resistivity Structure

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Summary

Here we describe an approach to constructing a rheological model of the lithosphere of the Great Basin extensional province with a central role for magnetotelluric (MT) data. The model will incorporate heat flow data, seismic models, more than 500 combined wideband and long period magnetotelluric stations, and identified empirical relations between temperature, fluid/melt content, and pressure. Such a model has the potential to inform seismic hazards, geothermal resources, and proposed mechanisms for tectonic deformation within the Great Basin.

Keywords: Magnetotellurics, Rheology, Extension, Great Basin, EarthScope

INTRODUCTION

The Great Basin (GB) is a wide active continental extensional domain located in the center of the North American cordilleran orogen, and is the most active portion of the broader Basin and Range province (Dickinson, 2006). There exist here distinct internal variations in the rate and degree of deformation. Rifting shows a N-S directed concentration along the Great Basin eastern margin and over its northwestern region, with a relatively high-standing central region. Province seismicity tends to cluster along the eastern and western margins, and along the NE trending Central Nevada Seismic Belt (CNSB) (Kreemer et al. 2010; Verdecchia and Carena, 2016).

Continental deformation is broadly viewed as reflecting the interplay between force and strength variations (Sonder and Jones, 1999). Numerous explanations for the driving forces behind western North American tectonics have been proposed, including gravitational collapse (Rey et al. 2001; Levandowski et al., 2014), plate boundary forces (Kreemer and Hammond, 2007), mantle flow (Becker et al., 2015), and thermally-driven lithospheric drip (Porter et al., 2014).

Lithospheric strength, on the other hand, is directly tied to controls on rock rheology. Factors governing rheology include composition, temperature, fluid/melt content, and to a lesser extent pressure (Bürgmann and Dresen, 2008). Composition and constraints on the thermal field have been provided by seismology for western North America (e.g., Levandowski et al. 2014; Schutt et al., 2018). Thermal field estimates come directly from the many, though unevenly distributed, heat flow data of the Great Basin (Blackwell et al., 2011). However, one of the strongest influences on rheology is the presence of fluids, especially in a feldspar-dominated lower crust. Here they can effect great reduction of strength through diffusion creep or through reduction of effective normal stress, even at low (< 1% wt) concentrations (Tullis et al., 1996; Sibson, 2001).

Insight into domains of fluid influence upon deformation either over broad continua or more discrete lithospheric fault zones may be provided through electrical conductivity imaging. Over more than a decade, wideband (WB) and long period (LP) magnetotelluric (MT) surveying of the Great Basin and bordering provinces has been assembled. Utilizing fully 3D inversion analysis, we undertake to produce a swath section view of electrical conductivity spanning the Great Basin and neighboring provinces through the crust and upper mantle. The view will be interpreted in terms of fluid/melt distributions, fault zones, and in some cases independent temperature constraints, to derive a model of regional scale rheology in concert with empirical rheological laws (Bürgmann and Dresen, 2008) for comparison to known deformation patterns and models of applied tectonic forces.

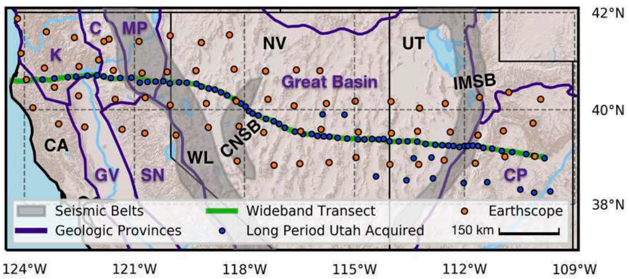

Figure 1. Digital elevation model map showing the distribution of wideband (green line) and long-period MT soundings (blue for U Utah acquired, orange for Earthscope) included for the study area. Also labeled are the Walker Lane (WL), Central Nevada Seismic Belt (CNSB), Intermountain Seismic Belt (IMSB), and US States. The following Geologic Provinces are included: Klamath Block (K), The Cascades (C), Sierra Nevada (SN), Modoc Plateau (MP), Colorado Plateau (CP), Great Valley (GV).

PROPOSED METHODS

Study Area

Classic Basin and Range style extension with development of horst-graben morphology began within the Great Basin during middle Miocene time (~17 Ma). Transtensional torsion of the continental interior stemming from shear traction along the San Andreas strike-slip fault system remains a commonly cited deformational force (Dickenson, 2006). Associated with this system is the parallel Walker Lane belt of eastern California and western Nevada (Verdecchia and Carena, 2015). Strike-slip displacement along this belt diminishes from southeast to northwest as extensional deformation accumulates to the east in the Great Basin.

Data Sources

The centerpiece of our MT data set is a well-sampled profile trending ~east-west of length ~1200 km (Figure 1). It is made up of 397 WB (~0.01 – 500 s period) plus 68 LP (~10 – 10^4 s) soundings. This period range suffices to resolve resistivity structure from depths of a few hundred m through the upper mantle (410 km depth extent). For lateral control and to help produce a more swath-like resistivity model section, an additional ~80 LP MT sites are integrated using a combination of the MT campaign of Wannamaker et al. (2008) and the Earthscope MT TA array in this region (Meqbel et al., 2014).

Constraints on thermal regime are available from the many heat flow measurements compiled by Blackwell et al. (2011). Moreover, Schutt et al. (2018) provide estimates of Moho temperature across the region from regional Pn velocity variations. Thermal conditions in the upper mantle have been interpreted based on regional S and P wave tomography (Goes and Van der Lee, 2002). All of these data sets will be checked for internal consistency.

Data Analysis

The central MT sounding transect was positioned to maximize the accuracy of a 2D structural assumption with respect to horst-graben morphology, modern extension directions, and province boundaries. Two-dimensional inversion analysis to date has considered only the WB component of the data which is sensitive to structure to a depth of ~70 km. Utilizing the transverse magnetic (TM) mode of impedance plus the tipper element K_{zy} (where x is assumed strike) an initial 2D resistivity cross section through crustal depths has been derived using the finite element algorithm (see Figure 2).

Principal among the structures resolved are a series of quasi-tabular conductors at deep crustal levels across the entire Great Basin. These lie at particularly shallow average levels in western Nevada and western Utah, where intensity of extension is relatively high. Based on geotherm and seismic velocity constraints, these conductors are interpreted to reflect basaltic magmatic underplating and hydrothermal fluid release (Wannamaker et al., 2008; Siler et al., 2014).

A primary analysis goal going forward is to produce a fully 3D resistivity model in a swath-like format by utilizing all components of the MT response for both the transect and the off-line LP control sites. For this, the MT data will be inverted using the HexMT algorithm developed by our group (Kordy et al., 2016a, b). This algorithm provides excellent inversion convergence through use of all direct solvers and is able to accommodate the commonly steep topography through deformable hexahedral elements. Although inversions incorporating ~300 sites have been run by us on a single-chassis, multi-core workstation with 0.5 TB RAM (e.g., Wannamaker et al., 2017), this is a larger data set which may require WB site subsampling or local lateral averaging to fit into available resources. However, a 3D analysis will provide a clear measure of the variation along presumed strike of underplating zones, lithospheric-scale faulting, and possible melt zones in the upper mantle.

The heat flow data base described in Blackwell et al. (2011) will be modeled assuming steady state conditions. Independent estimates of temperature can be provided by exploiting the reasonably established correlation between the top of the lower crustal conductors and the 500 C isotherm (Wannamaker et al., 2008).

Fluid domains and temperatures resolved using MT and other geophysical data combined with deformation mechanism maps in Bürgmann and Dresen (2008) will be used to define variable strength 'zones' below this swath of the Great Basin and marginal provinces. This should be a considerable improvement over the lower crustal viscosity estimates of Schutt et al (2018) due to limitations of seismic methods in imaging small fluid concentrations. Zones of lithospheric weakness will be compared to extension rates across the province (Hammond et al., 2014). These data should allow us to compare whether plate boundary, gravitational potential energy, or other forms of force distributions are more compatible with observed strength patterns.

Conclusions

Multiple deformation mechanisms have been proposed for the Great Basin extensional province. Many aspects of applied forces can be estimated from surface observables, however variations in lithospheric strength are not entirely evident from current geophysical studies. The sensitivity of electrical conductivity to fluid/melt presence can allow domains of rheological diffusion creep to be defined. We propose to develop a rheological model by analyzing a comprehensive MT data set spanning the entire Great Basin tectonic domain. This model will be compared to geodetically and geologically estimated strain rates across the province for compatibility with various force models. As this analysis continues, these data will better constrain proposed mechanisms for deformation and seismicity within the Great Basin.

Acknowledgements

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References

Becker, TW, et al. (2015) Western US intermountain seismicity caused by changes in upper mantle flow. Nature 524.7566: 458

Blackwell, et al. (2011) Temperature at depth maps for the conterminous US and geothermal resource estimates: Geothermal Resources Council Transactions 35: 1545-1550

Bürgmann R, Dresen G (2008) Rheology of the lower crust and upper mantle: Evidence from rock mechanics, geodesy, and field observations. Annual Review of Earth and Planetary Sciences 36: 531-567

Dickinson WR (2006) Geotectonic evolution of the Great Basin. Geosphere 2: 353-368.

Goes S, Van der Lee S (2002) Thermal structure of the North American uppermost mantle inferred from seismic tomography. Journal of Geophysical Research: Solid Earth 107: ETG 2-1-ETG 2-13

Hammond WC, Thatcher W (2005) Northwest Basin and Range tectonic deformation observed with the Global Positioning System. 1999-2003. Journal of Geophysical Research 110: B10

Hammond WC, Blewitt G, Kreemer C (2014), Steady contemporary deformation of the central Basin and Range Province, western United States, Journal of Geophysical Research, Solid Earth 119: 5235–5253

Kordy M, et al. 3-D (2016a) Magnetotelluric inversion including topography using deformed hexahedral edge finite elements and direct solvers parallelized on SMP computers–Part I. Geophysical Journal International 204.1 74-93

Kordy M, et al. (2016b) 3-dimensional magnetotelluric inversion including topography using deformed hexahedral edge finite elements and direct solvers parallelized on symmetric multiprocessor computers–Part II. Geophysical Journal International 204.1 94-110

Kreemer C, Blewitt G, Hammond WC (2010) Evidence for an active shear zone in southern Nevada linking the Wasatch fault to the Eastern California shear zone. Geology 38.5: 475-478

Kreemer C, Hammond WC (2007) Geodetic constraints on areal changes in the Pacific–North America plate boundary zone: What controls Basin and Range extension?. Geology 35.10: 943-946

Levandowski et al., (2014) Origins of topography in the western U.S.: Mapping crustal and upper mantle density variations using a uniform seismic velocity model. J. Geophys. Res. Solid Earth, 119.3: 2375-2396

Meqbel NM, et al. (2014) Deep electrical resistivity structure of the northwestern US derived from 3-D inversion of USArray magnetotelluric data. Earth and Planetary Science Letters 402: 290-304

Porter RC, Fouch MJ, Schmerr NC (2014) Dynamic lithosphere within the Great Basin. Geochemistry, Geophysics, Geosystems 15.4: 1128-1146

Rey P, Vanderhaeghe O, Teyssier C (2001) Gravitational collapse of the continental crust: definition, regimes and modes. Tectonophysics 342.3-4: 435-449

Schutt DL, Lowry AR, Buehler JS (2018) Moho temperature and mobility of lower crust in the western United States. Geology 46 (3): 219-222

Sibson RH, (2001) Seismogenic framework for hydrothermal transport and ore deposition. Reviews of Economic Geology 14: 25-50

Siler DL, Kennedy BM, Wannamaker PE (2014) Regional lithospheric discontinuities as guides for geothermal exploration. Geothermal Resources Council Transactions 38: 39-47

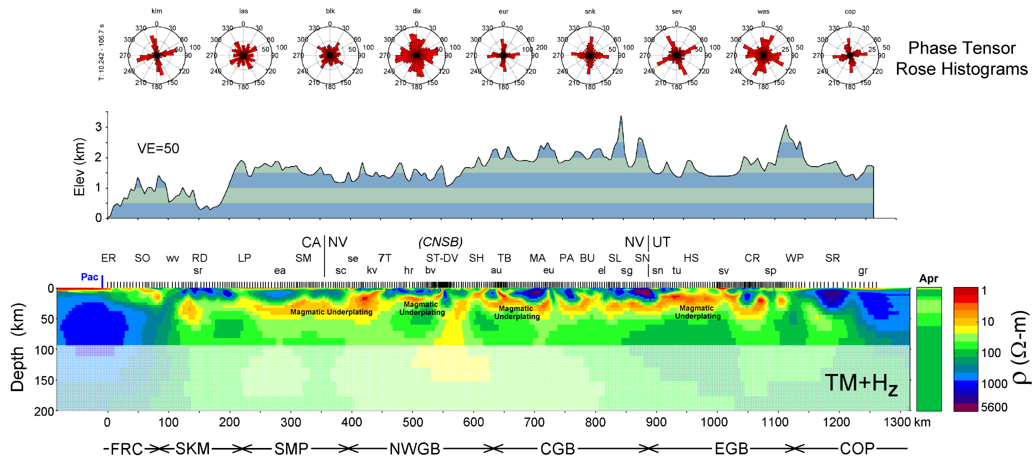
Sonder LJ, Jones CH, (1999) Western United States: how the west was widened. Annual Reviews of Earth Planetary Science 27: 417-462

Tullis JR, Yund, Farver J, (1996) Deformation-enhanced fluid distribution in feldspar aggregates and implications for ductile shear zones. Geology 24: 63-66

Verdecchia A, Carena S (2016) Coulomb stress evolution in a diffuse plate boundary: 1400 years of earthquakes in eastern California and western Nevada, USA. Tectonics 35.8: 1793-1811

Wannamaker PE, et al. (2008) Lithospheric dismemberment and magmatic processes of the Great Basin–Colorado Plateau transition, Utah, implied from magnetotellurics. Geochemistry, Geophysics, Geosystems 36

Wannamaker PE et al. (2017) Phase II of Play Fairway Analysis for the Eastern Great Basin extensional regime, Utah: status of indications. Geothermal Resources Council Transactions 41: 2368-2382



So Klamath – So Modoc – Great Basin – Colorado Plat MT Transect

Figure 2. Electrical resistivity cross section through the crust and into uppermost mantle from 2D inversion of wideband MT transect of Figure 1 emphasizing the TM mode and tipper Wannamaker et al. (2008).

Looking for magmatic structures beneath Osorno volcano, southern Chile

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SUMMARY

The Andean Southern Volcanic Zone (SVZ) includes at least 60 potentially active volcanoes of Chile and Argentina. Osorno volcano is of particular importance as it is emplaced close urban areas such as Puerto Varas and Puerto Montt. The main objective of this work is to obtain new geophysical data in order to identify and characterize magmatic structures beneath this volcano, seek for possible links between Osorno and Calbuco volcanoes (25 km to South-West, last eruption in 2015), and finally, improve the understanding of the magmatic arc of SVZ.

Magnetotellurics measurements were carried out in a first field campaign during December 2017. An array of 11 broadband stations were installed trying to form a ring around the Osorno Volcano. The data collected covers a period range from 0.001s to 1024s, while for its processing, robust processing and remote reference stations were used. The apparent resistivity ranges from 10-1000 Ωm.

A dimensionality analysis considering geomagnetic transfer functions, skew and phase tensor was performed. Induction arrows indicate a conductive anomaly close to the volcanic center for short periods, lower than 1s. In the following periods, the arrows show an anomaly to North-West of the volcanic edifice, however at periods greater than 128s, there is a change in their behavior, pointing to an anomaly to South-West. The phase tensor shows a conductive body mainly between 0.003s and 0.5s periods, while for longer periods no conductive anomaly appears suggested. The dimensional analysis shows a highly heterogeneous situation at different periods.

3D inversions have been calculated with this data, to model some of the conductive structures suggested in the dimensionality analysis. Even though the conductive anomalies at shorter periods could be related to volcanic structures, the ones related to greater periods could be linked to crustal electrical anisotropies identified near the study area in previous studies.

Keywords: Magnetotellurics, Volcanoes, Southern Andes, Electrical conductivity, 3D inversion.

Magmatic and hydrothermal structures related to the San Pedro-Linzor volcanic chain, North Chile, revealed by 3D magnetotelluric modeling

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SUMMARY

The San Pedro- Linzor volcanic chain is located in the Central Volcanic Zone of the Andes, in North Chile. This area comprises active volcanic centers, and it is close to El Tatio geothermal field and the recently opened geothermal plant of Cerro Pabellon.
Twenty broadband magnetotelluric stations were measured in the vicinity of the complex in 2017-2018, complemented with long period stations measured in 1990's, aiming to characterize the deep conductive structures previously observed in the area, with magmatic bodies associated with the adjacent volcanic system. Thermobarometry studies carried out in the area, point to the presence of magma at 8 km depth, related to Lavas de Chao, the largest dacitic dome worldwide, and deeper reservoirs (more than 20 km) associated with other volcanoes in the chain. Data from wells show the possible presence of a large hydrothermal system in the southwestern part of the complex.
A 3D modeling procedure considering inversions and several sensitivity tests was carried out, to deal with this particular case, in which the topography plays a really important role considering altitude differences of more than 1000 m between stations measured around the volcanic chain. Changes in the model associated with several parameters are explored to determine the best quality versus processing time relationship, indicating three fundamental conditions, the grid spacing, the size of the model and the conditions of the topography.
Interpretation and analysis of the conductivity structure obtained from a 3D modeling, indicate the presence of a geothermal system to the southwest of the complex, with maximum depths of about 5 km, and two possible magmatic reservoirs below Paniri volcano and between Paniri and San Pedro volcanoes. In addition, the presence of a highly conductive structure to the east is obtained, associated with the Altiplano-Puna magma body.

Keywords: volcanoes, magnetotellurics, Central Andes

Magnetotelluric characterization of the Alhama de Murcia Fault (Eastern Betics, Spain)

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SUMMARY

The Lorca Earthquake (11/5/2011, Mw 5.2) stands as the most destructive in Spain over the last 50 years, interpreted as having occurred in an intersegment zone of the strike-slip Alhama de Murcia Fault (AMF). A magnetotelluric study, consisting of two profiles crossing the main trace of the fault, SW (Torrecilla profile) and NE (Hoya profile) of Lorca, has been performed to characterize its signature in depth, as part of the multidisciplinary project “INTERGEOSIMA”. Data acquisition was challenging due to cultural noise (mainly from a high voltage electrical line, and proximity to populated areas, a highway and industrial zones). To mitigate noise effects, some sites were recorded over night, when anthropogenic activity is lower and which allowed obtaining enough samples and better statistics for the data processing. Several robust methods were used, to obtain the apparent resistivities and phases in the frequency domain, including a filter to reduce the effects of the 50 Hz and its harmonics. Given the short distance between stations, some pairs of them were recorded simultaneously, with magnetic sensors in only one of them. Data were first inverted using a 2D approach, which allowed depicting the main geoelectrical structures. In the Torrecilla profile a moderately conductive zone was interpreted as the main fault gauge, which was overlain by a resistive zone, interpreted as a block of Palaeozoic protolith. A second step was to invert the data using the 3D inversion code ModEM, for which we considered first that the electrical and magnetic fields were acquired at the same position for all stations and secondly, the interstation impedances (locating the electrical and magnetic fields at their actual acquisition positions).

Keywords: Alhama de Murcia Fault, Magnetotelluric, interstation impedance inversion

Magnetotelluric evidence for crustal conductors in Parnaiba basin, Brazil

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SUMMARY

Parnaiba cratonic basin, in northeast Brazil, covers an area of 600,000 km^2 being one of the largest basin in South America. An extensive magnetotelluric (MT) survey has been carried out along one E-W profile of approximately 1430 km long, crossing the Parnaiba basin. MT data spanning from 0.001 s to 50,000 s allowed an investigation depth of a couple of hundred meters to approximately 100 km, probing the subsurface resistivity structures of the Precambrian crust. Analysis of broadband data and 3D inversion of long period data revealed the presence of different lithospheric blocks limited by major electrical discontinuities. These lithospheric blocks are characterized by a predominantly resistive crust and upper mantle along the western part of the study area, comprising Amazonian craton and western border of Parnaiba basin; a central block characterized by broad highly conductive anomaly extending to upper mantle; and the eastern block characterized by two resistive verticalized anomalies intercalated with a conductive zone. The bulk conductivity increase in the crust beneath the central part of the Parnaiba basin is unexpected for a cratonic basement. Our results support that this is due to the impregnation of the lithosphere by conducting minerals related to tectonic events involving either the Brazilian orogenic processes or to dispersed magmatic residues associated with the continuous igneous intrusions that occurred during the Triassic and Cretaceous.

Keywords: Magnetotellurics, 3D inversion, crustal conductors, cratonic basin

Magnetotelluric imaging of Hudson Bay Basin and bounding units beneath the Kaskattama Highlands, Manitoba, Canada

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SUMMARY

A magnetotelluric (MT) survey was conducted in the Kaskattama Highlands, Manitoba, Canada as part of the GEM 2 program. The primary target was underlying Paleozoic-Mesozoic Hudson Bay Basin rocks: the survey crosses an area in which a drill-hole reveals anomalous stratigraphy including a Cretaceous shale unit and absence of some Silurian units. The MT survey is unusual in that there are additional secondary targets in both the underlying Precambrian rocks and the overlying Cenozoic sediments. The survey lies at the margin of the Archean Superior craton and Proterozoic Trans Hudson Orogen and Precambrian basement rocks include the Fox River Belt, close to its truncation by the Winisk River Fault. Overlying Quaternary deposits form the Kaskattama Highland, an anomalously thick accumulation of sediments, rising 200 m above the surrounding lowlands.

High-quality MT responses were obtained at 22 sites for the periods range 0.003 to 30 s. At short periods, the MT response is 1-D and images Quaternary sediments of the Kaskattama Highlands. The resistivity decreases from 65 Ω.m at the surface to 16 Ω.m at depth. At intermediate periods, the response is dominantly 2-D. The strongest MT control is from the Cretaceous shale unit which has a resistivity of 9 Ω.m. MT results show the unit extends 15 to 30 km in the northwest-southeast direction beneath the highland and at least 20 km in the southwest-northeast direction, indicating a non-fluvial source. At long periods, the MT response is increasingly 3-D with dominant strike parallel to the Winisk River Fault and the results also resolve a localized conductor in the Fox River Belt.

The MT survey has provided information on the Quaternary, Mesozoic, and Precambrian structures beneath the Kaskattama Highlands, helping constrain interpretations of tectonic processes, including possible fault re-activation.

Keywords: Magnetotellurics, tectonics, Canada

Magnetotelluric Imaging of Lower Crustal Melt in the Atlas Mountains of Morocco

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SUMMARY

The Atlas mountain belt system of North Africa is an intra-continental orogenic domain extending for more than 2,000 km through Morocco, Algeria and Tunisia with a predominant NE-SW trend. In Morocco, the system comprises three main branches: the northeast—trending Middle Atlas, the east—northeast—trending High Atlas, which constitutes the highest elevated region in the mountain chain with summits of 4,165 m (Mt. Toubkal in the western High Atlas), and the Anti-Atlas, which runs roughly parallel to the High Atlas. We present an electrical resistivity model of the crust from 3-D inversion of magnetotelluric data collected along a 250 km transect of southern portion of the Middle Atlas Mountains, High Moulouya Plain, the High Atlas and the Anti-Atlas Mountains. The key feature of the 3-D resistivity model is a zone of enhanced electrical conductivity (0.33 S/m – 0.1 S/m) in the middle to lower crust (17 - 35 km) that is centered beneath the High Moulouya Plain. We interpret the high conductivity region of the crust in terms of partial melting and associated deep-crustal fluids. Prior to quantifying the minimum melt fraction, we computed the probable temperature within the lower crust using Monte-Carlo simulations with a 1-D forward modelling code. The temperature estimates in the lower crust can be as low as approximately 500 ºC and as high as approximately 800 ºC. Since the calculated temperature estimates are low, the presence of dry melt, which was supported by very recent wide-angle seismic reflection results, can be ruled out. Instead, the magnetotelluric results favour hydrous melting in the lower crust, which must be initiated by the mantle derived H_2O - C_2O rich supercritical fluids. These fluids, which could be stemming from metasomatic alteration of the Atlas lherzolitic lithosphere during its partial melting, may have migrated to the lower crust and initiated its partial melting, therefore enhancing the electrical conductivity.

Magnetotelluric imaging of intracontinental deformation zones: example of the Musgraves Province in Central Australia

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SUMMARY

Central Australia has some of the largest geophysical anomalies in the world, indicating this region has undergone and continues to retain evidence of significant whole of crust, perhaps whole of lithosphere deformation. The Musgrave Province, situated in the southern region of Central Australia, is a region of complexly deformed Mesoproterozoic crystalline basement material. It is situated at the junction of the Southern, Northern and Western Australian cratons and has undergone widespread magmatic and ultra-high temperature metamorphism at the end of the Mesoproterozoic (c. 1220-1150 Ma) (Howard et al, 2015). More recently, reworking during the 570 Ma - 530 Ma intraplate Petermann Orogeny resulted in changes from weak to strong lithosphere and significant Moho offsets up to 15 km (Aitken et al, 2009). The respective expressions in the long-wavelength gravity anomalies exemplify the importance of this area for intraplate deformation and lithospheric strength.

Magnetotelluric (MT) data is presented that has been collected across the Musgraves Province, from Western Australia to South Australia as part of the South Australian component of the Australian Lithospheric Architecture Magnetotelluric Project (AusLAMP SA) project. Station spacing is roughly 50 km of the 91 stations across an area of 500 km $\times$ 700 km. We inverted the long-period impedance and tipper data across 21 periods from 8 s to 10,000 s period using a smooth 3D inverse algorithm (Egbert and Kelbert, 2012; Kelbert et al, 2014). We set error floors of 5% and 20% for the off-diagonal and diagonal impedance tensor elements, respectively.

This new MT data illuminates the structure of the crust and mantle beneath the Musgraves Province, mapping resistivity structure throughout the continental lithosphere which in turn provides constraints on the tectonic evolution of the Musgraves Province. Initial results show a number of significant lower crustal conductors coinciding with high gravity anomalies. These zones coincide with significant Moho offsets derived from 2D gravity forward modelling (Aitken et al, 2009) and likely represent the lower crustal response to the recent Palaeozoic deformation during the Petermann Orogeny.

Keywords: magnetotellurics, AusLAMP, Musgraves Province, intraplate deformation

REFERENCES

Aitken ARA, Betts PG, Weinberg RF, Gray D (2009) Constrained potential field modeling of the crustal architecture of the musgrave province in central australia: Evidence for lithospheric strengthening due to crust-mantle boundary uplift. Journal of Geophysical Research 114:–

Egbert GD, Kelbert A (2012) Computational recipes for electromagnetic inverse problems. Geophysical Journal International 189(1):251–267

Howard H, Smithies R, Kirkland C, Kelsey D, Aitken A, Wingate M, de Gromard RQ, Spaggiari C, Maier W (2015) The burning heart - the proterozoic geology and geological evolution of the west musgrave region, central australia. Gondwana Research 27(1):64 – 94

Kelbert A, Meqbel N, Egbert GD, Tandon K (2014) Modem: A modular system for inversion of electromagnetic geophysical data. Computers & Geosciences 66(0):40 – 53

Magnetotelluric investigations of the lithosphere beneath Edough Massif, NE Algeria

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SUMMRAY

The Edough Massif is the easternmost witness of the crystalline massif of Algeria. Its structural position related to the Alpine suture area which has been debated for a long time ago in the scientific community. The deep geological structure of Edough Massif is poorly known. To get more information about the electrical conductivity of the lithosphere under Edough Massif, data from 16 magnetotellurics sounding (three profiles) collected in Sept. 2017, with spacing 3-5 Km. The data were acquired during an average of 20h. The refrerence site chosen 35 Km north of the study area. The processing was carried out using SSMT2000 and MTeditor. As the study area is weakly affected by the anthropogenic noise, we recovered a good impedance tensor, apparent resistivity and phase in the frequency range between 300 Hz to 1000s. A dimensionality analysis has been conducted to choose an adequate inversion and modeling approaches. The dimensionality analysis using Bahr,1991 and Swift, 1967 parameters as well as the Skew angle of the phase tensor showed that the underground geology is 2D especially in the short and medium periods, i.e.< 100s. Strike direction is relatively constant for almost all sites showing an ambiguity direction of 85°N or N20°W. The real induction vector size following the Parkinson convention varies mostly in the period range of 0.01-10s. The direction of real vectors is generally oriented SW for the long-periods (>10 s). For data modeling and inversion of an area showing a steep topography, like our study area, we chose a finite element modeling and inversion software (MARE2DEM) uses unstructured triangular grid that permit discretization of complex modeling domain. The results of 2D modeling and inversion as well as sensitivity studies will be presented. A final geological and geophysical interpretation will be also showed and discussed.

Magnetotelluric investigation for structurally-controlled geothermal systems in active extensional basins: An example from Gediz Graben, western Anatolia, Turkey

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SUMMARY

The western Anatolia hosting a number of geothermal systems is one of the most rapidly deforming continental regions in the world. Recent north-south extensional tectonism, as a result of the northward movement of the Arabian plate and the westward movement of the Anatolian plate, results in high heat flow and seismicity, many active geothermal areas, several horsts and grabens, and normal faults throughout the western Anatolia. In the area, normal faults bounding the grabens lead to the deep circulation and heating of meteoric waters and also rising up to surface through the permeable faults. The geothermal systems, and hot springs and hot water wells corresponding to these geothermal systems are situated near the Gediz deteachment fault at the intersection of the nearly north-south striking transverse faults in the southern margin of the graben. In order to construct the electrical conductivity distribution of the subsurface and discuss its correlation with structural controls and geothermal system characteristics of the tectonically active this region, we generated three-dimensional conductivity models of the region. The magnetotelluric data (0.001-1000 s) from 152 sites have been considered from two different areas of the graben. The resulting models show that a conductivity structure with a highly resistive zone characterizing high-grade metamorphic rocks of Menderes core complex (Menderes Massif) is imaged below the conductive zone associated with Quaternary alluviums of the Gediz Graben and L. Miocene- Plio-Pleistocene sedimentary rocks of the graben basin. The metamorphic basement flanks the graben within its margins. A deep conductive zone, which may be associated with a shallow heat source for the geothermal systems located near the southern margin of the graben, is prominent on the conductivity models. Moreover, 3D models delineated an undulating graben floor, which changes in depth between 300 m and 2500-3000 m. The sedimentary fill of the graben also becomes much thinner toward the eastern end of the graben.

Keywords: Magnetotellurics, Conductivity, Geothermal, Western Anatolia, Gediz Graben

Improvement in magnetotelluric data processing by two novel pre-stacking data selection criteria

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SUMMARY

The West Bohemia region, characterized by the intersection of the Eger Rift and the Mariánské Lázně fault, is a geodynamically active area exhibiting repeated occurrence of earthquake swarms, massive CO_2 emanations and mid Pleistocene volcanism. It is the only known intra-continental region in Europe where such deep seated, active lithospheric processes currently take place. We present an image of electrical resistivity obtained from two-dimensional inversion of magnetotelluric (MT) data acquired along a regional profile crossing the Eger Rift. At the near surface, the Cheb basin and the aquifer feeding the mofette fields of Bublák and Hartoušov have been imaged as part of a region of very low resistivity. The most striking resistivity feature, however, is a deep reaching conductive channel which extends from the surface into the lower crust spatially correlated with the hypocentres of the seismic events of the Nový Kostel focal zone. This channel has been interpreted as a pathway from a possible mid-crustal fluid reservoir to the surface. The resistivity model reinforces the relation between the fluid circulation along deep-reaching faults and the generation of the earthquakes. Additionally, a further conductive channel has been revealed to the south of the profile. This feature can be associated to fossil hydrothermal alteration related to Mýtina and Neualbenreuth Maar structures or alternatively with the signature of a structure associated to the suture between the different tectonic units.

In addition, near-surface pathways of mineral fluids containing CO_2 have been imaged in detail with the RMT method. Two- and three-dimensional models indicate that the subsurface below wet degassing sites is characterised by an increase in electrical conductivity in form of channels connecting deeper aquifers. Gaseous CO_2 is more resistive and consequently inversion results of the northern measurement area seem to correlate with a dry mofette structure. These models are compared with ERT profiles and logging data from the nearby borehole.

Keywords: Magnetotellurics, Eger Rift, fluid pathways, CO_2 degassing, Earthquake swarms

Magnetotelluric signature of Tso-Morari dome at Indus-Tsangpo Suture zone in NW Himalaya, India

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Abstract

The Tso-Morari Crystalline (TMC) is a significant litho-unit between the north Indian continental margin and the south of the ISZ. In the northern region, the TMC dips towards NE while in the southern region it dips towards SW and therefore this region is referred as Tso-Morari dome. It has been observed that the TMC is High pressure eclogitefacies metamorphism that suggests a deep subduction of the Indian Plate underneath the Eurasian Plate (Mukherjee &Sachan 2004). The TMC and the ophiolites are well exposed in the Mahe valley as well as in the adjacent Nidar valley of the study area and are separated by Zildat Ophiolitic Melange.

The Magneto telluric (MT) method is used for deciphering subsurface geoelectrical characterization of Tso-Morari dome along a profile. The purpose of subsurface geoelectrical characterization of the TMC in the study area is to gain insight and develop an understanding about the evolution of TMC dome and about seismicity in the region. The MT data quality is quite high and robust processing of time series provide smooth apparent resistivity curves up to 1000 sec. Variation of sounding curves suggests complex resistivity structure along the profile. Although, dimensionality analysis using WALDIM tool suggest variable dimensionality depending upon the period and location of site but there is 3D/2D suggestions for responses over number of periods. Two dimensional resistivity model is obtained after rotation of impedance tensor to N43^{o}W. The model suggests decoupled upper and lower crust, indicative about evolution Tso-Morari dome. The poster will discuss different features of geoelectrical model and this significance in terms of surrounding tectonic regime.

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Magnetotelluric visualization of preferential fluid pathways in the geothermal system at Villarrica volcano, S-Chile

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SUMMARY

In the Southern Volcanic Zone of the Andes, the geothermal system surrounding the Villarrica volcano offers a natural laboratory to study the effects of intense volcanic activity and the high concentration of regional fault systems. This concerns also magnetotelluric methods that are standard in exploration of volcanic geothermal fields, but more difficult to apply in fracture dominated low temperature geothermal fields.

In order to provide a visualization of the preferential fluid paths in this geothermal system, we have carried out a magnetotelluric survey to reveal the sub-surface conductivity response. A number of 31 MT stations were measured along two profiles, one with E-W orientation and perpendicular to the branches of the Liquiñe-Ofqui Fault Systems (LOFS) and another with N-S orientation, sub-perpendicular to an Andean Transverse Fault (ATF) and the Villarrica-Quetrupillán-Lanín volcanic chain lineament that runs parallel to the ATF.

3D inversion of this data show two anomalies of maxima of electrical conductivity at shallow depth. One is located on the eastern LOFS branch characterized by an increased number of thermal spring. The second maximum is located below the volcanic chain. Thus, these anomalies are attributed to both tectonic and volcanic characteristics.

In conclusion, the 3D inversion reveals resistivity variation along the fault zone that can be attributed to preferential fluid pathways. Resistivity minima along the LOFS coincide with thermal springs and monogenetic volcanic activity in the northern part of the profile. In the southern part, active ascent of magma near the volcano coincides with these anomalies.

Keywords: magnetotelluric, geophysical exploration, geothermal system, Villarrica volcano

Mapping and characterizing lithosphere discontinuities: examples of southern Australia using AusLAMP MT

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SUMMARY

Major lithosphere boundaries play an important role for the understanding of the geodynamic history of the continental lithosphere and have a primary control on the location of the deposits at the surface. In South Australia, the traditional approach to use potential field methods show large ambiguity to infer large-scale boundaries beneath cover. Here, we show examples of the integration of magnetotelluric data, collected from the AusLAMP (Australian Lithospheric Architecture Magnetotelluric Project) and higher density in-fill surveys, with other geophysics and isotope geochemistry data sets to characterize and constrain the location of crustal scale boundaries. The integration of various techniques shows the unique importance of the magnetotelluric method to identify zones of lithospheric weakness which have led to Proterozoic reworking of Archean lithospheric cores in southern Australia.

Keywords: magnetotellurics, AusLAMP, lithosphere discontinuities, isotope geochemistry

INTRODUCTION

The identification of lithospheric discontinuities plays an increasing role in the characterisation of Archean and Proterozoic terranes, as it allows the mapping of stable and old cratonic lithospheric blocks, as well as their margins. In recent years, the insight into the relative position of cratonic margins and locations of repeated lithospheric deformation, concentration of magmatic and fluid flux (Richards, 2011), as well as the position of mineral deposits (Griffin et al, 2013; Richards, 2013), has highlighted the importance of mapping and understanding these discontinuities. Aside form the aforementioned vertical discontinuities, horizontal boundaries also play a role for geodynamic processes, e.g. the ability for magmas and fluids to penetrate to the surface (Davies et al, 2015). As examples, horizontal boundaries include the lithosphere-asthenosphere boundary (LAB) (O'Reilly and Griffin, 2010), the mid-lithospheric discontinuity (MLD) (Aulbach et al, 2017; Selway et al, 2015), the crust-mantle boundary (Moho), and mechanical boundaries within the crust, e.g. the brittle-ductile boundary (BDT) (Thiel et al, 2016).

We show comparative data sets including isotope geochemistry, seismic tomography models, heat flow analyses, potential field data sets, and seismic reflection studies together with magnetotelluric modelling results from continent-wide long-period AusLAMP arrays to focussed broadband surveys.

The Gawler Craton in South Australia has been an area of extensive focus for magnetotelluric deployment over the last 15 years (Heinson et al, 2006; Thiel and Heinson, 2010, 2013; Selway et al, 2011; Robertson et al, 2016). Here, we present results of the long-period AusLAMP MT deployment across South Australia and the result of smaller scale in-fill surveys using broadband equipment. The deployments show a heterogeneous distribution of resistivity structure in both the mantle and crustal lithosphere. In the first order, the lithospheric cratons seem to exert a primary control on focussing fluid and magmatic events in the Proterozoic. As a result the location of major IOCG deposits and prospects across the Gawler Craton align with the observed craton margins. In-fill MT survey using broadband equipment illustrate crustal structural control on the position of IOCG and uranium deposits at the surface (Heinson et al, 2018; Thiel et al, 2016). It shows that magnetotellurics is a pivotal tool for mineral exploration and for understanding the fertility of the lithosphere.

AusLAMP MT program

The Australian Lithospheric Architecture Magnetotelluric Project (AusLAMP) is a national Australian initiative to map the Australian continental lithosphere using magnetotelluric (MT) stations to obtain a resistivity model of the subsurface. It is a joint project between Geoscience Australia, state surveys, and Universities. The station spacing of the AusLAMP program is roughly 50 km. The data coverage across South Australia exceeds 95%, totalling close to 400 MT sites. The data is processed using robust processing codes (Chave and Thomson, 2004), and inverted using the 3D ModEM code (Egbert and Kelbert, 2012; Kelbert et al, 2014).

Results

The main insights of the AusLAMP SA program are as follows:

- The resistivity models show large-scale trans-lithospheric boundaries aty the margins of the Archean core of the Gawler Craton extending through the crust into the mantle. The low resistivity regions correlate with gravity highs, while the central part of the Gawler Craton shows a very resistive core into the mantle and corresponds to a gravity low.
- The thickest zone of resistive core also correlates well with LAB estimates derived from seismic tomography studies and thermal models of the lithosphere (Kennett et al, 2013; Czarnota et al, 2014).
- The north-western part of the Gawler Craton shows an extensive area of metasomatised mantle at depths around 100 km - 150 km, near the MLD.
- Large-scale vertical low resistivity zones often demarcate long-lived terrane boundaries, and these correlate with changes in the heat flow measurements. The differences point to changes in the abundance of heat-producing elements in the upper crust, which may have been emplaced through enrichment due to magmatic processes localised along the margins of the Gawler Craton.
- At the lithospheric boundaries, the BDT marks a strong mechanical layer controlling the fluid flux through the lithospheric column. MT signatures suggest ponding of fluids beneath the BDT in the ductile regime of the crust. In some cases, fluids were then able to penetrate into the upper brittle crust forming narrow pathways to the surface, which appear different to the wide-spread nature of ductile deformation in the lower crust.
- Isotope geochemical analyses of felsic and mafic magmatic rocks across the Gawler Craton suggest that the low resistivity zones imaged with MT are footprints of past magmatic and fluid flux events within the crust in the Proterozoic.
- The resistivity signature of the high conductivities in the crust correlates with the position of major iron-oxide copper gold deposits and gold deposits at the surface, and represent the mineral system footprint of the large mineral occurrences.

Acknowledgments

All inversions were performed using Raijin from the National Computational Infrastructure in Canberra, Australia. AusLAMP data were collected by Philippa Mawby, Geoffrey Axford and Bruce Goleby. The majority of funding for the AusLAMP SA program is from Geological Survey of South Australia with collaborative funding from Geoscience Australia for the Maralinga AusLAMP program.

References

Aulbach S, Massuyeau M, Gaillard F (2017) Origins of cratonic mantle discontinuities: A view from petrology, geochemistry and thermodynamic models. Lithos 268-271(Supplement C):364 – 382

Chave AD, Thomson DJ (2004) Bounded influence magnetotelluric response function estimation. Geophysical Journal International 157(3):988–1006

Czarnota K, Roberts GG, White NJ, Fishwick S (2014) Spatial and temporal patterns of australian dynamic topography from river profile modeling.

Journal of Geophysical Research: Solid Earth 119(2):1384–1424, DOI 10.1002/2013JB010436, URL http://dx.doi.org/10.1002/2013JB010436

Davies DR, Rawlinson N, Iaffaldano G, Campbell IH (2015) Lithospheric controls on magma composition along earth's longest continental hotspot track. Nature 525(7570):511–514

Egbert GD, Kelbert A (2012) Computational recipes for electromagnetic inverse problems. Geophysical Journal International 189(1):251–267

Griffin WL, Begg GC, O'Reilly SY (2013) Continental-root control on the genesis of magmatic ore deposits. Nature Geoscience 6:905–910

Heinson G, Direen N, Gill R (2006) Magnetotelluric evidence for a deep-crustal mineralizing system beneath the Olympic Dam iron oxide copper-gold deposit, southern Australia. Geology 34:573–576

Heinson G, Didana Y, Soeffky P, Thiel S, Wise T (2018) The crustal geophysical signature of a world-class mineral system. Scientific Reports accepted

Kelbert A, Meqbel N, Egbert GD, Tandon K (2014) Modem: A modular system for inversion of electromagnetic geophysical data. Computers & Geosciences 66(0):40 – 53

Kennett BLN, Fichtner A, Fishwick S, Yoshizawa K (2013) Australian seismological reference model (ausrem): mantle component. Geophysical Journal International 192(2):871–887, DOI 10.1093/gji/ggs065, URL http://gji.oxfordjournals.org/content/192/2/871.abstract, http://gji.oxfordjournals.org/content/192/2/871.full.pdf+html

O'Reilly S, Griffin W (2010) The continental lithopshere-asthenosphere boundary: Can we sample it? Lithos 120(1-2):1–13

Richards JP (2011) Magmatic to hydrothermal metal fluxes in convergent and collided margins. Ore Geology Reviews 40(1):1 – 26

Richards JP (2013) Giant ore deposits formed by optimal alignments and combinations of geological processes. Nature Geosci 6(11):911–916

Robertson K, Heinson G, Thiel S (2016) Lithospheric reworking at the Proterozoic-Phanerozoic transition of Australia imaged using AusLAMP Magnetotelluric data. Earth and Planetary Science Letters 452:27–35

Selway K, Hand M, Payne J, Heinson G, Reid A (2011) Magnetotelluric constraints on the tectonic setting of Grenville-aged orogenesis in central Australia. Journal of the Geological Society 168(1):251–264

Selway K, Ford H, Kelemen P (2015) The seismic mid-lithosphere discontinuity. Earth and Planetary Science Letters 414:45 – 57

Thiel S, Heinson G (2010) Crustal imaging of a mobile belt using magnetotellurics: An example of the Fowler Domain in South Australia. Journal of Geophysical Research 115(B6):B06102

Thiel S, Heinson G (2013) Electrical conductors in Archean mantle - result of plume interaction? Geophysical Research Letters 40:2947–2952

Thiel S, Soeffky P, Krieger L, Regenauer-Lieb K, Peacock J, Heinson G (2016) Conductivity response to intraplate deformation: Evidence for metamorphic devolatilization and crustal-scale fluid focusing. Geophysical Research Letters 43(21):11,236–11,244

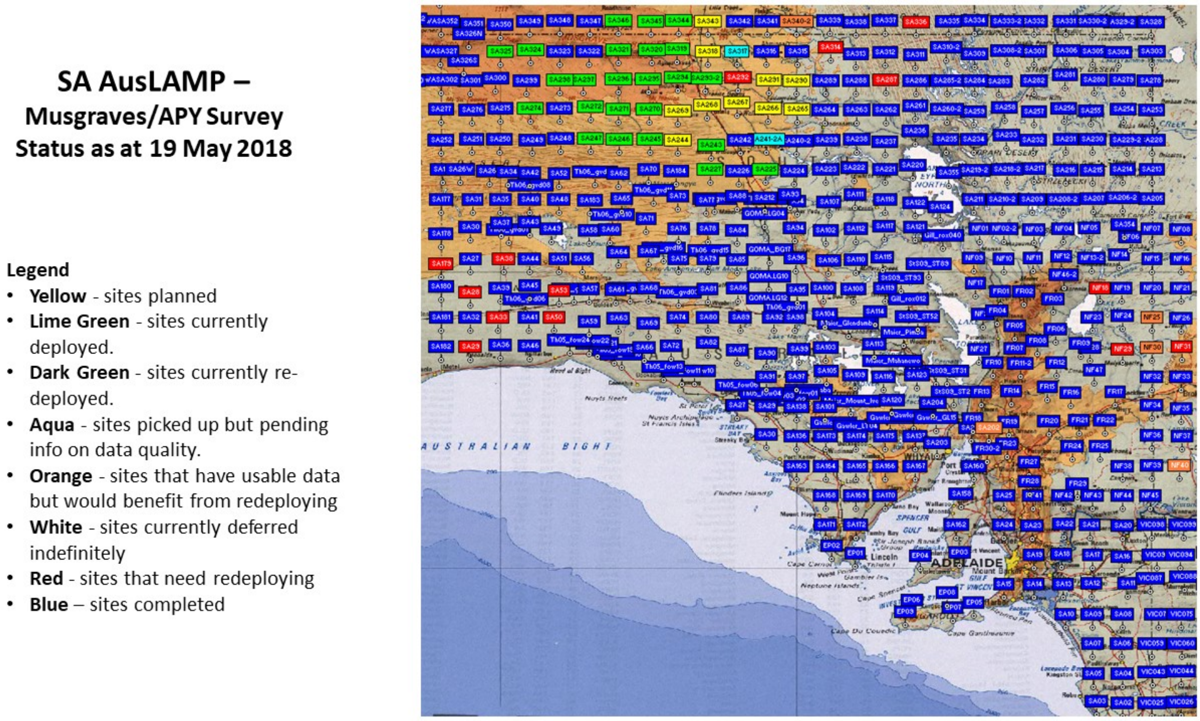

Figure 1: Deployment status of the South Australian AusLAMP deployment to date. Close to 400 long-period MT sites have been deployed to date spanning the Gawler Craton in the central-southern part of South Australia, extending across the Flinders Ranges and Curnamona Province in the east and the Eucla Basin to the west.

Measuring the hydrogen content variations in Southern African mantle

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SUMMARY

Hydrogen that resides within the structural lattice of nominally anhydrous minerals has been considered as a major controlling parameter on rheology of the Earth's mantle [*Demouchy and Bolfan-Casanova, 2016; Karato, 2006*]. Despite the existence of overt discrepancies, high-pressure experiments made on mantle minerals all agree that effect of structurally bound water on electrical conductivity is highly influential [*e.g. Wang et al., 2006; Yoshino et al., 2009*]. Using these experimental models, magnetotelluric (MT) measurements can be employed to put constraints on contributions of hydrogen to electrical conductivity within the context of thermo-chemical state of the medium. To achieve this goal, all available MT data from Southern African Magnetotelluric Experiment (SAMTEX) are inverted with three-dimensional modeling algorithms [*Kelbert et al., 2014; Siripunvaraporn and Egbert, 2009*] and tested meticulously to determine possible conductivity ranges. In addition to the existence of similar studies made before [*e.g. Fullea et al., 2011*], southern Africa was selected particularly due to the great variety of available geochemical and geophysical data that span over many regions attributed with different geological settings, thus will provide a good framework for developing new methodologies. A probabilistic inversion algorithm that incorporates all available thermal, chemical and MT data will be designed to produce hydrogen content maps as well as other compositional elements to make interpretations on lateral variation of physical parameters that govern the lithospheric strength and to recognize possible fingerprints of refertilization events.

Keywords: magnetotellurics, mantle, Southern Africa, xenoliths, rheology, conductivity

References

Demouchy S, Bolfan-Casnova N (2016) Distribution and transport of hydrogen in the lithosperic mantle: A review. Lithos 240:402-425 https://doi.org/10.1016/j.lithos.2015.11.012

Fullea J, Muller MR, Jones AG (2011). Electrical conductivity of continental lithospheric mantle from integrated geophysical and petrological modeling: Application to the Kaapvaal Craton and Rehoboth Terrane, southern Africa. Journal of Geophysical Research: Solid Earth 116(B10) https://doi.org/10.1029/2011JB008544

Karato SI (2006) Influence of Hydrogen-Related Defects on the Electrical Conductivity and Plastic Deformation of Mantle Minerals: A Critical Review. Earth's Deep Water Cycle:113-129 https://doi.org/10.1029/168GM09

Kelbert A, Meqbel N, Egbert GD, Tandon K (2014). ModEM: A modular system for inversion of electromagnetic geophysical data. Computers & Geosciences 66:40-53. https://doi.org/10.1016/j.cageo.2014.01.010

Siripunvaraporn W, Egbert G (2009). WSINV3DMT: vertical magnetic field transfer function inversion and parallel implementation. Physics of the Earth and Planetary Interiors 173(3-4):317-329. https://doi.org/10.1016/j.pepi.2009.01.013

Wang D, Mookherjee M, Xu Y, Karato SI (2006). The effect of water on the electrical conductivity of olivine. Nature 443(7114):977 https://doi:10.1038/nature05256

Yoshino T (2010). Laboratory electrical conductivity measurement of mantle minerals. Surveys in Geophysics. Surveys in Geophysics 31(2):163-206. https://doi.org/10.1007/s10712-009-9084-0

MT Observations in the Kitakami Mountains, NE Japan: Heavy current channelings and 3d resistivity model

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SUMMARY

NE Japan is a typical island arc and many geophysical observations have been conducted, including the regional EM studies starting from 1980s (Ogawa et al, 1987; Kanda and Ogawa, 2014). However, compared with the back-arc side, magnetotelluric imaging of the crust and upper mantle in the fore-arc of NE Japan has been hampered by the strong channeling where we have “conductive” Paleozoic sediments intruded by “resistive” Cretaceous granitic rocks. In this study we have made wideband magnetotelluric measurements in the Kitakami mountains in the fore-arc of NE Japan using a grid with ~10km site spacing. We here show three-dimensional modeling could overcome the heavy channeling problem.

For Northeast Japan, Ichiki et al (2015, JGR) analyzes the three-dimensional resistivity of the crust and upper mantle in the Tohoku region from a long-period MT observation. In their research, the MT site spacing was typically set to 20 km for the purpose of imaging the resistivity structure of the mantle wedge. Low resistivity was analyzed in the crust in the forearc side, however the site spacing was large and the frequency band is limited to less than 0.1 seconds, and spatial resolution was not enough to image the detailed structure within the crust. Mishina (2009, Gondwana Research) conducted broadband MT observation along the three lines passing from the backarc to the forearc and showed two-dimensional resistivity models. In the forearc, he showed sub-vertical conductors presumably implying fluid path from the subducting plate. We suspect that these might be due to channeled current, which leads to underestimate the 2d-TE mode apparent resistivity.

We have 21 magnetotelluric sites in the Kitamaki mountains in NE Japan forearc. The sites are distributed in a grid with ~10km. The full impedance tensor components at 8 periods (0.1~1000s) were used with 10% error floor. The 3d inversion code of Siripunvaraporn and Egbert (2009) was used. The initial model was a 100 ohmm uniform earth with fixed resistivity for ocean. Finally we obtained a model with rms of 1.52.

With the final resistivity model, we can explain the heavily channeled impedance data as well as imaging the resistivity at depth. We used the hypothetical event analyses with Hx only and Hy only inducing field and we can map [Zxx; Zyx] and [Zxy; Zyy] as telluric vectors respectively. With this approach we can intuitively visualize the channeling currents. Heavily channelings can be seen as “stagnant” current directions, regardless of the inducing current directions. The current pattern at 400 second period matches with the resistivity distribution at 1km, which is far less than the corresponding skin depth.

In the mid-crustal depth, the resistors (>1000 ohm) imply the distributions of granite and the patchy conductors (~10 ohmm) may imply fluids rising from the slab, or trapped fluids in the Miocene subduction system when the volcanic front was at the pacific coast.

Keywords:
Current Channeling, hypothetical event analyses, 3D MT inversion, Forearc, Fluids

Multi-stage evolution of the Ordos lithosphere from stochastic inversion of elevation, geoid, surface heat flow, Rayleigh wave dispersion data and magnetotelluric data

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SUMMARY

The North China Craton, constructed in the Archean and Proterozoic, underwent Mesozoic lithospheric delamination and crustal thinning in its eastern part whereas it exhibits thick lithosphere in its western part beneath the Ordos Block. The cause of the enigmatic present-day ~1300 m elevation of the Ordos Block, highly unusual for a Precambrian craton, remains debated, with highly variable estimates proposed of both crustal thickness (40–65 km) and lithospheric thickness (150–280 km). We use multi-observable thermochemical inverse modeling of available geophysical datasets to show that the crust of the Ordos block cannot be unusually thick, nor can the lithosphere be unusually thin, and both are comparable to other Precambrian cratons. Instead, the unusual elevation of the Ordos Block must arise in the composition of its lower lithosphere, which we show to be atypical of Archean upper mantle by being both unusually fertile, i.e., dense, and by incorporating a wet layer. We surmise that the Ordos Block must have either grown by secular downwards thickening and/or extensive lower lithosphere modification to produce a structure in which tectonothermal ages become younger with increasing lithospheric depth. We further speculate that the spatial correlation of the observed compositional depth variation of the Ordos Block with extrusives on the eastern and western boundaries of the so-called “Eastern Block” give support to the newly developing notion that the NCC was formed as a single entity and not by two distinct blocks amalgamated during Paleoproterozoic collisional orogeny along the putative “Trans North China Orogen”.

New data on the nature and structure of the Ladoga anomaly from DC and AMT research.

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Abstract

Keywords: Ladoga anomaly, electrical conductivity, DC profiling, AMT sounding, magnetometer array study.

Ladoga anomaly is a part of Ladoga-Bothnian zone (LBZ) with extansion of more then 1000 km . It is a subject of researches for more than four decades. Ladoga anomaly has been firstly discovered in the late 70s by Ukrainian research team (Rokityansky et al., 1981) with the use of magnetovariational method. The anomaly was interpreted as conductive body at the depth of about 10 km. In 70-th and 80-th the anomaly was studied in Russia (Vasin, 1988; Kovtun et al., 1984) and in Finland (Hielt, 1984; Pajunpaa, 1984; Adam et al., 1982). By results of digital 2D modelling it appears as conductive body with the resistivity falling down up to 2-20 Ω·m at thr depth of 20-30 km (Vasin, Kovtun, Popov, 1993). The third stage of the deep studies was realized in 2013-2015 by means of integrated magnetotelluric and magnetovariational profiling. Each of three stages were completed by construction of specific geoelectrical models of the anomalous area up to the depth of 30-40 km. In this presentation the fourth stage is presented, that has been done in 2015 and 2017 by means of DC electrical profiling with the use of multielectrode installations in complex with AMT soundings. According to results of the fourth stage, an unambiguous conclusion was drawn on the connection of the upper part of the Ladoga anomaly of 130 km width with electronically-conducting sulfide-carbonaceous rocks up to the depth of 0.3 – 0.6 km. The lower part of anomaly at the depth range of 20-30 km presumably is connected with fluids.

New geoelectrical characterization of a continental collision zone in the Central – Eastern Pyrenees: Constraints from 3-D joint inversion of electromagnetic data

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SUMMARY

Continent-continent collisions are responsible for the formation of large mountain ranges like the Himalayas and the Alps and play a primary role in the development of the continents. The continental collision between the Iberian and European plates during the Alpine Orogeny resulted in the formation of the Pyrenees. In this study new electromagnetic data from the Eastern Pyrenees were complemented with older data from the Central Pyrenees, constraining the physical and geological processes at the eastern end of the Pyrenean mountain range. The electrical resistivity distribution beneath the Central-Eastern Pyrenees was characterized by means of three-dimensional (3-D) joint inversion of three electromagnetic datasets: (1) the MT impedance tensor (Z), (2) the geomagnetic transfer function (T), and (3) the inter-station horizontal magnetic transfer function (H). The main finding was the non-continuity to the east of the major conductive anomaly observed previously beneath the Central and West-Central Pyrenees related to partial melting of the Iberian subducted lower crust. Lower amounts of water (related to the presence of muscovite and biotite) in the subducted lower crust beneath the Eastern Pyrenees were suggested to explain the lack of partial melting in this part of the mountain range. The electrical resistivity model also revealed higher electrical resistivity values for the lithospheric mantle beneath the Eastern Pyrenees than beneath the Central Pyrenees, thus supporting the hypothesis of an heterogeneous Iberian plate inherited from the Variscan Orogeny. A less clear signature was the lateral variation along the strike direction of the lithosphere-asthenosphere boundary beneath the Eastern Pyrenees (relatively flat, between 110 km and 140 km depth) and the Central Pyrenees (north dipping, between 80 km and 120 km depth beneath the Iberian Plate and between 110 km and 160 km depth beneath the European plate), supporting the hypothesis of a missing lithospheric root beneath the Eastern Pyrenees.

Keywords: Continental Collision, Pyrenees, Lithosphere, Lithosphere-asthenosphere boundary, Electromagnetic Geophysics, Joint inversion.

Northern Australian lithospheric architecture from AusLAMP

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SUMMARY

New datasets have been collected under Geoscience Australia's Exploring for the Future program (EFTF) in an under-explored part of northern Australia. The aim is to characterize the geology of this part of the tectonic plate from the surface down to the base of the lithosphere through multidisciplinary data collection and synthesis. The new datasets will provide pre-competitive data and knowledge for attracting exploration and reducing exploration risk.

This presentation will describe new datasets collected between Tennant Creek in the Northern Territory and Mount Isa in Queensland, a survey area of 700 km x 800 km, as part of the Airborne Electromagnetic survey (AusAEM) and the Australian Lithospheric Architecture Magnetotelluric Project (AusLAMP). Data from a total of 180 new AusLAMP sites have been acquired in this region as part of Geoscience Australia's EFTF program.

This presentation will show these new data and associated models from the survey area. Results from the data provide new insights on the lithospheric architecture and mineralisation in the region. The magnetotelluric inversion models show a crust/mantle-scale conductivity anomaly interpreted to be part of the Carpentaria Conductivity Anomaly, which is a major deep electrical conductivity structure across Queensland. The models also show some crustal conductivity anomalies aligning with major crustal boundaries. Those boundaries are considered to be important factors for mineralisation in the region, with some known mineral deposits occurring at the margin of these conductivity anomalies.

Keywords: Magnetotelluric, EFTF, AusLAMP, Architecture, Mineral

Radio magnetotelluric survey of the Quaternary Neualbenreuth maar in the Western Bohemian Massif (Germany)

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SHORT ABSTRACT

Only within the last few years, a Quaternary maar was discovered in the vicinity of Neualbenreuth (NE – Bavaria, Germany), which is related to the development of the Eger Rift system in the Czech Republic. It is one magmatic structure along the Tachov Fault Zone among the known scoria cones Komorní hůrka and Železná hůrka and the Quaternary Mýtina Maar, which was discovered a decade ago. An exploratory drilling project (NAR 2015) in the centre of the Neualbenreuth maar recovered its post-volcanic fill, which is a succession of mostly laminated sediments under a 15 m debris layer (Rohrmüller et al, 2017). These sediments are surrounded by crystalline bedrock with significantly higher electrical resistivity. While a refractions seismic survey in 2013 and geo-electric resistivity tomography (ERT) surveys in 2012 and 2016 revealed significant geophysical anomalies related with the maar, it does not show any geomagnetic imprint. Compared with ERT, our Radiomagnetotelluric measurements (RMT) are more sensitive to conductors and done with an areal coverage allow for a 3D inversion and interpretation. These measurements together with our RMT experiment are part of an ICDP drilling campaign (PIER-ICDP) into geodynamic key sites within the Eger Rift to shed light on the tectonic structure and related geodynamic processes. In April 2018, we recorded RMT data in a frequency range of (1MHz – 1kHz) along different profiles across the maar. For this purpose, we used the EnviroMT^{TM} instrument from Uppsala University, the MK5-SM25 instrument from the University of Cologne, as well as an additional broad-band Magnetotelluric (MT) station with induction coil magnetometers a S.P.A.M. Mk4 recording system. In the framework of a previous project, a combination of high-frequency MT and RMT data significantly stabilized a 2D inversion approach. Here, we will present first results of a 2D and 3D inversion and a comparison with other geophysical findings and borehole information.

Keywords: Radio magnetotellurics, ICDP, Bohemia, Eger Rift

Re-analysis of magnetotelluric responses from the northern Canadian Cordillera

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SUMMARY

The North American Cordillera is an outstanding example of an accretionary orogen and forms a prominent continental-scale mountain range. Magnetotelluric (MT) data from Corridor 2 of the LITHOPROBE Slave-Northern Cordillera Lithospheric Evolution Transect have been re-analyzed using modern techniques for dimensionality determination and inversion. Data consist of 69 MT sites from an 800 km long profile extending from the Stikinia terrane, across the Tintina Fault, and into Ancestral North American rocks. The MT period range is 0.0015 to >2000 s but many longer period responses are severely affected by galvanic distortion. Dimensionality and strike were examined using period- and depth-dependent Swift, WALDIM, phase-split, Becken-Burkhart, Groom-Bailey, and phase tensor approaches. Results reveal areas of increased phase-split, corresponding to strong 2-D and 3-D structure, including: in the Stikinia terrane; crossing the accreted Cache Creek, Quesnelia and Slide Mountain terranes; at the Tintina Fault; at the Muskwa Anticlinorium; and at the eastern end of the profile. Results of 2-D inversions of different parts of the MT data set, sensitivity analysis, and geologically-constrained MT modeling and inversion provide complementary information on the geometry and resistivity structure of Cordilleran terranes and faults. In the Stikinia terrane there is a conductive region in the mid to lower crust above a laterally-uniform lithospheric mantle. The accreted terranes are associated with resistivity structures in the upper to mid crust, overlying uniform resistivity in the west-tapering wedge of Ancestral North American rocks inferred from seismic data. Resistivity structures associated with the Tintina Fault are most strongly developed at mid to lower crustal depths, where the MT responses can be modelled as a sub-vertical resistive zone. At lithospheric depths the MT data require a west-to-east transition from more resistive to more conductive rocks and are consistent with this transition occurring at the Tintina Fault.

Keywords: Magnetotellurics, tectonics, Northern Cordillera, Canada

Resistivity structure in Akita prefecture, northeast of Japan

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SUMMARY

We carried out magnetotelluric measurements in the wide area in and around the Akita prefecture, northeast of Japan. By the annual campaigns the total number of the observed sites has piled up to more than 150 through 10 years. Meanwhile the 2011 off the Pacific coast of Tohoku Earthquake was occurred and the crust beneath northeast of Japan was affected severe damage by the stress and pressure changes. Just after this super large earthquake, several damaged earthquakes were induced inland of the arc in the east area of Japan. The epicenter of one of them was in the north area of Akita prefecture and the earthquake magnitude of JMA is moderately large M=5.0. In addition, the seismic activities were changed at several areas in the prefecture. We covered the area over the moderately large earthquake and over the seismicity changes. The covered area includes the area of 1896 Rikuu earthquake and 1912 Senboku earthquake. Inland of Akita prefecture the overall azimuth of fault system is around north-south. Consequently we set up the east-west magnetotelluric survey lines in the prefecture and firstly analyzed by two-dimensional structure models. Now we figure out the wide area outline of resistivity structure from the depth of 0.5 km to 40 km in Akita prefecture. We can discuss the feature of the resistivity structure with seismic activity, distribution of active faults, velocity structure of seismic wave, cructal movements, gravity, geomagnetic total intensity and so on.

Keywords: resistivity, the 2011 off the Pacific coast of Tohoku Earthquake, seismic activity, active fault, magnetotelluric sounding,

Role of fluids in the earthquake generation: The Nagamachi-Rifu reverse fault, Northeast Honshu, Japan

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SUMMARY

Overwhelming influence of 2011 Tohoku-Oki earthquake (M9) on the Japanese island arc effected the volcanic activity and induced significant modifications in the local seismicity, which are proven to be related to crustal fluid distribution. For this reason, figuring out the presence and capacity of the fluid reserve in the crust within a target area before this major event became crucial for understanding the dynamic behavior of the region and for making further comparisons. In this study, high quality wide-band magnetotelluric (MT) data, collected at 61 sounding locations near the Nagamachi-Rifu Fault, Northeast Honshu, Japan, prior to the Tohoku-Oki earthquake, were used to image the electrical conductivity structure and hence the fluid content. Magnetotelluric data collected along three profiles that orthogonally cross the almost NE-SW geoelectric strike were used to image the epicentral region of this active reverse fault and its vicinity. Sophisticated three-dimensional inversion schemes were utilized on the MT data in the “observed” and “rotated-to-the-geoelectric-strike” forms for modeling purposes to map the fluid-rich and/or -depleted zones. Inversions included 0.3 Ohmm cells with realistic bathymetry on both sides of the initial model representing the Japan Sea in the west and Pacific Ocean in the east to realize the ocean effect. Resulting models were compared with prior and post seismicity of the main event.

Keywords: Faults, fluids, conductivity, Nagamachi-rifu fault

Seismogenic context of the 2017 Jiuzhaigou Ms7.0 earthquake in the Songpan-Ganzi block inferred from 3-D Magnetotelluric imaging

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SUMMARY

A three-dimensional electrical structural model of the 2017 Ms7.0 Jiuzhaigou earthquake and surrounding area was obtained. The model indicate that the Jiuzhaigou earthquake occurred on the Huya fault and it is a steep electrical boundary zone in the electrical resistivity structure. The Huya fault is a boundary fault of Songpan-Ganzi block. Songpan-Ganzi block has a low resistivity middle-lower crust. The left-lateral strike-slip component of the East Kunlun fault was transferred to the Minshan mountain and the Huya fault in the form of uplift and left-lateral strike-slip respectively. Extrusion of these materials along the East Kunlun fault is the main source of structural deformation in the area.

Keywords: East Kunlun fault, Jiuzhaigou MS7.0 earthquake, Electrical structure

INTRODUCTION

On 8 August 2017, the Jiuzhaigou (JZG) Ms7.0 earthquake occurred near Zhangzha village in Jiuzhaigou County (http://www.csi.ac.cn). The event resulted in huge casualties which include 29 fatalities, 543 injuries and 1 people missing， (http://www.cea.gov.cn/publish/dizhenj/464/522/20171229103857324772935/index.html). It is another strong earthquake occurred in eastern Tibetan plateau after the 2008 Wenchuan Ms8.0 earthquake and 2013 Lushan Ms7.0 earthquake. The Wenchuan earthquake and Lushan earthquake occurred on the mid-southern section of the Longmenshan fault zone (LMSFZ) which is the boundary fault between the Songpan-Ganzi block (SGB) in eastern Tibetan plateau and the Sichuan basin (SCB) in southern China. The JZG earthquake occurred in the intersection area of the SGB and the West Qinling orogenic zone (WQLOZ).

The epicenter is located at (33.193° N, 103.855° E) by USGS with a depth of ~9 km. Focal mechanism solutions inverted simultaneously by the Cut and Paste (CAP) waveform inversion method has indicated that the rupture of this event was dominated by left-lateral strike-slips motion, the moment magnitude of the event is Mw6.4 and the occurrence of the main shock is at a shallow depth in the upper crust because the centroid depth is 5 km (Yi et al. 2017). There are no obvious surface ruptures were found during the field investigations after the earthquake (Xu et al. 2018). Relocated aftershock sequence of the JZG earthquake shows the aftershocks aligned along a sub-vertical fault plane striking ~153°, extending ~45 km along strike and ~22 km along dip, which also presents obvious temporal and spatial migration characteristics along strike direction (Fang et al. 2017). The Huya fault (HYF), the Minjiang fault (MJF) and the Tazang fault, also called east part of the East Kunlun fault (EKLF), are major active faults in this region. There are still debates in which fault caused the event, the seismogenic structure and the depth of main shock.

The JZG earthquake occurred near the east end of the EKLF. The EKLF is an important part pf eastward extrusion of the Tibetan plateau (Tapponnier et al. 2001). The slip rate along the EKLF decrease from 10~12 mm/a (on west section) to 1.4~3.2 mm/a (near east end). Some of the strike slip motion on the EKLF has transferred into the Min Shan Mountain (MSM) by uplift of it while other has transferred into the Longriba fault (LRBF) and the LMSFZ (Kirby et al. 2007; Ren et al. 2013). In this area of structural transformation, several strong earthquakes have occurred along the HYF and MJF according to historical records. Only in the 20th century, the 1973 Huanglong Mw6.5 earthquake and the 1976 Songpan earthquake sequence (include two Mw7.2 and one Mw6.5 earthquakes) have occurred on the HYF (Chen et al.1994).

In this region, the deep structural characteristics and seismogenic context have attracted continued attention because of the strength of these s earthquakes. Several geological and geophysical works after the JZG earthquake still lacking description of the seismogenic structure and dynamic model of the JZG earthquake (Xie et al.

2018; Zhao et al. 2018). More investigation need to take in this area to determine the seismogenic structure and context of the JZG earthquake. Magnetotelluric (MT) is a useful geophysical technique for imaging the activate fault, seismogenic structure and context (Unsworth et al. 1997; Becken et al. 2011). 3D electrical resistivity model inverted by dense distribution MT stations can determine unclear structure of earthquaks (Cai et al ,2017). After the JZG earthquake, China Earthquake Administration deployed such survey near the east end of the EKLF.

Data and Analysis

MT data were recorded at 188 stations in the JZG earthquake area and its vicinity (Figure 1) during October to November 2017. Time series of two electric components (Ex and Ey) and three magnetic components (Hx, Hy and Hz) were measured parallel and perpendicular to magnetic north by Phoenix MTU-5A instruments at each station. Data were collected for 40 hours at most stations. The time series were processed using the Phoenix processing software SSMT2000 with statistically robust algorithm (Egbert and Booker, 1986) and remote reference technique (Gamble et al. 1979) to calculate MT transfer functions. The frequencies of each station are in the range of 320Hz to 2700s.

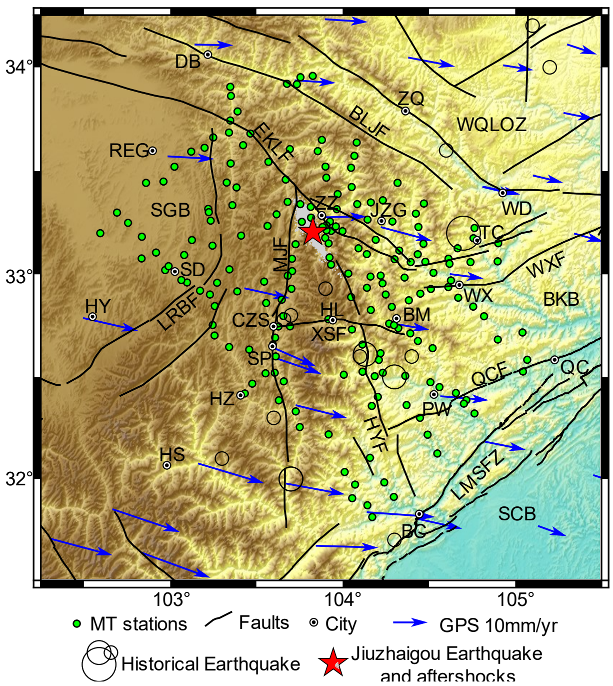

Figure 1. Topographic map and MT sites of JZG earthquake region. The green dots are broadband MT sites; black lines denote active faults. The black circles denote historical with magnitudes greater than 6.0. The blue vectors are GPS velocity observed in the period of 2009 to 2015 relative to the stable Eurasia. The red pentagram and grey dots denote main shock and aftershocks of JZG earthquake (Fang et al.2018). Abbreviations are: EKLF, East Kunlun fault; MJF, Minjiang fault; XSF, Xueshan fault; HYF, Huya fault; WXF, Wenxian fault; LRBF, Longriba fault; QCF, Qingchuan fault; BLJF, Bailongjiang fault; WQLOZ, West Qinling Orogenic Zone; SGB, Songpan-Ganzi block; BKB, Bikou block; LMSFZ, Longmenshan fault Zone; SCB, Sichuan basin; JZG, Jiuzhaigou; ZZ, Zhangzha; DB, Diebu; HY, Hongyuan; HS, Heishui; HZ, Hongzha; SP, Songpan; CZS, Chuanzhusi; HL, Huanglong; BM, Baima; PW, Pingwu; WX, Wenxian; WD, Wudu; ZQ, Zhouqu.

Skew angle (β) of phase tensor and geometric mean (φ2) of the maximum and minimum phase are used to analyze the dimensionality and vertical resistivity variation, respectively (Caldwell et al. 2004; Bibby et al. 2005; Heise et al. 2008;). Phase tensor of MT data showed that the SGB has a simpler structure (β<5) than surrounding area(β>5). It indicated that the research region contains a complex region that structure should be 3D, therefore a 3D inversion is needed.

The 3-D inversion and Results

The MT data were inverted by using the electromagnetic inversion program ModEM (Egbert et al. 2012;) to determine the 3-D electrical resistivity structure. MT data and model grids were rotated to NE45° to adapt location of stations and limits the amount of grids. The inversions were performed by using the off-diagonal apparent resistivity and phase data for 32 periods during 320Hz~2700s. The error floor is 5% and 2.84 (approximately 5%) for apparent resistivity and phase data respectively. The model grids was 68*86*76 cells in X, Y and Z directions, respectively. It has 52*70 horizontally uniform cells with a node spacing of 3.5 km in both directions and 8 padding planes with laterally increasing length by a factor of 1.5 to each horizontal boundary. Impression technique was employed to reduce the effects of the initial model (Cai et al. 2017). Here we show the electric structure of the JZG earthquake in map views at depths 10, 20, 30 and 40 km (Figure 2) and in cross sections through the JZG earthquake area (Figure 3).

The 3-D electrical resistivity model reveals that the SGB and the WQLOZ have distinct resistivity structures. The SGB exhibits a three-layer structure with alternating high-low-high resistivity. The structure of the WQLOZ is more complex, characterized by a discontinuous low resistivity body in the upper crust and an extensive relatively high resistivity body in the middle and lower crust.

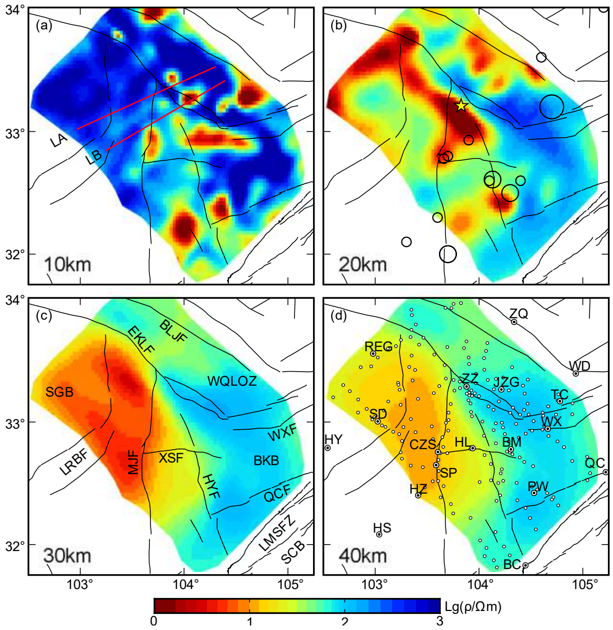

Figure 2. The 3-D inversion results show in map view for four depths from upper to lower crustal levels. Red lines in Figures 2a are locations of three cross sections in Figure 3. White dots denote MT site; black lines denote active faults. The black circles denote historical with magnitudes greater than 6.0. The yellow pentagram denotes main shock of the JZG earthquake

Discussion

The Jiuzhaigou M7.0 earthquake occurred between the MJF and EKLF. The dense distribution of the stations makes it possible to describe the seismogenic structures in detail. The electrical resistivity structure of the JZG earthquake region and the distribution of aftershocks (Fang et al. 2017) indicated that the seismogenic fault is the HYF. The HYF showed an almost upright shape and divided the SGB and the high resistivity body on the east side. High conductivity layer (HCL) in the southwest part of SGB reported by Zhao et al. (2012) and Zhan et al. (2013) has been found in most region of SGB. The top boundary of the HCL gradually shallow from southwest to northeast, it indicated that the HCL been block in the HYF.

Although all occurred on border of SGB, the JZG earthquake has different electrical resistivity and seismogenic context from the Wenchuan earthquake and the Lushan earthquake (Zhao et al. 2012; Zhan et al. 2013). The JZG earthquake occurred on a left-lateral slip fault while the Wenchuan earthquake and Lushan earthquake occurred on thrust and nappe structure.

Due to northeast motion of the Indian plate within the Tibetan Plateau, the HCL in the SGB crust may be associated with eastward extrusion along the EKLF. In the vicinity of MSM, this extrusion can be resolved into two components. One component is perpendicular to the MSM and causes uplift of the MSM due to blocking by the rigid Bikou block. The other component is along the HYF and leads to the southward movement of the MSM. The Jiuzhaigou earthquake, and other earthquakes which have occurred along the HYF, are the result of ongoing left-lateral slip at the eastern termination of the EKLF.

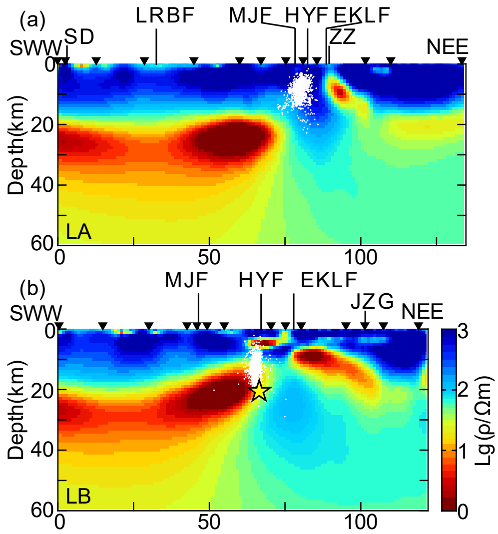

Figure 3. Cross sections extracted from the 3-D model (see Figure 2a for locations). The yellow pentagram and white dots denote main shock and aftershocks of the JZG earthquake.

Conclusions

We present a 3-D resistivity structure of the Jiuzhaigou earthquake and surrounding area. The model indicates that (a) The Jiuzhaigou earthquake occurred on the HYF. The HYF is a steep electrical boundary zone in the electrical resistivity structure. Together with the EKLF, it constitutes the eastern boundary of the HCL in middle-lower crust of the SGB; (b) There is a wide range of HCL in middle-lower crust of the SGB. Extrusion of these materials along the EKLF is the main source of structural deformation in the area. (c) The left-lateral strike-slip component of the EKLF was transferred to the Minshan mountain (between the HYF and MJF) and the HYF in the form of uplift and left-lateral strike-slip respectively.

Acknowledgements

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References

Becken, M., O. Ritter, P. A. Bedrosian, and U. Weckmann (2011), Correlation between deep fluids, tremor and creep along the central San Andreas fault, NATURE, 480, 87-90. doi:10.1038/nature10609

Bibby, H. M., T. G. Caldwell, and C. Brown (2005), Determinable and non-determinable parameters of galvanic distortion in magnetotellurics, GEOPHYS J INT. doi:10.1111/j.1365-246X.2005.02779.x

Cai, J., X. Chen, X. Xu, J. Tang, L. Wang, C. Guo, B. Han, and Z. Dong (2017), Rupture mechanism and seismotectonics of the Ms 6.5 Ludian earthquake inferred from three-dimensional magnetotelluric imaging, GEOPHYS RES LETT, 44, 1275-1285. doi:10.1002/2016GL071855

Caldwell, T. G., H. M. Bibby, and C. Brown (2004), The magnetotelluric phase tensor, GEOPHYS J INT, 158, 457-469. doi:10.1111/j.1365-246X.2004.02281.x

Chen, S. F., C. J. L. Wilson, Q. D. Deng, X. L. Zhao, and L. L. Zhi (1994), Active faulting and block movement associated with large earthquakes in the Min Shan and Longmen Mountains, northeastern Tibetan Plateau, Journal of Geophysical Research: Solid Earth, 99, 24025-24038. doi:10.1029/94JB02132

Egbert, G. D., and J. R. Booker (1986), Robust estimation of geomagnetic transfer functions, GEOPHYS J INT, 87. doi:10.1111/j.1365-246X.1986.tb04552.x

Egbert, G. D., and A. Kelbert (2012), Computational recipes for electromagnetic inverse problems, GEOPHYS J INT, 189, 251-267

Fang, L.H., Wu, J.P., Su, J.R., et al. 2018. Relocation of Mainshock and Aftershock Sequence of Ms7.0 Sichuan Jiuzhaigou Earthquake, Sci Bull, under review.

Gamble, T. D., W. M. Goubau, and J. Clarke (1979), Error analysis for remote reference magnetotellurics, GEOPHYSICS, 44, 959-968

Heise, W., T. G. Caldwell, H. M. Bibby, and S. C. Bannister (2008), Three-dimensional modelling of magnetotelluric data from the Rotokawa geothermal field, Taupo Volcanic Zone, New Zealand, GEOPHYS J INT, 173, 740-750. doi:10.1111/j.1365-246X.2008.03737.x

Kirby, E., N. Harkins, E. Wang, X. Shi, C. Fan, and D. Burbank (2007), Slip rate gradients along the eastern Kunlun fault, TECTONICS, 26, TC2010. doi:10.1029/2006TC002033

Tapponnier, P., X. Zhiqin, F. Roger, B. Meyer, N. Arnaud, G. Wittlinger, and Y. Jingsui (2001), Oblique stepwise rise and growth of the Tibet Plateau,SCIENCE, 294, 1671-1677

Unsworth, M. J., P. E. Malin, G. D. Egbert, and J. R. Booker (1997), Internal structure of the San Andreas fault at Parkfield, California, GEOLOGY, 25, 359-362.

Xie, Z.J., Zheng, Y., Yao, H.J. et al. (2018) Preliminary analysis on the source properties and seismogenic structure of the 2017 Ms7.0 Jiuzhaigou earthquake, SCIENCE CHINA Earth Sciences 61(3), 339-352. doi: 10.1007/s11430-017-9161-y

Xu, X.W., Chen, G.H., Wang, Q.X. et al (2017), Discussion on seismogenic structure of Jiuzhaigou earthquake and its implication for current strain state in the southeastern Qinghai-Tibet Plateau, Chinese J. Geophys. (in Chinese), 60, 4018

Yi, G.X., Long, F., Liang, M.J. et al (2017), Focal mechanism solutions and seismogenic structure of the 8 August 2017 M7.0 Jiuzhaigou earthquake and its aftershocks, northern Sichuan, Chinese J. Geophys. (in Chinese), 60, 4083

Zhan, Y., Zhao. G.Z., U, Martyn et al. (2013), Deep structure beneath the southwestern section of the Longmenshan fault zone and seimogenetic context of the 4.20 Lushan M_S7.0 earthquake,Chinese Science Bulletin, 3467-3474.

Zhao, D., C. Qu, X. Shan, W. Gong, Y. Zhang, and G. Zhang (2018), InSAR and GPS derived coseismic deformation and fault model of the 2017 Ms7.0 Jiuzhaigou earthquake in the Northeast Bayanhar block, TECTONOPHYSICS, 726, 86-99. doi:10.1016/j.tecto.2018.01.026

Zhao, G., M. J. Unsworth, Y. Zhan, L. Wang, X. Chen, A. G. Jones, J. Tang, Q. Xiao, J. Wang, J. Cai, T. Li, Y. Wang, and J. Zhang (2012), Crustal structure and rheology of the Longmenshan and Wenchuan Mw 7.9 earthquake epicentral area from magnetotelluric data, GEOLOGY, 40, 1139-1142. doi:10.1130/G33703.1

Shallow magma imaged by array MT data in the Taupo Volcanic Zone, New Zealand

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SUMMARY

More than 1000 broadband magnetotelluric (MT) measurements (with 2 km site spacing) have been acquired to form two arrays in the central part of the Taupo Volcanic Zone (TVZ), New Zealand. The TVZ is an actively rifting volcanic arc, with a central segment representing the largest rhyolitic volcanic system on Earth (since ~340kya). Heat flux across the TVZ is more than 10x the global mean for continental crust and is discharged through 23 high-temperature geothermal fields.

Previous results using subsets of these array MT data provide the first-ever images of connections between the shallow parts of the known geothermal fields and their deeper underlying heat source. Variations observed between the basement roots of the geothermal fields imply a strong connection with tectonic and volcanic structure that was not previously envisaged. The conceptual model of heat transport in the brittle crust is now advanced to a model of episodic intrusion around the geothermal fields, modulating the broad pattern of overall convective heat transport.

Recent MT measurements cover the Okataina Volcanic Centre (which has erupted 80km^3 within the past 22ka), and include Mount Tarawera; a series of rhyolite domes that experienced a Plinian basalt fissure (17km long) eruption in 1886. 3D resistivity inversion models of MT data in the Okataina Volcanic Centre suggest that Mount Tarawera straddles the eastern margin of a large basement low-resistivity zone. GPS and InSAR observations of subsidence (up to 2cm/yr) located above this low resistivity zone support interpretation as a body of magma, cooling-off (and contracting) within the upper crust.

Keywords: Taupo Volcanic Zone, Caldera, Geothermal

Southeastern Australian Lithosphere imaged by Magnetotelluric data: AusLAMP New South Wales

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SUMMARY

The Australian Lithospheric Architecture Magnetotelluric Project (AusLAMP) aims to collect long period magnetotelluric (MT) sites on a 0.5 degree (~55 km) grid across the Australian continent. Data and models produced from this program will help to inform our understanding of Australia's lithospheric architecture and tectonic processes.

Geoscience Australia is leading AusLAMP data collection in New South Wales, southeastern Australia under a National Collaborative Agreement with the Geological Survey of New South Wales and Victoria. This new dataset extends the coverage of 98 stations provided by the AusLAMP Victoria dataset (Duan et al., 2016). In New South Wales, data collection is ongoing with a total of 103 deployments completed so far. The combined dataset provides coverage across an ~1100 x 700 km area over southeastern Australia.

Victoria and southern New South Wales is made up of several Proterozoic to Paleozoic orogenic and cratonic belts, covered in part by Mesozoic to Cenozoic sedimentary basins. The Proterozoic Curnamona Craton extends westward from New South Wales and Victoria into South Australia and hosts the Broken Hill silver-lead-zinc deposit. Adjacent to the Curnamona craton is the Precambrian to Cambrian Delamerian Orogen, which separates the Precambrian cratons of Central Australia from the younger orogenic belts in eastern Australia (Glen, 2005). These include the Lachlan Orogen, located immediately east of the Delamerian Orogen, which hosts a number of copper gold and base metal deposits.

We will present data and resistivity models from this area, providing new insights into the lithospheric architecture and composition of the crust across this region. We will discuss implications of the new data and models for the tectonic development and mineralization in this region.

Keywords: AusLAMP, magnetotelluric, lithosphere, tectonic

REFERENCES

Duan, J., Taylor, D., Czarnota, K., Cayley, R., Chopping, R. (2016) AusLAMP MT over Victoria: New insight from 3D modelling highlights regions of anomalously conductive mantle and unexpected linear trends in the crust. Australian Society of Exploration Geophysics Extended Abstracts 2016: 25th Geophysical Conference and Exhibition, Adelaide, Australia.

Glen, R. A. (2005) The Tasmanides of eastern Australia. Geological Society of London Special Publication, 246, 23.

Surpassing coast effect to reveal fault's rheology: An example from Armutlu Peninsula, NW Turkey

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Summary

Relationship between fluids and fault geometry determines the rheological response of crustal structures under tectonic stresses. Stating the stress equilibrium is a useful way for understanding the characteristics of seismicity on a region. Fluids present near fault zones are one of the key elements in such an equipoise, due to their reduction effects on the normal stress. Since 1999 İzmit Earthquake (Mw = 7.4) transferred the stress accumulation to the west along North Anatolian Fault Zone, the epicentral region has been investigated extensively. In this study, fluid-sensitive geophysical tool magnetotellurics is used to probe the electrical conductivity structure of Armutlu Peninsula where westward-spreading aftershocks of 1999 İzmit Earthquake were concentrated. Indented coastline and disturbed bathymetry of the Marmara Sea were realized by applying veridical information to overcome the ocean effect during three-dimensional numerical modeling. Alternative attempts in inversion process prove that attaining a realistic model is crucial to interpret the results in geological point of view. The final model suggests that elongations of the faults in the region follow resistor-conductor interfaces and earthquakes show a tendency to occur on the resistive sides. Local high conductivity regions, which envelope both sides of the North Anatolian Fault, possibly cease the seismic activity by reducing effective normal stress. Furthermore, the conductivity pattern differs prominently in short intervals within the same segment, indicating heterogeneity along the fault zone.

Keywords: North Anatolian Fault, fluids, creep, coast effect, electrical conductivity

The crustal structure of the Cantabrian Mountains revealed by magnetotelluric soundings

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SUMMARY

The central Cantabrian Mountains represent a block of Variscan basement uplifted over the Duero foreland basin as a consequence of a southward displacement along a basement-involved thrust during the convergence between Europe and Iberia in the Eocene-Oligocene. We present a new long period magnetotelluric profile across this part of the Cantabrian Mountain and the Duero Basin. The MT profile consists of thirteen magnetotelluric sites over a 100 km long, N-S oriented profile. Dimensionality analyses indicate a dominant E-W direction but with a strong influence of 3D structures mainly at long periods. Accordingly, a 3D joint inversion of the full impedance tensor and the geomagnetic transfer function was carried out.

In the southern part of the area, the resistivity model shows the conductive sediments of the Duero basin over a high resistive and homogeneous Iberian lithosphere. Towards the north, beneath the Cantabrian Mountains, the model reveals a heterogeneous and conductive lithosphere, in which various elongated and dipping conductors in the upper and middle crust are associated with the major Alpine thrusts, one being the frontal thrust of the Cantabrian Mountains over the Duero basin. At deeper depths (between 20 and 35 km depth), the model shows the Iberian crust subducting to the north beneath a high conductivity zone interpreted as the hydrated mantle wedge of the north-Iberian continental margin.

Keywords: Magnetotellurics, Cantabrian Mountains, 3-D inversion

The deep structure of the triple junction of the East European Platform's segments based on magnetotelluric and seismological data

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SUMMARY

Studying of the large-scale tectonic nodes in relation with ancient and recent geodynamic activities is an important direction in the Earth's sciences. One of such nodes is a triple junction of Fennoscandian, Volga-Uralian and Sarmatian segments of the East European platform (EEP). This zone is located in the west of the Smolensk region (Russia) at the border with Belorussia. There is a hypothesis based on a number of factors on the existence of centripetal convergence of lithospheric plate flows in this region. We suggest applying a complex of electromagnetic and seismological sounding methods using natural fields to test the hypothesis and to study in details the deep electrical conductivity anomaly initially detected there in 1990s.

The current capabilities of simultaneous magnetotelluric (MT) and magnetovariational (MV) soundings and the receiver function seismological studies make it possible to study the entire crust-mantle structure of the tectonosphere to depths of 250-300 km. We plan to carry out up to 20 long-period MT/MV soundings and to set up several seismic stations. Basing on the new measurements, we will produce and analyze maps of the most important MT/MV data invariants, the crustal longitudinal conductivity, deep geoelectric models of different dimensions (1D, 2D+, quasi-3D and 3D) and seismic velocity sections.

The new geoelectrical and seismological information about the triple junction zone of the EEP segments in complex with potential fields data (including satellite observations) will allow us to draw conclusions about the nature of the revealed anomalies in the connection with contemporary geodynamic processes and to construct a general volume physical-geological model of this zone. This research will significantly complement the KIROVOGRAD project study of geoelectric structure at the western slope of the Voronezh Massif.

Keywords: East European Platform, lithospheric plates, suture zones, magnetotelluric and magnetovariational soundings, seismology

INTRODUCTION

Studying the modern geodynamic activities is an important direction in the Earth's sciences. A detailed study of the platform's activation areas structure makes it possible to identify the features of their development in the most recent geological stages and draw conclusions about the current dynamics of the geological environment deformation.

The goal of the project is geophysical investigation of the triple junction zone of the EEP segments (Figure 1) to diagnose the processes of modern geodynamic activation and to test the hypothesis of formation of centripetal convergence of lithospheric plate flows in this zone (Figure 2).

Using of MT methods for these purposes is very appropriate because of their special sensitivity to the processes of fluidization and the anomalous thermal state of the crustal mantle matter. In recent years, the capabilities of the MT/MV method have significantly expanded as a result of the approval of synchronous area surveillance systems that provide the use of multipoint methods for interference suppression of synchronous data and the use of 3D inversion of multicomponent MT/MV data (Varentsov 2015a,b). Cooperating MT/MV soundings with seismological studies by the receiving functions method provides a new quality of summary interpretation of the EM complex and seismological data within the entire tectonosphere to depths of 250-300 km. Additional support for planned studies can be obtained by using potential fields data, incl. observations from satellites.

The area of research is poorly studied with deep seismic methods. Relatively deep MT/MV soundings in this area are limited by only one Gomel-Mogilev meridian profile in Belorussia, carried out in the 1990s with CES-2 equipment. Despite the limited profile monitoring system and the mediocre quality of the MT/MV transfer operators, these studies indicate a deep anomaly of increased electrical conductivity in the investigated nodal zone (Figure 3).

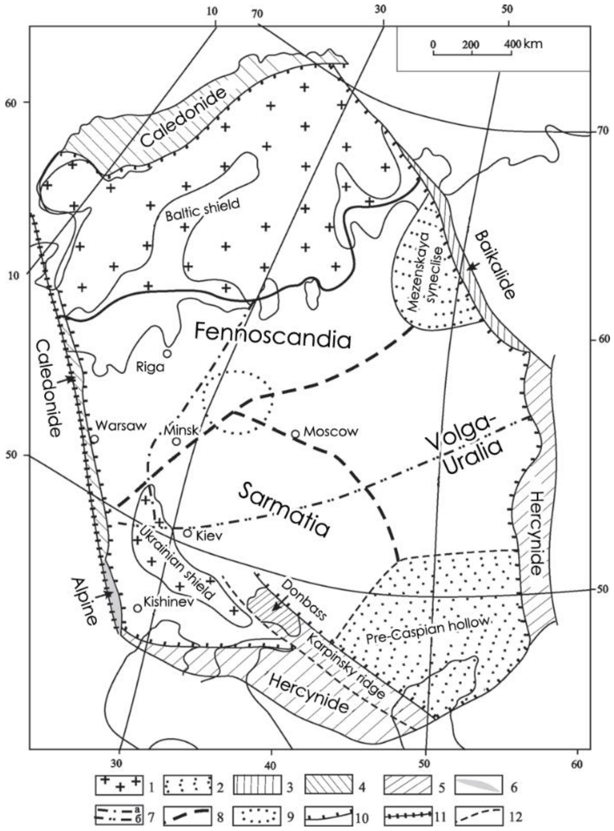

Figure 1. Scheme showing some features of tectonics and geodynamics of the EEP. 1 - outcrops of the foundation on the earth surface (the Baltic and Ukrainian shields); 2 - the deepest hollows (Pre-Caspian) and syneclise (Mezenskaya); 3-6 - marginal allochthonous structures: 3 - Baikalide (Timan), 4 - Caledonide, 5 - Hercynide (Ural, foundation of the Scythian plate), 6 - Alpine (Carpathians); 7 - the main tectonic axis of the platform: a - submeridional, b - sublatitude; 8 - the boundaries of the basement platform segments (Fennoscandia, Volga-Uralia, Sarmatia); 9 - Slobodskaya tectonic and geodynamic node; 10 - thrusts of marginal allochthonous structures - boundary of the platform; 11 - Teisser-Tornquist line of the Trans-European southeast zone; 12 - faults.

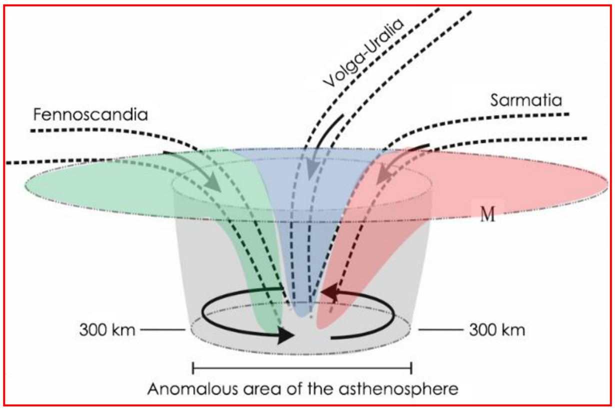

Figure 2. Structural scheme of the Slobodskaya tectonic and geodynamic node according to (Garetsky and Karataev 2014).

Proposed Approaches And Methods

The method of synchronous observations of the EM field and further multi-point technique of robust estimation of transfer operators, which provides a significant suppression of industrial EM noises, allows to achieve high quality sounding results up to periods of a few dozen thousands of seconds (Varentsov 2015b). MV measurements allow to get rid of MT data galvanic distortions and complement a set of interpreted transfer operators with a horizontal MV response that has a number of advantages over the other operators (Varentsov 2015b).

The planned observation system will consist primarily of deep (long-period, LMT) MT/MV soundings performed by Ukrainian LEMI-417 stations in the range of 10-10,000 s (Figure 3). The obtained data will make it possible to conceptualize the geoelectric structure of the tectonosphere to depths of 250-300 km. Data of long-period MT/MV observations from the stationary ALX station (at the geophysical base of the Moscow State University in the Alexandrovka village, Kaluga region) and a few geomagnetic observatory instruments will be used as remote bases for synchronous data processing and horizontal MV responses estimation.

The method of joint 2D+ inversion of MT/MV data (Varentsov 2015a) allows us to take into account the level of the 3D data distortion. It was effectively applied at the western slope of the Voronezh Massif for the profiles that will be continued to the west as a part of the planned study (Varentsov and Lozovsky 2014).

The method of multiple-film quasi-3D inversion of horizontal MV responses and tippers (Varentsov 2015b; Kovacikova and Varentsov 2016) was successfully tested during the international EMTESZ and KIROVOGRAD experiments and will provide a transition from the profile interpretation to area interpretation. Using this method on a regional scale at the Voronezh Massif and adjacent areas (Figure 3) already helped to primary localize the anomaly of electrical conductivity studied in this project. To solve 3D inverse problems with a multicomponent MT/MV complex data, the ModEM code will be used. The success of 3D inversion in many respects will depend on the construction of adequate starting models, which, in turn, must be based on the results of a deep analysis of transfer operators (Ivanov and Pushkarev 2010, 2012) and on solving inverse problems of a smaller dimension, and rely on the a priori geological and geophysical information.

Seismological studies using the method of receiving functions can reliably reconstruct the velocity sections of seismic waves to depths of 250-300 km. For this, there is a developed mathematical apparatus for processing data and solving inverse problems, tested in various geological and geophysical conditions, including in the research region (Kosarev et al. 2013). When studying modern geodynamic processes, seismological studies carry important information on structures with low velocities associated with the crust-mantle decomposition regions, fluidization and / or partial melting, and are thus an important addition to the MT/MV methods.

There are several researches dedicated to modern geodynamic processes in the triple junction zone of the EEP segments (Figure 1,2) (Garetsky and Karataev 2014). This region is characterized by radial convergence of the basement and suture segments, by the ring arrangement of faults forming a tubular or funnel-shaped structure, and by the anomalous structure of the magnetic and gravitational fields with elements of vortex twisting of the anomalies.

There is a hypothesis that the channels of the alleged tectonic flow are manifested in the form of anomalies of electrical conductivity. According to the available data of the 1990s, obtained by the CES-2 equipment along the Gomel-Mogilev meridian profile along the border of Belorussia and Russia, there is a deep anomaly in the zone under consideration, which is clearly manifested in the data of effective apparent resistivity (Figure 3). Its long-period structure significantly differs from the short-period structure because of conductive sediments of the Orsha hollow. For objective verification of this hypothesis and refinement of the revealed anomaly of electrical conductivity, it is necessary to construct stable and consistent 2D+, film quasi-3D and volume 3D geoelectrical models in the most important details in accordance with the results of synchronous MT/MV soundings to locate there crust-mantle structures with abnormally high conductivity.

ACKNOWLEDGEMENTS

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REFERENCES

Garetsky RG, Karataev GI (2014) The suture zones of Fennoscandia, Sarmatia and Volga-Uralia. Belorussian Science, Minsk (in Russian)

Ivanov PV, Pushkarev PYu (2010) Possibilities of interpretation of MT data, obtained on a single profile over 3D resistivity structures. Izv Phys Solid Earth 46(9): 727-734

Ivanov PV, Pushkarev PYu (2012) 3D inversion of the single-profile MT data. Izvestiya, Phys Solid Earth 48(11-12): 871-876

Kosarev GI, Oreshin SI, Vinnik LP et al. (2013) Heterogeneous lithosphere and the underlying mantle of the Indian subcontinent. Tectonophysics 592: 175-186

Kovacikova S, Varentsov IvM, KIROVOGRAD WG (2016) Quasi-3D inversion of horizontal MV responses: methodical developments and applications for the KIROVOGRAD sounding array. XXIII Workshop on EM Induction in the Earth (Extended Abstr)

Varentsov IvM (2015a) Methods of joint robust inversion in MT and MV studies with application to synthetic datasets. In: Spichak VV (ed) Electromagnetic sounding of the Earth's interior: theory, modeling, practice. Elsevier, pp 191-229

Varentsov IvM (2015b) Arrays of simultaneous EM soundings: design, data processing, analysis and inversion. In: Spichak VV (ed) Electromagnetic sounding of the Earth's interior: theory, modeling, practice. Elsevier, pp 271-299

Varentsov IvM, Lozovsky IN, KIROVOGRAD WG (2014) KIROVOGRAD experiment: 2D+ inversion of MT/MV data along the ZHIZDRA profile. XXII Workshop on EM Induction in the Earth (Extended Abstr)

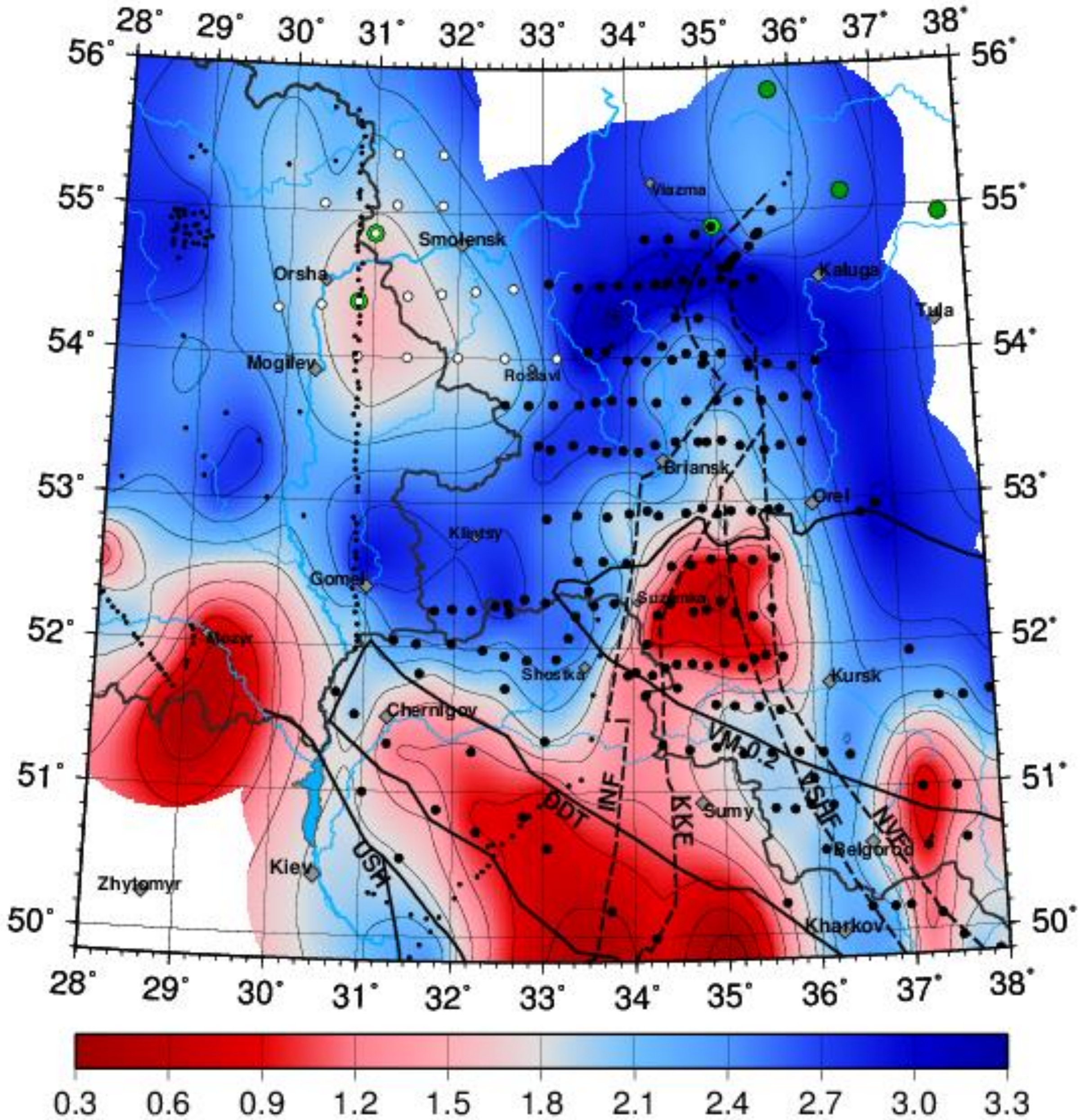

Figure 3. Map of apparent resistivity, calculated from the effective impedance, for the period 2500 s (color scale - Om·m, lg-scale). Points on the map indicate: large black - performed synchronous MT/MV soundings within the framework of the international KIROVOGRAD project; small black along the meridian 31° – performed in the 1990s MT soundings with CES-2 equipment; white - preliminary arrangement of new synchronous MT/MV soundings in this project; dark green - performed seismological soundings; light green - the design location of new seismological soundings inside the anomalous zone and at the ALX point.

The resistivity and thermochemical structure of the lithosphere beneath Northeast China from the joint inversion of magnetotelluric and other geophysical data

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SUMMARY

The Northeast (NE) China, lying between the North China Craton and the Siberian Craton, experienced extensive volcanism and extension in late Mesozoic. In order to reach consensus about the mechanism for the widespread intraplate volcanism and extension, it is necessary to study the resistivity, thermal, chemical structure and the water content of the lithosphere beneath the NE China, especially the characteristics of sub-lithospheric upper mantle. The magnetotelluric (MT) method has been widely used in probing subsurface structures at lithospheric scale and is sensitive to high electrically conductive body which are closely related to volcanism. We conducted 3-D inversion of MT array data which are combined by the broad-band data and long-period data to derive a general resistivity structure for the lithosphere of NE China. Also, the water contents and temperature distribution were estimated based on the obtained resistivity value to better constrain the interpretation of electrical anomaly. In addition to the MT array data, the Northeast China Extended Seismic Array (NECESSArray) Project has been deployed to provide further insight into the tectonic evolution of the NE China. This offered us a valuable opportunity to operate a joint inversion of different geophysical data. The Markov chain Monte Carlo (MCMC) method was then used for the joint inversion of MT data, ambient noise surface wave dispersion data, receiver function, surface heat flow and geoid height to generate reliable resistivity, velocity and thermochemical structure beneath the NE China.

Keywords: Northeast China, intraplate volcanism, resistivity, thermochemical structure, joint inversion

The Underplating-Delamination-Extension Process in Central Tibetan Plateau: Evidences from Magnetotelluric Data

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SUMMARY

In this study, we present new insight into the formation of the middle part of Tibetan Plateau by investigating its electrical structure of lithosphere. With 226 densely spaced broadband and long period Magnetotelluric array stations from SinoProbe Project, we were able to construct a three-dimensional resistivity model of the crust and uppermost mantle for the central part of Himalaya, Lhasa and Qiangtang Blocks. As revealed in previous 2D results from INDEPTH projects, this model images wide spread conductive structures in the mid-to-lower crust of Tibetan Plateau. However, the conducting features are not uniform as suggested by earlier studies, but with rather complex geometries. To the south of ~31°N, our new high-resolution model images a relatively continuous and highly conductive lower crust, with a gently north dipping fashion, which could result from the high level partial melting of the underplated India crust beneath Tibetan crust. This is also consistent with regional distribution of crustal-source Helium isotope and ultra-potassic volcanic rock with the India crustal signature. On the other hand, a distinct N-S aligning pattern of the conductive structures in the uppermost mantle are revealed to the north of 31°N, which also coincide with the region with an absence of continuous Mohorovicic discontinuity image from previous seismic receiver function research. Together this may indicate a de-coupling of the subducting India lower crust and upper mantle beyond that point, which could also suggest a transition to a steeper subduction to the north. As a result, the de-coupling may induce local delamination and the upwelling hot mantle material. Under a continuous N-S compression stress from the northward subduction, the crust in this region naturally experiences a perpendicular E-W extensional stress. Like the processes suggested in the east part of Tibetan Plateau, this could introduce localized extension of the crust, which further gives rise to the E-W opening of the N-S aligning rift systems of in the central plateau. This may also partly contribute to the east- and west-ward extrusion of the Tibetan plateau revealed by GPS studies.

Keywords: Tibetan Plateau, Magnetotellurics, delamination, extension

Three-dimensional electrical resistivity models around Mount St. Helens, Washington, USA

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SUMMARY

The Cascades magmatic arc in the Northwestern United States marks the subduction of the Juan de Fuca plate beneath western North America. The arc segment that includes Mount St. Helens (MSH), Mount Adams, and Mount Rainier is geologically enigmatic for multiple reasons including the fore-arc location of volcanic vents relative to the Cascades axis, the more felsic composition of magmas erupted at MSH, discrete zones of focused seismic activity, and a controversial crustal conductor (Southern Washington Cascades Conductor; SWCC).

The imaging magma under Mount St. Helens (iMUSH) project aims at identifying the sources of these peculiarities. Previously collected magnetotelluric (MT) data in the region include a focused 3D array surrounding MSH (*Hill et al., 2009*), the Café MT profile (*McGary et al., 2014*), select sites from the MOCHA and EarthScope arrays, and geothermal exploration investigations north and south of MSH. These data have been combined with ~150 newly acquired broadband MT stations to create two electrical resistivity models using ModEM (*Kelbert et al., 2014*). The first (regional) model spans the entire region between the three volcanoes, whereas the second (local) model is focused on MSH and the surrounding MSH seismic zone (SHZ).

The regional model images a conductive ring structure that approximates the shape of the SWCC, up to 5 km wide and extending from the near-surface to at least 7 km depth. One side runs through MSH and the SHZ while the other is located west of Mount Adams, but continues to the north through the Western Rainier Shear Zone. The conductive ring is attributed to carbonaceous Eocene metasediments deformed and metamorphosed by Miocene plutons, the most prominent being the Spirit Lake Batholith (SLB), the resistive center of the ring (*Bedrosian et al., 2018*). At ~20 km depth, a broad, linear conductive anomaly is imaged beneath the magmatic arc, interpreted as a crystal-rich melt zone as suggested by previous studies (*Hill et al., 2009; Bedrosian et al., 2018*). The composite model implies lateral transport of magma around the SLB; the viscous dacite melts at MSH are interpreted to result from localized extension within the SHZ, with magma ascent facilitated by mechanically-weak metasedimentary rocks. The resistivity model further reveals the SWCC to be a composite anomaly, with electrical conductance contributions from both inherited structure and modern tectonics.

The focused model is built upon the regional model and images a right-lateral step-over in the ring-like conductivity anomaly immediately north of MSH. In detail, earthquakes along the SHZ are focused north of MSH along the boundary between the metasedimentary rocks and the surrounding plutons at depths of 5-12 km. Both the micro-location of MSH and the patterns of seismicity are consistent with clockwise rotation of the fore-arc (*Wells et al., 1998*) expected to focus strain at relative weak points in the crust such as the imaged metasedimentary belts. As a whole, these results highlight the critical role that inherited structures play in controlling where seismicity and deformation occur as well as the distribution, and in some cases composition, of arc magmas.

Keywords: magnetotellurics, Mount St. Helens, Mount Rainier, Mount Adams, SWCC

Three-dimensional Imaging of Northern Geysers Geothermal Field, California with Magnetotellurics

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SUMMARY

The Geysers in California is one of the world's largest energy producing steam fields. The main steam field is confined between two large north-northwest trending bounding faults, the Maacama Fault zone on the west and the Collayomi Fault zone on the east, both related to the San Andreas Fault system. Smaller faults locally control geometry and depth of the steam field. The host formation of the Geysers steam field is the Franciscan Formation that includes metagreywacke, argillite, greenstone, melange, and serpentinite. The reservoir cap rock is the argillite with the reservoir being the 1 km thick metagreywacke. At a depth of around 2.5 km below mean sea level is a granitic rock called the 'felsite' that plunges to the north-northwest and is assumed to be related to the heat source. However, the heat source of the Geysers is not fully understood and zones of partial melt have not previously been imaged. The hottest part of the Geysers is in the northern part of the field where temperatures of up to 400 C have been measured. Currently, an enhanced geothermal system (EGS) is being developed to exploit the high temperatures and has been closely monitored with microseismics. In 2017, 40 magnetotelluric (MT) stations were collected in a 10 km x10 km area in the northern part of the field to image the heat source. Most stations were confined to old drilling pads because of topography and dense vegetation, hence no vertical magnetic fields were measured. The data quality was surprisingly good considering the amount of infrastructure and electrical noise present. A 3-D electrical resistivity model, including topography, was developed using ModEM, and correlates well with existing data. The argillite clay cap in the top 500 m is a strongly defined conductor (< 10 Ohm-m) that fits well data. The metagreywacke reservoir rock is more resistive (> 70 Ohm-m) and again correlates with well data down to 2 km. Below 3 km, the resistivity decreases with depth to around 20 Ohm-m at 5 km (this still needs to be tested for sensitivity), suggesting that if a zone of partial melt exists it is near the northeast side of the Geysers steam field and that the melt fraction is below 10 percent. Earthquake epicenters are typically confined laterally to within the resistive metagreywacke and vertically by the brittle-ductile transition at around 5 km with a few exceptions. One peculiar exception observed in the resistivity model is a vertical 1 km wide aseismic zone of high conductivity (< 20 Ohm-m) that extends from at least 5 km depth to near the surface. This zone is modeled as having a low V_p/V_s ratio, suggesting a highly fractured zone filled with either vapor or mineralization. Further investigation is needed to interpret this enigmatic zone. The next steps are to test model sensitivity to structures below 5 km to constrain the geometry of a potential heat source, and to try a constrained inversion using other geophysical data, specifically well data. Currently, electrical properties are being measured on samples of the different parts of the Franciscan Formation, this will help in interpreting the resistivity model.

Keywords: Magnetotellurics, Geothermal, Geysers

Three-Dimensional Lithospheric Resistivity Structure of NE Tibetan Plateau and Western North China Block and its Geological Significance

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SUMMARY

The neighbored region of the northeastern Tibetan plateau (TP) and the western North China Block (NCB) is a major place to study the northeastward channel flow of TP and the lithospheric relationship between the NCB and TP. The channel flow was thought to be composed of partial molten materials which should be low resistive. In contrast, the adjacent Alxa Block (AB) and Ordos Block (OB) should be high resistive since they belong to the NCB, a cratonic block and with its western part unaffected by the subduction of the Paleo-Pacific Ocean in the Mesozoic. Thus, with the obvious difference of lithospheric resistivity, magnetotelluric (MT) method is applicable to discuss the possible boundary of the northeastward escaping and the relationship between the TP and NCB.

Keywords: Tibetan Plateau, North China Block, Resistivity Model, Channel Flow

DATA AND INVERSION

This study used the data in geographical ranges of N34°-N42° and E99°-E109° collected by China University of Geosciences, Beijing with the funding of SINOPROBE project. It covered the eastern parts of the West Qinling (WQLB) and Qilian Blocks (QLB) of the northeastern TP and the whole AB and western part of the OB of the NCB. 608 broad-band MT (BBMT) stations were collected, and 55 long-period MT (LMT) stations were also acquired out of these BBMT stations. At least 20 hours and 7 days of data were recorded for each BBMT of LMT station respectively. Thus, a period range of 0.003 ~ 3000 s was obtained for BBMT stations, and for those BBMT+LMT stations, a period range of 0.003 ~ 10 000 s was achieved since the BBMT and LMT data were merged at a certain period between 10 to 1 000 s. The data quality was quite good as the noise level was quite low at that region.

Three south-to-north profiles were inverted with nonlinear conjugate gradients algorithm integrated in the WinGLink since major directions of strike are west-to-east. However, the results of phase tensor analysis (Caldwell et al., 2004)showed that one third stations can only be treated as 3-D when periods larger than 100 s. Thus, the modular system for electromagnetic inversion (ModEM) was employed for 3D MT inversion (Egbert and Kelbert, 2012; Kelbert et al., 2014). The full impedance of 480 stations were inverted at 30 periods in a period range of 0.01 to 10 000 s. Error floors of 10% and 5% of $|Z_{xy} \cdot Z_{yx}|^{1/2}$ were assigned to diagonal and off-diagonal components of impedance tensor respectively. The inversion started with a 100 Ωm half-space, and stopped after 400 iterations with the final RMS misfit of 1.59.

CONCLUSION

A layered resistivity structure of the WQLB was shown in the 3-D resistivity model, and a W-E trending very low resistive middle and lower crust was surrounded by the high resistive upper crust and lithospheric mantle. However, the resistivity structure of QLB is relatively complicated. The lithospheric mantle showed very high resistivity, indicating its basement of metamorphic complex formed in the Neo-Proterozoic. The upper crust is also high resistive and was interpreted as igneous rocks and granitic gneiss by comparing with the results of geological survey. However, the resistivity of middle and lower crust varied rapidly from very low resistivity to high resistivity from northwest to southeast. The southeast high resistivity zone was interpreted as granulite and mafic to ultramafic rocks. As to the northwest low resistivity area, it connects with the low resistivity middle and lower crust of the WQLB. In the north, the most lithosphere of AB is high resistive and indicates the AB is a stable block. According to geological data, the high resistive upper crust is composed of Archean to Proterozoic metamorphic and igneous rocks, and the middle and lower crust and lithospheric mantle are composed of Paleo-Archean mafic to ultramafic rocks. Taking N38° as the border, the southern OB showed a high resistive lithosphere and could be interpreted as Archean to Proterozoic crystallized basement, showing the features of a stable cratonic block. In contrast, low resistivity middle and lower crust and lithospheric mantle was discovered beneath the southern OB by the 3-D results. Therefore, the low resistivity anomalies in middle and lower crust of the WQLB and northwestern QLB extended from the TP indicates the possible northeastward channel flow, and is blocked by the stable lithosphere of the AB and southern OB. The huge low resistivity anomalies beneath the southern OB is interpreted as upwelled asthenosphere which indicates possible deconstruction of the cratonic block, which might be triggered by the northwestward subduction of the Paleo-Pacific Ocean or the northeastward development of the TP. One more notable feature of the resistivity model is that, a low resistivity layer tilted northeastward can be found between the AB and QLB, which was taken as the electrical evidence that the QLB subducted beneath the AB driven by the sinking of the Qilian Ocean (closed in the Late Ordovician) lithosphere. Moreover, the northeastward channel flow and growth of the TP during the Cenozoic was blocked by the steady AB, which pushed the QLB down into the AB, and thicken the crust of northeastern Tibet and adjacent areas.

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REFERENCES

Caldwell, T.G., Bibby, H.M., Brown, C. (2004). The magnetotelluric phase tensor. Geophysical Journal International 158, 457-469.

Egbert, G.D., Kelbert, A. (2012). Computational recipes for electromagnetic inverse problems. Geophysical Journal International 189, 251-267.

Three-Dimensional Magnetotelluric Imaging of the Cascadia Subduction Zone (NW USA) with an Amphibious Array

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SUMMARY

We present results from three-dimensional inversion of an amphibious magnetotelluric (MT) array consisting of 71 offshore and 75 onshore sites in the central part of Cascadia, to image down-dip and along-strike variations of electrical conductivity, and to constrain the 3D distribution of fluids and melt in this subduction zone. The array is augmented by EarthScope TA MT data and several legacy 2D profiles to provide sparser coverage of western WA, OR, and northern CA. The prior model for the inversion includes ocean bathymetry, conductive marine sediments, and a resistive (3000 ohm-m) subducting plate, with geometry derived from published models, extended by seismic tomography. The Siletz volcanics and correlative units are imaged clearly as an extensive resistive body in the forearc, extending in north-central Oregon through the crust to the subducting plate. Conductive features appear just above the plate interface in three zones. (1) a conductive layer, which we associate with fluid-rich sediments, extends eastward from the trench to underthrust the seaward edge of the resistive Siletz block. Conductivities are highest in north-central Oregon, correlating with an area of reduced plate locking inferred from geodetic data. (2) High conductivities, consistent with metamorphic fluids associated with eclogitization, occur near the forearc mantle corner. Conductivity in this zone is highly variable along strike, with more resistive patches at latitudes with lower rates of episodic tremor and slip. (3) High conductivities associated with fluids and melts are found in the backarc, again exhibiting substantial along-strike variability. The patterns are qualitatively consistent with differences in stress regime, from extensional in the south, to compressive in the north. It is likely that much of the along strike variability in both resistivity in the forearc, and mechanical behavior, is controlled by lithology of the overriding plate.

Keywords: Subduction zones, magnetotellurics, 3D inversion, Cascadia

Three-Dimensional Magnetotelluric Imaging of central part of the Parecis Basin, Brazil

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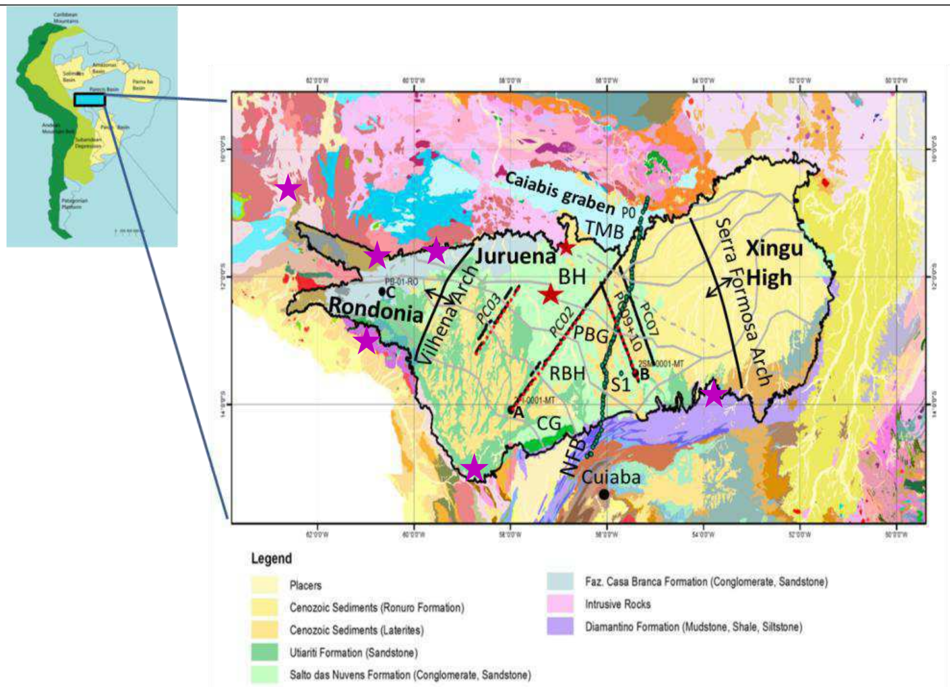
SUMMARY

We investigated the Parecis basin, an intra-cratonic Phanerozoic basin of western Brazil by magnetotelluric (MT) surveys, comprising four new densely spaced MT profiles and an old sparsely spaced regional MT profile (P0 in Fig. 1). Occurrence of kimberlites (pink star) and two major earthquakes of central Brazil whose epicenters fall within the basin (1955 - big red star and 1998/2005 - small red star in Fig. 1), have drawn attention for major exploration work. We used MT induction arrows and phase tensor invariants for the dimensionality analysis. Short periods up to 1.0 s suggest 1-D structures, but periods longer than 1.0 s depict 3-D features to be present. In view of this, we performed 3-D inversion for individual profiles and tested the effects of prior models and data types. Finally, we inverted all five profiles as a quasi-3D inversion, despite having large profile separation with a few crossover points, to map the main sedimentary structures and crustal-scale features. Induction arrows points towards the thicker conducting sediments of Pimenta-Bueno graben at central part of the basin. We estimated 5-6 km thick pile of sedimentary sequences in this graben. We also validated our 3-D modeling results with available coincident seismic lines (red dashed lines) and wells A and B (black dots in Fig 1). Previous GDS and MT study identified an S-shaped, 1200 km-long and 100 km-wide, upper to mid-crust conductivity anomaly in the south and south-west border of the basin, just outside our present study area. MT Induction arrows at period (~ 1000 s) for our profile P0 shows the presence of this anomaly, which is clearly imaged in our 3D resistivity model. Two of the four new MT profiles also imaged upper to mid-crust conductivity anomaly to the south. The resistive upper crust is thinned in the north and underlain by conducting mid-lower crust conductivity anomalies. We propose that the MT evidence of deep mid-lower crust conducting anomalies in close proximity to both the northern and southern borders of the basin have tectonic significance and is possibly linked with the attendant seismicity and the kimberlitic magmatism in Upper Cretaceous and Tertiary times in the study area.

Keywords: MT, GDS, Seismicity, Kimberlites, Parecis

Figure. 1



Tri-dimensional Magnetotelluric Imaging of the Iguatu Basin in Northeast Brazil

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SUMMARY

In this work data from 48 broadband magnetotelluric (MT) soundings placed along four profiles (one profile NW-SE and three profiles NW-SW) in the Iguatu Basin (northeast Brazil) were analyzed. Iguatu basin is an intracratonic sedimentary basin, with genesis related to the opening of the South-Atlantic Ocean (160-110 Ma). The basin is implanted over Pre-Cambrian basement of the Borborema Province. The sediments are Eo-Cretaceous (Iguatu Group, which is divided in three formations: Icó, Malhada Vermelha and Lima Campos, from the bottom to the top), Tertiary (Moura Formation) and Quaternary (alluviums coverings). The two-dimensional (2D) model result evidenced very low resistivity sediments filling the entire basin, probably due to the presence of shales rich in organic materials and saline fluids. Estimates of the basement depth reach a maximum of 1800 m - 2000 m, values slightly higher than previous results from gravimetric models. Considering the tri-dimensional nature of the basin and aiming at obtaining a better MT imaging, we propose to perform a tri-dimensional (3D) inversion using the Modular Electromagnetic Inversion software (ModEM) that minimizes an objective function considering the full impedance tensor using the Nonlinear Conjugate Gradient - NLCG algorithm. The work is in progress and we expect that with the 3D model results we can delimit the top of basement and better understand the tectono-sedimentary evolution of the Iguatu basin.

Keywords: MT, 3D inversion, Iguatu

Two Dimensional Crustal structure across Aravalli Craton, NW India, deduced from a magnetotelluric study

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Magnetotelluric studies across Aravalli Craton and Vindhyan sediments show a predominantly a low angle NW dipping tectonic fabric over the entire profile except over the south Delhi fold belt region, where a moderate resistivity of about 200-500 Ωm is delineated at the lower crustal depth (20-40 km). Further , the high density and resistivity of this feature indicate that this may correspond to mantle upwelling that corresponds to extensional related rifting.. A shallow low resistivity layer with resistivity of about 10 Ωm is delineated due to a major thrust boundary at the South Delhi fold Belt and Sandmata complex. A high angle NW dipping feature with resistivity of 80-120 Ωm located beneath the Hindoli sequences corresponds to the Jahajpur thrust and the great boundary thrust. The presence of several closely spaced high angle NW dipping seismic reflections parallel to the dip of the moderate resistivity indicate that both Jahajpur and great boundary thrust zones may correspond to an en -echelon fault system. On West of the profile two high conductive bodies are delineated at10 km and 20 km across the Marwar terrain correspond to LVL observed in seismic sections. The conductive body at 20 km is due to the rift related collision process. On the east of the profile, a thick Vindyan sediments are delineated with thickness of approximately 7-8 km and resistivity 10 Ωm.

Key Words: Magnetotellurics, North west Indian Shield, Archean tectonics, Compressional tectonics, Electrical properties, Crustal structure.

Using MT to constrain Greenland's glacial isostatic adjustment and ice loss

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Summary

Melting of the Greenland Ice Sheet has been accelerating in the past decade as the climate warms, becoming a major contributor to present and future sea level change. The rate of this ice loss is tracked through satellite and surface measurements of changing altimetry and density structure. However, these measurements are also influenced by the glacial isostatic adjustment (GIA), or post-glacial rebound, of the Greenland mantle in response to past changes in the ice sheet behaviour. The mantle may take several thousands of years to equilibrate after a change in ice loading and the patterns of surface deformation will depend strongly on mantle viscosity. Greenland's GIA is currently very poorly constrained and is considered to be the biggest uncertainty in ice loss calculations. We report on recently collected MT data from the Greenland ice sheet. By combining these new MT data with seismic data, we are improving constraints on mantle temperature and composition. From this, we will develop constrained estimates of mantle viscosity that including lateral viscosity variations. Our long-term goal is to feed these viscosity data into newly developed GIA and sea-level dynamic models, producing improved estimates of Greenland's GIA and, ultimately, of the current rate of ice loss from Greenland.

Keywords: Greenland, mantle, viscosity, GIA

Introduction

In order to track and mitigate the effects of climate change, the volume of ice lost from the great continental ice sheets in Antarctica and Greenland must be monitored. The methods employed to do this – satellite and surface gravity and altimetry measurements – rely on the fact that, as ice melts, mass is lost from the ice sheet. However, these measurements are complicated by the fact that the Earth responds both elastically and viscously to changes in ice sheet mass. This viscous response, glacial isostatic adjustment (GIA), may last for many thousands of years and is strongly dependent on the viscosity structure of the mantle.

Currently, the 3D mantle viscosity structure beneath Greenland is poorly known, seriously impacting the quality of ice loss calculations. For instance, Velicogna (2009) called the GIA correction 'the largest source of uncertainty in (the) ice mass estimate' in Greenland.

Mantle viscosity is dominantly controlled by temperature, hydrogen content and the presence of partial melt. It is best constrained with combined MT and seismic data. Previous MT experiments (e.g., Lauritsen, 2016) have highlighted the difficulty in collecting MT data in the complex fjord geometries of coastal Greenland. In this project, we will collect the first MT data on the Greenland ice cap. An additional benefit of this survey design will be the ability to image basal ice sheet melt layers and to investigate proposed links with mantle geotherms.

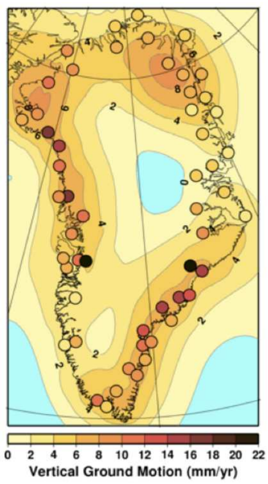

Fig.1 Measured uplift rates (circles, Khan et al., 2016) are poorly fit by current GIA and elastic estimates (contours)

The mantle viscosity and heat flow structure of Greenland is likely to be complex. Much of the exposed Greenland basement is Archean to Proterozoic in age and mantle xenoliths have highly depleted compositions (e.g., Bernstein et al., 2006), which would be likely to be associated with high viscosities. However, the Iceland Plume passed beneath central Greenland during the Cretaceous and early Cenozoic (e.g., Tegner et al., 2008), heating and possibly hydrating the mantle and reducing viscosities. High surface heat flow associated with the Iceland Plume track has also been linked to increased basal melting of the Greenland Ice Sheet (Rogozhina et al., 2016).

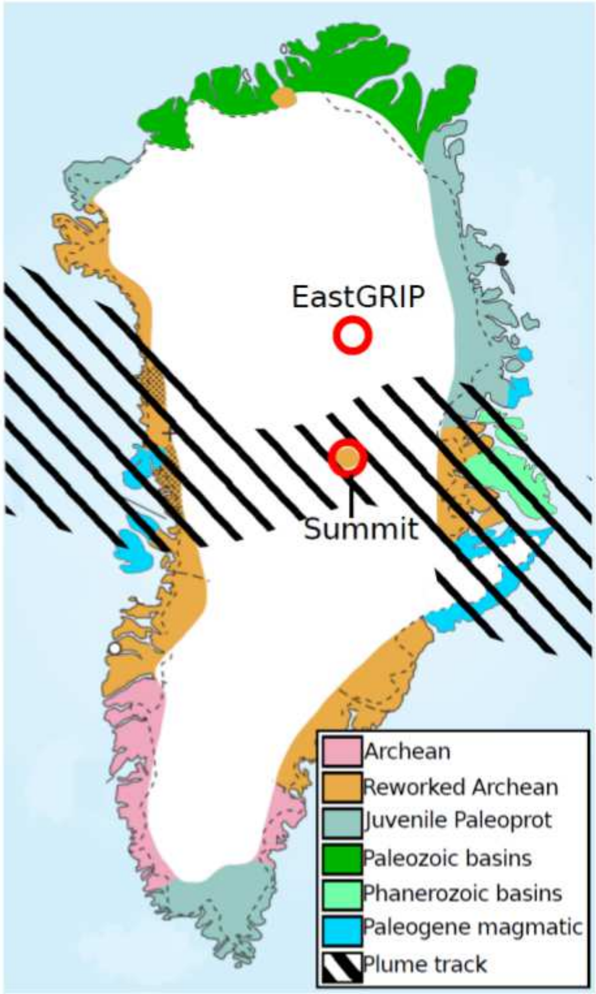

Fig. 2 The first field season will be based at Summit Station, which lies on the Iceland Plume track. Results will inform the survey parameters for future work, likely to utilise EastGRIP station.

Data collection for this project will start with a pilot survey at Summit Station in the central Greenland Ice Sheet in July 2018. This station lies on the Iceland Plume track, so these results will provide an initial measurement of the conductivity of the plume-affected mantle, as well as dimensionality and strike data. In addition, we will test various instrument and electrode configurations for the resolution of melt layers within and at the base of the ice sheet. These data will be used to optimise survey parameters for planned future surveys that will extend away from the plume track.

References

Bernstein, S., Hanghøj, K., Kelemen, P. B., & Brooks, C. K. (2006). Ultra-depleted, shallow cratonic mantle beneath West Greenland: dunitic xenoliths from Ubekendt Ejland. *Contributions to Mineralogy and Petrology*, *152*(3), 335.

Lauritsen, N. L. B. (2016). *Magnetotelluric investigation in West Greenland-considering the polar electrojet, ocean and fjords* (Doctoral dissertation, Technical University of Denmark (DTU)).

Khan, S. A., Sasgen, I., Bevis, M., van Dam, T., Bamber, J. L., Wahr, J., ... & Csatho, B. (2016). Geodetic measurements reveal similarities between post–Last Glacial Maximum and present-day mass loss from the Greenland ice sheet. *Science advances*, *2*(9), e1600931.

Tegner, C., Brooks, C. K., Duncan, R. A., Heister, L. E., & Bernstein, S. (2008). 40Ar–39Ar ages of intrusions in East Greenland: Rift-to-drift transition over the Iceland hotspot. *Lithos*, *101*(3-4), 480-500.

Rogozhina, I., Petrunin, A. G., Vaughan, A. P., Steinberger, B., Johnson, J. V., Kaban, M. K., ... & Koulakov, I. (2016). Melting at the base of the Greenland ice sheet explained by Iceland hotspot history. *Nature Geoscience*, *9*(5), 366.

Velicogna, I. (2009). Increasing rates of ice mass loss from the Greenland and Antarctic ice sheets revealed by GRACE. *Geophysical Research Letters*, *36*(19).

Wyloo Dome (Western Australia): From a small MT survey to the mineral systems concept.

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SUMMARY

An extensive magnetotelluric (MT) survey across the Capricon Orogen of Western Australia was conducted as part of a large multi-disciplinary geoscience project, the 'Distal Footprints of Giant Ore Systems'. Although most of the MT data were collected across the southern part of the orogen, data from a small and isolated group of MT sites were acquired in the north, close to the largest gold mine (Paulsens Mine, endowment of 1.1 MOz) in the orogen. The MT survey traversed across the Wyloo Inlier, composed of Archean to Proterozoic sedimentary and mafic volcaniclastic rocks overlying Archean granite-greenstones of the Pilbara Craton in the core.

The MT dataset consisted of 7 broadband MT sites. Analysis of the dataset reveals a 3-D geoelectrical behavior and extreme complexity of the MT responses. The inversions were computed with the ModEm code, and the results show a high-resistivity body in the core of the inlier, in agreement with the location of the Archean rocks of the Pilbara Craton, surrounded by two major low-resistivity south-west dipping structures.

Previous gravity studies performed in this area implied the inlier to have a relatively simple 'domal' crustal structure, with south-west and north-east dipping contacts zones with the adjacent rocks. Therefore, at first sight, the dipping tendency of the main geoelectrical features observed on the 3-D resistivity model disagree with this model and the known geology of the area. New potential fields forward models have been performed, including new information provided by the MT data. Preliminary results indicate that the low-resistivity structures are characterized by a high-magnetic susceptibility. The location of a major sulfide-rich, orogenic-style gold deposit in the vicinity of one of these crustal faults (Paulsens Mine), suggests that these low-resistivity, highly-magnetic structures may tentatively be interpreted as major, sulfide-rich, crustal-scale faults that have acted as conduits for the mineralizing fluids.

Keywords: 3-D MT, Mineral systems, Capricorn Orogen, Western Australia

Zones of concentrated deformation in the Central Tien Shan: geoelectric images and tectonic interpretation

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SUMMARY

In the paper results of the detailed magnetotelluric soundings executed for the last years in the territory of the Central Tien Shan and focused on the study of the concentrated deformation zones are presented. Parameters of detailed geoelectric sections of Kochkor, Naryn and Atbashi intermountain basins are discussed in the sense of their tectonic interpretation. New tectonic constrains, based on a complex interpretation of the upper crust structure of the investigated areas, including structural geology study of the Cenozoic sedimentary cover, the crustal geoelectric sections, the structural unconformities and occurrences of recent deformations in the basement rocks, are revealed.

The geoelectric model of the southern margin of the Kochkor basin reflects the complex system of folded and fault structures of this tectonic zone. The geometry and allocation of conducting zones in the geoelectric structure may indicate that, deformation of basement surface was mostly ductile and now is manifested in the tectonic structure by folds with oversteep basement/sediment stratigraphic and complex structure of basement block surfaces within the basin.

The complex geological–geophysical cross section along the profile crossing the geodynamic system “Naryn basin–Baibichetoo Ridge–Atbashi basin” provides a good agreement between the surface tectonic structures and the deep geoelectric model. The electric conductivity anomalies revealed as subvertical conductors striking along the flanks of basins may be explained by the zones of dynamic influence of faults and cataclasis of granite.

Keywords: magnetotelluric soundings, geoelectric section, tectonic settings, intermountain basins, Central Tien Shan.

INTRODUCTION

Due to activation of the Paleozoic Tien Shan fold region, a system of sublatitudinal intermountain basins has formed, starting in the Paleocene and continuing to this day. The basins were filled with Cenozoic sediments and were separated by the anticlinorium rises and the main ridges. At the later stages of tectonic evolution of the Tien Shan, the structure of the basement surface and the cover was complicated by overthrust-reverse faults and strike-slip faults; some linear zones had complex parageneses of foldedoverthrust and protrusive structures [Leonov 2012]. These linear zones concentrating the most recent deformations at the boundaries between the intermountain basins and anticlinorium protrusions of the Paleozoic basement are the key objects for studying Late Alpine tectonics.

We consider two such investigated zones at the territory of the Central Tien Shan: the southern margin of Kochkor basin and “Naryn basin–Baibichetoo Ridge–Atbashi basin” geodynamic system.

The deep structure of first such zone, the South Kochkor zone of concentrated deformation where the Late Cenozoic deformations occurred not only in the cover, but also in the Paleozoic granites on the hollow margins, is the main object of our studies using the magnetotelluric sounding method. Earlier, we conducted a high-resolution MT profile in the southeastern segment of Kochkor basin [Park et al. 2003]; by the results of interpretation of the magnetotelluric data, we estimated the thickness of the Cenozoic deposits buried under the overthrust and localized the probable position (based on the test model calculations) of the southern boundary of the conductive sedimentary complex. As a result of new magnetotelluric data and their complex interpretation, we determined the strike of the fault structures along the southern margin of Kochkor basin and assessed the natural mechanism of electrical conductivity for conductive objects in the geoelectric cross sections constructed.

For second investigated area – “Naryn basin–Baibichetoo Ridge–Atbashi basin” geodynamic system, special attention is paid to the deep structure of the Baibichetoo Ridge, which, according to the existing geoelectric models, is reflected as a zone of junction of deep, anomalously conducting structures and adjacent parts of the Naryn and Atbashi basins. We determined that electrical conductivity anomalies revealed as subvertical conductors striking along the flanks of basins may be explained by the zones of dynamic influence of faults and cataclasis of granite.

Geoelectric structure of investigated zones of Kochkor basin

New magnetotelluric data were obtained at the territory of the Central Tien Shan for two local profiles in the southern margin of Kochkor basin (Figure1).

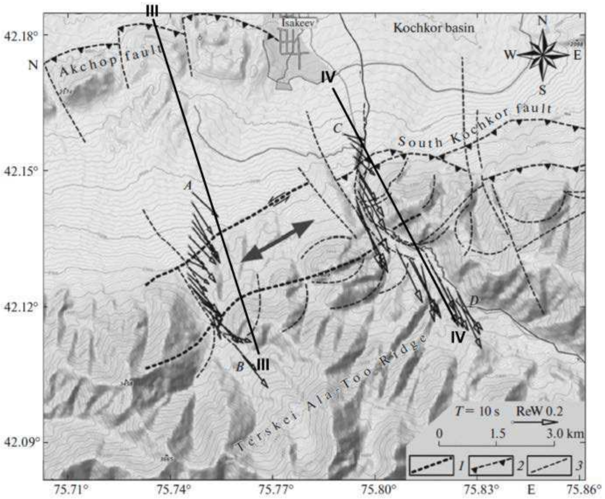

Figure 1. Location of magnetotelluric profiles in the scheme of the relief of Kochkor basin and Terskei Ala-Too Ridge in Central Tien Shan (the Ukok segment). Faulting: 1 is strike-slips, 2 is overthrusts, and 3 is zones of fracturing in granites and secondary faults. The arrows show the real Wiese induction vectors (ReW) for the period T = 10 s; the scale of the induction vectors is given in the explanatory notes. The double arrow means a strike of electrical structures along two MT sounding profiles within period range of 10–100 s. (III-III) and (IV-IV) – structural-geological profiles.

On the basis of these MT data the geoelectric models were constructed (Bataleva et al. 2017). These geoelectric models and geological sections along lines III-III and IV-IV are shown in Figure 2. The distance between MT profiles is about 4 km. To perform a comparative analysis of the cross sections and to create a 3D model of the segment, we used the same settings of 2D-inversion for both profiles during data inversion. In addition to the comparison of the cross sections by the most stable lithological features, for detailed description of the deformations in the cover complex, we used the procedure of immediate detection of horizon markers when mapping the key segments. The whole strata of the Cenozoic Pre-Quaternary deposits in the central cross section, which was the most stratigraphically full in the area of the Bizhe River, was divided into ten sequences that differed well by the lithological features. The first sequence corresponds to red beds in the Kyrgyz series, and others represent the overlying stratum of Neogenic rocks, the Kochkor sequence.

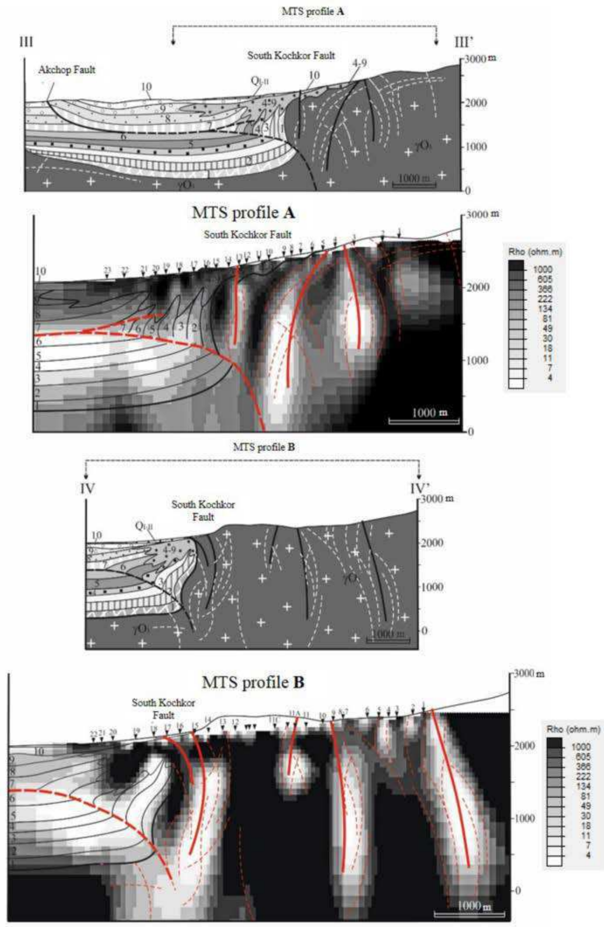

Figure 2. Geological sections along lines III-III 'and IV-IV' and geoelectric models on profiles A and B. Values of electrical resistivity (Ohm.m) and color gradation on the scale on the right. Profile lines and symbols are shown on the map, Fig. 1. Other symbols see (Przhiyalgovskii et. al 2018).

The factor of the geoelectric two-dimensionality of the South Kochkor concentrated deformation zone at the Ukok segment cannot be fully related to the individual faults. The southern margin of Kochkor hollow is represented mainly by blockwise disintegrated granite massifs the faults of which do not extend as single planes along the whole margin of the hollow. They can be displaced across the transverse faults, merge with the neighboring ones, branch out, or disappear; however, in general, the deformation zone retains its electrical characteristics. Thus, the increase or decrease in the total electrical conductivity of certain fault zones along the strike, as well as the change in their geometry, which is recorded when the cross sections obtained are compared, is quite explanatory. The geoelectric models show the similarity between the electrical conducting structures designated by numbers 1–6. The differences in the models are determined primarily by the dimensions of the conductive bodies, such as, e.g., subvertical zones (1) and (3). They are found in both cross sections, but their dimensions are considerably different.

Geoelectric model of "Naryn basin–Baibichetoo Ridge–Atbashi basin" system with tectonic interpretation

New magnetotelluric data were obtained at the territory of the Central Tien Shan for Karabuk profile crossing the "Naryn basin–Baibichetoo Ridge–Atbashi basin" geodynamic system (Fig. 3).

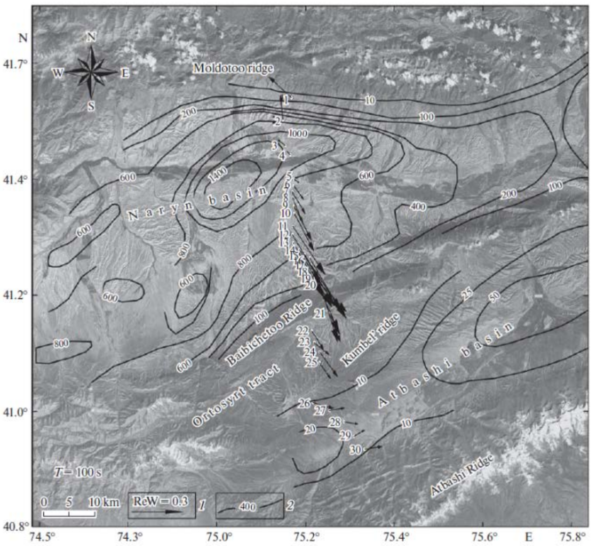

Figure 3. Scheme of the location of the Karabuk MT profile in the Naryn and Atbashi basins. Arrows (1) show the real Wiese vectors with a period of 100 s; isolines (2) indicate the total longitudinal conductivity of the cover (S) [Yudakhin 1983].

On the basis of these MT data the geoelectric model was constructed (Rybin et al. 2018). The profile geoelectric model and simplified geological cross section are shown in Figure 4. For clarity, the structures of the geological section and 2D geoelectric model compared are indicated in numerals in circles. They are in a good agreement with each other for gently dipping conducting structures in the sedimentary cover of the Naryn basin. The "hidden" faults in the basement assumed in the geological section of the Naryn basin are displayed by oblique and subvertical conducting zones with a width up to 1.5–2 km. The projections of the basement in the Naryn basin (structures (1–3) on the geological cross section) are displayed well in the geoelectric model as appropriate blocks. The projection of the Paleozoic basement forming the Baibichetoo ridge (4), which occupies the central place in the geoelectric cross section, is the key structure in the geological cross section as well. This high-resistance body with a width of ~10 km has a small slope to the NW. It is observed up to the depth of occurrence of the crustal conducting layer, which is located sporadically in the middle–lower crust on the whole territory of Tien-Shan. The structure of the cover and basement surface of the Atbashi basin in the geological cross section is more complex than that of the Naryn basin. In addition, this is evident from the presence of the conducting structure (5) and isolator (6) in the geoelectric model, which was predicted in the deep geological cross section (Morozov et. al 2014). From the north, the Atbashi basin borders with the Baibichetoo Tidge by a series of faults; this zone is represented by the inclining conducting structure up to a depth of 20 km in the geoelectric model.

It is necessary to mention that the vergence of conducting (fault) structures contouring the high-resistance projection of the Baibichetoo Ridge in the geoelectric model is not consistent with the vergence of relevant structures in the geological cross section, whereas the correlation of conducting zones in the geoelectric model and faults contouring the Atbashi basin is very high. The anomalies in electric conductivity revealed as subvertical conductors oriented along the flanges of basins may be controlled by the zones of dynamic influence of faults and cataclasis of granite.

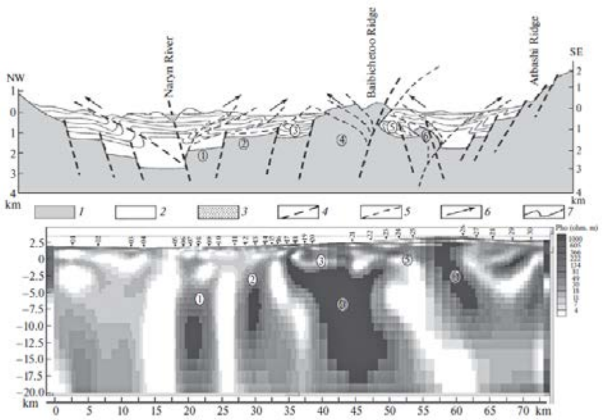

Figure 4. Simplified geological cross section of the Naryn basin–Baibichetoo Ridge–Atbashi basin geosystem, after (Morozov et. al 2014).
(1) Paleozoic basement; (2) Cenozoic cover;
(3) alluvium of the Naryn River; (4) faults crossing basement rocks; (5) faults in the cover complex;
(6) direction of displacements along faults; (7) folds in the cover complex. The 2D geoelectric model along the Karabuk MT profile is shown at the

bottom; the values of electric resistance are indicated in color; numerals in circles denote the structures compared; the location of MT profile is shown in Figure 3.

Conclusions

The results of the analysis of the parameters of the geoelectric models made a basic contribution to create new view on the modern tectonic structure of the studied zones of concentrated deformation in the Central Tien Shan. Consider these tectonic findings.

1. The geoelectric section of the steep margin of the Kochkor basin reflects the complex system of folded and fault structures of the South Kochkor tectonic zone of concentrated deformations. The distribution of electrical resistivity leads us to the conclusion that the deformation of the basement roof was predominantly plastic in nature and manifested in the tectonic structure by "visor" folds with oversteep stratigraphic contacts basement/cover and complex geometry of the basement blocks surface on the basin bottom.

2. The amplitude of displacements on the thrust faults determined in the South Kochkor fault zone, do not exceed 400-500 m, much less than the total magnitude of the vertical displacement of the Paleozoic basement surface on the border of Kochkor basin and Terskey-Ala-Too Range. These values are much smaller than previously obtained amount of the Paleozoic rock thrusting in the southern margin of the Kochkor basin [Park et al. 2003].

3. The "hidden" faults of the basement in the geological section of the Naryn basin in the geoelectric model are displayed by oblique and subvertical conductive zones with a width up to 1.5-2 km. The Projections of the basement in the Naryn basin (structures (1-3) of the geological cross section) are displayed well in the geoelectric model as appropriate blocks. The projection of the Paleozoic basement forming the Baibichetoo ridge (4), which occupies the central place in the geoelectric cross section, is the key structure in the geological cross section as well. This high-resistance body with a width of ~10 km has a small slope to the NW. It is observed up to the depth of occurrence of the crustal conducting layer, which is located sporadically in the middle–lower crust on the whole territory of Tien-Shan.

4. The structure of the cover and basement surface of the Atbashi basin in the geological cross section is more complex than that of the Naryn basin. In addition, this is evident from the presence of the conducting structure (5) and isolator (6) in the geoelectric model, which was predicted in the deep geological cross section (Morozov et. al 2014). From the north, the Atbashi basin borders with the Baibichetoo Ridge by a series of faults; this zone is represented by the inclining conducting structure up to depths of 20 km and more in the geoelectric model.

Acknowledgements

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References

Bataleva E.A., E.S. Przhiyalgovskii, V.Yu. Batalev, E.V. Lavrushina, M.G. Leonov, V.E. Matyukov, and A.K. Rybin (2017) New Data on the Deep Structure of the South Kochkor Zone of Concentrated Deformation Doklady Earth Sciences, Vol. 475, Part 2, pp. 930–934.

Leonov, M.G., (2012). Within-plate zones of concentrated deformation: Tectonic structure and evolution. Geotectonics, No. 6, 389–411.

Morozov Yu.A., M.G. Leonov and D.V. Alekseev (2014) Pull apart formation mechanism of Cenozoic Basins in the Tien Shan and their transpressional evolution: Structural and experimental evidence. Geotectonics, No. 1, 29–61.

Park, S.K., Thompson, S.C., Rybin, A., Batalev, V., Bielinski, R., (2003). Structural constraints in neotectonic studies of thrust faults from the magnetotelluric method, Kochkor Basin, Kyrgyz Republic. Tectonics 22 (2), 1–13.

Przhiyalgovskii E.S., E.V. Lavrushina, V.Yu. Batalev, E.A. Bataleva, M.G. Leonov, A.K Rybin (2018) Structure of the basement surface and sediments in the Kochkor basin (Tien Shan): geological and geophysical evidence. Russian Geology and Geophysics 59, 335–350.

Rybin A.K., E.A. Bataleva, Yu.A. Morozov, M.G. Leonov, V.Yu. Batalev, V.E. Matyukov, O.B. Zabinyakova, and V.O. Nelin (2018) Specific Features in the Deep Structure of the Naryn Basin–Baibichetoo Ridge–Atbashi Basin System: Evidence from the Complex of Geological and Geophysical Data. Doklady Earth Sciences, Vol. 479, Part 2, pp. 499–502.

Yudakhin F.N., (1983) Geophysical Fields, Deep Structure, and Seismicity of the Tien Shan (Ilim, Frunze) [in Russian].