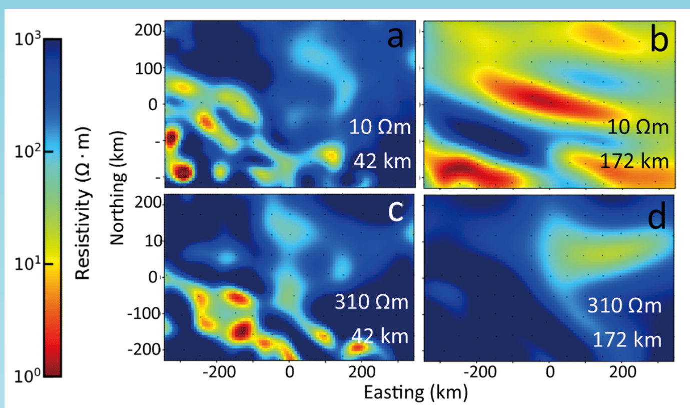
Earth, Planets and Space

Studies on Electromagnetic Induction in the Earth:
Recent advances and Future Directions



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PREFACE

Open Access

Special issue "Studies on electromagnetic induction in the earth: recent advances and future directions"

Paul A. Bedrosian[1*], Gerhard Schwarz[2], Kate Selway[3], Pierre Wawrzyniak[4] and Dikun Yang[5]

The research community that studies electromagnetic (EM) induction in the Earth and planets continues to grow. The breadth of EM research has expanded well beyond the traditional focus on magnetotellurics (MT) to include airborne, land, and marine controlled-source EM. Advancements in the processing, modeling, inversion and interpretation of EM data have accompanied this growth and led to an increased visibility of EM research within the Earth science community. The biennial workshops on Electromagnetic Induction in the Earth, first held in 1972, continues to be the premier event for the vibrant international community of EM researchers. The 24th workshop on Electromagnetic Induction in the Earth was held in Helsingør, Denmark, from August 13–20, 2018. More than 330 presentations were given spanning a range of topics including (1) instrumentation, sources and data processing; (2) EM theory, modeling and inversion; (3) exploration, monitoring and hazards; (4) tectonics, magmatism and geodynamics; (5) marine EM; (6) rock/mineral resistivity and anisotropy; (7) global and planetary studies and (8) EM induction education and outreach. This special issue presents a compilation of 10 papers, described below, that highlight recent advances and future directions within the EM research community.

Investigations of crustal and lithospheric architecture continue to be a mainstay of MT studies. Comeau et al. (2020) present a study of the tectonic terranes of Mongolia based upon a 350-km-long MT profile. Their resistivity model images zones of elevated upper-crustal conductivity coincident with surface faulting and seismicity; they interpret these zones to mark suture zones within the Central Asian Orogenic Belt. The authors further image a distinct zone of lower-crustal conductivity in part of the model and suggest this conductor may be related to an exotic terrane speculated from geochemical data to exist in the same region. Finally, a step in lithospheric thickness is interpreted beneath Southern Mongolia from the model.

The emergence of national-scale MT initiatives over the last two decades has led to an explosion in the number of three-dimensional (3D), tectonic-scale resistivity models presented and published. Thiel et al. (2020) present one such model, describing MT modeling of the Australian Musgrave province based upon data collected as part of the Australian Lithospheric Architecture Magnetotelluric Project (AusLAMP). They present a 3D resistivity model of the lithosphere, arguing that conductive structures within the model reflect tectono-magmatic processes associated with the reworking of the Australian continent, including the amalgamation of cratonic components and deformation during younger orogenies.

3D resistivity models, such as the study by Thiel et al. (2020), rely upon complex inversion algorithms with considerable flexibility with regard to model discretization and regularization, the choice of start and prior models and the treatment of data and errors. Robertson et al. (2020) present a model-space exploration of the 3D inversion ModEM3DMT (Egbert and Kelbert 2012; Kelbert et al. 2014) using for their testbed a subset of data collected as part of AusLAMP. The authors investigate the influence of model covariance, the prior model,

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cell size and the choice of inverted data—evaluating the results both in terms of data misfit and model structure. Their results suggest a practical workflow for 3D inversion and for assessing the resultant models.

Rivera-Rios et al. (2019) demonstrate the functionality of a new 3D vector finite-element forward modeling algorithm, MoVFEM. The authors validate their algorithm against analytic or accepted numerical solutions for a number of complex models, including a 3D community model, a halfspace model with topography and a halfspace model with transverse anisotropy. The authors' results demonstrate the capabilities of the MoVFEM software and hint at future modifications to incorporate the MoVFEM algorithm within adaptive-mesh strategies.

Also on the modeling front, a study of interstation MT impedance responses, calculated from magnetic- and electric-field data recorded at different locations, is presented by Martí et al. (2020). The authors compare models resulting from inversion of local, interstation and 'quasi-MT' (modeling of interstation response as if they were local) responses for two synthetic fault models and find that inversions of the quasi-MT responses do not fully reproduce the synthetic structure but provide generally valid models. The authors subsequently apply this approach to measured data across a seismogenic fault in Spain, identifying a prominent fault-zone conductor. Given the reality of missing or bad data channels, interstation MT responses are sometimes all that are available. In this context, the authors' findings provide reassurance that interstation responses can be reliably used within a traditional inversion approach.

MT inversions also typically assume data errors are uncorrelated by specifying data variances, but not covariances, within the inversion. Guo et al. (2019) investigate the impact of this assumption using a one-dimensional trans-dimensional Bayesian inversion approach. The approach is applied to both synthetic and measured data and in each case the authors compare inversions with and without data-error correlations. In the synthetic example, they demonstrate that ignoring data-error correlation has a tendency to overfit the data and underestimate model parameters uncertainty; the ability to recover model structure is also shown to suffer as data-error covariance increases. Applied to measured data, however, the model results are nearly identical, suggesting a weak correlation between data errors.

Quantification of uncertainty within MT resistivity models, particularly applied to interpreted boundaries such as depth-to-basement or stratigraphic layering, is challenging given the non-uniqueness of the geophysical inverse problem, the differential resolution of conductive and resistive interfaces and the impacts of regularization on the resulting inverse model. Simpson and Heinson (2020) present a case study in Australia where a dense MT data set is combined with limited well-log data to resolve basin layering and the basement interface. The authors undertook a synthetic modeling exercise based upon well-log data, considering both deterministic and stochastic inversions. After examining uncertainty within the synthetic study, the authors apply their approach to map geologic interfaces and their associated errors throughout a broad region. The authors approach provides a practical workflow for handling model uncertainty in areas with limited independent geologic constraints.

MT data are increasingly collected in areas impacted by infrastructure, where non-MT signals dominate measured time-series and can lead to severe degradation of estimated MT responses. A variety of approaches to signal–noise separation operate in the time, frequency, or wavelet domains, but most have difficulty when noise is spatially coherent across broad regions or when data from a reference station is not available. Li et al. (2020) present a machine-learning algorithm for removing noise from MT data contaminated by persistent or coherent noise. The authors present their improved shift-invariant sparse coding (ISISC) method and apply it to synthetic data contaminated with either pseudo-random square wave or impulsive noise sources. They demonstrate the performance and effectiveness of the ISISC algorithm, applying their approach to real MT data sets contaminated with controlled-source EM noise and unknown non-MT noise. This data-driven approach offers an attractive possibility for removing complex periodic noise signals (e.g., pipeline signals) from MT data and pushes the applicability of MT closer to urban areas.

Other sources of MT noise are unique to the seafloor environment. Motion-induced EM signals due to seafloor currents are a common source of noise plaguing seafloor measurements. Chen et al. (2020) describe an adaptive-correlation filter which incorporates seafloor current-meter data as a reference signal in order to reduce motion-induced noise in marine MT data. The authors demonstrate the effectiveness of their approach on time-series collected over a region near the edge of the continental-shelf with strong seafloor currents as well as in a marine basin with weaker currents. Within the former environment, their results highlight the effectiveness of the approach in producing stable MT responses that are not seen using traditional MT processing. Given the increased use of ocean-bottom EM receivers, this advance may lead to considerable improvements in the quality of processed seafloor responses.

Moving from the seafloor to air, Baranwal et al. (2020) present an interpretation of airborne electromagnetic (AEM) data collected over the Mesozoic Ramså Basin in Norway. Their AEM models, derived from a spatially constrained inversion approach, compare favorably to borehole logging data as well as a number of electrical resistivity tomography profiles. The authors find that the conductivity of pore waters has a significant impact on the bulk resistivity within both the rocks of the sedimentary basin and the basement. The AEM models are used to refine the extent of the Ramså Basin. Additionally, a pair of conductive zones also identified within the models are tied to a graphite and sulfide-bearing outcrop.

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References:

Baranwal VC, Brönner M, Rønning J-S, Elvebakk H, Dalsegg E (2020) 3D interpretation of helicopter-borne frequency-domain electromagnetic (HEM) data from Ramså Basin and adjacent areas at Andøya, Norway. Earth Planets Space 72:52. https://doi.org/10.1186/s40623-020-01177-3

Chen K, Zhao Q, Deng M, Luo X, Jing J (2020) Seawater motion-induced electromagnetic noise reduction in marine magnetotelluric data using current meters. Earth Planets Space 72:4. https://doi.org/10.1186/s40623-019-1129-0

Comeau MJ, Becken M, Käufl JS, Grayver AV, Kuvshinov AV, Tserendug S, Batmagnai E, Demberel S (2020) Evidence for terrane boundaries and suture zones across Southern Mongolia detected with a 2-dimensional magnetotelluric transect. Earth Planets Space 72:5. https://doi.org/10.1186/s40623-020-1131-6

Egbert GD, Kelbert A (2012) Computational recipes for electromagnetic inverse problems. Geophys J Int. 189:251–267. https://doi.org/10.1111/j.1365-246X.2011.05347.x

Guo R, Liu L, Liu J, Sun Y, Liu R (2019) Effect of data error correlations on trans-dimensional MT Bayesian inversions. Earth Planets Space 71:134. https://doi.org/10.1186/s40623-019-1118-3

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

Li G, Liu X, Tang J, Deng J, Hu S, Zhou C, Chen C, Tang W (2020) Improved shift-invariant sparse coding for noise attenuation of magnetotelluric data. Earth Planets Space 72:45. https://doi.org/10.1186/s40623-020-01173-7

Martí A, Queralt P, Marcuello A, Ledo J, Rodríguez-Escudero E, Martínez-Díaz JJ, Campanyà J, Meqbel N (2020) Magnetotelluric characterization of the Alhama de Murcia Fault (Eastern Betics, Spain) and study of magnetotelluric interstation impedance inversion. Earth Planets Space 72:16. https://doi.org/10.1186/s40623-020-1143-2

Rivera-Rios AM, Zhou B, Heinson G, Krieger L (2019) Multi-order vector finite element modeling of 3D magnetotelluric data including complex geometry and anisotropy. Earth Planets Space 71:92. https://doi.org/10.1186/s40623-019-1071-1

Robertson K, Thiel S, Meqbel N (2020) Quality over quantity: on workflow and model space exploration of 3D inversion of MT data. Earth Planets Space 72:2. https://doi.org/10.1186/s40623-019-1125-4

Simpson JM, Heinson G (2020) Synthetic modelling of downhole resistivity data to improve interpretation of basin morphology from magnetotelluric inversion. Earth Planets Space 72:69. https://doi.org/10.1186/s40623-020-01178-2

Thiel S, Goleby BR, Pawley MJ, Heinson G (2020) AusLAMP 3D MT imaging of an intracontinental deformation zone Musgrave Province, Central Australia. Earth Planets Space 72:98. https://doi.org/10.1186/s40623-020-01223-0

Publisher's Note

FULL PAPER **Open Access**

Effect of data error correlations on trans-dimensional MT Bayesian inversions

Rongwen Guo, Liming Liu, Jianxin Liu, Ya Sun and Rong Liu*

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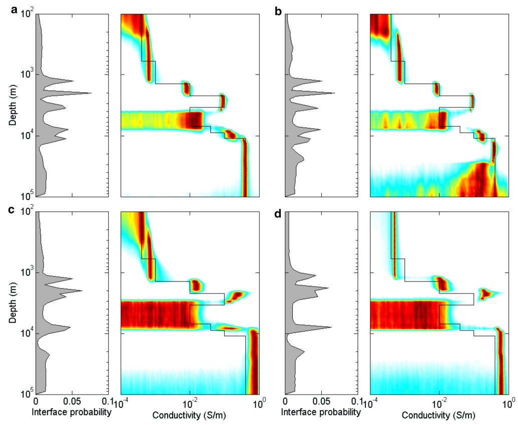
Abstract

Real magnetotelluric (MT) data errors are commonly correlated, but MT inversions routinely neglect such correlations without an investigation on the impact of this simplification. This paper applies a hierarchical trans-dimensional (trans-D) Bayesian inversion to examine the effect of correlated MT data errors on the inversion for subsurface geoelectrical structures, and the model parameterization (the number of conductivity interfaces) is treated as an unknown. In the inversion considering error correlations, the data errors are parameterized by the first-order autoregressive (AR(1)) process, which is included as an unknown in the inversion. The data information itself determines the AR(1) parameter. The trans-D inversion applies the reversible-jump Markov chain Monte Carlo algorithm to sample the trans-D posterior probability density (PPD) for the model parameters, model parameterization and AR(1) parameters, accounting for the uncertainties of the model dimension and data error correlation in the uncertainty estimates of the conductivity profile. In the inversion ignoring the correlation, we neglect the correlation effect by turning off the AR(1) parameter. Then the correlation effect on the MT inversion can be examined upon comparing the posterior marginal conductivity profiles from the two inversions. Further investigation is then carried out for a synthetic case and a real MT data example. The results indicate that for strong correlation cases, neglecting error correlations can significantly affect the inversion results.

Keywords: Trans-D Bayesian inversion, Autoregressive model, Parameterization, Magnetotelluric method



Graphical abstract

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FULL PAPER **Open Access**

Quality over quantity: on workflow and model space exploration of 3D inversion of MT data

K. Robertson*, S. Thiel and N. Meqbel

Earth, Planets and Space 2020, **72**:2 DOI: 10.1186/s40623-019-1125-4
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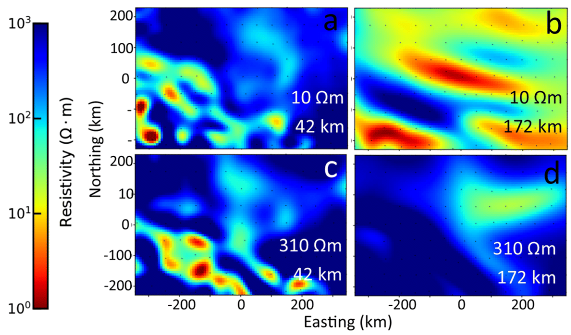
Abstract

3D inversions of magnetotelluric data are now almost standard, with computational power now allowing an inversion to be performed in a matter of days (or hours) rather than weeks. However, when compared to 2D inversions, these are still very computationally demanding. As a result, 3D inversions are generally not subjected to as rigorous testing as a 1D or 2D inversion would be, which has implications when these models are used for geological interpretation. In this study, we explore the parameter space for inversion of continent-scale datasets. The generalisations made regarding the effects of each parameter should also be scalable to smaller surveys and will enable MT practitioners to optimise their results. We have performed testing on a subset of the South Australian component of the eventual Australia-wide AusLAMP (Australian Lithospheric Architecture Magnetotelluric Project). The subset was inverted with different parameters, model setup and data subsets. Specifically, results from testing of the model covariance, the resistivity of the prior model, the inclusion of 'known' information into the prior model, the model cell size, the data components inverted for and the damping parameter λ were all investigated. In our testing of the 3D inversion software, ModEM3DMT, we found that the resistivity of the starting/prior model had significant effect on the final model. Careful selection of initial λ value can aid in reducing computational time whilst having a negligible effect on the resultant model, whilst large covariance values and model cell sizes enhanced conductive features at depth.

Keywords: Magnetotellurics, 3D inversion, AusLAMP, Electrical resistivity, ModEM3DMT



Graphical abstract

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FULL PAPER **Open Access**

Seawater motion-induced electromagnetic noise reduction in marine magnetotelluric data using current meters

Kai Chen*, Qingxian Zhao, Ming Deng, Xianhu Luo and Jianen Jing

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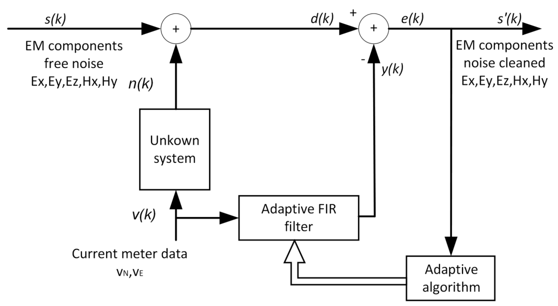
Abstract

Seawater motion-induced electromagnetic (EM) noise along the seafloor has a large impact on marine magnetotelluric (MT) data quality. Although the mechanical stability of ocean bottom electromagnetic receivers (OBEMs) has improved due to buoyancy optimization, completely eliminating EM noise generated by seafloor currents as a result of instrument rocking or induction from the Earth's magnetic field is still not possible. The velocity of the current represents the quantification of seafloor conditions. To mitigate this problem, we installed a current meter on an OBEM to measure the synchronous current velocity along with the OBEM data logger. For the marine EM surveys, we conducted two surveys composed of 42 marine EM data acquisition sites in the South China Sea. We observed a strong correlation between induced EM noise and current velocity when the speed was greater than 2 cm/s. Furthermore, we developed an adaptive correlation noise-canceling filter to reduce the induced EM noise, using the current meter data as a reference signal. The filter refined the coefficients using a least-mean-squares algorithm. We were able to reduce the induced EM noise by pre-filtering the raw time series data with an adaptive correlation noise-canceling filter and using current meter data from nearby sites. Since seafloor currents are clearly an issue that limits MT data quality, special efforts are necessary to reduce seawater motion-induced EM noise in marine MT surveys.

Keywords: Marine magnetotelluric, Adaptive correlation noise-canceling filter, Seawater motion-induced electromagnetic noise, Current meter



Graphical abstract

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FULL PAPER **Open Access**

Evidence for terrane boundaries and suture zones across Southern Mongolia detected with a 2-dimensional magnetotelluric transect

Matthew J. Comeau*, Michael Becken, Johannes S. Käufl, Alexander V. Grayver, Alexey V. Kuvshinov, Shoovdor Tserendug, Erdenechimeg Batmagnai and Sodnomsambuu Demberel

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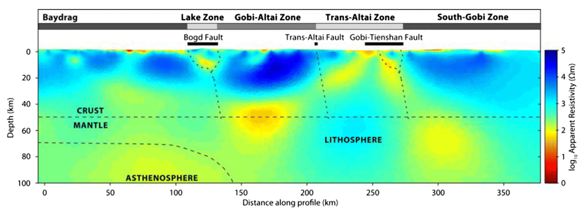
Abstract

Southern Mongolia is part of the Central Asian Orogenic Belt, the origin and evolution of which is not fully known and is often debated. It is composed of several east–west trending lithostratigraphic domains that are attributed to an assemblage of accreted terranes or tectonic zones. This is in contrast to Central Mongolia, which is dominated by a cratonic block in the Hangai region. Terranes are typically bounded by suture zones that are expected to be deep-reaching, but may be difficult to identify based on observable surface fault traces alone. Thus, attempts to match lithostratigraphic domains to surface faulting have revealed some disagreements in the positions of suspected terranes. Furthermore, the subsurface structure of this region remains relatively unknown. Therefore, high-resolution geophysical data are required to determine the locations of terrane boundaries. Magnetotelluric data and telluric-only data were acquired across Southern Mongolia on a profile along a longitude of approximately 100.5° E. The profile extends ~350 km from the Hangai Mountains, across the Gobi–Altai Mountains, to the China–Mongolia border. The data were used to generate an electrical resistivity model of the crust and upper mantle, presented here, that can contribute to the understanding of the structure of this region, and of the evolution of the Central Asian Orogenic Belt. The resistivity model shows a generally resistive upper crust (0–20 km) with several anomalously conductive features that are believed to indicate suture zones and the boundaries of tectonic zones. Moreover, their spatial distribution is coincident with known surface fault segments and active seismicity. The lower crust (30–45 km) becomes generally less resistive, but contains an anomalously conductive feature below the Gobi–Altai zone. This potentially agrees with studies that have argued for an allochthonous lower crust below this region that has been relaminated and metamorphosed. Furthermore, there is a large contrast in the electrical properties between identified tectonic zones, due to their unique tectonic histories. Although penetration to greater depths is limited, the magnetotelluric data indicate a thick lithosphere below Southern Mongolia, in contrast to the previously reported thin lithosphere below Central Mongolia.

Keywords: Magnetotellurics, Electrical resistivity, Southern Mongolia, Gobi, Terranes, Suture zones



Graphical abstract

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FULL PAPER **Open Access**

Magnetotelluric characterization of the Alhama de Murcia Fault (Eastern Betics, Spain) and study of magnetotelluric interstation impedance inversion

Anna Martí*, Pilar Queralt, Alex Marcuello, Juanjo Ledo, Emilio Rodríguez-Escudero, José Jesús Martínez-Díaz, Joan Campanyà and Naser Meqbel

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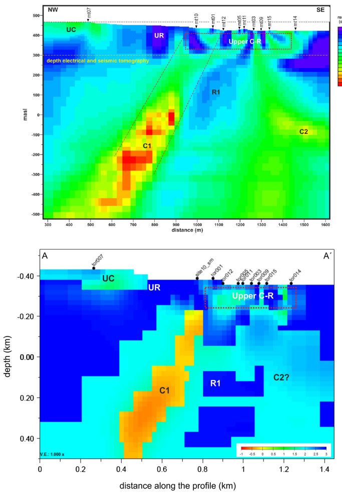
Abstract

The Lorca earthquake (May 11th, 2011, Mw 5.2) stands as the most destructive one in Spain over the last 50 years, interpreted as having occurred in an intersegment zone of the strike–slip Alhama de Murcia Fault (AMF) (Eastern Betics, Spain). Magnetotelluric data were acquired along a profile to the SW of Lorca (La Torrecilla profile), to characterize its signature at depth, as part of the multidisciplinary project "INTERGEOSIMA". Given the short distance between stations, some station pairs were recorded simultaneously, with magnetic sensors in only one of them. In order to properly understand the resulting impedances (called interstation impedances), and the effects of inverting them, we used synthetic models to compare the impedances and the interstation impedances and to analyze the corresponding inversion results, together with the inversion of the quasi-impedance (inversion of the interstation impedances, considering them as impedances). The results are sensitive to the location of the magnetic sensors and the resistivity underneath, but in general the use of the quasi-impedances in the inversion can be considered a valid procedure. Both the 2D and the 3D resistivity models obtained through the inversion allowed us to complement the previous ERT models and represent the continuation of the main fault gouge in depth showing its extension towards the SE.



Graphical abstract

Keywords: Magnetotellurics, Alhama de Murcia Fault, Interstation impedance inversion

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FULL PAPER **Open Access**

Improved shift-invariant sparse coding for noise attenuation of magnetotelluric data

Guang Li, Xiaoqiong Liu, Jingtian Tang, Juzhi Deng, Shuanggui Hu*, Cong Zhou*, Chaojian Chen and Wenwu Tang

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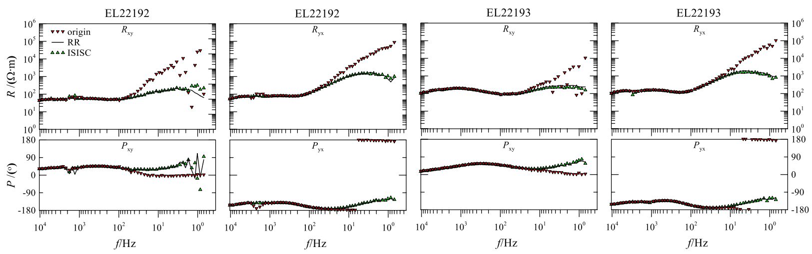
Abstract

Magnetotelluric (MT) method is widely used for revealing deep electrical structure. However, natural MT signals are susceptible to cultural noises. In particular, the existing data-processing methods usually fail to work when MT data are contaminated by persistent or coherent noises. To improve the quality of MT data collected with strong ambient noises, we propose a novel time-series editing method based on the improved shift-invariant sparse coding (ISISC), a data-driven machine learning algorithm. First, a redundant dictionary is learned autonomously from the raw MT data. Second, cultural noises are reconstructed using the learned dictionary and the orthogonal matching pursuit (OMP) algorithm. Finally, the de-noised MT data are obtained by subtracting the reconstructed cultural noises from the raw MT data. The synthetic data, field experimental data and measured data are tested to verify the effectiveness of the newly proposed method. The results show that our new scheme can effectively remove strong cultural noises and has better adaptability and efficiency than the predefined dictionary-based methods. The method can be used as an alternative when a remote reference station is not available.

Keywords: Magnetotelluric, Machine learning, Shift-invariant sparse coding (SISC), De-noising, Dictionary learning



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FULL PAPER Open Access

3D interpretation of helicopter-borne frequency-domain electromagnetic (HEM) data from Ramså Basin and adjacent areas at Andøya, Norway

Vikas Chand Baranwal*, Marco Brönner, Jan-Steinar Rønning, Harald Elvebakk and Einar Dalsegg

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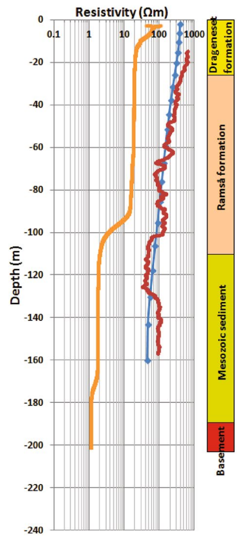
Abstract

The Ramså Basin is situated on the strandflat on the northeastern side of Andøya between Ramså and Skarstein. It is the only known Mesozoic sedimentary basin onshore Norway and therefore represents an easily accessible analogue to study the setting and development of the offshore Mesozoic basins along the Norwegian continental shelf. Basement rocks (100–10,000 Ωm) and sedimentary rocks (5–1000 Ωm) have distinct ranges of the electrical resistivity. Resistivity of the subsurface can be investigated by electric and electromagnetic (EM) methods to delineate the extent of the sedimentary basin. This paper presents the interpretation of helicopter-borne frequency-domain electromagnetic (HEM) data and their correlation with data obtained from borehole logging and two-dimensional (2D) electrical resistivity tomography (ERT). Resistivity data obtained from these methods show a good agreement. Spatially constrained inversion (SCI) of HEM presents a three-dimensional (3D) subsurface resistivity image of a larger area in comparison to what could have been drawn from few ERT lines and borehole logging. HEM interpretation together with other ERT and borehole resistivity data indicates the extent of Ramså Basin beyond the presently mapped boundary. This extension is also supported by interpretation of earlier collected gravity, magnetic and seismic data. The Ramså sedimentary basin shows a wide range of electrical resistivity between ca. 10 and 600 Ωm at different depths. Two highly conductive areas are newly identified by HEM data interpretation. In one of these areas, outcropping graphite and sulfide minerals were found by field observations.

Keywords: Airborne EM, Ramså Basin, Frequency-domain helicopter-borne electromagnetic (HEM), Spatially constrained inversion (SCI), Mesozoic bedrock



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Synthetic modelling of downhole resistivity data to improve interpretation of basin morphology from magnetotelluric inversion

Janelle M. Simpson* and Graham Heinson

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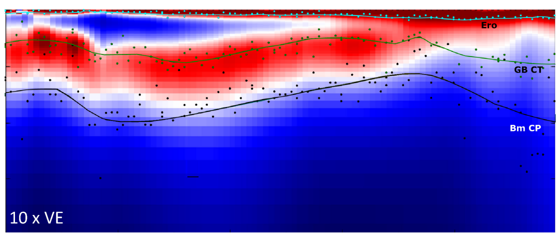
Abstract

Prospective Proterozoic units in the southern Mount Isa Province are concealed by a poorly defined extent of younger basin cover, leading to poor exploration success. Collection of a magnetotelluric (MT) survey in the area containing 809 broadband MT (BBMT) and 855 audiomagnetotelluric (AMT) stations in 2014–2015, offers an opportunity to better model the depth to basement to enable effective exploration. MT inversion models are inherently non-unique, requiring independent geophysical and geological constraint to reduce model uncertainty. Where data are not available to constrain inversion, alternative approaches to dealing in inversion variability are required. This study uses synthetic modelling based on well data combined with two kinds of inversion to generate an interpretation and quantify associated uncertainty. Downhole resistivity logs were obtained from three petroleum wells adjacent to the study area, and 1D resistivity models were generated from the downhole data. A suite of 1D and 2D MT inversion algorithms were tested to determine their ability to resolve basin layering and the basement interface. All inversion algorithms reproduced basin layering, but the basement interface was poorly resolved. A combination of Occam2D and 1D rjMcMC inversions were used to produce interpretation of the base of the Eromanga Basin, an intra-Georgina Basin low-resistivity layer and depth to basement, all of which have associated error estimates. This work highlights the importance of understanding inversion variability during interpretation of geological features, particularly in the absence of constraining information. Distribution of uncertainty between the interpretation features is significantly non-uniform, necessitating careful consideration of inversion results. By quantifying uncertainty rather than ignoring it, we produce an interpretation commensurate with data limitations that still provides valuable new information about the geology of the southern Mount Isa Province.

Keywords: Depth to basement, Magnetotelluric inversion, Synthetic modelling, Uncertainty quantification, Mount Isa Province, Georgina Basin, Eromanga Basin



Graphical abstract

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FULL PAPER **Open Access**

AusLAMP 3D MT imaging of an intracontinental deformation zone, Musgrave Province, Central Australia

Stephan Thiel*, Bruce R. Goleby, Mark J. Pawley and Graham Heinson

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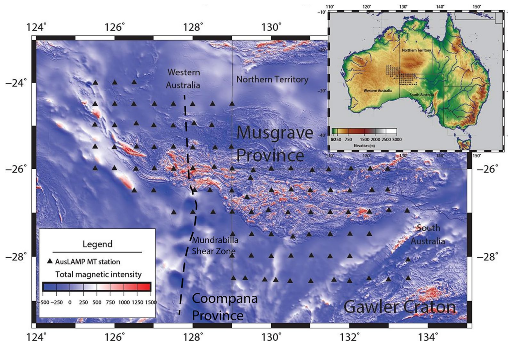
Abstract

The central Australian Musgrave Province at the junction of the South, North and West Australian cratons has undergone and continues to retain evidence of significant whole-of-crust, and most likely 'whole-of-lithosphere' tectono-magmatic processes. The area is known for some of the largest geophysical anomalies related to significant Moho offsets of up to 15 km, which resulted from repeated intracratonic reworking since the Neoproterozoic. New magnetotelluric (MT) data have been collected across the Musgrave Province in Western Australia and South Australia as part of the Australian Lithospheric Architecture Magnetotelluric Project (AusLAMP). Station spacing was ~50km between 96 sites over an area of 500 × 700 km. Long-period MT impedance and tipper data over a bandwidth of 8 s to 10,000 s period have been inverted using a smooth 3D inverse algorithm. The 3D model shows two predominant resistivity trends. There are deep (>65 km) north–south mantle conductors that we infer to be related to the Palaeo- to Mesoproterozoic north-trending arc-related rocks that experienced ultra-high temperature metamorphism and widespread magmatism during the Mesoproterozoic Musgravian Orogeny. These conductors are preserved in the crust south of the Musgrave Province. The upper mantle also contains a localised resistive zone that possibly represents generation of mafic- to ultramafic magmas during the c. 1090–1040 Ma Giles Event. The crust (<65 km depth) contains strong east–west crustal conductors interpreted to reflect the east–west structural grain that initiated during the c. 1090–1040 Ma Giles Event and overprinted the older N–S-oriented mantle anomalies. These E–W crustal conductors coincide with magnetic anomalies that represent crustal-scale structures, and high gravity anomalies associated with significant Moho offsets resulting from further reactivation during the c. 630–520 Ma Petermann and c. 450–300 Ma Alice Springs orogenies.

Keywords: Magnetotelluric, AusLAMP, Musgrave Province, Intraplate deformation, Intracontinental deformation, Central Australia



Graphical abstract

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TECHNICAL REPORT **Open Access**

Multi-order vector finite element modeling of 3D magnetotelluric data including complex geometry and anisotropy

Aixa M. Rivera-Rios*, Bing Zhou, Graham Heinson and Lars Krieger

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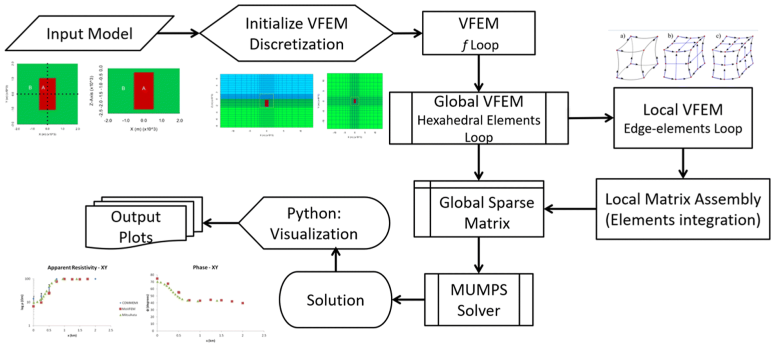
Abstract

We introduce MoVFEM, a computational algorithm for the modeling of three-dimensional magnetotelluric (MT) data using a vector finite element method of specific order from multiple elements' orders. Our algorithm allows complex geometries, topography, and anisotropic resistivity structures. The software calculates secondary electric and magnetic fields for a plane-wave primary magnetic field. Accurate calculation of fields in the boundary regions of the computational domain are ensured by the implementation of the Generalized Perfect Matched Layers method. We validate the MoVFEM algorithm by applications to various scenarios, which allow a comparison with analytical or accepted numerical solutions where available. The respective results of our algorithm are in good agreement with existing solutions.

Keywords: Numerical modeling, Electrical resistivity anisotropy, Finite element method, Edge elements, Magnetotellurics



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Contents

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