Journal of Applied Geophysics 135 (2016) 261–269

Contents lists available at ScienceDirect

Journal of Applied Geophysics

journal homepage: www.elsevier.com/locate/jappgeo

Combining electromagnetic measurements in the Mygdonian sedimentary basin, Greece

U. Autio[a,*], M.Yu. Smirnov[b], A. Savvaidis[c], P. Soupios[d], M. Bastani[e]

[a] Oulu Mining School, University of Oulu, P.O. Box 3000, FI-90014 Oulu, Finland
[b] Department of Civil, Environmental and Natural Resources Engineering, Luleå University of Technology, 971 87 Luleå, Sweden
[c] Institute of Engineering Seismology and Earthquake Engineering, P.O. Box 53, 55102 Finikas, Thessaloniki, Greece
[d] Department of Environmental and Natural Resources Engineering, Technological Educational Institute of Crete, Chania, Greece
[e] Geological Survey of Sweden, Box 670, SE-75128 Uppsala, Sweden

ARTICLE INFO

Article history:
Received 31 July 2015
Received in revised form 14 October 2016
Accepted 17 October 2016
Available online 19 October 2016

Keywords:
Time-domain electromagnetic method
Magnetotellurics
Controlled source
Inversion
Mygdonian basin

ABSTRACT

We present a novel approach where time-domain electromagnetic (TEM) data are transformed and subsequently used in two-dimensional (2-D) magnetotelluric inversion of the determinant of the impedance tensor. The main idea is to integrate TEM with magnetotelluric (MT) data to produce subsurface electrical resistivity models. Specifically, we show that 2-D MT data inversion of the determinant of the impedance tensor supported by inclusion of TEM–MT-transformed data has superior resolution at the near surface and at the same time static shift afflicting the MT data can be addressed. Thus, the approach allows for practical express integration of TEM data with MT measurements as opposed to a full combined 3-D inversion, which requires significant resources. The approach is successfully applied in the Mygdonian sedimentary basin located in Northern Greece. In addition to TEM and MT data, also controlled source — and radiomagnetotelluric data are available from the Mygdonian basin, which have been subjected to 2-D analysis previously. We have extended the analysis to a full 3-D inversion using ModEM code. All obtained models are analysed and are in a good agreement.

1. Introduction

Electromagnetic (EM) methods imaging electrical resistivity of the subsurface have important applications in many areas including mineral and geothermal exploration. Often multiple geophysical methods are used to improve reliability and resolution of the results. Information from different methods can be combined in different ways to accomplish this. Full 3-D combined inversion is not always feasible due to high demand for computer resources and sophisticated tools. Thus, there is still a need for simpler data integration schemes.

It is common practice to use time-domain electromagnetic method (TEM) with inductive coupling to the ground to correct for static shift often afflicting magnetotelluric (MT) data (Meju, 1996; Pellerin and Hohmann, 1990; Sternberg et al., 1988). This fact makes the combination of TEM with MT particularly appealing. However, using TEM data only for static shift correction is the least use of the existing information. To this end Meju (1996) jointly inverted apparent resistivity data from TEM with impedance phase data from MT to recover one-dimensional (1-D) resistivity distribution. Similarly, Arnason et al. (2010) conducted 1-D combined inversion of TEM and MT data and regarded static shift as an additional model parameter. Here, we present a scheme where TEM data are first transformed to MT apparent resistivity and impedance phase (TEM–MT-transform) after which they are used to support 2-D inversion of MT data. The TEM data provides extended period range towards the shorter periods. The transformation step is similar to what is used when correcting MT data for static shift. However, instead of only shifting of MT apparent resistivities towards TEM derived apparent resistivities we integrate the latter into 2-D magnetotelluric inversion of the determinant of the impedance tensor. Thus, we regard the TEM–MT-transformed impedance as the determinant average.

In addition to TEM and MT data, radiomagnetotelluric (RMT) and controlled source magnetotelluric (CSMT) data have been measured in the Mygdonian basin using the EnviroMT system (Bastani, 2001). Combination of these two methods is called CSRMT. As the CSRMT data coincide in position with the TEM data, they can be used to evaluate the correctness of our TEM–MT-transform. The two methods have overlapping depths of investigation, but different resolution, hence we find it useful to compare them. Finally, as

* Corresponding author.
E-mail address: uula.autio@oulu.fi (U. Autio).

http://dx.doi.org/10.1016/j.jappgeo.2016.10.014
0009-2541/

the CSRMT data cover a considerable part of the Mygdonian basin, results from three-dimensional (3-D) inversion of the CSRMT data will be presented, which clearly illustrates the major near-surface features in the basin and confirms earlier 2-D CSRMT inversion results presented in Bastani et al. (2011).

The remainder of the paper is organised as follows. First a brief geologic description of the Mygdonian sedimentary basin is provided. Next, the relevant geophysical measurements are described with emphasis on the TEM method. Comparison of the TEM and the CSRMT methods will be also discussed before we move on to present details and results regarding the inversion of MT data supplemented with TEM–MT-transformed data. The paper will be concluded with a discussion and a summary of our results.

2. Measurement setting

The measurement data analysed in the study are shown on a geological map in Fig. 1. The Mygdonian sedimentary basin is located in northern Greece 30 km east from the city of Thessaloniki. Seismic activity in the area has resulted in multiple faults with main trend in NW–SE-direction (Raptakis et al., 2005; Tranos, 2003). The studied area is situated between the villages of Profitis and Stivos, bounded by gneiss bedrock in the north and the south. This part of the basin has been of specific interest to seismic research as it has been a multipurpose test site, EUROSEISTEST, since 1993 (Pitilakis et al., 2013). The original 2-D EUROSEISTEST seismic profile traverses between Profitis and Stivos.

The lower part of the basin consists of conglomerates, sandstones, silt and sand sediments and red beds (Raptakis et al., 2000). The upper part consists mainly of mixtures of sands, silts and clays (Raptakis et al., 2000). The borehole S1 at the center of the area reaches weathered and unweathered bedrock at 185 m and 196 m depth, respectively.

3. Electromagnetic data

All data sets used here have been studied to some extent previously i.e. the CSRMT data by Gurk et al. (2007a) and Bastani et al. (2011), MT data by Gurk et al. (2007b) and the TEM data by Gurk et al. (2008) and Soupios et al. (2013). CSRMT and MT measurements have been described in these previous studies, thus only a short description is given here. More detailed description is provided for the TEM measurements.

3.1. MT

During the years 2006–2007 a total number of 92 MT sites have been installed in the Mygdonian basin. The sites were measured on roughly regular grid with site spacing of about 1 km. Some areas in the mountain and around villages are not covered due to increased EM noise or due to their inaccessibility. The time series have been processed with the robust remote reference code (Smirnov, 2003). Generally the data are of a good quality.

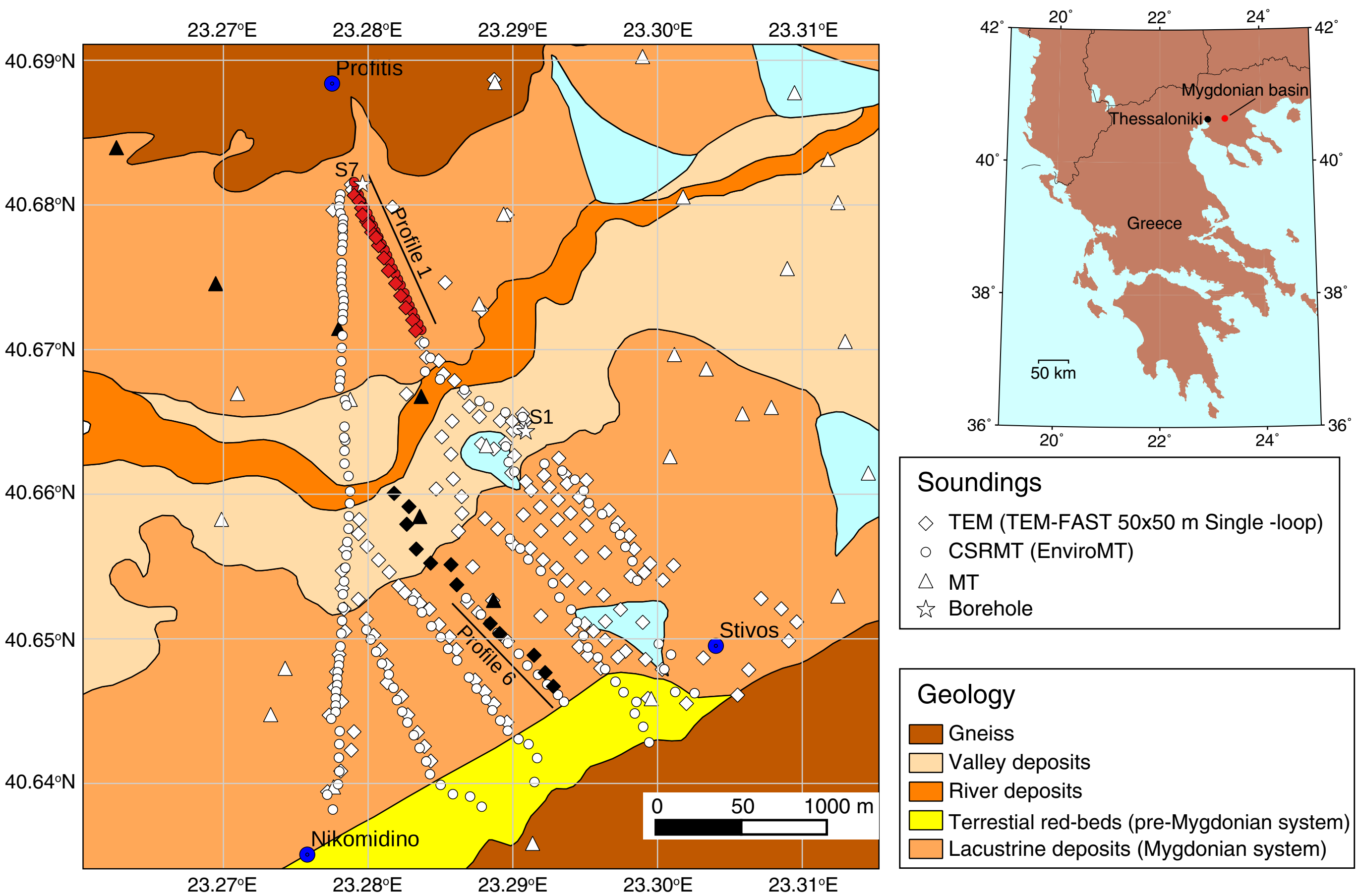

Fig. 1. Location of TEM, CSRMT and MT stations shown on a geological map of the area. The Mygdonian basin has an approximate east–west trend and is bounded by the gneiss bedrock in the north and the south. Red symbols: TEM and CSRMT sites along profile 1, see Section 5.1. Black symbols: sites along combined TEM and MT profile, see Section 5.2. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)