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Crustal Structure of the Eastern Part of Central Anatolia (Turkey)

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Abstract: This study aims to examine crustal structure in the eastern part of central Anatolia using the magnetotelluric (MT) method. MT data have been collected from 37 stations along a north–south 220 km profile crossing in succession the Tokat Massif (Pontide basement), the Ankara-Erzincan Suture Zone, the Kırşehir Massif, the Pınarbaşı-Divriği Ophiolitic Belt and the Tauride-Anatolide Belt. Data were modelled to derive a geo-electrical model using 2-dimensional inverse techniques. Low resistivity values (<38 Ohm.m) extend to a maximum depth of 7 km beneath the Sivas Basin, 4 km in the Kangal Basin, 10 km in the Gürün Basin, 6 km in the Ovacık Basin and 6 km in the Elbistan Basin and are interpreted as sediment infill. Three high resistive zones (>981 Ohm.m) coincide with the southern part of the Pontide Magmatic Arc, the Kırşehir Block and the Tauride-Anatolide Belt and are interpreted as upper crust of igneous and metamorphic origin. Low resistivity values (< 981 Ohm.m) are identified below the upper crust and the layer accepted as lower crust ranges from 10–15 km beneath the high resistive zones. Total crust thickness is approximately 45 km in the Tokat Massif, Kırşehir Massif and Tauride-Anatolide Platform. Two vertical conductive zones have been detected beneath the Ankara-Erzincan Suture in the north and the Divriği-Pınarbaşı Ophiolitic Belt in the south. The northern conductive zone identifies the Ankara-Erzincan Suture and the southern conductive zone corresponds to the Divriği-Pınarbaşı Ophiolitic Belt where it provides evidence for an Inner Tauride Suture. The relationship between the gravity and resistivity data has been researched and the high gravity anomalies were found to be consistent with high conductive zones along the MT profile.

Key Words: crustal structure, magnetotelluric, sutures, Central Anatolia, Turkey

Orta Anadolu'nun Doğu Kesiminin (Türkiye) Kabuk Yapısı

Özet: Bu çalışmanın amacı manyetotellürik (MT) yöntemi kullanarak Orta Anadolu'nun doğu kesiminin kabuk yapısını incelemektir. MT verileri kuzeyden güneye Tokat Masifi (Pontidlerin temeli), Ankara-Erzincan Kenet kuşağı, Kırşehir Masifi, Pınarbaşı-Divriği Ofiyolit Kuşağı ve Torid-Anatolid Kuşağı'nı kesen 220 km'lik bir profil boyunca 37 istasyonda alınmıştır. Bu veriler 2-boyutlu ters çözüm yöntemi kullanılarak modellenmiştir. Sivas Havzası'nın altında maksimum 7 km, Kangal Havzası'nda 4 km, Gürün Havzası'nda 10 km, Ovacık Havzası'nda 6 km ve Elbistan Havzası'nın altında ise 6 km derinliğe kadar uzanan düşük özdirenç değerli kesimler (<38 Ohm.m) çökel dolgusu olarak değerlendirilmiştir. Kırşehir Bloku, Torid-Anatolid Kuşağı ve Pontid Magmatik Yayı'nın güney bölümüne karşılık gelen üç yüksek özdirençli zon (>981 Ohm.m) belirlenmiştir. Bu yüksek özdirençli zonlar üst kıtasal kabuk olarak yorumlanmıştır. Üst kabuğun altında ise düşük özdirenç değerleri (< 981 Ohm.m) görülmektedir. Alt kıta kabuğu olarak kabul edilen bu katmanın, yüksek özdirençli zonun altındaki kalınlığı 10–15 km arasında değişmektedir. Toplam kabuk kalınlığı Tokat Masifi, Kırşehir Masifi ve Torid-Anatolid Platformu'nda yaklaşık 45 km dir. Kuzeyde Ankara-Erzincan Kenedi ve güneyde Divriği-Pınarbaşı Ofiyolit Kuşağı'nın altında iki düşey iletken zon belirlenmiştir. Kuzeydeki iletken zon Ankara-Erzincan Kenedi'ni doğrulamaktadır ve Divriği-Pınarbaşı Ofiyolit Kuşağı'na denk gelen güneydeki iletken zon ise İç Toros Süturu'nun bir kanıtı olabilir. Ayrıca MT hattı boyunca gravite değerleri ile iletkenlik ilişkisi araştırılmış ve yüksek gravite anomalilerinin yüksek iletkenlik zonları ile uyum içinde olduğu görülmüştür.

Anahtar Sözcükler: kabuk yapısı, manyetotellürik, kenetler, Orta Anadolu, Türkiye

Introduction

Anatolia is a segment of the Alpine-Himalayan mountain belt which has been accreted and shaped by collision between Laurasia in the north and Afro-Arabia in the south. This continental convergence was the result of two main episodes of ocean growth and consumption, namely the Paleotethys (Carboniferous to Triassic) and Neotethys (Triassic to Cretaceous) (Şengör & Yılmaz 1981). The eastern part of central Anatolia consists of seven east–west Paleotethyan and Neotethyan tectonic belts.

From north to south these belts are the Pontides (Pontide Magmatic Arc and the Tokat Massif), the İzmir-Ankara-Erzincan Suture Zone, the Kırşehir Massif, the Pınarbaşı-Divriği Ophiolite Belt, the Tauride-Anatolide Platform, the Bitlis-Zagros Suture Zone and the Arabian Platform (Figures 1 & 2).

The Pontides comprise an orogenic belt formed by the Cimmeride and Alpine orogenic events (Şengör & Yılmaz 1981), and the Pontide Magmatic Arc which mainly consists of Upper Cretaceous volcanic rocks and intercalated sediments intruded by granitoids (Boccalatti *et al.* 1974; Şengör & Yılmaz 1981; Okay & Şahintürk 1998). This magmatic arc is interpreted to have formed during northward subduction of the Ankara-Erzincan Ocean (Akın 1978; Şengör & Yılmaz 1981). The Tokat Massif comprises metamorphic basement of the Eastern Pontides and can be correlated with the Karakaya Complex, which generally is interpreted as an accretionary prism (Tekeli 1981; Okay 2000; Pickett & Robertson 1996, 2004). Around the Tokat Massif are pre-Liassic low-grade metavolcanic and sedimentary rocks, an ophiolitic olistostrome made up exotic blocks including Silurian to Triassic limestones, and ophiolites in a metaclastic and metavolcanic matrix, an Upper Cretaceous ophiolitic mélange and heterogeneous metamorphic rock associations. From bottom to top the latter consist of metaclastic and metabasic rocks, phyllite, marble and meta-volcaniclastics with exotic blocks (Özcan *et al.* 1980; Yılmaz 1980, 1982; Yılmaz & Yılmaz 2004).

The Ankara-Erzincan Suture was the collisional site of the main Tethys Ocean between Laurasia and Gondwana during the Late Palaeozoic–Early Tertiary interval (Okay & Tüysüz 1999) and is composed of a range of different ophiolitic tectono-stratigraphic units. Some of these units are internally chaotic dismembered ophiolites (Yılmaz 1980; Norman 1988) but also include slivers of ordered ophiolites (Yılmaz *et al.* 1993) obducted into their present tectonic setting during the Late Cretaceous and reworked during the Eocene. An ophiolitic mélange association was obducted onto the Pontides, and south-vergent thrusts were developed during the Late Cretaceous (Yılmaz *et al.* 1993, 1997). Ophiolite nappe packages, mainly composed of thick and dismembered ophiolitic slices, were reworked during the Eocene (Yılmaz *et al.* 1993 and Figure 3). Rice *et al.* (2006) suggested that the İzmir-Ankara-Erzincan Suture Zone in the Central and Eastern Pontide regions comprises Upper Cretaceous units that record the development of an accretionary complex, a volcanic arc, a forearc basin and a rifted back-arc basin.

The Kırşehir Massif consists of magmatic (CAG: Central Anatolian Granitoids), metamorphic (CAM: Central Anatolian Metamorphics) and ophiolitic rock (CAO: Central Anatolian Ophiolites) assemblages which

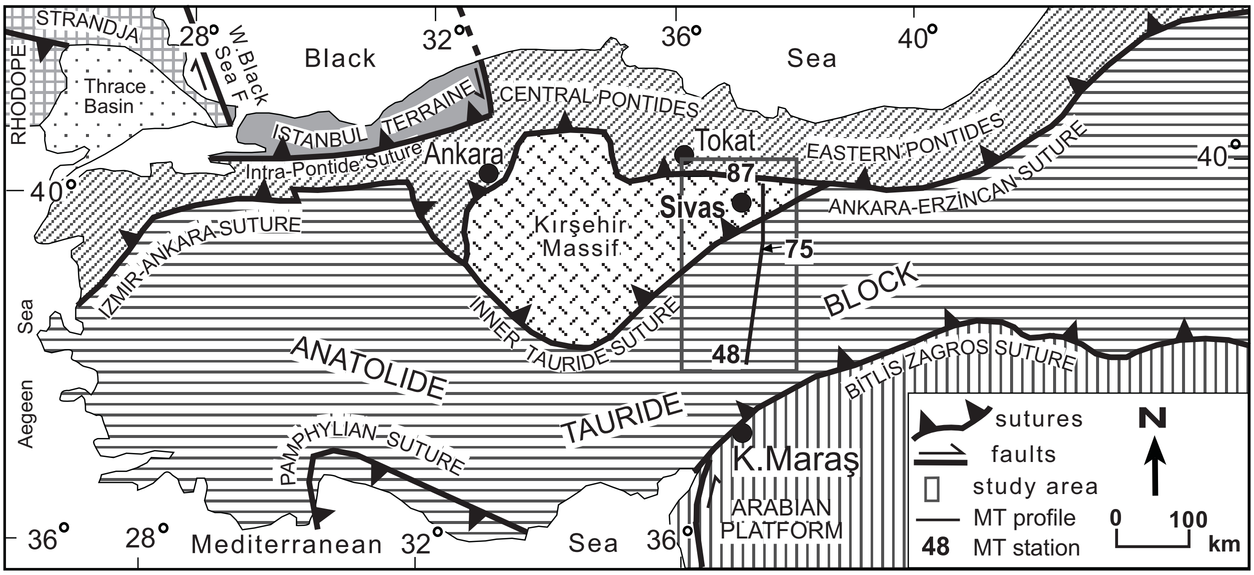

Figure 1. Simplified tectonic divisions of Turkey (from Okay & Tüysüz 1999) and the location of the study area with the MT profile.

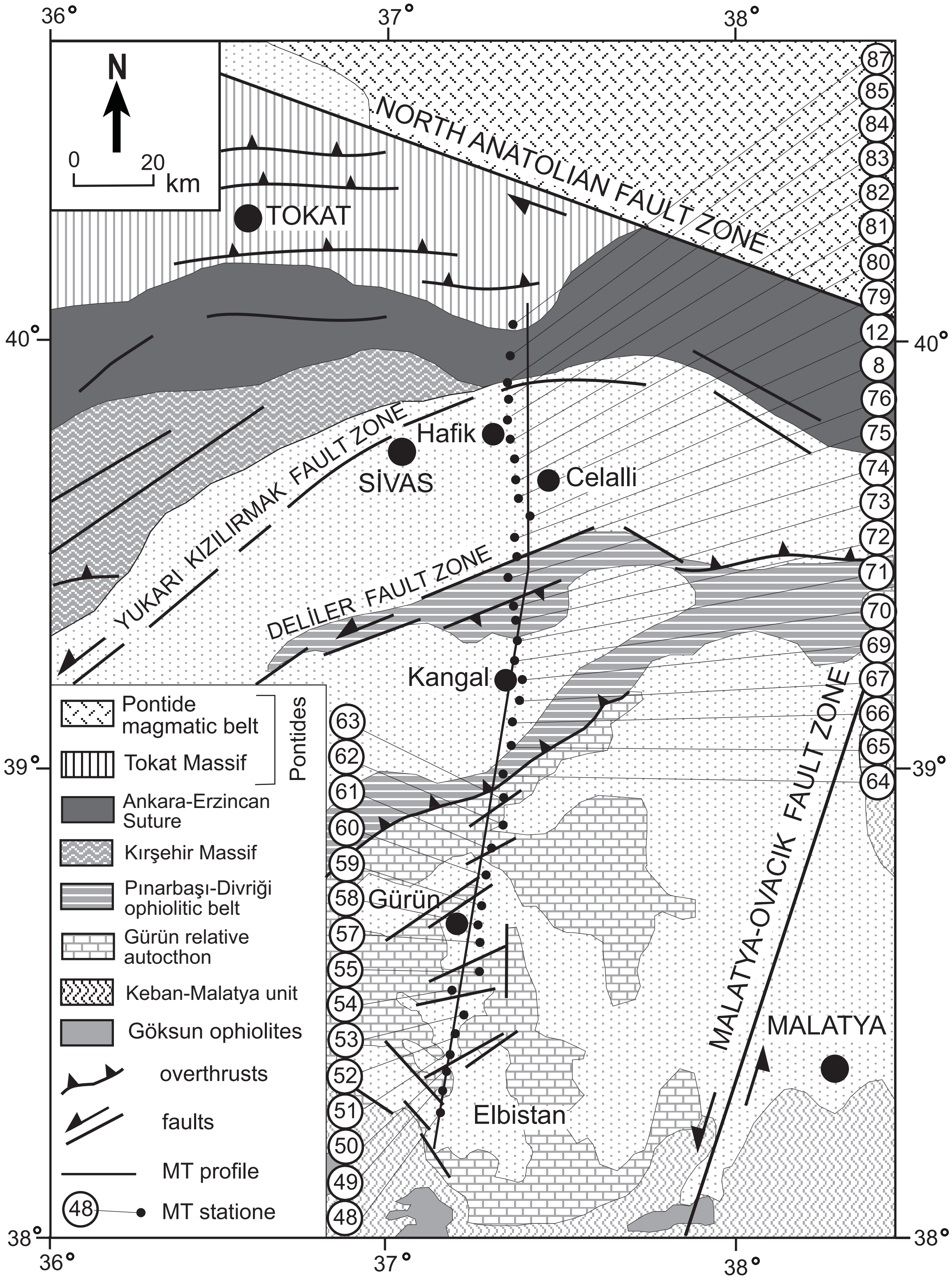

Figure 2. Major tectonic divisions in the eastern part of Central Anatolia (after Ketin 1966; Okay 1989; Okay & Tüysüz 1999).

are collectively termed the Central Anatolian Crystalline Complex (Göncüoğlu *et al.* 1991, 1994). The CAG, comprising Late Cretaceous granitoids and syenitoids, cuts the CAM and CAO. The CAM consists of metamorphosed platform-type successions subjected to pre-early Late Cretaceous polyphase medium-high-grade metamorphism (Göncüoğlu 1986; Göncüoğlu *et al.* 1991). The CAO is a partially preserved ophiolitic sequence containing metamorphic tectonites, cumulate and isotropic gabbros, plagiogranites, diabases, pillowed basalts, and epi-ophiolitic sediments (Yalınız & Göncüoğlu 1998). This sequence exhibits a supra-subduction zone chemistry (Göncüoğlu & Türeli 1993; Yalınız *et al.* 1996, 1999; Floyd *et al.* 1998, 2000; Yalınız & Göncüoğlu 1998) and its formation age is Turonian to Santonian (Yalınız *et al.* 1996)

An ophiolitic belt also crops out south of the Kırşehir Massif near Divriği (Sivas) and Pınarbaşı (Kayseri) and comprises an ophiolitic mélange (Erkan *et al.* 1978; Yılmaz *et al.* 1989; Yılmaz *et al.* 1993) and partly altered ophiolites (Yılmaz *et al.* 1993; Yılmaz *et al.* 2001). The origin of the Divriği-Pınarbaşı Ophiolitic Belt is controversial and according to some researchers, the ophiolitic suite originated in the Maastrichtian–Late Eocene (Şengör & Yılmaz 1981) Inner Tauride Ocean (Demirtaşlı 1977; Şengör & Yılmaz 1981; Koçyiğit 1990; Görür *et al.* 1984; Robertson & Dixon 1984; Gökten 1993; Gökten & Floyd 1987; Andrew & Robertson 2002; Clark & Robertson 2002). Alternatively it could belong to the northern branch of the Neotethys and comprise rootless ophiolitic slices transported from north to south (Kelling *et al.* 1989; Cater *et al.* 1991; Yılmaz *et al.* 1993; Göncüoğlu *et al.* 1996–1997).

Ophiolitic rocks tectonically overlie the Tauride-Anatolide Platform (Yılmaz & Yılmaz 2004) and consist of the Gürün Relative Autochthon and the Keban-Malatya Unit (Yılmaz *et al.* 1993).

The Gürün relative autochthon mainly consists of limestone and clastic rocks and the Keban-Malatya Unit is composed of gneiss, schist, marble and carbonate rocks intruded by Palaeozoic granitoids (Perinçek & Kozlu 1984). This north-dipping unit is interpreted as a Late Palaeozoic–Mesozoic carbonate platform sequence that formed part of the Tauride Carbonate Platform to the north of the Southern Neotethys Ocean (Robertson *et al.* 2006). Some ophiolitic rocks (Erkan *et al.* 1978; Yılmaz 1983) tectonically overlie the Tauride-Anatolide Platform in the south.

The study area is underlain from north to south, by the Sivas, Kangal, Gürün, Ovacık and Elbistan basins. The Sivas Basin underlain by the Kırşehir Block (Görür *et al.* 1998) or a mosaic comprising the Kırşehir Massif and ophiolitic rocks (Clark & Robertson 2005; Yılmaz & Yılmaz 2006). The Kangal Basin developed on the Pınarbaşı-Divriği Ophiolitic Belt. The Gürün and Ovacık basins developed on the Gürün relative autochthon, and the Elbistan Basin developed on the Gürün relative autochthon and Keban-Malatya Unit (Figure 3). In summary, the crust of the study area is built up of five major structural divisions comprising the Pontide (Pontide Magmatic Arc and Tokat Massif), the Kırşehir Block, the Anatolide-Tauride Platform, the Ankara-Erzincan Suture, the controversial Inner Tauride Suture and some sedimentary basins developed on these geotectonic units.

The magnetotelluric (MT) method has been used to investigate deep crustal structure, upper mantle and crustal thickness, and for geothermal (heat source) exploration (Vozof 1972; Jupp & Vozof 1977; Beblo *et al.* 1983; Hersir & Björnssonn 1991; Simpson & Bahr 2005). The MT method has also been used successfully to investigate the geometry of sedimentary basins (Gupta & Jones 1990; Jones & Craven 1990; Pomposiello *et al.* 2002; Bayrak *et al.* 2004; Bayrak *et al.* 2006) and ancient subduction/collision zones (Jain 1964; Jones 1993; Bayrak *et al.* 2004). Following the rationale of these studies the method has been applied here to investigate the signature of the sedimentary basins and ancient subduction zones in a study spanning the Anatolian accretionary complex described above.

Some geophysical methods have already been applied to determine the shape of the Sivas sedimentary basin. Erez (1974) was the first worker to identify the existence and continuity of some deep low velocity zones in this region by seismic measurements in a well 3645 m deep near Celalli in the east of the Sivas Basin. Low density values calculated from low seismic velocity values were recognised to be compatible with low gravity values in the Sivas Basin. By 2D modelling of gravity data Tufan & Ateş (1995a, b) suggested that the maximum depth of the Sivas Basin is approximately 9 km and direct current resistivity surveys in the eastern part of the Sivas Basin indicated an anticlinal structure at 5 km depth (Duvarcı 1993; Tanıdır & Karlı 1993). However, no geophysical studies have yet investigated the deeper structure in the study area.

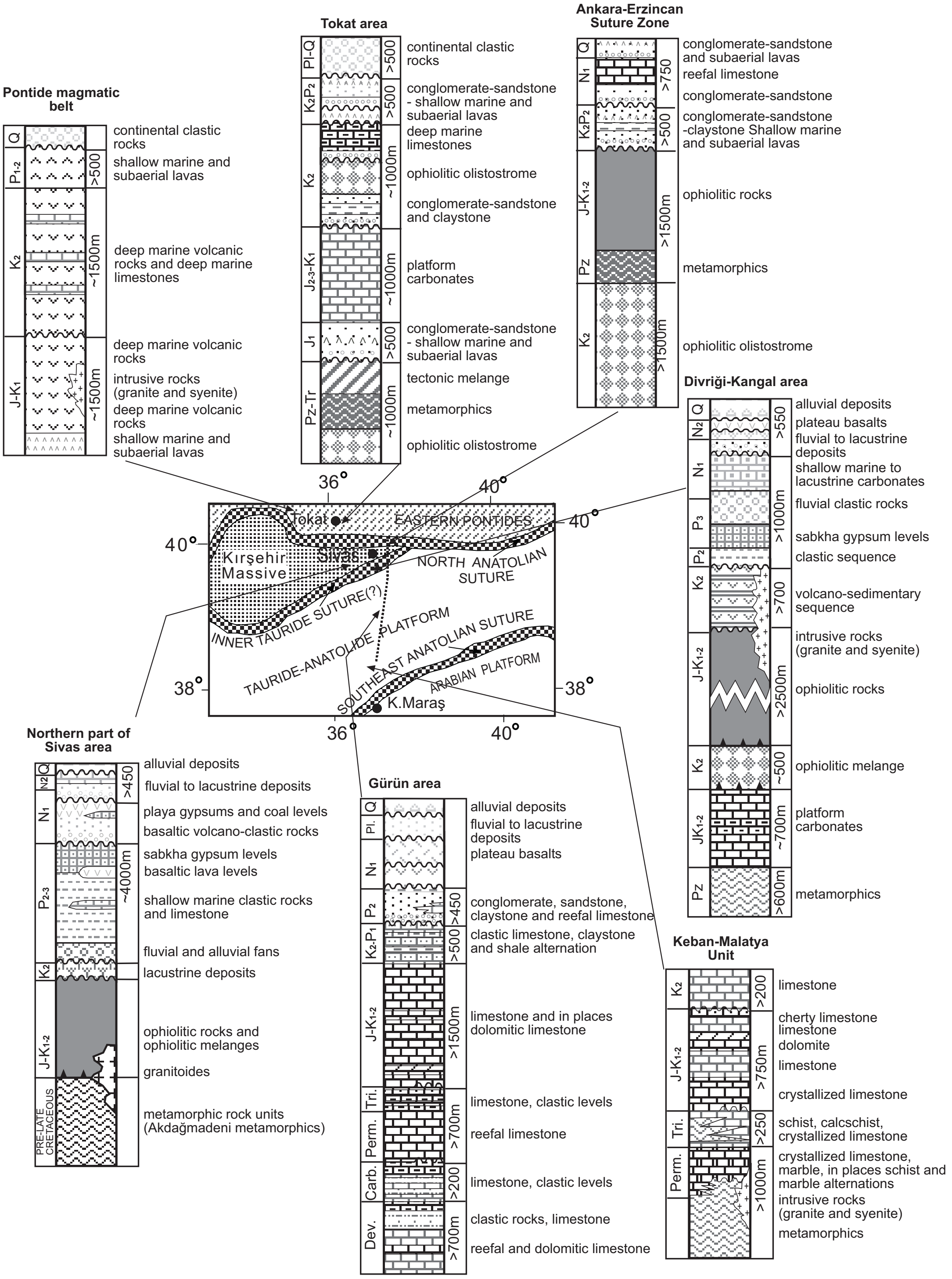

Figure 3. Generalized columnar sections of the tectonic zones in the eastern part of Central Anatolia. The sources are: Pontides (after Gedikoğlu 1978; Özsayar *et al.* 1981); Tokat area (after Öztürk 1979; Yılmaz 1981, 1983); Ankara-Erzincan Suture (after Bergougnan 1976; Tatar 1978; Buket 1982; Bektaş 1984; Yılmaz 1985); Sivas area (Yılmaz & Yılmaz 2006); Divriği-Kangal area (Yılmaz & Yılmaz 2004); Gürün area (Yılmaz *et al.* 1993).

Thus the aim of the present study is to investigate the deeper crustal structure of the southern part of the Pontides, Ankara-Erzincan Suture, Kırşehir Massif, Pınarbaşı-Divriği Ophiolite Belt and Tauride-Anatolide Platform along a North–South-trending profile between Hafik (Sivas) and Elbistan (Kahramanmaraş), and to constrain the depth of the Sivas, Kangal, Gürün, Ovacık and Elbistan basins located along the same profile (Figure 1).

Magnetotelluric Method

In the MT method, the orthogonal components of the horizontal electric and magnetic fields induced by natural primary sources are measured simultaneously as a function of time. The natural time varying EM field can be observed as variations in the Earth's magnetic field. The sources used for the magnetotelluric method are called micro pulsations and have frequencies of less than 1 Hz. Most micro pulsations originate in the Earth's magnetopause from motions of charged particles ejected from the Sun.

Data Acquisition

Phoenix V5 MT equipment was employed to record three orthogonal (N–S, E–W and vertical) magnetic (**H**) fields and two orthogonal (N–S and E–W) electrical (**E**) field components. One hundred metre electric dipoles extending in N–S and E–W geomagnetic directions and Pb-PbCl electrodes were used for the **E** field. The horizontal components of the **H** field were measured with an induction coil and the vertical component of the **H** field was recorded with an air loop on the ground. MT data were collected at 37 stations along a N–S direction and the profile length was approximately 220 km from Elbistan to Hafik. The average station interval between the MT stations was approximately 5 km.

The V5 system produces all MT parameters in real-time. The high frequencies level is 320–7.5 Hz. In this system, data acquisition is divided into two frequencies levels which were processed using Fourier transform techniques in a frequency band. Each band contains two frequencies and the low frequency level (6–0.00055 Hz) is processed using cascade decimation (Wight & Bostick 1980).

The relationships between the electric and magnetic components are

$$E_x=Z_{xx}H_x+Z_{xy}H_y \qquad (1)$$

$$E_y=Z_{yx}H_x+Z_{yy}H_y$$

where Z_{ij} are transfer functions called impedances and are a measure of Earth's response to magnetic fields in the x and y directions. If the subsurface is homogeneous or horizontally stratified (one dimensional), the impedances Z_{xx} and Z_{yy} are equal to zero and Z_{xy} and Z_{yx} impedances will conform to the equation below:

$$Z_{xy}(f)=E_x(f)/H_y(f) \qquad (2)$$

If the direction of the electric field (E) is parallel to the geoelectrical strike, the vertical magnetic field is polarized linearly and called Transverse Electric (TE) mode or E-polarization. In this situation the direction of the electric field depends on two orthogonal axes. If the direction is along the x axis alone the impedance is $Z_{xy}=E_x/H_y$.

If the magnetic field is along the geological strike, it will be linearly polarized. If 'y' is perpendicular to strike, the Transverse Magnetic (TM) mode or H polarization is defined as $Z_{yx}=E_y/H_x$ and the components of Z_{xx} and Z_{yy} are zero. As the geological strike is not known, MT measurements are recorded in a geographical extension (e.g., north–south and east–west). To calculate the impedances of the TE and TM modes, all tensor components need to be rotated so that Z_{xx} and Z_{yy} tensor components have minimum values and the difference between Z_{xy} and Z_{yx} is maximised.

For a homogeneous earth, it is a straightforward matter to calculate resistivity from the elements of the impedance tensor. The formula for apparent resistivity is (Cagniard 1953):

$$\rho\ (f)= (|1/ w\mu)|Z_x|^2 \qquad (3)$$

However, to obtain an accurate interpretation of MT data it is essential to eliminate the static-shift effect resulting from three dimensional near surface small bodies (Park *et al.* 1983; Wannamaker *et al.* 1984; Park 1985; Pellerin & Hohman 1990; Stenberg *et al.* 1988). For this purpose the transient electromagnetic method (TEM) with central loop configuration was applied to each MT station in the present study. The TEM loop was square and the sides were selected to be equal to MT E-lines. Static shifts were removed from the MT data using transient electromagnetic data. All TEM windows were converted to pseudo frequency (Stenberg *et al.* 1988) and both MT and pseudo MT (converted from TEM) apparent resistivities plotted together as the same scale log-log graph. TE and TM apparent resistivities were then shifted towards the pseudo MT apparent resistivity (Figure 4).

Two-Dimensional Interpretation of the MT Data

In this study, we used the WinGLink™ interpretation package to derive 2-D earth models in which the MT interpretation section is based on a network analogy. It uses a finite difference scheme to calculate forward MT response and has a 2D inversion code denoted d2inv–nlcg2–fast (Mackie *et al.* 1997), which reveals the resistivity distribution in the Earth via.2D inversion of both TE and TM modes considered jointly. The derived information relates to both the direction and the depth, and since this algorithm is based on the nonlinear conjugate gradient method (Rodi & Mackie 2001) it is quite fast and requires much less memory than traditional Gauss-Newton algorithms.

The initial model was taken to be a homogeneous half space of 100 Ohm-m and comprises 37 stations represented by a mesh of 81 by 136 cells. The maximum number of iterations was set at 50. The software required observed resistivity and phase values. Additionally, some parameters needed to be initialised. The first one was a smoothing factor, tau, taken as 3 for this study. Error floors for all data were kept at 5% as is the default of the code. The RMS value for the initial half space of 100 ohm-m for this model was found to be 15.76 although it decreased to 3.95 after 50 iterations. Pseudo sections of apparent resistivity and phase of impedance for observed and calculated data are given in Figure 5. As seen in this figure, there is a good match between the observed and calculated data.

Gravity Method

Forward modelling with gravity data has been described in detail by various authors (Grant & West 1965; Parker 1973; Oldenburg 1974). In this study, gravity data was calculated along the MT profile obtained from the Bouguer Gravity Map of Turkey (MTA 1999) (Figure 6). Interpretation of two-dimensional modelling with a constant density (ρ_0=2.670 gr/cm^3) was carried out using the WinGLink Software Package.

Discussion and Conclusions

The correlation of the MT model generated using 37 MT sounding sites and the geological structure of the region is important for evaluating the deeper relationship to large scale structures. For this purpose we have constructed a geological cross section along the MT profile and Figure 7a shows the geological cross-section of the MT profile with the shallow part of the MT model (up to 25 km depth) seen in Figure 7b. We find specific correlations between the electrical model and large scale structures in thıs eastern central part of Anatolia. There are some areas with low resistivity values (<38 Ohm.m) extending to a maximum depth of 10 km beneath the surface in the geoelectrical resistivity model. These areas correlate with the sedimentary basins (Kangal Basin, Gürün Basin, Ovacık Basin and Elbistan Basin) along the MT profile and the extension of the low resistivity values (<38 Ohm.m) probably indicates the thickness of the basin fill. For example, according to this study the maximum depth of the Sivas Basin is 7 km and this value is similar to estimates from some previous geophysical studies (e.g., Tufan & Ateş 1995a, b). As a corollary the depths of the basins along the MT profile can be estimated: low resistivity values (<38 Ohm.m) interpreted as basin fill extend downward to a maximum depth of 7 km beneath the Sivas Basin, 4 km in the Kangal Basin, 10km in the Gürün Basin, 6 km in the Ovacık Basin and 6km in the Elbistan Basin.

Figure 8a shows observed and calculated gravity best fit values along the MT profile. Figure 8b shows the entire crustal model, which is data sensitive to resistivity structure down to 65 km depth and Figure 8c illustrates an interpretive cross section based on electrical resistivity of MT profile and gravity data. There are three resistive zones and two conductive zones in the geoelectrical section (Figure 8b). The northernmost resistive zone (>981 Ohm.m) extending approximately 25 km to a maximum depth correlates with the southern edge of the Pontide Magmatic Arc and another body with similar resistivity values beneath the Sivas Basin defines the eastern extension of Kırşehir Massif and has a maximum depth of about 33 km. There is a high resistive layer (>981 Ohm.m) extending to a maximum depth of about

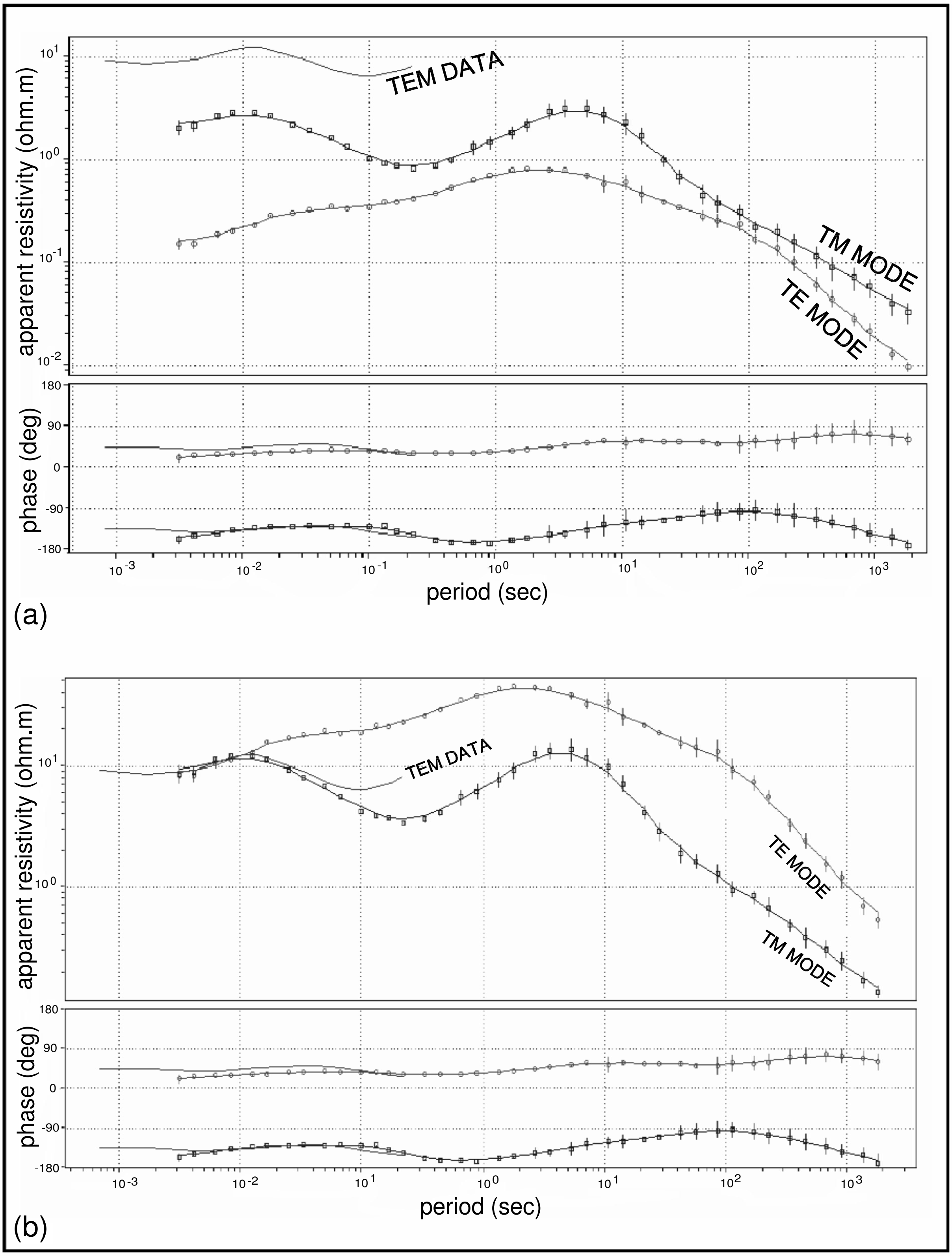

Figure 4. MT and TEM sounding curves. (a) Before and (b) after static-shift correction.

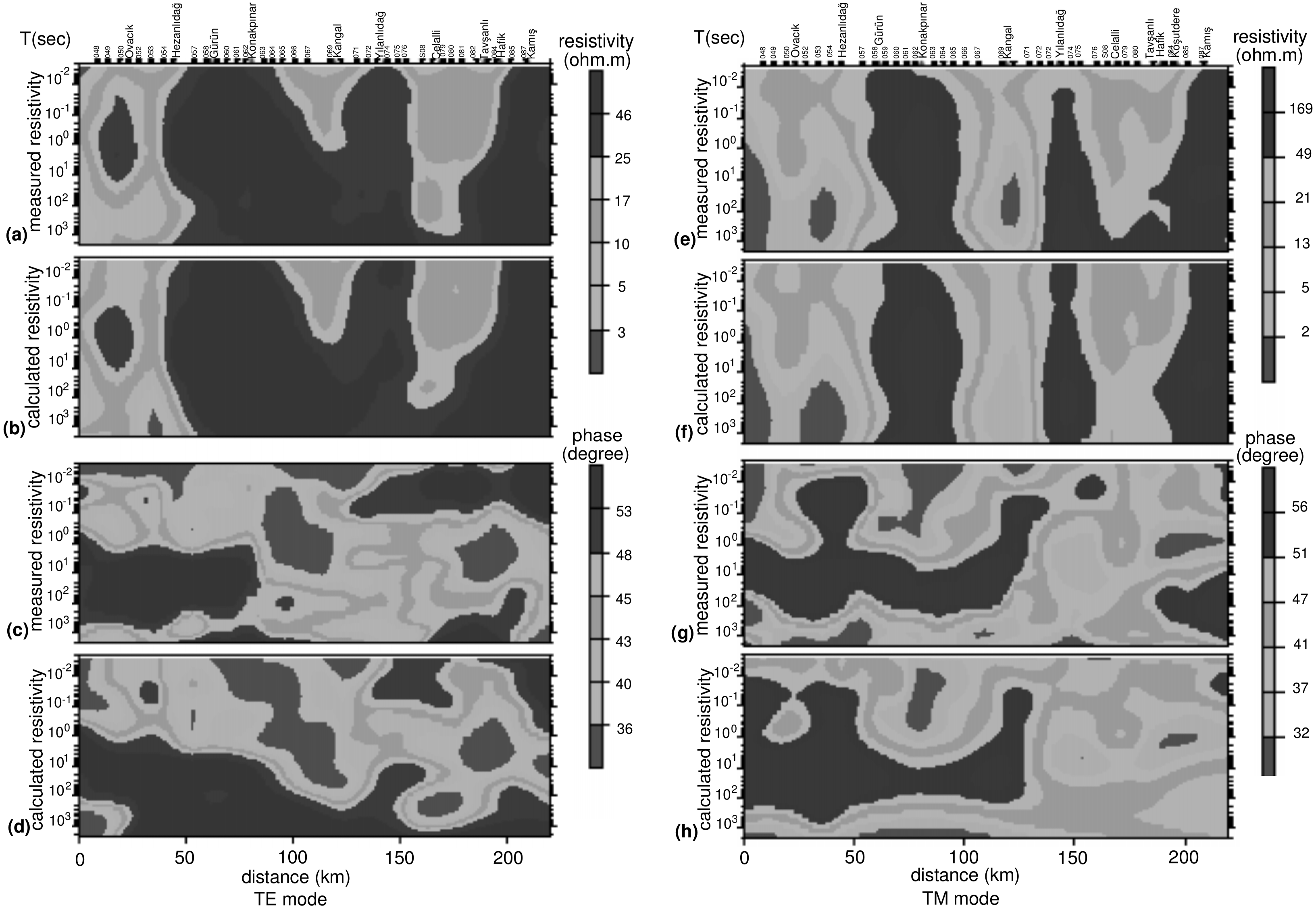

Figure 5. Pseudosections of the MT (a) measured resistivity, (b) calculated resistivity, (c) measured phase (d) calculated phase for TE mode and pseudosections of the MT (e) measured resistivity, (f) calculated resistivity, (g) measured phase, (h) calculated phase for TM mode.

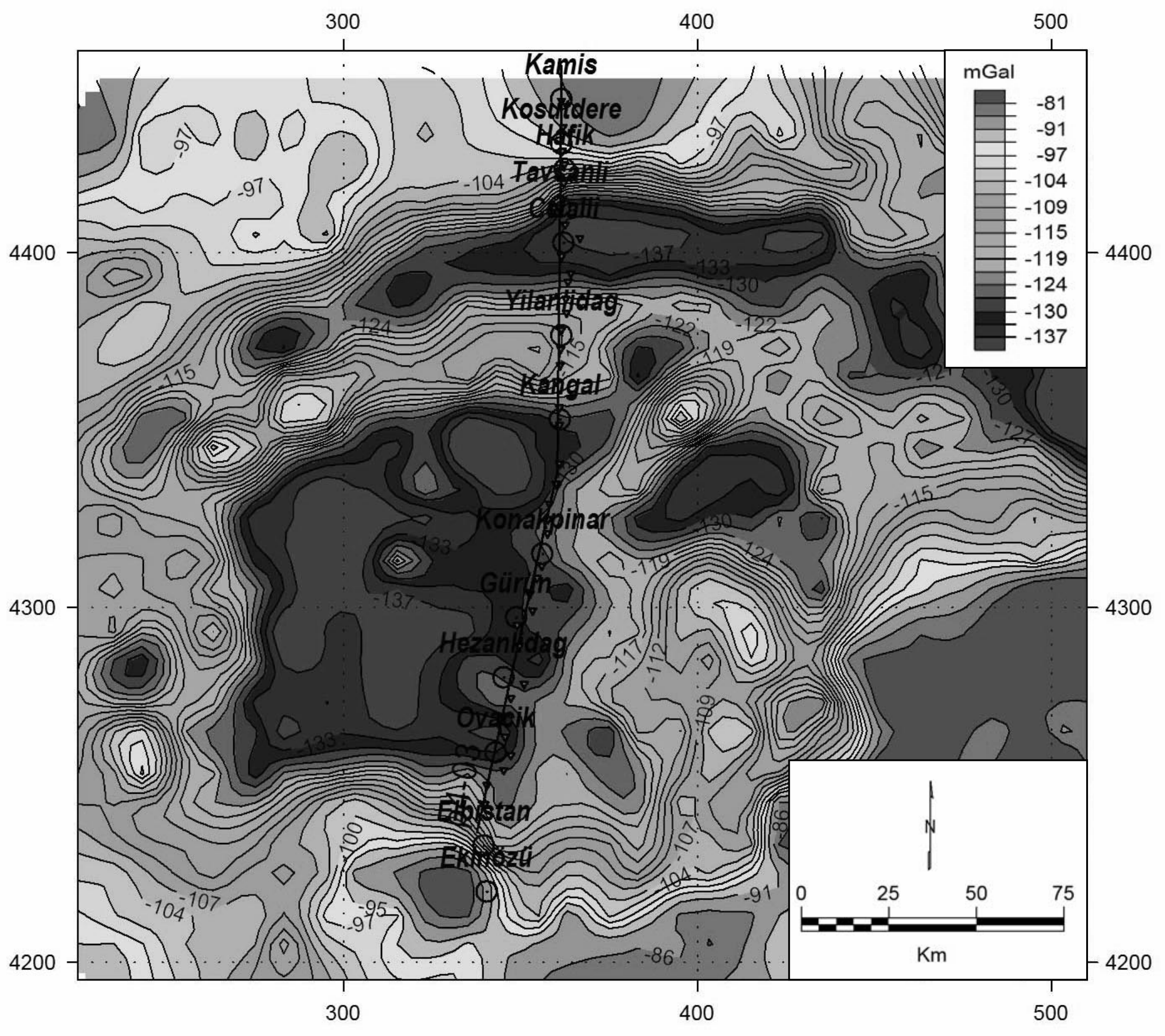

Figure 6. Bouguer anomaly map of study area (MTA 1999).

35 km beneath the Tauride-Anatolide Platform. These high resistivity values define the upper crust and lower resistive values (<981 Ohm.m) are seen below. The layer accepted as lower crust beneath the high resistive zone varies between 10 and 15 km thick and the thickness of the total crust is approximately 45 km in the Pontide Magmatic Arc, Kırşehir Massif and Tauride-Anatolide Platform. These values correspond well with the average crustal thickness (45–47 km) in this region proposed by Zor *et al.* (2003).

The boundary between the lower and upper crust is not seen beneath the Ankara-Erzincan Suture and the Divriği-Pınarbaşı Ophiolitic Belt and the base of these low resistive (or relatively conductive) zones (<981 Ohm.m) is imperceptible. Enhanced conductivity in the lower crust is most commonly explained by the presence of interconnected fluid phases as brines or partial melts (Hyndman & Hyndman 1968; Shankland & Ander 1983; Gough 1986; Jones 1987) or as carbon films on grain boundaries (Duba *et al.* 1989; Frost *et al.* 1989;

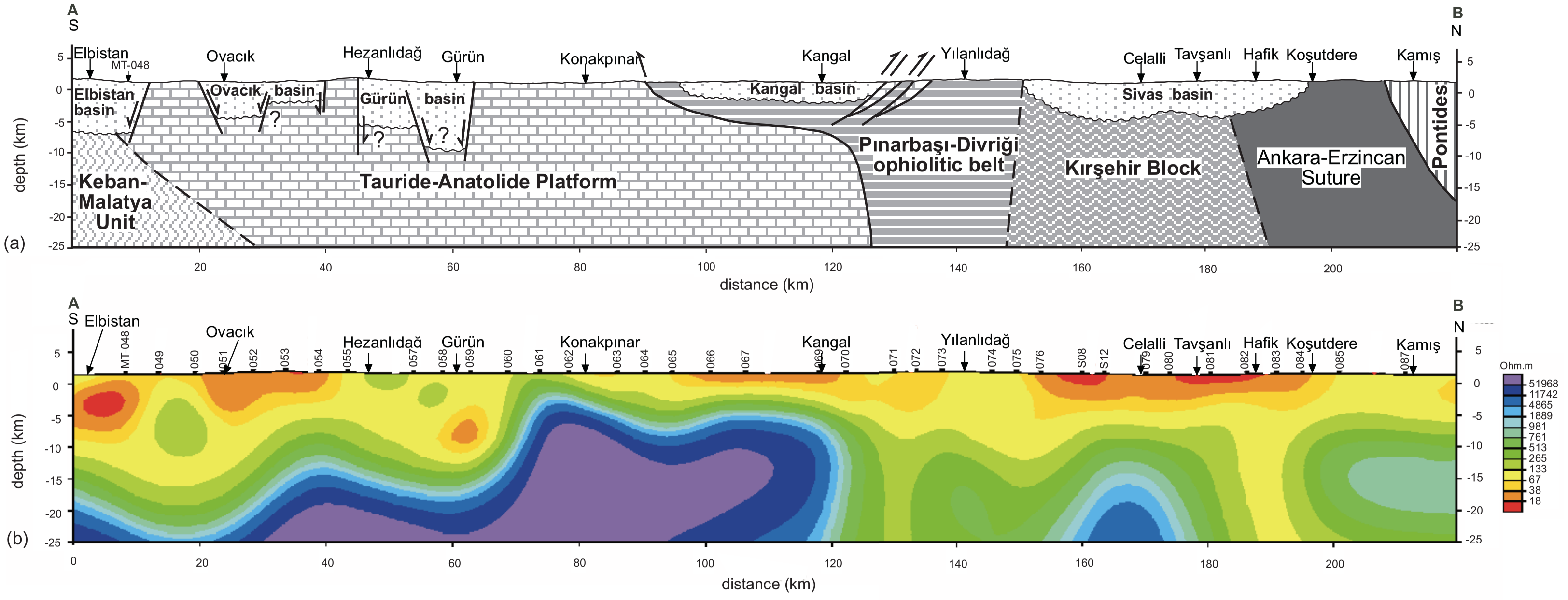

Figure 7. (a) Geological cross-section. (b) Final MT geoelectrical resistivity model obtained by 2-D inversion. The uppermost 25km is illustrated on figure.

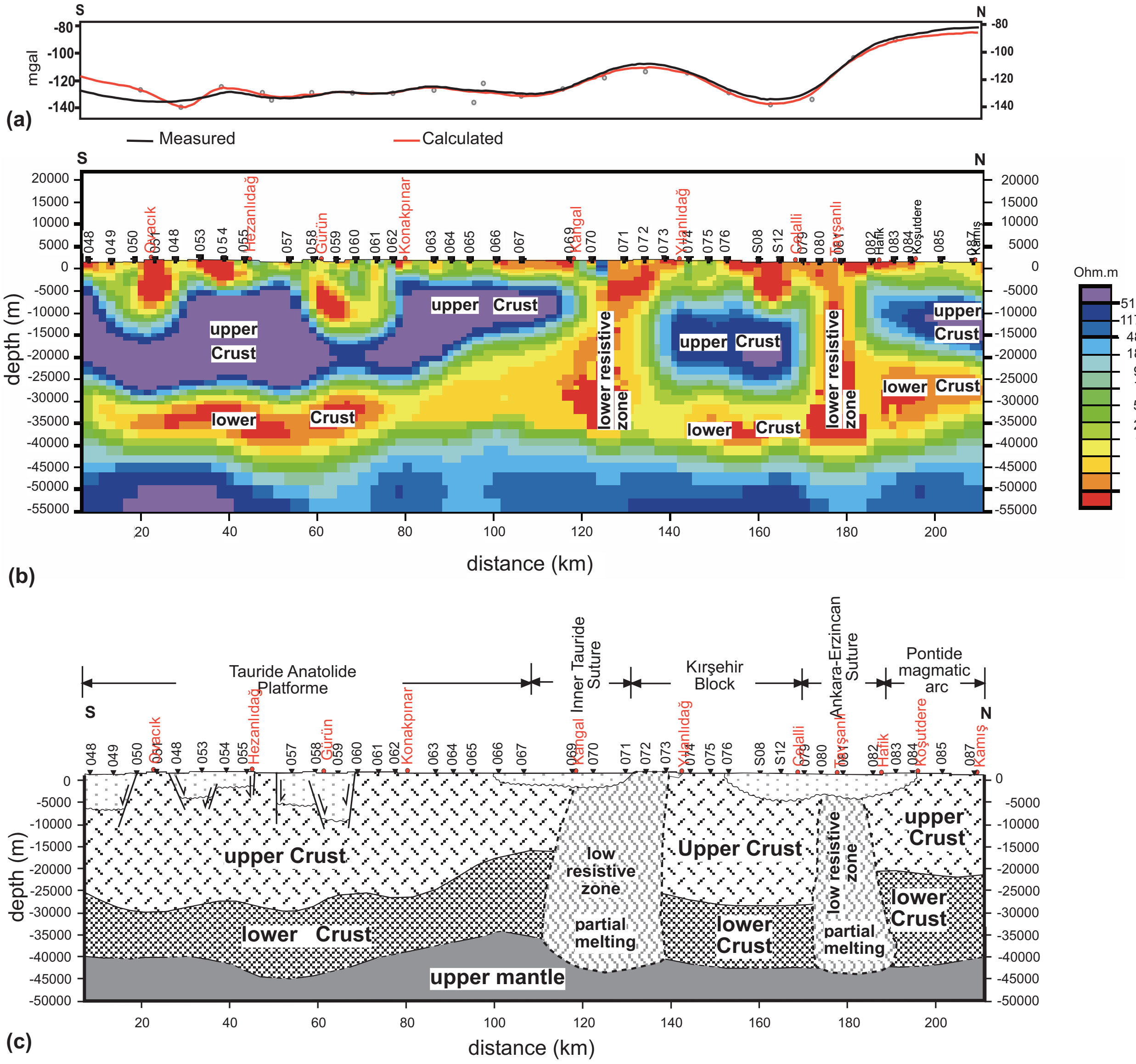

Figure 8. (a) Calculated and observed gravity anomalies for entire crustal model along MT section. (b) The entire crustal model data sensitive to resistivity structures to 65 km obtained by 2-D inversion of MT data and 2-D forward modelling of gravity data. (c) Interpretive cross section based on electrical resistivity of MT profile and gravity data.

Mareschal 1990; Haak *et al.* 1991). Quaternary volcanic rocks, seen in a geological columnar section of the Ankara-Erzincan Suture (Figure 3) can be considered as evidence of partial melting. Pliocene volcanism in the Divriği-Pınarbaşı area is also a product of partial melting (Alpaslan *et al.* 2004) and Keskin *et al.* (1998) report volcanic activity as products of post-collisional crustal melting related to rapid regional block uplift in eastern Anatolia. Aydın *et al.* (2005) have presented a Curie point depth map of Turkey and note that shallow depths in the Curie-point depth map generated by spectral treatment of aeromagnetic data correlate well with young volcanic areas and geothermal potential fields and also with heat-flow highs. There are two areas with shallow Curie depth in our study area on their map. One is south of Sivas and corresponds approximately to the Divriği-Pınarbaşı Ophiolitic Belt and the other is north of Sivas and coincides approximately with the Ankara-Erzincan suture.

Partial melting and the presence of geothermal fluids may therefore be responsible for the enhanced conductivity of the lower crust in these regions.

MT studies have successfully imaged anomalies of enhanced electrical conductivity associated with modern, Mesozoic, Palaeozoic and Early Proterozoic subduction zones at various locations around the globe, and electromagnetic images of subduction zones and collisional orogens show greatly enhanced conductivity, by one or two orders of magnitude, compared with the host medium (Jones 1993). These anomalies have been interpreted as due to either saline fluids generated by dehydration reactions in subducting oceanic plates, or by fluids expelled from subducting sediments (Jones 1993).

Two conductive zones determined in this study correspond to the Ankara-Erzincan suture and the Divriği-Pınarbaşı Ophiolitic Belt. There is a consensus about the Late Palaeozoic and Early Tertiary collisional origin of the Ankara-Erzincan suture (Okay & Tüysüz 1999) but two alternative explanations have been proposed for the origin of the Divriği-Pınarbaşı Ophiolitic Belt. Either these ophiolitic rocks belong to the Maastrichtian–Eocene Inner Tauride Suture (Demirtaşlı 1977; Şengör & Yılmaz 1981; Koçyiğit 1990; Gökten 1993; Gökten & Floyd 1987; Andrew & Robertson 2002; Clark & Robertson 2002), or the Divriği-Pınarbaşı Ophiolitic Belt is a rootless ophiolite that belonged to the northern branch of the Neotethys before being displaced southwards (Kelling *et al.* 1989; Cater *et al.* 1991; Yılmaz *et al.* 1993; Göncüoğlu *et al.* 1996–1997). The electromagnetic image of the deeper structure beneath the Divriği-Pınarbaşı Ophiolitic Belt is similar to the Ankara-Erzincan suture and supports the existence of the Inner Tauride Suture. Besides, high gravity anomalies are consistent with high conductive zones along MT profile (Figure 8), and this makes it less likely that high conductivity in these zones results from high porosity/permeability of neotectonic zones in the area. The nappes exposed in the Divriği-Pınarbaşı Ophiolitic Belt at the south of Yılanlıdağ are sub-horizontal, whereas the high conductive zone beneath them is steep. These ophiolite nappes correspond to the leading edge of the obducted ophiolites, but their root zones may be located further north. Thrusting is represented by ramp and flats. The initial geometry of the thrust surfaces has been modified in later stages of the collisional period and steepen in the root zone. Similar structures have also been reported from the Alps (Rosenbaum & Lister 2005; Ortner *et al.* 2006; Lüschen *et al.* 2006).

As a result, the main geotectonic units in the eastern part of central Anatolia, from north to south are identified as the Pontide (Pontide Magmatic Arc and Tokat Massif), the Ankara-Erzincan Suture, the Kırşehir Block, the Inner Tauride Suture and the Tauride-Anatolide Platform. The Sivas Basin developed on the Kırşehir Block and the basement of the Kangal Basin is the Inner Tauride Suture. The Gürün, Ovacık and Elbistan Basins were developed on the Tauride-Anatolide Platform.

Acknowledgements

This study includes results of the Master's thesis by Sevda Özel (Özel 2005) and was financially supported by Cumhuriyet University Research Foundation (project number of M-251, CUBAP). The authors wish to thank the General Directorate of Mineral Research and Exploration (MTA) for the MT data analyzed in this research, which came from Earth Crust Project of Turkey (ECPT), and Cemal Kaya for his interpretation of this MT data and fruitful discussions. Special thanks go to Ali Yılmaz for valuable suggestions, criticism and drafting throughout the study and to Süha Özden for discussion and valuable contributions. We are also grateful to John D.A. Piper for his assistance in improving our English text and the referees and Erdin Bozkurt for their constructive reviews that improved the quality of the present manuscript. John A. Winchester edited the English of final text.

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Received 02 July 2006; revised typescript received 12 February 2007; accepted 29 March 2007