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THE AIRBORNE MAGNETIC SIGNATURE OF GÖKOVA GULF

Uğur AKIN[a,*] and Ahmet ÜÇER[a]

[a] *General Directorate of Mineral Research and Exploration (MTA), Department of Geophysical Research, 06800, Ankara, Turkey*

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ABSTRACT

Gökova gulf situated in the Aegian extension zone in Turkey has been considered very interesting for numerous research workers. Gökova gulf is located in the N-S regional extentional tectonic regime. N-S extension of western Anatolia initiated development of E-W extended grabens here. The bay extends 100 km E-W and 25 km N-S directions. Datça peninsula is in the south, Bodrum peninsula is located in the north of the Gökova gulf.

In recent years ‘Full Tensor Gradiometer Potential Field’ methods (FTG) has found a practice area in between the gravimetric and magnetic methods. In the past as it was in the gravimetric methods vertical component of the magnetic field measurments used to be recorded. In recent years total field (x, y, z components) measurments have become more applicable. This method has been applied to the airborne magnetic field data. Total magnetic data components of the airborne survey have been calculated and FTG method has been used. Gökova gulf is seismicly very active. There is a magnetic anomaly recorded in the Gökova gulf. To be able to bring a new outlook to the geology of the bay, the magnetic anomaly has been analysed by using ‘Full Tensor Magnetic Gradiometer’ (FTG) method. At first T_x, T_y, T_z magnetic field components of the airborne anomaly have been calculated. To the calculated components T_{xx}, T_{xy}, T_{xz}, T_{yy}, T_{yz}, T_{zz} derivatives have been applied to have an impression of the geological feature causing the anomaly. The anomaly in the bay indicated that ultramafic rocks, ophiolitic melange in the Datça peninsula continue under the sea to the Gökova gulf. Data indicate that northern boundary of the peridotites continues up to about 9 km to the northern coast of the bay. The method is considered to be useful to help mapping of the geological features with different magnetic sensitivities.

1. Introduction

Airborne magnetic data collected during 1978-1989 have been used in this work to study the geological feature causing a magnetic signature under the sea in the Gökova gulf in the south western Turkey. Airborne magnetic anomalies of the ultrabasic rocks, Upper Cretaceous ophiolite melánge present in the area assisted to the understanding of the airborne magnetic signature in the bay. Using the magnetic data extension of the geological units, position and geometry have been studied. Data of the total magnetic field tensors (T_x, T_y, T_z) have been calculated.

In recent years with the technological developments correct and reliable measurement techniques have been developed in potential methods. In recent years full tensor gradiometer measurements on moving platforms became applicable in gravimetric methods.

Traditional total magnetic field studies for mineral and oil explorations have been compared with the

* *Corresponding author: U. AKIN, ugurakin11@gmail.com*

magnetic gradient tensor studies of recent years. Many workers claimed that latter method is more advantages (Christensen and Rajagopalan, 2000; Schmidt and Clark, 2000; Heath et al 2003).

Murphy (2004) associated FTG method with the underground geology. In this association horizontal components (T_{xx}, T_{xz}, T_{xy}, T_{yy} ve T_{xz}) provides information in geological boundaries, vertical component (T_{zz}) provides information on depths of geological features.

Bracken and Brown (2005) using proto type tensor magnetic gradiometer carried out a successful study on buried explosive materials. The result map they prepared showed that the anomalies well coincided on the target object.

Because of the scalar measurements it took some time, new generation potential field studies to be accepted as such. FitzGerald et al (2006) in his studies used randomly selected complex appearing data group so helped developing the method.

Murphy (2007), Murphy and Brewster (2007), Murphy and Dickinson (2010) worked with gravity gradient tensor data. They joined all/or certain tensor components together. Purpose of their study was using new tensor models (presentations) to collect data towards understanding extension and orientation of underground geological structures.

FTG is one of the methods applicable to the ground, sea and airborne gravimetric and magnetic studies. Wan et al (2008) used this method to study hydrocarbons in sea, salt domes and complex geological structures.

Rompel (2009) used full tensor magnetic gradiometer method in more then 20 studies during the course of 3 years. He used the method to study some dikes with weak magnetic signals or no magnetism at all.

Mataragio et al (2011) to explore iron oxide minerals in particular, they carried out magnetic method together with airborne full tensor gradiometer method covering 600 km^2 areas in Brazil. By studying positive high amplitude anomalies over the iron ore deposit they worked out lithology and structure of the study area, suggested ground survey for possible new iron ore targets.

2. Regional Geology

Study area is located in the southwest Turkey. Gökova gulf is surrounded by Bodrum peninsula in the north, Datça peninsula in the south and Greek Kos island in the west (Figure 1). The region is under extensional tectonic regime and seismically active, so it continues to be one of the most interesting areas in Turkey. As a result of extensional tectonic activities numbers of grabens such as Büyük Menderes, Gediz, Burdur grabens developed. The Gökova gulf is located in one of this E-W oriented graben.

One of the most noticeable E-W oriented depressions in western Turkey is the Gökova graben

Figure 1- General position of the study area (red circle), (http://www.hgk.msb.gov.tr).

filled up by Aegean Sea. Gökova gulf has developed under the control of E-W oriented normal faults. Offsets of the faults gradually increase from north towards south reaching up to 1 km dislocation on the southern border fault (Görür et al 1995).

In south western Turkey geologically, allocthon masses known as Likya Nappes are located in between the Menders Massif and Beydağları autochthon and were thrusted on to the Beydağları autochthon in Early Langien (Figure 2). Likya nappes are consisted of different rock units developed in different various settings and have thrusted on to each other. Likya nappes have been separated into 5 main tectonic units. They are Tavas nappe, Bodrum nappe, Domuzdağı nappe, Gülbahar nappe and Marmaris nappe. Marmaris ophiolite nappe in general overlies the Bodrum nappe. Tectonic slices of the Marmaris nappe can be seen under the Bodrum nappe and even under the Tavas nappe. Marmaris ophiolite nappe consists of ultrabasic and basic rocks, ophiolite melange and Kızılcadağ melange and olistostrome (Şenel 2007)

Gökova gulf is in the Denizli sheet in the 1/500.000 scale geological map of Turkey. Akın and Duru (2006) carried out heat flow potential study of Turkey. They calculated the heat flow of the study area as 86 mW/m^2. This value is much higher than Turkey's average. Akın and Çiftçi (2011) analysed gravimetric, magnetic and geological data of the region. They showed that gravimetric and magnetic discontinuities run along NE-SW (30^o-60^o) directions, geological discontinuities also have equal affect on NW-SE and NE-SW directions.

3. Geophysics Applications

Mineral Research and Exploration General Directorate (MTA) carried out airborne magnetic surveys in 1978-1989 periods to study general geological settings, tectonic positions and mineral resources of Turkey. During these 11 years period flights covered 460000 km at 610 m altitude. At the end regional airborne magnetic map of Turkey was prepared (Ateş et al 1999, Aydın et al 2005). Flight lines were 1-5 km spaced. IGRF magnetic corrections have been applied to the measurements. During the airborne survey topography and geology of the country were taken into consideration.

Before FTG studies carried out, total airborne magnetic field measurements for the Gökova gulf were reduction to the pole during data processing (Figure 3).

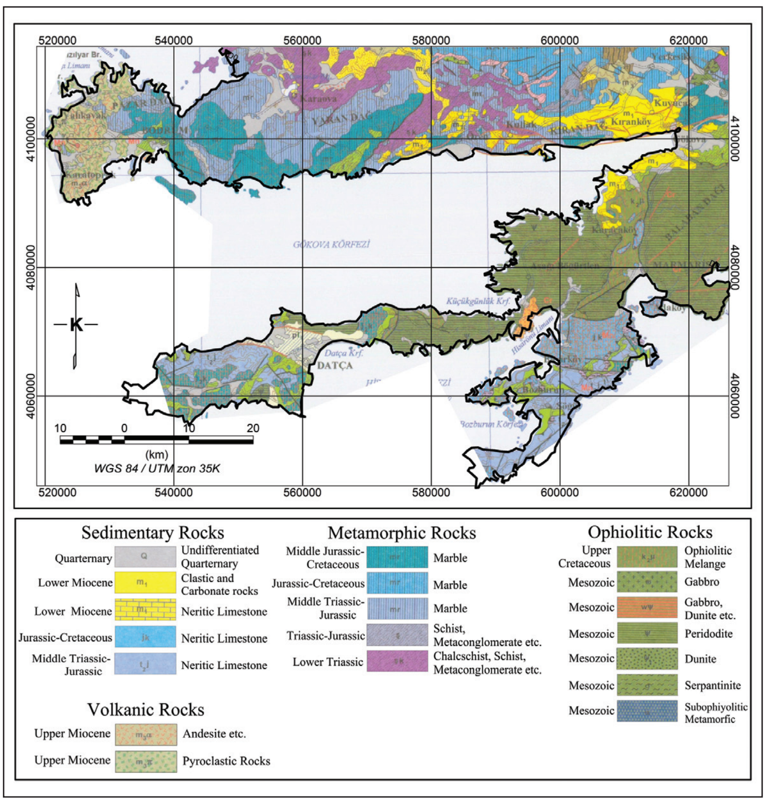

Figure 2- Geological map of the area (MTA, 2002).

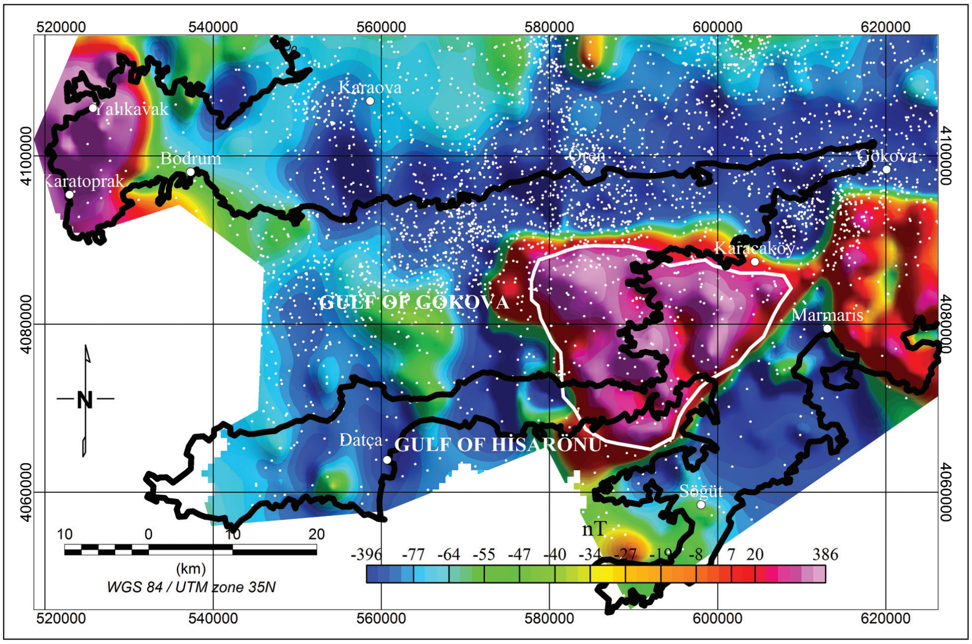

Figure 3- Reduction to the pole=RTP and earthquake epicentre map marked with white spots. Earthquakes with magnitudes greater than 3 took place since 1919. Earthquake data have been obtained from the Boğaziçi University, Kandilli Observatory, Earthquake Research Centre

In the RTP map there are 3 distinct anomalies. First anomaly is located in the NW on the Upper Miocene andesites and pyroclastics in Yalıkavak. The western part of the anomaly is not closed as it is outside Turkey's boundary and has not been flown. Second anomaly (patchy) is in the east of Marmaris and is on the Mesozoic peridotites. The third anomaly which is the subject of this work has 25 km long wave lengths along EW and NS directions (Figure 3). Almost half of the anomaly is on the land on the Mesozoic peridotites. On these peridotites high susceptibility values have been measured in between $8x10^{-3}$ ile $16x10^{-3}$ SI.

Gökova gulf is covered with up to 2.5 km thick Miocene-Pliocene sediments (Kurt et al 1999).

In recent years the region started displaying high seismicity. In Gökova gulf, in the study area 3497 earthquakes have been recorded since 1919. Epicentres of the earthquakes with magnitudes higher than 3 is calculated to be 14.8 km deep. 178 of these earthquakes coincides with the ophiolites. Again the anomalies with higher than 3 magnitude have 32.5 km epicentre depth.

Study area is about 4968 km^2, the ophiolite anomaly is 471 km^2 area, this is about 10% of the study area, 5% of the earthquakes are on this ophiolite anomaly (Figure 3).

The other interesting thing is 88% of the earthquakes took place in the last 10 years. This shows that in recent years seismicity in the area increased considerably.

Reduction to the pole magnetic data's field components along *x, y, z* directions have been calculated with the return path (T_x, T_y ve T_z). Tensors position in a fixed coordinate system along *x, y, z* is presented (Figure 4).

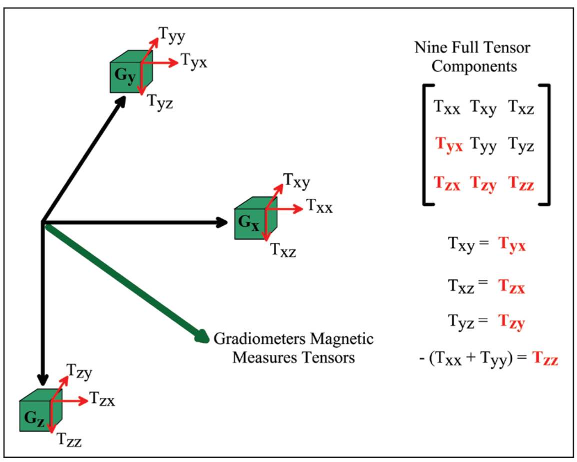

Figure 4- Tensor presentation.

• T_{zz} tensor location of the target mass,

• T_{xx} and T_{yy} tensors bordering north/south and east/west end of the target mass,

• T_{xz} and T_{yz} tensors along with defining central axis's of the target mass, definition of faults from heights and sharp drops,

• T_{xy} brings out anomalies near to the centre of the mass (Figure 4),

T_{xx} tensor divided the anomaly into parts as negative and positive. This anomaly at the same time borders the ophiolite in the east and west sides (Figure 5).

T_{xy} tensor divides the anomaly along SW-NE; division strength along NW-SE is not very definite (Figure 6).

Grey line marks the boundary of the ophiolite anomaly. T_{xz} tensor divides the ophiolite anomaly into two from the central axis along east/west direction (Figure 7).

T_{yy} tensor divides the anomaly into two as negative and positive parts. This anomaly also borders the ophiplite in the north and south. But T_{yy} division is not as clear as T_{xx} tensor's (Figure 8).

T_{yz} tensor, grey line marks the ophiolite anomaly's boundary. This anomaly is divides into 2 as north and south (Figure 9).

T_{zz} tensor clearly marks the ophiolite boundary, marked with grey line (Figure 10)

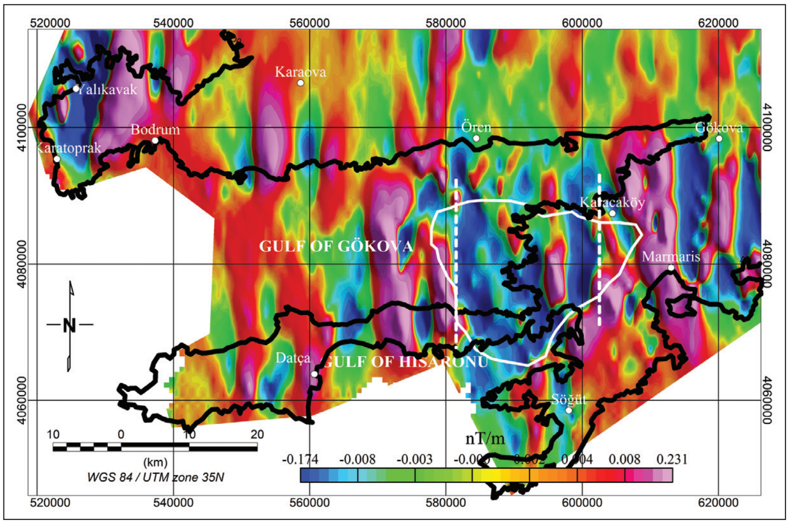

Figure 5- FTG T_{xx} map

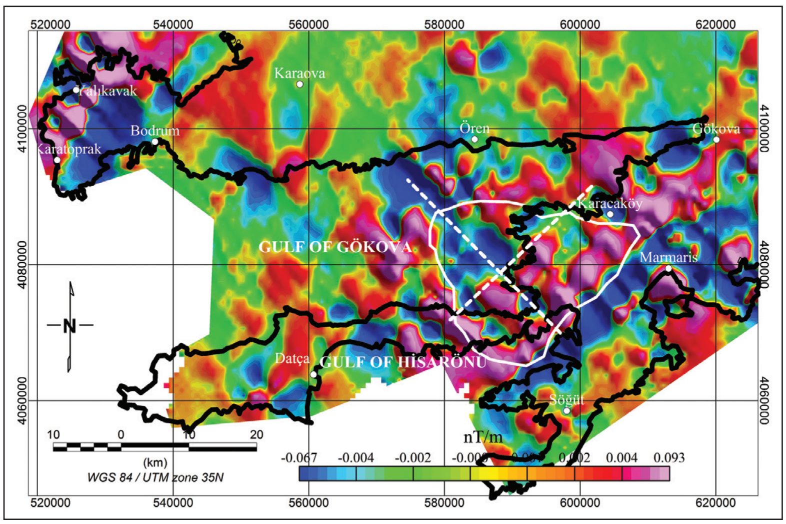

Figure 6- FTG T_{xy} map.

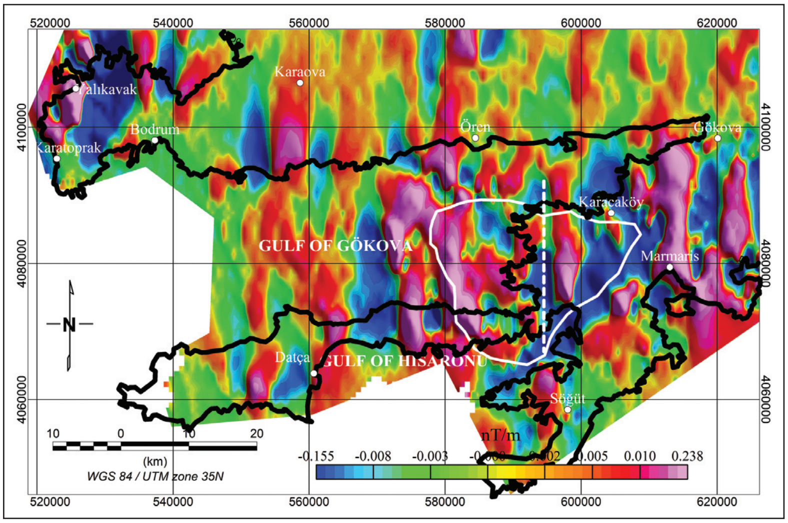

Figure 7- FTG T_{xz} map.

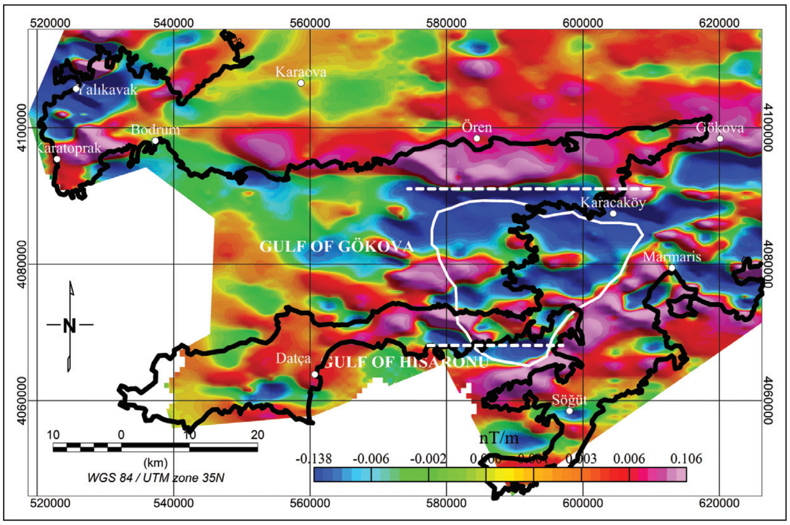

Figure 8- FTG T_{yy} map.

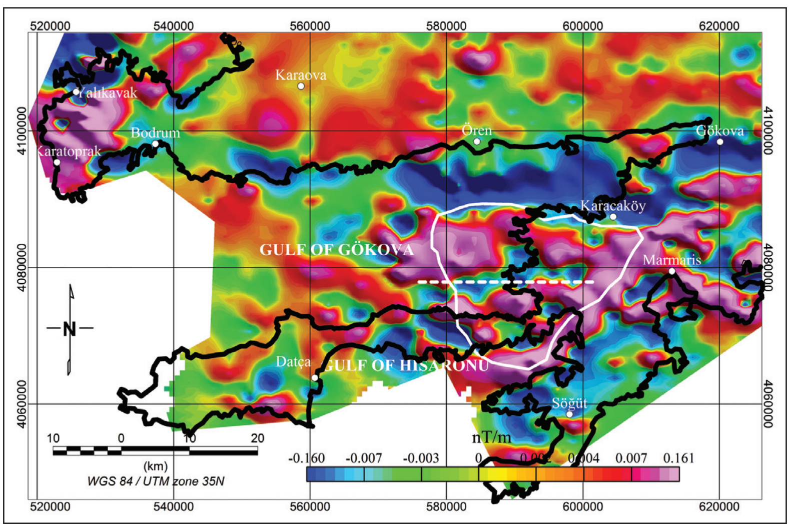

Figure 9- FTG T_{yz} map.

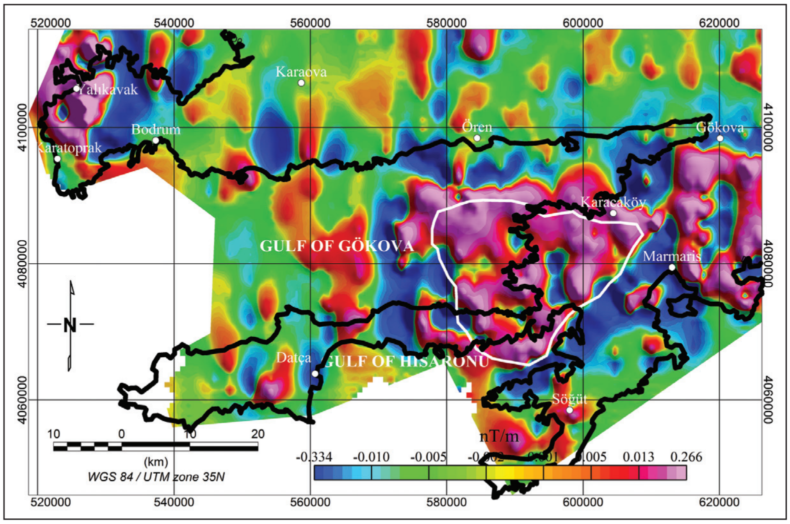

Figure 10- FTG T_{zz} map.

Rotational constant 1(R_1) and rotational constant 2 (R_2) were defined for the first time by Pedersen and Rasmussen (1990). In this study these constants have been calculated. To calculate R_1 and R_2 rotational constants T_{xx} T_{xy} T_{xz} T_{yy} T_{yz} ve T_{zz} maps (Figures 5, 6, 7, 8, 9, 10) have been used.

$$R\_1= ((T_{xx}T_{yy}+T_{yy}T_{zz}+T_{xx}T_{zz})-(T_{xy}^{\ 2}\,T_{yz}^{\ 2}+T_{zx}^{\ 2}))^{1/2}$$

$$R\_2= ((T_{xx}\,(T_{yy}T_{zz}-T_{yz}^{\ 2})+T_{xy}\,(T_{yz}\,T_{xz}\ -\ T_{xy}\,T_{zz})+T_{xz}\,(T_{xy}\,T_{yz}-T_{xz}T_{yy}))^{1/3}$$

R_1 rotational, made shape and borders of the small intrusions more distinct. Three small intrusions have been recognized within the circle defining main body of ophiolite unit (Figure 11).

In Figure 12, R_2 has been calculated. R_2 rotational brought out shapes of very small structures. In Figure 12 presence of ophiolite mass has been made more distinct.

By using data in Figure 12 shallow structures on the main structure with short wave lengths have been made more distinct with the calculation of 1st degree derivative (Figure 13). Main body is within the ophiolite boundary. 1st vertical derivative of the R_2 rotation has separated shallow small structures from deep main target mass.

4. Conclusions

There is an airborne magnetic anomaly in the Gökova bay. Meaning of this anomaly has been

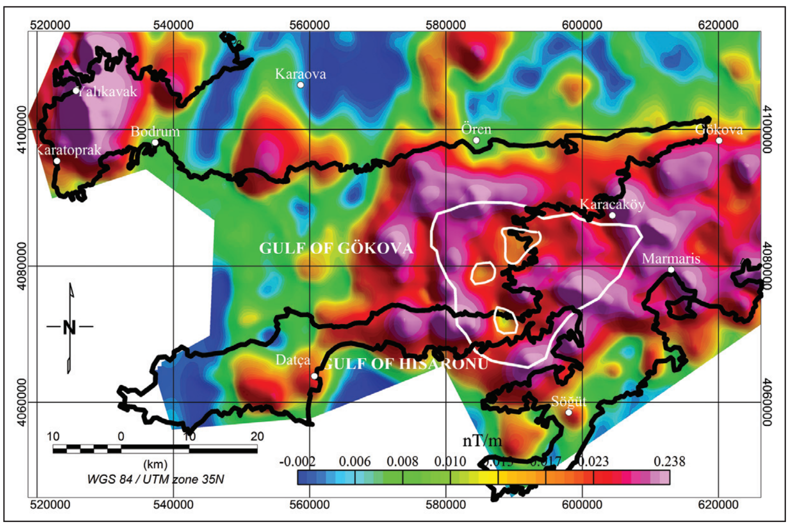

Figure 11- R_1 Rotational map.

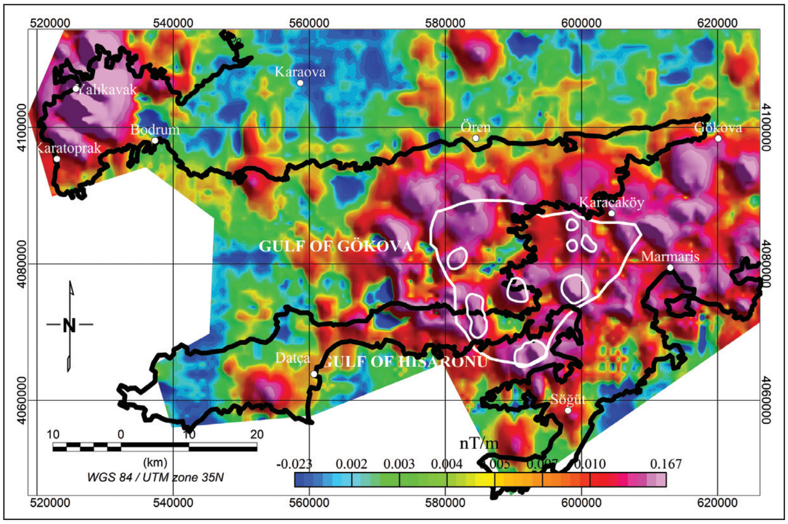

Figure 12- R_2 Rotational map.

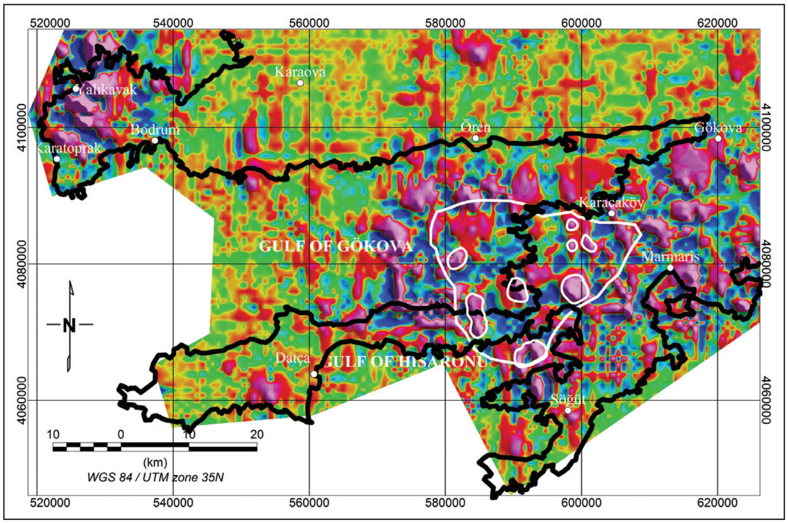

Figure 13- 1st vertical derivative map of the R_2 rotation

analysed in this work. Total airborne magnetic anomaly has been studied by applying FTG method. The anomaly represents continuation of the Marmaris ophiolite nappe in the gulf.

There are two distinct anomalies in the RTP map in Figure 3. The anomaly in the west (the one in the gulf) closes in itself. The anomaly in the east is extending beyond Turkey's frontier, so meaning of it has not been analysed.

We carried out some power spectrum studies (unpublished study), according to the findings of this study, in the study area there is about 2 km thick sediments lying on the top. Under this sedimentary unit Marmaris ophiolite nappe with 5-6 km thickness is located.

Magnetic field components (T_x, T_y, T_z) have been calculated. Following conversions, in the components' (T_{xx}, T_{xy}, T_{xz}, T_{yy}, T_{yz} ve T_{zz}) maps strong negative and positive contrasts have become noticeable. With the FTG method amplitudes and sharpness of the anomalies have become important. Prepared FTG maps showed that covered geological structure in the Gökova gulf caused the subject anomaly.

In western Turkey numbers of grabens developed as a result of N-S extensions in western Turkey. In the Gökova gulf, like in many others, extension developed. It is 100 km long along EW and 25 km long along NS directions.

In recent years seismic activities in the Gökova gulf increased considerably. It is understood that many of these seismic activities, recognizable as magnetic anomalies which have developed along the borders of the ophiolite unit. With the FTG method borders of ophiolite units and tectonic belts have been identified. Earthquake epicentres are mainly located along the borders of the ophiolite units and beyond. There is not any tectonic activity in the ophiolite itself. It is pointed out that as earthquakes occur in the ophiolite border zones and in the parts beyond it, so these parts are tectonically active zones.

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