Aeromagnetic modelling of a compressional contact between the Ionian and pre-Apulian zones, Ionian Islands, Greece

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Abstract: *Compressional tectonics and westward directed thrusting took place in western Greece since upper Oligocene times. In addition to that, clockwise rotation has affected the area. The question then arises whether the sedimentary cover alone or the basement as well is affected by these displacement modes. Qualitative interpretation of aeromagnetic maps (a 100 km residual of the reduced to the pole magnetic anomaly map together with the horizontal gradient of the 50 km residual) and two-dimensional quantitative modeling along a magnetic profile are in support of the "basement" deformation which should be taken to represent a valid hypothesis in the deformation history of western Greece.*

Key words: *Aeromagnetic, Compressional tectonics, Ionian Islands, Greece.*

INTRODUCTION

Northwestern Greece has been subjected to a large-scale compressive regime since the Upper Oligocene. This zone of continental collision is considered to be the northwestern portion of the Aegean arc, evidenced by the gradual shallowing of the earthquake foci from 150-200 km under the Aegean Sea to the surface in the Ionian Islands (Kissel et al., 1985; Beck et al., 1994). Three main phases of compressional tectonic activity have been recognized. They occurred during the Middle Miocene (Late Burdigalian), the Lower Pliocene and the Lower Pliostocene. The three phases are characterized by a westward migration: during the Middle Miocene the main compressive front was situated to the east of the Ionian Islands, in the Ionian zone, while the Pliocene and Quaternary phases have mainly affected the Ionian islands. This complex tectonic history has resulted in the development of overthrusts, large elongated structures, and synclines and anticlines with horizontal axes, some of which are over a hundred kilometres in length. As indicated by extensive palaeomagnetic studies a two-step rotation process has taken place in the region, which accounts to a total of 45^{o} clockwise rotation of the entire region (Kissel et al., 1984). As a result, a horizontal displacement of at least 100 km was inferred (Kissel et al., 1985). Deformation in the sedimentary cover is characterized by successive eastward dipping foreland-vergent thrusts. New thrusts have been formed in the footwall of previously formed thrusts. This happened during the propagation of the orogenic front westwards to the foreland of the Fold and Thrust Belt.

The question whether the sedimentary cover alone or the basement as well is affected by the deformation is discussed in the present study.

GEOPHYSICAL DATASET

Aeromagnetic maps produced by LCT during the First Licensing Round in western Greece in 1997 were made available by TRITON Hellas. A 120 m modified drape elevation was reported for the aeromagnetic survey. Total magnetic field is 45488 nT with inclination of 54.52^{o} N and declination 3.12^{o} E.

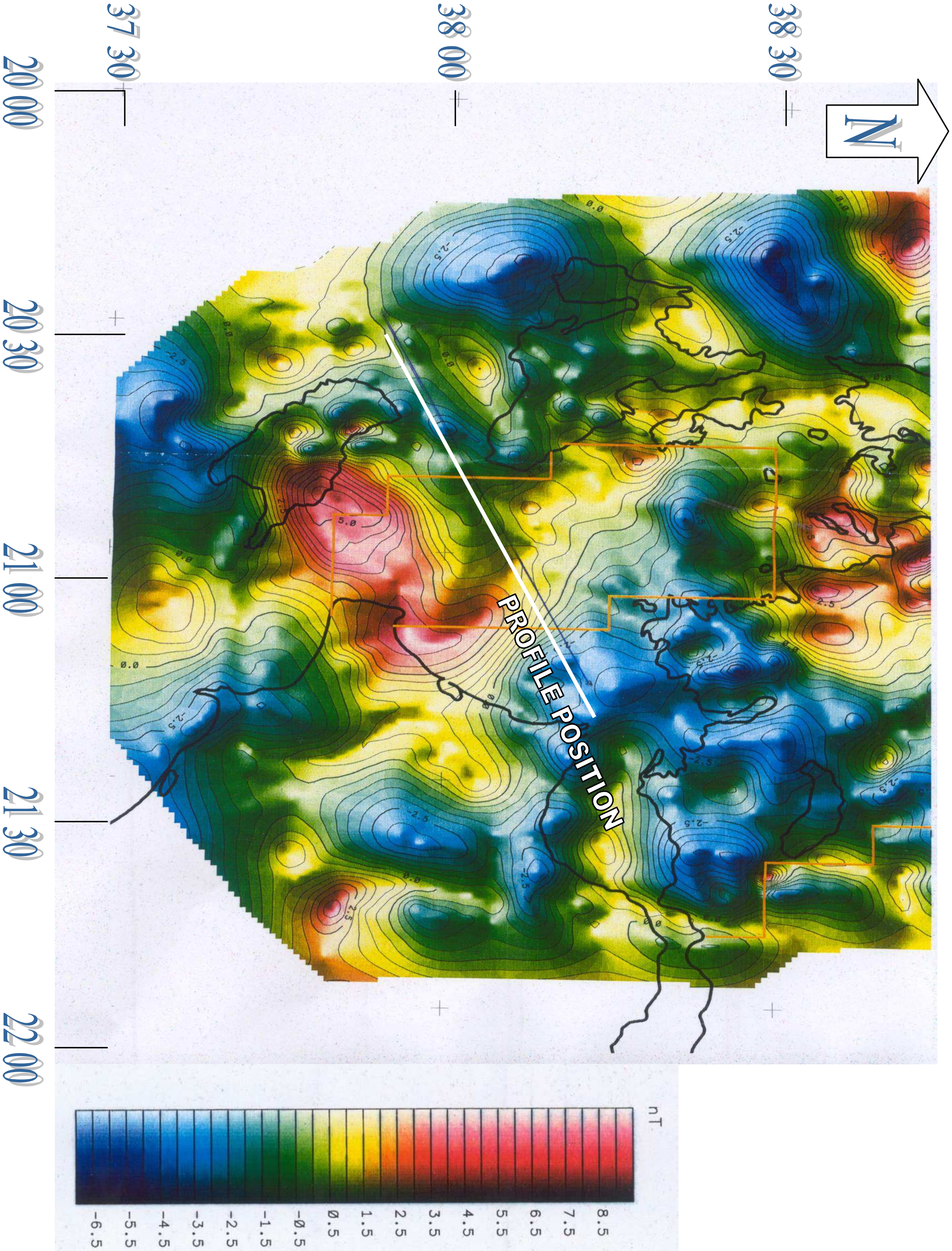


Fig. 1: 100-km residual magnetic anomaly reduced to pole contour interval 0,5 nT.

A 100 km residual of the reduced to the pole magnetic anomaly map is shown in Figure 1 together with the horizontal gradient of the 50 km residual (Fig.2). These processes are performed to represent the structures associated with a major compressional tectonic zone occurring in the contact area between the Ionian and Pre-Apulian zones in depth. (Kissel et al., 1986; Kamberis et al., 1996).

The original total intensity magnetic anomaly map at contour interval of 2nT is dominated by a minimum at zero which is located approximately 30 km to the west of the mid point between the islands of Kefallinia and Zakynthos. Magnetic field contours are parallel in the NW-SE direction with values that increase eastwards at an average rate of approximately 2 nT for every 5 km.

The 100 km residual magnetic anomaly reduced to the pole (Fig. 1) is contoured at intervals of 0.5 nT. A local high of approximately 5.5 nT is located between Zakynthos island and the western coast of Peloponesse whilst a local maximum of 1.5 nT is outlining the same feature along the interpreted profile approximately 20 km to the north (Fig.1 and Fig.3).

The horizontal gradient map of the 50 km residual at contour interval of 0.02 nT shows a local maximum of approximately 0.60 nT in the eastern zone between the islands of Kefallinia and Zakynthos whilst a group of local minima of 0.10 nT is characterizing the area between these islands and the Peloponesse, interchanged with fewer local highs at about 0.40 nT. These values are well above the typical International Geomagnetic Reference Field (IGRF) background (nongeologic level) values of 0.2 to 0.5 nT/m for horizontal gradients, given by the 1975 model for an altitude of 300 m (Hardwick, 1984).

The main focus of this study is the area between the islands of Kefallinia and Zakynthos and to the east, where independent geophysical information exists from a previous geophysical study (Kamberis, et al., 1996).

Aeromagnetic modelling in the contact area between the two zones is carried out along a profile of approximately 80 km running from W-SW, between the islands of Kefallinia and Zakynthos, towards Patraikos Gulf in the E-NE. This profile is chosen to be spatially coincident with the strike of a deep (17 sec two-way travel time) seismic line (STREAMERS). Kamberis et al. (1996) was derived a depth model along the STREAMERS line using interval velocity information from adjacent wells.

The values of the 100 km residual of the reduced to the pole magnetic anomaly map were plotted along the 80 km profile for subsequent aeromagnetic modelling performed by the magnetic software MAGMOD-3 of Patras University. The main function of the optimisation algorithm of MAGMOD-3 is to adjust the parameters of a simple geometrical model of a magnetized body, to give the "best fit" between the observed data and the calculated anomaly of the model. The quality of fit is measured numerically by calculating the weighted sum of squared deviations between the observed data and the model response. For the Tabular 2 model that is used here the weighted sum to be minimized is given by

$$S= SUM(W_i[T_i-(T_o+ax_i)\; f(x_i;x_o;M,Q,i,c,d,h,t,X,Y;I,D,S,P)]^2),$$

where T_i is the observed magnetic anomaly value at the point x_i, T_o is the regional background level for T at x=0 (adjustable), a is the slope of the regional background in the anomaly neighbourhood in the x direction (adjustable).

No such regional was removed because the studied anomaly is considered as a residual anomaly along the profile. This assumption is satisfactory for the size of the structures to study, based on the geological information and previous geophysical modelling.

The other parameters are the theoretical magnetic anomaly value of the interpretation model (*f*), the coordinate of the center point of the upper horizontal surface of

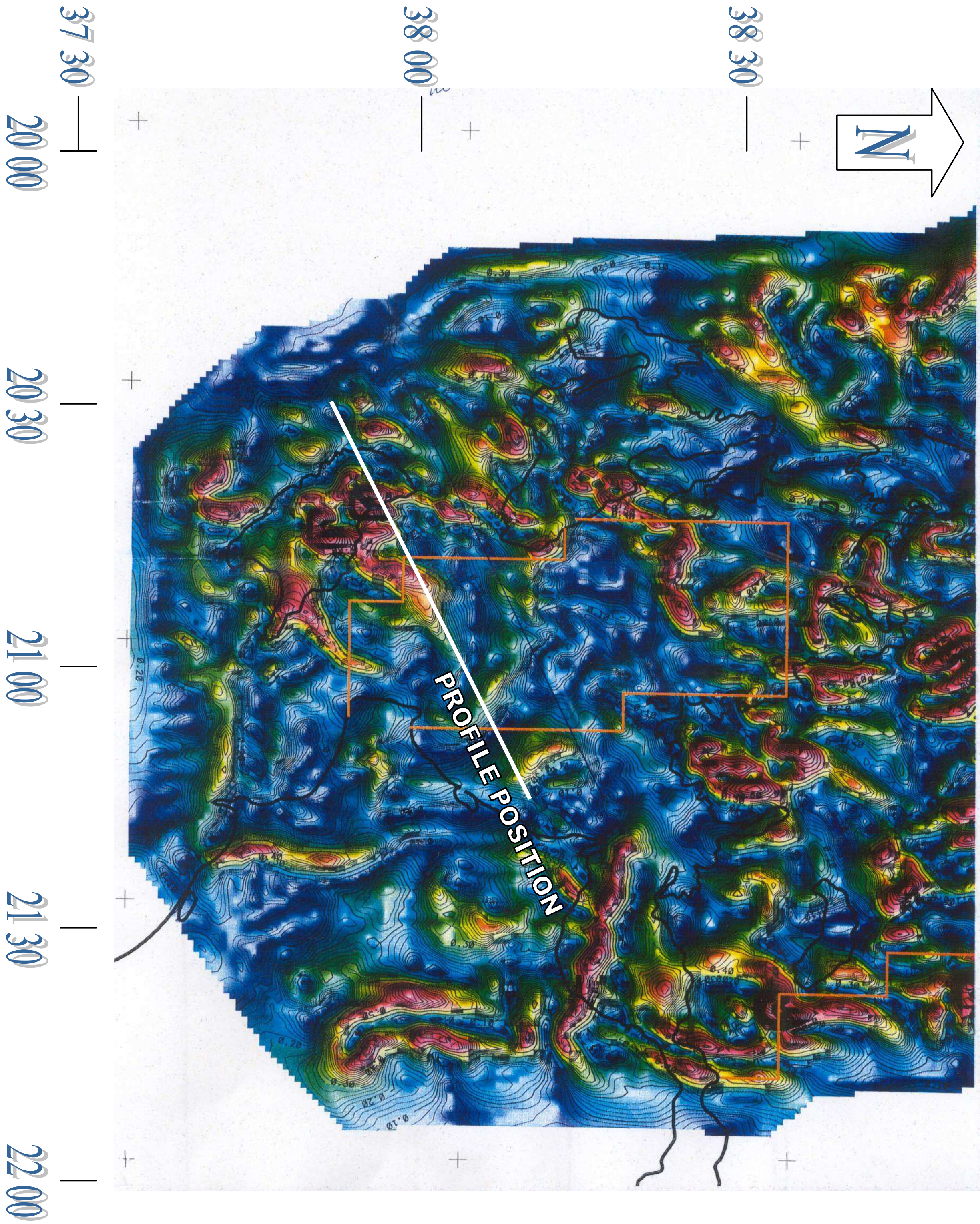


Fig. 2: Magnetic anomaly reduced to pole.
Horizontal gradient of the 50 km residual.
Contour interval 0.02 nT

the body (x_o) (adjustable). w_i is the weight assigned to the observation at x_i.

The adjustable model parameters are magnetisation (M), ratio of remanence to magnetisation (Q) (Koenigsberger Ratio), remanence inclination (i), remanence declination (c), dip (d), depth (h), thickness (t), half-width (X) and half-length (Y). The fixed parameters are magnetic inclination (I), magnetic declination (D), strike perpendicular (S), traverse direction (P).

GEOPHYSICAL RESULTS

The above modelling procedure leads to the following results. A simplified approach of a two-dimensional single body is used to represent the contact area between the two zones. A rectangular body perpendicular to the strike of the profile with its top surface at depth of 8,98 km (Fig. 3) is satisfactory for this purpose. Total body width is 29 km, its thickness 14,3 km and total length of 79 km. Based on the strike of the profile, this body is spatially coincident with the NW-SE strike of the Hellenides in western Greece. Body geometry suggests that the main cause of the magnetic anomaly has its focus from within this rectangular "box".

Scenario (b) by Kamberis et al. (1996) points out the case where basement is involved in the deformation, in which the decollement surface at the base of the Permo-Triasssic sedimentary cover is broken as a result of the westward migration of the deformation. The top surface of our model at about 9 km is considered as representing the decollement level in the area of interference between the tectonic zones. The western flank of the body, when projected, intersects the profile at surface at 22 km from its western origin. This coincides with the point where the eastwards dipping thrust meets the surface (when projected along the profile). The fact that the source of the magnetic anomaly is restricted below a horizontal zone of about 30 km width, is interpreted as representing the basement involvement in the deformation, below the decollement level and down to depth of approximately 23 km. This supports the scenario (b) of Kamberis et al. (1996) being consistent in terms of sediment and basement geometries.

The best fit was obtained when a remanent component as well as the magnetization due to the Earth's induced field is considered. The Koenigsberger ratio was estimated to be 6.63 which corresponds to a Remanent intensity value of $192*10^{-3}$ SI. The computations are as follows

$H = B/\mu_0=(45488 * 10^{-9})/ (4*\pi*10^{-7})= 36,2$ SI,

$I = 0,8*10-3 * 36,2 = 28,96 * 10^{-3}$ SI,

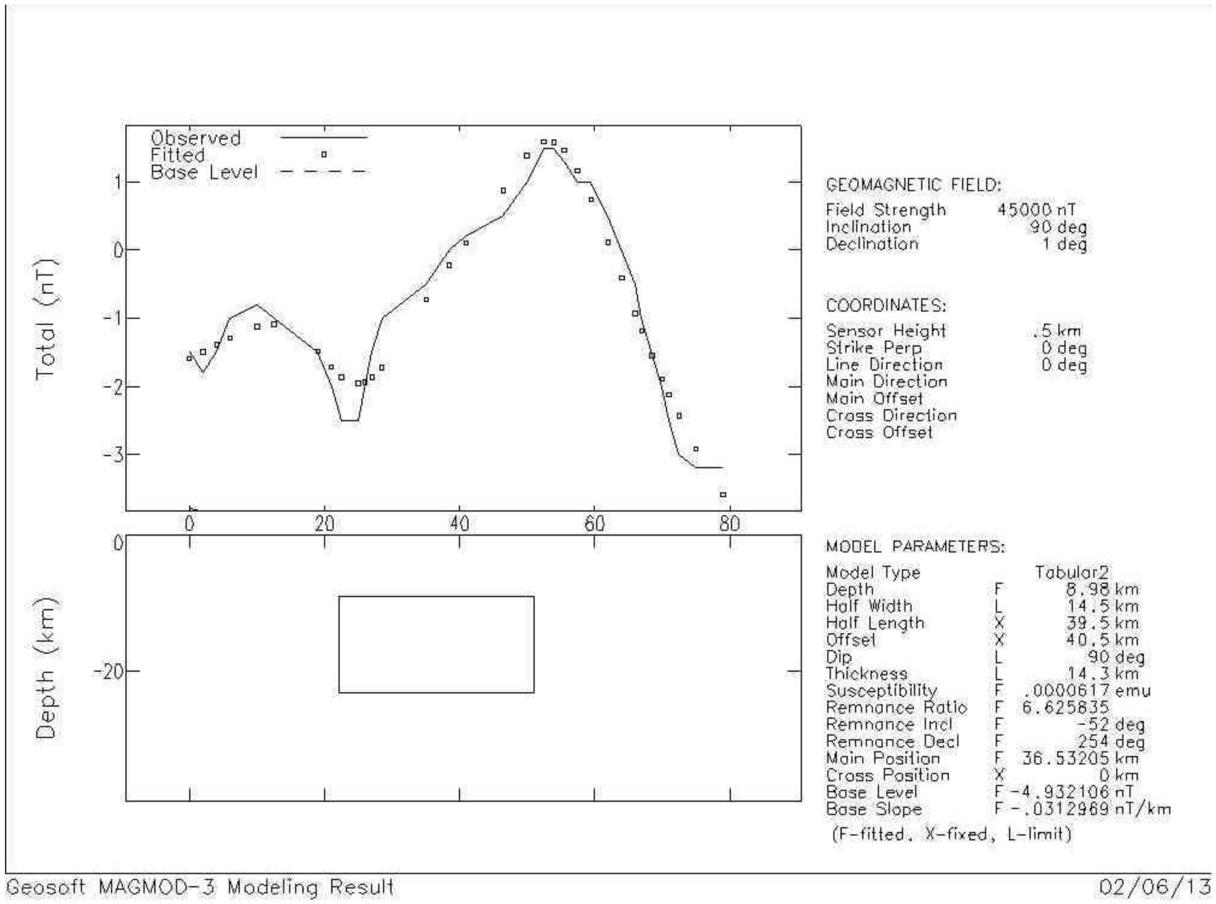
$\text{Remanent} = 6,63*28,96 *10^{-3} = 192*10^{-3}$.

The remanent inclination and declination were calculated to be -52 and 254 degrees, respectively. Negative inclinations in the range of –23 to –82 degrees are reported from the Ionian flysch samples for which NRM intensity ranges between $75*10^{-3}$ to $3*10^{-3}$ SI (Kissel et al., 1985).

The model susceptibility of $62*10^{-6}$ emu or $0.8*10^{-3}$ SI was calculated as a result of the optimisation. This is considered as representing the pre-Miocene basement consisting of gneisses and schist (Maltezou, 1987; Telford, 1976)

In addition, the horizontal gradient map shows its highest values of approximately 0.60 nT at about 30–35 km from its western origin. These are distinctive lineament systems that are interpreted as the continuation of the tectonic compressional contact in the N-S direction on either side of the profile. Horizontal gradient techniques are the most intuitive derivative methods. Vertical geological boundaries separating two homogeneous blocks give rise to horizontal gradients in gravity and pseudogravity (magnetic) data that are steepest directly over those boundaries. This is where the contour spacing of the magnetic field anomalies is least, i.e. the ascent or descent is steepest and therefore the horizontal gradient magnitude is greatest.

Consistent with growing evidence that some hydrocarbon traps may be systematically



controlled by deeper structures in the basement (Jones, 1980; Greggs and Greggs, 1989; Misra et al., 1991; Gay 1994) horizontal gradient can assist in their prediction together with hydrocarbon shows and borehole information existing in the area.

Our view of Western Greece, based on this study is that the magnetic anomalies are sourced in the underlying crystalline basement. Small anomalies may nevertheless occur due to local intra-sedimentary magnetite-rich placers (magnetite is the main magnetic carrier in the Ionian flysch according to Kissel et al. (1986), secondary hydrothermal mineralization and minor igneous rocks above the basement.

Our model and its derived parameters, together with the gradient map strengthen the “basement” scenario that should be taken to represent a valid hypothesis in the deformation history of western Greece.

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