THE ISLAND OF ELBA - NORTHERN TYRRHENIAN SEA AEROMAGNETIC AND GRAVITY DATA

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ABSTRACT

The magnetic maps of the northern Tyrrhenian Sea show anomalies belonging to bodies with high magnetic susceptibility, distributed according to a north-south trend over arcuate belts from the Elba area towards N-NW. A qualitative analysis of the anomalies shows that, among the high amplitude and short wave length anomalies, submarine ophiolites and/or volcanics occur.

The high frequency anomalies connected with the ophiolites show a complex pattern, justified in the tectonic context of the area. Two main belts of ophiolites are identified: the inner (western) belt lies between the Corsica basin and the Capraia, Elba, and Pianosa islands; the external (eastern) one lies between the Gorgona, Elba islands and the Tuscan coast line.

The volcanics consist of magmatic bodies (Miocene-Quaternary). Magnetic anomalies with longer wavelength, lower amplitude and low susceptibility are attributed to the magnetic basement.

Based on the interpretation of the magnetic and gravity data, an appraisal of the tectonics of this area is presented, where both oceanic (ophiolites) and continental affinity crustal units occur, locally intruded by Pliocene granodioritic stocks.

The main SW-NE discontinuities, crossing the Elba ridge and extending to onshore Tuscany, complete the structural framework of this sector of the Tyrrhenian Sea and the contiguous northern Apennine domain, as the result of the Mio-Pliocene and Pleistocene tectonics.

INTRODUCTION

The magnetic survey maps of the northern Tyrrhenian Sea exhibit an area affected by positive anomalies, at times considerably intense, which characterize and divide the area into three specific sectors: eastern Corsica, the Island of Elba and the Apennines offshore.

The quantitative interpretation of the data reconstructs the depth and the present structure of the magnetic basement, identifies the horizontal and vertical distribution of the ophiolitic units, localizes the bodies of the volcanics and the granodioritic batholiths and defines the lineaments of the main fault discontinuities.

In particular, the high intensity magnetic anomalies highlight a central area with a N-S axis, which extends northwards as far as the “Massiccio di Voltri” in the Ligurian Alps. The anomalies are related to both the ophiolitic units and the basement. The latter shows features of relict crust from the Jurassic Ligurian-Piedmont Ocean.

On the whole, the anomalies help to characterize a structure which marks the transition between the Alps and the northern Apennines, in the past referred to as the “Ophiolitic Suture”.

The Neogene volcanic bodies are mainly located along E-W and NE-SW discontinuities. Locally, some magnetically susceptible bodies, especially the granodioritic masses, are characterized by reversed magnetic polarity.

The gravity maps and the interpretation of the relevant data complete and integrate the study of the area.

MAGNETIC DATA

As part of Agip’s project for the plotting of a Magnetic Map of the Peninsula and the surrounding seas, an aeromagnetic survey of the Tuscan Tyrrhenian sector was carried out in 1978, in agreement with Rimin. A high sensitivity magnetometer was used during the survey and measurements spaced according to a 56 m pattern were taken at an altitude of 1,450 m, along a set of survey lines and tie-lines forming a 2x5 km grid (Agip 1982; Cassano et al., 1986).

For the purposes of the Elica Meeting, the data so obtained were reprocessed according to a 2x2 km grid restricted to an area between 42° and 44° Lat. and 9° and 11° Long. (Fig. 1). The map shows a series of high amplitude and high frequency anomalies which develop in a N-S direction, south of the island of Elba, amid a background of lower average frequency anomalies. Another series of equally high frequency anomalies occurs offshore and onshore, to the north of the island.

In order to be able to proceed more confidently to the interpretation of the lower amplitude anomalies as well, the data were “downward continued” to a theoretical elevation of 1,100 m.

At the same time, the map was “reduced to the pole” to give anomalies of the pseudo-gravity type and a position corresponding more clearly to that of the geological elements generating them (Fig. 2).

Since this map confirms the simultaneous presence of anomalies of at least two different wavelengths, two filterings were performed. The first, a band-pass filter with wavelengths between 4 to 40 km, was carried out to highlight the anomalies associated with shallower susceptible bodies of a basically intrasedimentary nature (Fig. 3). The location of the volcanic and ophiolitic elements is clearly defined. The higher amplitude anomalies related to the ophiolites are particularly concentrated in the Tyrrhenian Sea and in Tuscany, in the northern sector of Elba. The lower amplitude anomalies, attributed to volcanic and intrasedimentary bodies, display a curved trend and, given the direct and reversed magnetization, a recent age (Marinelli, 1975; Savelli, 1988; Eriksson and Savelli, 1989). The second filtering, a low pass filter with wavelength <24 km (Fig. 4), mainly shows the trend of the deeper magnetically susceptible formations, probably magnetic basement.

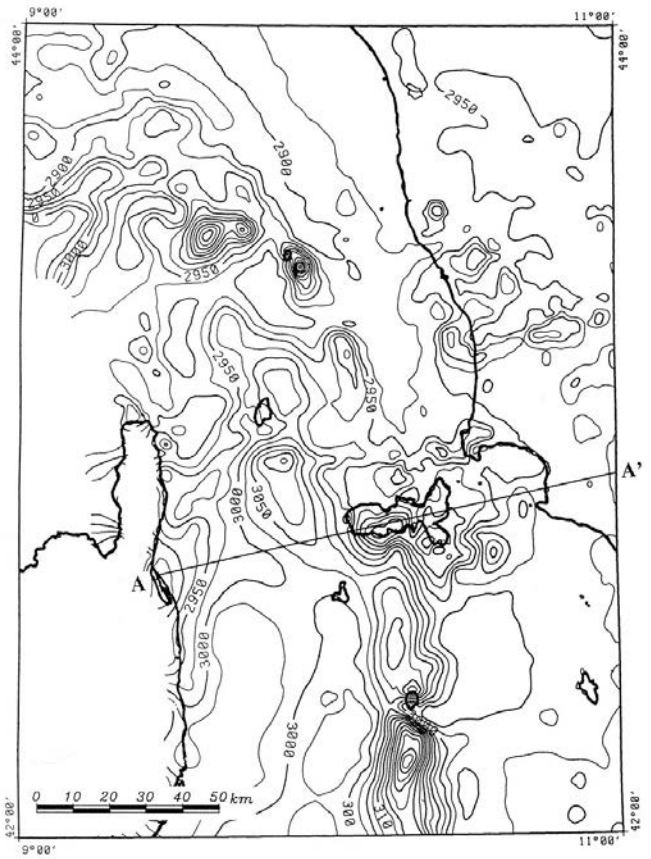

Fig. 1 - Residual Magnetic Field. Flight altitude = 1,450 m a.s.l.; contour interval = 25nT.

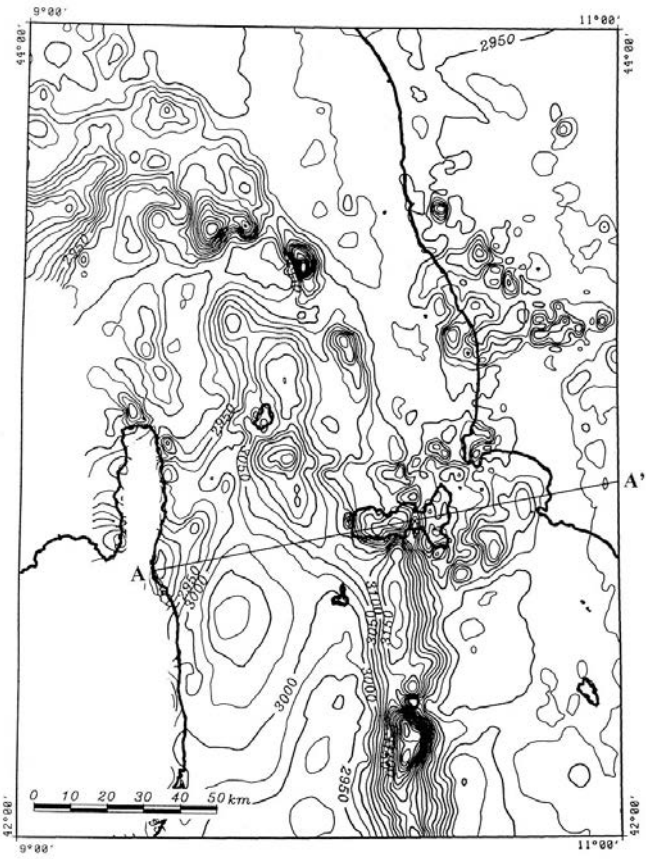

Fig. 2 - Reduced to the Pole on R.M.F. Computed downward at 1,100 m a.s.l.; contour interval = 25nT.

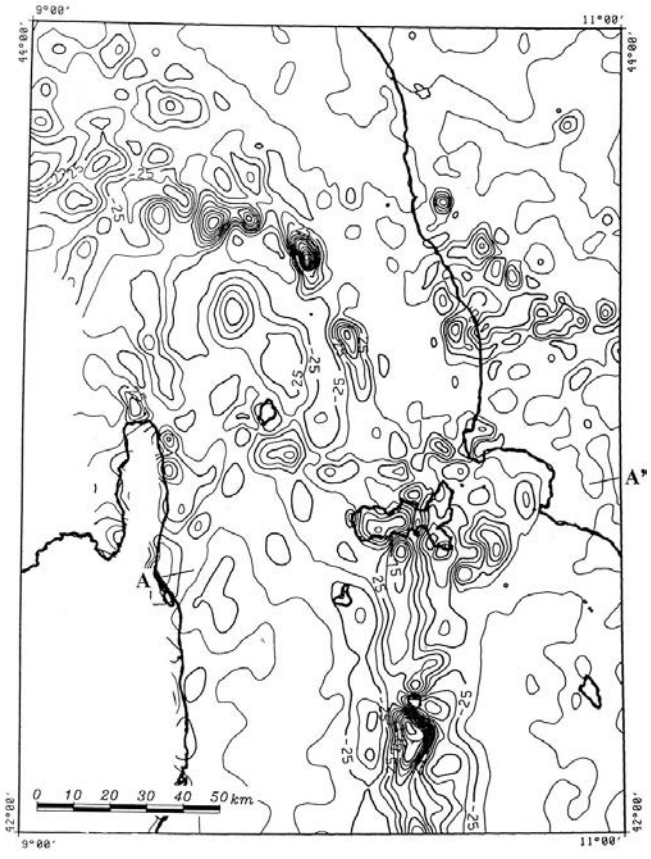

Fig. 3 - Band pass filter λ = 4 - 40 km on reduced to the Pole. Contour interval = 25nT.

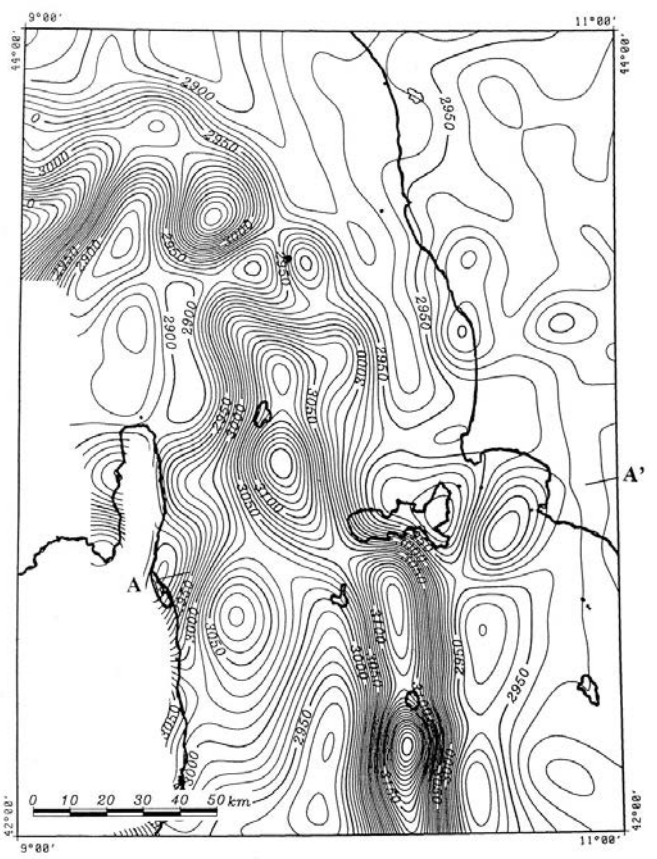

Fig. 4 - Low pass filter λ = 24 km on reduced to the Pole. Contour interval = 10 nT.

The more intense anomalies have a N-S trend, south of the Island of Elba, whereas to the north these exhibit a clearly curved trend. The two sets of anomalies are separated by the transverse discontinuities surrounding the island of Elba.

GRAVITY DATA

Thanks to the integration of the data of Agip's onshore and offshore surveys with the results of the 1973 O.G.S. marine survey, a new Bouguer Anomaly Map was obtained (Fig. 6). For the purposes of the Elica Meeting, this map was restricted to the area between 42° and 44° Lat. and 9° and 11° Long. (C.N.R., 1986; Finetti and Morelli, 1973).

This map is characterized by a series of N-S oriented, higher amplitude anomalies centered on the island of Elba, with a clear westward rotation in the Gorgona Island area. Rather weak, mostly negative anomalies occur in the Tyrrhenian area between Corsica and the Elba Island.

Particularly interesting is the positive anomaly over the western portion of Elba, corresponding to the magnetic minimum of Fig. 2.

For an analysis of the deeper and regional data, the map was filtered with a low pass filter with wavelength = 80 km (Fig. 7). The gravity high crossing the island in a N-S direction, despite the westward rotation in the northern section, shows a significant low frequency anomaly.

The map shows also the large minimum between Elba and Corsica.

GEOLOGICAL DATA

The northern Tyrrhenian Sea is an extensional basin formed in the Late Miocene- Pliocene time (Selli, 1985; Trincardi and Zitellini, 1985; Wezel, 1985; Zitellini et al., 1986). Neogene extensional tectonics are responsible for the present configuration and geometry of the basin, while the normal faults almost totally overprint the pre-existing thin-skinned fold and thrust belt (Bartole, 1990a; 1990b; Boccaletti et al., 1990; Bartole et al., 1991; Pertusati et al., 1993). However, geometric evidence of the tectonic units structurally ascribed both to the Alps and Apennines is locally preserved.

Between Corsica-Elba and the Apennines, large fragments of ophiolites are present. The ophiolites are lithospheric remnants of the Jurassic "Ligure-Piemontese" oceanic basin, which was involved in the lithosphere processes of consumption and subduction since the Cretaceous (Piccardo, 1977; Reutter et al., 1978; Reutter et al., 1982; Principi and Treves, 1984; Kastens et al., 1986; Piccardo et al., 1990; 1997).

During the Neogene a basic magmatism, related to an extensional regime, widely occurred within the Corsica, Elba and Tuscany basement, coeval with the emplacement of granodioritic bodies (Daniel and Jolivet, 1995; Keller et al., 1990).

Besides oceanic materials, slices of continental crystalline rocks and low grade metamorphic rocks occur in the area. The structural relations among the different lithologies are the result of the collisional tectonics between crustal elements of the Europa and Apulia plate margins (Malinverno and Ryan, 1986; Della Vedova et al., 1991; Carmignani et al., 1995).

The "Alpine" successions of continental and oceanic domains crop out in Corsica: the "Schistes lustrés" and the ophiolites make up the structurally higher units in the West-verging Ligurian sequences.

Two lithological units separated by a tectonic contact outcrop in the Gorgona Island: the calcschists analogous to the "Schistes lustrés", and the underlying metaophiolites. Both metasedimentary and metaophiolitic units can be correlated with those of Corsica and the Ligurian Alps (Capponi et al., 1990).

The successions of the "Ligurian" and "Tuscan" units occurring on Elba make up a very complex "Apennine" structure (Bortolotti et al., 1991; Duranti et al., 1992; Pandeli et al., 1995; Corti et al., 1996). They form an east-verging tectonic prism characterized by an imbricate pattern. The island displays Neogene magmatic activity represented by the emplacement of granodioritic plutons (Monte Capanne and Monte Calamita) as a result of extensional tectonics.

Tectonic conditions similar to those on Elba favoured formation of the granitic bodies of the Giglio and Montecristo Islands.

On the Pianosa Island, there are outcrops of clastic sediments of the Neogene cycles overlying Epiligurian successions like the ones penetrated by the Martina and Maria wells (Agip, 1977).

The "Tuscan Archipelago" is a magmatic province with anatectic melts and hybrid magmas from the crust and the mantle. The oldest volcanism occurred in the Miocene - Pliocene, and is best exposed on the Capraia Island, whereas type areas of the Pliocene - Quaternary volcanism are on the islands of Montecristo and Giglio.

The ophiolitic sequences, even though highly deformed in the tectonic prism, represent the basal units of the Upper Jurassic - Paleocene sedimentary succession. They include the complete oceanic sequence or else are made up of ophiolitic breccias and mafic and ultramafic volcanic intrusions. The main lithological associations are a gabbro-peridotite complex characterized by lithological features similar to the present oceans, which was formed in a "Low-Spreading Ridge"; a complex of dikes and basaltic layers; ophiolitic breccias embedded into basic lavas correlated with MOR basalts (Tiepolo et al., 1997; Tribuzio et al., 1997). The gabbro-peridotite and the basalt complexes are magnetically characterized by high susceptibility. As a result, they are easily distinguished from other lithological units, especially the sedimentary sequence, at times metamorphosed to blueschist to greenschist facies.

The basement, i.e. the non-ophiolitic complex, is made up of sialic crustal units, with an average-low magnetic susceptibility, of both the Alpine and the Apennine domains. On the other hand, the basement of the so-called "Elba ridge" displays very high susceptibility, with magnetic features of oceanic crust or transformed crust, enriched by mafics and ultramafics.

INTERPRETATION

The map of the magnetic interpretation of the northern Tyrrhenian Sea exhibits anomalies characterizing three different sectors in the area between Corsica, the island of Elba and the northern Apennines (Fig. 5). Particularly significant is the central portion which stretches for several tens of kilometers from south of Elba northwards as far as the "Massiccio di Voltri" in the Ligurian Alps.

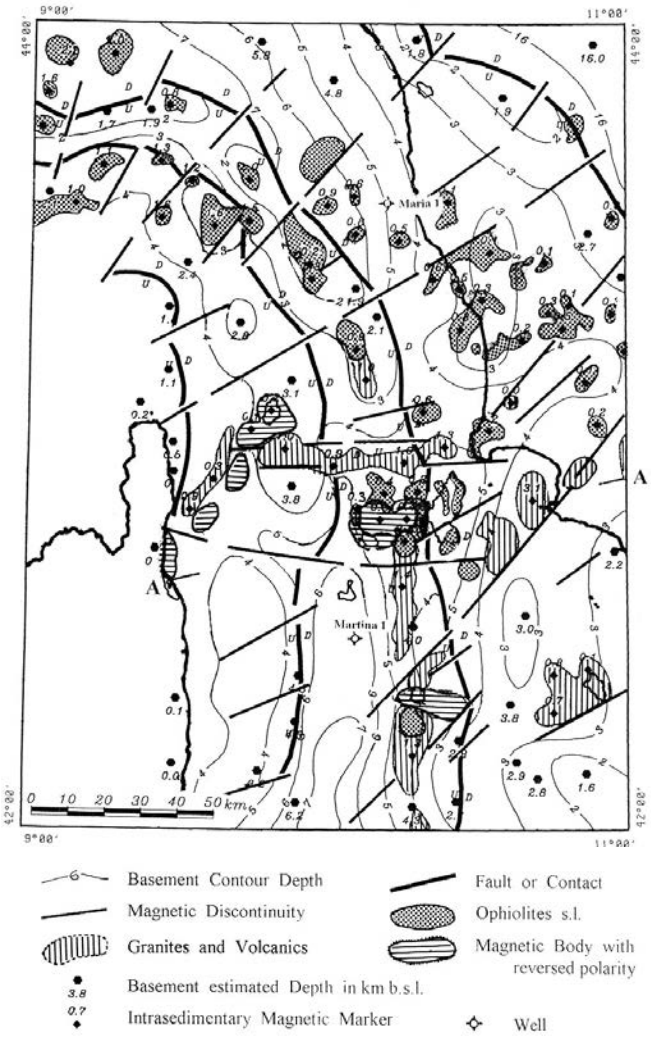

Fig. 5 - Structural Magnetic Interpretation.

The more intense anomalies, reconfirmed by the filtered maps, reflect the presence of a culmination of the basement and of the highly susceptible overlying units producing a N-S oriented complex structure. This structure, which stretches from Gorgona to Montecristo at the latitude of Elba, is offset in a sinistral sense by E-W transverse discontinuities, along which dykes, volcanic rocks and plutons are located. To the north of Elba, the N-S trend of the positive magnetic anomalies is interrupted several times by other NE-SW trending discontinuities, which highlight fault lineaments, again with a left lateral sense of displacement, and which cause the axis to follow a curved trend, concave to the west (Naudy, 1970).

The gravity data confirm the presence of dense bodies behind the axial zone of this structure; these bodies should represent the granodioritic intrusions, even though these bodies have low megnetic susceptibility and show reversed magnetic polarity (Fig. 8).

On the whole, the gravity and magnetic data outline a structural situation which is similar to the one indicated by the profiles and the seismic maps of the ‘70s. The culmination of the so-called “Elba ridge” results from the envelopment of compressional structures.

The evidence of seismic reflectors dipping towards the west indicates that the stratigraphic-tectonic units verging towards the Apennines contribute to the structure. This complex of stacked tectonic units is dissected by more recent extensional tectonics, resulting in horst and graben structures (Finetti and Del Ben, 1996; Bartole, 1990a; 1990b; Bartole et al., 1991).

In the Corsica sector, the gravity and magnetic data do not help identify the tectonic geometries of the cropping out units, which show a western vergence. The interpretation only resolves the geometries of the extensional regime, marked by high angle faults with considerable throw, towards the depocenter of the Corsica Tertiary basin.

Along the axis of the Corsica basin, a marked magnetic anomaly indicates the presence at depth of an extensive magnetically susceptible body, resembling a local high of the continental basement. It likely represents an element of the continental crust of Corsica, even though one cannot exclude the possibility that it represents tectonic units of the Alpine belt, lowered by extensional faults. In any case, this is a magnetically well-distinguished body compared with the ones causing the shallower anomalies associated with the ophiolitic units of eastern Corsica.

The magnetic panorama of the Apennine offshore sector outlines a continental platform made up of “Tuscan” basement, which progressively deepens westwards, as far as the tectonic contact with the N-S crustal structure referred to as the “Elba ridge”. The anomalies of this sector are the expression of the allochthonous ophiolite masses of the Ligurian units, which are very abundant and more common in the N-NE part of Elba, and less widespread in the sector to the S-SW of Elba. Locally, the volcanics with associated dykes and plutons intrude the “Tuscan” basement.

GEOLOGICAL-GEOPHYSICAL INTERPRETATIVE SECTION

The section represents the computerized interactive modelling of the observed and calculated magnetic and gravity data (Fig. 9). The detailed analysis allowed the separation of the anomalies associated with the basement from those related to the overlying tectonic units and ophiolites. The sizes, the geometry, the depths of the causative bodies were determined directly on the basis of the qualitative and quantitative resolution of the anomalies (Talwani, 1965).

The section stretches from Corsica to the gulf of Follonica, passing through the island of Elba.

The geophysical data formed the subject of comparison and were interpreted in the light of the existing geological models. The result provides a hypothetical framework in which the geometry of the basement and its depth are outlined, and which optimizes the contacts between such basement and the ophiolitic units. The basement exhibits two N-S aligned culminations bounded by reverse faults on the eastern flank. The easternmost culmination has a highly susceptible basement which dips westwards, overlaid by stacked ophiolitic units so as to form an accretionary prism with an overthrust structure and vergence towards the Apennines.

The section highlights a structure near the transition between the Alpine domain to the west and the Apennine domain to the east. The tectonic and metamorphic imprint of the ophiolitic and Ligurian units in blueschist facies metamorphism of the Corsica-Elba sector, as well as the magnetic features of the basement immediately underlying the Island of Elba, which resemble relict oceanic crust, are related to lithospheric-scale processes involving lithospheric thinning, subduction, and uplift of the subducted units to shallower levels.

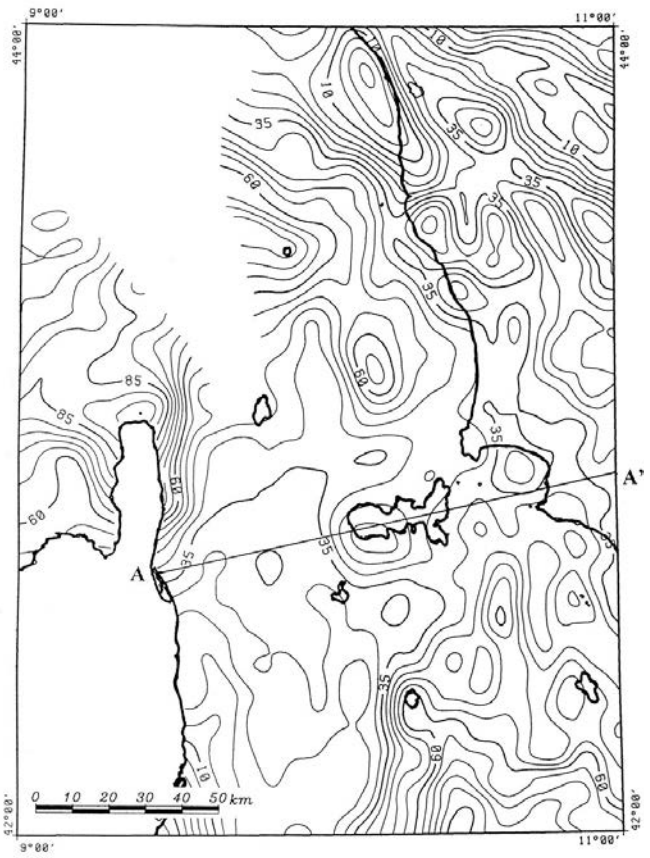

Fig. 6 - Bouguer Anomaly. Density 2.4 g/cc; contour Interval = 5mGal.

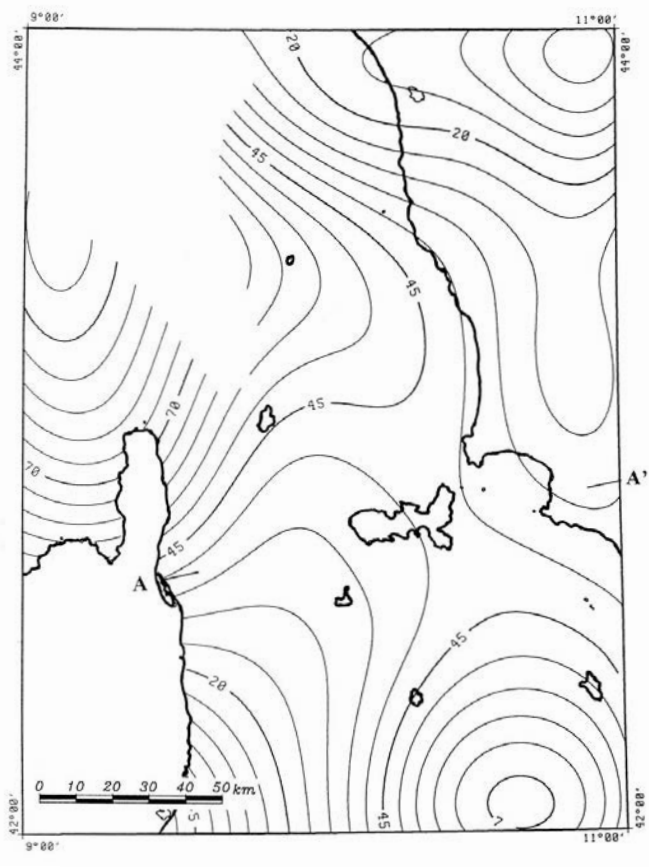

Fig. 7 - Low pass filter λ = 80 km on Bouguer anomaly. Contour interval = 5 mGal.

Fig. 8 - Gravity Qualitative Interpretation.

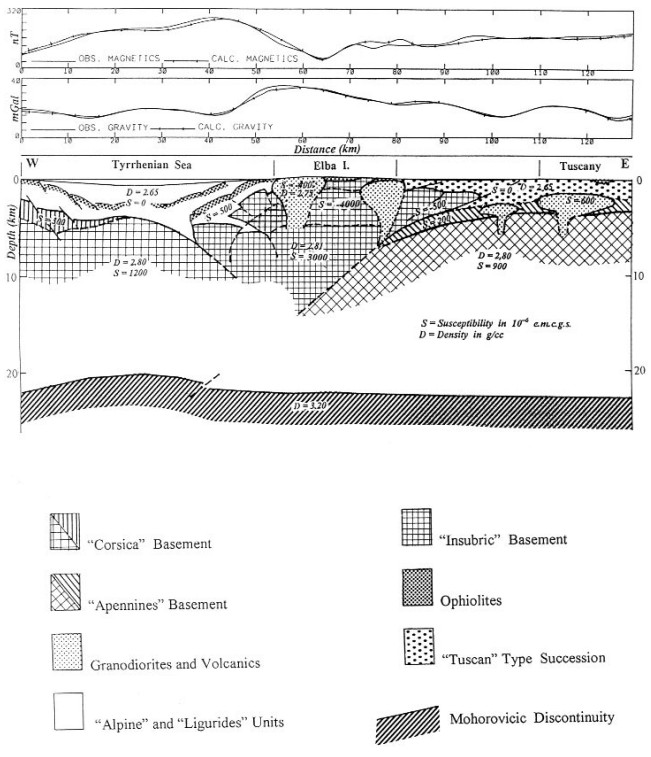

Fig. 9 - Modelling 2.75D. Interpretative Section A – A' of Fig. 8.

On the basis of this interpretation, the Alps-Apennines boundary, which in Liguria is represented by the Sestri-Voltaggio line, might occur in central Elba, as it was assumed to coincide with the Portoferrario - Punta della Contessa alignment (Perrin, 1975).

CONCLUSION

The magnetic maps show how the Tyrrhenian area, between Corsica, Elba and the northern Apennine, is characterized by large amplitude anomalies outlining a N-S trending crustal structure, in which ophiolitic units and oceanic basement are involved.

The two sets of anomalies, trending N-S, are offset by transverse discontinuities.

The more intense anomalies extend from south of Elba northwards. The ophiolitic sequences show elements of correlation with the lithofacies of the "Gruppo di Voltri". Like the Sestri-Voltaggio line in Liguria, the N-S structure can be related to the junction between the Alps and Apennines, in the past referred to as the "Ophiolitic Suture", owing to its width, size and development for several tens of kilometers.

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