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Models for interpretation of the magnetic anomaly of the Ivrea body

by Roberto LANZA *

ABSTRACT. – The extensive regional magnetic anomaly observed along the Western Alps from Locarno to Turin can be related to the Ivrea body. The models so far put forward to explain the anomaly are compatible with the seismic and gravimetric data, and consist of a slab-like body dipping to the SE. One major difference, however, lies in the fact that the thickness of this slab is only 2 – 5 km in the magnetic models, whereas it is of the order of 12 – 20 km in the seismic models. This would imply a division of the Ivrea body into two parts, with magnetically differentiated rocks in the tectonically upper part only. The physical and geometrical findings in the magnetic models proposed are in agreement. By contrast, no single interpretation is available with regard to the geological nature of the magnetically different materials. Two suggestions have been made : Ivrea-Verbano Zone metabasites; Lanzo Massif type serpentinized peridotites. More detailed investigation and a more extensive examination of the magnetic properties of these rocks are needed before a final choice can be made between these two candidates. There is also a possibility that the magnetic anomaly is not due to the Ivrea body at all, but attributable to the top of the south-Alpine crystalline basement. The theories advanced with respect to the nature of the magnetically anomalous unit imply different relations between the Ivrea body and the south-Alpine and west-Alpine blocks.

1. INTRODUCTION

A lithospheric unit known as the Ivrea body has been identified at the feet of the Western Alps. It is formed of a slice of material with typical lower crust – upper mantle features (high density and high seismic velocities) that lies near the earth's surface and is almost entirely surrounded by crustal material. Seismic and gravimetric studies led to the description of its main characteristics at the Symposium "Zone Ivrea-Verbano" (1968), and subsequent geophysical investigations have furnished interpretation models that have not introduced any major changes. A simplified map of the Bouguer anomaly (Fig. 1) shows the general lie of the Ivrea body. It commences in the Locarno area, proceeds SW as far as Ivrea and Lanzo, and then bends S to Cuneo. BERCKHEMER's (1968) model of a cross-section to the N of Biella (Fig. 2), which takes the seismic and gravimetric data into account, may be taken as the general pattern of the Ivrea body's structure. Models for more southerly sections (CHOUDHURY *et al.*, 1971) show gradual sinking of the body's seismically determined upper surface (Ivrea surface auct.), coupled with an equally gradual decrease in its slope.

Magnetic field anomalies were detected in this part of the Alps in the 19th century. The first systematic report for the Ivrea body, however, did not appear until 1949 and more extensive studies were not carried out until the seventies. These have not always led to the same interpretations. The main difficulty is raised by identification of the geological nature of nonoutcropping, magnetically anomalous

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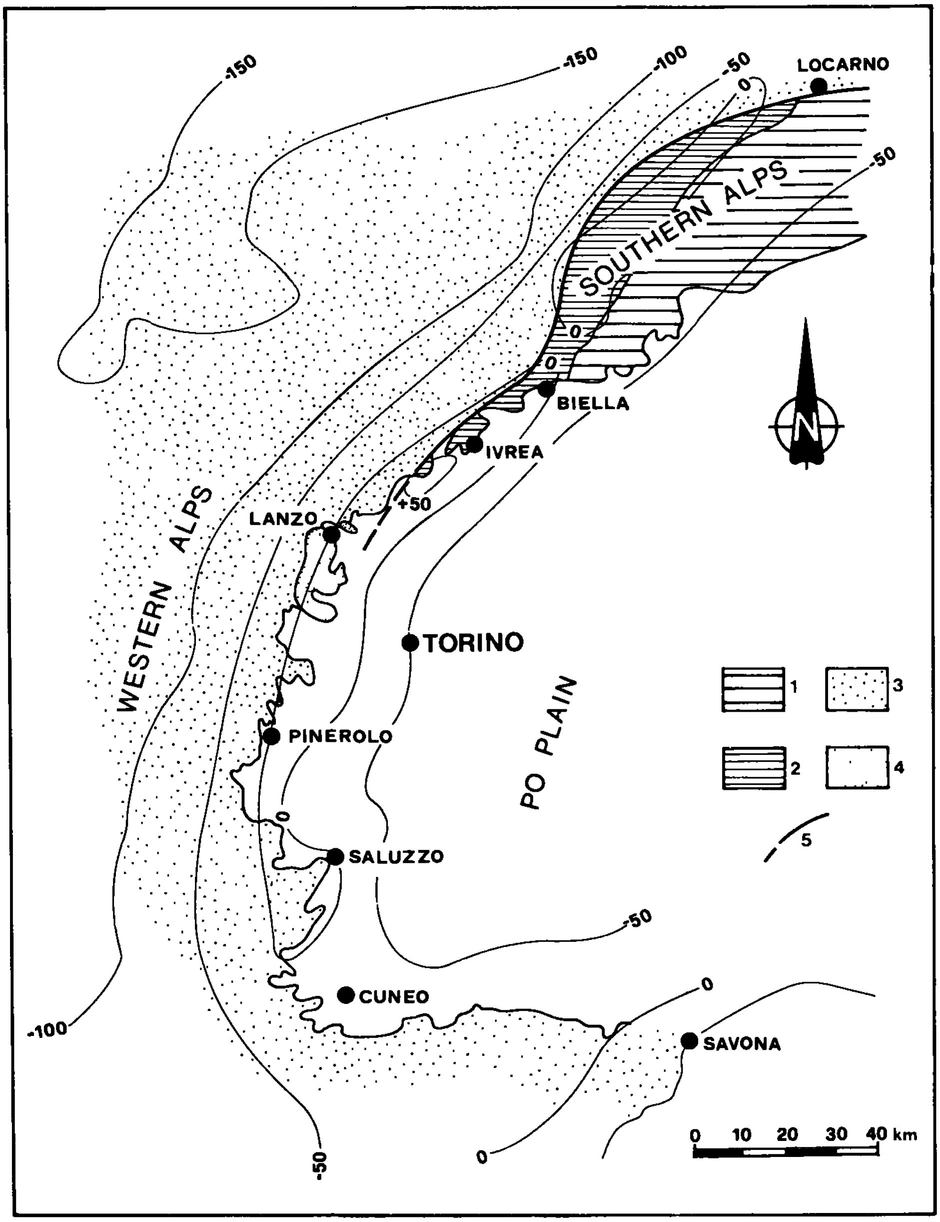

FIG. 1. – Map of the Bouguer's anomaly in the Western Alps. Contour interval: 50 mgal. Symbols: 1) Southern Alps; 2) Ivrea-Verbano Zone; 3) Western Alps; 4) Lanzo Massif; 5) Canavese Line.

units and their correlation with known Alpine units. Several rock types with a high magnetic mineral content are found, in fact, each of which could represent the rocks forming the deep anomalous units. At present, no one hypothesis can be regarded as convincing. This paper examines the interpretations that have been advanced and the difficulties that prevent the elaboration of a well-defined structural model.

2. THE MAGNETIC DATA

In what follows, six explanations of the main magnetic anomaly are examined. This anomaly is correlated with the gravimetric and seismic anomaly. The several minor magnetic anomalies observed will not be discussed. The sketch-map in Fig. 3 gives the location of the magnetic maps and profiles.

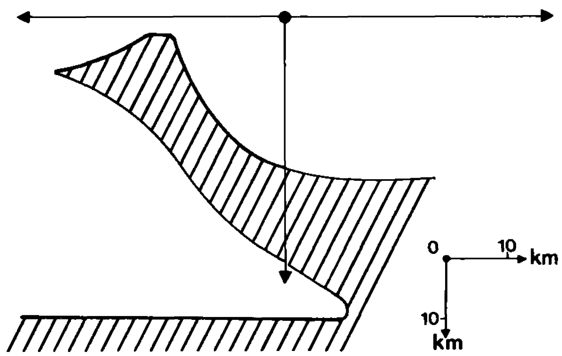

FIG. 2. – Cross section of the Ivrea body according to BERCKHEMER (1968).

1) WEBER *et al.* 1949).

This study forms the first investigation of the Ivrea body magnetism. It consists of a vertical and a horizontal component anomaly map for the area between the Italo-Swiss border and Locarno. This, as we have seen, is where the body begins. It is also where the basic and ultrabasic outcrops of the Ivrea-Verbano Zone start. The area coincides with the initial section of a structure that stretches for over 200 km, and this unfortunate location prevented the writers from obtaining sound structural information. They were, however, able to detect a certain agreement between the lie of the anomaly axes and that of the Ivrea-Verbano Zone outcrops, and thus drew the conclusion that the rocks in this area were in fact responsible for the anomaly observed. The magnetic susceptibility of some rock samples was measured and values of over 0.5×10^{-3} cgs emu were found.

2) ALBERT (1974).

This author published about 20 profiles of the vertical component taken transversally to the Ivrea body between Locarno and Turin. A regional anomaly was a constant feature of this area, and its interpretation was based on a model drawn from that in Fig. 2, namely a slab-like body dipping about 60° in a SE direction and extending to about 20 km (conventionally regarded as the depth of the Curie point isotherm). There is, however, a major difference between the two models : the thickness of the slab is only 2 – 3 km in the magnetic interpretation model, as opposed to 12 – 20 km according to the seismic and gravimetric models. Since the magnetic anomaly lies to the E of the gravimetric anomaly, it may be supposed that only the top of the body structure immediately below the Ivrea surface exhibits a magnetic difference.

The minimum depth of the upper surface of the slab is about 1.5 km in the N, and gradually increases to 2.5 – 3 km as one moves SW. Only the induced magnetization is taken into account, with susceptibility values lying between 5×10^{-3} and 10×10^{-3} cgs emu. From the geological standpoint, the anomalous unit is equated with the basic rocks of the Ivrea-Verbano Zone, especially amphibolites, since their susceptibility values are similar to those used to calculate the characteristics of the model. In the present writer's opinion, this correlation is illogical. If the nature of a deep anomalous unit is determined from the susceptibility values of surface samples, this supposes continuity between the outcrop and the deep material. ALBERT, on the other hand, places the termination of the magnetically different material at about 2 km. In other words, the material between this depth and the surface does not contribute to the anomaly. Furthermore, if the upper surface of the slab were brought closer to the earth's surface, this would give anomaly curves increasingly different from that of the anomaly actually measured.

3) WEBEL & WAGNER (1973); WAGNER *et al.* (1979).

These authors have presented 12 transverse profiles for the area between Locarno and Cuneo, with measurements of the total intensity of the earth's magnetic field. Their findings, however, have so far been presented at congresses only, and cannot be evaluated with precision. The view that a symmetrical main anomaly is associated with the Ivrea body (in the – 300 to + 300 nT range) does not appear to fit in with the findings of other authors. In particular, a symmetrical anomaly should be even more evident in aeromagnetic profiles, whereas in this case no trace of one can be found (see par. 5). The geological interpretation of WAGNER et al. follows the procedure adopted by ALBERT, i.e. metabasites and amphibolites of the Ivrea-Verbano Zone are regarded as the most likely constituents of the magnetic part of the Ivrea body in the light of the surface susceptibility ($\simeq 1 \times 10^{-3}$ cgs emu). The remanent magnetization is regarded as negligible, since the Königsberger ratio is $\leqslant 1$.

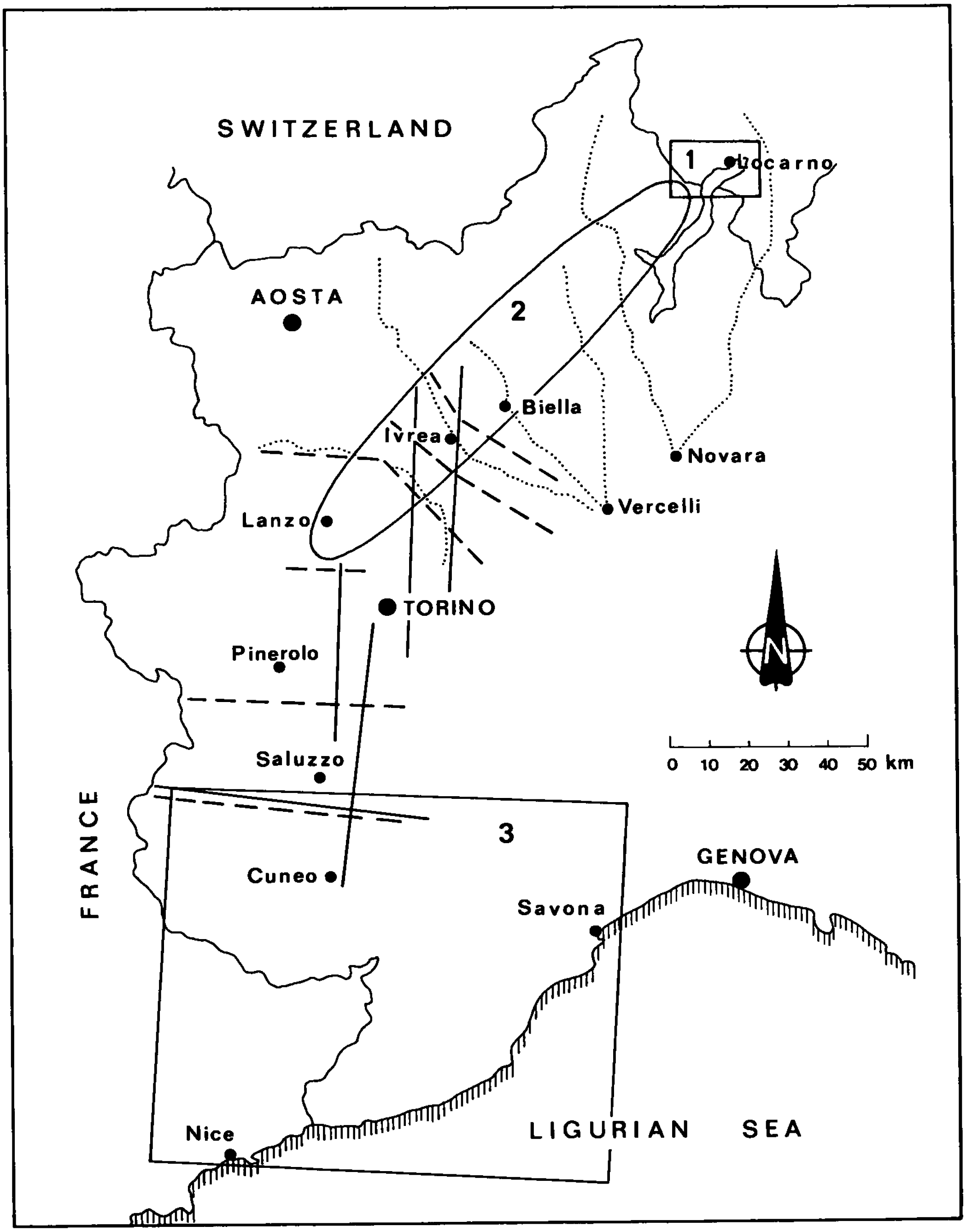

FIG 3. – Location of the magnetic surveys carried out in the Ivrea body area.
(1) WEBER *et al.* (1949), map. (2) ALBERT (1974), area surrounding the profiles. (3) FROIDEVAUX & GUILLAUME (1979), map. Full line = ARMANDO & RATTI (1977), aeromagnetic profiles. Dashed line = LANZA (1975), profiles. Dotted line = WEBEL & WAGNER (1973), profiles.

4) LANZA (1975).

Six transverse total intensity profiles between Biella and Cuneo show that the magnetic anomaly is no longer discernable S of Pinerolo. Interpretation of the northernmost profiles (between Biella and Lanzo) results in a model whose susceptibility values (5×10^{-3} – 7.5×10^{-3} cgs emu) and geometry are much the same as those of ALBERT, except that the thickness of the slab is 4 – 5 km. A different view, however, is expressed with regard to the geological nature of the body. The difference in thickness between the magnetic and the seismo-gravimetric models is explained by assuming that the upper part of the unit is composed of partly serpentinized peridotites. Three reasons are put forward in support of this hypothesis : 1) the density and seismic velocity values for the Ivrea body as a whole are those of peridotites; 2) the magnetic susceptibility of peridotites increases with their degree of serpentinization; 3) a serpentinized peridotite band would mean a gradual transition from crustal to mantle density and seismic velocity values, and this is compatible with current seismic and gravimetric models (KAMINSKI & MENZEL, 1968).

Movement between the Ivrea body and the deep South-Alpine crust may have caused serpentinization to a depth of several kilometres. This phenomenon, plus its accompanying magnetic anomaly, can be observed on a reduced scale (to a depth of about 1 km) in the Lanzo Massif. This outcrops at one of the Ivrea body's gravity anomaly peaks, and is regarded by many authors as a minor slice that has been uplifted to the point of outcropping.

In LANZA'S view the basic rocks of the Ivrea-Verbano Zone make no contribution to the regional anomaly, and are merely responsible for short-wave disturbances. This hypothesis, however, is not based on a sound experimental evidence, and is partly belied by the fact that some lithotypes in this zone display high susceptibility values. A much greater data coverage, and above all susceptibility and remanent magnetization measurements in greater number and better distributed than those at present available will be needed before the rocks of the Ivrea-Verbano Zone can be assigned a merely secondary role.

5) ARMANDO & RATTI (1977).

These authors presented aeromagnetic profiles for the area between Ivrea and Cuneo. The anomaly is clear along the northernmost profiles, and absent in the S profile (about 20 km N of Cuneo). One interesting feature is the existence of a continuous transverse anomaly running from Pinerolo eastwards, and to the S of Turin, particularly since it lies in the very area where the Ivrea body's magnetic anomaly disappears. Since no quantitative interpretation has been offerred, no judgement can be expressed with respect to the nature of this new anomalous body.

6) FROIDEVAUX & GUILLAUME (1973, 1979).

A ground-level total intensity map for the Ligurian and Piemontese region S of Saluzzo is presented and discussed by these authors. This reveals a large number of anomalies. Only that SW of Cuneo and attributed to the presence of the Ivrea body will be discussed here. This is assigned a model formed of a series of prisms, whose upper and lower surfaces are 6 – 8 km and 15 km deep respectively, and regarded as the Ivrea body, though this does not take into account the gravimetric and seismic data, which suggest a much greater depth for the southern part of the Ivrea surface, namely $\simeq$ 15 km in the case of the latters (GIESE & MORELLI, 1975; GIESE & PRODEHL, 1976; STEIN *et al.*, 1978). The anomaly SW of Cuneo, therefore, is certainly not the result of the structure usually described in the literature as the Ivrea body. If it desired at all costs to correlate these anomalous bodies with the Ivrea body, they must be assimilated to smaller slices that have separated from the main body and risen to a considerable degree, as mentioned earlier with respect to the Lanzo Massif.

3. INTERPRETATION MODELS

The quantitative interpretations of the magnetic anomaly of the Ivrea body reviewed in the previous section were obtained with the indirect method, using an infinitely long, two-dimensional plate as the model. This was given fixed initial physical and geometrical values, which were then modified in accordance with best fitting procedures. A generally valid schematic model can best be obtained by repeating the interpretation of some profiles with the most objective method. For this purpose, three profiles provided by various authors for the area around Ivrea (ALBERT, 1974; LANZA, 1975; ARMANDO &

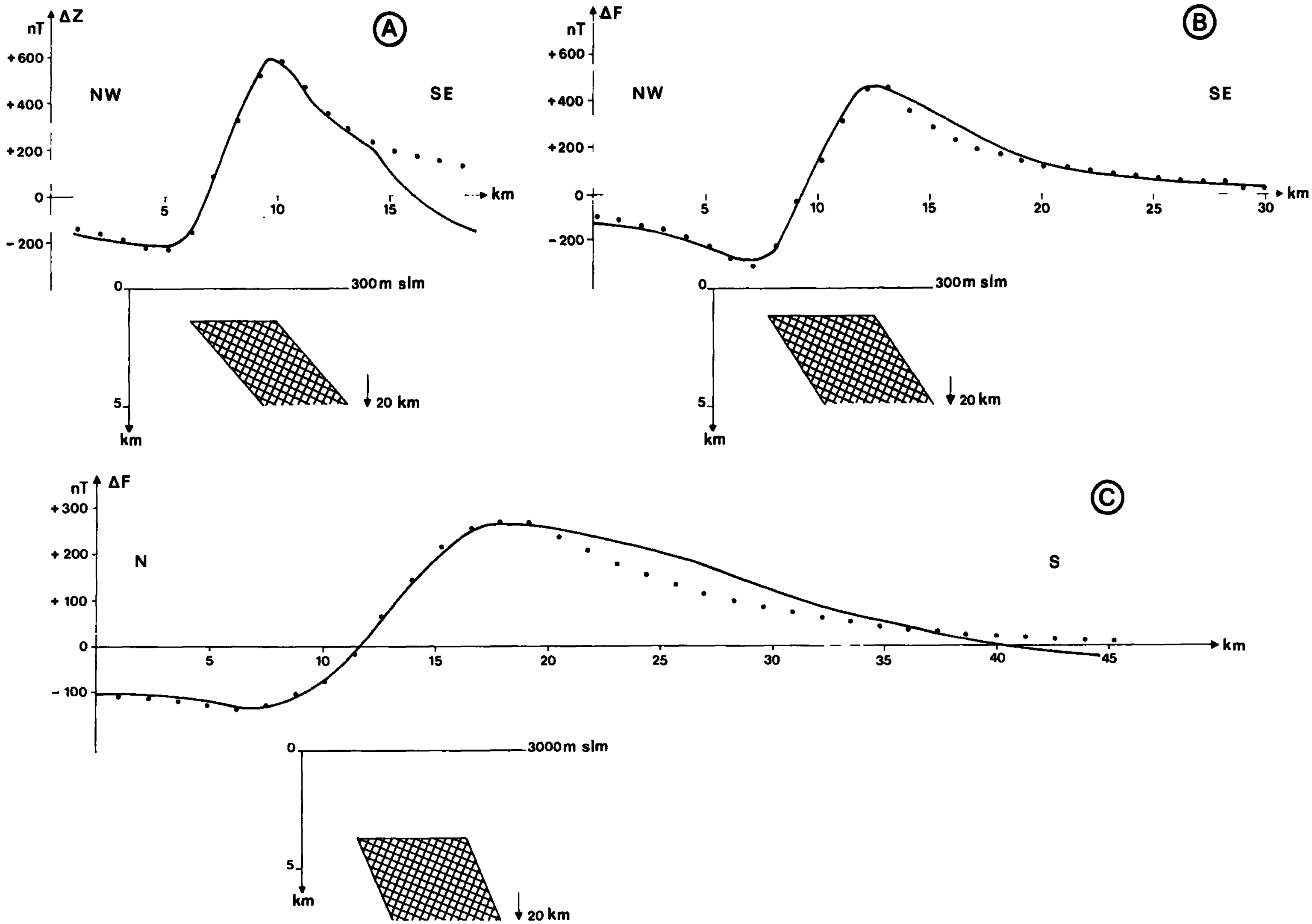

FIG. 4. – Field (full line) and calculated (dotted line) anomaly curves along profiles A, B, C in Table 1. The tabular body shown in section descends to 20 km. (The nT scale for curve C is half that used in curves A, B).

RATTI, 1977) have been interpreted in accordance with the direct method of KOULOMZINE *et al.* (1970). This procedure gives all the interpretation parameter values, and its only initial hypothesis is that the anomalous body is a slab of infinite length. The following table sets out the interpretation values, while a comparison between the calculated curves and the field curves (slightly redrawn) is presented in Fig. 4.

TABLE I
Values of the interpretation parameters according to the KOULOMZINE *et al.* (1970) method for the profiles :
A = profile no. 70, ALBERT, 1974.
B = profile no. 1, LANZA, 1975.
C = profile no. 4, ARMANDO & RATTI, 1977.

	A	B	C	
Depth, h (below sea level)	1.0	0.8	0.9	km
Width, w	3.8	5.0	4.8	km
Slope, i	49°	56°	67°	
Susceptibility contrast, $\Delta\chi$	4.5	3.8	5.5	$\times 10^{-3}$ cgs emu

The concordance seen in the table I is even more significant when account is taken of the fact that it refers to non-systematic findings from a structure, which, while taken to be two-dimensional, in fact displays by no means negligible longitudinal variations (LANZA & ARMANDO, 1979). There is excellent agreement between the field and the calculated curves in the centre of the anomaly, whereas this becomes less true as one moves S and SE.

The classic pattern used for seismic models can thus be applied to the magnetic anomaly, namely a slab dipping SE, whose planimetric position, depth and slope are well known. The fact that the magnetic anomaly can no longer be clearly observed near Pinerolo also fits the picture provided by the seismic model, since the depth of the Ivrea surface is greater and its slope decreases. As a result, the magnetic anomaly may be supposed to decrease in amplitude to a considerable degree, and spread to such an extent that the observations carried out so far have been too restricted to detect it. The magnetic model gives much lower thickness values for the slab than the seismic model, thus introducing a two-part division of the body itself, in which the upper part is composed of rocks with high magnetic mineral content, while the lower rocks display magnetic characteristics similar to those of the surrounding crust. The composition of the upper part has not yet been established. Both the Ivrea-Verbano Zone metabasites and the Lanzo Massif type serpentinized peridotites are possible candidates.

All the authors quoted so far have assumed in their models that the magnetic anomaly is attributable to the Ivrea body. Yet this has not been demonstrated, and may be questioned to the extent that the calculated curves (see Fig. 4) do not display a good fit with those measured in the S and SE parts of the profiles. One could overlook this fact by suggesting that the lie of the slab in depth is not as regular as that assumed in the models. It could, on the other hand, be seen as evidence that the (seismic) Ivrea body is entirely composed of rocks with no marked magnetic properties, and that the anomaly is caused by the rocks of the Ivrea-Verbano Zone, these being now regarded as the extended basement of the South-Alpine block, and not as a part of the (seismic) Ivrea body. A model for AMANDO & RATTI's aeromagnetic profile no. 4 (1977) is shown in Fig. 5. It consists of a series of prisms, several kilometres across and of infinite length, whose depth gradually increases towards the SE. This model is just as sound as that of a single slab reaching a depth of 20 km. This stepped structure for the South-Alpine basement is equally applicable to the other profiles in Fig. 4, and could also support the idea that the transverse Pinerolo-Turin anomaly is due to the southern end of the basement itself.

4. CONCLUSIONS

Study of the regional magnetic anomaly observed at the foot of the Western Alps is not enough to solve the complicated question of the tectonic picture of the area. Even so, it makes a worthwhile contribution to an understanding of the "boundary conditions" that must be borne in mind when putting forward a model for its interpretation. A brief account can thus be given of the conclusions that can be drawn from each of the models examined here.

A stepped South-Alpine basement (Fig. 6a) offers little information concerning the Ivrea body, since it

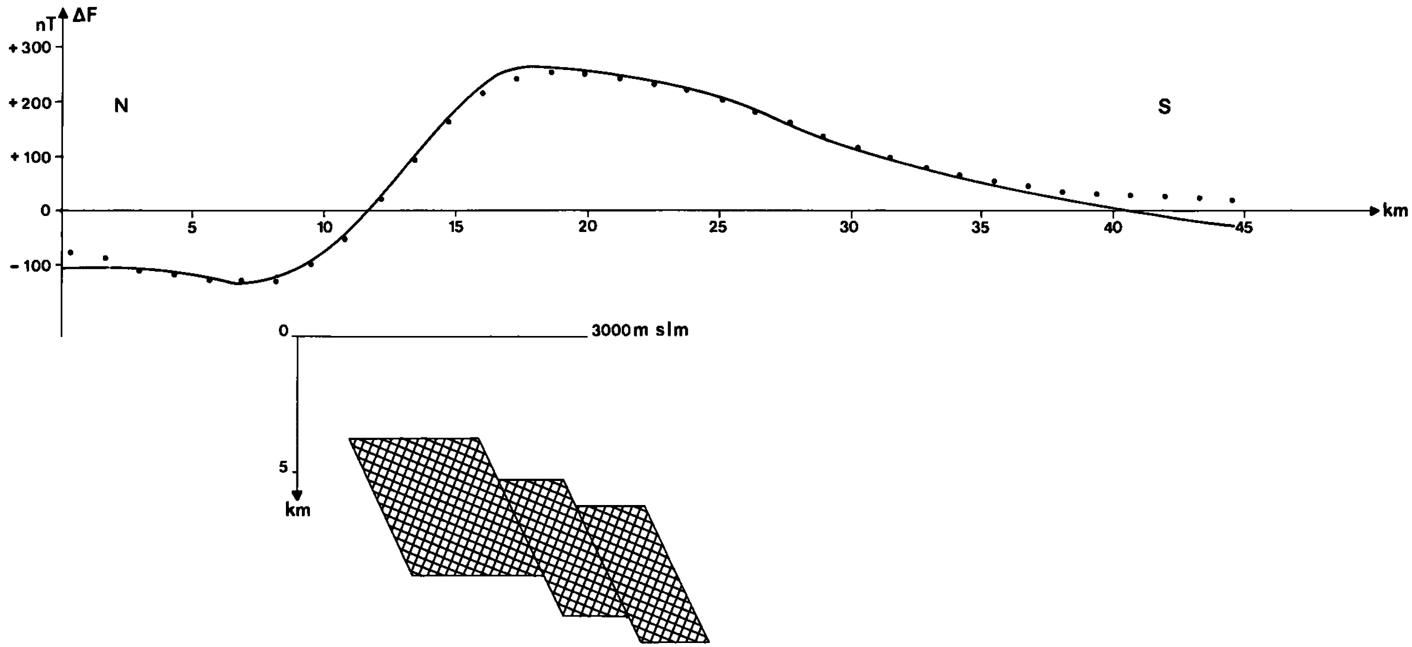

FIG 5. – Same curves as Fig. 4, profile C: model based on surficial prisms. The susceptibility contrast is $\Delta\chi = 5 \times 10^{-3}$ cgs emu.

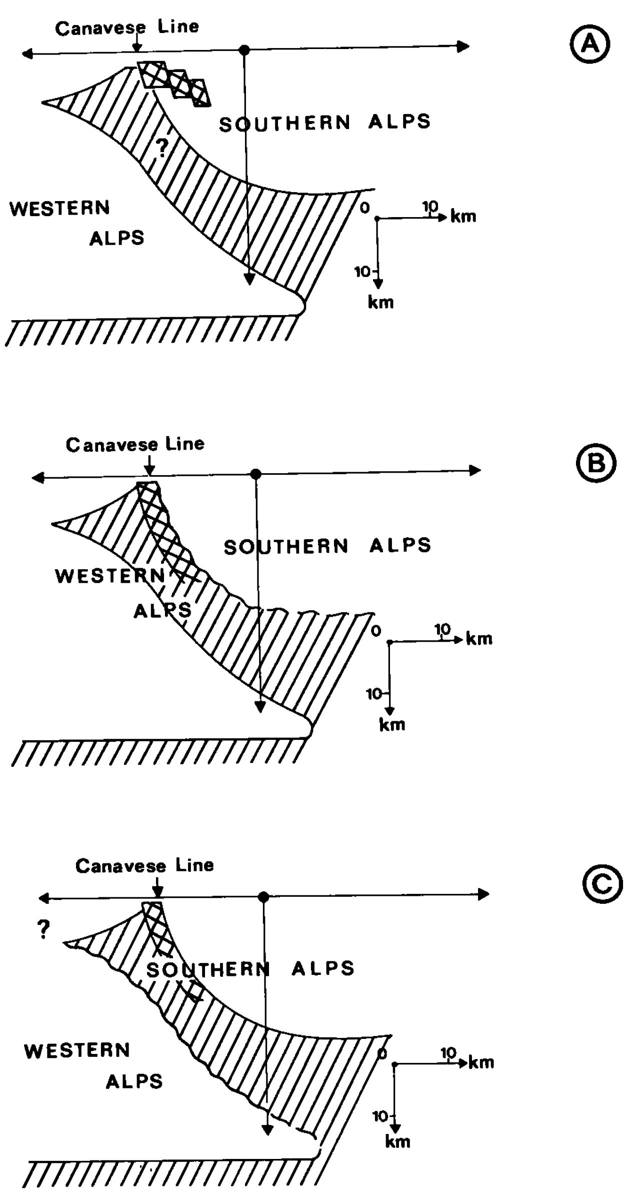

FIG 6. – Possible relations between the Ivrea body, the Western Alps and the Southern Alps (see text). Cross-hatching is used for the magnetically differentiated rocks; the wavy line represents the probable boundary between the two blocks.

is relatively surficial, and its attitude is the result of deeper phenomena as yet undetermined.

A slab-like body formed of serpentinized peridotites of the Lanzo Massif type (Fig. 6b) almost inevitably leads to the conclusion that the serpentinization band corresponds to the maximum tectonic slip horizon, and hence to the probable boundary between the South-Alpine block and that of the Western Alps. The Ivrea body can be seen as a slice of suboceanic mantle wedged between the Western Alps and the deep South-Alpine basement.

A slab-like unit composed of the Ivrea-Verbano Zone metabasites (Fig. 6c) presupposes a considerable extension of such rocks in depth, and this in turn can only be ascribed to distinct uprighting of the NW edge of the South-Alpine basement. The Ivrea body would thus be seen as its subcrustal mantle.

A full discussion of these three working hypothesis, however, would require a summary of the geophysical, geological and petrological data that would overstep the limits of this paper.

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