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A discussion of contour maps in the Toce subdome of the Penninic realm (Switzerland, Italy)

by *Eva M. Klaper*[1]

Abstract

The contact between basement and cover descends from 4 to 5 km in the external western Aar and Gotthard massifs to an estimated depth of about –2 to –3 km before it rises again in the Verampio culmination to an altitude of 1.2 km. In the internal zone, sheets of basement rocks form a stack of imbricates overlying the Verampio culmination. The average thickness of these nappes is around 2 km and their geometry is strongly influenced by post-nappe folding. In many of the basement bodies Late Variscan granitoids exert an influence on the Alpine deformation, forming the cores of anticlines and controlling the overall shape of parts of the nappes.

Keywords: Penninic Alps, Switzerland, Italy, basement-cover relations, basement nappes, external massifs.

Introduction

The Penninic zone in southern Switzerland and northern Italy consists of a stack of basement nappe sheets, typically a few kilometres thick, which are separated by thin zones of Mesozoic cover rocks. Early authors (Schmidt and Preiswerk, 1908; Argand, 1911 among others) described these structures as fold nappes, but Milnes, (1974b) could show that large scale folding postdates the emplacement of the thrust sheets. The regional attitude of the foliation within these thrust sheets of the Penninic zone defines an overall dome shaped structure which is separated by the "Maggia Querzone" (Niggli et al., 1936 and references therein) into two classic subdomes, the western "Toce" and the eastern "Ticino" subdome. The structure of the basement-cover contact of the nappes representing the Ticino subdome (Simano, Adula, Tambo, Suretta) and its western boundary, the Maggia nappe, have been described in Pfiffner et al. (1990).

The objective of this paper is to outline the three dimensional shape of the basement bodies in the Toce subdome (Antigorio, Lebendun, Monte Leone, Berisal nappes) and its western boundary, the Simplon Fault Zone (Bearth, 1956; Mancktelow, 1985, 1990; Steck, 1987), using geological surface data and subsurface extrapolations based on available structural data. The data will be presented in the form of structural contour maps. From these maps and previous work (e.g. Hall, 1972; Klaper, 1988; Milnes, 1974a, 1974b) it is obvious that large scale post-nappe folding and differential uplift affected some of the basement imbricates. The compilation of geometric data presented in this paper will certainly help to solve the remaining kinematic problems as for example the kinematics of the spectacular duplication of the Antigorio nappe around the Wandfluhhorn (Merle et al., 1989).

General Geology

Within the stack of the lower Penninic nappes of central southern Switzerland the Maggia nappe is the unit which is seen to separate the broad region of uplift of the classic Toce-Ticino culmination (the Lepontine dome) into two subdomes (Fig. 1). In the western "Toce subdome" the Antigorio nappe overlies the Verampio gneiss as the lowermost unit outcropping in the Verampio-Baceno window. The Antigorio nappe is in turn overlain by the Lebendun, the Monte Leone and the Berisal nappes. Figure 2 illustrates the basement-cover contact of these nappes and of the external massifs in a NW–

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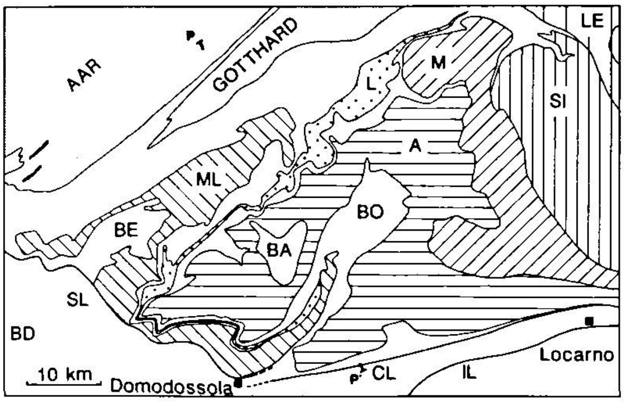


Fig. 1 Map showing the major tectonic units: A: Antigorio, BA: Baceno-Verampio window, BD: Bernhard, BE: Berisal, BO: Bosco structure, L: Lebendun, LE: Leventina–Lucomagno, M: Maggia, ML: Monte Leone, S: Simano, CL: Centovalli Line, IL: Insubric Line, SL: Simplon Line. P–P': Trace of cross-section (Fig. 10).

SE section, the trace of which is marked in figure 1. Contacts situated east or west of this line have been projected along the regionally dominant foliation.

To the west, these nappes are cut by the Simplon Fault Zone. The Simplon Fault Zone is a southwest dipping (low angle) normal fault (MANCKTELOW, 1985; STECK, 1987) separating the lowermost Penninic units from the upper Penninic sheets (Monte Rosa and Bernhard nappes).

This fault zone is characterized by a young abrupt structural discontinuity (the Simplon Line) and a zone of ductile overprint (the Simplon Fault Zone). The ductile overprint consists of a zone of mylonites and a strongly foliated zone of about 1 km thickness. Deformation related in space or time to movements on the Simplon Fault Zone are termed the Simplon phase (19 to 6 m.y.) (MANCKTELOW, 1990 and references therein). It has been demonstrated by SCHMID et al. (1987) that the beginning of the Simplon phase of deformation was roughly coeval with the end of backthrusting and backfolding during the Insubric phase (25 to 20 m.y.) (ARGAND, 1916; SCHMID et al., 1987).

The major lithological units within the Toce subdome are metasedimentary rocks (schists, gneisses, amphibolites) of probable pre-Variscan age (KÖPPEL et al., 1981), intrusive granitic to granodioritic rock bodies (e.g. Matorello, Cocco) of probable late Variscan age and Mesozoic quartzites, marbles, metapelites and calcareous schists, the latter also termed "Bündnerschiefer".

The Penninic (Lepontine) structural dome coincides with the metamorphic dome described by WENK (1970). The grade of metamorphism within this dome increases towards the south and reaches a maximum of upper amphibolite grade near the Insubric Line which truncates the structural and metamorphic features.

Structural elements

Figure 3 is a horizontal section at the 2000 m level showing the major nappe contacts as well as foliation traces (Fig. 3a) and stretching lineations (Fig. 3b). In addition to previously unpublished data, the following publications were used: HUNZIKER, 1974; MANCKTELOW, 1985; WIELAND, 1966; JOOS, 1969. It should be noted that the foliations and stretching lineations compiled in figure 3 are not the result of one single deformation phase. Rather they represent various deformation phases and are thus diachronous. Nevertheless a number of features which are important for the following discussion emerge from this picture.

Within the Toce subdome there is a strong tendency for the foliation traces to follow the nappe contacts (Fig. 3a). Although the intensity of the

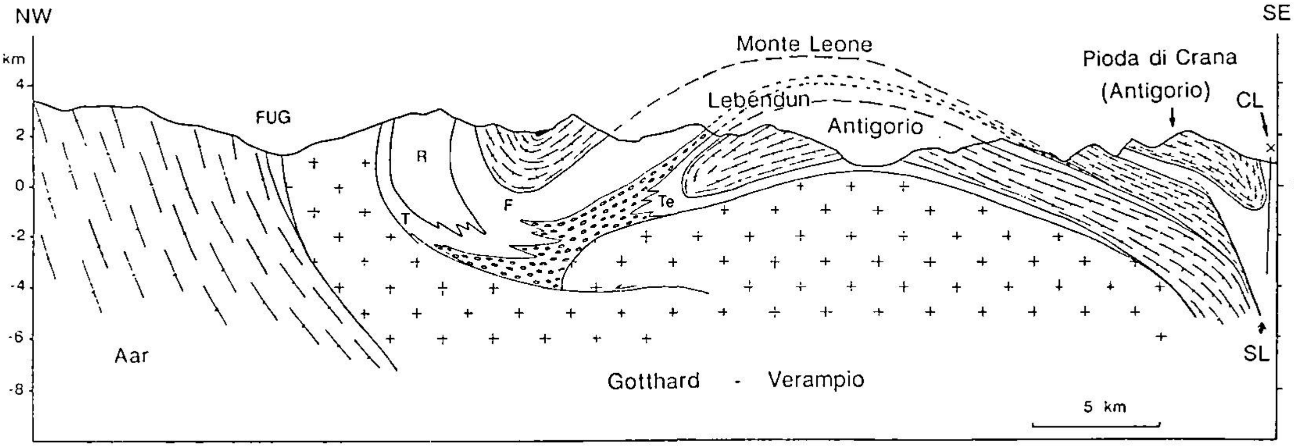
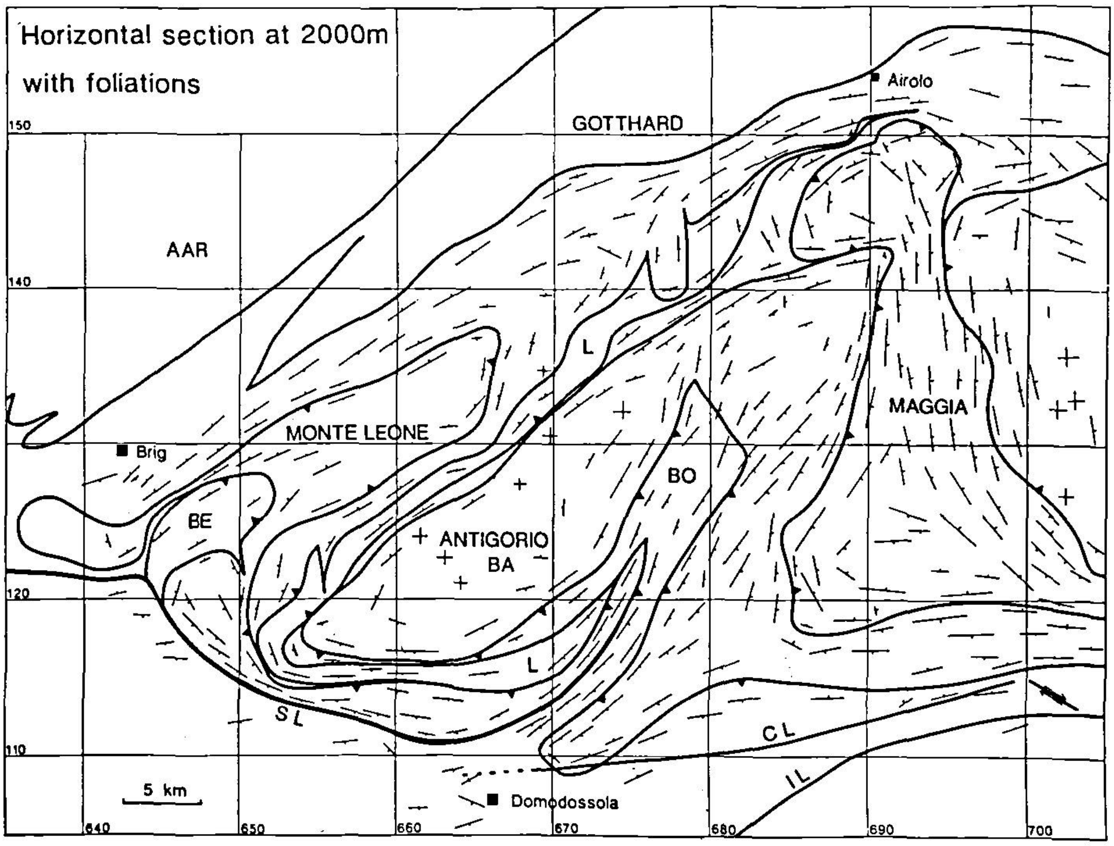


Fig. 2 NW–SE section across the Toce subdome. Trace of profile given on figure 1. F: Fäldbach Series, FUG: Furka-Urseren-Garvera Zone, R: Rosswald Series, T: Termen Zone, Te: Teggiolo Zone, CL: Centovalli Line, SL: Simplon Line.

3a



3b

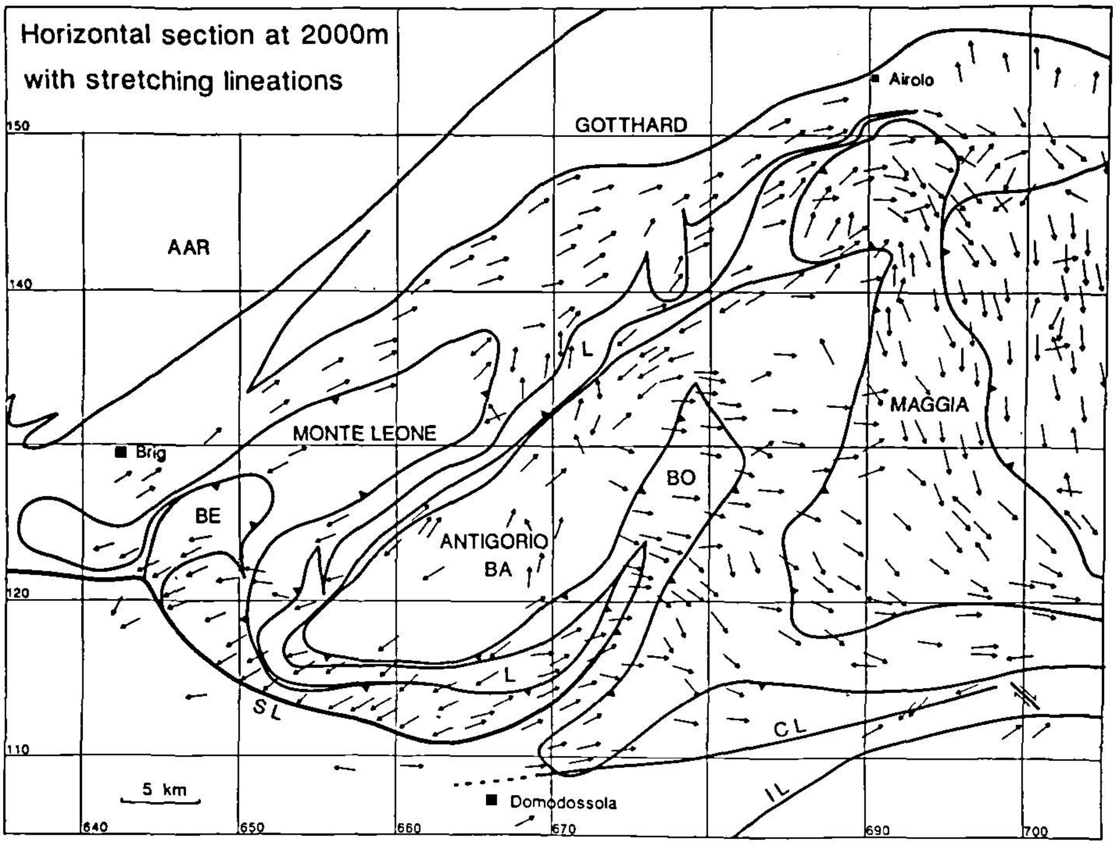


Fig. 3 Horizontal section at 2000 m showing the nappes of the Toce complex and displaying a compilation of foliation traces (a) and stretching lineations (b). Note that the age and significance of these foliations and lineations vary troughout the area represented. Abbreviations as in figure 1, sawteeth are on upper plate. In this and all the following maps, the grid lines correspond to the Swiss National km-Grid system.

foliation varies within the nappes, an almost triangular shaped dome defined by the foliation traces is clearly recognizable. The flat-lying centre of the dome is situated in the Verampio-Baceno area. Towards southwest, south and east the dome is bounded by moderately dipping flanks with the foliation following the Simplon Fault Zone, the Bosco structure and the Antigorio-Maggia nappe contact, respectively. Along the contact to the Gotthard Massif the foliation has a steep attitude due to the late backfolding. Southeast of the triangular dome the foliation is steeply dipping and parallels the contacts of the Maggia nappe, the Centovalli and Insubric lines.

As for the stretching lineations (Fig. 3b) two predominant orientations are common to the nappe pile: a N–S stretching lineation and a SW–NE to W–E trending stretching lineation. The N–S trending lineations prevail in tectonically low positions like the Verampio-Baceno window and can also be found in the stem of the Maggia nappe and in the Simano nappe. The N–S oriented lineations predate the other lineations and are interpreted as being related to the nappe transport (HALL, 1972; HIGGINS, 1964; KLAPER, 1985; SIMPSON, 1982 among others). These lineations formed under increasing or already high metamorphic grade (HALL, 1972; KLAPER, 1985; LÖW, 1987; MERLE and LE GAL, 1988; MERLE et al., 1989).

The SW–NE trending lineations dominate in tectonically higher units, specially in the Simplon domain. MANCKTELOW (1985) showed that the greenschist-grade SW–NE trending stretching lineation in the Simplon area is identical to the "top to the west" transport direction along the Simplon Fault Zone. The more W–E oriented stretching lineations dominate in the Bosco structure and in the eastern half of the Antigorio nappe. These easterly dipping lineations in the upper part of the Antigorio nappe are related to "top to the east" shear movements by KLAPER (1988) similar to the "top to the east" movements observed along east dipping lineations by MAYERAT (1989) further to the east (Tambo nappe). A study of quartz c-axis fabrics (KLAPER, 1988) indicated this "top to the east" movements with an ENE dipping transport direction in the upper part of the Antigorio nappe. This transport direction is slightly oblique to the more easterly dipping stretching lineation which Klaper considered to represent a finite strain state. However, MERLE and LE GAL (1988) and MERLE et al. (1989) relate these easterly dipping stretching lineations in the upper part of the Antigorio nappe to an overall "top to the west" transport.

These variations in the observed movement directions clearly show that there is no simple movement pattern related with the lineation pattern in the Penninic Alps. It is beyond the scope of this paper to discuss the kinematics of nappe emplacement and the internal deformation of the nappes. However, the interpretation of foliation and lineation data and of the kinematic significance of stretching lineations obviously have to be carried out with care and require consideration of much additional information.

The external Aar and Gotthard Massifs

Figure 4 shows the southwestern part of the external Aar Massif which is characterized by a hogback shape with a steeply dipping southern flank and a moderately dipping and strongly folded western surface (PFIFFNER et al., 1990). The Aar Massif shows a culmination at a minimal altitude of about 5 km which is defined by the highest peaks still consisting of crystalline rocks. The subsurface part of the southern flank of the Aar Massif has been contoured with additional information from a seismic line (NFP-20 western traverse) described by FREI et al. (1989, Fig. 16). From the data presented by these authors for the seismic line Stalden–Zermatt, a south dipping contact is postulated for the top of the Aar Massif. Major backfolds are postulated by DU BOIS et al. (in press) to affect the Aar Massif further to the west (Val d'Anniviers). However, according to figure 16 in FREI et al. (1989) it seems that these backfolds do not affect the contoured part of the top of the Aar Massif between Stalden and Zermatt within the area of figure 4.

The basement-cover contact of the western part of the external Gotthard Massif is also given in figure 4 and forms a wedge shaped body that widens towards the east. The northern contact parallels the southern basement-cover contact of the steeply south dipping to overturned Aar Massif and is overlain by Permo-Carboniferous sediments of the Furka-Urseren-Garvera zone. The southern contact of the Gotthard massif is overturned and dips steeply to the north along the entire length of the unit. This orientation is due to the late backfolding in the Northern Steep Belt (MILNES, 1974a) that affected the Gotthard massif. The synformal shape of this major backfold is indicated by the more southern position of the 0 m contour line compared to the 1, 2 and 3 km lines for the top of the Gotthard Massif within the study area. The positions of the 0 and –3 km contour lines have been inferred from the vertical section in figure 2 and from LEU (1986). This large scale backfolding observed east of the Simplon Line does not have an equivalent structure with comparable amplitude west of the line and it only occurs to the east and below the Simplon Line discontinuity.

The contoured main branch of the Simplon fault surface is shown in figure 4 to approach tangentially an orientation parallel to the top of the Aar Massif above the Rhone valley. This fault surface shows roughly a W–E trend in its western part along the Rhone valley (STECK, 1987) and a NW–SE trend in the classic central part (MANCKTELOW, 1985, 1990; STECK, 1987).

The shape of the Penninic basement nappes

a) Verampio-Baceno window

The Verampio granite outcropping in the Verampio-Baceno window forms the lowermost unit exposed in the Toce domain of the Penninic realm. This granite is overlain by 200 meters of garnet schists, the Permo-Carboniferous Baceno schists,

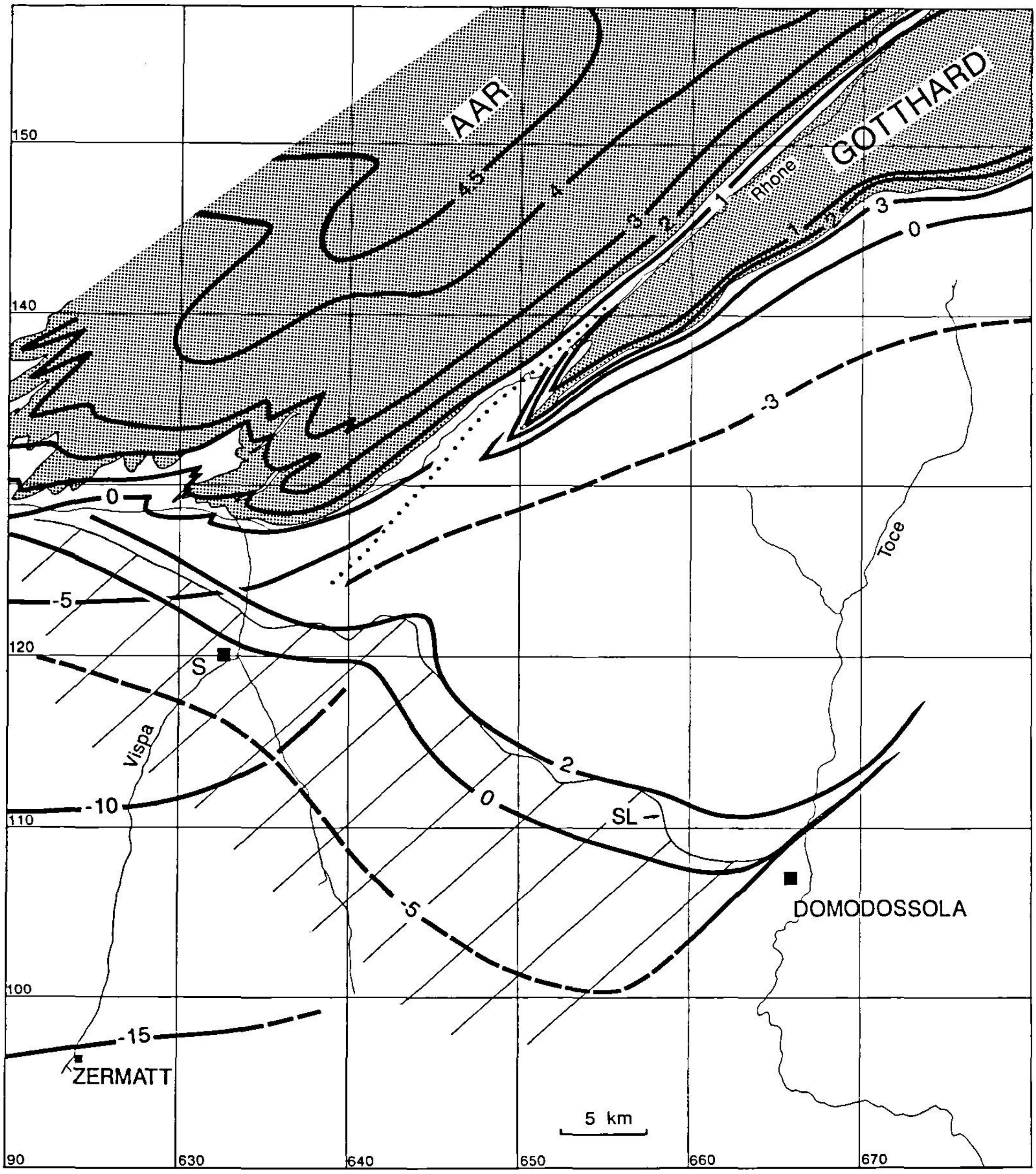


Fig. 4 Structure contour map for the basement-cover contact of the western part of the external basement massifs (grey) and contour lines for the Simplon Fault Plane (hatched). Dotted line marks change of contoured surface. S: Stalden.

and Mesozoic sediments of the Teggiolo Zone. These sediments seem to occupy a synformal position between the Verampio granite and the next higher Antigorio nappe according to LEU (1986).

The culmination of the Verampio-Baceno window (Fig. 5) reaches a maximum altitude of about 1200 m above sea level. The top surface of the window dips moderately from the culmination away to the south as indicated by the position of the 500 m contour line. The dip of the top surface away from the culmination to the north is inferred from the northward dip of the local foliation. The top surface of the Verampio-Baceno window is likely to connect with the top of a suite of Permo-Carboniferous to Mesozoic rocks outcropping in Val Cairasca, about 8 km to the west (SCHMIDT and PREISWERK, 1908). Except for the 1 km line, the contour lines in Val Cairasca are not constrained by surface data. However, the Antigorio nappe overlying the Verampio area has a thickness of approximately 2 km (see Fig. 6). This thickness and the contour lines of the top of the Antigorio nappe have been used to deduce the approximate position for the 0 m contour line in figure 5.

Therefore, an elongate shape can be inferred for the top of the Verampio-Baceno window. It also follows from figure 4 that the long axis of the Toce culmination is parallel to the extension direction (towards 240°, MANCKTELOW, 1985) ascribed to the Simplon phase of deformation.

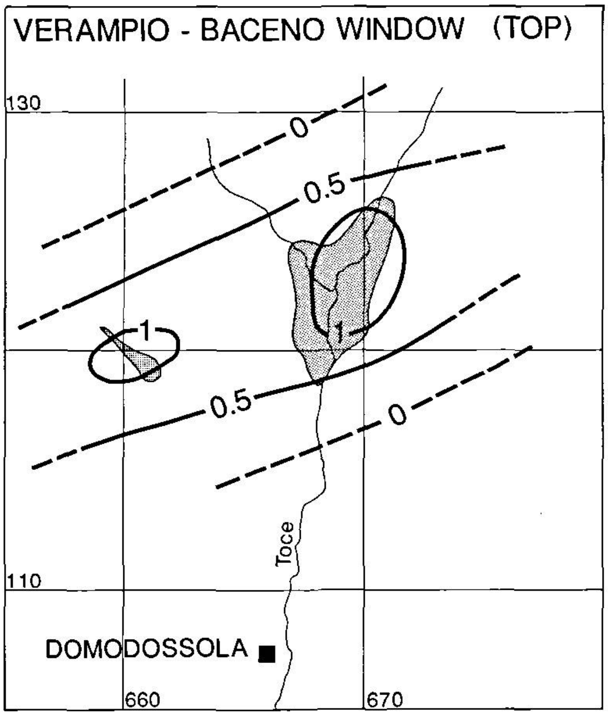


Fig. 5 Structure contour map of the Verampio-Baceno window (top). In this and the following maps the surface (map) extent of the particular basement rocks is shown by grey shading. Dashed contour lines: position interpreted.

b) Antigorio

The Antigorio nappe overlies the Verampio-Baceno window and surrounds the Bosco structure (Fig. 1) forming a western and an eastern part (= Pioda di Crana zone) of the nappe. The structure contours for the whole nappe are shown in figure 6. The basement-cover contact of the western part of the nappe is outlined by the overlying outcrops of marbles and schists (Bündnerschiefer) which are likely to represent the slightly detached cover of the Antigorio nappe.

In the southwest, the top of the Antigorio nappe dips moderately towards southwest. There, the foliation asymptotically approaches the orientation of the Simplon mylonites. Towards the north the basement-cover contact and the regional foliation of the Antigorio nappe becomes vertical and even overturned (0 m contour line in Fig. 6) to form a large frontal antiform. The geometry of the frontal steep zone has been extrapolated from the exposed segment and from local fold structures (GRECO, 1985). In the northwestern corner of the Antigorio nappe the development of this antiform is also related to the presence of a very weakly deformed orthogneiss within the Antigorio basement.

Comparison of the position of the top contacts of the western part of the Antigorio nappe and the Verampio-Baceno window shows that the western part of the Antigorio nappe is a 2 km thick slab of basement rocks. The overall geometry of this western part of the Antigorio nappe is that of an elongate dome with its long axis parallel to the southwest-northeast trending front of the nappe as well as parallel to the stretching lineation (Fig. 3b) observed to be related to the formation of the Simplon Fault Zone.

The eastern part of the Antigorio nappe, also termed the Pioda di Crana Zone, is responsible for the complex outcrop pattern of this nappe. The Antigorio nappe is folded around the Bosco structure with a major fold hinge observable at the Wandfluhhorn (e.g. HALL, 1972; MILNES, 1974b; KLAPER, 1988). The upper surface of the western part of the nappe becomes the lower contact of the eastern part due to this folding. This structure is responsible for the crossing of certain countour lines in figure 6 where both, the upper and lower contacts around the Bosco structure are represented. The position of the 2 and 1 km contour lines around the Bosco structure in figure 6 are well constrained by outcrop data. The position of the 0 m contour line is a matter of interpretation and depends on the geometrical concept applied to the

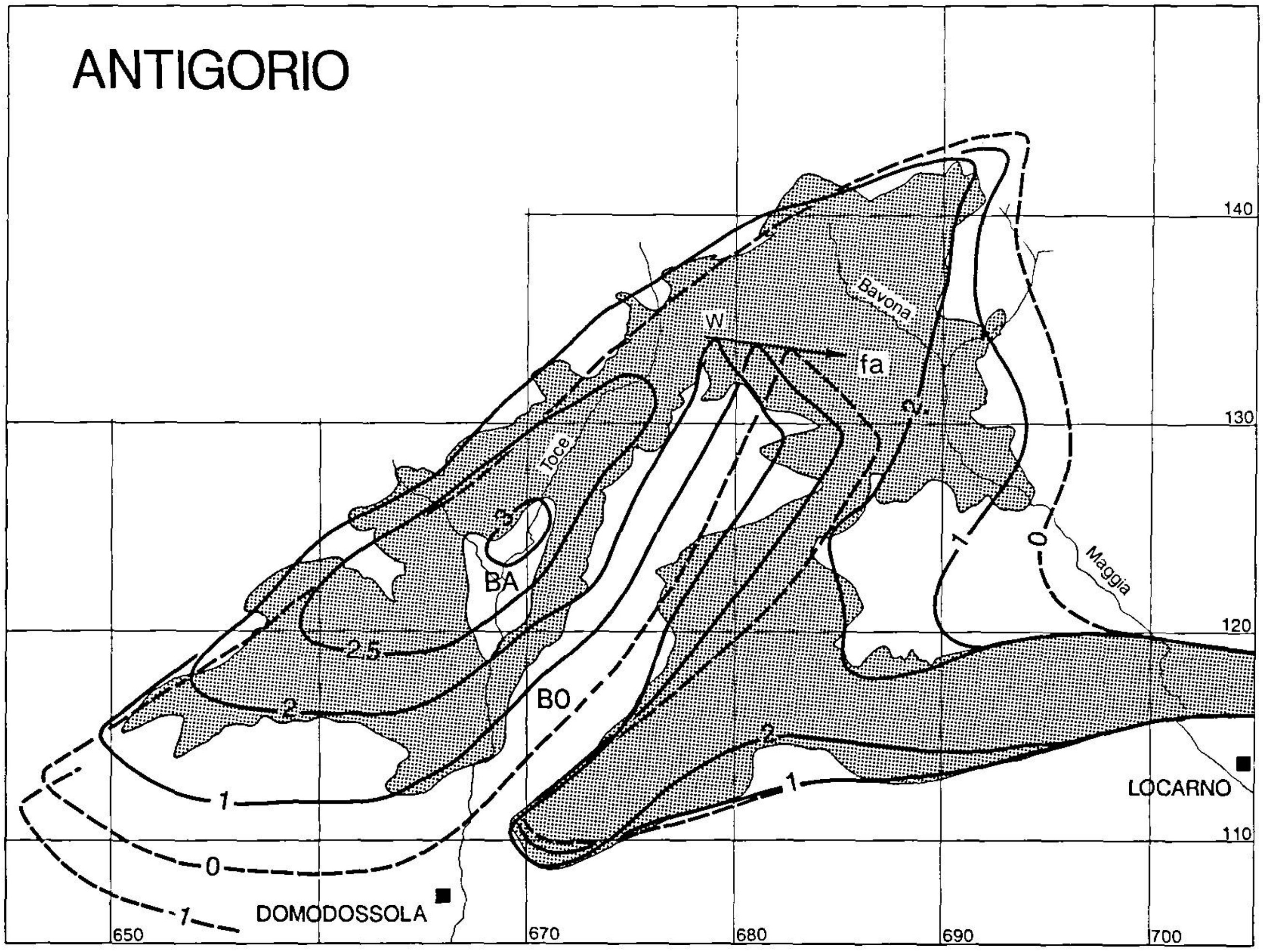


Fig. 6 Structure contour map of the Antigorio nappe (top and bottom contact). BA: Baceno-Verampio window, BO: Bosco structure, W: Wandfluhhorn fold, fa: Wandfluhhorn fold axis. Dashed contour lines: position interpreted.

Wandfluhhorn fold. In figure 6 a constant dip of the regional foliation has been assumed for the construction of the 0 m contour line. The northernmost points of the three contour lines surrounding the Bosco structure mark the position of the Wandfluhhorn fold axis (fa in Fig. 6). This orientation, 100/20, is also given from field evidence (HALL, 1972; KLAPER, 1988).

The top of the Pioda di Crana Zone, the eastern half of the Antigorio nappe, dips moderately to the east under the overlying Maggia nappe. The Antigorio–Maggia contact is marked by thin bands of Mesozoic marbles and Bündnerschiefer in the north and, less well defined, by small marble lenses along the contact towards south. In its southern part the foliation of the Pioda di Crana Zone is affected by backfolding in the southern steep belt (MILNES, 1974a).

There remains the kinematic problem of the spectacular duplication of the Antigorio nappe as seen in map view and of the continuation of the Wandfluhhorn hinge line. A discussion of the kinematic aspects of the internal deformation of the Antigorio nappe is beyond the scope of this paper. However, one possible interpretation for this duplication has been presented by MERLE and LE GAL (1988) and MERLE et al. (1989).

c) *Maggia*

The Maggia nappe forms the eastern boundary of the Toce subdome. The overall shape of the Maggia nappe has been described as synclinal structure (NIGGLI et al., 1936; MERLE and LE GAL, 1988) cutting across the strike of the Central Alps. The structural contours of the lateral contacts of the Maggia nappe with the Simano and Antigorio nappes have already been given in PFIFFNER et al. (1990, Fig. 8) and support a synformal geometry.

The head of the Maggia nappe is formed by a spoon shaped structure of basement rocks surrounding the Matorello granitoid body and overlying a large mass of Bündnerschiefer. The transverse part of the Maggia nappe has also been wrapped around a rigid body, namely the Cocco granodiorite (Fig. 7). The western contact of the Maggia nappe with the Antigorio unit dips moder-

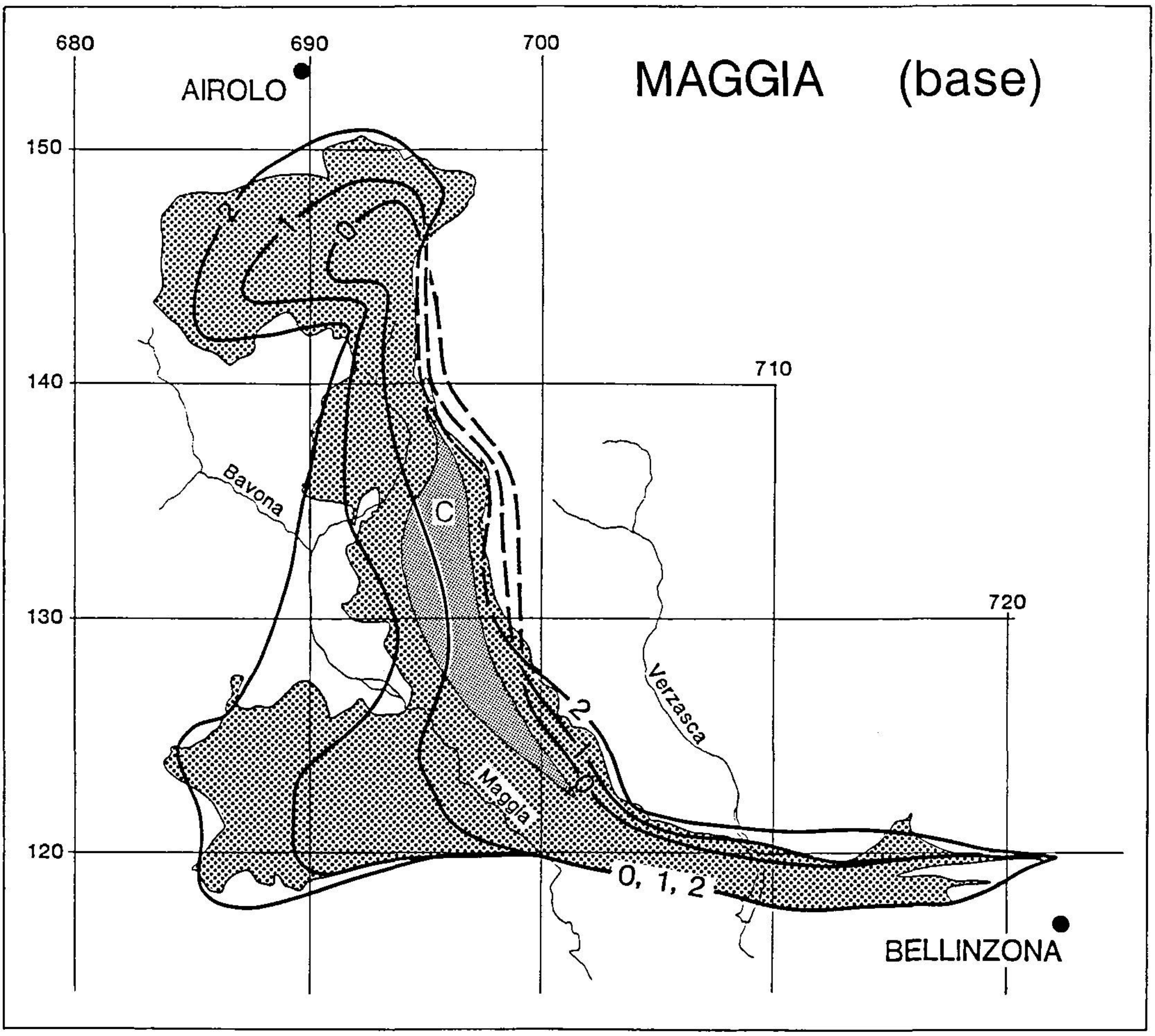


Fig. 7 Structure contour map of the Maggia nappe (basal and lateral contacts). C: Cocco Granodiorite. Dashed contour lines: position interpreted.

ately to the east and has been overprinted by a large open fold which is responsible for the "bulging" of the contact (KNUP, 1958) into the Antigorio nappe. Towards south, the eastern and the western contact of the Maggia nappe swing into an E–W direction and become vertical.

d) Lebendun

The Lebendun nappe which is shown in figure 7 has a very complex U-shaped outline in map view. The southwestern part of this sliver of rock is pinched in between the Antigorio and Monte Leone nappes. Towards the south the nappe terminates within the Bosco structure. There, the separation of the Monte Leone and Lebendun gneisses is difficult due to the lack of dividing Mesozoic rocks. In figures 8 and 9 the southeastern end of the nappe has been drawn according to WIELAND'S (1966) interpretation. In its eroded central part above the Verampio window, the Lebendun nappe has been horizontally overlying the western half of the Antigorio nappe (still visible on Monte Cistella) and very clearly outlined the dome structure. Towards the northeast the nappe first separates the Antigorio and Monte Leone nappes and then forms a band of varying thickness running all along the northern boundary of the Maggia nappe as far as Airolo. The original lateral extent of the Lebendun nappe is not known.

e) Monte Leone

The Monte Leone nappe overlies the western part of the Antigorio and the Lebendun nappes and shows an outline of similar complexity compared to the latter. The northern boundary of the nappe is parallel to the southern border of the

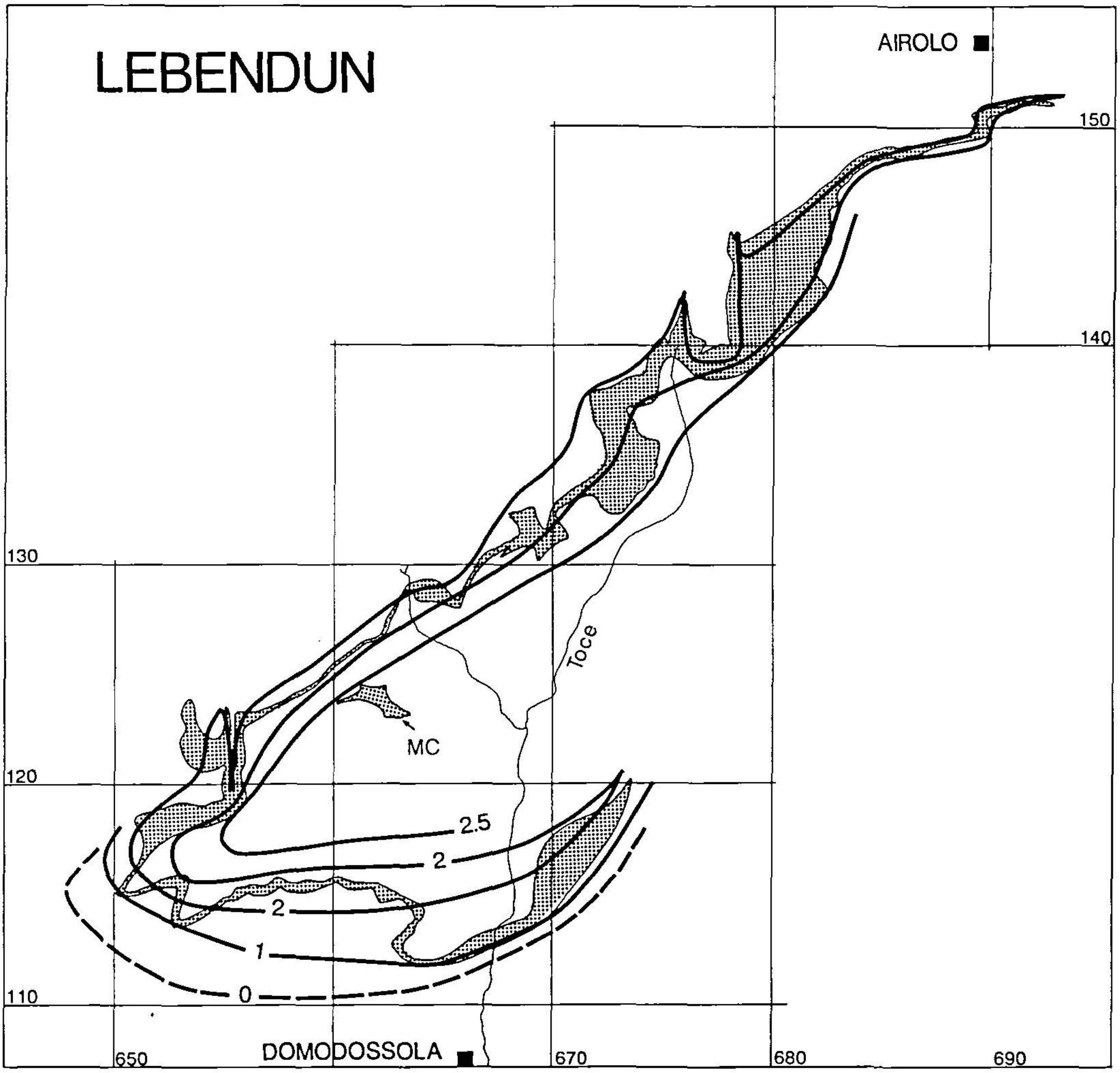


Fig. 8 Structure contour map of the Lebendun nappe (top and bottom contact). MC: Monte Cistella. Dashed contour lines: position interpreted.

Gotthard massif. This northern part of the Monte Leone nappe has been affected by the late backfolding phase (LEU, 1986). As is the case for the Lebendun nappe, the central flat lying part of the Monte Leone nappe that extended over the Verampio locality has been eroded except for a small area (Punta Valgrande / Monte Leone). The 3 km contour line is inferred from the regional foliation orientation, from the underlying nappe geometries and the thickness of the underlying units, but is not constrained by surface geology.

To the southwest the Monte Leone nappe is truncated by the Simplon Fault Zone. This southwesterly dipping fault zone is characterized in the Simplon Pass area (MANCKTELOW, 1985, 1990) by a young abrupt structural discontinuity (the Simplon Line) and a zone of ductile overprint (the Simplon Fault Zone). The pervasive mylonitic foliation associated with the Simplon phase of deformation is also clearly shown in figure 2a to parallel the Simplon Line. To the west, the Simplon Fault Zone follows the southern border of the Gebidum "Lappen" which is a westward digitation of the Monte Leone nappe and then runs into the Rhone valley. Towards south the Simplon Fault Zone can be traced to the Domodossola area where the foliation swings into the Bosco structure (MANCKTELOW, 1985).

Within the Bosco structure the Monte Leone nappe forms a thin wedge terminating at Alpe Bosa

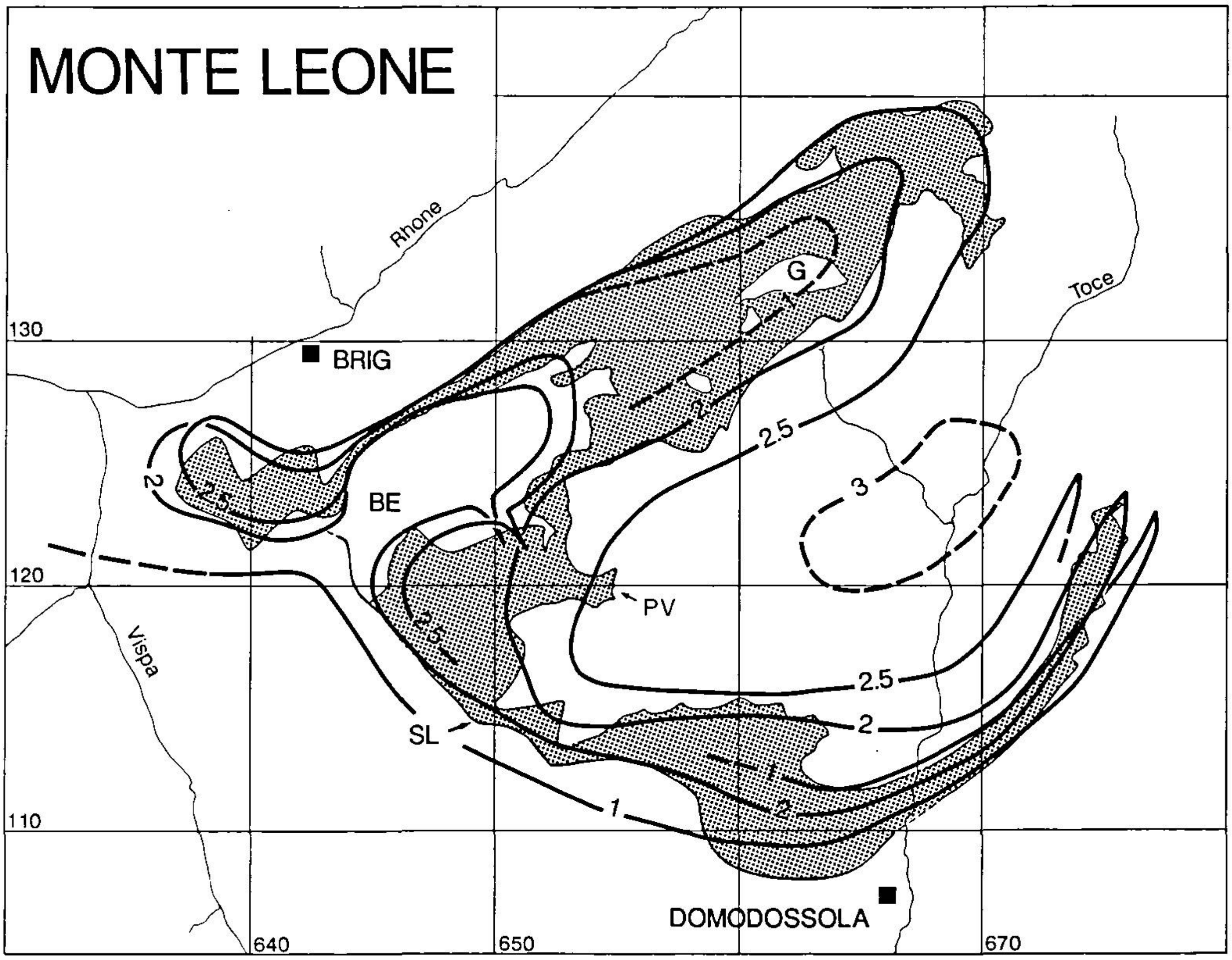


Fig. 9 Structure contour map of the Monte Leone nappe (top and bottom contact). BE: Berisal nappe, PV: Punta Valgrande. Dashed contour lines: position interpreted.

within the Bosco structure forming the core of a major fold hinge. This hinge is surrounded by rocks of the Bosco Series which in turn form the core of the Wandfluhhorn fold.

f) Berisal

The Berisal unit overlies the Monte Leone nappe in its northwestern part as shown in figure 9. It occupies a pre-backfolding synformal position. The southwestern part of the Berisal nappe is also cut off by the Simplon Fault Zone.

Conclusions

The basement-cover contacts which are shown in the cross-section in figure 2 indicate the presence of a stack of basement imbricates. The pronounced polyphase post-nappe deformation (folding and differential uplift) that overprinted this stack of imbricates is one reason for its complexity shown in figures 4 through 9. The 3-D geometry of the nappes is well constrained for depths above sea level by surface data. Going from north to south the following observations can be made.

The culmination of the Aar Massif (Fig. 3) above 4.5 km reflects the strong Alpine crustal shortening which is accommodated by a basement uplift in the external massifs and by a combination of thrusting and folding in the Penninic realm. Within the Penninic domain the structure can be characterized by multiple imbrication of basement slabs and subsequent folding. Based on lithostratigraphic features of the Mesozoic cover rocks, Leu (1986) distinguished an external part of the Penninic realm consisting of the Gotthard, Lebendun and Verampio units from an internal part consisting of the Antigorio and Monte Leone sheets. The western part of the Antigorio and the Monte Leone units have a typical thickness of less than 2.5 km and have lateral extensions of at least up to 30 times 40 km. Taking the external Gotthard-Lebendun-Verampio complex as a mega-unit forming the bottom of the internal lower Penninic pile of imbricates at least a 3-fold imbrication with overlaps exceeding 20 km can be observed. This allows for a rough estimate of minimum shortening across the lower Penninic nappes, disregarding the considerable internal deformation of the individual units.

The originally relatively planar topography of the basement-cover contact in the Penninic domain was severely affected by folding, differential uplift and by backfolding and backthrusting. From the presently available data the sub-Verampio structure is not known. Today all the nappe geometries are related to a characteristic elongate dome shaped structure, the Toce subdome (Figs. 2 and 3a).

The axis of the Toce subdome is parallel to the SW–NE trending stretching lineation that is related to the formation of the Simplon Fault Zone. This suggests that the formation of the Toce subdome and the Simplon phase of deformation are closely related in time. It could be shown by MANCKTELOW (1990) that a SW–NE oriented (gravitational) extension took place along the Simplon Fault Zone overlapping with a period where NW–SE directed compression was still active. The timing of these events (FRANK and STETTLER, 1979; HUNZIKER, 1974; HURFORD, 1986) shows that movements along the Simplon Fault Zone lasted from 19 m.y. to only 6 m.y. ago forming first the ductile mylonite zone and then the discontinuity as a last feature of the Simplon phase of deformation. The uplift of the Verampio area seems to have lasted until 15 to 12 m.y. ago (HUNZIKER and BEARTH, 1969; JAEGER, 1967).

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