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The Lavagna and Antola Nappes in the upper Lavagna and Bisagno Valleys (N. Italy)

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Abstract

Comprehensive structural geologic studies reveal a complex tectonic history of the Antola and Lavagna Nappes. Within the slightly metamorphic Lavagna Nappe the effect of five phases of folding have been established. The first phase (F1) is characterized by large isoclinal folds with an originally southwestern vergence. During the second phase (F2) large-scale open folding took place, whereas F3 and F4 produced folds with a northeastern vergence on a regional scale. These first four phases all produced co-axial folds with NW-SE trends. F5-folds are open and have an approximately NE-SW trend. Internal thrusting, associated with F1 and F3 has been established. After a first period of folding, the non-metamorphic rock sequences of the Antola Nappe thrusted over the Lavagna Nappe. Associated with this, thrusting within the S part of the Lavagna Nappe took place. The first four folding phases of the Lavagna Nappe and its metamorphosis were achieved prior to nappe-emplacement. The mutual stacking of the Antola and Lavagna Nappes must have taken place before the Eocene-Oligocene transition. Only F5 postdates the nappe-emplacement.

Introduction

The study area is situated just E of Genova, Italy. It comprises the upper drainage basins of the Lavagna and Bisagno Rivers within the Ligurian region (Fig. 1).

The Northern Apennines are made up of a pile of nappes of which the Ligurian units form the uppermost part. They are underlain by Tuscan and Romagnan-Umbrian units and are unconformably covered by the sequences of the Piemont Tertiary Basin (Fig. 1). The Ligurian units are composed of oceanic rock assemblages of Late Jurassic to Middle Eocene age. Internal thrusting of the Ligurian units already took place during the Early Paleocene (Van Wamel, 1987). Final emplacement of the Ligurides on top of the Tuscan units commenced during the Middle Miocene (Den Haan, 1979). Within the Ligurian pile, the Lavagna and Antola Nappes are the highest units and they are generally thought to have originated from the innermost zone of the Apenninic orogen. However, the palinspastic position of the Antola Nappe has never been established unambigiously (Van Wamel, 1987; Sagri & Marri, 1980).

The first comprehensive study of the geology of this particular region is from Casella & Terranova (1963) who described the stratigraphy in great detail and who constructed several geological sections through the area. Marini & Terranova (1980) made a comparison of the different lithologies throughout the Lavagna Nappe. Work on the tectonic structures includes that of Marini & Terranova (1977) who ran a traverse from the Voltri Massif into the Lavagna Valley and that of Casnedi (1982) who studied the relation between sedimentation

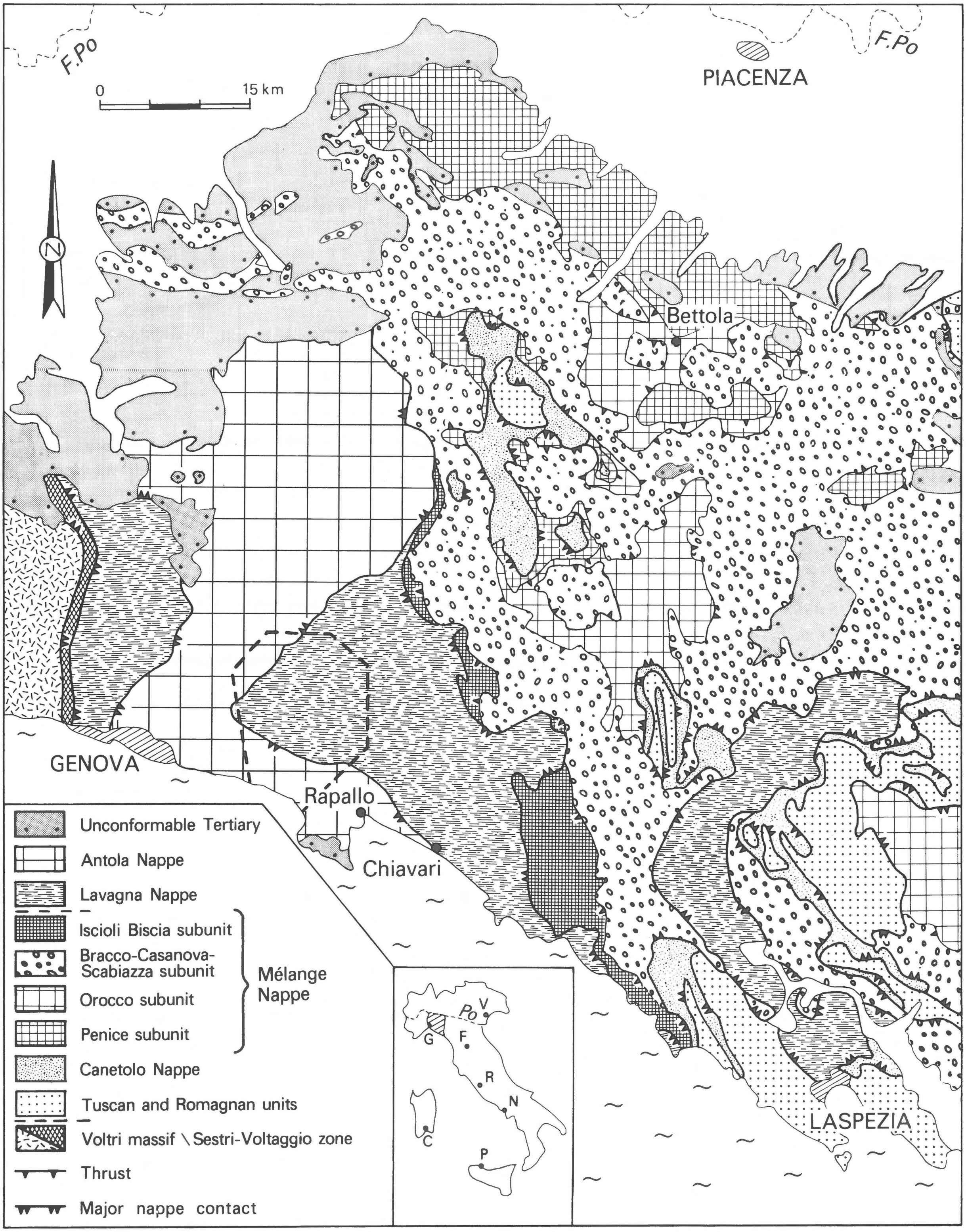

Fig. 1. Schematic structural geologic map of the northern part of the N. Apennines (after Van Wamel et al., 1985).

and tectonics. Pertusati & Horrenberger (1975) made an analysis of small-scale deformation structures, like parasitic folds, cleavage and lineations, and they were the first to distinguish several deformation phases in the field.

This point was taken up by Grandjaquet & Haccard (1977) in their regional study in which they applied the concept of polyphase deformation to the larger scale structures. The latter authors were the first to recognize the southwestern vergence of the first (isoclinal) folding phase which they related to a SW directed overthrusting of the Antola Nappe. The low grade metamorphism in the area has been studied by Bonazzi et al. (1987) by means of vitrinite reflectivity and illite crystallinity. In the region immediately E of the present study area Van Zutphen et al. (1985) made a structural analysis of the Lavagna Nappe, using microstructures as well as large-scale relations. Their study revealed the effect of five folding phases of which the first (F1) produced large isoclinal, originally SW-facing folds. A second phase (F2) led to the development of open folds without cleavage, whereas F3 and F4 generated NE-vergent folds with axial plane crenulation cleavages. A final (F5) phase of gentle folding was found by Van Zutphen et al. (1985) to be co-axial with F1-F4, causing undulations of the nappe boundaries. The methods used in the present study are identical to those used by Van Zutphen et al. (1985) and aim to reveal the complex tectonic history of the region and to compare its deformation phases with those earlier found by Van Zutphen et al. (1985).

Stratigraphy

The Lavagna Nappe

The stratigraphy of the Lavagna Nappe, in its most extensive development, consists of an ophiolitic base covered in sequence by an Upper Jurassic and Lower Cretaceous pelagic series and by Upper Cretaceous and Lower Tertiary flysch sequences. In the upper Lavagna Valley only the uppermost part from these series are found, in particular the flysches (see Fig. 2).

The *Scisti Manganiferi* are characterized by an alternation of black slates and grey manganese bearing sandstones, that were weathered to a dark-brown colour. The thickness of the sandstone beds ranges from 5 centimetres up to 1 metre. Especially the thicker beds show turbidite structures like sole marks, graded bedding and cross lamination so that top and bottom can be established reliably. The slates show a very good fissility and very often several families of cleavage planes can be distinguished. In the lower parts of the formation, especially in the Lavagna Valley, there are occurrences of brown and grey limestone beds which have been called pseudopalombini by Casella & Terranova. The age of the formation is Aptian-Albian (Casella & Terranova, 1963).

The *Scisti Zonati* consist of a very regular alternation of layers with blue/grey shales and brown siltstones with thicknesses of about 5 to 10 centimetres. The shales are fissile and often one can see refraction of the cleavage planes in the siltstone beds. Towards the contact with the overlying Ardesie di Monte Verzi/Arenarie Superiore the beds become thicker but keep their regularity. The age is Aptian to Cenomanian (Casella & Terranova, 1963). To the north the siltstone content increases and the shale nearly disappears.

The *Ardesie di Monte Verzi* and *Arenarie Superiore* are best developed in the region N and NW of Cicagna (Fig. 3). The *Ardesie di Monte Verzi* are characterized by thick (up to 2 metres) arcosic sandstone turbidites, alternating with beds of marl (ardesie) ranging up to 11 metres. Grainsizes in the turbidite beds vary from centimetre-scale rock-fragments at the base to millimetre-scale grains at the top. The marls are very fine grained and contain a slaty cleavage which in the turbidites turns into fracture cleavage. The age ranges from Late Albian to Cenomanian (Casella & Terranova, 1963). Because of their homogeneity and the presence of only one dominant set of cleavage planes the marls (ardesie) are excavated throughout the region for the production of rooftiles.

The *Arenarie Superiore* consist mainly of an alternation of sandy turbidites and black slates. In contrast to the Ardesie di Monte Verzi, intercalations of marl beds are only rare in the Arenarie

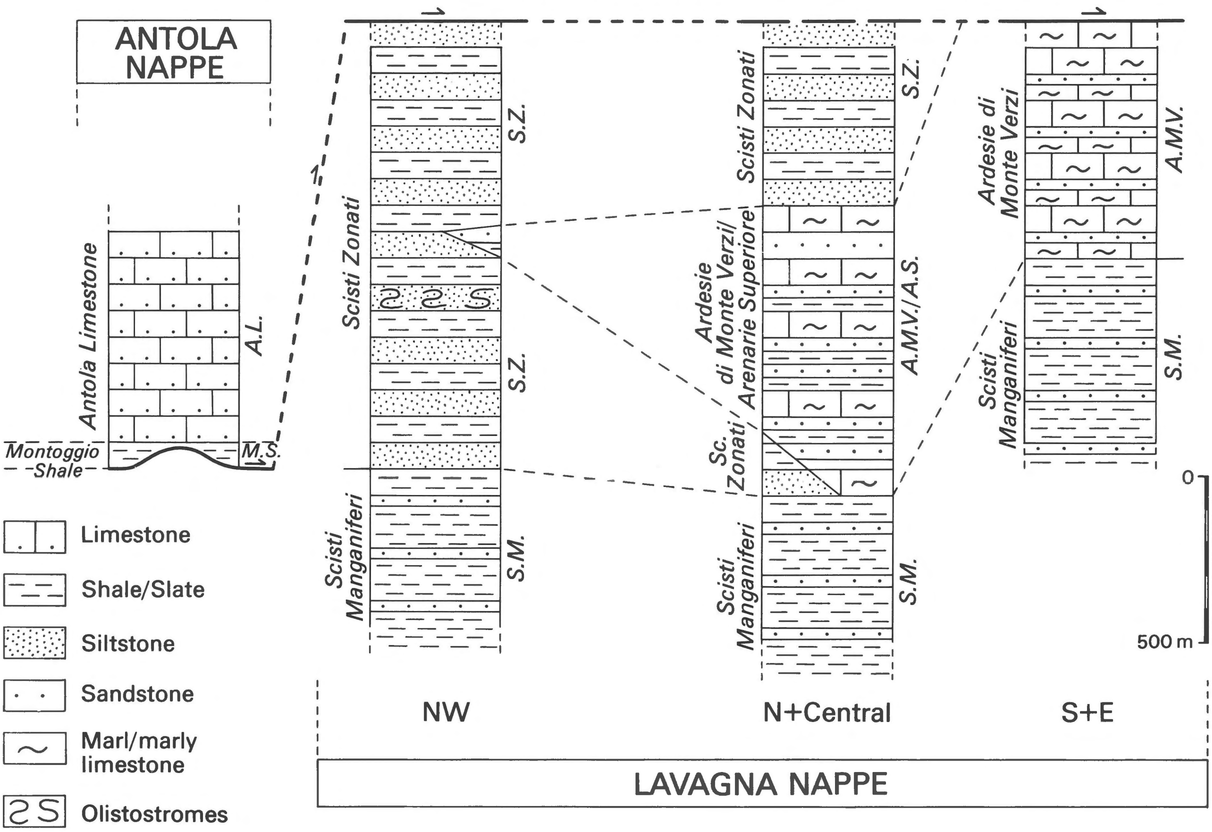

Fig. 2. Tectono-stratigraphic scheme of the studied region.

Superiore. Nilsen & Abbate (1985) included the Arenarie Superiore in the Gottero sandstone formation which in their opinion has been deposited as a deep marine fan. The occurrence in the present area has been interpreted as a distal part of the fan system which received its material from Hercynian rocks of Corsica (Sagri & Marri, 1980; Nilsen & Abbate, 1985). However, recent reconstructions by Van Wamel (1987) cast doubt on this assumed Corsican provenance of the Arenarie Superiore and Gottero sandstones. The age of the Arenarie Superiore is Albian to Cenomanian (Casella & Terranova, 1963).

Stratigraphic relations between the formations of the Lavagna Nappe

Casella & Terranova (1963) recognized that the lithostratigraphy in the region is characterized by lateral and vertical transitions between the formations. If we take the base of the Ardesie di Monte Verzi to represent one single event throughout the region, then the upper part of the Scisti Manganiferi must grade laterally into the Scisti Zonati. Also, the formations younger than the Scisti Manganiferi are lateral equivalents but the precise relations cannot be established due to the deformation and the low degree of outcrop. Nevertheless, we shall now describe some trends in the stratigraphy across the region (Fig. 2).

South of the Lavagna Valley the stratigraphy of the post-Manganiferi series is entirely made up of Ardesie di Monte Verzi. Here, the sedimentary transition from Manganiferi to Verzi is abrupt but in most cases the boundary between the two formations is clearly tectonic (Fig. 3). North of the Lavagna Valley the transition is more gradual and further along strike the Scisti Zonati appear at the boundary between Manganiferi and Verzi. The Scisti Zonati become more important to the northwest where eventually the Verzi marls wedge out.

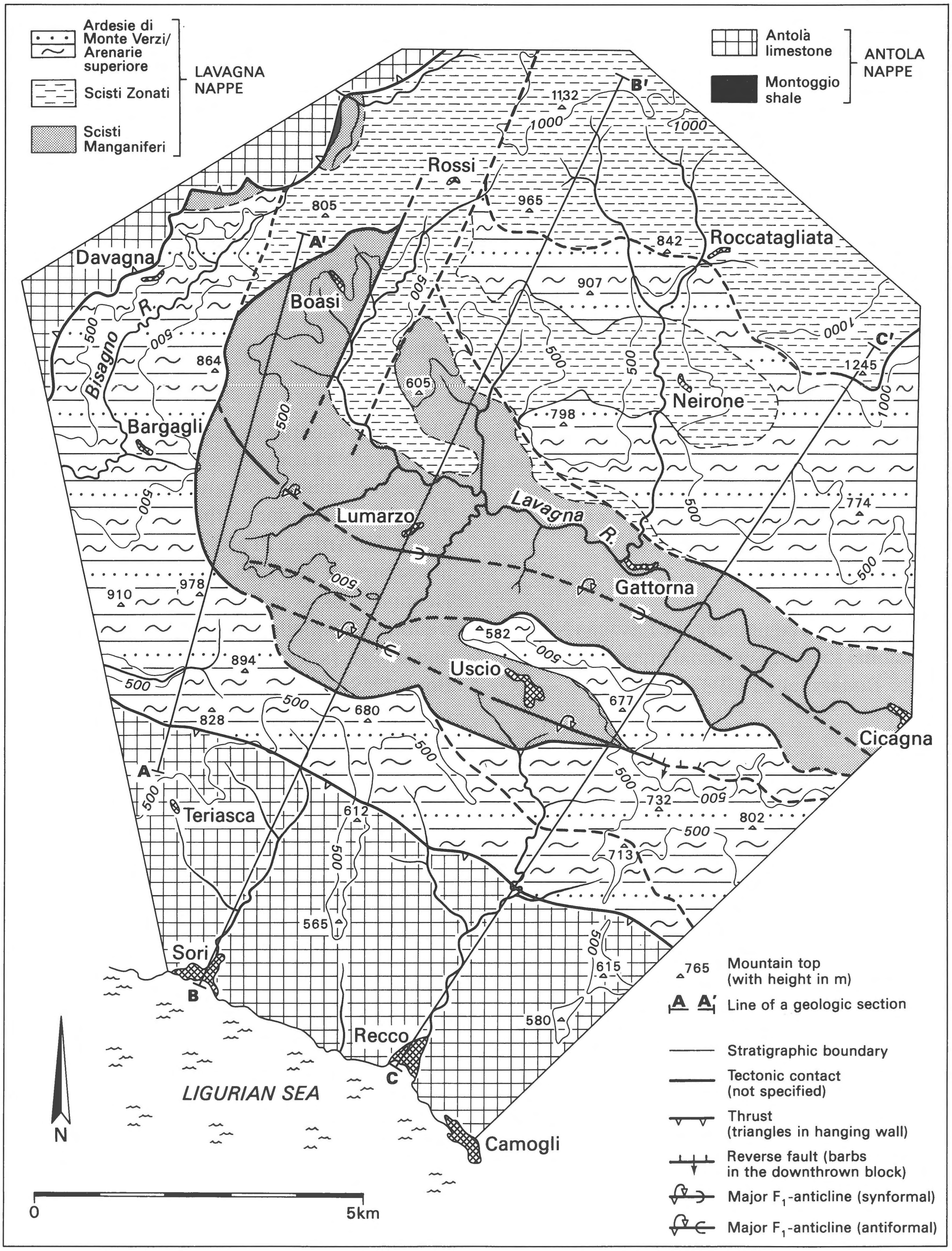

Fig. 3. Structural geologic map of the studied region.

In the NE part of the region the Ardesie di Monte Verzi seem to grade into the Arenarie Superiore. These are topped again by Scisti Zonati and wedge out towards the west, so that in the northwestern part the stratigraphy of the Lavagna Nappe is almost solely made up of Scisti Zonati with occasional lenses of Verzi marls. The re-occurrence of Scisti Zonati on top of the Arenarie Superiore, as well as the lateral transitions into the Scisti Zonati suggest that the whole Verzi/Arenarie Superiore complex comprises only a relatively short episode in the deposition history of a Scisti Zonati dominated basin.

If we compare the present column with that of the adjacent region around Monte Ramaceto (Van Zutphen et al., 1985) it follows that the Forcella siltstone in that region probably is equivalent to the higher occurrence of Scisti Zonati in the present area and therefore the Arenarie Superiore may be older than the Ramaceto sandstones.

Metamorphism
The rock sequences composing the Lavagna Nappe are anchizonal to upper-epizonal metamorphic according to Bonazzi et al. (1987).

The Antola Nappe

The Antola Nappe is the uppermost tectonic unit of the Northern Apennines. To the north it is bounded by the Varzi-Villavernia lineament and to the west by the Sestri-Voltaggio Zone (Fig. 1). No sedimentary relations are known between the rock sequences of the Antola Nappe and the stratigraphic units of underlying nappes. For this reason the Antola Nappe is often considered to be of distant, Alpine origin (Van Wamel et al., 1985).

The *Montoggio shales* form the discontinuous base of the Antola Nappe. These Cenomanian to Turonian (Abbate & Sagri, 1970) black shales are restricted to the area west of the upper Bisagno Valley, occurring at the supposed contact between the Antola- and Lavagna Nappe (Fig. 3). The shales show a moderate fissility but lack any consistent set of cleavage planes and in this respect they differ from the Scisti Manganiferi.

The *Antola limestones* constitute by far the bulk of the Antola Nappe. They consist of an alternation of thick calcarenitic turbidites, marls and shales. The base of the turbidites may contain flute- and groove casts while on top one often finds traces of Helminthoids (Fig. 4). Abbate & Sagri (1970) indicated a Turonian? to Maastrichtian age for the Antola limestones. North from the study area they are unconformably covered by the Paleocene/Eocene Albirola formation (Abbate & Sagri, 1970).

Metamorphism
The rock sequences from the Antola Nappe are non-metamorphic.

There is considerable confusion on the delineation of the Antola formation south of the Lavagna Valley (e.g. Marini & Terranova, 1980; Boni, 1969). This is primarily due to the close resemblance between the Ardesie di Monte Verzi and the Antola limestones in this area. Taking the occurrence of Helminthoids as indicative of Antola limestones, we found a boundary further southward than anyone before (see e.g. Casella & Terranova, 1963; Boni, 1969). This boundary coincides with a shear zone north of Teriasca (Fig. 3) as well as with an abrupt increase in metamorphic grade, determined by illite crystallinity and vitrinite reflectivity (Bonazzi et al., 1987).

Structural geology

Deformation in the Lavagna Nappe

The rocks of the Lavagna Nappe have undergone intensive polyphase deformation. By using the overprint relations of structural elements, like cleavage and lineations, we have been able to distinguish and characterize these phases.

Synsedimentary deformation, FO
Traces of slumping are occasionally present in the upper parts of the Scisti Manganiferi. Throughout the Scisti Zonati we found olistostromes with Palombini limestone components. The latter originate from a stratigraphic unit which underlies the

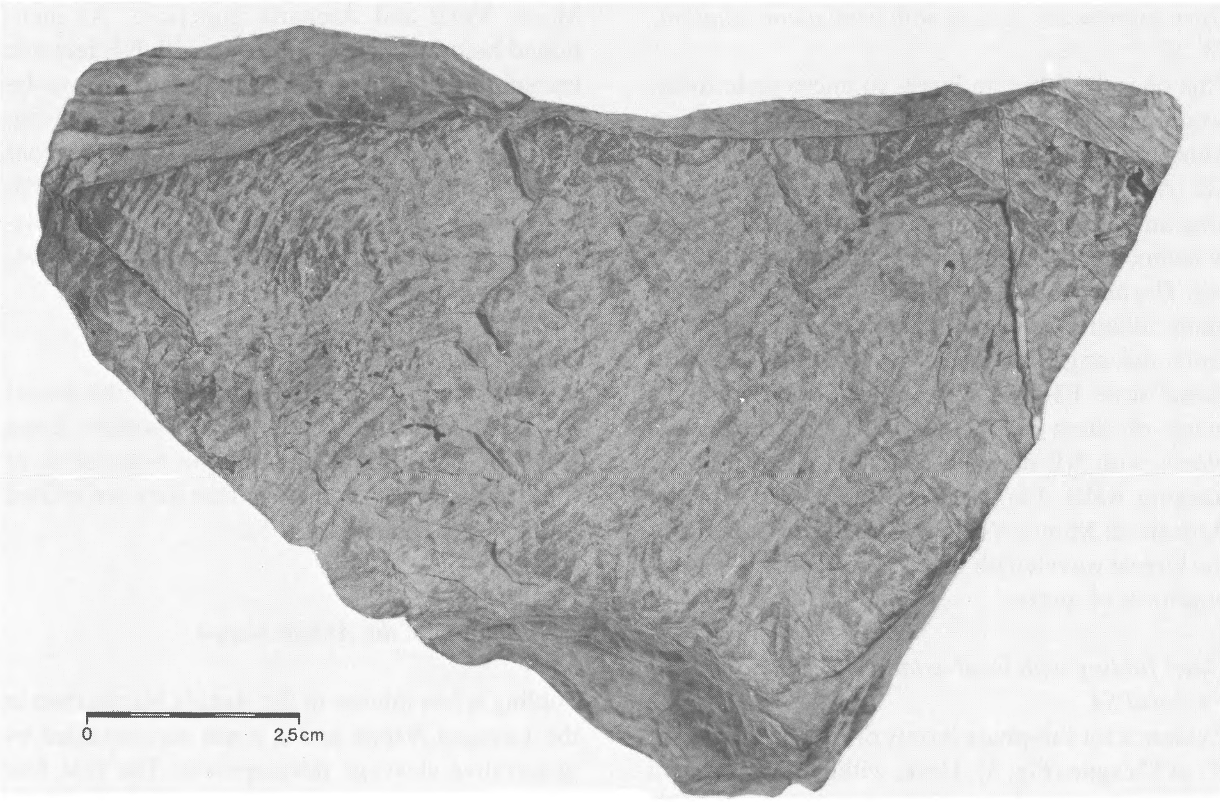

Fig. 4. Traces of Helminthoids from the Antola limestone, found north of Teriasca.

Scisti Manganiferi in the region east of the study area (e.g. Van Zutphen et al., 1985).

Isoclinal folding with axial plane foliation, F1, S1

This is the most intensive deformation phase in the area and it has resulted in isoclinal folding on scales ranging from several centimetres to 20 kilometres. It has been accompanied by a penetrative axial plane cleavage which is particularly well developed in the Scisti Manganiferi and the Scisti Zonati as slaty cleavage. The angle between the cleavage (S1) and the bedding is very small and the relation between the two may only be established reliably within the Scisti Manganiferi and Scisti Zonati. In the Ardesie di Monte Verzi and Arenarie Superiore S1 is only rarely visible, probably due to overprinting by S3. The F1-fold axes have a NW-SE subhorizontal orientation. Because of the intensity of the folding often only the beds in the hinge-zones of the parasitic folds are preserved while the limbs have been sheared out. In the thick-bedded Ardesie di Monte Verzi and Arenarie Superiore small- or meso-scale parasitic F1-folds have not been developed. The main F1-anticline in the area is situated in and around the Lavagna Valley (Figs. 3 and 5). Reconstruction shows that the original vergence of this first order F1-fold must have been SW, contrary to the folds resulting from later phases. The nearest main F1-structure is the Monte Ramaceto syncline (Van Zutphen et al., 1985), immediately east of the present area.

Open folding without axial plane foliation, F2

The most prominent effect of this phase is the folding of the axial surface of the main F1-anticline (Fig. 5). F2-folds have a steep axial plane and a maximum wavelength probably exceeding 10 kilometres; also parasitic F2-folds on decametre-scale have been found. The F2-fold axes are oriented NW-SE.

Open asymmetric folding with axial plane foliation, F3, S3

This phase resulted in large- to micro-scale folds, accompanied by a penetrative axial plane foliation which crenulates S1. F3-fold axes are oriented NW-SE. Asymmetric F3-folds have a slightly inclined long limb, almost lacking parasitic folds; the steeply inclined short limbs show intense parasitic folding. The angle between the long limbs and the axial plane foliation is up to 30°, whereas for the steep limbs this angle may measure up to 90°. On a regional scale F3-folds were originally NE-vergent, many of them show shearing along their axial planes with NE directed tectonic transport of the hanging walls. Large-scale F3-folds occur in the Ardesie di Monte Verzi and Arenarie Superiore, the largest wavelength of the F3-folds being several hundreds of metres.

Open folding with local axial plane foliation, F4, local S4

Evidence for this phase is only present in the region N. of Cicagna (Fig. 3). Here, within the Ardesie di Monte Verzi and Scisti Manganiferi open folds with a steep axial plane foliation (S4) overprint S3. The wavelength of the F4-folds amounts up to several metres, although Van Zutphen et al. (1985) concluded that F4 may be apparent on larger scales. F4-folds trend NW-SE.

Gentle folding without axial plane foliation, F5

In the study area only the western parts of the Lavagna Nappe seem to be affected by this phase. It is responsible for the bending of S0, S1 and S3 within the Lavagna Nappe from a general SE-NW trend to a NNW-SSE trend (Fig. 3). Bending seems to have occurred around NE-SW directed axes during F5.

Thrusts

In the Lavagna Nappe faults often coincide with formation boundaries and/or bedding. In some cases these faults form the boundary between sequences of beds with opposite sedimentary younging and most probably these faults were initiated during the isoclinal folding (F1). They are particularly common in the thick-bedded Ardesie di Monte Verzi and Arenarie Superiore. As mentioned before, internal thrusting with NE tectonic transport of the hanging walls was found to be associated to F3. The thrusts dissecting the Lavagna Nappe between the Lavagna River and the front of the Antola Nappe (Fig. 3) cut F1-, F2- and F3-structures. There is no indication for an age relation with F4. Most probably these thrusts are related to the emplacement of the Antola Nappe.

High angle faults

A set of NNE-SSW striking normal faults dissect F1- to F3-structures in the region around Boasi (Fig. 3). Taking into account the orientation of these faults, it seems possible that they are related to the last folding phase (F5).

Deformation in the Antola Nappe

Folding is less intense in the Antola Nappe than in the Lavagna Nappe and it is not accompanied by penetrative cleavage development. The first fold generation in the Antola Nappe trends ESE-WNW in the southern part of the region. In the west this trend is NNW-SSE, due to refolding around a NE-SW oriented axis. This latter folding phase is probably equivalent to F5, earlier described from the Lavagna Nappe.

The basal thrust of the Antola Nappe constitutes a 40 to 50 metres thick shear-zone. Intense intermixing of hanging wall and foot-wall material occurs in this zone, which dips approximately 60° to the SSW in the southern part of the area. Here, drag structures and slip-striations indicate a NW to NE direction of tectonic transport. The Antola thrust cuts off F1-, F2- and F3-structures in the Lavagna Nappe and it seems to be folded by F5.

Discussion

Comparison with earlier studies

The present results differ considerably from those obtained by earlier workers like Casella & Terranova (1963), Marini & Terranova (1977) and Cas-

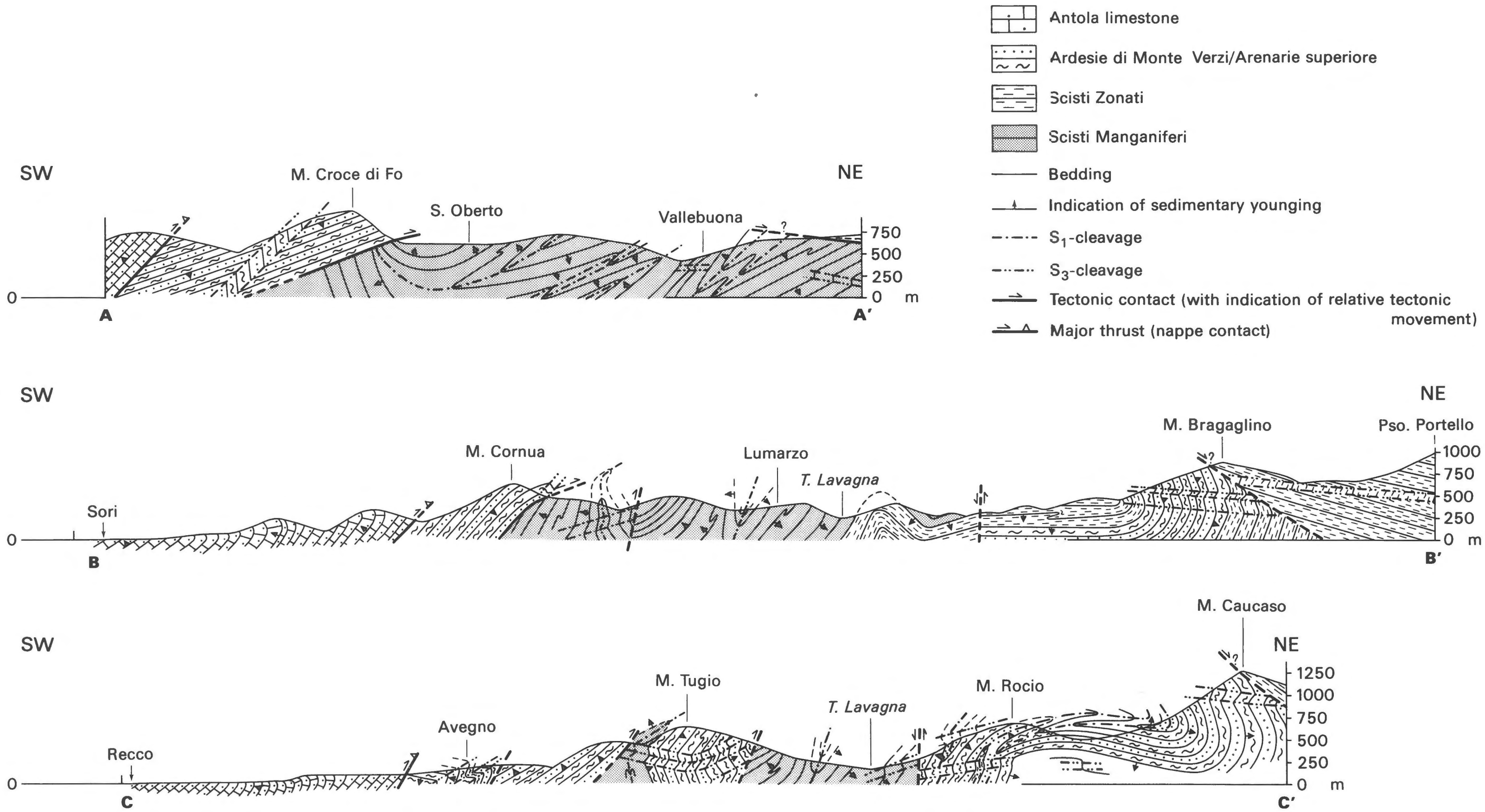

Fig. 5. Geologic sections. For their location see Fig. 3. No vertical exaggeration.

nedi (1982). The most dramatic difference is the interpretation of the main F1-structure in the Lavagna Valley, which previously has been considered to be an anticline but in fact is a synformal anticline (Fig. 5). The latter interpretation has primarily been derived from the S1/S0 relations found within the Scisti Manganiferi on both limbs throughout the region. Moreover, the direction of sedimentary younging on both limbs indicates that this synform in fact is a SW-, downward facing F1-anticline. It seems highly interesting to compare our results to those of Pertusati & Horrenberger (1975), since they used similar methods in the adjacent region of Monte Ramaceto. Pertusati & Horrenberger (o.c.) recognized two phases of folding, both accompanied by the development of cleavage. These correspond to our F1 and F3. Since they concentrated their observations on isolated sections in the region, they were not able to distinguish our F2. It is possible that our F4, due to its local nature, has not been developed in their sections.

Our results are comparable to those of Grandjaquet & Haccard (1977) as far as the overall fold geometries and vergences within the Lavagna Nappe are concerned. These authors, however, connected the generation of the SW-vergent F1-folds of the Lavagna Nappe with southward thrusting of the Antola Nappe. In our opinion it is very unlikely that the emplacement of the Antola Nappe took place during F1, since the basal thrust of the Antola Nappe was found to cut off F3-structures. On these grounds we suggest that the Antola Nappe was emplaced during or after F3.

Comparing the present results with those of Van Zutphen et al. (1985) we note that they agree well for F1 to F4. The gentle folding (F5) recognized by Van Zutphen et al. (1985) is more or less co-axial with F1-F4. On the other hand, F5 distinguished in the present paper is approximately perpendicular to F1-F4. Since our F5 appears to be limited to the western part of the area, it is possible that it did not develop in the Ramaceto region, studied by Van Zutphen et al. (1985).

Timing of the tectonic events

The first indications for tectonic movements are apparent in the stratigraphic record (Fig. 2) in the form of syntectonic deposits like turbidites and olistostromes, which started during the Aptian. Synsedimentary tectonic activity continued till the Cenomanian, as is proved by thick-bedded turbidite formations such as the Arenarie Superiore. From the Paleocene age of the youngest formation of the Lavagna Nappe, the Giariette shales (Van Zutphen et al., 1985), and the occurrence of F1-structures within these it can be concluded that F1 was still active during or after that period. Since the contact between the Antola- and Lavagna Nappe is unconformably covered by Eocene-Oligocene sediments west of the studied area (Fig. 1), it follows that their mutual stacking had been accomplished before the Eocene-Oligocene transition (see also Van Wamel et al., 1985). The F1- to F4-structures and metamorphosis are restricted to the Lavagna Nappe, this implies that they were also generated before the Eocene-Oligocene transition. Only the last folding phase (F5) postdates nappe-emplacement and thus may be of Eocene-Oligocene or of a younger age.

Conclusion

The tectonic history of the Lavagna Nappe in the upper Lavagna and Bisagno Valleys is far more complex than previously assumed. After a comprehensive structural analysis, on both large- and small-scale, we have been able to establish a tectonic history of five folding phases, the first having an originally southwestern vergence. The first four phases (F1 to F4) are co-axial with a NW-SE trend, the last phase (F5) has an approximately NE-SW trend. Emplacement of the Antola Nappe took place between F3 and F5, before the Eocene-Oligocene transition.

The stratigraphic relations suggest that the Arenarie Superiore and Ardesie di Monte Verzi of the study area are merely members of the Scisti Zonati Formation. Moreover, the Arenarie Superiore of the present region may be older than the Ramaceto sandstone (Van Zutphen et al., 1985) to the east.

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