Geologie en Mijnbouw 64: 373-384, 1985

The structure of the Lavagna Nappe in the region of Monte Ramaceto and Val Graveglia (Ligurian Apennines, Italy)

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Received 27 March 1985; accepted in revised form 4 October 1985.

Abstract

Van Zutphen, A.C.A., W.A. van Wamel & A.J. Bons 1985 The structure of the Lavagna Nappe in the region of Monte Ramaceto and Val Graveglia (Ligurian Apennines, Italy) – Geol. Mijnbouw 64: 373-384

Detailed structural analysis and mapping in the Lavagna Nappe reveals the effect of various phases of deformation on a regional scale. The earliest phase produced large isoclinal, originally SW-facing folds (F_1). A second phase led to the development of open folds (F_2). The vergence of the younger folds (F_3, F_4) is NE.

Thrusting occurred in two stages: postF_2-preF_3 and synF_4. Hereafter the previously stacked thrustsheets, together forming the Lavagna Nappe, were emplaced on top of the Mélange Nappe by NE-directed thrusting. A final phase of gentle folding (F_5) caused an undulation of all older structures.

Introduction

The Lavagna Nappe in the Ligurian Apennines is tectonically situated below the Antola Nappe and above the Mélange Nappe (Van Wamel et al. 1985). It is made up of mainly clastic sediments of Cretaceous and Palaeocene age, most probably deposited on oceanic crust (a.o. Galli et al. 1972). The formation of oceanic crust in the Ligurian domain started in the Late Jurassic (Decandia & Elter 1972; Bernoulli & Jenkyns 1972). At the end of the Early Cretaceous the tensional regime changed to compressional, and from the Palaeocene the sedimentary pile was subjected to intense deformation (Van Wamel et al. 1985).

The structure of the Lavagna Nappe has been studied by several authors. Pertusati & Horrenberger (1975) studied mesoscopic folds and the associated microstructures and distinguished various phases of folding. They did not extend their interpretations to a macroscopic scale.

The dominant macrostructure in the studied area is a horseshoe-shaped mountainridge formed by a thick sandstone formation (figure 1: Ramaceto sandstone formation). Previous studies present various controversial explanations for this structure. It has been interpreted as a synformal syncline (Terranova 1966; Casnedi 1982), but also as a antiformal syncline (Grandjacquet & Haccard 1977).

The present study presents the result of detailed structural analysis and mapping in the Lavagna Nappe, revealing the effect of multiphase folding on a regional scale.

Stratigraphy

The stratigraphy of the Lavagna Nappe shows lateral variations, illustrated in figure 2. The following formations have been defined by the authors*.

Palombini shale formation

The oldest outcropping rock in the Lavagna Nappe belongs to the Palombini shale formation. It mainly consists of alternating light grey very fine grained limestones and dark grey to black shales. The

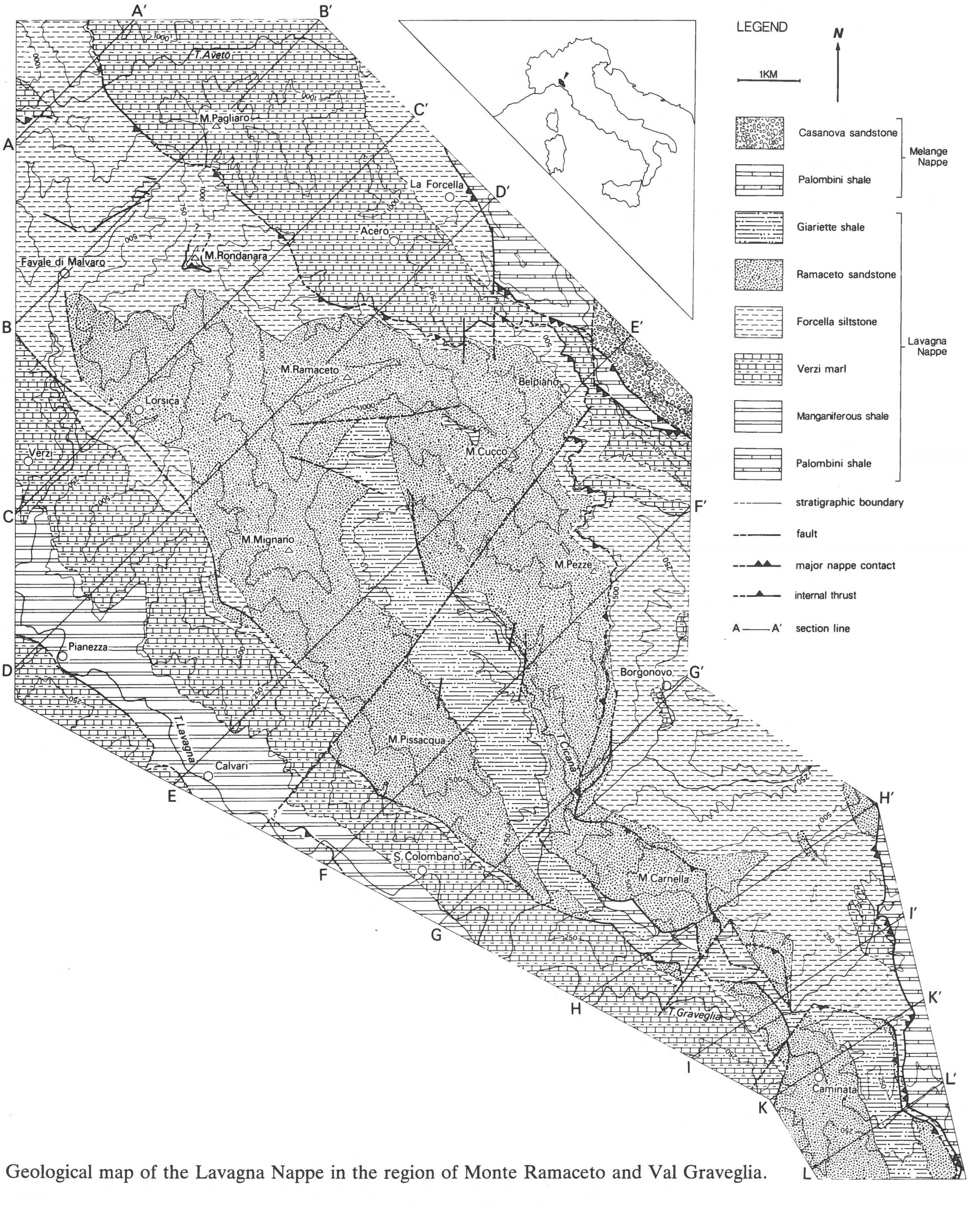

Fig. 1. Geological map of the Lavagna Nappe in the region of Monte Ramaceto and Val Graveglia.

limestone beds commonly are several tens of centimetres thick and are silicified at their top and base. The shale beds vary in thickness from a few centimetres to several metres.

There is a gradual transition from the Palombini shale formation to the overlying Manganiferous shale formation.

The limestone beds are interpreted as distal turbidites of resedimented hemipelagic calcilutite (Decandia & Elter 1972).

Manganiferous shale formation

The Manganiferous shale formation mainly consists of manganiferous shales with violet-brown weathering colours. The shales are regularly interbedded with siltstones and fine grained sandstones. The interbeds are generally up to 30 cm thick, and are often graded.

The formation grades into the overlying Verzi marl formation.

The siltstones and fine grained sandstones are interpreted as distal turbidities of terrigenic clastics, intercalated in hemipelagic shale.

Verzi marl formation

Characteristic for the Verzi marl formation are light-grey marls up to 10 m thick, with thin interbeds of arenite and shale. The marls mostly have a good fissility, for which they are mined in numerous small quarries. The arenite beds occasionally have flute and groove casts at their base.

*In the literature various names have been used for the formations in this area. Current synonyms are:
Palombini Shale: Argille a Palombini, Argille Scagliose con Palombino.
Verzi Marl: Ardesie di Monte Verzi, Ardesie di Monte Campenardo.
Forcella Siltstone: Argilloscisti Zonati, Scisti Zonati.
Ramaceto Sandstone: Arenarie di Monte Ramaceto, Arenarie di Monte Zatta, Arenarie di Monte Gottero, Arenarie Superiori.
Giariette Shale: Argilliti di G(h)ia(r)iette, Argilliti di Cichero, Argilliti di Passo del Bocco, Scisti Policromi.
Manganiferous Shale, Verzi Marl and Forcella Siltstone have often been grouped under the names Formazione di Val Lavagna or Argilloscisti della Val Lavagna.

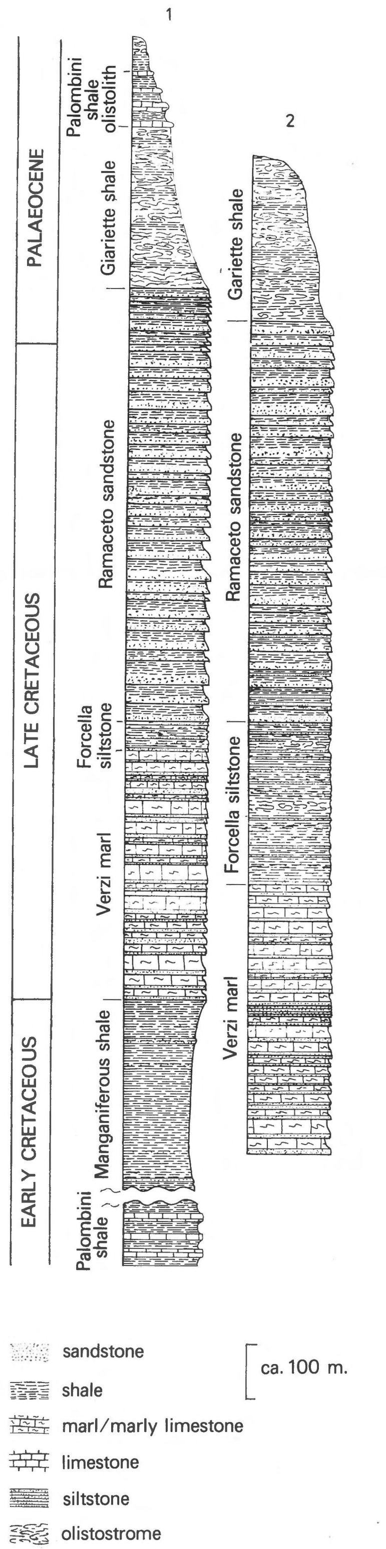

Fig. 2. Stratigraphy of the Lavagna Nappe; 1) for the SW part; 2) for the NE part. Dating after Abbate & Sagri (1970).

The formation grades upwards and laterally into the Forcella siltstone formation.

The Verzi marl formation is interpreted as a sequence of terrigenous clastic turbidites.

Forcella siltstone formation

The Forcella siltstone formation is comprised of light-grey shale and laminated light-brown siltstone, occasionally interbedded with marl. Slumps and olistostromes, containing material derived from the underlying Palombini Shale and Manganiferous Shale are abundant.

Upwards, the formation grades into the Ramaceto sandstone formation; the top of the formation is chosen at the lowest 1 m thick sandstone bed.

The Forcella siltstone formation is interpreted as a turbidite sequence.

Ramaceto sandstone formation

The Ramaceto sandstone formation is characterised by arkosic sandstone beds, up to several metres thick, often with groove, load or flute casts at the base of the beds. The sandstone beds grade upwards into dark silty shale, that may reach thicknesses of up to 3 m.

The formation is interpreted as a turbidite series, deposited as a prograding fan (Casnedi 1982).

Giariette shale formation

The Giariette shale formation is mainly made up of multi-coloured shales, occasionally with interbeds of siltstone and sandstone. Olistostromes are abundant and may contain material derived from all outcropping formations in the Lavagna Nappe; a more than 100 m thick olistolith of Palombini Shale is present south of Monte Carnella.

The Giariette Shale is the youngest formation in the Lavagna Nappe. After its deposition sedimentation stopped (Abbate & Sagri 1970; Dalan-Nardi & Nardi 1975).

The stratigraphy of the *Mélange Nappe* is described by Van Wamel et al. (1985).

Structural geology

The rocks of the Lavagna Nappe have been affected by several phases of deformation. Synsedimentary deformation was succeeded by eutectonical deformation, including 5 more or less coaxial phases of folding (F_1-F_5), thrusting and normal faulting. A summary of the deformation history is schematically shown in figure 3.

Synsedimentary deformation structures

Distinction between folds related to slumping and eutectonical folds in general is delicate, especially in an area where both occur. However, in many localities the folds can be clearly attributed to either slumping or to one of the eutectonic folding phases, using the criteria given by Rupke (1978) and Woodcock (1976). In addition to slumps,

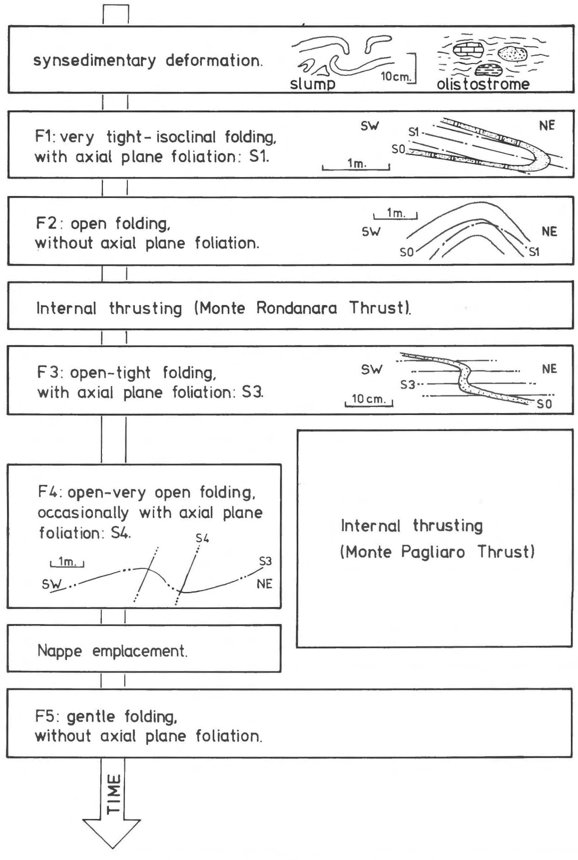

Fig. 3. Summary of the deformation history of the Lavagna Nappe and the expression of the deformation on a mesoscopic scale.

Fig 4. Isoclinal F_1-fold in the Forcella Siltstone near la Forcella.

olistrostromes are often observed (Naylor 1981, 1982). Synsedimentary deformation was generated by a gentle south-west dipping slope, most probably caused by the compression which began at the end of the Early Cretaceous and persisted at least until in the Palaeocene (Van Wamel et al. 1985).

Very tight to isoclinal folds with axial plane foliation: F_1, S_1

Isoclinal folds have been observed on both a regional and an outcrop scale (figure 4). On a regional scale the folds usually are apparent from abrupt changes in the direction of younging. The isoclinal folding was accompanied by the development of an axial plane foliation (S_1). S_1 can be recognized in many outcrops as a slaty cleavage intersecting bedding at a low angle. The associated deformation was locally accompanied by boudinage and transposition. The analysis of the structure reveals the existence of NW-plunging, isoclinal SW-facing folds on a regional scale.

Open folds without axial plane foliation: F_2

In some outcrops open folds without axial plane foliation are recognized. These folds affected bedding and S_1 preserving their original relationship. The relative timing of the F_2-folding is demonstrated by the overprinting of these curved bedding-S_1 relationships by the generally horizontal S_3 foliation, that crenulates S_1 and bedding (figure 5).

The S_3 foliation commonly shows a large angle to both bedding and S_1, but in a number of localities S_3 is almost parallel to bedding and S_1. This phenomenon demonstrates the effect of the second phase of folding on a regional scale.

The analysis of the structures reveals that the initial orientation of the axial plane of F_2 was almost vertical with a NW-SE strike.

Tight to open folds with axial plane foliation: F_3, S_3

Tight to open folds, with an axial plane foliation that is developed as a horizontal to slightly dipping disjunctive or crenulation cleavage (S_3), are abundant in the studied area. Generally the folds are asymmetrical with a long horizontal limb and a short steep limb. The angle between the horizontal limb and the axial plane foliation is at most 30°, whereas for the steep limbs the angle may reach values up to 90°. The deformation is more apparent in the steep limbs where parasitic folds occur more frequently and cleavage is more pronounced.

In a number of localities F_3-folds show signs of shearing along their axial planes, the upper limbs being displaced to the NE with respect to the lower limbs.

On a regional scale F_3-folds are NE-vergent and F_3-foldaxes trend SE-NW. F_3-folds are tighter as they overprint deeper parts of the pre-existing F_1-F_2 structure.

Open to very open folds with steep axial plane: F_4, S_4

Open folds with a steep axial plane are present in a number of outcrops. In the deeper parts of the regional structure these open folds are occasionally

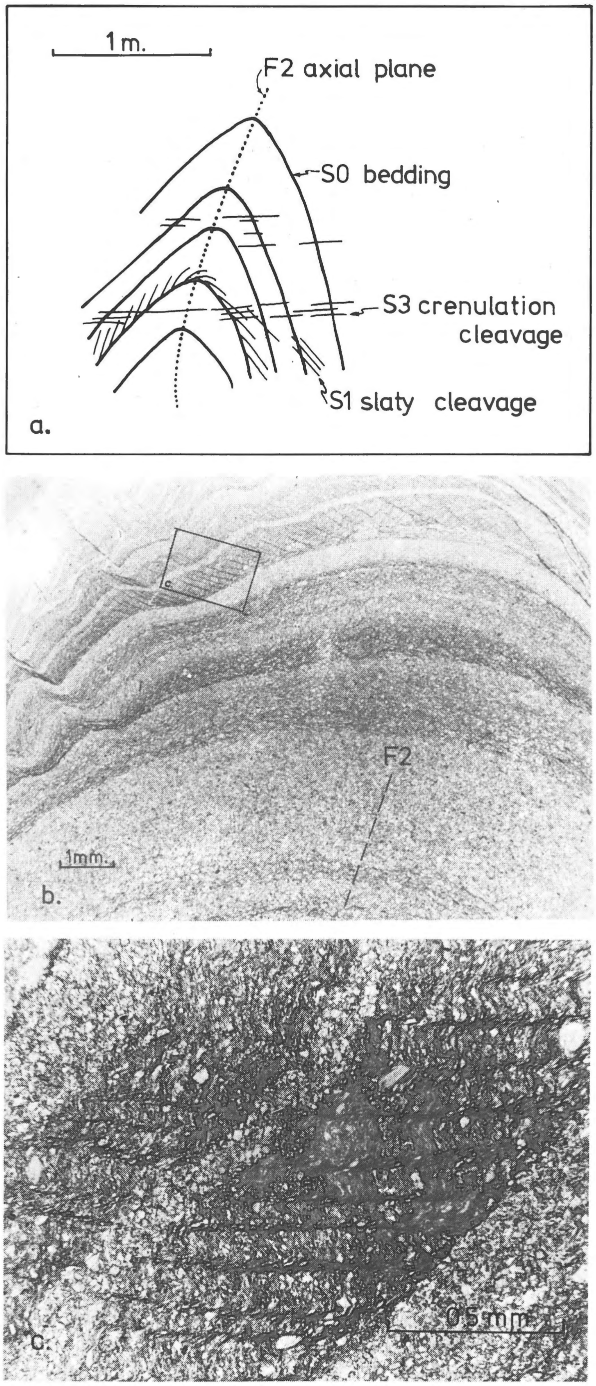

Fig. 5. F_2-folds in the Forcella Siltstone in the Upper Val d'Aveto:

a. sketch of the outcrop, showing relations between bedding, S_1-cleavage, F_2-axial plane and S_3-crenulation cleavage;
b. micrograph of F_2-folding;
c. detail of figure b, showing S_1 and S_3-cleavage morphology.

associated with a crenulation cleavage (S_4). On a regional scale these folds cause an undulation of S_3.

Gentle folds without axial plane foliation: F_5

Gentle folds have been recognized on a regional scale by the undulation of nappe boundaries (Van Wamel et al. 1985). F_5-folding is more or less coaxial with F_1-F_4.

Thrusts

Thrusting occurred at various stages in the deformation history. In outcrop, the thrustplanes consist of zones rich in cataclastics, occasionally with many veins, disharmonic folds and deformed cleavages. The thrusts, bordering the Lavagna Nappe postdate F_3 as they dissect the F_3-structure, and S_3 is observed to have been deformed within the thrustzones. Two internal thrusts have been observed. The M. Rondanara Thrust is dated postF_2-preF_3, as it dissects the F_2-structure on a regional scale and is folded by F_3. The M. Pagliaro Thrust is dated postF_3-preF_5 because it intersects the F_3-structure and is folded by F_5.

The sections (figure 6) and the geological map (figure 1) show the result of deformation on a regional scale.

The internal Monte Pagliaro Thrust (postF_3-preF_5) divides the Lavagna Nappe in two parts along the line Monte Pagliaro - Belpiano - Monte Pezze - Monte Carnella - Frisolino. This internal thrust has been correlated with a sudden change in illite crystallinity, indicating a higher grade of anchizone metamorphism in the upthrown SW-block.

NE of the Monte Pagliaro Thrust horizontal SW-vergent F_1-folds are overprinted by gentle SW-dipping S_3-cleavages. F_3-folding locally resulted in steeply inclined upward facing F_1-folds.

The southwestern part of the area has a more complicated structure because of the influence of F_2. Due to F_2 the recumbent SW-facing F_1-syncline under Monte Ramaceto (see figure 6; sections D, E and F) passes into a downward facing syncline with a steep SW-dipping axial plane in the Val Graveglia

(Frisolino) (see figure 6; sections K and L).

F_3-folds between Monte Ramaceto and Val Graveglia are well developed and can be traced along the fold axes over a distance of several kilometres. Section E-E′ near Monte Cucco shows that the effect of F_3 is less obvious in localities where the bedding of the pre-existing F_1-F_2 structure becomes parallel to S_3.

A fault along the line Lorsica-Graveglia intersects the structure oblique to the foldaxes.

Reconstruction of the pre-F_3 structure

A reconstruction (figure 7) has been made of the pre-F_3 structure; i.e. F_3, F_4 and F_5 folds have been unfolded assuming that folds are coaxial and cylindrical, and the movements along thrusts that postdate F_3 have been restored.

To present a complete section of the F_1-F_2 structure of the Lavagna Nappe between Monte Ghiffi and the Mediterranean coast the section has been extended outside the map area of figure 1, based on our own observations and existing literature.

The reconstruction clearly shows the SW-facing F_1-isoclinal folds on a regional scale. F_1 folding produced SW facing isoclinal folds, with at least one overturned limb of about 10 km between Cogorno and Belpiano. PostF_2-preF_3 thrusting occurred along the Monte Rondanara Thrust. The thick pile of Forcella Siltstone and the absence of Verzi Marl and Manganiferous Shale near Monte Rondanara can be explained by assuming a NE-directed movement along the Monte Rondanara Thrust.

The antiformal structure of the Monte Ramaceto can be explained as a recumbent F_1-syncline, that has been folded by F_2 into an antiform.

Conclusions

Detailed structural analysis and mapping in the Lavagna Nappe reveals the effect of multiple folding on a regional scale. The various generations of folding are approximately coaxial, with axes plunging NW on a regional scale. The first phase of folding produced SW-facing isoclinal folds initially with gently NE-dipping axial planes and at least one overturned limb of about 10 km. After a second phase of open folding, NE-directed thrusting took place. The following tight to open F_3-folding is consistent with a transport direction to the NE. A postF_3 internal thrust divides the Lavagna Nappe into two parts, superposing deeper parts of the structure in the SW-block and shallower parts in the NE-block. Open to very open F_4-folding caused undulation of the F_1-F_3-structure. The Lavagna Nappe and the Antola Nappe were emplaced on top of the Mélange Nappe by NE-thrusting during a stage postdating the intense F_1-F_4 folding. Gentle F_5-folding caused the undulation of all older structures on a regional scale.

Acknowledgments

We thank R.C.M.W. Franssen for his data on the northeastern part of the area, and M.M.P. van Zutphen for valuable suggestions improving the manuscript. This study was partly financed by 'het Utrechts Universiteitsfonds' and 'de Stichting Molengraaff-fonds'.

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Fig. 7. Idealized composite section of the preF3 structure of the Lavagna Nappe.

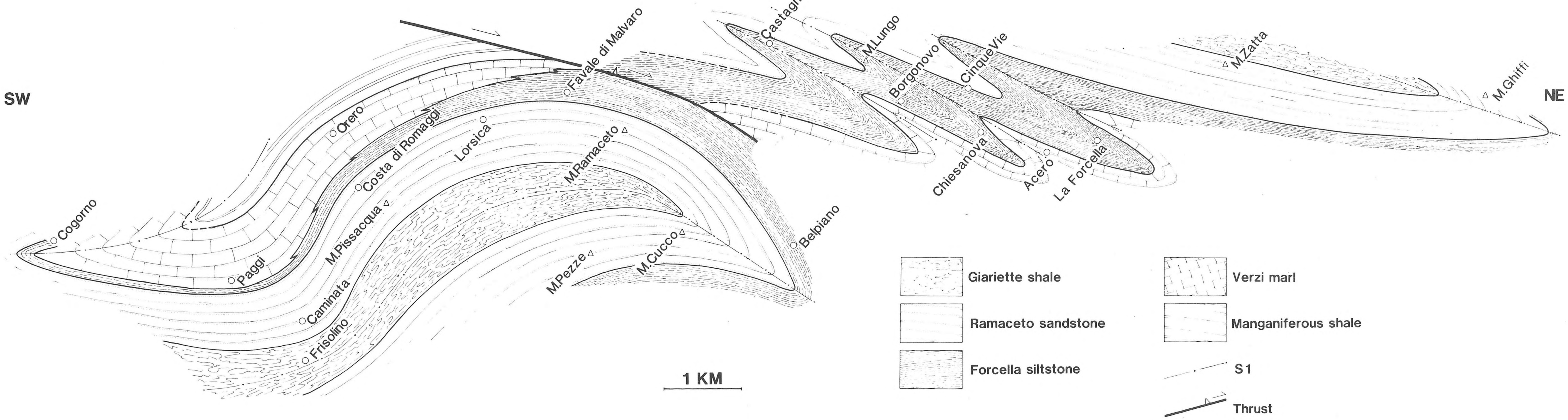

Fig. 6.

CROSS SECTIONS THROUGH THE LAVAGNA NAPPE (LIGURIA, ITALY)

VAN ZUTPHEN, VAN WAMEL & BONS

AZIMUTH:

SECTIONS A – F: 225°–45°

SECTIONS G – L: 236°–56°