GEOLOGIE EN MIJNBOUW© VOLUME 58 (2), p. 277-288 1979

OVERTHRUSTS IN THE CENTRAL BERGAMASC ALPS, ITALY

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ABSTRACT

De Jong, K. A. 1979 Overthrusts in the Central Bergamasc Alps, Italy. *In*: W. J. M. van der Linden (ed.): Fixism, mobilism or relativism: Van Bemmelen's search for harmony – Geol. Mijnbouw 58: 277-288.

Earlier tectonic interpretations indicated the presence of northward as well as southward overthrusts in the Central Bergamasc Alps. In the present study it was found that all overthrusts are southward. The extent of the overthrust sheets is much greater than previously believed. All Late Triassic and younger formations south of the Central Bergamasc Alps, previously thought to be autochthonous, have been moved a maximum of 9 km to the south. Overthrusting in the Bergamasc Alps was the result of gravity tectonics.

INTRODUCTION

R. W. van Bemmelen's students wrote eight theses on the geology of the Southern Alps. I had the pleasure of being one of these students and it is my thesis which is partially summarized in this paper.

The Southern Alps are relatively uncomplicated in comparison with the Alps north of the Periadriatic fault (Fig. 1). Nappes and *major* overthrusts are absent, and alpine metamorphism does not exceed the greenschist facies. Yet the Southern Alps form a major element in the Alpine orogene. They are near the frontal edge of the Italian block which moved northward relative to Middle Europe, closed part of the Tethys and caused the deformation in the Eastern and Central Alps (STAUB, 1924; ARGAND, 1924; VAN BEMMELEN, 1973; DEWEY ET AL., 1973).

The Southern Alps are bordered on the north by the Periadriatic fault. The Central and Eastern Alps were uplifted along this fault after the major tectogenetic phase of Eocene and/or Early Oligocene age (TRÜMPY, 1973). During the uplift, the Southern Alps were tilted southward, and east-west and northeast-southwest oriented faults were formed with downthrown southern blocks. This generally east-west structure was superimposed upon a north-south system of basins and platforms which were active from the Permian through the Cretaceous (BOSELLINI, 1965, 1973). In the Lombardic and Carnic-Bellunese basins (Fig. 2) the presence of two evaporite horizons facilitated detachment and minor overthrusting of the overlying rock sequence. In the platforms, however, these horizons are less well developed, and the sedimentary rock sequence appears to be 'nailed down' to the crystalline basement by volcanic plugs of Triassic age.

The structural style of the Southern Alps and the presence of considerable relief during the Cenozoic suggested to several authors that the compressional features in the sedimentary rock sequence were created by differential uplift of the Southern Alps, and not by shortening of the crust or lithosphere. In 1950, FALLOT considered all structures in the Southern Alps the result of gravity tectonics. DE SITTER (1949, 1950, 1956, 1963) maintained that the same was true of the Bergamasc Alps with the exception of some overthrusts in the Central Bergamasc Alps because their movement appeared to have been directed toward the north, against the regional gradient of the Southern Alps. These anomalous overthrusts are the main topic of this paper.

TECTONIC INTERPRETATIONS OF THE CENTRAL BERGAMASC ALPS

The first tectonic interpretation of the Central Bergamasc Alps was from TARAMELLI (1896) who believed that the Cima Verde (J-6; the letter-number combinations indicate locations on the geologic and tectonic maps) was part of an overturned fold. PORRO (1903) recognized two northward overthrusts (Figs. 3a and 5a) and CACCIAMALI (1930), one southward overthrust (Figs. 3b and 5b). Southward movement was also recognized by VISSER (1937; Figs. 3c and 5c). SWOLFS (1938-a) and KROL (1939) mapped west and east of Visser's area (Fig. 6), and disagreed with his findings. They distinguished between the southward Presolana overthrust

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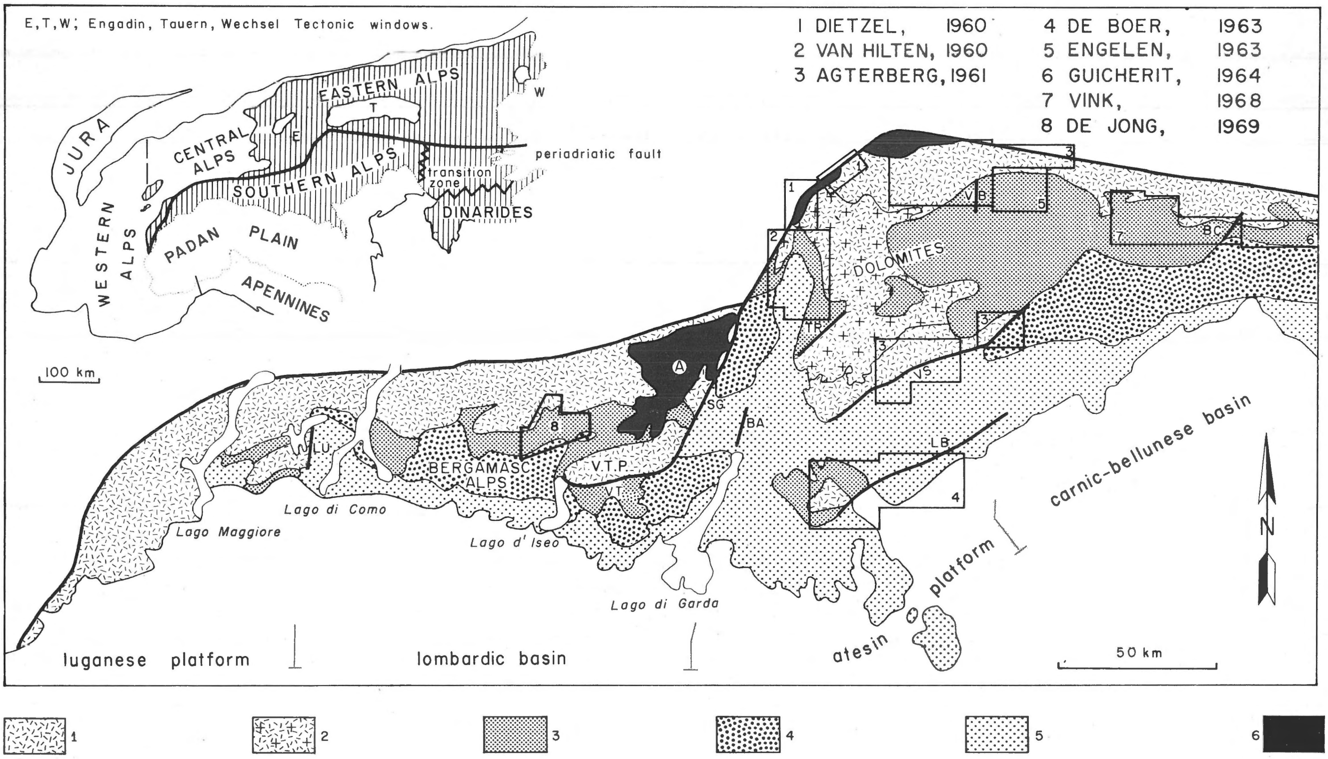

Fig. 1
Geological sketch map of the Southern Alps. Areas mapped by Van Bemmelen's Ph. D. students are indicated. Legend, 1: crystalline basement and Permian rocks; 2: Permian extrusives; 3: mainly Lower and Middle Triassic; 4: mainly Upper Triassic; 5: mainly Jurassic and younger formations; 6: Tertiary intrusions (A = Adamello); LU: Lugano fault; V. T. P.: Val Trompia Plateau; VT: Val Trompia fault; SG: Southern Giudicaria fault; BA: Ballino fault; LB: Bassano fault; VS: Val Sugana fault; VB: Val Badia fault; BC: But-Chiarso fault.

and the northward Ardesio and Timogno overthrusts (Figs. 3d and 5d). Their interpretation, which follows DOZY (1935), is schematized in figure 4: the northward movement of the Southern Alps caused the uplift of the northern Bergamasc Alps, and pushed the sedimentary cover against this barrier (Fig 4a); concomitantly the Ardesio and Timogno overthrusts formed where the Lower Triassic detachment horizon was absent (Fig. 4b); the frontal edge of the northward moving sedimentary cover was first transported upward, and then later backward toward the south (Fig. 4c). This scheme is in agreement with STAUB's (1924) interpretation as expressed in his, at that time, very influential 'Der Bau der Alpen' (p. 224): 'Die Südbewegung der Dinariden existiert als solche nicht. Alle primäre Bewegung ging wie in den Alpen nach Norden, und die südgerichteten beobachteten lokalen Ueberfaltungen und Ueberschiebungen innerhalb der Dinaridenscholle sind nur sekundäre Rückfaltungen . . .'.

DE SITTER (1949) and, independently, FALLOT (1950)

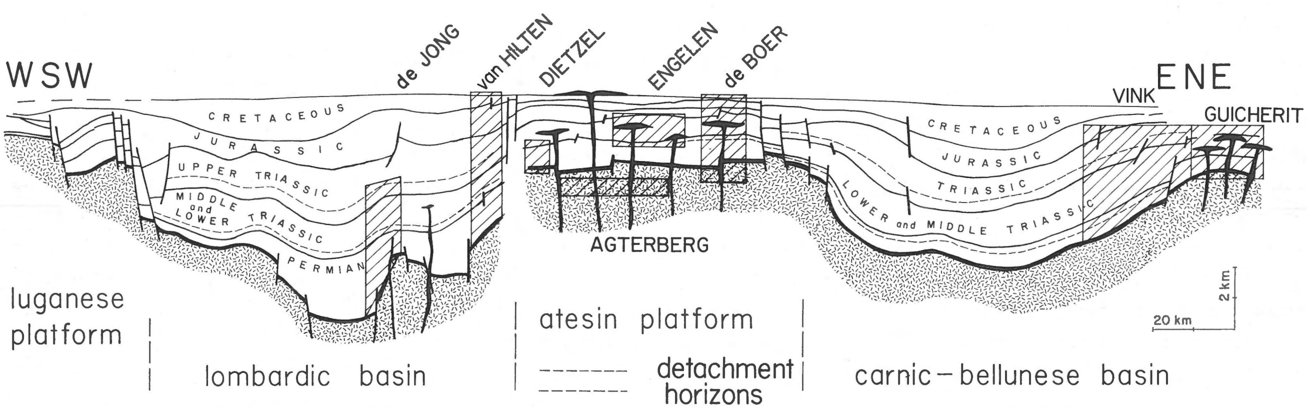

Fig. 2
Schematic section of the Southern Alps showing basins and platforms (mainly after Bosellini, 1965).

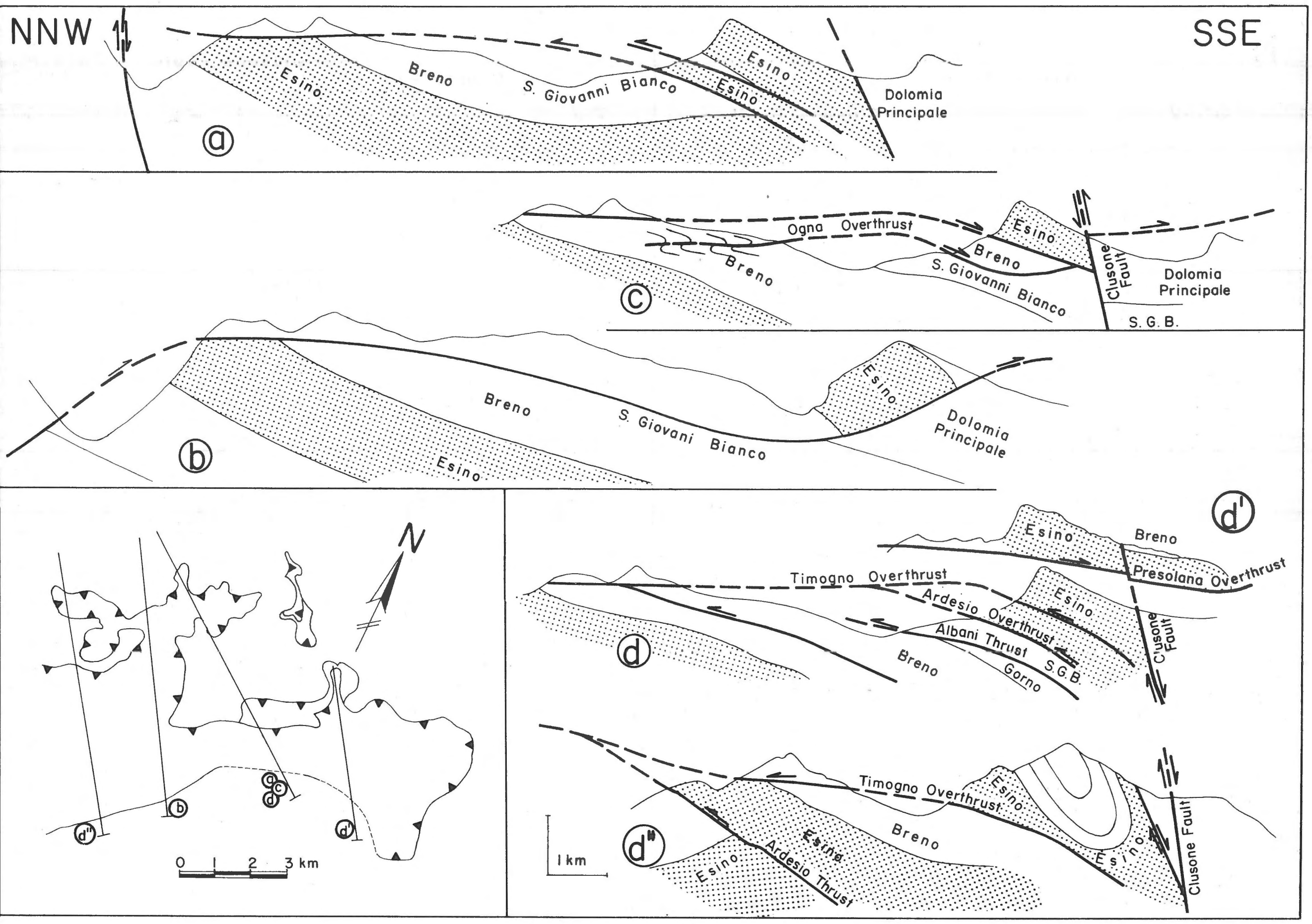

Fig. 3
Geologic sections of the Central Bergamasc Alps according to Porro, 1903(a), Cacciamali, 1930 (b), Visser, 1937(c), Swolfs, 1938-a (d''), and Krol, 1939 (d, d').

reached the conclusion that the southward overthrust movements in the Southern Alps were the result of gravity tectonics. FALLOT believed that the northward overthrusts in the Central Bergamasc Alps had also been caused by gravity (p. 187): 'Si certaines parties avancées de celle-ci ont subi un freinage suffisant, il est compréhensible, pour peu qu'un accident fortuit ait abaissé localement les couches de la partie septentrionale en mouvement vers le S, que se soit produit, par inertie, un chevauchement local à regard N. Lorsque, ultérieurement, le mouvement d'ensemble vers le S a repris ou continué, les nouveaux chevauchements se sont produits, tous orientés vers le S'. DE SITTER (1949, 1956, 1963; Fig. 5e), on the other hand, felt that these northward overthrusts indicated crustal shortening. The apparent absence of crustal

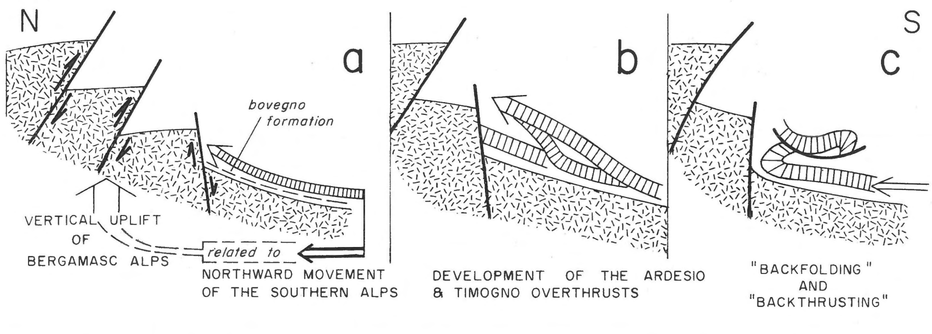

Fig. 4
Origin of tectonic deformation in the Central Bergamasc Alps according to the interpretation of Dozy (1935), Swolfs (1938-a), Krol (1939) and De Sitter (1939).

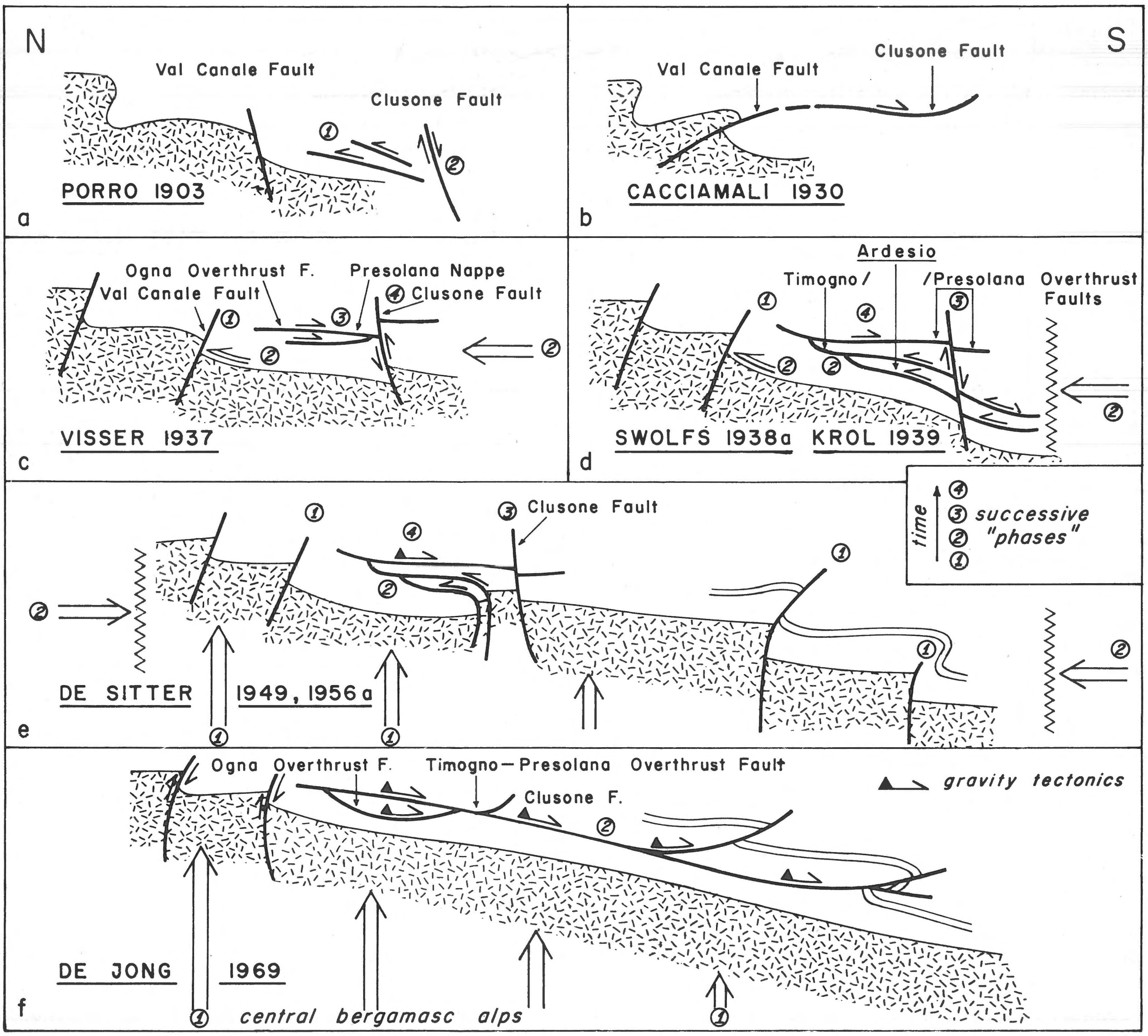

Fig. 5
Cartoons showing the various tectonic interpretations of the Central Bergamasc Alps.

shortening in other parts of the Southern Alps (VAN BEMMELEN, 1966; DE JONG, 1967) made the northward overthrusts in the Bergamasc Alps of considerable interest. During the summers of 1966, 1967 and 1968 I mapped these overthrusts, and concluded (DE JONG, 1969) that *all* overthrust sheets in the Central Bergamasc Alps had moved to the south and that they had been emplaced by gravity (Fig. 5f).

LITHOLOGY

The purpose of my field work was to prepare geologic and tectonic maps and sections. It was sufficient therefore to study the general lithology without considering in detail the depositional facies and fossil content of the sedimentary formations. Of great help, of course, were the existing geologic maps of the Central Bergamasc Alps (Fig. 6).

The nomenclature of the sedimentary formations largely follows ASSERETO & CASATI (1965). Age assignments are shown in figure 7, and estimated thicknesses are given in the inset of the geologic map (enclosure I). A short description of the formations is given below.

Dolomia Principale Fm. – Grey algal dolomite. Thick-bedded (1-10 m) near Valle Nossa (A-8), massive elsewhere. Conglomeratic limestone at the base. Sedimentary breccia common.

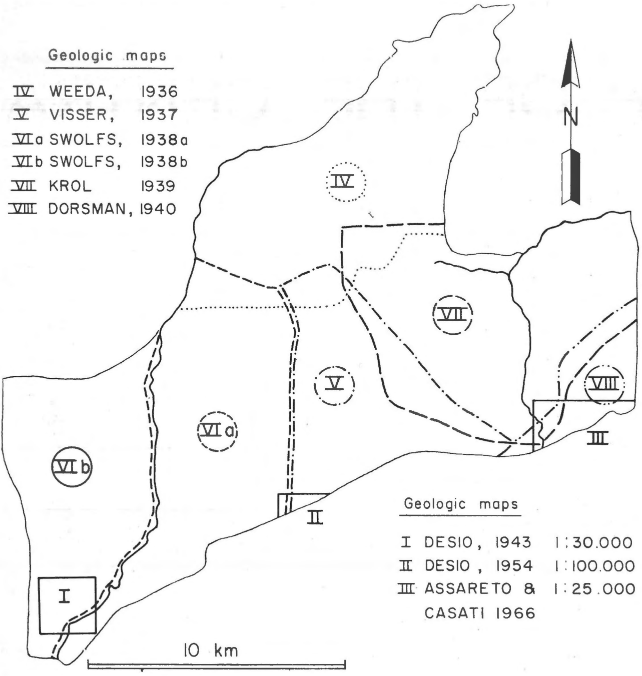

Fig. 6
Location of previous geologic maps of the Central Bergamasc Alps. The new geologic map (enclosure 1) was made (with the aid of 1:10,000 enlargements of the 1:25,000 sheets. These sheets (18II SE, 19III SO/SE, 33I NE/SE, 34IV NO/NE/SO) were surveyed in 1933-1935. Some roads constructed after 1935 have been sketched in.

San Giovanni Bianco Fm. (Abbreviated in Figs. 3 & 9 as SGB) – Multicoloured shale and marl. Thin-bedded limestone (10-50 cm) and dolomite (30-300 cm) in the lower part. Gypsum layers (max. 1 m) in the upper part (south of Stalle Muschelo, H-6).
Gorno Fm. – Well-stratiflied (10-100 cm) limestone with many lamellibranchiates. Dark grey marl and shale common in the upper part.
Breno Fm. – Thick bedded (1-2 m), moderately well stratified reefoid limestone, time equivalent of the Gorno and the lower part of the San Giovanni Bianco Formations. The Breno Formation includes the Calcare Metallifero Bergamasco Formation of ASSERETO & CASATI (1965).
Esino Fm. – Generally unstratified light-coloured reefoid limestone.
Lozio Fm. – Dark grey unstratified shale weathering into pencil-shaped splinters. Coeval with both Esino and Wengen Formations.
Wengen Fm. – Well-stratified limestone and thin-bedded sandstone (max. 10 cm) with intercalated shale. Pale green tuffites. Sandstone beds are generally graded. Fragments of fossil plants.
Buchenstein Fm. – Dark green well-stratified limestone with light green tuffite and tuff. Conglomerate north of the Stalle Muschelo (H-6). Chert layers and chert nodules. Wengen, Buchenstein and Lozio Formations are inter-reef formations

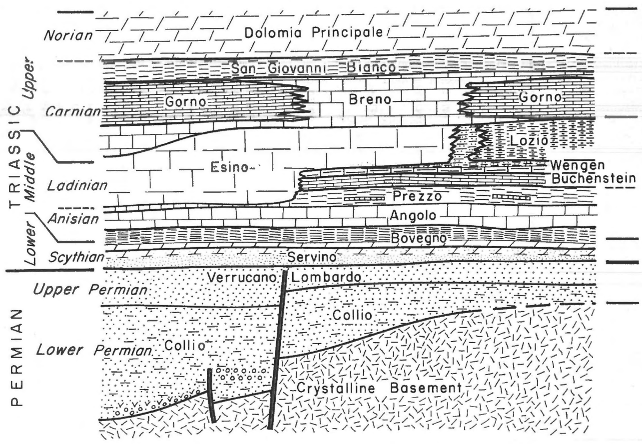

Fig. 7
Lithostratigraphic column of the Central Bergamasc Alps.

between the Esino reefs.
Prezzo Fm. – Black shale and limestone. Mainly shale in the eastern area, and thin-bedded limestone (5-20 cm) in the western area.
Angolo Fm. – Dark grey limestone with beds up to 5 m thick. Locally massive. Bedding plane undulating; in places nodular.
Bovegno Fm. – Yellow 'rauhwacke' and grey dolomite. A 20 m thick gypsum bed occurs west of Vilminore (San Andrea, L-6).
Servino Fm. – Well-stratified yellow, brown and grey sandstone and dolomite.
Verrucano Lombardo Fm. – Pale red conglomerate and coarse-grained sandstone; red fine-grained sandstone and siltstone. Massive in the lower part, well stratified in the upper part.
Collio Fm. – Conglomerate, sandstone and shale. Tuffite occurs near the base. A 10 m thick red sandstone occurs east of the Vigna Soliva (1-2/3); all other rocks are grey or brown in color; some shale beds show mudcracks and raindrop impressions.
Crystalline basement – Mica schist, paragneiss and quartzite.

STRUCTURE

The structure of the Central Bergamasc Alps is shown in the geologic map (Encl. I), tectonic map (Fig. 8) and geologic cross sections (Fig. 9). Several overthrusts occur. KROL (1939), SWOLFS (1938-a) and DE SITTER & DE SITTER-KOOMANS (1949) distinguished the northward Timogno overthrust from the southward Presolana overthrust in the central portion of the study area. However, a single overthrust sheet is indicated because (1) there is no major fault between the two thrust sheets – the Pozzera fault (1-7) is of local importance only – ; (2) a small klippe west of the Valle Scura fault (section II) suggests that the two sheets had been previously connected;

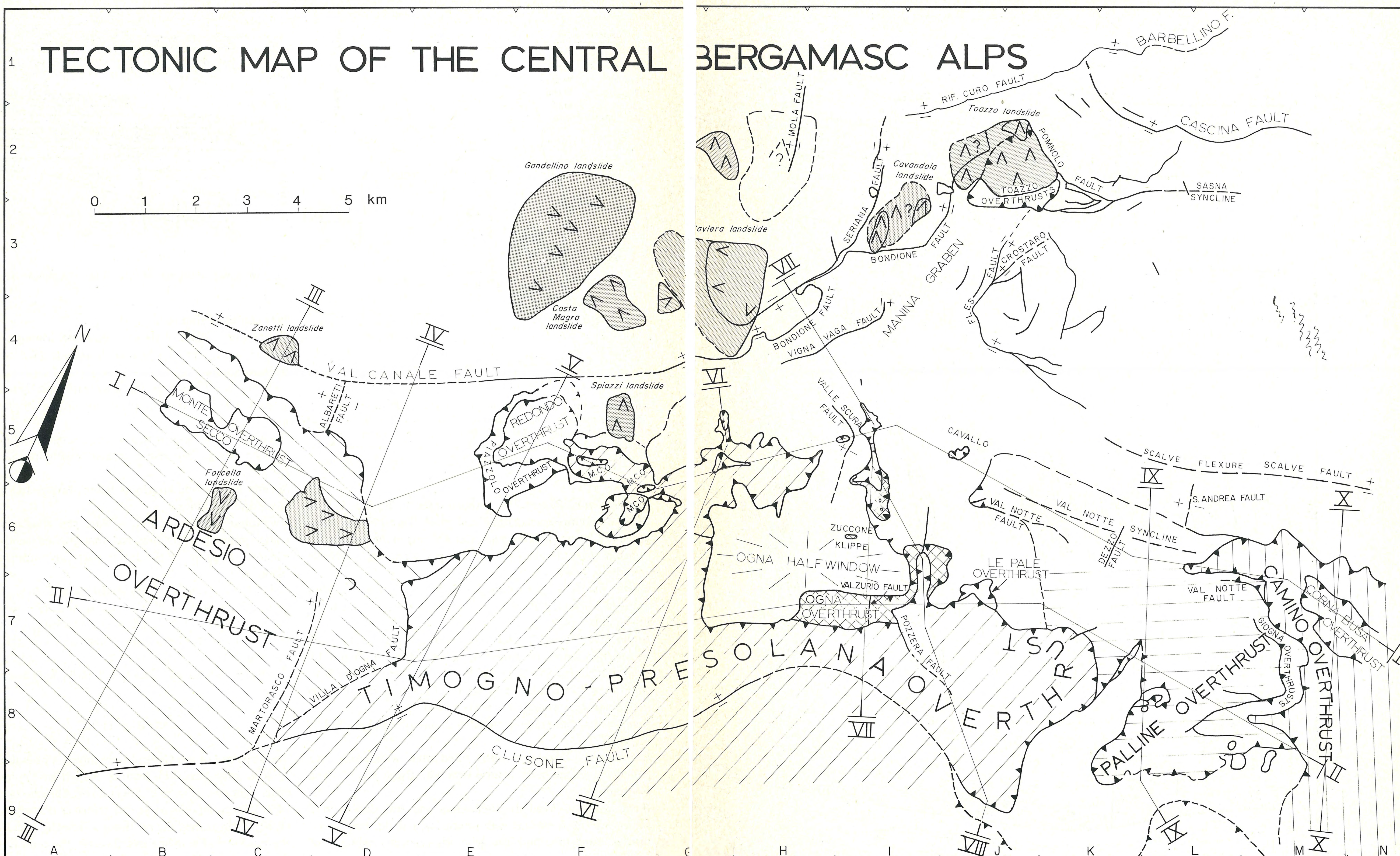

Fig. 8
Tectonic map of the Central Bergamasc Alps. M.C.O.: Monte Corru Overthrusts. Landslides are shown on the tectonic map because several of them were partially mapped as tectonic features. For example, the Costa Magra landslide was mapped as a graben (Swolfs, 1938a), and the extensive slip planes of the Toazzo and M. Cavlera landslides were mapped as tectonic faults (Weeda, 1936).

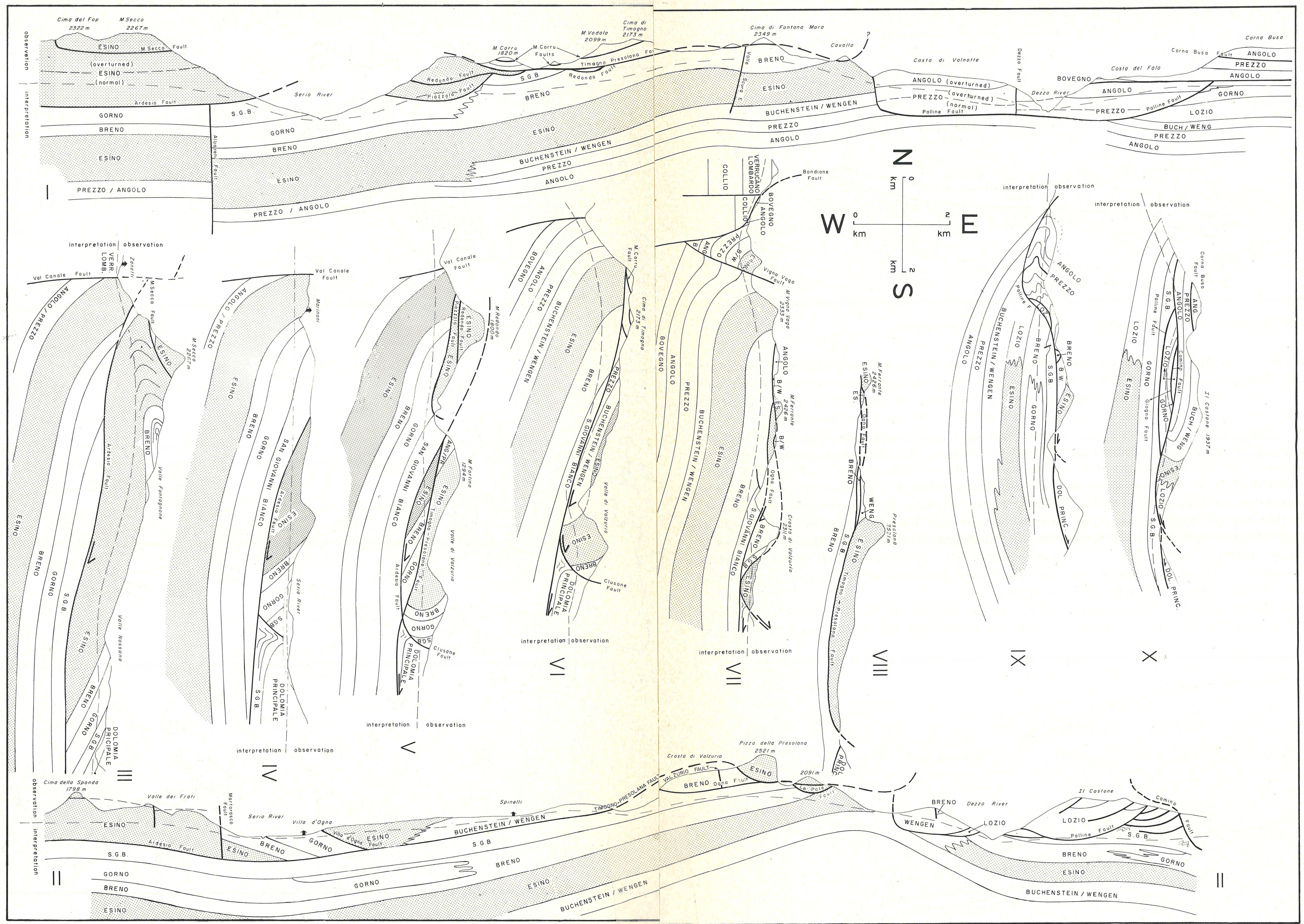

Fig. 9
Geologic cross sections of the Central Bergamasc Alps.

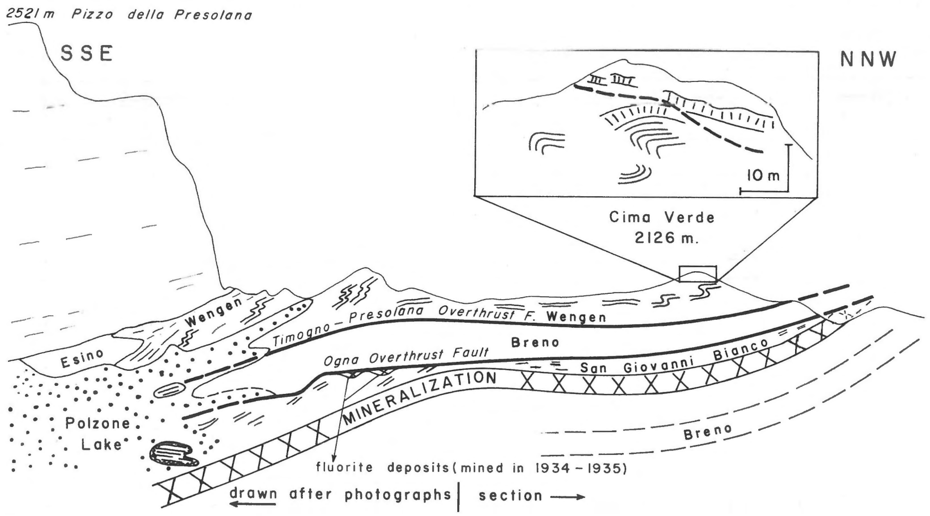

Fig. 10
Part of the Ogna- and Timogno-Presolana overthrust sheets seen from the east.

and (3) south-directed thrust slices are present near the major overthrust planes: the Redondo and Piazzolo overthrusts (section V); Monte Corru overthrusts (section I); Ogna overthrust (sections II and VII); Le Pale overthrust (section II); and Corna Busa overthrust (section X).

Movement of the Timogno-Presolana overthrust sheet and associated thrust slices was to the SSE as indicated by the folds in the allochthonous rocks (Fig. 10). Also, two lenses of fluorite were dragged southward, and it appears that the Valzurio fault in the Ogna overthrust (D/E-6/7, section II) represents an extension of the upper part of the Valle Scura fault in the authochthonous series (I-5, section I).

The Clusone fault (sections V, VI and VII) may be an extension of the Timogno-Presolana thrust fault (Fig. 11a), but it is also possible that this thrust fault may extend south of the Clusone fault (Fig. 11b). This question can be answered by considering the western part of the Central Bergamasc Alps where the displacement of the Clusone fault progessively decreases and the fault eventually disappears (cf. sections VI, V, IV and III in that order). West of the village of Nossa (A-8) the contact between the San Giovanni Bianco and Dolomia Principale Formations appears to be conformable with a southward dip of 30° (section III). I conclude that the Clusone fault is *not* an extension of the Timogno-Presolana thrust fault; and that the Dolomia Principale Formation near Nossa has moved as far to the south as the older stratigraphic units above the Ardesio fault (about 9 km in section III). The Ardesio and Timogno-Presolana overthrust sheets thus extend well to the south of the Central Bergamasc Alps.

The Ardesio and Timogno-Presolana overthrust sheets are not continuous, but separated by the Villa d'Ogna fault (sec-

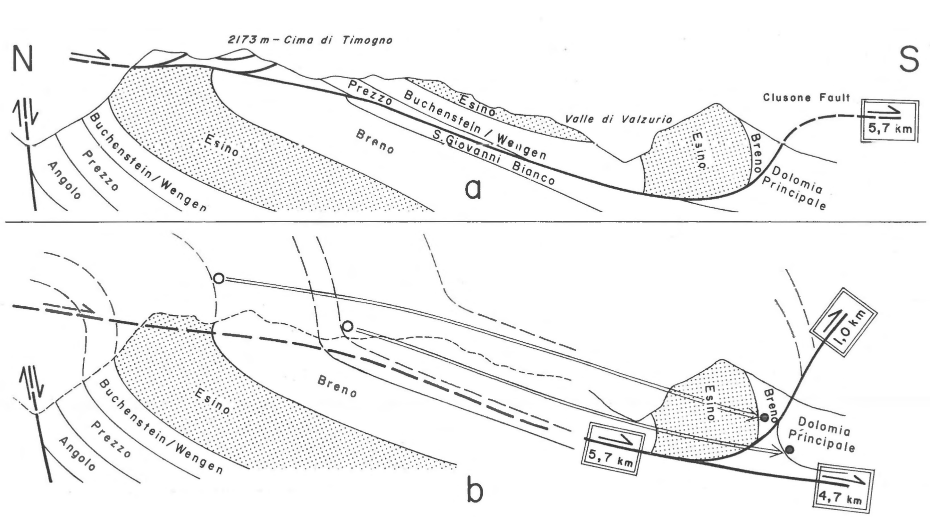

Fig. 11
Two different interpretations of the Clusone fault (cf. section III). Fig. b is a genetic cross-section.

tion II). The Timogno-Presolana overthrust sheet moved about two km farther south than the Ardesio overthrust sheet, the same distance over which the Piazzolo and Redondo thrust slices moved to the south (section V). This is more than just a coincidence. The Triassic formations east of the Villa d'Ogna fault in the Timogno-Presolana overthrust sheet are not faulted, which indicates that the thrust sheet must have been emplaced before the Redondo and Pizzolo thrust slices had been formed. After the emplacement of a continuous Ardesio-Timogno-Presolana overthrust sheet the thrust slices and the eastern part of the overthrust sheet moved about two km to the south. This resulted in a separation between the Ardesio and Timogno-Presolana overthrust sheets.

The emplacement of the Ardesio-Timogno-Presolana overthrust sheet apparently occurred after the formation of the vertical Albareti fault (D-4), as this fault is truncated by the Ardesio fault. The Martorasco fault (C-7) probably constitutes the truncated part of the Albareti fault, implying a SSE movement of the Ardesio overthrust sheet.

In the Valle di Scalve area, east of the Pizzo della Presolana (I/J-7), the Timogno-Presolana overthrust sheet dips generally to the east. Near Castello (K-8), however, it curves abruptly and dips 35° to the west. This suggests that the Timogno-Presolana fault does not override the Palline thrust sheet completely, but rather developed into a subvertical strike-slip fault just east of Castello (section II). The Palline and Timogno-Presolana overthrust sheets were apparently never a single thrust sheet as was the case for the Ardesio and Timogno-Presolana sheets. Similarly, the Camino overthrust sheet (M-8) overrides the Val Notte syncline in the northern part of the Palline overthrust mass, and is thus younger than the Palline overthrust. The Giogna overthrust (M-8, section I) which appears related to the Camino overthrust is also younger than the Palline overthrust sheet.

The eastern termination of the Timogno-Presolana overthrust sheet and the presence of smaller separately moving thrust sheets may be related to the abrupt facies change between the Esino and Lozio-Wengen-Buchenstein Formations. Pre-overthrust north-south oriented vertical faults, such as the San Andrea fault (L-6, section I), may also have influenced the tectonic evolution of the Valle di Scalve area.

DISCUSSION

The major results of the present study are: (1) the extent of overthrust sheets in the Bergmasc Alps is much greater than previously thought: and (2) all tectonic movements were southward. It is further suggested that these movements were the result of gravity sliding.

The fact that the Ardesio, Timogno and Presolana overthrusts represent one single overthrust sheet, and, most importantly, that the Late Triassic and younger sedimentary units south of the Central Bergamasc Alps are also part of

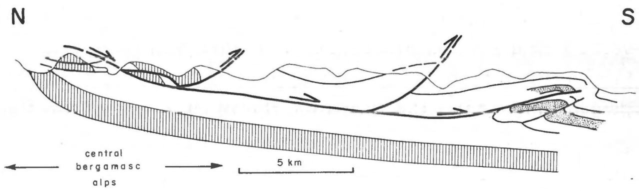

Fig. 12
Schematic section of the Bergamasc Alps, along the Valle Seriana. Surface data of the region south of the Central Bergamasc Alps according to Desio (1954). The overthrust sheet in the Central Bergamasc Alps is the northern part of a much larger sheet which extends to the Padan plain. The maximum movement of about 9 km occurs at the western edge of the Central Bergamasc Alps. Farther west the displacement appears to have decreased.

this same overthrust sheet (Fig. 12), demonstrates the great areal extent of overthrust sheets in this region. The displacement of the Late Triassic and younger units ranges from about 9 km in the Valle Seriana area (section III) to about 5 km east of Clusone (section VI). Farther to the east, in the Valle di Scalve area, the widespread occurrence of shale and marl of the San Giovanni Bianco Formation below the Palline and Camino overthrust sheet suggests that also in this area the Late Triassic and younger formations moved southward. They were followed immediately by the Palline and Camino overthrust sheets which covered the San Giovanni Bianco Formation before it could be eroded. The minimum movement of the Upper Triassic in the Valle di Scalve is 5 km. The Late Triassic and younger formations of the Bergamasc Alps (Fig. 1) are thus not autochthonous but rather allochthonous. Their displacement of a maximum of 9 km appears insignificant compared with the thrust movements of dozens of kilometres in the Swiss and Austrian Alps. Still, it is a rather unexpected find, with important implications for the general structure of the Southern Alps. That structure has been described in the past as large steps separated by vertical faults (DE SITTER, 1949, 1956, 1963, Fig. 5e). Although the steps are there, they are separated by overthrust structures, and underlain by an unbroken basement (Figs. 5f, 12). The presence of an overthrust at the southern margin of the Carnic-Bellunese basin (Fig. 1) was demonstrated by MARTINIS (1966), and similar overthrust can be expected in the Southern Bergamasc Alps.

All overthrusting was south-directed. The thrust planes cut upward through the stratigraphic column from north to south. The major overthrust faults are step faults (or ramp faults) which connect detachment faults in the Bovegno Formation with detachment faults in the San Giovanni Bianco Formation. The upper part of the Bovegno Formation is present at M. Corru (F-5) and north of Azzone (L-6). The upper detachment plane, visible at several localities, is now overlain by older formations.

The subhorizontal attitude of the Ardesio-Timogno-Presolana overthrust and its steeply dipping footwall near the Val Canale fault indicate that the monocline south of the Val

Canale fault is older than the thrusting. The north-south subvertical faults (Albareti fault, D-4, Valle Scura fault, I-5, and San Andrea fault, L-6), also appear to be older than the thrust faults. After the thrusting, the block north of the Val Canale fault rose, perhaps as a result of isostatic adjustment after the removal of part of its overburden by tectonic denudation. The absence of major thrust faults in the crystalline rocks and Permian formations in the tectonic-denudation area indicates that gravity tectonics was the major emplacement mechanism of the overthrusts in the Central Bergamasc Alps.

ACKNOWLEDGEMENTS

I thank Rein W. van Bemmelen: without him neither my Ph.D. thesis nor this article would have been written. I also thank Hennie Tjong-Tjin-Joe, Chris Klootwijk and Theo van Hengel for their help with the field work; Frans Hensen and Isaac Santoe for the preparation of the figures and maps, and the Topographic Survey of The Netherlands for the colour separation of the geologic map. Ringrazio il dottore Roberto Rossetti (Pavia), e le sequenti persone delle Alpi bergamasche: Bonomo Zamboni (Miniera di Manina), Umberto Farenzena (Miniera della Presolana); Gino Bendotti (Dezzo di Scalve). Ringrazio infine Silvio Santus (Gromo) e la sua famiglia che mi hanno ospitato con squisita gentilezza.

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