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Structure and History of the Antigorio Nappe (Simplon Group, North Italy)

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With 3 figures in the text and 2 plates

Abstract

The area under consideration comprises the lowest units in the Pennine nappe pile. The rocks are subdivided into two general groups: metamorphosed Mesozoic sediments and deformed masses of pre-Mesozoic basement. In spite of the Alpine deformation, pre-Mesozoic features can still be clearly recognized in the latter, particularly in the Antigorio nappe. The history of the rocks during the Alpine orogeny has been deduced. It is suggested that this is to be considered as a continuous development.

INTRODUCTION

For nearly a century the Antigorio gneiss mass has been recognized as a nappe. GERLACH, who first described it, suggested that its present position was due to a "seitlich nach N stattgefundene *Verschiebung*" (GERLACH, 1869, p. 121). Four decades later, however, we read:

„Dass diese Kuppel (i. e. Antigorio) eine nach Norden übergelegte *Antiklinale* ist, erkennt man in den tiefen Taleinschnitten der Cairasca und des Devero, wo die Schiefer der Fenster von Varzo und von Baceno unter dem Antigoriogneiss zutage treten. Im Simplon-Tunnel ist der Mittelschenkel der liegenden Falte nahe der Gewölbebiegung durchfahren worden." (SCHMIDT and PREISWERK, 1908, p. 38.)

GERLACH's interpretation was not discussed and features which would rule out the earlier idea were not described. The climate of geological ideas had changed.

The present work takes a third look at the nappe (for details, see MILNES, 1964) and the interpretations presented indicate a further

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change in climate towards the conditions of a century ago. The discussion fold v. thrust, however, is considered redundant. The history of the nappe, its life story and ancestry, is the subject of this paper.

GENERAL GEOLOGY

The distribution of the major lithological types in space is summarized in the Plate I and Fig. 1. Lithologically we have two general sub-divisions: gneisses (Baceno "schists", Antigorio gneiss, Lebendun gneisses) and calcareous to non-calcareous schists (b_{1-4}). From the regional setting of the area, the schists represent the metamorphosed sedimentary infilling of the Alpine geosyncline (called variously schistes lustrés, Bündnerschiefer, calcescisti). They were sediments laid down in Mesozoic times; in particular, the marble at the base of b_2 (see Fig. 1) is generally considered to have been a Triassic limestone. The Alpine orogeny, however, distorted the Mesozoic stratigraphy almost out of recognition and the units distinguished here represent a structural succession (b_1 the lowest, b_4 the highest). I think of the gneisses, on the other hand, as representing parts of the pre-Mesozoic basement of the geosyncline. The features from which this impression was obtained and some details of their structure are summarized below.

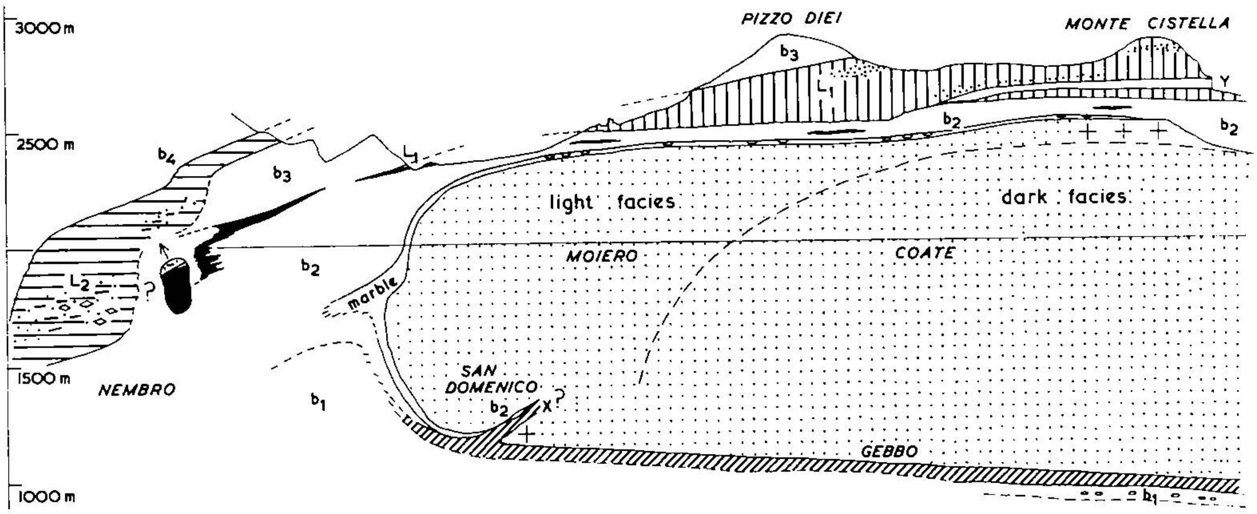

Fig. 1. Composite lithological profile through the frontal part of the Antigorio nappe as it is seen on the southwest flanks of Monte Cistella (for explanation of ornament, see Geological Map).

Antigorio gneiss

Systematic modal analysis of some 200 thin-sections showed that two facies of Antigorio gneiss exist, with less than and more than 8 vol.% biotite (Plate II). The contact between these is usually a gradual transition, sometimes a heterogeneous mix-zone in which blocks of the light component are enclosed in the dark. In places at the upper surface of the nappe, the Alpine overprinting was very weak and intrusive relationships can be seen between biotite-rich and biotite-poor components in the mix-zone (best seen around the peak Scheggia di Marsasca). The biotite-poor component appears here as an unfoliated granite, rounded boulders of which are abundant in the overlying marble. "Lamprophyric" dykes rise vertically through the granite and end sharply on reaching the contact with the marble. The original stratigraphic nature of this contact is strongly suggested in the field. Thus, in restricted parts of the Antigorio nappe, the pre-Mesozoic geology can still be clearly recognized.

Lebendun gneisses

Above the nappe, thin slices of conglomeratic gneiss occur at two levels in the schist matrix (L_1 between b_2 and b_3, L_2 between b_3 and b_4). These were formerly thought to represent one structural horizon and known as the Lebendun nappe. Each slice has a knife-sharp lower contact and a gradational upper contact. The lower contact of L_1 cuts lithological boundaries within L_1 discordantly (e. g. horizon Y, Fig. 1). That these slices also represent parts of the basement is suggested by the occurrence of thin "lamprophyric" dykes in L_1 with relations similar to those in the Antigorio nappe.

Baceno schists

In spite of the name, the development of schistosity is variable and often in the field the term "gneissose" must be used. Systematic modal analysis showed this to be due to reciprocal variation of the muscovite and felspar contents. This variation is also found in the Antigorio nappe, where, however, it is recognizably due to progressive shearing of the original granitic felspars during the Alpine movements (Plate II c). Hence it is suggested that the Baceno schists also represent quartzo-felspathic basement rocks, in which, however, the Alpine movements have been much more intense. In both the Varzo and the Baceno windows, the Baceno schists are divided into an upper and a lower division by a heterogeneous zone of mainly calcareous rocks with often chaotic lithological variations (b_1).

Only in the schist matrix of these gneiss masses can we be sure that we see only the effects of the Alpine orogeny. Comparison of the fabric of the schists with those of the Lebendun and Baceno rocks, however, reveals close correspondence. Hence in deducing the Alpine structural history the non-Antigorio units may be considered together.

STRUCTURAL HISTORY AND METAMORPHISM OF THE NON-ANTIGORIO UNITS

Metamorphism

Consideration of the mineral assemblages, particularly in the impure calcareous rocks b_1 and b_2, reveals the general metamorphic grade to be of the lower part of the almandine-amphibolite facies (staurolite-almandine sub-facies). In surrounding regions it has been shown that the isograds intersect the nappe boundaries (WENK, 1962), i. e. that the period of high temperature took place after the nappes had reached their present relative positions.

In the present work, Alpine time is sub-divided into three periods — main Alpine, late Alpine and post-crystalline — by the rise and fall of temperature. In main Alpine times, basement rocks and waterlogged sedimentary infilling reacted differently to the deformative forces. The difference was most marked between the Antigorio mass and its surroundings. With rise in temperature, the sedimentary material crystallized, the deformed basement minerals re-crystallized, so that in late Alpine times all rocks reacted in a similar way to imposed stresses. Post-crystalline refers to the later period of deformation, after the fall in temperature, during which re-crystallization could not take place. The deformation history can be followed continuously across these temperature-dependant boundaries.

The main Alpine fabric

The main Alpine deformative forces left their mark on the sediments and basement rocks in the following ways: compositional banding was strongly folded on a minor scale; a foliation was developed parallel to the axial plane of these folds; minerals and mineral aggregates were elongated parallel to the minor fold axes. These features are well seen when strong planar compositional differences are present, e. g. quartzite horizons in b_2, light gneiss horizons (Y) in L_1. In many areas, compositional variation is unsystematic and gradational and the resulting folding diffuse, the only remaining structure being an irregular flat foliation.

The planar structure designated foliation is seen under the microscope to be complex. It can be described as a combination of three elements, the relative importance of which varies greatly from thin-section to thin-section:

I. Microscopic segregations. Many rocks show segregations of minerals into plate-like or lensoid aggregates. It is often difficult to decide whether such a planar structure is to be considered as "compositional banding" or "foliation" (see later). Occasionally, the aggregates are folded and the succeeding foliation elements are then orientated in the axial plane of the folds.

II. Mineral flattening. This term is used to indicate the texture whereby a non-platy mineral has acquired a lensoid or tabular habit and shows preferred shape orientation. When calcite is abundant it shows good flattening at the expense of quartz and felspar which remain equant. In non-calcareous rocks, quartz and sometimes felspar are well flattened in the axial plane of the folds.

III. Mica orientation. Muscovite shows good preferred orientation which is usually the dominant element of the planar structure. Crystals with cleavage at high angle to foliation are always present, however. Biotite is usually larger than muscovite and shows a smaller degree of preferred orientation (more cross cleavages). The micas thus reflect the foliation mimetically. They are rarely strained.

a) Attitude of foliation and vergence of folds

Observation of the shape of conglomerate pebbles in the Lebendun gneisses showed that the orientation of the regional deformation ellipsoid at the end of main Alpine times was:

X axis (maximum compression) — sub-vertical
Y axis — NW-SE
Z axis (maximum extension) — NE-SW

Regional irrotational deformation with these axes could have produced the vergence pattern of the minor folds (Fig. 2), if it acted on lithological boundaries which already had essentially their present position, i. e. on an already emplaced nappe. On the other hand, the emplacement of the nappe itself must have taken place by rotational deformation. Thus the following model is proposed for the main Alpine deformation path: At an early stage the regional deformation was rotational with a sub-horizontal rotation axis but with time the ellipsoid axes ceased to rotate. The later stages of the deformation were dominated by regional irrotational deformation with axes as above. During these stages, the Antigorio acted as a relatively incompressible mass thus causing the deviation of foliation around its edge (Fig. 2).

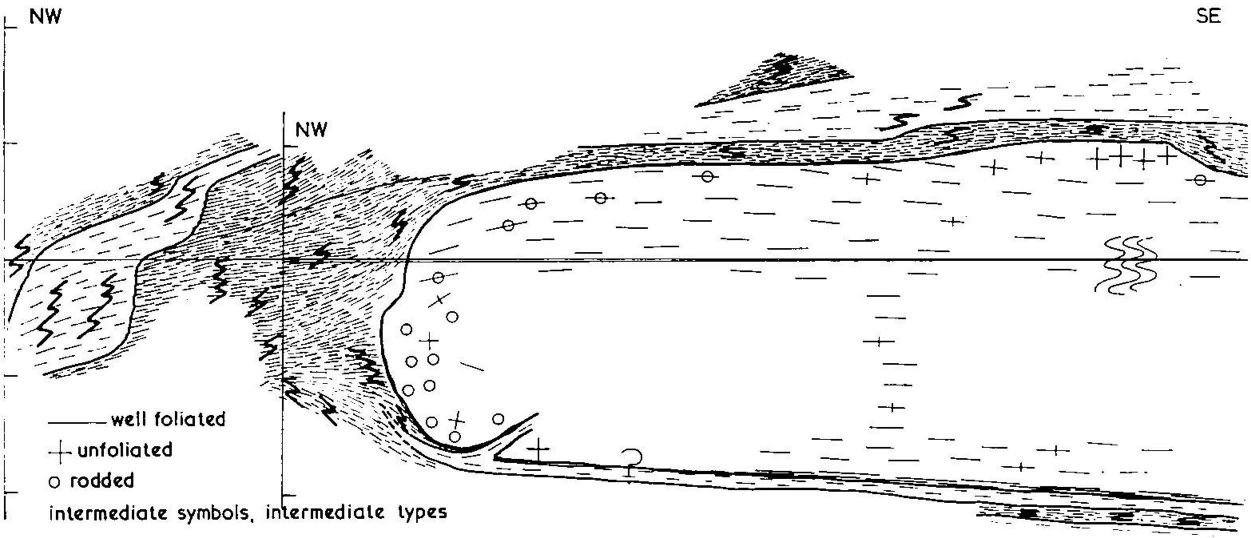

Fig. 2. As Fig. 1, showing the attitude of foliation and vergence of main Alpine minor folds in the non-Antigorio units (note also major folds of the whole L_2 slice). Within the nappe, the variation in the degree of development of the gneiss foliation is indicated schematically.

b) The linear fabric

The possible trend of linear structures is variable within well defined limits. One limit is 55—235°, which is also the trend of the nappe edge. The other limit is 0—180°. These limits are independent of position within the present map area — if many readings are taken from any sub-area the position and amount of the statistical spread is the same (Fig. 3a). It has recently been shown (Flinn, 1962) that such a spread which contains the Z-axis of the deformation ellipsoid and lies close to the ZY-plane, is the expected result of progressive deformation.

The late Alpine deformation

The main Alpine foliation shows the effect of later deformation in two ways. Firstly, boudinage of bundles of foliation planes occurs. This boudinage may be symmetrical or asymmetrical, and asymmetry can occur in both senses. Secondly, folding of the foliation on a very minor scale (crinkling of micas) is sporadically distributed. In contrast to the boudinage, the vergence of these folds is constant, westwards or southwards depending on the trend of the individual fold axis. During this folding, the micas remained parallel to the fold limbs and there was no mineral flattening in the axial planes.

The axes of these late Alpine linear structures may have any trend (Fig. 3c). It is suggested that during these times the region was undergoing uniaxial compression with a sub-vertical regional compression axis. I think of this weak deformation as representing the final dying stages of the main Alpine movements. The apparent separation into two distinct fabrics is caused by the change in the conditions in the rock brought about by the rise in temperature, i. e. by the impingement of the newly grown grains.

The post-crystalline era

The consistence of vergence of the late Alpine folds throughout the area suggests that towards the end of late Alpine times another regional rotational element entered the stress field. This can be followed through the time of falling temperature into the post-crystalline era. Here it appears as low-angle striated shear planes and associated tension joints (Fig. 3d shows the statistical striation direction, Fig. 3e the variation in attitude of the tension joints). The close relation between para-crystalline folds and post-crystalline shear planes is demonstrated in the Baceno schists where the planes seem often to form an ill-defined strain-slip cleavage.

Alkaline solutions circulated through the tension joints and deposited quartz, muscovite and chlorite in the joint spaces. But these minerals were then immediately slickensided in response to the same stress system. Now, however, the striations indicating movement direction are splayed out in the SW semicircle (Fig. 3f). The rotational element is dying and its effect becoming diffuse.

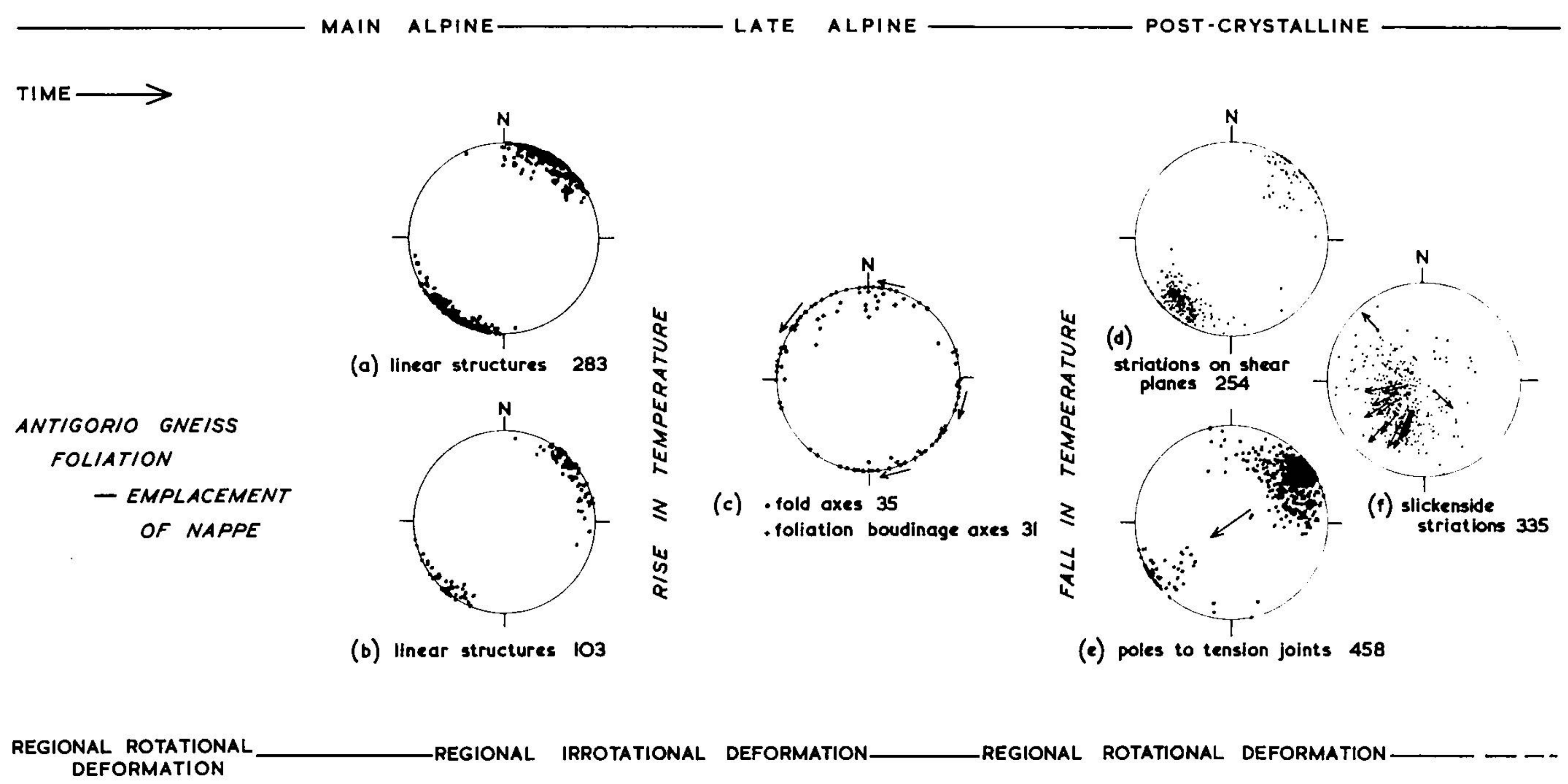

Fig. 3. Statistical information from minor structures, placed in the historical framework (for explanation, see text). The arrows indicate the movement direction of the rock above the structure relative to that below during the late regional rotational deformation.

HISTORY FROM THE MACROFABRIC OF THE ANTIGORIO NAPPE

Within the Antigorio nappe, linear structures are heterogeneously and sporadically distributed and the folds have no consistent vergence. The trend of linear structures gives statistically a similar spread to that of the external fabric and the structures are similar, i. e. mineral elongation lineations, folds with sub-horizontal axial planes sometimes marked by mica orientation or quartz flattening. Thus the linear fabric inside the nappe corresponds to the external fabric and was also produced essentially after the nappe had reached its present position.

The gneiss foliation

Areas in which folding is well developed, however, are few and far between and are separated by large stretches of flat foliated gneiss. This foliation mainly consists of the element "microscopic segregation" (see above), of alternating microscopic lamellae of quartz and felspar. The shape of the quartz aggregates in the felspar matrix determines the "degree of development" of this foliation: — parallel sided plates — well foliated, thick roughly orientated lenses — poorly foliated, equidimensional masses — unfoliated. Unfoliated granite occurs in places, mainly immediately below the upper surface of the nappe, whereas the basal few metres are strongly foliated. In the main mass of the nappe the foliation is between these two extremes and varies irregularly from place to place. Passing towards the edge of the nappe, the planar structure often disappears, the quartz aggregates becoming rod-shaped. The other foliation elements are present in variable degrees parallel to the dominant planar structure.

This microscopic segregation foliation shows the effects of later deformation in two ways. Firstly, it was folded to give the above linear fabric (there is no evidence for the transposition of the folded microscopic segregations into flat segregations of the same shape and size order in the axial plane of the folds). Secondly, it is cut discordantly by shear planes and zones, the rock of which under the microscope is seen to be completely recrystallized (Plate IIc). This shearing can still be recognized as having been a progressive process and can be traced back until it is almost indistinguishable from the process which formed the gneiss foliation. It is interpreted as having taken place towards the end of main Alpine times, the reaction of the relatively incompressible nappe to the regional compressive and extensive forces.

Thus the dominant foliation element in the gneiss was produced earlier than the other structures. I think of this foliation as being produced during the rotational deformation in early Alpine times, i. e. during the emplacement of the nappe. The quartz aggregates represent the deformed and re-crystallized grains of the original granite. During the emplacement, however, most movement took place in the underlying Baceno rocks (now "schists" due to the breakdown of felspar to muscovite during this deformation). Perhaps most lateral movement took place along a zone in the middle of the Baceno rocks, now the zone of b_1 with its chaotic lithology.

In the unfoliated granite, the pre-Mesozoic lamprophyric dykes are sub-vertical, in foliated gneisses obliquely discordant to concordant. In future work, a study of the deformation of these dykes may yield a better understanding of early Alpine deformation history.

DEDUCTIONS FROM THE MICROFABRIC OF THE ANTIGORIO GNEISS

During the period of high temperature, the deformed quartz in the emplaced nappe completely recrystallized and now shows a definite c-axis orientation pattern. The felspars, on the other hand, occur in two generations, the old deformed grains of the former granite (I) and the new grains which grew in the period of high temperature (II). The features of these minerals can be summarized as follows:

Alkali felspar I — typically perthitic, complex and simple twinning in the same crystal, small rounded quartz inclusions localized along the plagioclase lamellae of the perthite.

Plagioclase I — typically antiperthitic, abundant small inclusions of euhedral biotite platelets and rounded quartz droplets, vague discontinuous polysynthetic twinning with the twin lamellae ending abruptly against the biotite inclusions.

Alkali felspar II — of the order of a tenth the size of *I*, never perthitic, complex twinning only.

Plagioclase II — of the order of a tenth the size of *I*, never antiperthitic, twinning sparse and represented by a few fine lamellae crossing the whole crystal.

The old minerals I are most abundant in the unfoliated granite and become progressively rarer the stronger the foliation: they are absent in the strongly foliated and sheared gneisses. The ease of recrystallization depended on the amount of coldworking before the period of high temperature.

Myrmekite is a typical feature of the gneiss. In the light of recent experimental work (CARMAN and TUTTLE, 1963; DUFFIN, 1964), it is interpreted as the result of a combination of exsolution and recrystallization. The idea that myrmekite quartz could be derived by exsolution from the felspar originated with the observation of quartz droplets distributed along the plagioclase lamellae in alkali felspar I. Thus myrmekite is considered as having developed in the gneiss during the period of high temperature, i. e. as a product of the Alpine metamorphism. It is a transient feature which is destroyed by continued recrystallization and hence is less well developed in the better foliated rocks.

The original aim of this work was to determine the sequence of events in and around the Antigorio nappe during the Alpine orogeny. The final conclusion is that we are dealing with one continuous process, a continuous variation in type and intensity of deformation, in temperature and in conditions in the rock. This continuity is still to be seen in the now immobile rocks.

I would like to thank Prof. E. Wenk (Basle), Prof. P. Bearth (Basle), and Dr. J. G. Ramsay (London) for their help and encouragement through the course of this work. The work was made possible by N.A.T.O. and the receipt of their Studentschip is acknowledged with many thanks.

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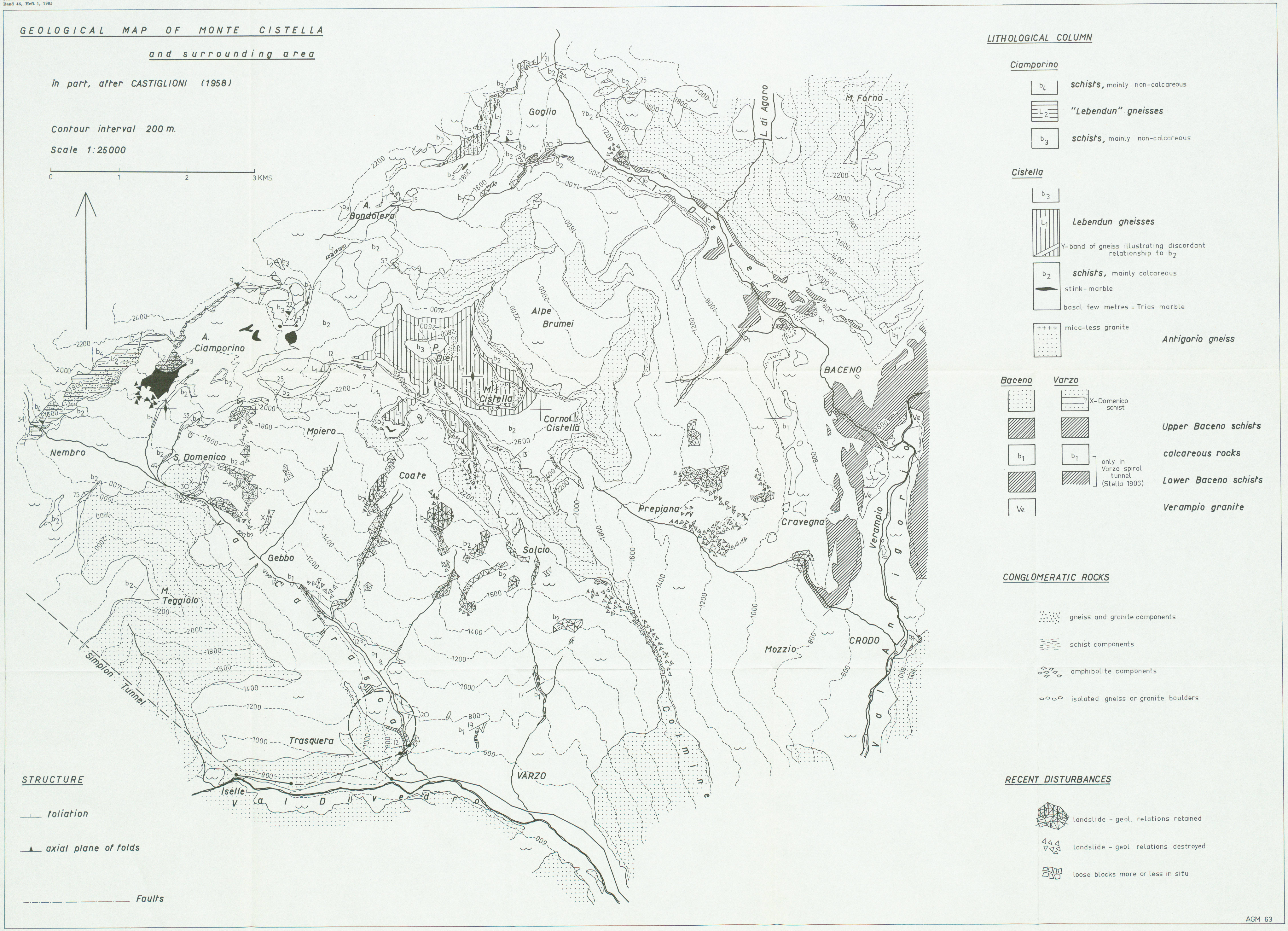
PLATE I

A. G. MILNES: Structure and History of the Antigorio Nappe (Simplon Group, North Italy)



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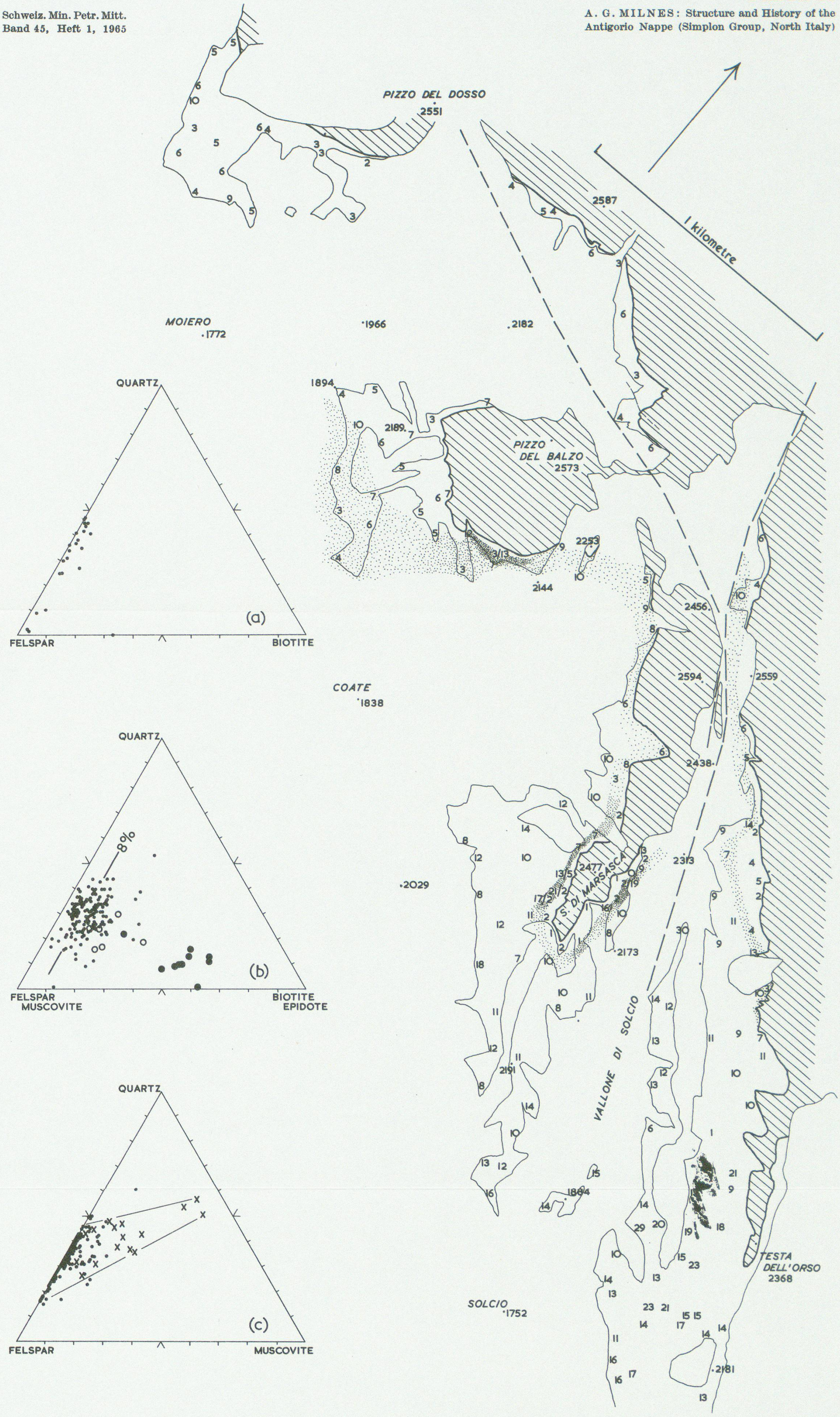

Systematic modal analysis of part of the Antigorio gneiss

(see Geological Map for location)

Numbers on the map are biotite contents (% volume) and the light facies-dark facies transition zone is stippled. Tight stippling indicates areas of heterogeneity; numbers separated by / respresent the biotite contents of adjacent light and dark components in these heterogeneous mix zones.

(a) Unfoliated "normal" gneisses i. e. granites (mainly around Scheggia di Marsasca).

(b) Foliated "normal" gneisses (·) showing the vague low density trough at around 8% biotite. Dark component from heterogeneous mix zones ○; "lamprophyric" dykes ●.

(c) Muscovite content of "normal" (·) and sheared gneisses (×).

Spot heights in metres.

Rocks overlying the Antigorio nappeshaded.