ATTI

DELLA

SOCIETÀ TOSCANA

DI

SCIENZE NATURALI

RESIDENTE IN PISA

MEMORIE - SERIE A

VOL. LXXIX - ANNO 1972

PROCESSI VERBALI 1972

ARTI GRAFICHE PACINI MARIOTTI - PISA - 1972

INDICE

PROCESSI VERBALI

Atti Soc. Tosc. Sci. Nat., Mem., Serie A, **79** (1972),
pagg. 213-222, ff. 4, t. 5.

S. CAPEDRI, G. RIVALENTI (*)

FIRST RESULTS OF AN INVESTIGATION ON PLASTIC DEFORMATIONS IN THE IVREA-VERBANO ZONE IN AN AREA BETWEEN VAL SESSERA AND VAL SESIA (VERCELLI) (**)

Riassunto — Il rilevamento preliminare di una zona tra la Val Sessera e la Val Sesia ha mostrato che le rocce hanno subito una complicata evoluzione strutturale. In ordine di età, si distinguono le seguenti strutture planari:

— contatti litologici originari (S_0);
— foliazione piano-assiale (S_1) connessa con la deformazione più antica (D_1);
— foliazione piano-assiale (S_2) connessa con la deformazione D_2;
— foliazione piano-assiale (S_3), connessa con la deformazione D_3.

Le foliazioni S_1 e S_2 sono «penetrative» su scala regionale, mentre la S_3 è intensa in certe zone.

Sono state distinte quattro fasi successive di deformazioni plastiche (D_1, D_2, D_3 e D_4). Le loro caratteristiche e le strutture di interferenza risultanti vengono descritte e discusse nel testo.

Abstract — A first inspection of an area between Val Sesseria and Val Sesia shows that the rocks have a complicated structural history. The ricognizable *planar structures* are, in order of age:

— the original lithological contacts S_0;
— an axial-plane S_1 foliation connected to the oldest D_1 deformation;
— an axial-plane S_2 foliation related to D_2 deformation;
— an axial-plane S_3 foliation connected to D_3 deformation.

The S_2 and S_1 foliations are penetrative on a regional scale while the S_3 is only locally intense.

Plastic deformations, of which four phases have been distinguished, have the following characteristics:

— D_1: small isoclinal intrafolial rootless folds;

(*) Istituto di Mineralogia e Petrologia. Università di Modena.

(**) The work was carried out with the financial support of the Consiglio Nazionale delle Ricerche.

— D_2: similar, sometimes disharmonic, generally tight to close, steeply inclined, moderately to steeply plunging folds of variable orientation;
— D_3: similar, sometimes disharmonic, close to open, seldom gentle, gently to steeply inclined, gently to moderately plunging folds of variable orientation, but generally oriented northwards;
— D_4: open to gentle, moderately plunging, steeply to moderately inclined folds, with an E-W orientation.

The interference patterns have been studied and are discussed in the text.

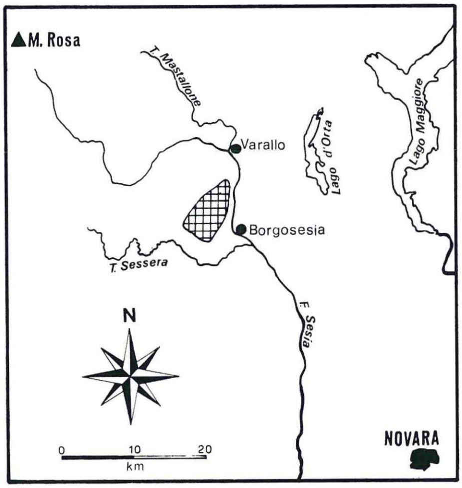


Fig. 1 - Location of the area examined (shaded).

INTRODUCTION

The area examined extends from Torrente Strona, tributary of Sessera river, to Foresto, Val Sesia, Western Italian Alps (fig. 1) and consists of pelitic biotite-garnet-sillimanite-cordierite-graphite-bearing gneisses and, subordinately, of marbles and amphibolites. The whole complex is affected by pegmatitic swarms related to different ages. These units have undergone very intense plastic deformations. General reconstruction is problematical on account of both the complexity of the structures and the heavy cover; study of the mesoscopic structures has nevertheless unabled us to gain an insight into the deformation pattern of the area. Some results are presented in this paper.

PLANAR AND LINEAR STRUCTURES

The earliest recognizable *planar structures* comprise lithological contacts S_0 generally parallel to a planar orientation of mica or to a thin internal metamorphic layering, which gives an S_1 foliation. As a consequence of a plastic deformation described hereafter (D_2) there appears, very evidently in the Strona Valley and less towards the Sesia Valley, an S_2 axial-plane foliation (Plate I, d) marked by mica and caused by a strain slip cleavage of the S_0 and S_1 foliation. The S_2 foliation cuts the S_0 and S_1 on the limbs of the D_2 folds (see below) at a shallow angle, and is seen to be clearly discordant to the lithology only in the closures of the same folds.

Sometimes an S_3 foliation, again marked by mica, appears in some particular horizons (e.g. phlogopitic layers in the marbles, Plate I, a) and in some zones (e.g. in the southeastern zone of the Strona Valley) and is connected with the D_3 deformation. However, the S_3 is not as penetrative as the S_1 and S_2 discontinuities are.

Lineations of many kinds have been found. They consist of: linear orientation of amphibole and pyroxene, sillimanite, the intersection of S_2 and S_1 or S_0, rodding of quartz-feldspatic material in the fold hinge, crenulations of fold hinges. As these lineations are not very evident in the gneisses, it is difficult to establish exactly their relative age.

PLASTIC DEFORMATIONS

The rocks have undergone at least four periods of plastic deformation. The characteristics of each set are reported below in order of age.

D_1 - This is the oldest recognizable deformation present in the area. Generally, it appears as isoclinal or very tight rootless intrafolial folds (Plate I, b), following the therminology of TURNER and WEISS [1963, p. 117]. It is evidenced only when an S_0 surface can be distinguished and when it is refolded by D_2 folds (Plate IV, a). The closure of D_1 folds are wedge-shaped. As the S_1 foliation is subparallel to S_0 on the limbs and is cut by the clo-

sures, we suggest that the S_1 is an axial-plane transposed foliation connected with the D_1 deformation.

D_2 - Folds of D_2 age are very common in the Strona Valley, while they are more seldom seen towards the Sesia Valley. The style of the folds is generally similar (Plate I, c). Some disharmony is present when layers of different competency are folded together. In the felsic gneisses it appears as a very tight folding with pointed closures (Plate I, d), while in the amphibolites the closures are more often semicircular (Plate II, a), although the style remains tight or close. In the marbles this folding is very often isoclinal (Plate IV, b). The axial plane, marked by the S_2 foliation (Plate I, d), generally strikes to E or NE and, if not deformed by other folds, is generally planar. Its dip is generally subvertical or nearly so. The fold axis, and the lineations connected to it, show a large spread both in trend and in plunge, as is to be expected, but a northwards orientation is statistically frequent. The whole style of these folds is therefore that of tight, steeply inclined, moderately to steeply plunging folds (TURNER and WEISS [1963, p. 119]; FLEUTY [1964]; RAMSAY [1967, p. 360]).

Very often, mainly in the Strona Valley, these structures are found as rootless intrafolial folds consisting mainly of folded amphibolite schlieren (Plate II, b) or by thin pegmatitic veins. Obviously the axial plane of the intrafolial folds is parallel to the main gneiss foliation. A discordance between S_2 or S_1 is seen in the limbs truncated by S_2 and in the closures. Intrafolial folds consisting only of gneiss have also been seen (Plate II, c), but they are less common. In the latter case the limbs of the folded gneiss boudin are not sharply truncated by the S_2 but fade out by thinning along the strike. The features reported above indicate not only that the D_2 deformation has been intense on a regional scale, but also that, in part of the area, the regional S foliation is a transposed S_2 (TURNER and WEISS [1963, p. 117], RAMSAY [1967, fig. 3-60]).

In the field, garnet does not appear to be deformed by this folding and interrupts the biotite foliation without causing deformation (post-tectonic crystallization). Sillimanite, which is not to be linked, however, to only one generation, is either deformed in the D_2 closures or aligned parallel to the fold axis. These observations have yet to be confirmed by further microscopic examinations.

D_3 - The D_3 folds are more common towards the Sesia Valley. The style of these folds is generally close to open (Plate III, a), seldom gentle, gently to steeply inclined, gently to moderately plunging. The axial direction may generally vary from N to NW and the axial plane strikes variably owing either to the successive deformation or to the fact that D_3 acted on an already deformed surface. The folds are often similar and disharmonic when different lithotypes have been folded together; Plate III, c, for example, shows a marble disharmonically folded together with a gneiss. The fold hinge is often crenulated, giving lineations parallel to the fold axis. Rods of quartz-feldspatic material are sometimes formed parallel to the axis. The axial plane does not generally show any foliation, except for some already mentioned cases and areas where an S_3 foliation appears (Plate I, a).

Garnet is deformed and elongated by S_3 deformation, which suggests that it is pre-tectonic. The deformed garnet assumes the shape of a two- or three-axis ellipsoid. When it is a three-axis ellipsoid the major axis is aligned parallel to the D_3 fold axis, the intermediate being parallel to the gneiss foliation.

D_4 - This deformation has given open to gentle, moderately plunging, steeply to moderately inclined folds. The axial orientation is E-W, as is that of the axial planes. Mesoscopic structures of this set are somewhat more difficult to observe than the preceding ones, because they are generally manifested only by bucklings whose wavelenght reaches up to 7 metres. No particular secondary structure is associated with the D_4 folds.

INTERFERENCE PATTERNS

The interferences among the various foldings are essentially of two types.

First type - In the field this type of interference gives patterns such as those shown in fig. 2 a. This is the commonest case and refers to interferences between folds whose axes are sub-parallel and whose respective axial planes are inclined to each other at a certain angle (between 0° and 90°; RAMSAY's type 3 [1967, p. 531]). On the basis of the characteristic features described in the preceding paragraph, it has been seen to occur between the D_3 and D_2 folds (Plate III, a and b) and, when unmistakable D_1 folds are identified, also between the D_1 and D_2 (Plate IV, a and b).

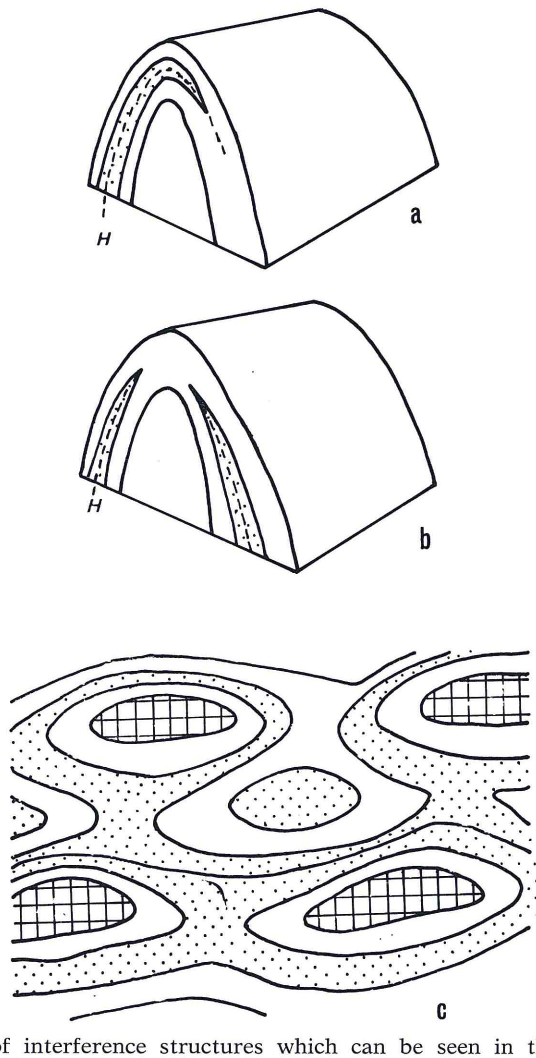


Fig. 2 - Types of interference structures which can be seen in the field: a) first type; b) and c) second type. H = trace of the deformed axial plane (see text for explanation).

Second type - This type occurs when a D_4 refolds a D_3 or D_2 fold (Plate I, d). In the field it gives two different features depending on the face on which the pattern is observed. It may give double--prong patterns (fig. 2 b) or domes and basins (fig. 2 c, Plate V a) which are generally elongated and slightly asymmetric. Domes and basins are formed when the fold axes of the interfering sets are normal to each other, or nearly so, and the axial planes are also roughly normal. Moreover, the plane containing the two fold axes must be normal to both the axial planes of the interfering sets. On the other hand, as will be shown, the association of domes and basins to doble-prongs indicate that the reciprocal position of axes and axial planes was not exactly normal.

Complex patterns consisting of an association of both the above types have also been observed, albeit rarely (Plate V, b).

To get a better overall idea of the deformation pattern we attempted a reconstruction in plasticine (fig. 3). After having fold-

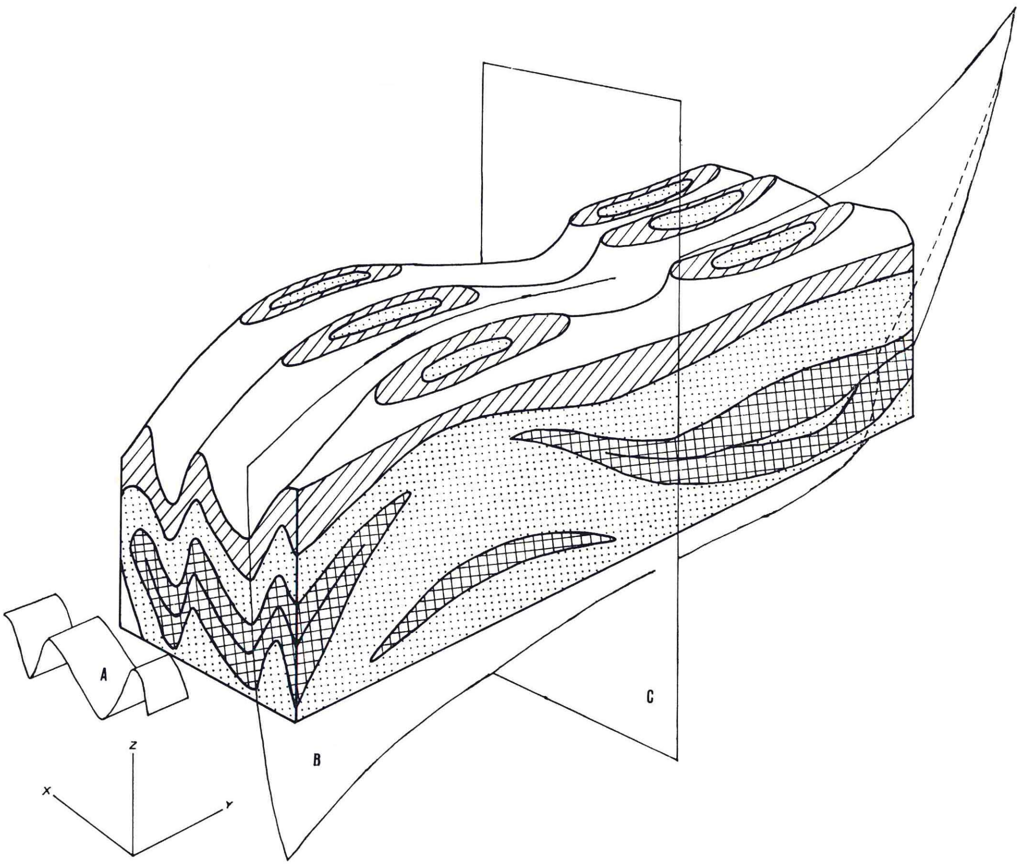


Fig. 3 - Interference figures which can be seen on mutual normal surfaces intersecting a thrice folded complex. The interference shown in fig. 2a is seen on the XZ plane, the one of fig. 2b on the ZY plane, the one of fig. 2c on the XY plane. A. B and C are the D_2, D_3 and D_4 axial planes, respectively. See text for further explanations. (Drawing from a plasticine model).

ed two layers (D_2), we superimposed a third layer and refolded the whole around new axes parallel to the first with axial plane sub-normal to the first (D_3); in this way the former layers suffered both deformations (D_2 and D_3) while the letter underwent only the second (D_3). The D_2 deformed axial plane is seen in sections cutting the fold axes. The whole was deformed again around axes forming an angle of some 20° to the old axes and, while the former axial plane (D_3) was normal to the horizontal, the latter axial plane was inclined by some 75°. Sectioning (fig. 3) the structure thus obtained with a ZX plane, the axial D_3 surface appears undeformed, while the D_2 axial surface is deformed and gives figures of the first type. In the plane ZY both the D_2 and D_3 axial surfaces are deformed by the D_4, giving the double-prong interferences of the second type. In the plane XY more or less regular domes and basins are formed both between the D_2 and D_4 or D_3 and D_4.

The model presented above is the one which fits best with the field observations. It can be concluded that:

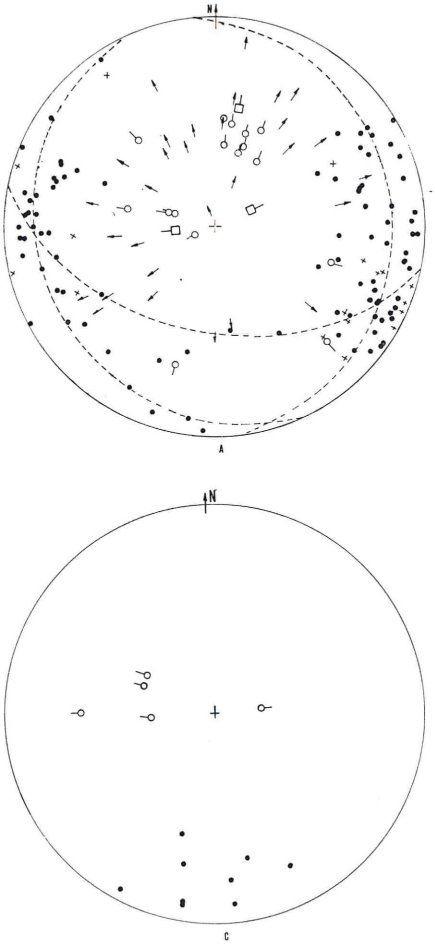
i) the D_3 deformations has axis parallel and axial plane roughly normal to the D_2; the same probably holds between D_2 and D_1;

ii) the D_4 axial plane was nearly, but not, normal with respect to the D_3, as were the respective fold axes.

The less common occurrence of interferences of the second type depends on several causes. We believe that the most important is the gentle character and the large wavelength of the D_4 folds, which therefore gives very elongated domes or basins difficult to be seen owing to the bad exposures.

Equal-area plots

The field measurements were plotted on a Lambert equal-area net, lower hemisphere. Figs. 4a, b, c show the diagrams where the poles of the axial planes, the lineations and the fold axes are plotted for D_2, D_3 and D_4 respectively. The data are as yet scanty and the interpretation is therefore doubtful, particularly as it has not so far been possible to divide the area into structurally homogeneous zones, since the mapping is in its early stages and the area supports a heavy cover. Full interpretation will therefore be postponed untill the mapping is finished, but in the meantime certain hypotheses can be put forward.



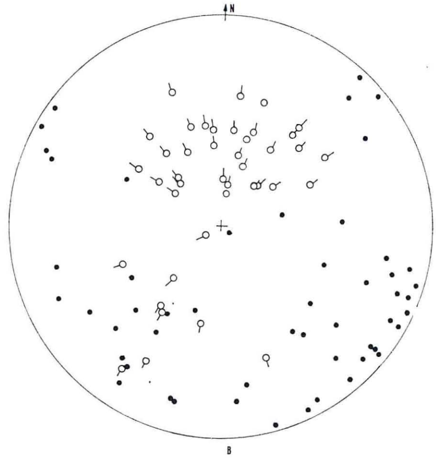


Fig. 4 - Plots on a Lambert equal-area net, lower hemisphere, of axial plane poles (dots), fold axes (dots with a tail), lineations (arrows); a) D_2 structures (squares with tail are calculated β axes); b) D_3 structures; c) D_4 structures. See text for further explanations.

In the diagram of fig 4 a the axial plane poles plot on two great circles, with β axes plunging steeply to W and ENE respectively. Moreover, the two great circles each contain a maximum which could enable another great circle to be drawn with its pole NNE. Although other interpretations may be put forward, we suggest that the spread on two great circles is the consequence of the D_4 deformation (the non excessive spread indicates open or gentle folds), while the third great circle is the consequence of a close or tight D_3 folding. The spread of the fold axes and lineations can be explained by the two-fold deformations suffered by these structures.

We do not dare to draw conclusions or formulate hypotheses for the plot of D_3 axial planes because the data are too scanty. It can be noted (fig. 4 b) that the axes generally pluge to N with some spread which could be tentatively ascribed to the D_4 folding. Fig. 4 c shows that the few D_4 plotted axial planes trend generally E-W with slightly different degrees of dip to the N, and that the fold axes are also E-W.

Conclusions

The preceding description shows that the rocks of the examined area have a complicate structural history with at least four phases of plastic deformations. At present the area exhibits transposed foliations formed during the D_1 and D_2 phases. The original lithological contacts S_0 and the S_1 and S_2 foliations intersect each other at variable angles. This is of importance in the geological mapping, as a confusion between the S_2, S_1 and S_0 can lead to erroneous extrapolations of some lithological horizons, such as, for instance, amphibolites and marbles.

REFERENCES

Fleuty M. J. (1964) - The description of folds. *Geol. Assoc. Proc.*, **75**, 461-492.

Ramsay J. G. (1967) - *Folding and fracturing of rocks.* McGraw-Hill Book Company, New York, London.

Turner F. J., Weiss L. E. (1963) - *Structural analysis of metamorphic tectonites.* McGraw-Hill Book Company, New York, London.

(*ms. pres. il 6 luglio 1972; ult. bozze il 26 febbraio 1973*)

PLATES

PLATE I

a) - D_3 fold in marble (near Locarno). There is an S_3 foliation in the phlogopitic layers.

b) - Isoclinal rootless intrafolial D_1 fold (Valle Strona).

c) - Similar D_2 folds in the gneisses and amphibolitic layers (near Brugarolo). The D_2 axial plane is curviplanar because of D_3 refolding.

d) - D_2 folds in the gneisses (Brugarolo). The closures are wedge-shaped and there is an evident S_2 axial-plane foliation.

PLATE I

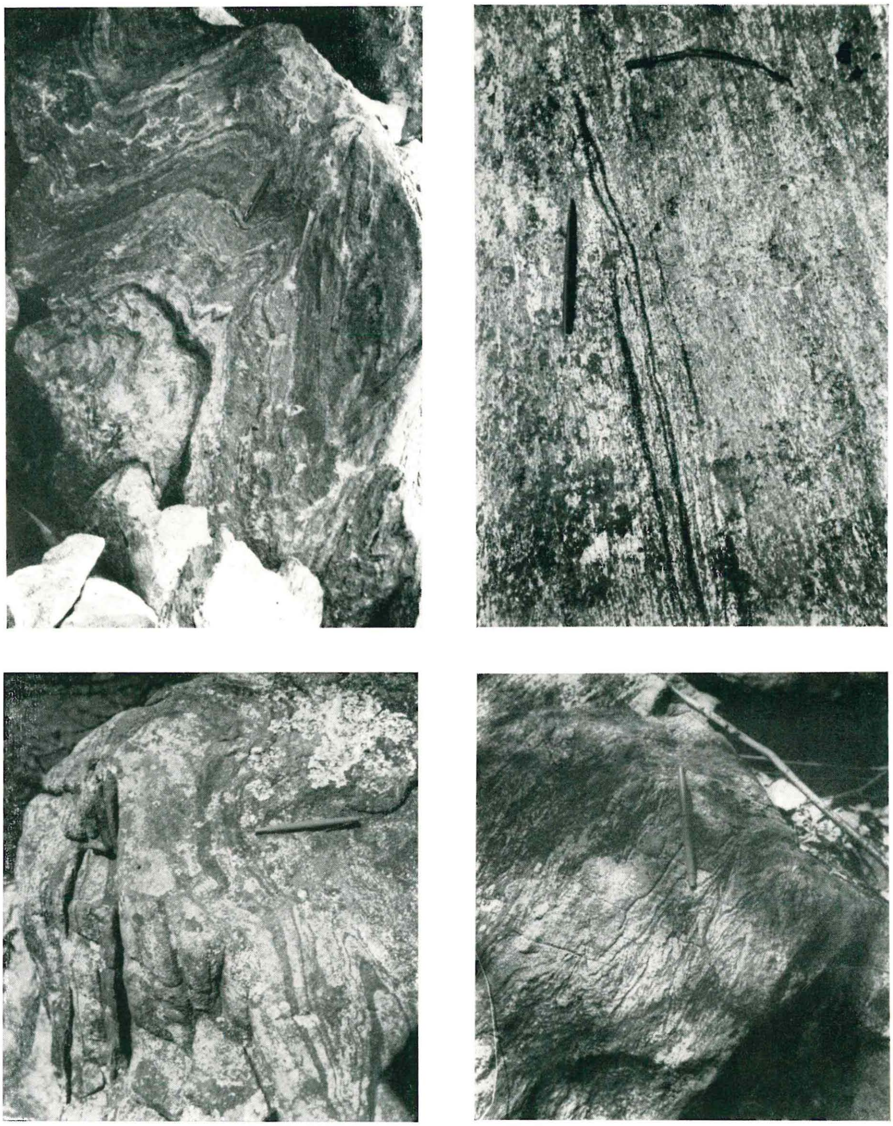


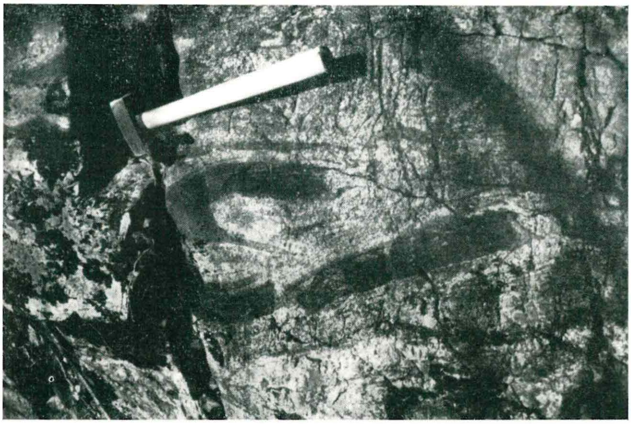
PLATE II

a) - Semicircular D_2 closure in amphibolitic layers (Valle Strona). The fold is viewed normal to the fold axis.

b) - Rootless intrafolial D_2 in amphibolitic boudins (Valle Strona).

c) - Intrafolial D_2 fold in the gneisses (Valle Strona).

PLATE II



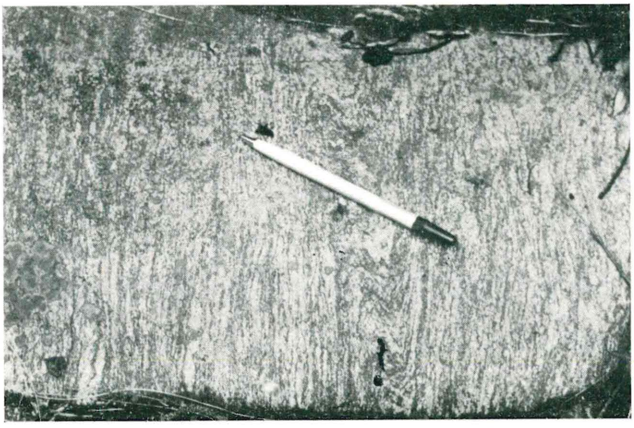


PLATE III

a) - D_3 fold refolding a D_2 in the gneisses (near Foresto).

b) - First-type interference between D_2 and D_3 (near Doccio). The pencil on the right is parallel to the D_2 axial-plane trace, while that on the left is parallel to the D_3 axial plane trace.

c) - Disharmonic D_3 fold affecting gneisses and marbles. While in the gneisses the closure is semicircular, the marbles are disharmonically folded and décollement structures are present (see RAMSAY, 1967, p. 420).

PLATE III

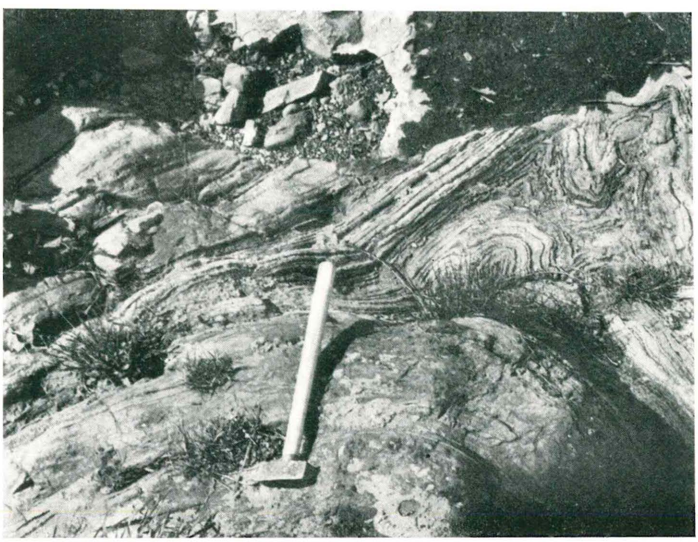


PLATE IV

a) - First-type interference between D_1 and D_2 (near Brugarolo). The D_1 limbs have been contoured by a marker.

b) - D_2 refolding a D_1 fold in the marbles near Varallo. The D_1 closure is seen on the left just above the head of the hammer.

PLATE IV

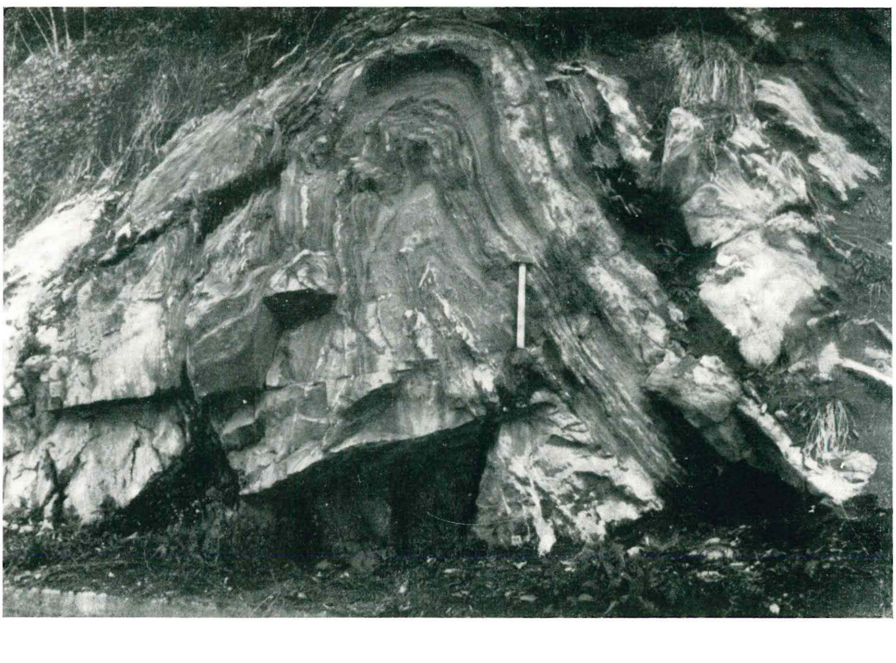


PLATE V

a) - Interference between D_3 and D_4 forming domes and basins (Valle Strona).

b) - Interference pattern in three phases of folding. A D_1 fold (closure top left) has its axial plane folded by a D_2, whose axial plane is in turn deformed by D_4 (Alpe Cravoso).

PLATE V