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HOLOCENE SLOPE DEFORMATIONS IN VALFURVA, CENTRAL ALPS, ITALY (***)

ABSTRACT: FORCELLA F. & OROMBELLI G., *Holocene Slope Deformations in Valfurva, Central Alps, Italy* (IT ISSN 0084-8948, 1984).

Forms and structures recognized on both sides of the Valfurva Valley (Central Alps, Italy) are here described. They are indicative of Holocene slope deformations and are represented by: 1) discontinuous sequences and sheaves of uphill-facing scarps; 2) downhill-facing scarps; 3) open tension cracks, furrows and trenches. Uphill-facing scarps with walls up to 10 m high prevail on the northern side of the valley, while downhill-facing scarps and trenches are more common on the southern side.

On both sides the above mentioned structures cut moraines and rock glaciers of Late-glacial age, while in other cases they are covered by similar deposits. These forms are commonly related to gravitational spreading of ridges and/or deep seated rock creep. Nevertheless in this case the relatively uniform attitude of the shear surfaces, dipping northeastwards, independently from the aspect and inclination of the slope, suggest that such discontinuities are the superficial expression of neotectonic deformations, which fit into the framework of the present neotectonic activity in Central Alps.

RIASSUNTO: FORCELLA F. & OROMBELLI G., *Deformazioni oloceniche dei versanti in Valfurva, Alpi Centrali, Italia* (IT ISSN 0084-8948, 1984).

Vengono esaminate forme e strutture presenti sui fianchi della Valfurva (Alpi Centrali, Italia) indicative di deformazioni oloceniche dei versanti. Si tratta di: 1) sciami discontinui di contropendenze di versante, talora associate o solcate trasversalmente da trincee naturali beanti; 2) superfici di collasso immerse a franapoggio, o rotture di pendio, che determinano scarpate rivolte verso valle; 3) fessure di trazione e trincee naturali beanti con aperture fino a 1-2 m.

Sul versante orografico destro della valle sono in prevalenza presenti contropendenze, con pareti alte fino a 10 m, sul versante opposto prevalgono invece nettamente superfici di collasso e rotture di pendio.

Su entrambi i versanti le strutture descritte tagliano in taluni casi morene e rock-glaciers tardo-glaciali. Queste forme sono diffusamente presenti anche in aree limitrofe ove sono state attribuite a cedimento di versante in seguito a decompressione. In questo caso tuttavia la relativa uniformità delle giaciture dei piani di discontinuità verso NE, indipendente dalla locale orientazione ed esposizione del pendio, il movimento per incrementi successivi accertato lungo una di tali superfici, la distribuzione areale di tali strutture, che formano una fascia allungata in direzione WNW-ESE parallela all'asse della Valfurva, suggeriscono che la fenomenologia presente possa essere stata controllata da deformazioni tettoniche recenti inquadrabili nel campo di stress che determina l'attuale evoluzione neotettonica delle Alpi Centrali.

TERMINI CHIAVE: Neotettonica; stabilità di versante; Olocene; Italia; Alpi Centrali.

INTRODUCTION

Lineaments or sheaves of lineaments were traced with the photogeological analysis in a wide area of the Central Alps in occasion of the participation to the CNR Neotectonics Subproject (FORCELLA & *alii*, 1982). A few of these lineaments were considered active during the last 70 000 years (interval $IV^c + V$ of the above mentioned Subproject).

Three groups of fractures belonging to this cathegory have been recognized in the area covered by the IGM topographical map « Bormio ». In particular the sheaf trending WNW-ESE, located between Bormio and S. Maria di Livigno, was synthetically described as follows: « Fractures parallel to the thrust surface between the Sedimentary Unit and the Crystalline Unit, slightly transversal to the schistosity. To the East they are emphasized by slope breaks represented by subvertical rock walls, further to the West by the drainage system and by the saddling of Passo d'Eira. The eastward continuation of these structures is represented by the Valfurva valley, whose direction is opposite with respect to the Adda River main valley. The alignment of the springs of S. Caterina Valfurva, Bagni di Bormio (thermal) and S. Michele in Val Viera di Livigno is parallel to these discontinuities » (FORCELLA & *alii*, 1982, p. 254).

Afterwards we analysed some large-scale air photographs of the Valfurva area (Lombardy Region flight, 1975-76) and the particular frequency of recent deformations on the slopes of this valley was verified.

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GEOLOGICAL OUTLINE OF THE EXAMINED AREA

The studied area belongs to the Ortles Austroalpine Nappe. The sedimentary cover outcrops on the northern margin of the area and is locally represented by the steeply northward dipping strata and banks of the Cristallo Dolomite. The WNW-ESE trending Zebrù Line separates the carbonate formations from the crystalline basement outcropping to the South and its strike and dip are conformable with those of the Cristallo Dolomite (Pozzi, 1965; 1968).

Such line is interpreted on the geological map « Bormio » (1st edition, 1970) as the thrusting of the Sedimentary Unit onto the Crystalline Basement, but the fact that it may represent a simple décollement surface cannot be excluded, as frequently mentioned in the literature. The prevailing lithotype of the crystalline basement is represented by the Bormio Phyllites, with interbeddings of lineated muscovite-gneiss, amphibole-schist, quartzite, and saccharoïdal limestone and it has been recently studied by Argenton & *alii* (1980).

Superficial deposits of various types are very common, mainly of Late-glacial and Holocene age. They cover large areas of the slopes and of the valley bottom. They are Late-Würm glacial deposits, often forming end moraines of the main Valfurva glacier or of minor glaciers of the lateral valleys. Late-Würm outwash deposits, locally forming terraces, are also present, as well as rock glaciers, mostly located in the upper part of the lateral valleys. The Holocene deposits are represented by widespread talus and flood plain deposits and by big moraines near the glacier fronts. Some of them were mapped or described by Desio (1967) and Catasta & Smiraglia (1978). Only the deposits that either appear deformed or cover undisturbed the movement surfaces are represented in fig. 1.

FORMS AND STRUCTURES

The forms and structures recognized in the studied area are:

a) downhill dipping shear surfaces that generate slope breaks and downhill-facing scarps; *b*) uphill-facing scarps related to various types of mechanisms; *c*) furrows and trenches along the slopes and open tension cracks whose width ranges from a few dm to a few metres; *d*) denudation scars in superficial deposits and/or in the bedrock.

These phenomena are arranged almost continuously on both sides of the Valfurva, even if they are more concentrated in some areas. The most significant zones are here described.

Alpe Cristallo

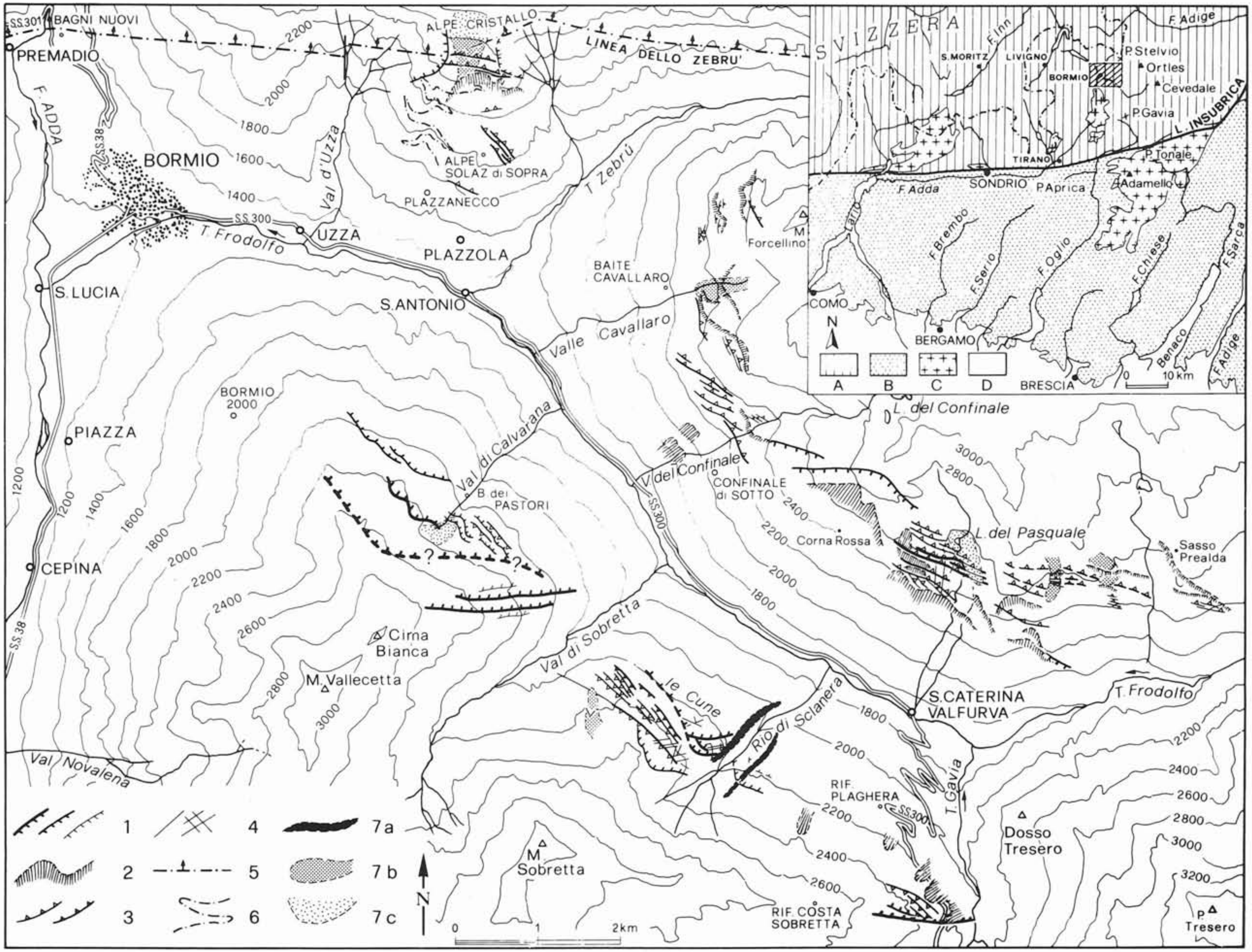
A sheaf of uphill-facing scarps, striking WNW-ESE and from 1 m to 5-6 m high, is present between 2,480 and 2,560 m elevations, just downstream the Zebrù Line. In the easternmost part of Alpe Cristallo such scarps affect the metamorphic bedrock and the regolith cover and intersect minor morphological features due to the presence of small valleys and interfluves, whose trend is transversal with respect to the scarps themselves. The same morphologic features are upthrown downstream and the displacement is 5-6 m without any sign of transcurrent movements (fig. 2).

The central sector of Alpe Cristallo is covered by a Late-Würm moraine complex whose internal part looks like a rock glacier with blocks up to several cubic metres in size deriving from the overlying carbonate wall of the Rèit. Two uphill-facing scarps belonging to the above mentioned sheaf also displace the moraine-rock glacier complex and their maximum height is about 3 m (fig. 3).

One of these two uphill-facing scarps is the continuation of one of the scarps affecting the bedrock. They clearly break the continuity of the crest line of the moraines and the concentric structures of the rock glacier and generate locally a few small blind valleys. The northernmost of these structures disappears inside the moraine-rock glacier complex, while the southernmost one cuts it transversally and penetrates again into the metamorphic bedrock where it generates scarps up to 3.5 m high. Generally the uphill-facing scarps produce asymmetric ridges with the uphill slope steeper than the downhill one (fig. 4). This kind of asymmetry – opposite to the one of lateral moraines – proves the deformational nature of such surfaces and excludes any possibility that they are right-lateral moraines of the Late-Würm valley glacier of Valfurva, as suggested by other Authors. This is also excluded by their overlapping onto the local moraine-rock glacier complex of Alpe Cristallo, contrary to the usual relationships between tributary and main valley end moraines.

The uphill-facing scarps that affect the rock basement are clearly higher and more frequent than those affecting the moraine deposits. This indicates that the mechanisms, which produced such shear surfaces, were

Fig. 1 - Studied area. 1) Collapse surfaces dipping downhill, marked by sharp slope breaks or band-shaped denudation scarplets. They are represented with a dashed line when presumed, the thickness of the line is proportional to the height of the scarp. 2) Denudation scars of the bedrock and/or debris with blocks of different sizes. They are mostly associated with surfaces of type 1. 3) Uphill-facing scarps, related to uphill dipping surfaces (3a), or associated with natural trenches caused by release of the slope (3b). The triangles are uphill-facing. 4) Minor open tension cracks and other unclassified features. 5) Zebrù Line, arrows indicate plunge of the fault plane. It separates the sedimentary cover of the Ortles Nappe (to the North) from the metamorphic basement of the Ortles and other Austroalpine units (to the South). 6) Military road of the Rèit, cut by a surface of type 1 at 2,261 m elevation. 7) Accumulation forms of various nature: end moraines (7a), rock glaciers (7b), debris accumulations (7c). Only those covering or cut by the above mentioned forms and structures are represented here. Symbols of the key map: A) Austroalpine and Pennidic Units. B) Southern Alps. C) Main intrusive bodies of Alpine age. D) Alluvial and glacial deposits along the northern margin of the Po Plain.



SS.301
BAGNI NUOVI
PREMADIO
ALPE CRISTALLO
LINEA DELLO ZEBRU'
F. ADDA
SS.38
BORMIO
Val d'Uzza
ALPE SOLAZ di SOPRA
PLAZZANECCO
SS.300
UZZA
T. Frodolfo
PLAZZOLA
T. Zebrù
M. Forcellino
BAITE CAVALLARO
S. LUCIA
S. ANTONIO
Valle Cavallaro
BORMIO 2000
PIAZZA
Val di Calvarana
B. dei PASTORI
V. del Confinale
CONFINALE di SOTTO
L. del Confinale
Corna Rossa
L. del Pasquale
Sasso Prealda
CEPINA
Cima Bianca
M. Vallecetta
Val di Sobretta
le Cune
Rio di Sclanera
S. CATERINA VALFURVA
T. Frodolfo
Val Novalena
RIF. PLAGHERA
T. Gavia
Dosso Tresero
M. Sobretta
RIF. COSTA SOBRETTA
P. Tresero
1 2 3 4 5 6 7a 7b 7c
N
0 1 2km
SVIZZERA
F. Inn
S. MORITZ
LIVIGNO
BORMIO
F. Adige
P. Stelvio
Ortles
Cevedale
P. Gavia
L. INSUBRICA
TIRANO
P. Tonale
Adamello
F. Adda
SONDRIO
P. Aprica
Lario
F. Brembo
F. Serio
F. Oglio
F. Chiese
F. Sarca
COMO
BERGAMO
Benaco
F. Adige
BRESCIA
A B C D
0 10 km

FIG. 2 - Sheaf of uphill-facing scarps cutting the crystalline basement of Alpe Cristallo at 2,500 m elevation. The slope is interrupted, with the downhill side upthrown, without any sign of transcurrent movements. M indicates the eastern limit of the end moraine complex, the crystalline basement outcrops in the foreground. B indicates the bend of the military road of the Rèit also shown from the opposite side in fig. 3.

already active before the deposition of the local moraine complex and were reactivated after its deposition. Therefore the height of the scarps in the bedrock should be the result of repeated increments. These scarps are related to upslope dipping shear surfaces, as proved by their intersection with the aforementioned small valleys and interfluves.

Immediately downstream from the sheaves of uphill-facing scarps, a wide denudation band affects both the crystalline basement and the moraine complex, exposing crumbled walls in the basement and blocky debris in the moraines.

To the East and to the West the Alpe Cristallo is bordered by steep slopes under rapid erosion, emphasized by spoon-shaped collapse surfaces dipping downslope. In the western sector (Val d'Uzza), along the military road of the Rèit, built during the 1st World War, the bend at 2,261 m elevation is intersected by a well defined collapse surface. The road pavement is cut by an ENE-WSW trending shear surface and is entirely

FIG. 3 - One of the uphill-facing scarps that penetrate into the end moraine complex of Alpe Cristallo where it generates minor scarps (1-3 m high), indicated with black arrows. B: as in fig. 2, but from the opposite viewpoint.

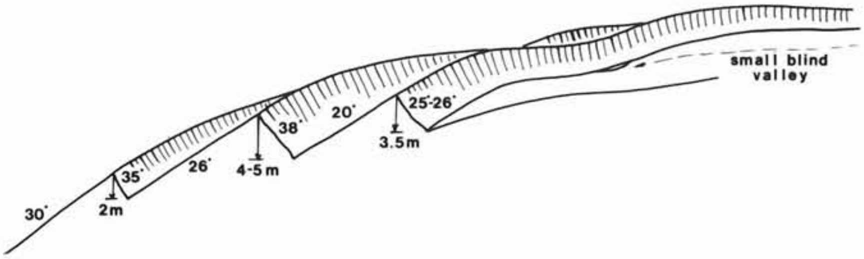


FIG. 4 - Cross section of the uphill-facing scarps at 2,500 m elevation and their main geometrical characteristics.

FIG. 5 - Uphill-facing scarps that intersect the southern flank of Alpe Cristallo between the 2,000 and 2,100 m elevations near Alpe Solaz di Sopra (indicated with white arrows). They are locally associated with natural trenches of moderate width.

downthrown about 5 m northwestwards. The collapse surface in this place seems to affect only superficial deposits. Other uphill-facing scarps, isolated or grouped into sheaves, are present at lower elevations along the same slope and their trend ranges from E-W to NW-SE. Locally they are associated with natural trenches in the bedrock, 1-2 m wide and up to 5 m high (fig. 5).

The dip of the uphill-facing scarps ranges from 30° to 48°. Also in this case the shear surfaces are postglacial, because they intersect rock surfaces shaped by the Late-Würm glaciers, and they do not show any sign of glacial erosion themselves.

AREA BETWEEN CORNA ROSSA AND LAGO DEL PASQUALE

A sheaf of uphill-facing scarps can be observed along the western flank of the Valle del Pasquale. They trend WNW-ESE and are rather regularly spaced between 2,400 and 2,700 m elevations. The scarps at lower elevations develop on gently dipping grassy slopes and their height is 2-3 m (fig. 6). Their geometrical characteristics and the resulting topography are similar to those generated by the uphill-facing scarps at Alpe Cristallo, previously described. Because of the grass cover it was not possible to ascertain whether they affect the rock basement or superficial deposits.

Upstream the slope is furrowed by other uphill-facing scarps much more evident than the previous ones. These scarps generate steps up to 8-10 m high and break the metamorphic basement which outcrops almost continuously above 2,450 m elevation. The outcropping basement is crumbled and supplies coarse material that forms bands embanked by the single scarps. Furthermore the bedrock is cut by a network of subvertical open tension cracks generally a few dm, but locally up to more than 1 m wide. They are arranged in two main groups which are almost perpendicular: the trend of the first one ranges from 110° to 140° and is almost parallel to the strike of the scarps, the second one ranges from 40° to 60° and cuts them almost perpendicularly. The continuity of the rock crest of the scarp is interrupted by transversal trenches with wall surfaces so complementary that their previous fitting can be recognized. Such tension cracks are locally open down to several meters depth, in some cases they are covered on top by a natural roof, probably because of lateral sliding of rock slabs according to models which can also be observed at a smaller scale (fig. 9).

The whole area between Lago del Pasquale and Baite del Pastore shows a block topography and the blocks are completely disrupted by the intersection of the two above mentioned systems (fig. 7). The uphill-

FIG. 6 - Sheaves of uphill-facing scarps between the 2,400 and 2,500 m elevations on the northern flank of Valfurva Valley upstream from the S. Caterina Valfurva village (that can be seen on the valley bottom). They strike WNW-ESE and run upslope diagonally in a direction which is opposite to the downflow ofthe main river. This fact, as well as the clearly asymmetrical cross sections with an upslope side which is much steeper than the gradient of the slope that they cut, excludes any possibility that they are lateral moraines related to the Würm valley glacier. The uphill-facing scarps at greater elevations represent a levee for the debris bands supplied by the overlying crumbled outcropping bedrock. The black arrow in the foreground points to a natural trench that cuts the scarps themselves.

FIG. 7 - Open tension cracks striking in various directions, which dissect the topography on the western slope of Valle del Pasquale. They are indicated with black arrows.

facing scarps of the western flank of Valle del Pasquale continue southeastwards inside the stream bed itself which is covered by coarse debris. The scarps are smaller but still clearly distinguishable in the river channel, as already observed on deposits of different kind at Alpe Cristallo.

Eventually it has to be stressed that the rock surface of the uphill-facing scarp at 2,580 m elevation appears very smooth though it does not coincide with the foliation of the rock. That is clearly in contrast with the rough and crumbled morphology of the rock outcropping along the sections of the slope lying between the scarps themselves.

RIO DI SCLANERA

Two lateral moraines can be observed WSW of S. Caterina Valfurva, along the Sclanera Stream. They were deposited by a glacier that during Late-glacial time was coming down from Mount Sobretta and joined the main glacier of Valfurva at 2,042 m elevation. The two moraines can be followed from 2,275 m elevation down to the aforesaid confluence. On the air photograph the right moraine appears intersected by two discontinuity surfaces trending NW-SE, which generate steps on the crest line, and the downstream tracts appear to be downthrown. The lowermost discontinuity can be observed at 2,170 m elevation and appears as a slope break marked by a scarp 4-5 m high. A small level ground is present at its base. The slope break occurs in correspondence with an outcrop of bedrock and could have been generated by a step of the substratum on which the moraine is lying. Another break in the crest line, much more evident and continuous, can be observed at 2,250 m elevation. In detail it consists of three scarps, close to one another, transversal to the moraine and trending NW-SE. The uppermost one is not more than

FIG. 8 - A collapse surface dipping downhill (indicated with white arrows) intersect a lateral moraine (M) and an outwash plain (A) on the right side of the Rio di Sclanera Valley. It generates a scarp 4-5 m high.

1.5 m high and can be followed for a short distance, the intermediate one is the biggest and is about 4 m high, its dip is 30° and it shows a good continuity for several tens of meters. The lowermost one is a simple undulation of the crest. The main scarp continues along the inner side of the moraine and cuts two more recent moraines. On the outer side the scarp continues and runs across a marginal outwash plain, where it generates a step 4-5 m high (fig. 8).

A little further on, where the bedrock is outcropping, a trench in the rock can be observed trending NW-SE (140°), discontinuous and slightly winding. It is 1-2 m wide and bordered upstream by a scarp 3-4 m high. The trench does not generate any uphill-facing scarps and its origin seems to be related to a discontinuity surface dipping downhill. The rock outcrops are also intersected by numerous open tension cracks trending approximately N-S (0°-10°).

The whole slope shows rock surfaces shaped by the glaciers, subsequently fractured and partly dismantled because of collapses. Also the slope between the Sclanera Stream and the Sobretta Valley is affected by a remarkable sheaf of uphill-facing scarps trending NW-SE, which are cut by a network of trenches and open tension cracks trending ESE-WNW and NW-SE, with the downhill sector downthrown.

Val di Calvarana

The northeastern flank of Cima Bianca is affected by shear surfaces, trending NW-SE, that generate scarps, slope breaks and trenches with the same trend. These elements affect the metamorphic complex of the Bormio Phyllites and locally also superficial deposits.

Near Grasso di Solena at about 2,300 m elevation trenches in the rock were observed trending WNW-ESE and NNW-SSE, 1-2 m wide and down to 5-6 m deep. On the whole the morphology is that of a rock relief broken into blocks downthrown in a downhill direction.

Other remarkable trenches can be observed from Baita dei Pastori to Mount Sobrettina (fig. 9). The biggest ones trend NW-SE, they are up to 10 m wide and show a good continuity for more than 200 m. All these forms are mainly due to shear surfaces dipping downhill in a northeastern direction with dips of 40-55°, as indicated by the intersection of these surfaces with reliefs transversal to them. Yet uphill-facing scarps are also present, which can be related to shear surfaces dipping uphill, that is in the opposite direction. These scarps are less important and less frequent than the previous ones. Also in this sector the shear surfaces must be considered postglacial because they cut an outwash apron and a probable moraine of Late-glacial age.

CONCLUSIONS

Some general observations can be made about the forms and structures previously described.

These are slope deformations in a topographic context characterized by a high energy relief. They are due to relative movement along shear surfaces or to simple

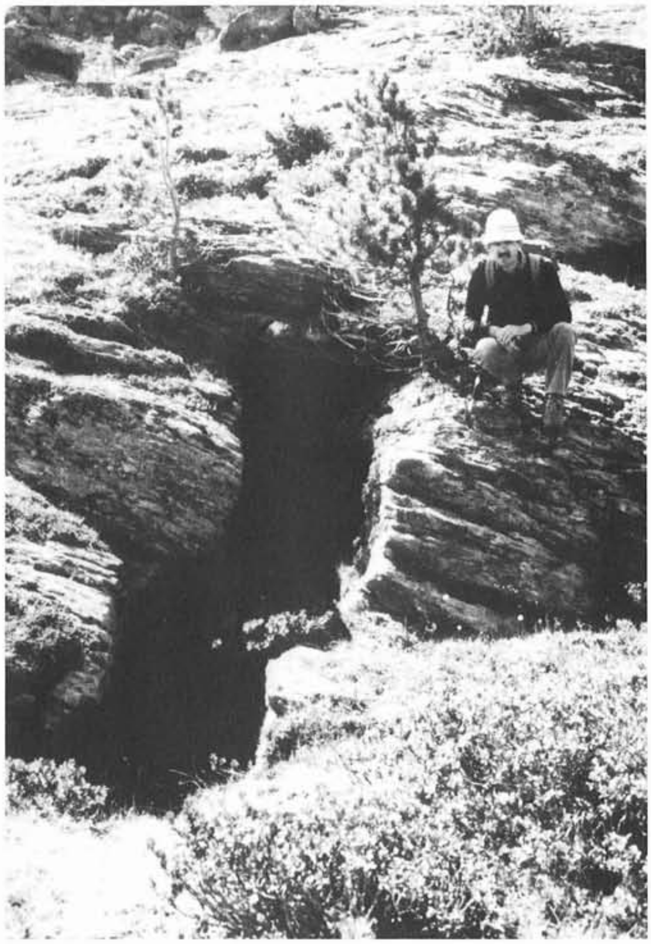


Fig. 9 - An open fracture covered on top by a natural roof on the southern side of Valfurva, near Baita dei Pastori. It is open down to several meters depth where it seems to wedge out. Compare this fracture with the smaller one present on the lateral surface of a block. The movement may have taken place by opening of an extremity of the rock mass (black arrow) around a subvertical axis (background in the figure).

parting of the two sides. The surfaces of movement are never single, but arranged into sheaves that form bands a few hundreds of meters wide and up to 3 km long. They develop in the middle of the slope between 2,000 and 2,700 m.

The displacement along each discontinuity ranges from a few dm to 10 m, the cumulative displacement along a single sheaf is up to 100 m. The age is recent, mostly Holocene, as it can be inferred by considering the relationships with Late-glacial forms and deposits.

On the whole the trend of such surfaces ranges from WNW-ESE to NW-SE, parallel to the Valfurva axis. Therefore they are generally conformable with the contour lines, but locally they can be arranged transversally or even perpendicularly to them. In particular this happens at the confluence of the Valfurva Valley with the Zebrù Valley, which represents a valley of analogous rank. This indicates that there is no exact correlation between topography and the strike of such surfaces. Furthermore their strike does not coincide with that of the schistosity and forms an acute angle with the main local structure, represented by the Zebrù Line.

As it can be deduced from their intersection with the topography, the surfaces of movement are mostly represented by planes, and only locally do they appear slightly spoon-shaped. They plunge mainly northeastwards and their dip ranges from 35° to 55° about. This produces a non specular distribution of the forms on both slopes of Valfurva. In fact on the northern slope the shear surfaces dipping uphill are almost exclusive and generate uphill-facing scarps, while downhill dipping surfaces prevail on the opposite southern slope and produce scarps and trenches. Slope deformations similar to the above described ones have already been reported in the literature and have been variously named and interpreted as: deep-seated large-scale rock slides, deep-seated mass rock creep, deep-seated gravitational slope deformation, Hangtektonik (slope tectonics), Sackung (« sagging »), Gleitung (sliding), gravitational spreading of ridges, etc. (Heim, 1932; Sander, 1948; Radbruch-Hall, 1978; Sorriso-Valvo, in press).

Examples of slope deformation have already been recorded in the neighbouring areas (Forcella, 1983, in press); these were considered as the result of gravitational tectonics due to slope failure caused by pressure release. Yet from certain points of view the phenomena described here seem to be different from those of the adjoining areas. In fact the recorded asymmetry of their distribution leads us to think that only the features of the southern slope can be related to slope gravitational gliding, characterized by main collapse surfaces, sometimes associated with minor antithetical surfaces. The latter produce uphill-facing scarps arranged *en échelon* downhill along the slope. On the contrary this model does not seem to be applicable to the northern slope, where there are no traces of main gliding surfaces congruent with the numerous uphill-facing scarps, which should represent the conjugate gliding planes. It is not even possible to include the features of the northern slope into a collapse model of the crest area of M. Forcellino-M. Confinale, with ridge spreading, because an adequate assemblage of forms and structures is not present on the crest and on the northern flank of the ridge. And not even the proposal of Jäckly (1965), that postulates a differential uplift of the valley bottom with respect to the slopes due to melting of the valley glaciers, seems to be in accordance with what we have observed.

If we consider that: 1) some of the gliding surfaces (Alpe Cristallo) show a stick slip type activity; 2) the area of Bormio is characterized by a seismic activity, even if modest (Belloni, 1974; Pavoni & Mayr-Rosa, 1978); 3) the observed structures are limited to an area elongated in a WNW-ESE direction, parallel to one of the two trends congruent with the field of stresses presently active in this part of the Alps, we can hypothesize that such phenomena represent the superficial response to neotectonic movements, even if controlled by the gravitational component always present in areas of high energy relief. Such neotectonic movements could have produced a step morphology in the area with the NE sectors systematically downthrown.

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