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GEOLOGICAL EVIDENCE OF RECENT FAULT EVOLUTION. EXAMPLES FROM CAMPO IMPERATORE (L'AQUILA - CENTRAL APENNINES)

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RIASSUNTO - *Evidenze geologiche dell'evoluzione recente di faglie. Esempi a Campo Imperatore (L'Aquila - Appennini centrali)* - Il Quaternario, **5**(2), 1992, p. 181-200 - Vengono segnalate e descritte analiticamente due manifestazioni di tettonica fragile recente, riconosciute nella conca di Campo Imperatore (L'Aquila). Esse sono caratterizzate entrambe da una serie di evidenze morfologiche che le accomuna con molte altre manifestazioni consimili riconoscibili sia nella catena appenninica che in quella alpina: il Sistema di faglie delle Mandrucce determina infatti sul versante settentrionale della conca di Campo Imperatore la nascita di una serie continua di bacini idrografici secondari di tipo calancoide nel settore sollevato relativamente; questi si restringono bruscamente all'intersezione con le faglie, in corrispondenza alle quali danno luogo ad una serie di faccette triangolari o trapezoidali; la Faglia delle Cocchiare interferisce invece con il Rio della Fornaca di cui taglia trasversalmente la conoide terrazzata: la scarpata che ne rappresenta l'espressione morfologica, rivolta verso monte, separa nettamente la successione di depositi torrentizi del tratto a monte da quella pure terrazzata, presente a valle, la quale è caratterizzata però da diverso spessore dei singoli corpi sedimentari e da diversa distribuzione altimetrica delle superfici di appoggio basale, le quali non appaiono correlabili geometricamente con quelle della successione terrazzata a monte.

In tutte e due le manifestazioni descritte sono stati rinvenuti però degli elementi di natura geologica che consentono di stabilire con certezza che queste situazioni morfologiche sono legate alla presenza di faglie soggette ad evoluzione in tempi geologicamente molto recenti (Olocene superiore). Nel caso delle faglie delle Mandrucce sono state infatti riconosciute superfici di taglio che dislocano, talora in maniera visibilmente polifasica, depositi molto recenti (detriti stratificati correlabili cronologicamente con i depositi glaciali più recenti dell'area e prodotti colluviali posteriori alle ultime pulsazioni glaciali locali); queste faglie presentano tipologie leggermente diverse che vengono interpretate come manifestazioni di un'unica fase deformazionale fragile, manifestatasi però a profondità progressivamente sempre minori: le manifestazioni più superficiali e più recenti risultano quindi sovraimpresse su quelle più profonde e più antiche progressivamente esumate. La situazione morfologica descritta per la Faglia delle Cocchiare può essere spiegata unicamente con l'interazione dinamica tra l'evoluzione relativamente veloce della struttura, che è stato possibile osservare in un affioramento effimero, e gli episodi di erosione e di sedimentazione torrentizia molto rapidi del Rio della Fornaca.

I risultati di questa analisi suggeriscono l'opportunità di riesaminare alcune delle numerose manifestazioni di attività tettonica recente segnalate in letteratura sulla sola base di evidenze morfologiche, per verificarne la reale consistenza alla luce di dati geologici significativi.

ABSTRACT - *Geological evidence of recent fault evolution. Examples from Campo Imperatore (L'Aquila - Central Apennines)* - Il Quaternario, **5**(2), 1992, p.181-200 - Two recent brittle tectonics manifestations recognised in the Campo Imperatore basin, L'Aquila (Italy), are reported and analysed. Both are characterised by a series of morphological features common to many similar manifestations in both the Apennines and the Alps. The Mandrucce fault system has produced a continuous series of secondary badland-type hydrographic basins on the NE slope of Campo Imperatore. These basins are located in the relatively uplifted sector and are sharply restricted at the intersection with the faults; here they give rise to a sequence of triangular or trapezoidal facets. The Cocchiare fault, on the other hand, transversely cuts the terraced fan of the Rio della Fornaca. The scarp representing the morphological expression of this fault distinctly separates the succession of stream-borne deposits of the uphill sector from that of the equally terraced downhill sector. The latter, however, is characterized by the different thickness of the individual sedimentary bodies and a different altimetric distribution of its basal support surfaces, which cannot be geometrically correlated with those of the uphill terraced sector.

Both manifestations, however, display geological features that make it certain that these morphological features are linked to the presence of faults that have undergone evolution very recently (Upper Holocene). In the Mandrucce system, in fact, have been recognized fault planes that displace, often in a polyphasic manner, very recent deposits (stratified debris chronologically correlatable with the area's most recent glacial deposits, and sheet erosion products younger than the last local glacial advances).These faults display slightly different typologies that are interpreted as manifestations of a single, brittle deformation phase that took place at progressively lower depths. The most surficial and most recent manifestations are thus overprinted on the progressively exposed, deeper and older manifestations. The morphology of the Cocchiare fault is attributable solely to dynamic interaction between the relatively rapid evolution of the structure, as observed in an excavation, and the very rapid fluvial sedimentation and erosion episodes on the part of the Rio della Fornaca.

The results of this analysis suggest that it would be advisable to review some of the many manifestations of recent tectonic activity described in the literature on the strength of morphological features alone to see whether they are really supported by significant geological data.

Parole chiave: Neotettonica, geomorfologia, Gran Sasso, Italia
Key-words: Neotectonics, geomorphology, Gran Sasso, Italy

1. INTRODUCTION

This paper describes some particularly evident manifestations of Holocene tectonics which have been identified in the Campo Imperatore morphological depression — hereafter referred to as "Campo Imperatore basin" (Central Apennines, L'Aquila Province, Italy) — by one of the writers during the preparation of his thesis (Giardino, 1990). The aim of this paper, in addition to that of reporting the phenomena, is the description of neotectonic manifestations which, thanks to the availability of significant geological infor-

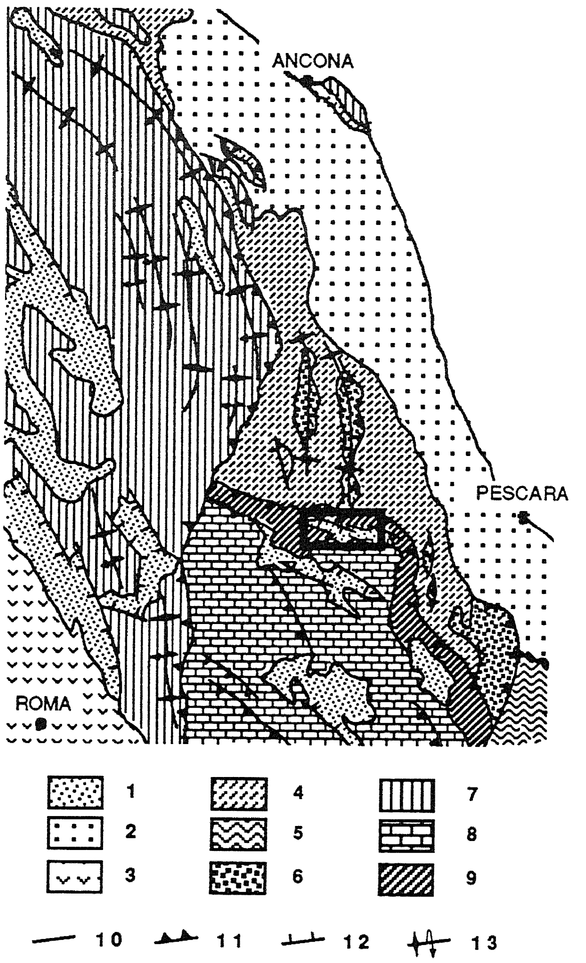

Fig. 1 - Structural map of the Central Apennines. The study area is that encircled by the heavy solid line.
1) Continental and marine formations of intra-Apenninic depressions. 2) Continental and marine formations of the Bradanic Foredeep. 3) Volcanic rocks of the Latial volcanic edifices.4) Laga Formation. 5) Allochthonous formations of the Molise Basin. 6) Marches Basin Units. 7) Umbria Basin Units. 8) Carbonatic Units of the Latium-Abruzzi Platform. 9) Transition Units between the Latium-Abruzzi Platform and Marches Basin. 10) Geological boundaries. 11) Major thrust. 12) Normal fault. 13) Anticline systems (arrows indicate overturned folds).

Carta strutturale dell'Appennino Centrale: il riquadro nero racchiude l'area di studio.
1) Formazioni marine e continentali delle depressioni intra-appenniniche. 2) Formazioni marine e continentali dell'Avanfossa Bradanica. 3) Vulcaniti degli apparati Laziali. 4) Formazione della Laga. 5) Formazioni alloctone del Bacino molisano. 6) Unità del Bacino marchigiano. 7) Unità del Bacino umbro. 8) Unità carbonatiche della Piattaforma laziale-abruzzese. 9) Unità della zona di transizione tra la Piattaforma carbonatica laziale-abruzzese ed il Bacino marchigiano. 10) Limiti geologici. 11) Principali contatti di sovrascorrimento. 12) Faglie normali. 13) Sistemi di pieghe anticlinali (la freccia indica quelle rovesciate).

mation, can be interpreted univocally. The morphological evidence alone, entirely similar to that of numerous other situations, could only lead to a circumstantial attribution to neotectonic activity.

2. GEOGRAPHICAL AND GEOLOGICAL BACKGROUND

The area concerned is included in Foglio 140, "Teramo", of the 1:100,000 map of Italy. More specifically, the districts discussed are included in the 1:25,000 I.G.M. Tavolette III NE "Pretara" and III SE "Santo Stefano di Sessanio".

The Campo Imperatore basin lies about 2 km S of the Gran Sasso chain thrusts and is one of the outermost intrapenninic morphological depressions. The local structural situation is both geometrically and chron-ologically complex. The tectonic setting is dominated by the thrust system created by the piling up of units refer-able to the domain of transition between the Lazio-Abruzzo shelf and the Umbria-Marche basin (Parotto & Praturlon, 1975) (Fig.1). The complex of tectonic slices, in turn, is regionally superposed to the Laga Flysch and the Tortonian units of the Marche basin (Ghisetti & Vezzani, 1988). The axes of the principal and oldest structures ("Gran Sasso thrust system" in Ghisetti & Vezzani, 1988) generally strike WNW-ESE, and the thrust surfaces, which are locally evidenced by thick bands of fault rocks, dip between 30° and 50° towards SW. These tectonic units are overprinted by minor, brittle distensive structures sometimes associated with bands of cataclasites (Demangeot, 1965; Ghisetti & Vezzani, 1986a; 1986b; Ambrosetti *et al.*, 1987). The most important of these correspond to normal faults primarily directed E-W and WNW-ESE. The main faults bound the Campo Imperatore basin to the North and also define some of the isolated reliefs within it. In view of the presence of supposedly Upper Pliocene breccias, apparently derived from the evolution of these structures Demangeot (*op. cit.*) concludes that they were emplaced and then evolved between Pliocene and Quaternary. Geological evidence of a very recent evolution, in fact, has been reported, for some faults of this system, in adjacent areas (Bosi, 1975).

The surficial formations of the Campo Imperatore basin are primarily: glacial deposits, alluvial fans, and colluvial deposits. The glacial formations are composed of both lodgment till, mainly on the bottom of the depression, and ablation till, primarily preserved on both sides of the basin itself. Landforms and deposits make up a slightly terraced sequence. Large-scale palaeoclimatic considerations led Demangeot (*op. cit.*) to attribute the deposits closest to the depression floor to the Würm I and III advances. For similar reasons Federici (1979) assigned the moraines at the foot of the Monti della Scindarella to a stadial age.

In a recent paper, Frezzotti & Narcisi (in press) report the local presence, on these deposits, of a discontinuous pedogenised tuff sheet ("andosoil"). In addition, our study identified a series of ash deposits interbedded with colluvial products at the base of the oldest glacial episode. Both of these volcanic levels are still under study and it is hoped that they will become the key to the clarification of the chronology of the glacial deposits. Recently, Frezzotti & Giraudi (1990) report the presence at Campo Imperatore of eolian sediments related to two Late Pleistocene depositional phases, marking regional dry climatic phases.

3. THE MANDRUCCE FAULTS SYSTEM

The geological and morphological description that follows refers to the South slope of the ridge bounding Campo Imperatore to the North, whose main terminations are Monte Aquila (2494 m) and Monte Brancastello (2385 m) (Fig. 2).

The distribution of the morphological, lithostratigraphic and structural features described and discussed in this section will be explained with reference to the morphological units indicated in Figs. 3a÷3c.

3.1 Data

3.1.1 Morphography

The slope section, in which the phenomena discussed in this paper were observed, extends for about 3 km NW-SE, over a range of elevations between about 1700÷1950 metres and can be subdivided into two small bands separated by a very contorted boundary (see Fig. 3b): the upper band (morphologic Unit A) has a relatively regular 25÷30° slope and is excavated by some shallow (few metres deep) gullies which are coherent with the dip of the slope; the lower band (Unit B) is divided into a series of deep basins with the appearence of bad lands; the longitudinal profiles of these minor basins are nearly vertical at the heads, but quickly become almost horizontal further down.

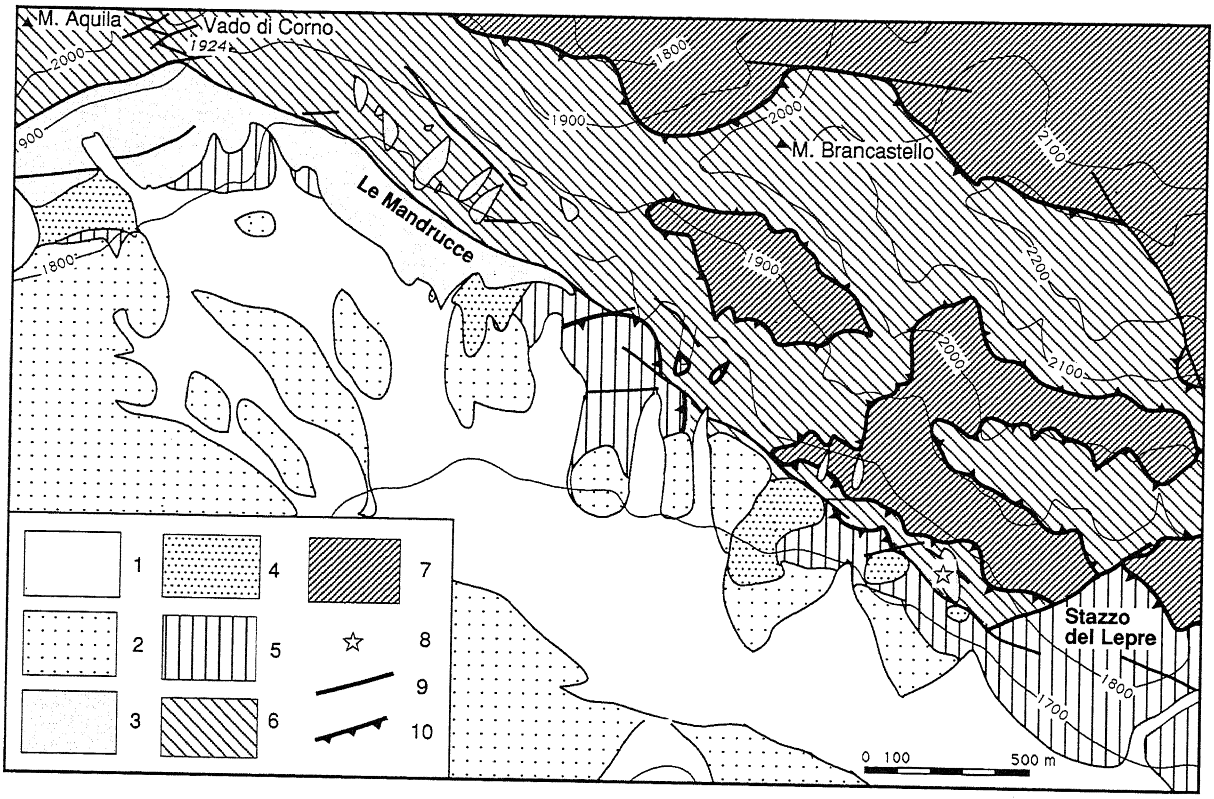

Fig. 2 - Geological map of the Mandrucce area.
Quaternary cover: 1) alluvial deposits; 2) glacial deposits; 3) colluvial deposits; 4) stratified debris. Pre-quaternary substratum: 5) Colle dell'Omo Morto Unit; 6) Vado di Corno Unit; 7) S. Colomba Unit; 8) fault cutting colluvial deposits; 9) fault lines (a dash shows the lowered part in normal faults); 10) thrust lines.

Carta geologica dell'area delle Mandrucce.

Copertura quaternaria: 1) depositi alluvionali; 2) depositi glaciali; 3) depositi colluviali; 4) detriti stratificati. Substrato prequaternario: 5) Unità di Colle dell'Omo Morto; 6) Unità di Vado di Corno; 7) Unità di S. Colomba; 8) faglia nei depositi colluviali; 9) linee di faglia (faglie normali con il trattino verso la parte ribassata); 10) linee di thrust.

In Unit B as a whole, the individual erosional forms are more extensive and deeper than they appear on the IGM map (1954 survey). Very recent gullies (not shown on the topographic map) carve the slope; the base of the slope is in places in fact banded by very recent deposits (not indicated on the 1:25,000 map) which partly

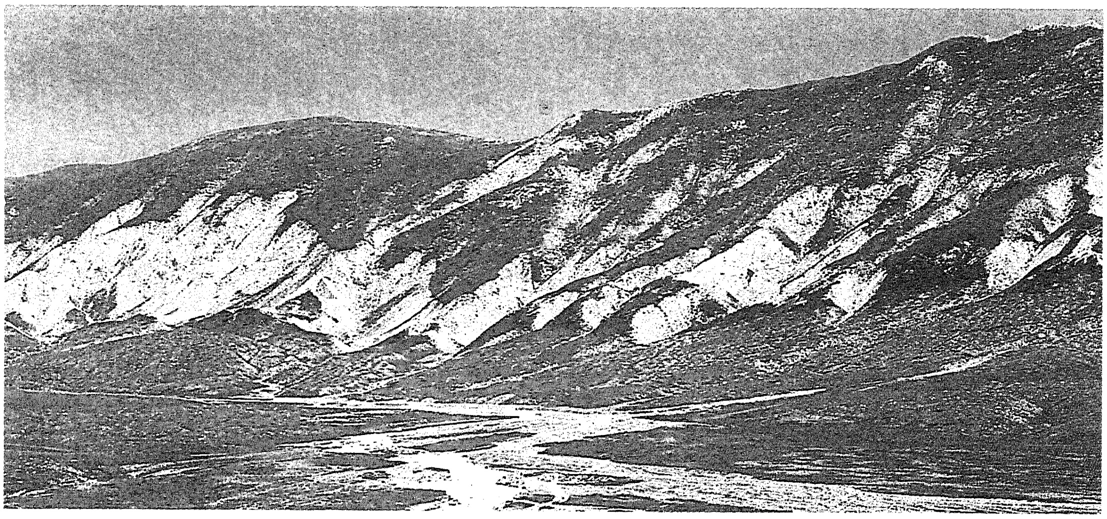

Fig. 3a

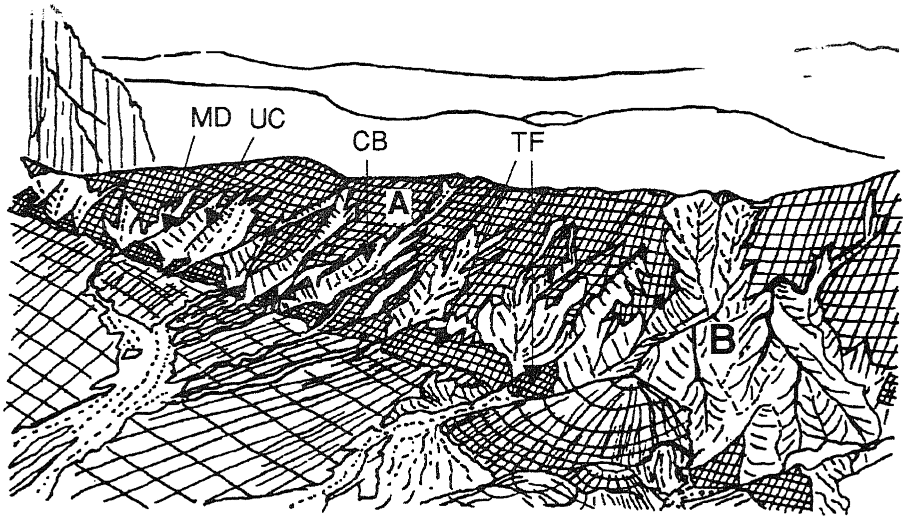

Fig. 3b

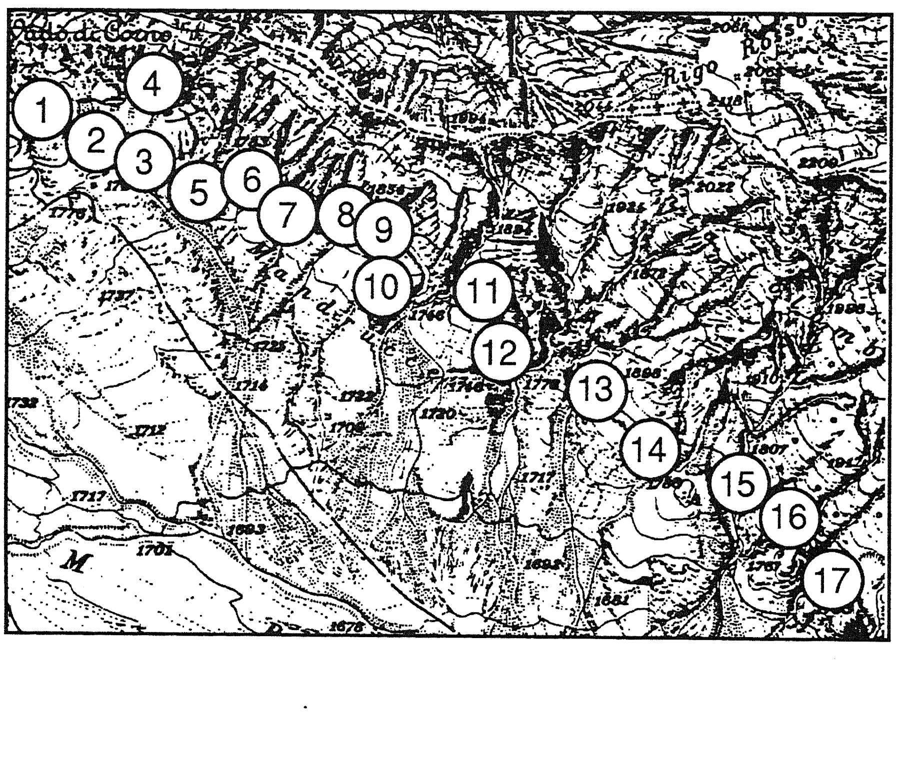

Fig. 3c

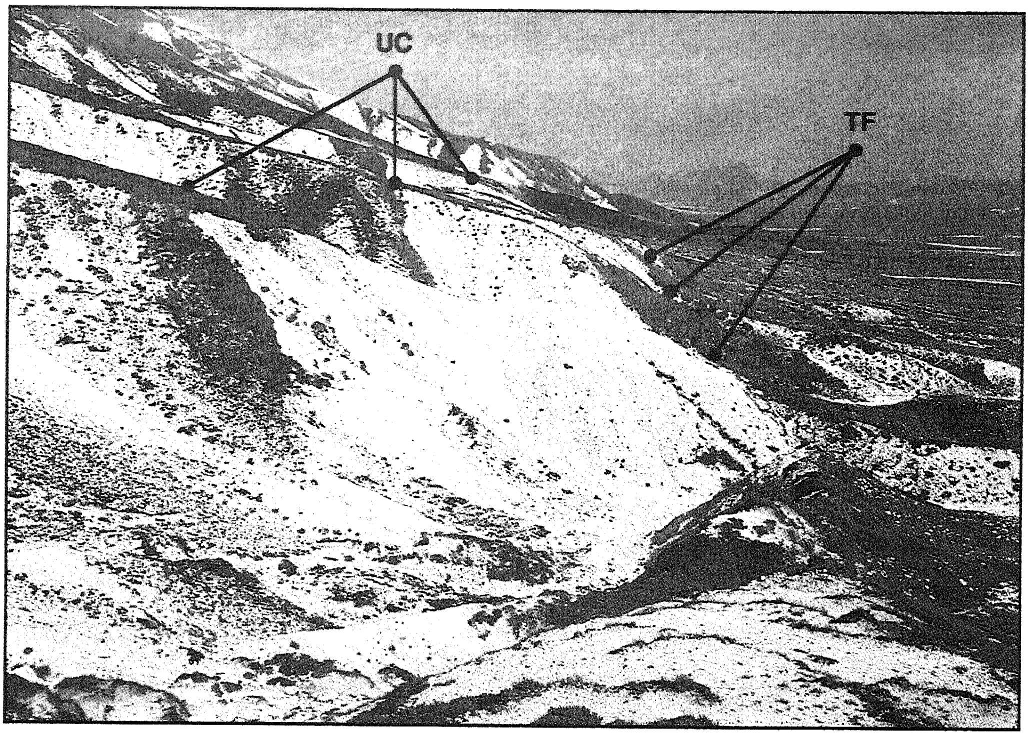

Fig. 4 - Minor ridges separating the badland-like basins: the profile (transverse to the slope) shows the ridges (UC) marking the watersheds between minor basins, and the triangular or trapezoidal facets (TF) developed towards the base of the slope.

Dorsali minori che separano i bacini calancoidi: il profilo (trasversale al versante) evidenzia i crinali sommitali (UC), che segnano gli spartiacque tra i bacini minori, e le faccette triangolari o trapezoidali (TF) che si raccordano alla base del versante.

cover shrubs and grass.

The individual basins are separated from each other by a series of small ridges (*minor divides* in Fig. 3b).

The crests have a very different appearance in their uphill and downhill ends. The former are made of grass-covered tongues with a regular dip (15÷20°), inserted with a clear break in the slope at the base of Unit A. The latter suddenly acquire a sharpish or, occasionally, humpbacked transverse profile (Fig. 4) with no grass cover. The distribution of the two configurations varies greatly from one ridge to another and, in some instances, only one is present along the entire crest. The boundary between them in the ridges does not identify any alignment.

The spurs are triangular, or trapezoid grassy surfaces (*triangular or trapezoid facets* in Fig. 3b). Their slope is sometimes very regular (40°) (Figs. 3, 4 and 5). Their bases reduce the cross-section of the minor basins at the lower join of the slope.

Unit B comprises secondary watersheds formed by flattish tongues sloping 20÷25° downhill and covered in some places by evidently recent colluvial deposits (Fig. 6). Where adjacent basins are relatively distant from each other (*i.e.* between basins 10 and 11 and between 13 and 14 in Fig. 3c), the slope section between them is sometimes broken along the extension of the basins by a bare, steep (even more than 45°) escarpment. The junction between the lower part of the slope and the bottom of the basin is marked by the surfaces of very weakly dipping fans (5÷10°) that are inserted, sometimes repeatedly terraced, on the mouths of the side valleys. As a whole, the floor of the basin is slightly undulating, subhorizontal or very weakly dipping SSE (3÷4°).

Fig. 3 - The Mandrucce fault system. a) photographic view; b) morphological subdivisions: minor divides (MD), upper crests (UC), badland-like basins (CB), triangular or trapezoidal facets (TF) (redrawn from Demangeot, 1985); c) topographic map (the numbers indicate the "secondary basins" into which the slope has been divided).

Il sistema delle Mandrucce: a) panoramica fotografica; b) suddivisioni morfologiche: spartiacque secondari (MD), dorsali sommitali (UC), bacini calancoidi (CB), faccette triangolari o trapezoidali (TF) (il disegno è ripreso da Demangeot, 1965); c) carta topografica (i numeri contraddistinguono i "bacini secondari" in cui è stato suddiviso il versante).

3.1.2 Lithostratigraphy

Pre-Quaternary substratum

The slope segment described in the previous paragraph consists of a sequence of three units (Fig. 2) laid one upon the other. The lower structural element (Santa Colomba Unit) outcrops here and there in a tectonic window in some parts in the central-eastern sector. It is composed of pale-brown, micritic limestones with chert lenses and nodules (Middle Lias "Corniola"), calcareous marls and leafed greenish marls with thin calcarenite

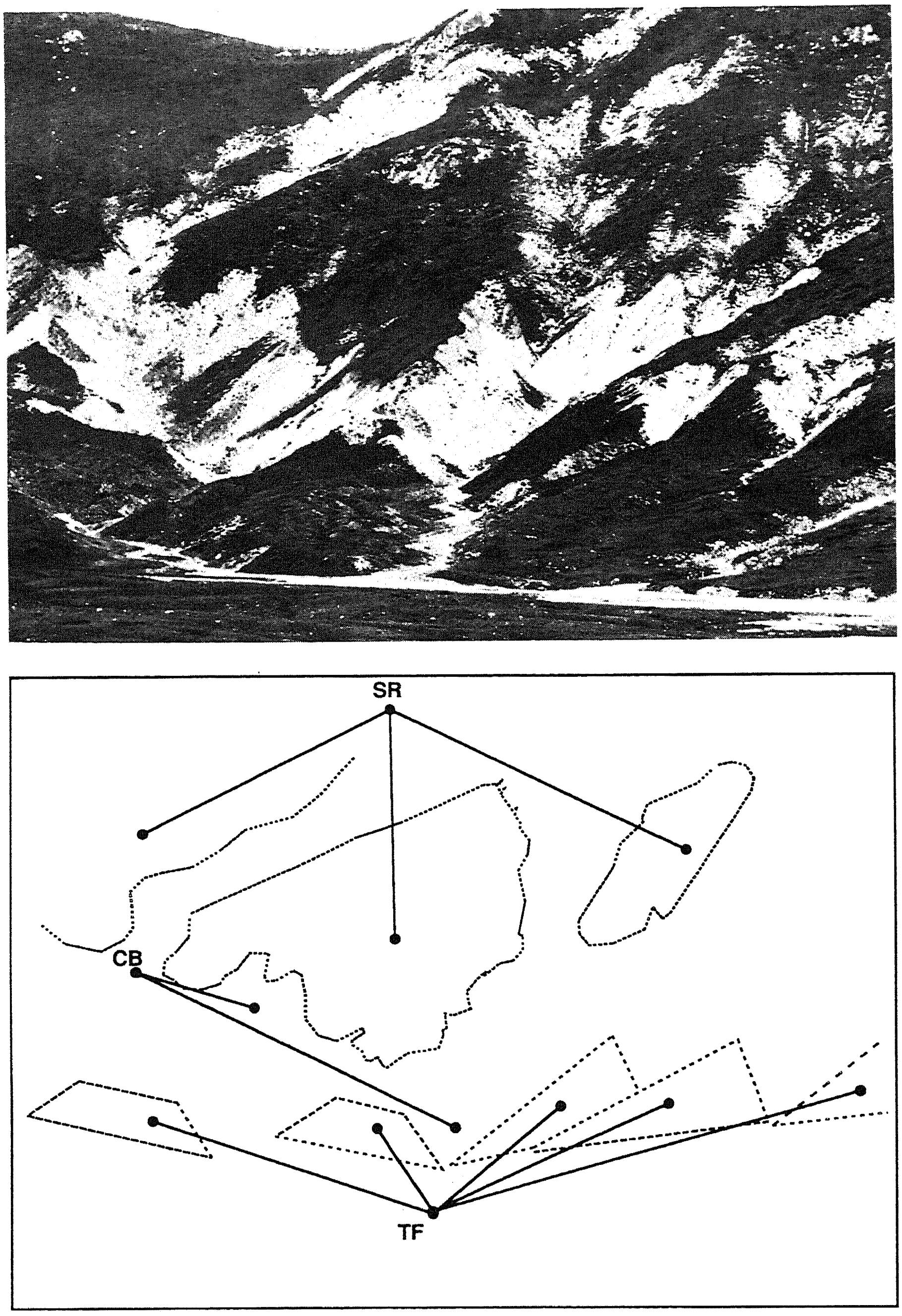

Fig. 5 - Characteristic shapes of morphological unit B: SR = summit ridges; CB = badland-like basins; TF = triangular or trapezoid facets.
Forme caratteristiche dell'Unità morfologica B: SR = crinali sommitali; CB = bacini calancoidi; TF = faccette triangolari o trapezoidali.

(Upper Lias-Dogger "Verde Ammonitico"), and detrital and biodetrital limestones in banks of flow-turbiditic origin, one to ten metres thick (Dogger-Lower Cretaceous "Calcareniti ad Entrochi").

The intermediate structural element is the one more often outcropping. It is known as the Vado di Corno Unit and it is mainly composed of white, "powdery" dolomites layered in banks 20÷40 cm thick, sometimes with stromatolithic foliations (Lower Lias "Dolomie Bianche").

Near the contact between the Vado di Corno Unit and the overlying Colle dell' Omo Morto Unit, within the "Dolomie Bianche", there is a discontinuous band of cataclastic rocks (see 3.1.3), up to about 20 m in thickness, with an average dip of 40° towards SSW.

The upper structural element ("Colle dell'Omo Morto Unit") is locally preserved at the base of the slope only. It is formed of rocks of the "Corniola", "Verde Ammonitico", "Calcareniti ad Entrochi" formations, and a thin (maximum 10 metres) layer of ivory-white micritic cherty limestones (Lower Cretaceous "Maiolica") changing upwards to indistinctly stratified calcirudites and whitish bioclastic calcarenites (Upper Cretaceous-Eocene "Calciruditi a Rudiste").

Quaternary cover

The Quaternary cover is locally composed of the following types of deposits, starting with the earliest.

- *Glacial deposits,* probably ablation till, form on the surface a series of small terraced strips whose edges develop between 1,640 and 1,700 metres of elevation, i.e. suspended about 80 metres above the present floor of the basin. They can be recognised by their typical wavy appearence, surficial random distribution of large blocks, and good, reciprocal altimetric correlation. No significant outcrops have been found.

- *Stratified debris*, mainly composed of fragments of Corniola Formation micritic limestones, constitute some isolated deposits with a local thickness of more than 50 metres. These are found only in the sector comprised between the three easternmost secondary basins, where they form a stratigraphic set of two terms, the lower and the upper with mean dippings of, respectively, 35° towards SSE and 20° towards SSW. Both complexes are cemented, sometimes heavily, particularly in the upper part. The best exposures reveal numerous fractures and small faults with both direct and inverse movement, variously oriented. These structures do not cause directly any morphological pattern on the top surface, but create a morphological contrast in the accelerated erosion wall forming the left-hand slope of basin 14 (Fig. 7). They are described in § 3.1.3. The deposits constitute isolated masses, separated from the slope; the Corniola Formation does not outcrop in the segment of slope above them, but only a hundred metres or so further to the NE.

- *Colluvial deposits* with a generalised distribution in strips ranging from a few to about a hundred square metres. In the individual morphological units, these deposits display various differences in the attitude of their basal support surface and the geometry of their sedimentary bodies, as well as slight differences in their facies.

In the strips preserved in the crests of the ridges bounding the secondary basins (see § 3.1.1.), the basal support surface is erosional (see Fig. 8), and slightly undulated and irregular. The geometry of the sedimentary bodies, which are visibly dissected from the heads of the basins, is sometimes increasing and sometimes decreasing downhill. While the increasing geometry is primary, the decreasing one is the result of remodelling. The thickness of this colluvial cover varies from one point to another: the maximum visible and/or preserved thicknesses are around 7÷8 metres. At one point (shown with an asterisk in Fig. 2; see also Figs. 3b and 9), one can observe a distinct normal, polyphasic fault displaying no morphological evidence, whose displacement will be described in § 3.1.3. In the triangular or trapezoid facets marking the downhill termination of the secondary ridges (cf. § 3.1.1), the basal support surface corresponds, case by case, to:

- an erosional surface shaped within the "Vado di Corno Unit" cataclasites (cf. § 3.1.2.1);
- an erosional surface shaped within the fractured dolomites;
- one of the various types of fault surfaces observed in this sector (see § 3.1.3 and Fig. 9).

In cases where the basal support is a surface fault, the lower part of the deposit is underlain by a few centimetres thick layer of pink, more minute and matrix-richer cemented debris, whose colour becomes progressively paler nearer the support surface.

The geometry of the bodies formed by these deposits already increases slightly downhill. Their thickness ranges from decimetres to 4÷5 metres.

The basal surface never outcrops in the marginal sector of the floor and its nature and trend are unknown. The thickness and geometry of the sedimentary body cannot be determined either, though its thickness in the outcrops is between 1 and 5 metres.

In the crests bounding the secondary basins and in the marginal sector of the floor, the colluvial deposits are composed of jagged carbonate fragments measuring from 0.5 to 10 cm in diameter with weak surface alterations consisting of few millimetres of a patina with a Munsell Soil colour of 10 YR 7/3 when dry and 10 YR 6/6 when wet. The fragments are made of dolomites only in the Western sector, while in the Eastern sector they are polygenic (dolomites and micritic limestones). This composition mirrors that of the slope segment immediately above. The composition, in the Eastern sector is also characterized by a subordinate clay-silt matrix which is extremely reduced in the Western sector.

The sizes of the clasts and their relationship with the matrix in the triangular or trapezoid facets are the same as in the other two sectors. The debris is less cemented, however, while its colour varies throughout its thickness and its chaotic texture. A constant feature of this sector is the steep dipping (40°) of the basal support surface.

- The heterometric *alluvial deposits* should also be included among the Quaternary cover deposits. These deposits form extensive, flat, and in some cases terraced, fans with decreasing geometry, genetically derived from mostly braided temporary watercourses.

- *Loose debris* (omitted from Fig. 2 for easier reading) formed of jagged carbonate fragments measuring from a few decimetres to a few centimetres in diametre. This term discontinuously covers wide sectors of the slope, especially the less steep portions of the badland-like basins, where it maskes the lithotypes and simulates the presence of fractured dolomites in the place of the underlying cataclasites.

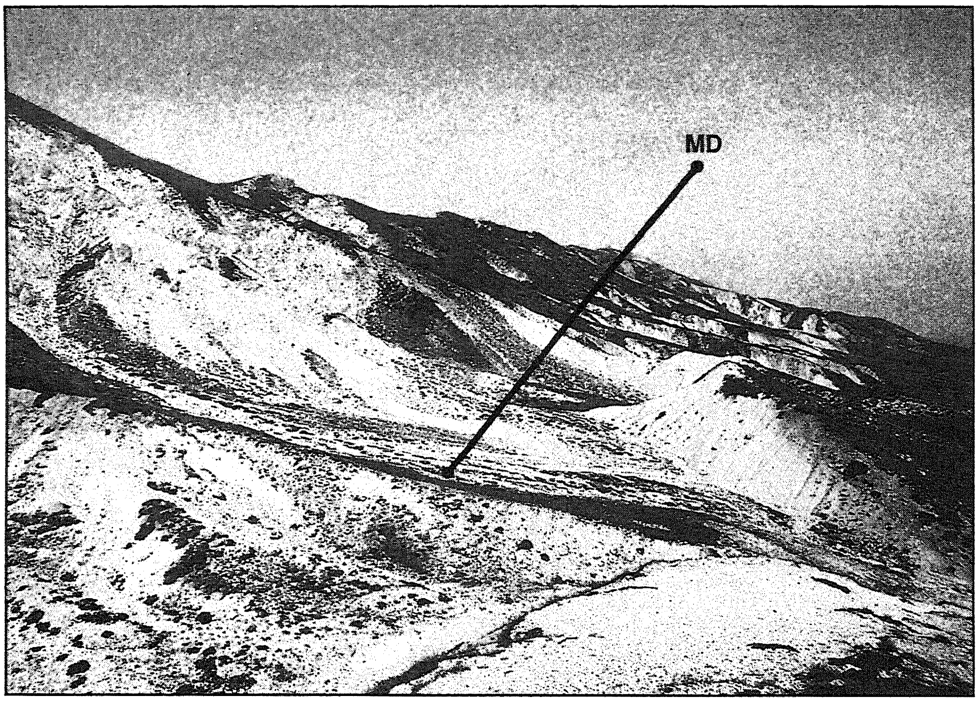

Fig. 6 - Badland-like basin of morphologic Unit B and its minor divide (MD).
Bacino calancoide dell'unita morfologica B e relativo spartiacque secondario (MD).

In the light of their reciprocal geometric relations and leaving aside the obviously recent loose debris, the youngest of these terms are the fan deposits. The colluvial deposits also are more recent than the cemented, stratified deposits, since they rest on erosional surfaces carved within the stratified debris. The basal support surface of these deposits is linked to lower glacial terraces and thus the stratified debris can be correlated with one of the last local glaciation pulses.

3.1.3 Structure

Three superposed structural units outcrop in the sector in question. They represent three tectonic slices belonging to the Gran Sasso thrust belt.

The inner stuctures of the upper unit (Colle dell'Omo Morto Unit in Ghisetti & Vezzani, 1986b) dip 25÷50° towards NE. The base of this unit is a thrust plane (f1 in Ghisetti & Vezzani, *op. cit.*) that crops out discontinuously along the slope due to the extensive Quaternary cover and to the interference of normal faults the latter of which also cause its irregular orientation (15÷45° towards 190÷230°).

The dip of the inner structures of the intermediate Vado di Corno Unit, ranges from 20° towards 350° to 35° towards 10°, with some exceptions in the Eastern sector, where there are layers weakly dipping to the South. Much of this unit, however, is characterized by intense cataclasis that has almost completely wiped out the traces of the original dolomite stratification. Here the dolomites are intensely disrupted and look like random-fabric fault rocks with juxtaposed domain of different grain size and degree of cementation. They appear mainly cohesive ("crush breccias" and "cataclasites", acc.to Sibson classification, 1977); sometimes outcrops "fault breccias" and "fault gouge". This is particularly evident near the unit's basal thrust plane (f5 in Ghisetti & Vezzani, *op. cit.*), which dips 20÷40° towards 185÷205° and borders the tectonic-window outcrops of the Santa Colomba Unit below. The attitudes in this sector of the Santa Colomba Unit are sub-parallel to the tectonic contact with the Vado di Corno Unit.

A system of more recent displacements ("Mandrucce system") is overprinted on the previous thrusts system in a general WSW-ESE direction. The former is composed of faults, the most frequent and longest of which dip 50÷70° towards 195÷210° (about parallel with the slope), linked by nearly vertical minor faults with strike 60÷70° (see Fig.10). The various elements sometimes delineate a rhombic pattern (Fig. 11). The fault planes display signs (mechanical furrows, rock grooves and steps, occasional striae in fibrous calcite) indicative of a predominantly normal movement with a subordinate dextral transcurrent component.

The Mandrucce System is mostly emplaced within the cataclastic belt of the Vado di Corno Unit, its trend, however, does not exactly coincide with that of the brecciated gouge zone. The normal faults also cut some white dolomites of the Vado di Corno Unit and the calcarenites of the Colle dell'Omo Morto Unit. As already stated in § 3.1.2.2, some of the elements of the Mandrucce system cut the Quaternary stratified debris and colluvial deposits. Its relations with the thrust planes

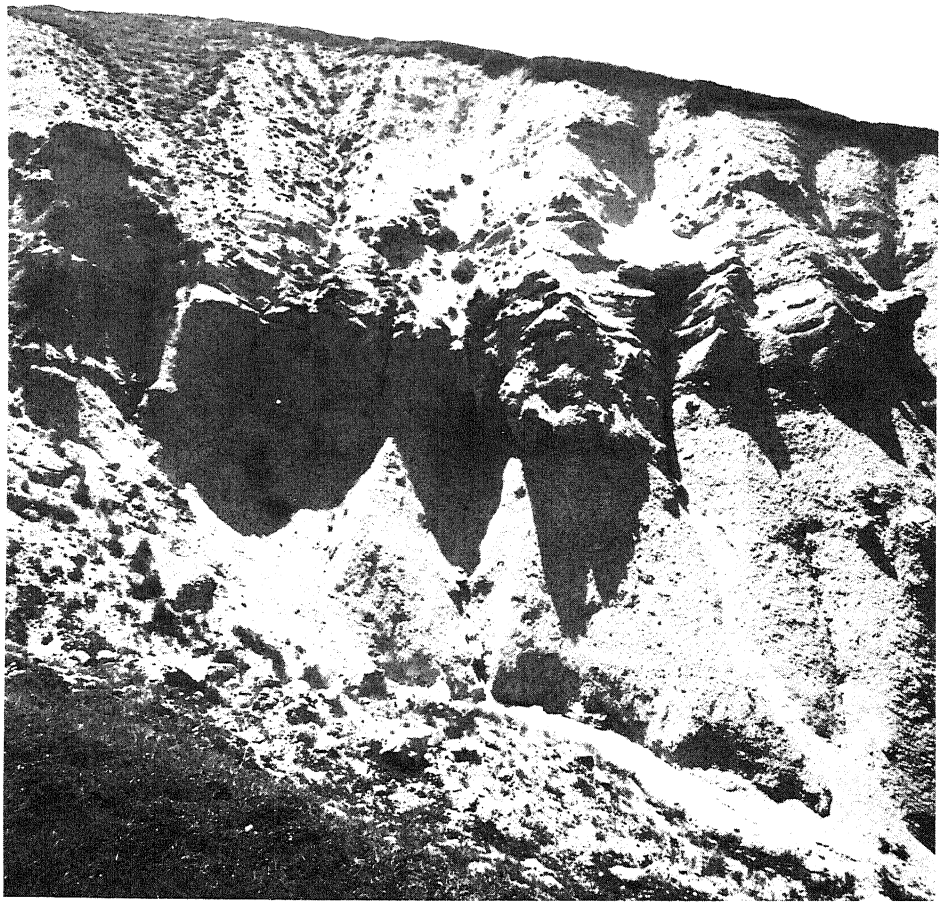

Fig. 7 - Fractures and faults with varying orientations in the cemented stratified debris.
Fratture e faglie con orientazione variabile nel detrito stratificato cementato.

are evident locally. In some cases, the faults visibly displace the thrust surface. Where their orientation is almost coincident with that of f1, superposition of the two shear zones results in complex structural interference. The material form of contact f1 is a fault rock 5÷40 cm thick composed of a fine, reddish micrite, associated with cataclasites from the dolomites of the upper unit. The displacements that constitute this system can be divided into three types based on the evidence of their outcrops. These types are somewhat artificial, since intermediate situations exist:

a) sharp faults with a distinct slip plane and no evidence of associated breccias or fault rocks;
b) faults underlined by decimetric layers of fault rocks ("crush breccias" and "fault breccias", acc.to Sibson, *op. cit.*) with millimetric to centimetric elements;
c) faults with heterogeneous fault rocks ("crush breccias", "protocataclasites" and "cataclasites" in conformity with the proportion of matrix; Sibson, *op. cit.*) composed of different coloured bands derived from micritic material mixed with various types of clasts; under the microscope this rock reveals evidence of cataclastic flow and rotational movements of sparry calcite grains.

In the outcrops, represented by the badland-like basins, there are always at least two-three faults belonging to three types. In some cases the faults of "c" type have re-used the "a" or "b" type movement surfaces, whereas in some other instances they have formed new structures displacing the others.

Due to the variations in attitude and extent of the areas without outcrops separating the basins from each other, it is impossible to follow the development of each structure along its entire length. In two sectors, however, namely between basins 10 -11 and 13 -14, lacerations of the slope extending, respectively, for 150 m and 300 m mark the junction between type "a" faults cropping out in the adjoining basins. A normal type "b" fault, visibly affecting the colluvial debris cover, can be seen on the watershed of the righthand slope of basin 17 (Fig. 12). Its shear plane, dipping 60° towards 195°, lowers the basal support surface as a whole by some 2.5 metres in the downhill sector. The polyphasic displacement is revealed by some hook-like stone-lines that curve less sharply as they proceed upwards and can be regarded as drag folds. As mentioned earlier (§ 3.1.2.2) and shown in Fig. 12, this structure has no morphological evidence. As it continues for about 300 m to the East, this fault changes its dip (as far as 55° towards 180°) and finally cuts the thrust plane f5. The direction of the latter is almost coincident with the fault plane, but its dip is about 10° less.

Type "c" faults with a dip 45÷50° towards 190÷200° can be seen in basins 1, 2 and 3. In addition to displaying signs of normal movement (mechanical furrows and grooves with dip pitch, clearly visible on the extremely smooth shear plane), these faults are associated with structures (lesser shear planes, fractures, cleavages: see Fig. 13) immediately at the bottom of the main shear plane, whose geometrical arrangement and kinematics reveal variously oriented stress fields. The associated fault rock is typically "heterogeneous" (type "c"). Two layers of differing colour can be differentiated, both with micritic materials arranged in bands, whose microscopic analysis reveals fine matrix-flow structures around clasts and brittle microdeformations displacing the layers along a normal movement plane.

3.2 Interpretations

Comparison between the distribution of the deposits, the structural situation and the morphological picture described in the preceding paragraphs suggests that the following interpretations can be put forward:

- the three types of fault forming the Mandrucce System (of recent displacements overprinted on the Pliocene compression structures) represent manifestations of a single geodynamic stage (Upper Pliocene-Quaternary in the literature) exhumed at different levels by erosion. Evidence of this can be seen, despite their different appearence, in the overall affinity of their attitudes and their close association. Displacements underlined by type "c" (which show cataclastic flow-structures and larger amount of deformation) suggest deeper conditions of formation and are clearly dislocated by other types: consequently they appear to be the oldest. Knife-edge faults (type "a"), which occurred and evolved under surficial conditions, are extremely recent. Those of type "b" were formed at an intermediate depth and time. Continuous dynamic interaction between displacement and erosion has now brought to the surface structures formed at different depths and at different times within a single geodynamic phase. As we mentioned before, depending on the local attitude of the structures of the previous phase, in some cases the faults of the more recent phase have re-used the prior slip-surfaces, whereas in some other instances they have formed new structures, displacing the previous ones.
- the colluvial deposits that provide the surface cover of the three "Unit B" situations described above (§ 3.1.1 and 3.1.2.2), do not correspond to three generations of deposits, but constitute a single, displaced lithostratigraphic unit. The changes in attitude and thickness noted at the passage from one situation to the

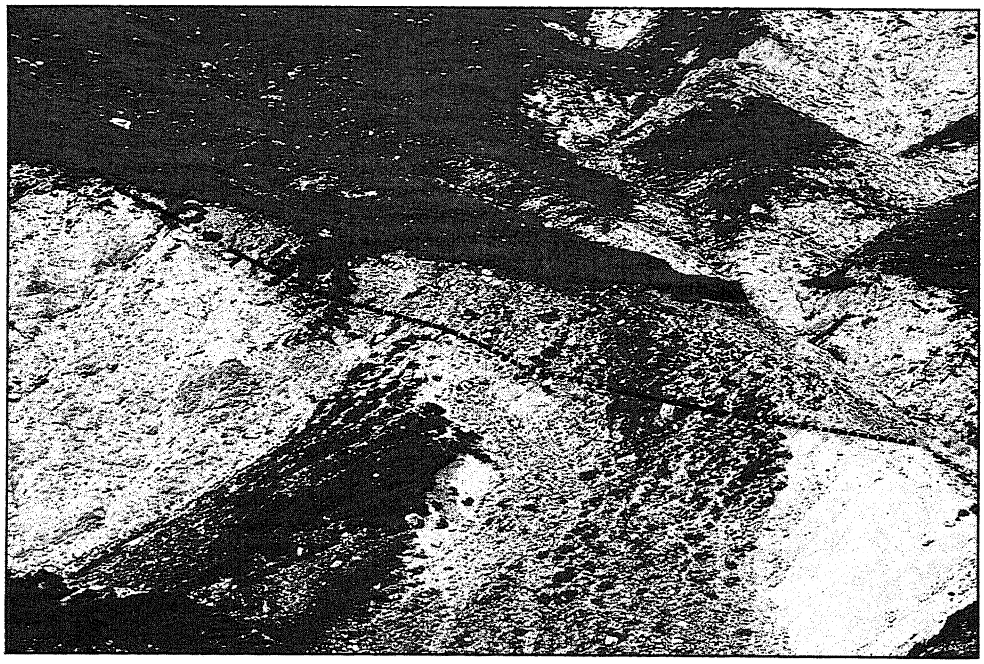

Fig. 8 - Erosional basal support surface of the colluvial deposits.
Superficie di appoggio basale, di natura erosionale, dei prodotti detritico-colluviali.

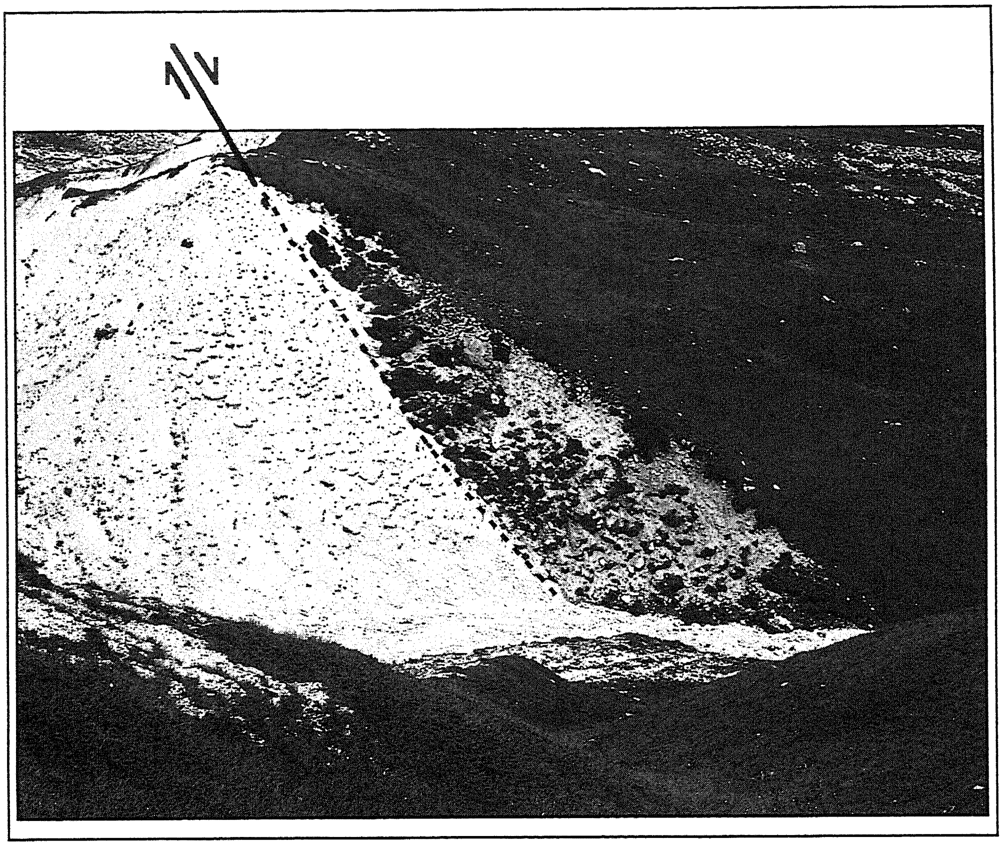

Fig. 9 - In some of the triangular facetes, the basal support surface of the colluvial deposits is represented by a fault surface (basin no. 2).
In alcune faccette triangolari la superficie di appoggio basale dei prodotti colluviali è rappresentata da una superficie di faglia (bacino n. 2).

next are the outcome of the evolution of faults during and after the time of deposition. As mentioned in § 3.1.2.2. the facies and degree of weathering of the deposits in the upper and lower morphological units are the same. The deposits, covering the triangular or trapezoid facets marking the downhill termination of the secondary ridges, display some facies differences (mottling, chaotic texture) and above all differences in their degree of aggregation compared with those of the slope and of the margin of the basin; their basal support surface is steeply inclined. This series of features suggests that these deposits are derived from the reworking of the same formation as it was gradually dragged across the surfaces. Triangular and trapezoid surfaces may thus be seen as the result of "stretching" of the slope due to the more recent evolution of the faults. A similar explanation can be found for the formation of the steep segments with no plant cover marking the junction between the upper and lower part of the slope in the places where there are no badland-like basins, *i.e.* between secondary basins 10 -11 and 13 -14.

In this sector, the erosion surface forms the basal support of the reworked colluvial debris. As mentioned earlier, it occasionally corresponds to older, deeper fault surfaces (types "b" and "c" in § 3.1.3; cfr. Fig. 9). This type of relation cannot be regarded as primary, in the sense that the fault rock must have formed at depth and cannot have been formed at the contact with the reworked products. Its present position is obviously the result of exhumation: the fact that in these cases it constitutes the topographical surface, is due to its better preservation relative to the cataclasites or fractured dolomites; the latter, in fact, once at the surface, break up very quickly into loose surficial debris.

- Further proof of the unique genesis of the colluvial deposits is provided by the fact that their lower band rests uphill directly against the triangular or trapezoid facets, which are obviously not their source rock.
- The change in morphology, that can be detected even studying a 1954 map, is also illustrated by other features: 1) presence of manifestations associated with different structural levels of a given fault in a confined morphological context, 2) deep state of morphological dissection of the layered debris, coheval with the series of recent glacial deposits, and 3) above all by the almost complete obliteration of the source rock. All this points to a very high evolution rate that cannot be explained solely through the local climatic conditions.

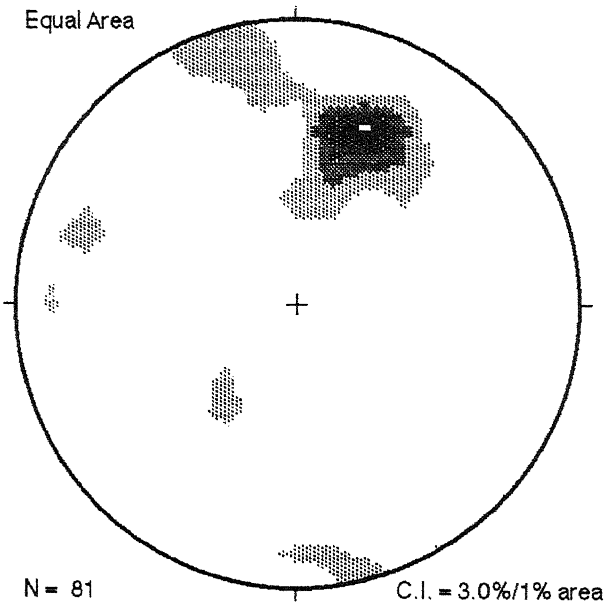

Fig. 10 - Frequency diagrams of the Mandrucce principal fault planes.
Diagramma di frequenza dei piani di faglia principali del Sistema delle Mandrucce.

4. THE COCCHIARE FAULT

This fault is also located within the Campo Imperatore basin, some 7 km ESE of the Mandrucce System. Its most significant point is situated in the segment where the Rio della Fornaca cuts the Mt. Paradiso - Mt. Mutri ridge (Fig. 14).

4.1 Data

4.1.1 Morphography

The almost completely barren Mt. Paradiso - Mt. Mutri relief has an average width of a little over a kilometre. It interrupts the floor of the basin and runs NW-SE for about 2.5 km. To the South, it is separated from the Southern slope of the basin by the deep canyon of the Eastern sector of Valle Cortina; to the East by the Western branch of Rio della Fornaca. This whaleback hill rises mostly less than 50 metres above the basin floor, in some places, however, it reaches 100 metres. Its gentle slopes (mean gradient about 30%) are carved by a series of furrows running mainly N-S in the Eastern sector (Mt. Mutri) and ENE-WSW in the Western sector

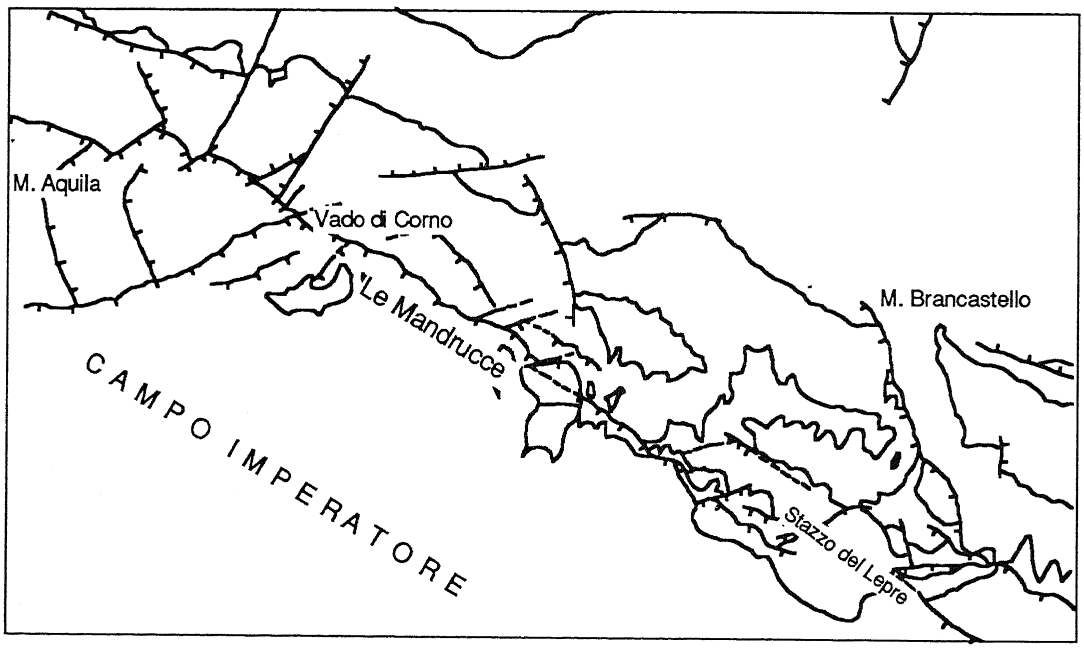

Fig. 11 - Tectonic map of the Mandrucce fault system and its related structures.
Carta tettonica del Sistema delle Mandrucce e delle strutture che vengono in rapporto con questo.

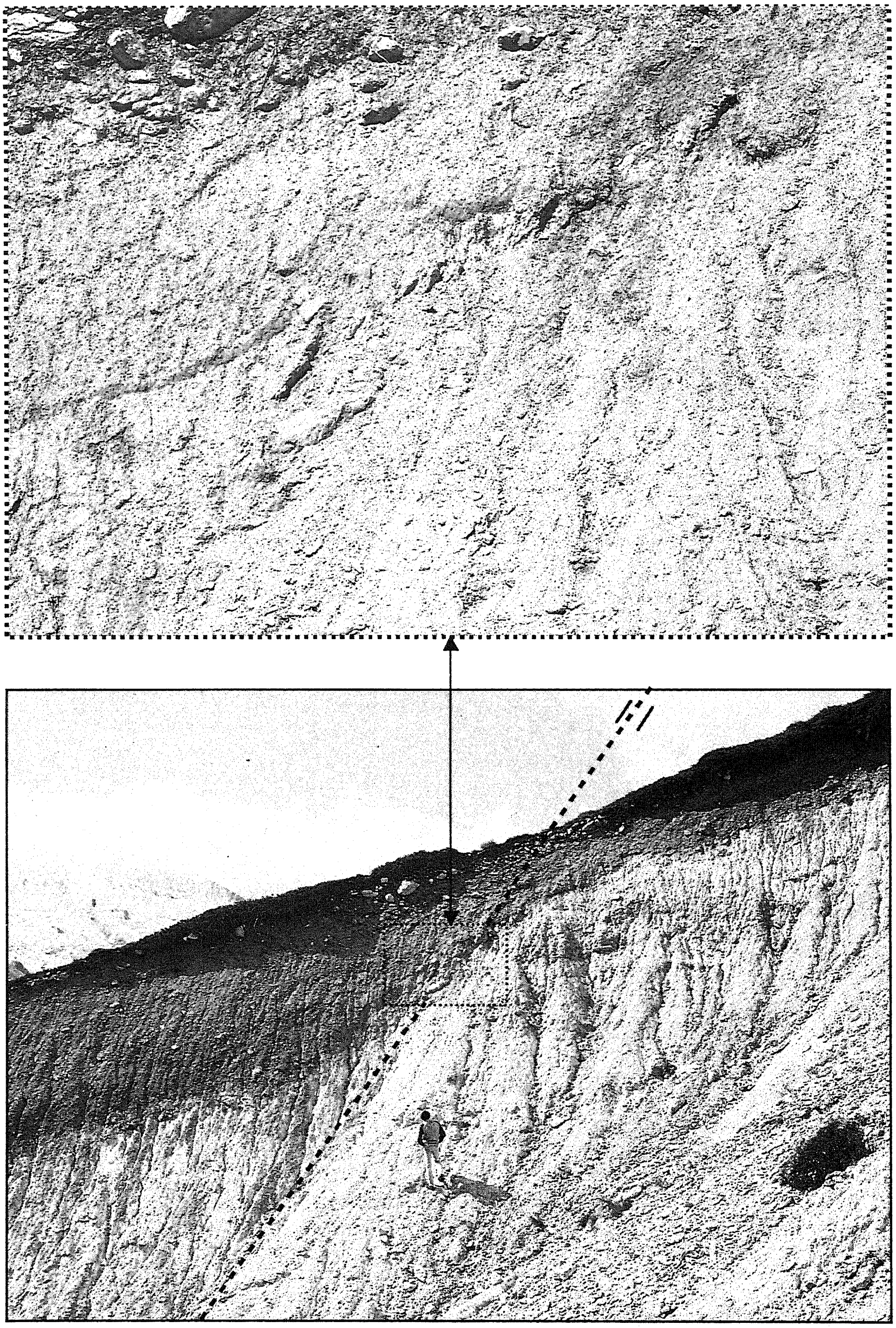

Fig. 12 - Direct fault displacing the colluvial deposits in basin no.17, and details of the deformational features within the deposits.
Faglia diretta che disloca i prodotti detritico-colluviali e particolare della deformazione entro i sedimenti (bacino n. 17)

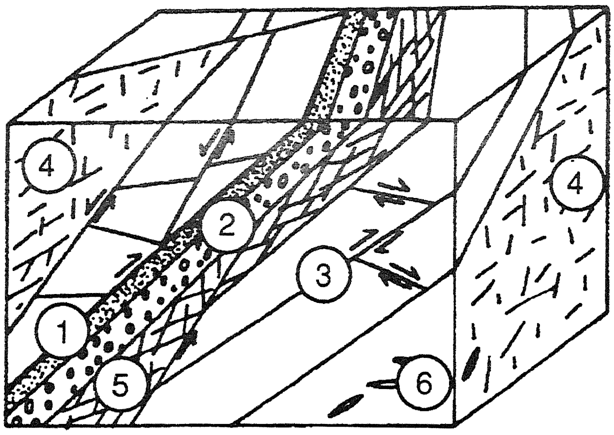

Fig. 13 - Block diagram showing the relations between types of fault in the Mandrucce system and the minor structures associated with such faults. 1. major shear plane; 2. heterogeneous rock fault; 3. minor shear planes; 4. variously oriented fractures; 5. cleavage; 6. extension veins.

Blocco-diagramma illustrante le relazioni tra i diversi tipi di faglia del Sistema delle Mandrucce e le strutture minori ad esse associate: 1. piano di taglio principale; 2. roccia di faglia eterogenea; 3. piani di taglio minori; 4. fratture variamente orientate; 5. clivaggio; 6. vene di estensione.

(Mt. Paradiso).

The relief is broken, near the branch of the Rio della Fornaca, by a slightly undulating, terraced surface covering an area of about 300 m^2 and dipping as a whole 3° toward SSE. Unlike the rest of the relief, this strip is covered by a meadow. A more irregular terraced strip, at the same height and similar in shape, is present on the other side of the stream.

A terraced fan, beginning about 2 km further North, comes to a sudden end against the NE edge of this relief at the mouth of the Valle della Fornaca. The fan covers an area of about 4 km^2 and can be divided into three parts (A1, B1 and C in Fig.15).

The highest part (A1) is preserved only to the right, where it forms a terraced shelf suspended about 40 m above the present bed in the upstream section and 5 m in the downstream section (convergence angle <1°). Near its tip, there is an elongated depression, about 5 m deep and a little less than 200 m wide, which stretches N-S for about 500 metres. The mean inclination of this surface is about 10% towards the South. To the West, the unit coalesces into the oldest portion of the fan of the contiguous Rio La Canala. The second part (B1) is broken up into a series of isosceles triangular strips, whose tips point towards the origin of the fan at the mouth of the valley. This unit too, is suspended by means of a scarp converging on the valley floor: the maximum height (10 m) falls to about 1 m at the boundary with the relief, and zero towards the Eastern margin. The surface has an average inclination of 5% towards SSE.

The lowest unit (C) corresponds to the present day

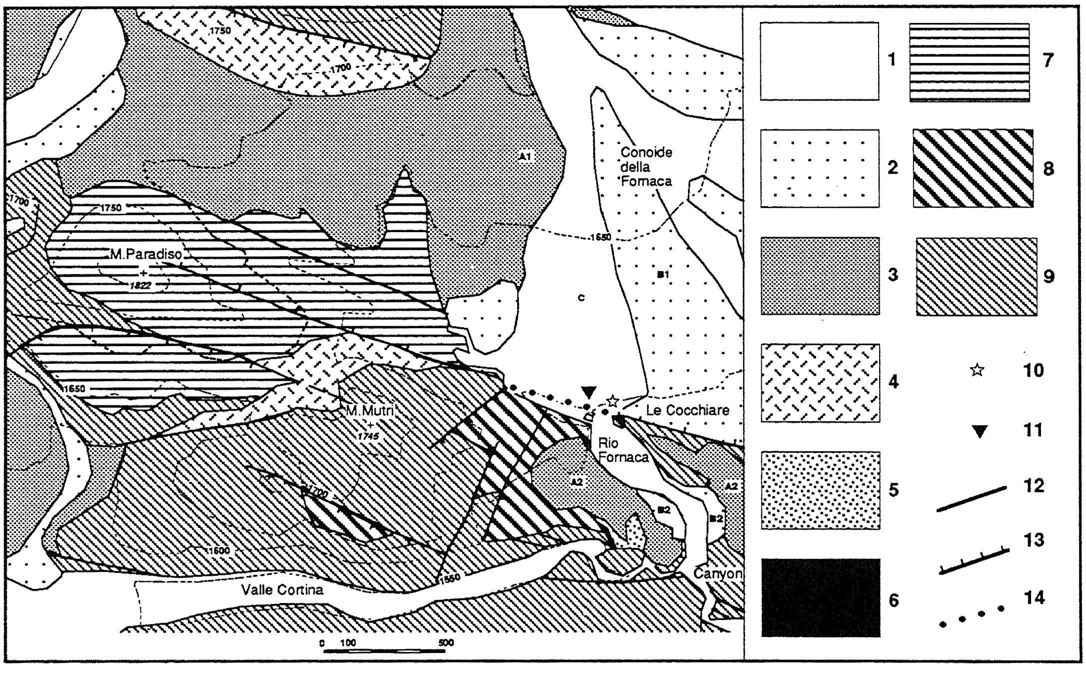

Fig. 14 - Geological map of the Cocchiare area.
Quaternary cover: 1) Alluvial deposits (Unit C). 2) Alluvial deposits (Unit B). 3) Alluvial deposits (Unit A). 4) Debris-colluvial deposits. 5) Glacial deposits. 6) Valle Cortina ash deposit. Pre-Quaternary Substratum: 7) Mt. Paradiso conglomerate. 8) Mt. Mutri calcirudite. 9) Calcirudite with Rudists. 10) Outcrop of the low-angle fault. 11) Ephemeral outcrop of the Cocchiare fault. 12) Fault line. 13) Normal fault line (dashes are towards the lowered part). 14) The Cocchiare fault-scarp.

Carta geologica dell'area delle Cocchiare. Copertura quaternaria: 1) Depositi alluvionali (Unità C). 2) Depositi alluvionali (Unità B). 3) Depositi alluvionali (Unità A). 4) Prodotti detritico-colluviali. 5) Depositi glaciali. 6) Cineriti di Valle Cortina. Substrato prequaternario: 7) Conglomerati di Monte Paradiso. 8) Calciruditi di M. Mutri. 9) Calciruditi a Rudiste. 10) Affioramento della faglia a basso angolo. 11) Affioramento temporaneo della superficie di faglia delle Cocchiare.12) Linee di faglia. 13) Linee di faglia normali (trattino verso la parte ribassata). 14) Scarpata di faglia delle Cocchiare.

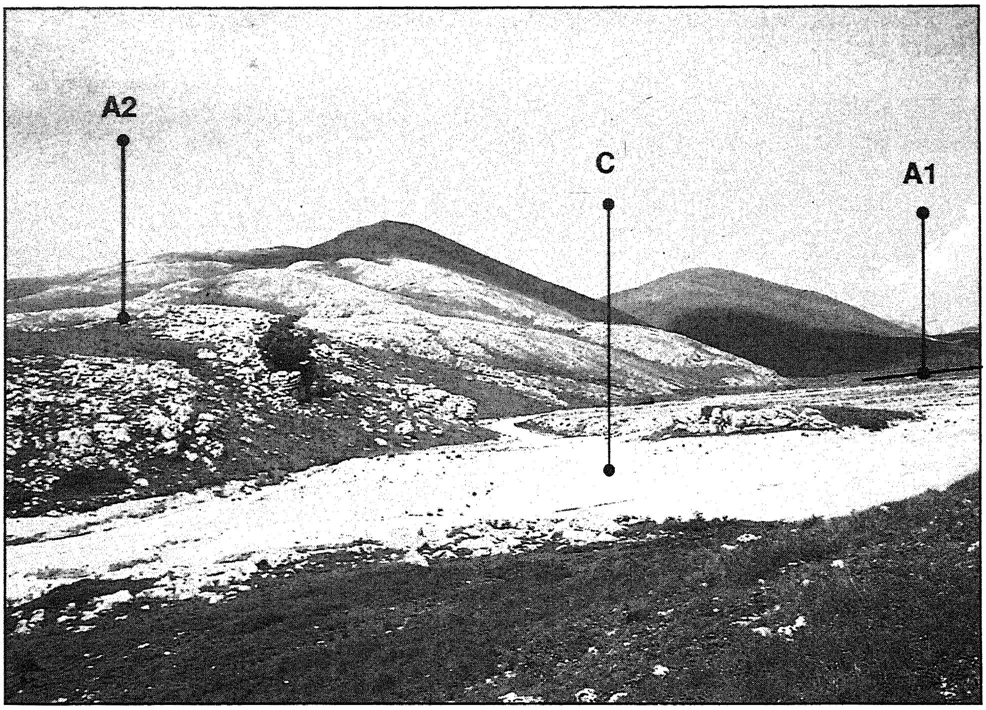

Fig. 15 - Part of the step representing the morphological expression of the Cocchiare fault. On the right, the sudden downhill termination of the Rio della Fornaca fan; on the left, the Mt. Mutri - Mt. Paradiso relief. The terraced surface A^2 is the uplifted downhill continuation of the uphill unit A^1, a strip of which can be seen on the right of the photo.

Parte del gradino che rappresenta l'espressione morfologica della Faglia delle Cocchiare: sulla destra la brusca terminazione verso valle della Conoide del Rio Fornaca; a sinistra il Rilievo M. Mutri-M. Paradiso. In quest'ultimo la superficie terrazzata A^2 rappresenta la prosecuzione, sollevata, a valle della faglia, dell'unità A^1 presente a monte, di cui nella foto è visibile un lembo.

Fig. 16 - The strip of the Valle Cortina ash deposits.

Il lembo di Cineriti di Valle Cortina.

bed. This is of the braided type and dry for most of the year. It has three branches. The westernmost branch runs roughly N-S at an average slope of 6% and is the one that is most frequently reactivated. Unit (C) joins the bottom of the cut of the Western branch of Rio della Fornaca at the Eastern boundary of the relief. This cut is between 70 and 150 metres wide. Its bottom has an average gradient of 3.5% towards SSE and is usually dry. Two small terraced strips of alluvial deposits are suspended on both slopes about 3 m above the valley floor.

The boundary between the two morphological units (the Mt. Paradiso - Mt. Mutri relief and the Rio della Fornaca fan) corresponds locally to a straight step running WNW-SSE and turned towards the NNE with an average height of 7 m and inclined at 40° to the vertical ("Cocchiare fault scarp": see § 4.1.3).

4.1.2 Lithostratigraphy

Pre-Quaternary substratum

Field work performed by one of the authors (M.G.) has brought to light the fact that the succession of the formations that make up the relief of Mt. Mutri - Mt. Paradiso is substantially more complex than the previous literature would suggest.

The pre-Quaternary substratum is mainly represented here by calcirudites and whitish, bioclastic calcarenites with a poorly distinguishable stratification ("Calciruditi a Rudiste"). These are superposed with unconformity by calcirudites with well-rounded carbonate clasts in graded, laminated metric layers ("Calciruditi del Monte Mutri", dated Lower Miocene, based on their palaeontological content and stratigraphic features, by Giardino, 1990). These in turn, are separated by a second discordance from polygenic conglomerates consisting of well-rounded clasts of arenitic and crystalline carbonatic rocks (< 50%). Their stratigraphic position makes them comparable with those recognised a few kilometres to the East by Ghisetti & Vezzani (1986b), called the "Conglomerati di Monte Coppe" and referred to Upper Miocene - Lower Pliocene on the basis of their setting.

Quaternary cover

The field data have established the following succession within the surficial formations in decreasing order of age:

- Ash deposits

These were found in the course of the thesis work from which this paper was derived. They consist of a pocket of mottled brown to reddish clayey-sandy material, with a decametric major axis. The pocket is located along the road running through Valle Cortina, roughly at the point where the valley becomes a canyon (cf. Figs. 14 and 16 were they are indicated as "Cineriti di Valle Cortina"). This material rests on the calcarenite and bioclastic calcirudite substratum and crops out with a visible thickness of a little more than one metre. The edges of the outcrop are masked by colluvial products derived from the reworking of these ash deposits and the morphologically more elevated glacial deposits. The ash deposit consists of a 1 m long band of brown ashes covered by a decimetric layer of ochreous ashes. Preliminary microscopic analysis has revealed the presence of abundant volcanic glass, augite, dark mica and sanidine associated with "dirty" detrital quartz. Samples are now being examined by E. Locardi.

The relations between this pocket and other units are never directly visible, except for its direct placement on the substratum. Its general trend (Figs.14 and16), however, suggests that these ash deposits are overlain by the glacial deposits.

- Glacial deposits

These outcrop in the same locality as the ash deposits, in a single strip measuring about one hectare; only rarely they are composed of more than decimetric carbonatic clasts (mainly white dolomites) which are sometimes faceted, polished and striated, and immersed in a quantitatively subordinate mass of grey-whitish silts. The clast lithotypes include grey to hazel-brown micritic limestones and whitish bioclastic calcarenites. The thickness of the deposit cannot be judged from the small outcrops present only in the Valle Cortina escarpment. The minimum outcrop thickness, however, is 5 metres. The basal support surface is never visible. The situation already described suggests that these deposits rest partly on the ash deposit and partly on the Pre-Quaternary substratum.

As mentioned earlier (see § 2), Frezzotti & Narcisi (in press) have reported the presence of the same soil developed on tuff ("andosoil") covering smaller strips of glacial deposits which, on the basis of their altitude, appear to be correlatable to the main strip. The authors, on the strength of their mineralogical composition and stratigraphy, regard the pyroclasts as genetically linked to the episode that emplaced the Tufo Giallo Napoletano 13,000 years ago.

- Terraced alluvial deposits

These are present in a variety of attitudes both uphill and downhill from the morphological step crossed by the Rio Fornaca and marking the NE edge of the Mt. Mutri - Mt. Paradiso relief ("Cocchiare fault-scarp"; see § 4.1.1 and 4.1.3).

Two distinct terraced units are present in the sector uphill from the scarp.

The higher and older unit (A^1 in Figs. 14 and 18) is expressed morphologically by its extensive terrace suspended up to 40 m above the present valley floor. There are extensive outcrops at the scarp facing the watercourse; in these outcrops relatively homometric

Fig.17 - Aerial photo of the glacial deposits covering the northern sector of the Campo Imperatore basin.
Vista aerea dei depositi glaciali che rivestono il settore settentrionale della conca di Campo Imperatore.

gravels (max. diameter 20 cm) with a slight sandy matrix, consisting of bioclastic calcarenites, whitish dolomites and micritic limestones can be observed. This deposit displays good plano-parallel stratification in the upper part and crossed stratification at a small angle in the lower part; locally it is weakly cemented. The upper part of the formation, immediately below the terraced surface, bears no appreciable signs of pedogenesis; "buried pedological horizons", however, are present within the deposit.

Frezzotti & Giraudi (in press) describe these horizons: ^{14}C analyses on vegetable remains contained in the lower horizon have given a date of 31,500±500 y B.P. while the organic substance of the upper level dated 17,840 ± 200 y.

The top surface of the distal part of this unit is covered by deposits from the more recent terraced unit.

The basal support surface never crops out and no direct knowledge can be gained on the nature of the substratum, the thickness of the unit, nor the real geometry of the sedimentary body. The maximum visible thickness at the scarp is 40 metres.

The top surface is rooted in an evidently epigenetic filled cut to the right of the present mouth of the valley.

The younger unit (B^1) consists of a sequence of terraces shaped like elongated strips flanking the still active branches of the large fan. These are suspended up to some ten metres above the present river bed in the proximal sector: the escarpments taper off to zero as they approach to the fault-scarp, where their surface are still subject to flooding.

The dimensions and lithology of the gravels that form this unit are exactly the same as those in unit A^1. Here, too, the support basal surface is not visible and the maximum thickness visible in the outcrop is about 10 metres.

There are two units also in the sector downhill from the scarp. The higher unit (A^2) is preserved in the form of two irregular terraces constituting the top surface of the relief in which the Rio Fornaca gorge, which originates from the scarp, is carved. Its original almost-flat morphology has been variously altered by reworking which has completely removed the deposit near the scarp. In this unit there are only a very few small outcrops, whose sedimentological features suggest a substantial similarity between this deposits and those of the other units. The basal surface is carved on the Pre-Quaternary substratum and can be seen in the uphill section of both strips. The maximum visible thickness is 7 metres. In the distal segment, the lateral support surface cuts into the Cenozoic Calcirudites of Mt. Mutri. This happens at a higher level (up to 1,610 m) than that of the basal support surface of the glacial deposits (not-outcropping) of Mt. Mutri (1,540 m).

On both sides of the canyon, two stripes of a lower terrace (B^2) are present; these show similar lithologic characteristics and are suspended by about 2 m.

- Recent alluvial deposits

These (C in Fig. 18) form the bed of the three still

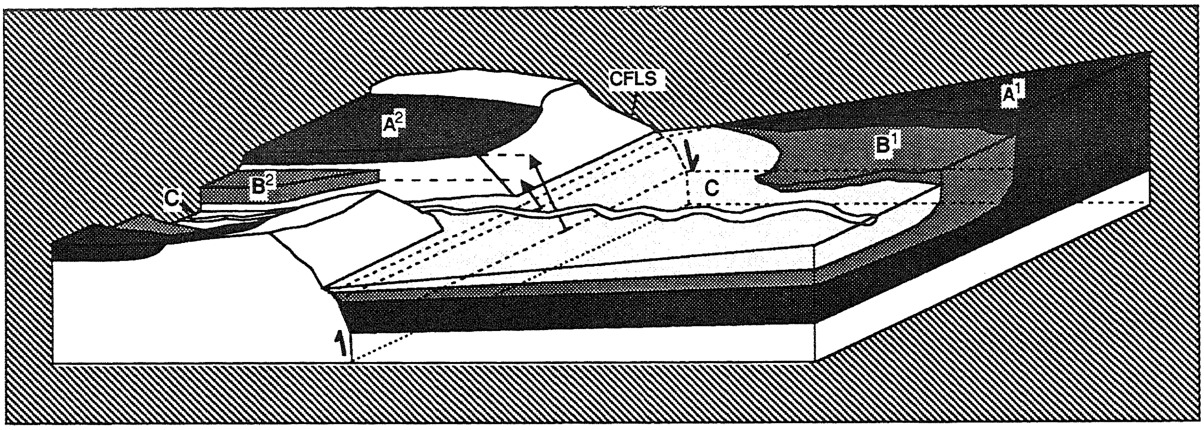

Fig. 18 - The stereogram is a possible model of the morphological situation connected with the Cocchiare fault (for explanation, see text).

Stereogramma interpretativo della situazione morfologica in relazione con la Faglia delle Cocchiare (per la spiegazione si veda il testo)

active branches of the large Rio Fornaca fan and that of the wide cut originating from the scarp. They consist of gravel whose grain size and lithology are similar to those of the terraced deposits. Their surface has a regular longitudinal profile and runs without interruption between the uphill and downhill sectors of the scarp. The basal support surface is never visible, hence neither its progress nor the thickness of the deposits can be determined. The lateral support surfaces are modelled in units AI and BI in the uphill segment, and, partly in the Pre-Quaternary substratum and partly in units A^2 and B^2, in the downhill segment.

4.1.3 Structure

The Mt. Mutri - Mt. Paradiso ridge has been shaped into a series of slabs separated from each other mostly by subvertical, normal faults directed WNW-ESE (Fig.14).

The attitude of the Pre-Quaternary stratigraphic units (cf.§ 4.1.1.1) varies in the individual slabs: the "Calciruditi a Rudiste" layers dip 30÷45° towards 210÷220° in the Southern slope and 20÷30° towards 30÷40° in the Northern slope. The "Calcirudite di Mt. Mutri" bodies dip 10÷40° towards NE and are thus discordant on the other bodies. Lastly, the attitudes of the "Conglomerati di Mt. Paradiso" range from horizontal to 30÷35° towards15÷30°.

This structural picture is rendered even more complicated by two features:

1) the presence of a thrust surface (not indicated in Fig. 14) dipping 30° towards 20° that cuts the stratification of the "Calciruditi di Mt. Mutri" at a low angle. This surface has been exhumed for several metres from the Quaternary deposits of the Fornaca alluvial fan (black triangle in Fig.14) and it is not visible in the immediately adjacent relief on either side of the cut, which is here composed of the "Conglomerati di Mt. Paradiso" that probably seal the fault. The spatio-temporal location of the thrust within the structural stack in relation to the other low-angle shear surfaces present in the Gran Sasso thrust belt cannot be precisely determined. Probably it could be correlated (outside the area examined in this paper) with the thrusts in the Eastern sector of the Gran Sasso chain which is responsible for the superposition of the higher tectonic units. These thrust-faults are partially sealed by the "Conglomerati di Mt. Coppe" (cf. Ghisetti & Vezzani, 1986b), which, as already stated, are stratigraphically correlated with the "Conglomerati di Mt. Paradiso".
2) The attitude data suggest that the previous thrust surface is intersected at low angle (10÷20°) by a fault with the same direction: the "Cocchiare fault-scarp" (described in § 4.1.1) represents its morphological expression. As mentioned earlier, the sector to the South of the scarp is at a higher altitude than the Northern one (Fig.15): on the left of the present cut of Rio Fornaca, it corresponds to the contact between the alluvial deposits and the Eastward continuation of the Mt. Mutri ridge. An excavation within these deposits, located at the point indicated by an asterisk in Fig. 14, has shown that this scarp coincides with a fault surface dipping 70° towards 10°.

4.2 Interpretations

The considerable thickness of the Valle Cortina ash deposits, although partly due to local reworking by extensive surface runoff immediately after sedimentation, suggests that their deposition was due to a substantial nearby volcanic event. In particular, their exceptionally good local preservation in a single strip, evidently is due at least in part to the the glacial deposits cover. As mentioned earlier, these deposits are now being examined. The preliminary findings, especially those from the rare earth values, indicate that they do not belong to any known Mediterranean body. Locardi (pers. comm., 1991) regards these deposits as associated with autochthonous alkaline volcanism with a carbonatic trend, characterised by freatic-magmatic manifestations. Radiometric datings of samples from volcanic manifestations in the outer sector of the Central Apennines (among which we tentatively include the one which produced the ash deposits of Valle Cortina), have been assigned an age of 460,000 years B.P.(I. Villa, acc. to Locardi, pers. comm.).

The glacial deposits are clearly lodgment deposits, they are associated with a landscape that was appreciably different from the present one. In fact they form a strip suspended at least 20 metres above those forming the floor of Valle Cortina. The deposits covering the bottom of the Northern sector of Campo Imperatore (Fig. 17), are visibly linked to the tongues that descended from the SW side of the depression (Mt. Scindarella). Those of Mt. Mutri, on the other hand, have been laid down by a much more extensive ice mass that occupied the entire floor of the basin, as shown by relics at a higher level than the present floor.

These deposits are not recorded on the maps available in the literature. Due to the complete lack of direct evidence, we can only attempt to date them based on the following consideration: bearing in mind the inclinations of the basal support surfaces, they constitute a terrace that is not altimetrically correlatable with the series of glacial deposits that extensively cover the bottom of the basin (*i.e*: three units in relation to the modest reciprocal terracing). The latter, based on general palaeoclimatic considerations, have been attributed to Würm 1 and Würm 3 by Demangeot (*op. cit.*). The Mt. Mutri glacial deposits are suspended at least 20 metres above them. In addition, the age of the Mt. Mutri deposits is constrained by those of their underlying and overlying tuff deposits. If we accept the interpretation advanced thus far by Locardi (1991, pers. comm.), the glacial episode that produced the Valle Cortina deposits may be placed either in the Middle or in the Upper Pleistocene (in accordance with the scale proposed by Richmond: see AIQUA, l982).

Turning now to the terraced fluvial deposits of Rio Fornaca, the examination of Fig. 18 shows that, in the absence of chronologically significant data, at a first guess the two units described in the downhill sector of the "Cocchiare fault scarp" (A^1 and A^2 in Fig. 14) can be considered the homologues of those in the uphill sector (B^1 and B^2). In addition, the sudden downhill termination of the uphill deposits against the rock scarp, is reflected in the equally sudden appearence of the two units in the downhill sector; their geometry clearly increases downhill and they are sharply truncated as they approach the scarp.

This above situation can be readily interpreted as the product of evolutive interaction between sedimentation and erosion on the part of Rio Fornaca, and evolution of the fault morphologically represented by the Cocchiare fault scarp. The examination of Fig. 18 and the reconstruction of the evolution of the two sectors, in fact, enable two different successions of theoretical isochronic lines to be drawn. In the uphill sector, where unit B^1 is directly superposed on unit A^1, the most recent line is higher than the oldest, whereas in the downhill sector, where units B^2 and A^2 are related by a scarp, the most recent line is lower than the oldest (and "wedged" under it).

This situation represents the interplay of two phenomena with very different evolutionary patterns: 1) fluvial sedimentation and erosion, whose high-altitude streams with heavy flows of solid material, as in the Rio Fornaca basin, are very fast and distinctly episodic; 2) the differential movement of the fault, which is fast when compared with that of other recent evolution faults, but very slow when compared with the rate at which stream deposits and gutters are formed.

The present situation, therefore, must be thought of as the result of dynamic interaction between these two processes. The displacement of the two terraced units must have taken place during their sedimentation and after they had become terraced. This sedimentation lasted a very short time, however, and the displacement that accompanied it cannot be discerned by the examination of the two bodies, since their geometry is interrupted, as if the movement only took place after their formation. By contrast, the displacement between the two sectors becomes much clearer owing to the relatively long interval between two sedimentary episodes: 1) relative lowering has led to substantial stability, thus to reduced erosion, in the uphill sector; 2) on the contrary erosion has brought about rapid lowering and hence terracing of the deposits in the strongly uplifted downhill sector. This model explains the situation described with regard to the present Rio Fornaca deposits. It can readily be understood that, despite the very probable ongoing evolution of the fault, the surface of these deposits appears to be undisturbed at the intersection with the structure itself: the rate of movement of the fault, and hence the rate of evolution of the Cocchiare fault scarp, are less than the rate at which individual fluvial sedimentation and/or erosion events are altering the present surface of the deposits. It is possible that the basal support surface of this unit may form an uphill-facing step at the Cocchiare fault scarp: this will be the case if the initial sedimentation of the most recent fluvial unit was sufficiently far back in time to be able to record the movement of the fault. The height of such a step obviously will be directly proportional to the magnitude of time elapsed since sedimentation began.

It is, of course, possible that these two units may not be homologues. This, however, would imply that the homologue of unit A^2 in the uphill sector has been completely removed, which appears improbable on statistical grounds alone. Moreover the homologue of B^1 would have been completely cancelled in the downhill sector (the tongues of unit B^2, in fact, develop at a lower elevation than the downhill prolongation of B^1), a circumstance that also seems unlikely.

The terracing of the Rio Fornaca fluvial deposits, with respect to the Mt. Mutri glacial deposits, indicates that their age lies between Middle-Upper Pleistocene and Holocene. It follows that the evolutionary process that we have reconstructed covers this time interval. The extent of the Quaternary movement along the fault cannot be measured as the basal support surface of the deposits is not visible in the uphill sector; how-ever, it is certainly greater than the 15 metres corresponding to the height of the Cocchiare fault scarp. The recent age of this movement is in keeping with the fact that the fault-scarp, where visible follows quite tightly the fault surface itself.

5. FINAL REMARKS

The importance of these local phenomena depends mainly on the fact that their morphological features are quite comparable with those of many similar occurrences in both the Apennines and the Alps. In this specific case, however, the presence of significant outcrops in the surficial formations makes it unmistakably clear that such features, which could be interpreted in various ways, are the product of recent tectonic activity.

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