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ILLUSTRATIVE NOTES OF THE GEOMORPHOLOGICAL MAP OF THE UPPER ARMA VALLEY (STURA DI DEMONTE VALLEY, MARITIME ALPS)

ABSTRACT: SPAGNOLO M., *Illustrative notes of the Geomorphological Map of the Upper Arma Valley (Stura di Demonte Valley, Maritime Alps)*. (IT ISSN 1724-4757, 2007).

The present-day morphology of the upper Arma Valley (Maritime Alps) is the result of the complex interaction among glacial, periglacial, gravitational, running water, anthropogenic, karstic and structural processes. The overall geometry of the valley is related to the main thrusts separating the Briançonnais, Subbriançonnais and Dauphinois Domains. Although most glacial and periglacial processes are no longer active, present-day cryoclast processes, mostly on the southern flanks, are still feeding the numerous gravitational debris-fans, slope talus and debris-flow fans. The reconstructed glaciers that once occupied the Cavera and Serour valleys, likely coeval, gave a similar ELA of about 2100 m asl. Embryonic protalus rock glaciers have been found on almost every northern slope above 1800-2000 m, while other larger rock glaciers have developed from lateral and frontal moraines. Because of the widespread presence of soluble rocks, most of the Valley is characterized by ephemeral channels and other surface karstic features that have developed both on rocks and deposits. The presence of clays, derived from weathered schists, have brought about the formation of badlands, also favored by freeze and thaw processes. Finally, the upper Cavera Valley S-facing flank is widely affected by a complex deep-seated gravitational movement that is responsible for the presence of several trenches along the slope and doubled-crests along the divide.

KEY WORDS: Geomorphological map, Arma Valley, Maritime Alps.

RIASSUNTO: SPAGNOLO M., *Note illustrative della Carta Geomorfologia dell'Alto Vallone dell'Arma (Valle Stura di Demonte, Alpi Marittime)*. (IT ISSN 1724-4757, 2007).

La morfologia attuale dell'alto Vallone dell'Arma (Alpi Marittime) è il risultato della complessa interazione tra processi glaciali, periglaciali, gravitativi, fluviali, antropogenici, carsici e strutturali. La geometria generale del Vallone è legata ai sovrascorrimenti principali che separano i Domini Brianzonese, Subbrianzione e Delfinese. Sebbene la maggior parte dei processi glaciali e periglaciali non siano più attivi, le numerose falde e coni detritici e da debris-flow, soprattutto nei versanti meridionali, sono ancora alimentati da processi crioclasitici attuali. I ghiacciai ricostruiti che un tempo occupavano le valli Cavera e Serour, probabilmente coevi, sono caratterizzati da una ELA simile di circa 2100 m slm. Protalus rock glaciers embrionici sono stati riconosciuti su quasi tutti i versanti settentrionali sopra i 1800-2000 m, mentre rock glaciers più estesi si sono sviluppati a partire da morene laterali e frontali. Data la presenza di rocce solubili, gran parte del Vallone è caratterizzata da canali effimeri ed altre morfologie carsiche superficiali sviluppatesi sia in roccia che su depositi. La presenza di argille, derivate dall'alterazione di rocce scistose, ha reso possibile la formazione di calanchi, favoriti anche dall'azione del gelo e disgelo. Infine, la porzione sommitale destra della Val Cavera è ampiamente coinvolta in una deformazione gravitativa profonda, responsabile della presenza di diverse trincee lungo il versante e di doppie creste lungo lo spartiacque.

TERMINI CHIAVE: Carta geomorfologia, Vallone dell'Arma, Alpi Marittime.

INTRODUCTION

Although its geological complexity has attracted several researchers (Franceschetti, 1962; Gabert, 1962; Sturani, 1962; Merlo, 1968; Malaroda & *alii*, 1970; Gidon, 1972), the geomorphology of the Arma Valley, located in the northern portion of the Maritime Alps (see location sketch on the Geomorphological Map), has never been analyzed before, apart from a morphometric analysis of its middle-lower portion (Spagnolo 2005) and a study currently in progress by T. Celentano. The study area's varied lithology and structure and the great elevation range makes this valley a good area for focusing on genetically-different landforms and their relationships. In fact, the morphology of the area is the result of seven different surface processes that have acted diachronically in some cases and simultaneously in others. Glacial, periglacial, gravitational, running water, anthropogenic, karstic and structural landforms

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were identified in the field (2004 and 2005 summer campaigns) and transferred onto a geomorphological map of the valley at a scale of 1:15,000. The illustrative notes of the map and some insights into the morphometry of both the drainage network and the mountain flanks of the Upper Arma Valley are the subject of this paper.

SETTINGS

The Arma Valley is the largest (70 km^2) and longest (19 km) northern tributary valley of the Stura di Demonte Valley in the Maritime Alps. The study area is the upper portion of the Arma Valley, from the Cavera Pass (2429 m) to the village of San Giacomo (1293 m) for an overall extension of 17 km^2 and a range in elevation of almost 1200 m. Several peaks surround the valley along its divide, far exceeding 2000 m (e.g. Mt. Omo at 2613 m and Cima Fauniera at 2517 m, see fig. 3). In the upper portion of the study area there are two main valleys, the Cavera and the Serour valleys. Once joined together, they become the Arma Valley, drained by the Cant Torrent, the longest right bank tributary of the Stura di Demonte River, which is part of the Po River drainage system that flows into the Adriatic Sea.

From a climatic point of view, the closest meteo-station available is that of Fedio San Giacomo, at 1310 m, at the extreme lower end of the upper Arma Valley. Unfortunately, only rainfall data, collected for the last 40 years, are available. The three wettest months are April (126.6 mm), October (116.4 mm) and March (109.2 mm). In a year, there are on average 971.3 mm of rainfall in 82.9 rainy days. Temperature analyses from nearby meteo-stations (Rio Freddo), recorded at similar elevations, suggests that there are at least 200 times in a year when the temperature goes below 0°C, justifying the intense cryoclastism whose effects have been observed in the field.

The geology of the study area is rather complex, with the outcropping of formations belonging to three different paleogeographic domains: the Briançonnais, Subbriançonnais and Dauphinois Domains (see geological sketch in the Map). These domains are elongated from SE to NW and they are separated by two main thrusts. The valley itself is elongated from NW to SE, following the direction of the main tectonic structures. The various formations can be clustered into six different rock type groups that have affected the morphology of the area (see Map for their outcrop) in different ways. They are:

- limestones and dolomites, usually highly fractured, which are responsible for the large amount of debris involved in the surface processes. They represent the most frequent rock type of the upper Arma Valley. In places, these rocks are affected by karst processes. This morpholithological unit also includes some localized outcrops of calc-schists, easily identifiable because they are always connected to land flow processes.
- *Carniole* and gypsums, very weak rocks, heavily affected by micro- and macrokarst phenomena. They are particularly evident at the Cavera Pass.
- Ardesian-calcareous schists, argillites, calc-schists, quartzose-sericitic schists, all rocks which, by weathering, turn into a highly plastic and clayey ground that is often involved in large landslides.
- Quartzites, only outcropping in very limited portions below the divide Cima Viribianc - Mt. Borel and Mt. Gorfi.
- Riolites, only outcropping at the divide between Colle Viribianc and Mt. Borel.
- *Annot* flysch, a regular succession of arenaceous-pelitic turbidite sequences, whose alteration is responsible for the formation of colluvial deposits and landslides.

Morphometry

The drainage network was derived from the 10 m DTM of the area by using hydrological GIS tools. Finally, it was automatically ordered according to the Horton-Strahler classification (see hydrography sketch in the Map) and some morphometric parameters, such as the bifurcation ratio, direct bifurcation ratio and bifurcation index (Avena & *alii*, 1967) were evaluated (tab. 1). The whole network is characterized by 152 channels, from the first to the fifth order, and a general dendritic pattern. In the Serour and Cavera valleys the main channels are only of the third order, probably because of the presence of soluble rocks that did not favor a high drainage density. By looking at the number of channels and the bifurcation ratio among the channel orders, it is possible to identify a contrast between the abundant channels of first and second orders on one side and the paucity of channels from the third order or more, on the other side. This is likely due to the presence of a relatively large portion of the study area being characterized by a narrow valley drained by the main Arma Torrent that here collects several first or second order lateral tributaries whose basins are too small to develop a more organized (above the second order) drainage system. It is also important to notice that the average length of the third order channels is shorter than that of the fourth order. This is due to the fact that the whole Cavera Valley is drained by a very long third-order channel, probably because the several karstic processes

TABLE 1 - Some morphometric parameters analyzed on the drainage network: Order, number of channel of a given order (N), mean length of the channels of a given order, Bifurcation Ratio (Rb), number of channels of a u order that directly flow into channels of u+1 order (Nd), Direct Bifurcation Ratio (Rbd), Bifurcation Index (R). For more details on these parameters see Avena & *alii* 1967

Order	N	Mean Length	Rb	Nd	Rbd	R
I	114	293		80		
			3,9		2,8	1,2
II	29	613		19		
			4,8		3,2	1,7
III	6	1603		6		
			3,0		3,0	0,0
IV	2	1440		2		
			2,0		/	/
V	1	2788		/		

recognized here did not make it possible to develop a more organized drainage system.

The hypsometric curve (fig. 1) is very regular, almost resembling a straight line, with an approximate increase in area of 2 km^2 every 100 m in elevation.

The basin is characterized by slope values up to 76° (see slope sketch in the Map). A large strip of low-value slope is typical of both the Serour and Cavera valley bottoms, suggesting that both are U-shaped valleys, probably glacial in origin. Besides the valley bottoms, there are only a few more areas characterized by an almost flat surface. Some of them correspond to deposits, mostly moraines or landslide heads. Some others, like that of Cima Viribianc, are found near the divide and could represent a hanging paleo-surface that was not reached by glacier erosion. Overall, there is an evident connection between rock type and slope. Steep flanks are found wherever limestones and dolomites outcrop. Conversely, gentle slopes are characterized by schist rocks.

A GIS-based statistical analysis on the aspect map derived from the 10 m DTM of the area shows that the two most frequent flank aspects are SW and E. In general, aspect seems to influence surface processes especially in terms of the formation of debris. In particular, southward flanks are characterized by more abundant debris than northward flanks, probably because cryoclastism affects the southern slopes more intensely than the northern slopes. No relationship between aspect and badlands was found in the Arma Valley.

STRUCTURAL LANDFORMS

The geometry of the Arma Valley has been conditioned by the complex structure of this area. The presence of several almost parallel NW-SE thrusts have determined the elongation of the valley itself. Both the main Cant River downvalley and the Serour Torrent upvalley flow along the thrust separating the Subbrançonnais Domain from the Briançonnais Domain. Two other important NW-SE thrusts are present respectively on the SW and NE flanks of the Valley (Malaroda & *alii*, 1970) and in some cases they have clearly affected the geometry of the minor drainage network, such as in the valley SE of Punta Parvo, or determined the formation of high passes, such as that of Pera Puntua. The alignment of portions of lateral valleys and passes on the entire left flank of the Arma Valley, together with other morphometric evidence, suggests the presence of an original valley, parallel to the Arma Valley, which was eventually captured by the Cant Torrent (Spagnolo, 2005). This original valley probably extended upstream for the entire Cavera Valley and the head of the Madonna Valley, which was eventually captured by the regressive erosion of the Madonna Torrent.

Besides these three main thrusts, two faults have been recognized here. The lower Cavera Torrent flows along one of these faults, while the other fault crosses the valley from SW to NE, dislocating both the main Subbrançonnais-Briançonnais thrust and the left flank thrust. It is a direct fault that has lowered the SE portion of the valley with respect to the NW, resulting in the formation of an evident knickpoint along the valley profile (see longitudinal profile on the map).

Other passive elements present in the Valley are the morphoselective landforms, and in particular the rocky peaks usually made up of a hard core of limestone or dolomite surrounded by easily erodable rocks. Particularly evident are the two twin peaks that surmount the Serour Valley, the «Due Uomini» (*two men*) of the Colle Salé (Gidon, 1972), both very pronounced (more than 50 m high) and sharp, easily visible even from the main town of Demonte, several kilometers downvalley of the study area.

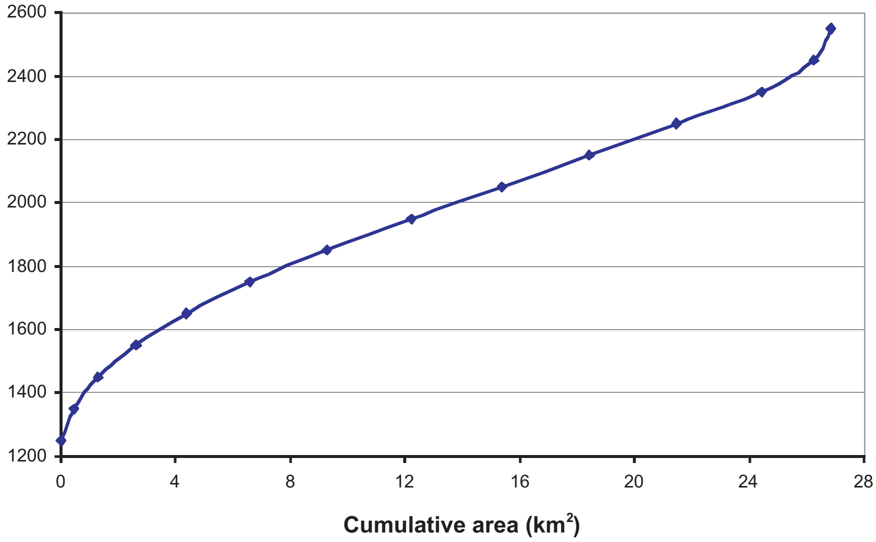

FIG. 1 - Hypsometric curve of the upper Arma Valley. Cumulative area is expressed in square kilometers, elevation in meters above sea level.

GLACIAL LANDFORMS

The average ELA of current glaciers in the Maritime Alps is 2800 m (Federici & *alii*, 2000). Glaciers no longer exist in the Arma Valley and all glacial features have to be considered relict forms. Although the lower portion of the Arma Valley is characterized by a V-profile and shows very little evidence of former glaciations, the entire Valley was probably glaciated all the way to its mouth on the Stura di Demonte Valley at its maximal extension. The lack of evidence is due to a combination of intense regressive erosion of the main Cant Torrent, which occurred when glaciers retreated and it was favoured by the presence of relatively weak rocks outcropping at the valley bottom. In the upper portion of the Arma Valley, where glaciers have modeled the landscape for a longer time span, several glacial features have been recognized.

Glacial cirques are present at the head of almost all valleys, especially those facing north. Only the head of the Cavera Valley represents an exception with a badly preserved glacial cirque, probably because of the outcropping of weaker rocks and the presence of a transfluence gap, with the Cavera glacier overflowing into the nearby Madonna Valley. Another glacial transfluence is that between Punta Parvo and Cima Fauniera. In this area the glacier formed in the Cima Fauniera cirque probably had two tongues, one flowing in the Parvo Valley towards North and the other in the Cavera Valley towards South.

Almost all tributary valleys of the Cavera and Serour valleys show a typical glacial erosional U-profile and were occupied at times by cirque glaciers or valley glaciers. In some cases, these secondary valleys were clearly suspended on the main glacial valley, as was the Morti Valley on the Cavera Valley. In other cases, there is only evidence of the cirque threshold and glacial step. Along the valley flanks, especially in the Cavera Valley and in the lateral tributary valleys of the Serour Valley, some scarp edges have also been recognized.

The Cavera Valley is characterized by the presence of glacial erosional surfaces all along its bottom, in some cases clearly ascribable to whale backs (fig. 2). Calc-schists that sparsely outcrop along the Valley bottom are very probably responsible for the presence of a thin layer of eluvial deposits and soil, covered with grass, which covers most of these erosional surfaces. For this reason, no polished or striated rocks have been found.

In some cases the post-glacial evolution of glacial deposits into rock glaciers have modified their original shape while in other cases glacial deposits with their original moraine crests are still clearly visible. A typical modified glacial deposit is that of the Viribianc Valley. Here only the lower moraine crest (at the Gias Viribianc Superiore) is still visible. Uphill from this moraine crest, the originally glacial deposits are now part of a rock glacier complex. Another similar case is that of the upper Serour Valley, near the Passo Sale, where again a rock glacier has developed from the glacial deposits.

Besides the moraine of Gias Viribianc Superiore (1930 m, facing SE), three more frontal moraines have been recognized in the area. Two of them are located in the Serour Valley, one in the upper portion at 2050 m and the other at the confluence with the main Arma Valley, near the Gias Serour at 1750 m. The last moraine is located below

FIG. 2 - The aspect of the rocky erosional glacial landforms of the Cavera Valley (smoothed surface above the fluvial canyon). Also note the evident impact of the cow paths along the slopes.

the Gias Cavera and it is composed of at least three longitudinal crests, almost parallel to each other. The lowest crest reaches an elevation of 1800 m and, because of its slightly arching shape, it is thought to be the remnant of a latero-frontal moraine of the glacier that occupied the Cavera Valley. The upper crests could represent lateral moraines related to pulsations of the same glacier. The missing frontal moraine was probably eroded by the postglacial fluvial erosion of the Cavera Torrent. Its intensity can be evaluated by looking at the fluvial canyons this same Torrent has built below the glacial erosional surfaces, a few hundred meters above the moraine (fig. 2). The intense karstification on the limestone and dolomite deposits and an embryonic development into a rock glacier has given to the Gias Serour moraine a typical hummocky aspect, and only a few crests are clearly distinguishable.

According to the position of their moraines, both the original Cavera and Serour glacial valleys were hanging on the main Arma Valley, along the scarp formed on the hanging wall of the abovementioned SW-NE fault, whose offset is not known. They are both relatively large with limestone and dolomite blocks dispersed in abundant matrix and they are now mostly covered by grass. The Gias Cavera and Serour moraines are both characterized by multiple crests and are situated at similar elevations. The hypothetical glaciers that occupied these valleys were reconstructed (fig. 3) taking into account the frontal moraines and evidence of the trimline upvalley. Their ELA was evaluated by using both the BR (Balance Ratio) (Furbish & Andrews, 1984) and the AABR (Altitude Area Balance Ratio) (Osmaston, 2005) methods, in both cases applying the default BR value of 1,67. With the BR method the Serour and Cavera glaciers had an ELA of 2092 m and 2062 m respectively. With the AABR method the Serour ELA was 2089 m and the Cavera ELA was 2098 m. Besides the slight differences between the ELAs derived with the two methods, in both the Cavera and Serour cases the ELA values of the glaciers are very similar, suggesting the synchronicity of the two systems.

These values closely agree with ELAs of former glaciers reconstructed from several other moraines found in the Maritime Alps (Federici & *alii*, 2003) that have been grouped in the «phase-3», tentatively referred to the Oldest Dryas advance (Puccioni, 2005). This would confirm the hypothesis that during the Last Glacial Maximum the Arma Valley glacier arrived further downvalley from the study area, possibly all the way to the confluence of the Arma Valley with the Stura di Demonte Valley (Federici & Malaroda, 2006).

PERIGLACIAL LANDFORMS

Most periglacial features recognized in the Arma Valley are no longer active, in agreement with the fact that the presence of discontinuous permafrost in the Maritime Alps has been evaluated above 2670 m (Federici & *alii*, 2000). Nevertheless, some active periglacial landforms found in the area testify that locally, probably during spring and autumn and in specific locations (such as North-facing slopes), periglacial processes are still affecting the landscape of the upper Arma Valley.

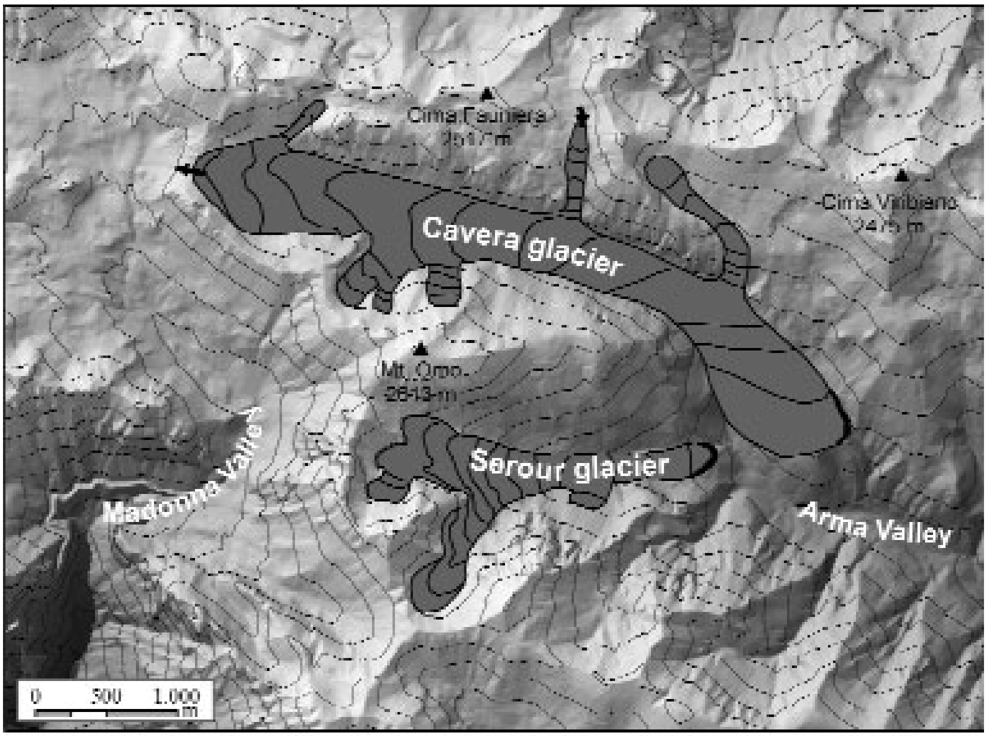

FIG. 3 - The reconstructed Cavera and Serour glacier extensions when their ends were at the frontal moraines (in black) of Gias Cavera and Gias Serour respectively: contour lines on glaciers every 50 m, on topography every 100 m; black arrows indicate possible transfluence paths.

Active periglacial landforms include avalanche-related features and several microforms, such as gelifluxion lobes and patterned grounds (e.g. earth hummocks). According to the local inhabitants, avalanches occur with a frequency of about 10 years along the northern flanks of the valley and they are mostly concentrated in the lower portion of the study area, as also indicated in the Avalanche Map of Piemonte (Capello, 1977; Ansaldi & *alii*, 2005). Avalanches usually involve the detachment of vegetation, soil and rocks, concurring at the erosion of the channel they flow into and causing the formation of a terminal fan once the channel meets the valley bottom.

Among the inactive landforms, rock glaciers are the most frequent and the more easily recognizable landforms. Only in a few cases, such as in the upper Viribianc and Serour valleys, have rock glaciers developed from glacial deposits and can possibly be referred to as ice-cored rock glaciers. Otherwise, most of them are typical protalus rock glaciers (fig. 4), formed on even very short, but usually steep debris fans or talus slopes. They have rarely developed more than two concentric crests and they usually rise above the nearby slope for no more than 10-15 m. Due to their dimmed morphology, these protalus rock glaciers can all be considered embryonic landforms. They are found on almost every northern slope above 1800-2000 m, wherever enough debris is present, usually on limestone-dolomite areas. In similar settings, also some nivation hollows have been recognized, possible preceding the formation of glacier cirques that never had the time to develop.

Other inactive periglacial landforms are rock fields and rock streams. The former mostly occur along the main divide between Mt. Borel (2272 m) - Mt. Viridio (2496 m) and between Mt. Omo (2613 m) - Rocca Tipurero (2424 m), in the northern and southern portion of the study area respectively. The latter are frequent on the Mt. Borel and Mt. Viridio southern flanks, at elevations between 1900 m and 2200 m. On these same flanks, some of the inactive flow landslides recognized there have a very irregular morphology, suggesting a possible complex genesis related to both gravitational and periglacial processes.

GRAVITATIONAL LANDFORMS

In the upper Arma Valley, the present-day surface processes are dominated by gravity. The combination of gravitational landforms and cryoclastism is very evident, with active gravitational processes mostly present on northern slopes, where microclimatic conditions favor the detachment of debris from rock walls. This is evident along both the Cavera and Serour valleys and their minor tributary valleys, although above 2200 m most gravitational processes can be considered active irrespective of aspect. Almost everywhere below rock cliffs there are gravitational debris fans, sometimes blended together in a talus slope. Several blocks with a diameter of 2-3 m are commonly found at the bottom part of these taluses, while on top the clasts have usually a diameter of less than 0.01 m. In the case of heavy rains, the talus materials are typically removed downvalley by means of debris flows. Slides are frequent wherever flysch outcrops, i.e. on the lower North-facing portion of the study area, while flows occur mainly

FIG. 4 - A protalus rock glacier near the cemented road downvalley of the Cavera Pass, southern flank of the Valley.

on schists. Flows are usually shallower than slides and are mostly concentrated along fluvial channels. As mentioned above, the presence of several crests within the flow bodies could be the effect of a combination of gravitational and periglacial processes. It is possible that the uppermost and most surface portions of these flows are moved downhill by a sort of frost-creep related to snowmelt and refreezing of the water captured in the clay material present in these bodies. Also some complex landslides have been recognized, like that of the Gias Viridio Superiore, where it seems that an original slide developed into a flow, fragmented in various bodies.

On the upper left side of the Cavera Valley limestones are involved in deep-seated gravitational deformations. Several parallel trenches along the slope and doubled-crests on top were found in this area. They split the rock mass into several blocks that moved and tilted downvalley at various intensities. The area is also highly affected by karstic processes that contribute to the enlargement of the trenches and possibly concur in creating deep-seated planes along which the rocky masses move downvalley. Considering that the valley has been clearly occupied by a glacier that was partly covering these lateral cliffs, the consequent post-glacial rebound could have represented the initial mechanism that triggered the deep-seated processes. Finally, on the geologic map (Malaroda & *alii*, 1970) the area of the deep-seated landslide is bordered downvalley and upvalley by two suspected faults, hidden below Quaternary sediments, which suggest a structural control in the formation of this landform.

SURFACE RUNNING WATER LANDFORMS

The study area can be divided into two portions separated by the water springs between 1600-1800 m where the two Serour and Cavera valleys meet. Above this point most channels are ephemeral, dry for most of the year because of the soluble limestone and dolomite bedrocks. Nevertheless, several running water features have been recognized here. In most cases, they are inactive landforms likely associated to more humid conditions related to a different climate and/or to a greater availability of water melting from the glaciers that occupied these valleys. This is the case of the peat bogs, often associated with glacial counter-slopes. Peat bogs were found along the Cavera Valley and in the glacial cirques tributary to the Serour Valley. Also the Cavera Valley fluvial erosion scarps (fig. 2), sometimes up to 20 m in height, or its flat-shaped small valleys, can be counted as relict landforms likely associated with the deglaciation processes. Still above the 1600-1800 m water springs, there are also some active running water landforms. Their presence suggests that during paroxysmal pluvial events and/or during the snow melt season, some channels experience surface running water able to locally determine the formation of small V-shaped valleys or the occurrence of debris flow in rocky channels. Debris flows are particularly common in the Serour Valley where they flow along rocky channels and they deposit characteristic levees, carve meandering channels on talus fans and finally deposit lobes at the end of the fans.

Below the 1600-1800 m threshold, the main channel that drains the valley, the Cant Torrent, is usually characterized by perennial running water that flows in its own deposits, sometimes cutting them with the formation of small fluvial terraces and related erosional scarps. As can be noted in the A-B profile, the Torrent is characterized by a regular and relatively gentle profile. On the plain, its course is not very regular, often meandering around the mass-flow (mostly debris) fans that characterize the mouth of the lateral tributaries. On these fans, several and partly-overlapping lobes related to these mass flows have been found. They have been considered inactive fans because the frequency of these flows seems to be very low. In fact, lobes are always covered by a more or less thick soil and the oldest lobes are colonized by sparse *Larix decidua L.* trees.

There are water falls along the left tributaries of the Cant Torrent, at the contact between rocks of different erodibility, and in particular between schists, limestones and cavernosi limestones.

A high-slope energy associated with schistose rocks, is the perfect combination for the formation of running water erosive landforms such as badlands, which were always found wherever these two conditions are present. Their formation and evolution has probably very little to do with the arid conditions that are usually essential in other contexts. In fact, the overall climate of the area is quite humid and no relationship between aspect and the badlands was found. In this mountainous area it is likely that badlands are the result of running water and freeze and thawing processes. Several badlands were found North of the Mt. Di Vinadio and SE of the Gias Viridio.

Colluvial deposits are especially frequent near the channels that drain the flysch area. These deposits, made up of fine matrix and sparse blocks with a diameter of 0.1-0.5 m, slowly move downvalley, filling the channel beds.

KARSTIC LANDFORMS

The presence of chemically dissoluble rocks, together with abundant snowfall (low temperatures favor the concentration of CO_2 in the water), makes the upper Arma Valley particularly suitable for karstic surface processes. Karstic dolines are frequently found both in the Serour and Cavera valleys, with a diameter and depth rarely exceeding 20 m and 15 m respectively. The doline bottom is usually flat, partly filled with sediments, soil and grass. Some dolines were also recognized on the glacial deposits made up of limestone and dolomite blocks of the Serour Valley. In this case though, it is likely that these morphologies were formed pre-glacially as bedrock dolines and were then covered by glacial sediments. Also dead ice collapses could have contributed to the formation of these landforms. The ridge that connects Mt. Omo to Gias Cavera is also very rich in karstic phenomena, mostly karrens and other microforms of various sizes, together with sparse dolines, sometimes fused together and aligned in a karstic trench. Similar but more abundant karstic landforms were also found between Cima Fauniera and Punta Parvo, where karrens and other microforms are particularly frequent. Along the Cavera Valley, there are irregularly-shaped karstic depressions, all very large and relatively shallow with a flat bottom. Their origin is uncertain, but glacial and karstic processes might have acted together in their formation. Near the Cavera Pass and west of Mt. Ruissas, there are two doline fields, with dolines much smaller and more abundant than those described in other areas. Both could be related to the dissolution of Triassic evaporitic rocks that outcrop here and there in the Valley. While the Mt. Ruissas dolines are all covered by soil and grass and it is hard to exactly decipher the nature of the bedrock, at the Cavera Pass (fig. 5) the dissolution processes are still very active and the uncovered dolines clearly show the presence of thick levels of gypsum. The process acting here seems to be very rapid and the dolines can be classified as funnel dolines, with diameters usually less than 8 m and depths usually greater than 10 m. The cemented road that connects the Arma Valley to the Grana Valley passes across these dolines and it is clearly threatened by the rapid evolution of these landforms.

Besides karrens and other microforms, and dolines and other karstic depressions, other evidence of karstic phenomena is represented by the dead creeks that can often be found in the SW facing flanks of Mt. Gorfi and in the Cavera Valley bottom. Here, the main draining channel is almost always dry, depending on the season, the intensity and duration of the rainfall. The presence of a sub-surface karstic system is suggested by the occurrence of several water springs at around 1700 m, at least 100 m lower than the Cavera Valley bottom.

ANTHROPOGENIC LANDFORMS

Although there are no permanent settlements, human impact on the morphology of the upper Arma Valley cannot be neglected. The area has been overworked by summer bovines grazing for at least the last century. At the present day, several hundreds of cows spend at least three months a year in the area. Besides shepherd facilities (houses called «Gias» and white roads), the greatest morphological impact of this activity is due to the daily movements of the relatively heavy cows along the slopes. The result is an acceleration of downhill movements of soil and colluvium («grazing creep») and the formation of small terraces (no larger than 50 cm) along the flanks, which represent the cow paths («pieds de vaches») (fig. 2). Indirectly, the grazing activity, together with an urgent need of fuel during the last war, was probably one of the main reasons for the change in vegetation of the area. Almost no trees can be found above the Gias, in areas much lower than the natural tree-line in the Alps. Tree cutting and fires have probably greatly enhanced hillslope erosional processes, although no precise measurements have ever been taken.

FIG. 5 - The aspect of the gypsum landscape with funnel dolines at the Cavera Pass.

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