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EROSION AND TRANSPORT PROCESSES ON BADLANDS SLOPES IN BARONNIES MOUNTAINS (FRENCH SOUTHERN ALPS)

Abstract: LHÉNAFF R., COULMEAU P., LECOMPTE M. & MARRE A., *Erosion and transport processes on badlands slopes in Baronnies Mountains (French Southern Alps)* (IT ISSN 0391-9838, 1993).

Badlands slopes are frequent in Baronnies Mountains. Previous observations with the purpose of selecting study areas for measurements of slope evolution have shown the following process interaction: marls are broken up by frost action in winter and alternate wetting and drying in summer. Little fragments of desintegrated marls are transported on steep slopes by debris falls and grain flows when ice thaws, with possible wind action, and by splash erosion during showers. Marly debris accumulate downslope and form a thick cover in which seeped waters generate pipe flow. Now and then, the roof of a pipe breaks down and from the pipe outlet occurs a mud-flow which carries away marly debris in the talweg. This process brings about instability of the downslope cover of marly debris and generates debris slides, so that fresh marls are again exposed to weathering. As a consequence of these processes, slopes retreat, but is it a downwearing or a backwearing? Happens bedrock erosion in talweg? Field measurements will give answers to these questions.

KEYWORDS: Badlands, Piping, Southern French Alps.

Riassunto: LHÉNAFF R., COULMEAU P., LECOMPTE M. & MARRE A., *Processi di erosione e trasporto su pendii di tipo calanchivo nei monti Baronnies (Alpi Francesi meridionali).* (IT ISSN 0391-9838, 1993).

Pendii di tipo calanchivo sono frequenti nei M. Baronnies. Osservazioni preliminari, eseguite allo scopo di individuare aree per studi quantitativi sull'evoluzione dei versanti, hanno messo in evidenza le seguenti interazioni: le marne sono frammentate dall'azione del gelo durante l'Inverno e dall'alternanza di periodi secchi e umidi durante l'Estate. I piccoli frammenti originati dalla disgregazione delle marne sono trasportati su pendii acclivi per gravità e flusso granulare quando si scioglie il ghiaccio, con il possibile contributo del vento, e per erosione da impatto durante i rovesci. Il detrito di marne si accumula alla base del pendio a formare una spessa coltre nella quale, il lento flusso dell'acqua genera fenomeni di soffusione. L'evoluzione di questo fenomeno porta alla formazione di colate di fango che trasportano il detrito marnoso verso il fondovalle. Il processo induce una certa instabilità nella parte basale della copertura detritica, causando frane superficiali, sicché marne non alterate sono nuovamente esposte alla degradazione. In conseguenza a questi processi il versante arretra, ma si tratta di un approfondimento o di un arretramento? Avviene erosione del sustrato lungo il fondovalle? Misure di campagna forniranno risposte a queste domande.

TERMINI CHIAVE: Calanchi, Soffusione, Alpi Francesi meridionali.

Numerous gullies have developed in the marls of Southern Baronnies mountains (DUMAS & *alii*, 1987). They incise graded slopes as well as glacis with which they strongly contrast by their widely, and sometimes totally, bare aspect. Occasionally, small roughly parallel gullies striate the slope; more often, gullies organized into a more or less ramified branching network generate a landscape of badlands.

However, badlands have a restricted occurence in the landscape: they are confined to some slopes and they do not exceed some tens to some hundreds of meters widthwise and one to some tens of meters in height. More spacious areas have been gullied in historical times, but only a few of badlands are now active. The bigest ones present gullies digged from one to ten meters below the surface of the slope; according to lithology, their sides are inclined from 35 to 43°, their longitudinal profile is concave with an average gradient from 21 to 24°, whereas the divides are inclined from 22 to 32°.

The authors of this note have set up a programme in order to carry out a study of these badlands in 1988. The examination of numerous gullies in marls that are more or less clayey and more or less armed with layers of marly-limestones (Oxfordian «*Terres noires*», Valanginian, Gargasian and Cenomanian marls), in various tectonic contexts and in diverse exposures, led to a selection of seven sites where graduated markers could be placed in order to measure the evolution of the interfluves and the gullies' bottoms (fig. 1A and 1B). The results obtained since 1988

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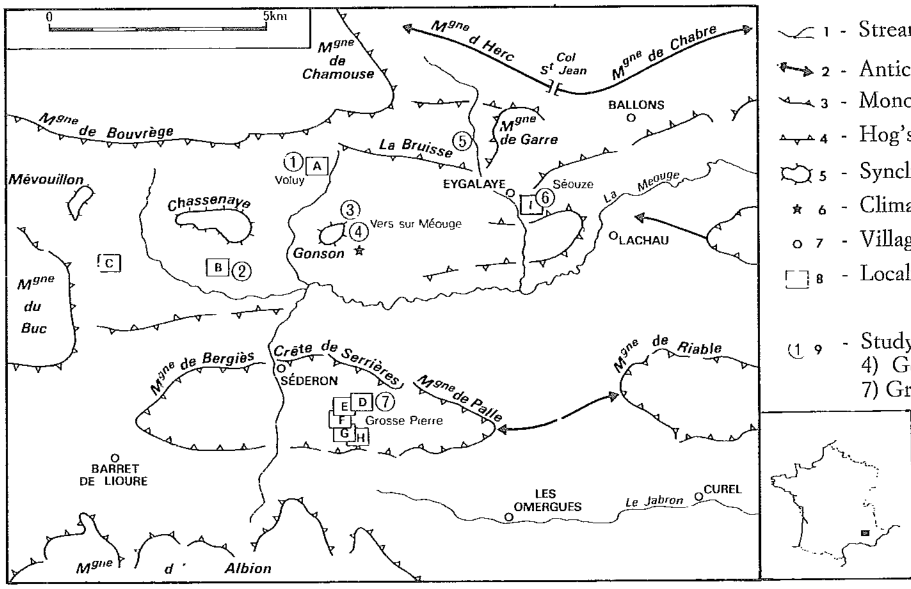
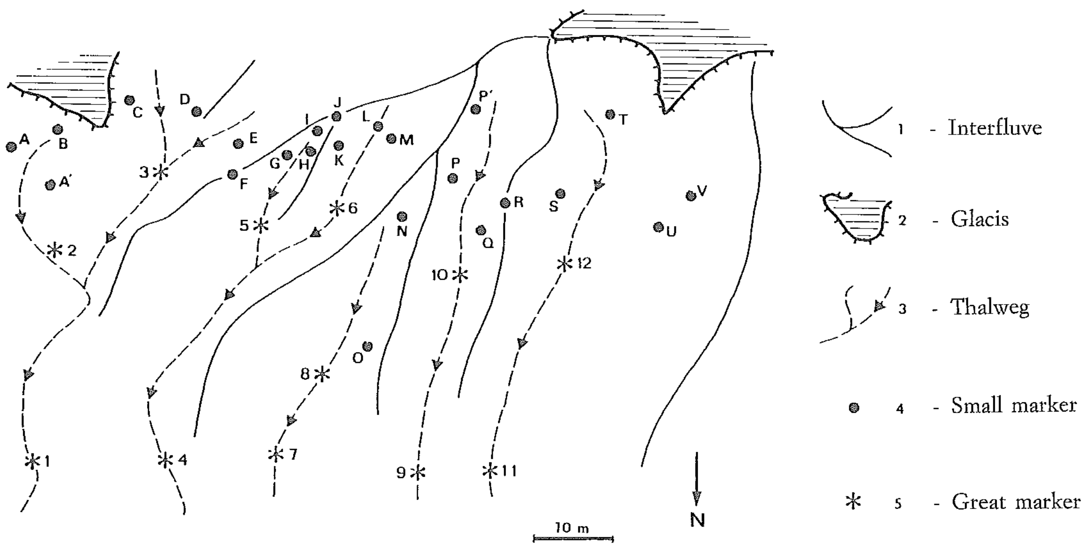


FIG. 1 - A: Sketch map of study area.



Vertical extent: 39 m

B: Sketch map of study area of Séouze Pass.

can not be significant over such a short period. On the other hand, from now on, the first visual observations suggest a way of evolution of these badlands which can not be explained only by the overland flow.

Indeed, we have been surprised by the thickness of the marly debris which are covering the bottom of the gullies and the inferior part of their sides forming a very permeable mantle in which waters infiltrate, limiting somewhat the overland flow.

I - GENESIS AND TRANSPORT PROCESSES OF MARLY DEBRIS IN GULLIES.

The origin of material and the process of their transport to the bottom of the gullies are constituing the first stages of the gullies' evolution.

1. THE GENESIS OF MARLY DEBRIS.

It can be the result of two processes, frost and thaw cycles in winter and wetting and drying cycles in summer (COULMEAU, in CEMAGREF, 1987; FANTHOU & MARQUET, 1987; DESCROIX, 1985). If the second process is probably playing a role, we have not been able to estimate its efficiency for the moment; actually, some shrinkage cracks can be observed in summer, particularly in marl rich in smectites (Oxfordian marls notably); they generate heavy tensions in the superficial part of the marl, but this process has still to be studied.

On the contrary, the frost/thaw cycles are of great efficiency: on December, 9th 1988, by sunny weather, when the temperatures at night went down to $-6°C$ (according to the weather station set in the commune of Vers sur Méouge, at an altitude of about 841 m, NW of the hamlet of Pré Rond), we have noticed that, in badlands around

Voluy, the rock was completely desintegrated on the first centimeters (2 to 5 cm); some ice was gathering particles together, and was exposing to thaw small marlflakes of a size inferior or equal to 1/2 cm. More deeply, ice was coming into the fissures and was pushing them away by cutting up centimetric to pluricentimetric fragments, whose size was increasing with depth. The rock was frozen up to 20 cm from the soil surface. Resulting from this, a mantle of desintegrated marl of variable thickness, according to the more or less important compactness of the rock, which does not exceed about 20 cm and which controls the infiltration water.

This process due to the frost action is frequent under the sunny climate of the southern Baronnies mountains, even at low altitudes, because of a high rate of daily frost/thaw cycles. From 80 to 90 days in average under shelter over the three years of measurements at Vers sur Méouge's station, staggering from November to April. Moreover, it would be advisable to refine these datas taking into account the topoclimates. Actually, there are very important temperature contrasts by clear weather between the bottoms of the valleys and the slopes. The differences concerning the minima can reach 7 to 8 °C by steady weather on about a hundred meters of altitude variance. Concerning the maxima, the differencies bound above all to unequal periods of sunshine are much less but enough to allow the persistance of frost all day long in winter in the less favoured areas (*ubacs* and pronounced holes). Marl is thus pulverized into thin fragments so that water can easily infiltrate into the slightest fissures of the rock which is desintegrated when freezing conditions occur. The action of frost can progress even faster since the mobilization of marly debris by ablation process is quicker.

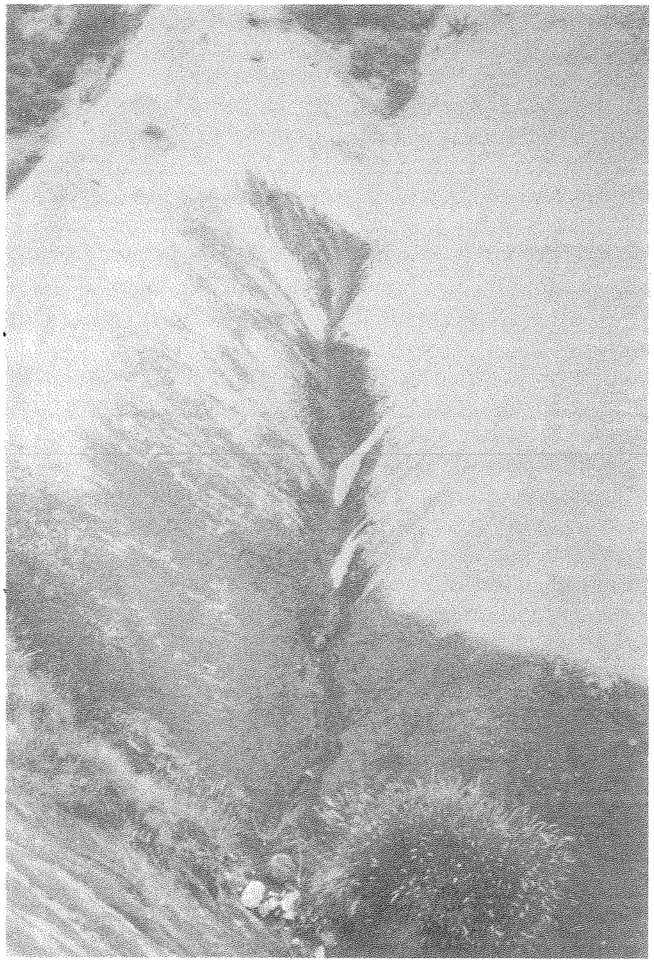


FIG. 2 - Gully cutting the Chassenaye glacis. Slopes of the gully are dried up superficially, except in the inferior part of the slope which remains in shadow, like the bottom of the gully where seeped water is more abundant. From slopes, thawed and dried up at sunshine, fine marly debris are going down by gravity and channeled in rills by grain flows. These grain flows are more clear than the mantle of debris still wet to which they are superposed. Take notice of the presence in the axis of main gully of coarse debris reworked from the heterometric detrital cover of a glacis, and clumps of «*bauche*» (*Calamagrostis argentea*). (Site B).

2 - THE TRANSPORT PROCESS OF MARLY DEBRIS ON THE INTERFLUVES.

The slope of gullies' sides is steep, about 35 to 45°; therefore, the gravitational processes are very active. At Voluy's station, we have witnessed the fall of debris at time of thaw in the morning. At the top of the slope, where the detrital mantle is thin and discontinuous, pipkrakes had lifted small amounts of marlflakes which during the melting were crumbling, rolling and desintegrating on the slope. Their light weight did not allow them to go a lot further than about ten centimeters at the very most. Below, down the slope, the detrital mantle was getting thicker, the partial thaw of the superficial part of the debris was tipping micro-screes of thin marly debris or small masses of debris still bound by ice, out of micro-cornices high of 2 to 5 cm and spaced from one to a few decimeters; the thinest were stabilizing on the still steep slope immediately downhill. This general fall of micro-talus was occuring almost nearly constantly during the morning hours of thaw but with sudden accelerations caused by gusts of wind (*mistral*) alternating with short breaks. During the strongest blasts of wind, the whole surface of the slope was getting covered by a thin coat of tinking debris, whereas the thinest particles were lifted and blown off by wind. At these moments, the talus temporarily stabilized down the micro-cornices were mobilized once more under the impact of the moving micro-talus.

Some rills slightly incised in the slope (a maximum of some centimeters) were also collecting thin moving marly debris. They were accumulating there, reaching a thickness of several centimeters until they were unstable: then, taking advantage of an additional supply, the whole mass of these debris was moving constituing a grainflow, making its way along on about ten centimeters before stabilizing, describing a tongue edged with centimetric levees and ended by a convex lobe (fig. 2).

The debris were thus gradually falling downwards the bottom of the slope where they were feeding accumulation cones which were visibly getting thicker when piling up, so that after a while, the whole bottom ot the slope was covered by a mantle of marly debris thick of 20 to 30 cm. As far as the water of the brook situated at the foot of the slope was frozen (at least superficially, water still flowing under the ice), the small cones formed by marly debris were going up and progressing on the ice. When this ice was melting, the brook was saping the cones, making them crumble in waves and was progressively evacuating the debris.

This winter process that we could observe in many other gullies at the same season, is completed in summer and above all in automn and spring by splash erosion of great efficiency because of the importance of showers beating down on badlands. At Séouze's station, equipped in 1988, the graduations painted on the markers were no more visible at the end of spring (May, June) because of the splash up to 30 or 40 cm above the soil. Actually, we know that ablation by pluvial erosion is more important when the slope gets steeper and this process is proportional. The value of the measured slopes in badlands let us imagine the great efficiency of this process which contributes to the mobilization of the thinest marly particles and to the filling up of the slightly incised channels on the slopes of the gullies.

The result of these two first processes is a general fall of the marly debris, without any intervention of the overland flow, with the two following consequences: the materials issued from the desintegration of the rock by purely mechanical processes, frost action and secondarily water action, are evacuating as fast as they are formed at the top of the slopes, the rock is simultaneously laid bare; this allows the continuation of the weathering process. Moreover, the foot of the slopes and the bottom of the rills and gullies are covered by a marly debris' mantle which can reach a thickness of several decimeters in the thalwegs of the deepiest gullies. This tends to protect the rock from weathering. We must nor forget that actually, the frost edge does not reach the depth of ten centimeters in a thin material exposed to the sunshine at the weather station of Vers sur Méouge (DUMAS & *alii*, 1987).

II - THE ABLATION PROCESS AT THE BOTTOM OF THE GULLIES.

The debris mantle which covers the foot of the slopes and the bottom of the gullies is very porous. Waters are seeping up to the level of the fresh rock which, because of its compactness, constitutes a watertight surface. Thus, a hypodermic flow is generated and it tends to concentrate in line with the rills and gullies. This flow has picked up our attention in the landscape in spring 1988 since one or two days after the rain, the material were drying out and turning to a pale grey shade, while the thalweg of the rills and gullies was keeping the dark grey colour of waterlogged materials. This waterlogging can express capillary rising through the muddy and clayey component of these materials from the subsurface drainage or an intersticial circulation because of an excess of water in the drainage network.

This concentrated subsurface drainage infers an ablation of thin particles over the base of the detrital mantle and progressively digs a pipe. As soon as this pipe is widening, waters are running faster and faster and are getting a rising dragging force susceptible of mobilizing marly debris of greater dimensions, so that the pipe is gauging itself and can reach a diameter of about ten to twenty centimeters.

When the pipe reaches a critical size, its roof easily collapses (fig. 3). This phenomenon has been observed in April 1988, when one of us walked on it in one of the gullies near Séouze. The collapsing materials mixed with water were forming a viscous bulk which was suddenly strong enough to destabilize, immediately downhill from the point where the collapse occured, the walls of the pipe whose roof was collapsing in turn. So, within a few decimeters, a mudflow was «sweeping» the bottom of the gully, dragging along materials which were crumbling from the edges. This mudflow was slowly moving forward and was caught

FIG. 3 - Rills on the side of a gully (Foot of the Buc mountain). Dark grey colour of the bottom of rills, filled with fine debris of marl, points out waterlogged materials by underflow which digs out pipes (see the outlet of a pipe lateraly to the main rill). (Site C).

up with clear waters which were going out of the pipe at the initial breaking point, transforming the mudflow into a mud stream powerfull enough to clear away the materials in line with the gully.

At the gully's outlet, about ten meters downhill from the pipe initial break point, the mud stream has spread out on a small alluvial cone built during the previous flows. Then, the water level has slowly lowered and simultaneously waters were becoming clearer. Within a few minutes, the alluvial cone had raised up of 4 to 5 cm. The waters of the stream which runs at the foot of the ravined slope of Séouze were saping afterwards the distal part of the cone.

This process is not by far an exceptional event. During the same period, we happened to see numerous thalwegs in which a «gorge» had been dug up to the fresh rock in the soft materials of the gully's bottom; this gorge was (on a variable distance) going uphill and was ending up with a small amphitheater at the pipe outlet (fig. 4). This same process is more complicated when it is occuring in the rills which incise the sides of the gullies: the materials

FIG. 4 - Rill cutting gully side of Grosse Pierre (anticlinal depression of Sederon). Roof of pipes have broken down and «gorges» are cutted as far as fresh marls. Instability of sides of these gorges is identified by cracks. (Site D).

which had accumulated there had been evacuated by mudflows which had not always reached the base of the slope, ending then in the middle of the slope by a convex lobe. The water supply was not enough in those little rills, so that the rising load of the mudflow was stopping its way downhill.

It is worth noting that certain gullies going up to a cornice made of fresh coherent rock or to edge of a quaternary glacis whose surface is lined by a heterometric detritic cover, some coarse debris, or even blocks, can be found in the channel. They may have been thrown by gravity from the cornice, or after an undermining process in the soft materials which were gluing them together. They may also have slid down on the sides of the gullies where some of them are still staying in precarious equilibrium. The mudflows and mud streams that are starting in those gullies can, according to our observations, carry these coarse debris along. But this ability is unequal. The mud streams have a limited ability; thus, during the mud stream observed in a gully of Séouze in April 1988 (cf. above), limestone debris reaching 6 to 8 cm have moved from the area where the flow had started to the alluvial cone; but bigger blocks (up to 40 cm of cross section) found in the uphill part of the gully have not moved. In that case, a fast decrease in the size of the debris from uphill, where a big limestone layer is situated is to be notice downhill; visibly, the biggest debris are transported only after an undermining process of their substratum and they are jolting now and then. Besides they are ensily jamming against the slightest obstacle narrowing the channels.

The mudflows, on the contrary, do not seem to be so limited and can sweep away bigger blocks. In the gullies breaking up to slope of Serrière's ridge, close to La Mourier farmhouse, in the anticlinal depression of Sederon, some former mudflows which can be spotted easily have gone down to the bottom of the gullies, carrying along limestone blocks, and they have stopped there, obstructing them.

Thus, mudflows and mud streams closely linked to subsurface drainage in the materials covering the thalwegs seem to be the two dominating factors of the process of debris' evacuation in small gullies. On these very porous materials, the actual overland flow seems on the contrary to have a limited effect; it has a temporary impact on the rocky bottom of the gully, once this one is cleaned by the mudflow, and it evacuates then the materials which crumble in waves from the unstable walls of the «gorges». This process is limited in time since the bottom of the gully is filling in very quickly after a sliding of the debris mantle from the slopes of the gully.

III - MASS MOVEMENTS ACTIVATED BY ABLATION AT THE BOTTOM OF GULLIES.

The digging within a few minutes of a gorge in the materials covering the bottom of the gullies makes the foot abutment of the colluvial cover of the slope disappear. The resulting instability leads to more or less generalized mass movements.

Those show themselves firstly by curved fissures affecting the debris mantle. They can even appear before the formation of the gorge, by an extraction linked to the widening of the pipe. These fissures are developping more particularly in the windings' cavities of the gullies. Soon, they are accompanied with small thrustfaults between the bulks which they demarcate, showing the beginning of a sliding, and generating new fissures uphill, according to the principle of the retrogressive propagation of landslides. As far as the water is running in the gully, even intermittently, and that the sliding is slow enough, the gorge can stay open, the materials beeing progressively evacuated; but it is getting again obstructed when a whole mass of materials is sliding to the bottom of the gully.

These mass movements can reach a certain extent and clean a whole slope of its debris' mantle, laying the marl bare again. This is more frequent where, because of the windings of the gully, waters are undermining a concave bank. The sliding of a whole colluvial mantle is pushing the waters away towards the other bank which saped in turn, is affected by the same process. This saping process is even more efficient when a rocky promontory situated between two gullies falls back down on the brook running along the foot of the ravined slope.

All these debris' movements are depending on superficial mass movements. But deep sliding affecting the rock in place, when it is fissured, can also occur. We could observe many examples of this process, notably in Sederon's depression and at the base of Buc's mountain (side of the gully developped under the «*Grotte de l'Ours*»). They are located on gullies' slopes touching the glacis. On the surface of the glacis, water is seeping in the detrital cover and coming in the marls thanks to discontinuity surfaces (bedding planes straighten by tectonic breaks, cracks and various fissures). Considering the important slope angle of the gullies' sides, a slight overload in water of the marls is enough to the failure of the shearing off resistance. The destabilized mass is sliding, the scarps of the glacis with its detrital mantle and its vegetation can be found several meters below (fig. 5). In the case of a slump, a slope in opposite direction is hampering the water flow. Waters are accumulating and penetrating along the sliding surface, favouring the restart of the slid mass which is progressively evacuated. A curved recess is then remaining, constituing the origin of a new gully.

IV - DIRECTION OF THE EVOLUTION: THE ROLE OF LITHOLOGY, SLOPES AND HYDROLOGY.

If the describes processes help to understand the wearing away of the gullies' slopes, they do not prove the reality of their cutting role in the rock in place. Actually, ablation only concerns soft materials and it does not affect a fresh rock. In order to cut in the fresh rock, it must beforehand be subjected to a desintegration process which,

FIG. 5 - Side of Grosse Pierre gully. Adjacent gullies of the Pierre Grosse gully are developping below a glacis whose surface is lined by a heterometric detritic cover including limestone blocks. This glacis is covered by a herbaceous vegetation. The incision of rills and gullies destabilized the edge of the glacis, a piece of which slipped with its detritic cover and vegetation. (Site H).

in the study area, seems principally to be due to frost action (cf. above).

For this, the rock must be bared or only recovered by a thin mantle of debris, not sufficient to deaden the night frost edge. The eventuallity of the cutting of the gullies implies then the frost action on their rocky bottom. It consequently depends on the balance between the interfluves' ablation and the evacuation by the trenches of the gullies of the debris which are obstructing them. Then, there are two possibilities:

1 - In the slope basins of great dimensions, the flows can be enough to clean regularly the bottom of the gullies and expose it to frost (Laragne and Digne areas: CEMAGREF, 1987; BUFALO & *alii*, 1988; OLIVRY, 1988).

2 - In smaller basins or slopes, like the ones studied here, if the debris production is important and is faster than the evacuation speed, the bottoms of the gullies are most of the time covered and no cutting is possible. If,

on the contrary, the evacuation is faster, the bottom of the gullies is more frequently bared and a cutting is then possible. According to the case, the gullying can be active or the gullies can be only inherited and beeing regulated.

It is so necessary to analyse the behaviour of the varibles controlling the production of debris and their evacuation. The first one depends on the resistance of the rock which is notably determined by its microfissuration and its clayey composition; observations and measurements made *in situ* can provide a total approach of the behaviour of the rock, completing laboratory studies.

The second one depends on slopes combinations in relation with hydrography. On steep gullies, the slopes are rapidly cleaned of their debris (cf. above) which are obstructing the channels. Moreover, the mobility of the support is hampering the installation of a perennial vegetation. The channels are thus preserved from frost action and their cutting is slowed to a steep slope running lenghtways. The preservation of the latter supposes an active emissary stream excessively powerful to sap its banks and eventually to cut its bed.

In the frequent case where the emissary stream is running slowly or intermittently, the gullies get obstructed by debris, besides, they can also be stabilized by coarse materials coming down from a steep slope. They are constituing then loose stones beds in the cavities of the gullies. The erosion of the gullies' interfluves is going on as long as they are regularly cleaned of their debris. They are wearing down thus until the diminution of their slopes allows the stabilization of their debris and the installation of a hardy vegetation.

This one firstly settles the bottom of the gullies which is more humid, with the *bauche* (*Calamagrostis argentea*), then the rounded summit of the interfluves by spreading the surrounding species. The slope is evolving towards a kind of equilibrium undulating in «*ronde-bosse*», remarkably fixed by forestation. Finally, the middle part of the gullies' sides, which is steeper, stays bare for a long time and exposed to an erosion restart, overall on a rock very fragile and not armed by hard layers. Besides, the *bauche* is modifying the flow of heavy showers in the channels. Water is flowing around its clumps and if other plants do not contribute to the protection of the soil, their roots are laid bare laterally and from underneath and are finally carried away with a mass of debris. Thus, the *bauche* can temporarly ease the concentration of the overland flow, while hampering perhaps the formation of pipes by its root hair.

Exceptional climatic events, or a restart of a continuous flow at the foot of the slope, can compromise the equilibrium of the slope. Thus, at the pass of Séouze, a watertrickle has been pushed away against the gullied slope by a huge sliding affecting the opposite slope. It has slightly incised the base of this slope, provoking a strong restart of headwards erosion in the fragile gargasian marls. Yet the affected slopes in spite of their steepness, are covered by a continuous sturdy vegetation whose dense network is spreading over the inferior parts, while they are beeing scoured (fig. 6).

The flow of the stream is sufficient to evacuate the overload of gelifracts going through the gullies' channels and which are coming from the interfluves, which are getting bare, subjected to an intense frost action. Nevertheless, it does not seem to be sufficient to unblock the bottom of these channels on a long term basis and to expose them by the way to frost. A new regulation phase of the gullies should thus occur by pulling down the interfluves on the new channels network, engraved somewhat below the previous one.

This type of dynamics is also easily visible on the slope of Voluy's station whose divides have gone backwards of 2,5 cm within two years. Now, this slope which is about 30 m long, is completely isolated from uphill; this is limit-

FIG. 6 - Badlands of the pass of Séouze. The slope, covered by a continuous sturdy vegetation was incised at the base by a small stream pushed away against this side by a slide affecting the opposite side. This incision has initiated a headwards erosion in the fragile gargasian marls. (Site I).

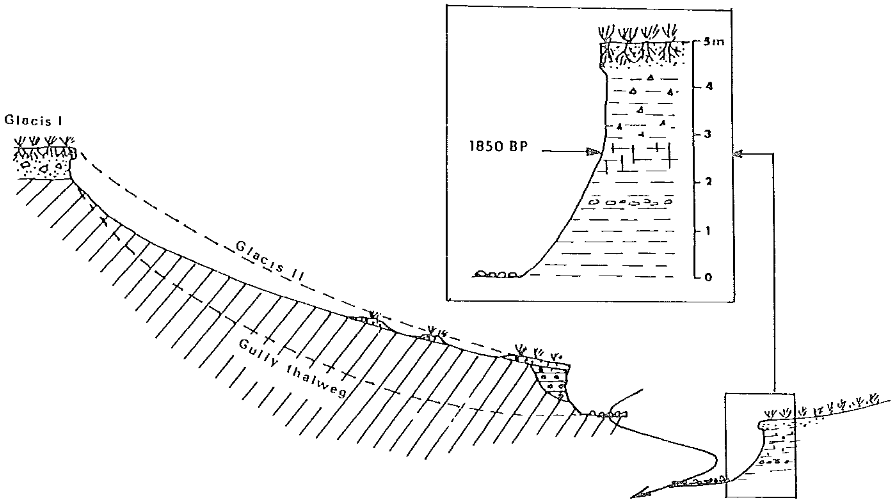


FIG. 7 - Section of the terrace linked with low glacis broken up by badlands on the southern slope of the Chassenaye mound.

ing its proper *impluvium*. It becomes so obvious that its fast evolution is only due to the action of the stream running along the base. For a big part, the evolution of the gullied slopes is depending on the relative strenght of their proper flow and of the emissary stream, and so the respective development of these slopes and of their hydrographical basin.

It is certain that, at least, about ten years of measurements would be necessary to determine which one of these evolutive tendancies (stabilization or active cutting) is prevailing in each study station. But the measurements will have to be, as far as possible, controlled before beeing extrapolated in the long run. In this respect, it is worth noting that the station situated on the southern slope of the Chassenaye mound, badlands are breaking up low glacis linked with a small terrace perched 5 m above the principal thalweg (fig. 7). At a dead angle where the terrace material is thiner, we have discovered charcoal dating back to 1850 BP (EVIN dating, Lyon). There has been, thus, a major historical cutting here, certainly bound to a high demographic pressure. But is this cutting still continuing nowadays?

CONCLUSION

Observations made in the southern Baronnies must be linked to those of SCHUMM (1956, 1964) in the United States, to those of BRYAN & *alii* (1978), of HODGES & BRYAN (1982) and of GERITS & *alii* (1987) in the semi-arid regions of Alberta (Canada) and of the South East of Spain, to those of GUASPARRI (1978) and VITTORINI (1977) in Italy, and also to the observations of HARVEY (1987) in the North West region of England. They are showing evidence, as well as the lattest, to a seasonal rythm of the morphogenesis which combines a huge number of processes: frost action on the marl and the evacuation of the debris by gravitational movements and grain flow during the cold season, ending at a filling up of the channels and of the bottom of the gullies; pluvial erosion, subsurface drainage, mudflows and mud streams during showers in autumn, spring and summer; mass movements generated by the clearing away of the materials accumulated in the gullies and scouring the slopes of their debris' mantle, so that the rock laid bare is another time exposed to frost action. Thus, close interactions between erosion linked to water and mass movements appear.

The combination of this processes according to the fragility of the rock, to the steepness of the slope and glacis, to their extension comparatively to this of the hydrographical network could explain, as it has been just suggested, the orientation of erosive dynamics and of the morphogenesis to an intensification or, on the contrary, to a certain stabilization.

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