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QUATERNARY EVOLUTION OF THE SERRA DO MARÃO AND ITS CONSEQUENCES IN THE PRESENT DYNAMICS

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RESUMO

Situada no Norte de Portugal, a Serra do Marão faz parte de um conjunto orográfico que separa a área montanhosa de Entre Douro e Minho da área planáltica de Trás-os-Montes. As características do tempo nas épocas mais frias do Quaternário foram muito importantes no que respeita aos processos morfogenéticos, que actuaram sobre as suas vertentes, criando depósitos que então as regularizaram e que hoje condicionam a dinâmica actual.

Palavras chave: Quaternário, depósitos periglaciares, dinâmica de vertentes, ravinas, deslizamentos.

ABSTRACT

Localised in the north of Portugal, Serra do Marão is part of a mountainous range that separates the mountains of Entre Douro e Minho from the plateaux of Trás-os-Montes. Weather characteristics of Quaternary coldest times were very important in terms of morphogenetic processes, which acted on its slopes, creating deposits that, nowadays, are conditioning the present dynamics.

Key words: Quaternary, periglacial deposits, slope dynamics, gullies, landslides.

RÉSUMÉ

Située dans le nord du Portugal, la Serra do Marão fait partie de l'ensemble orographique qui sépare les hauteurs de l'Entre Douro et Minho des plateaux du Trás-os-Montes. Les caractéristiques des temps froids du Quaternaire ont été très importantes en ce qui concerne les processus morphogénétiques existants sur les versants, aujourd'hui conditionnant la dynamique actuelle.

Mots clé: Quaternaire, dépôts périglaciaires, dynamique de versants, ravins, glissements.

Introduction

The Serra do Marão (as it is called locally) is a mountainous massif situated in the North of Portugal formed mainly of Palaeozoic structures. It is strongly marked by the Hercynian orogeny, which is responsible for a large number of faults and fractures. Neo-tectonic phenomena, which are quite common in northern Portugal, influenced this structure and created new faults which made the morphostructure of this area even more complex.

The Marão is part of a mountainous range with a north-south direction and is therefore parallel to the Atlantic coast, which explains the heavy rainfall on the slopes turned to the west in contrast to a much lower precipitation on the slopes facing the east.

During the Quaternary the action of the cold weather was very important in terms of the morphogenetic processes that acted on the slopes. On the one hand, the deposits regularised the slopes; on the other, they conditioned the present dynamics, as will be demonstrated in this paper.

Geomorphologic features

The Serra do Marão is one of the most impressive topographic structures that can be singled out in the vast orographic range that separates the northwest of Portugal from the plateaux of Trás-os-Montes (Fig.1). It is one of a series of mountain ranges that are traditionally seen as a whole: the mountainous range that separates Minho from Trás-os-Montes, the two most characteristic regions in northern Portugal. Starting from the frontier of Galicia and moving southwards several mountain ranges are to be found: Peneda (1373 m), Gerês (1300 m), Larouco (1527 m), Cabreira (1262 m), Alvão (1285 m) and Marão (1416 m). The latter borders on the Douro valley. Still another mountain range can be added to the list – Montemuro (1381 m) but it lies south of the river Douro. The highest points in northern Portugal are to be found in this range.

This group of mountain ranges and elevated plateaux constitute (not only on account of their height, but also of their bulk) an obstacle which determines a more or less rapid transformation in the Atlantic character of the landscapes; because of that it is commonly termed condensation barrier. The Marão is situated in one of the areas of the country with the heaviest rainfall and is simultaneously the one that offers the strongest contrasts in terms of the distribution of temperature. These two characteristics – heavy rainfall and large temperature range – make it unique among the different/various Portuguese mountain ranges.

The action of tectonics is fundamental to the understanding of the formation of the Marão. The Hercynian orogeny was the main factor responsible for the uplift and folding of the metasediments of the Pre-Ordovician, the Ordovician and the Silurian (Fig. 2). It was also during this orogeny that the intrusion of the different granitic rocks, which are found on the periphery of the mountain range, took place. These orogenic movements explain many of the fractures and faults that are still today important features in the morphology of the area.

In spite of the importance of the Hercynian movements in this mountain range, there is no doubt that the present-day relief forms are related with the alpine orogeny. This may have had a basically epeirogenetic action which contributed to the uplift both of the mountain ranges of the Marão and the Alvão. Consequently, these two mountain ranges function as

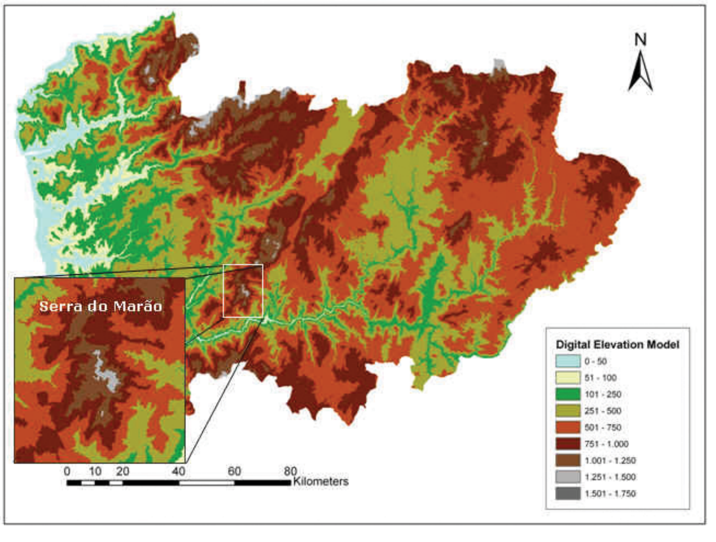

Fig.1 - Localisation of the Serra do Marão.

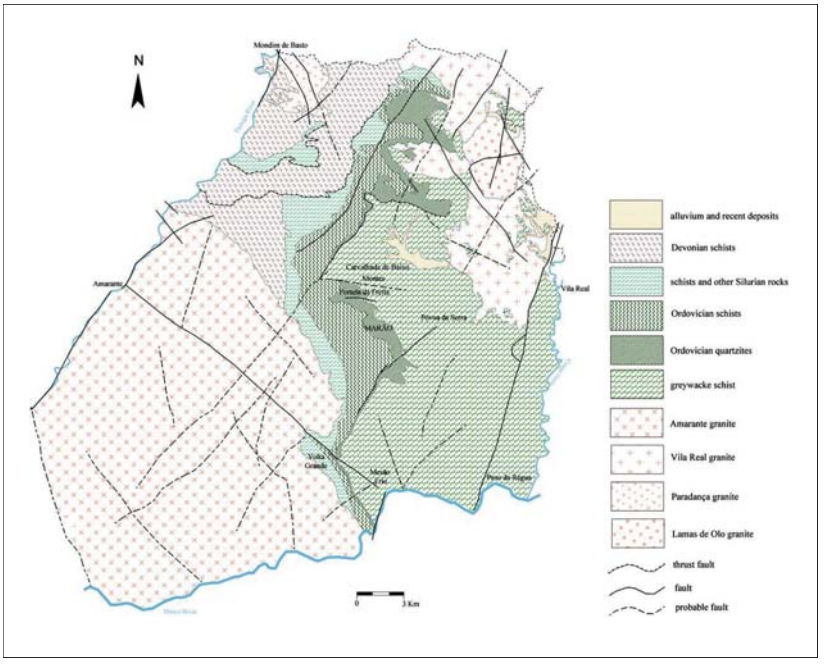

Fig. 2 – Geological sketch map of the Serra do Marão.

a horst both in relation to the group of tectonic depressions where the river Corgo flows and also to the graben of the river Tâmega. In fact, the effects of the orogeny are still to be felt and the neo-tectonics goes on acting on the present relief forms (Pedrosa, A., 1993, 1994). That is, tectonic action continues to transform them; thus it is a permanent risk that must be taken into account, notably when building infrastructures such as roads, railways, dams and even houses.

Lithology is another important science that can explain some relief forms that are found in the Marão. The different granitic rocks, for example, are responsible for the great number of alveoli that exist there. No matter what their form and size are or the height at which they may be found, they are undoubtedly related to the different types of granite. They also account for a series of microforms such as tors, block chaos, "vascas", "caneluras" which are clearly connected with the physical, chemical and mineralogical characteristics of these rocks.

The quartzite is a type of rock that has a special importance in the morphology of the Marão (Pedrosa, 1993) in spite of being quite often found in the upper parts of its slopes. They are almost always found halfway up the slopes, which can be explained by the action of tectonics. Nevertheless, although this type of quartzite outcropping is more exposed to erosive processes due to its situation, it undoubtedly contributes to the fact that though the inclination of the slopes is always steep the erosion acts more slowly.

In the schist areas there are several depressions of tectonic origin, but the fundamental characteristic is in this case the regulation of the slopes by deposits related to morphogenetic processes which took place in the recent Quaternary and which were caused by the freeze/thaw action. As such, they correspond to colder climates, which are responsible for a very rapid evolution of the slopes (Photo1).

Origin of the deposits

The effects of the different morphogenetic processes which happened in the past can only be inferred from vestiges that are still observable nowadays: the slope deposits. It is not always easy to interpret them. Many have been destroyed, thus proving the existence of a powerful morphogenetic action which is related to colder climates in the course of the Quaternary.

The deposits which were found are important evidence of the evolution of the slopes, not only at a high altitude (Pedrosa, A.,1994a) but also in areas at low altitude in places near the coast (Pedrosa, A.,1989, 1994c; Rebelo, F. & Pedrosa, A.,1993).

Photo 1 - Schist slope regularised by Quaternary deposits.

The climate must then have been much more unstable than it is now with temperatures that made gelifraction in situ possible, above all in higher places where vegetation was scarce or non-existent.

The material must have been made transported along the slopes by gelifluction associated with a cold, dry climate (Daveau, S., 1973; Rebelo, F. 1986; Cordeiro, A. R., 1986a; Pedrosa, A., 1993, 1994a); it is possible to observe the existence of coiffes (Valadas, B., 1984). Nevertheless, the above mentioned movement must not have been carried out only by the action of ice but also by means of more or less generalised solifluctions or even by debris flows and sheet floods. The existence of palaeogullies may lead to the conclusion that there were larger quantities of water, at least during part of the year; this would make possible the formation of gullies in the materials accumulated at the foot of the slopes by other morphogenetic processes.

Thus, the accumulation of materials along the slopes would have been necessary for the formation of such palaeogullies but the morphogenetic processes could have been different. Absolutely necessary for their formation was, however, the alternation of drier, colder periods with others which were damper and hypothetically less cold (Pedrosa, A.,1993).

The palaeosols found seem to indicate climatic fluctuations during which the existence of colder climates, hypothetically drier, contrasted with periods of higher biostasis which might mean that there were higher quantities of rainfall and/or milder temperatures.

The oldest deposit found in the Marão is prior to 28000 BP; it was possible to find a palaeosol that fossilises it dating back to 28440 +/- 490 BP. It may correspond to the so called Würm II (Pedrosa, A.,1993). It is a deposit with heterometric characteristics, probably the result of the deposition of material transported by debris flow, although the possibility of its having resulted from glacial action is not to be put aside (Fig. 3).

After the deposition of the materials that form that deposit, the climate may have evolved; it may have become moister and the temperatures milder. This may have been responsible for the pedogenesis and the appearance of the above mentioned paleosoil. The climate must have become slightly warmer in comparison with the prior phase; this fact gave way to the pedogenesis and the colonisation of the slopes by vegetation, making them reach a dynamic equilibrium.

Later on the climate must have turned cooler, which led to the formation of new slope deposits which fossilised the palaeosoil. Due to the disappearance of the vegetation, the slopes must have been more exposed to the action of fragmentation by the action of ice. The analysis of the deposits allows the observer to conclude that the morphogenetic processes must have been not only mass movements of the solifluction type but also debris flows. And again comes a period of pedogenesis which dates back to around 21340 +/- 350 BP.

The next phase corresponds to the influence of the "Upper Würmian Full Glaciation" (Pleniglaciar superior Würmiano), the last glacial stage of the Pleistocene. This phase was extremely important in the evolution of the slopes in northern Portugal. In fact, there is a large number of slope deposits whose origin is to be found in this period (Photo 2). The climate must have been cold and relatively dry because it is responsible for the gelifraction of the rocks (Daveau, S., 1973; Rebelo, F., 1986; Cordeiro, A. R.,1986b; Rebelo, F., & Pedrosa, A., 1993).

The analysis of these deposits demonstrated that the main process of transportation along the slopes was the action of the ice – gelifluxion, further proved by the existence of coiffes (Valadas, 1984). Other processes such as the action of gravity are, however, not to be ignored. The study of the stratified slope deposits does not exclude the possibility of other movements such as debris flows at least in some parts of the slopes.

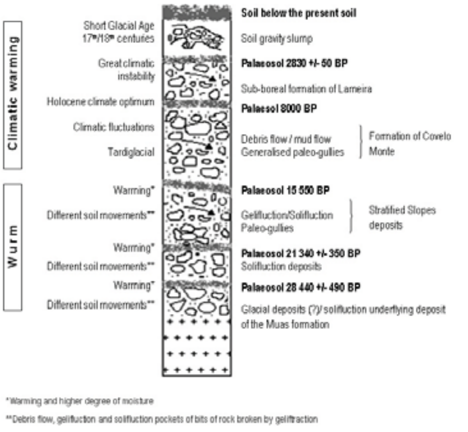

Fig. 3 – Stratigraphic column of the superficial formations in the area of the Serra do Marão.

Photo 2 – Stratified slope deposit near Campanhó, where it is possible to observe paleogullies.

With the beginning of the Tardiglacial (Cordeiro, A. R.,1990) the climate must have become warmer and the rainfall heavier, which must have altered the morphogenetic processes; now the most common are those connected with the runoff and fluvial dynamics instead of those related to the action of the ice.

Parallel to the significant movement of materials which occurred in this period there was an extensive movement of materials resulting from prior morphogenetic processes transported more by fluvial action than by the action of the ice and solifluctions in periods of thawing. (Pedrosa, A.,1993). They contributed to the filling of the bottoms of small valleys and the regularisation of a large part of the slopes (Rebelo, F., 1975; Rebelo, F. & Pedrosa, A., 1993; Pedrosa, A., 1988, 1993).

However, the climate warming verified at the beginning of the Tardiglacial cannot have been linear (Coude-Gaussen, G.,1981; Ferreira, A. B., 1985; Rebelo, F., 1985, 1986; Cunha, L., 1988; Cordeiro, A. R., 1986a, 1988).Today the existence of at least three moments in the last Tardiglacial are recognised (Nonn, 1966; Guillien, 1962; Daveau, 1973, 1978), with an interphase and a recurrence of a very cold, dry phase (Jorda, 1980; Garmendia, 1989; Vliet-Lanoe, 1988). In fact, it seems that the Tardiglacial is characterised by the existence of several climatic fluctuations (Cordeiro, 1990; Pedrosa, A., 1994c); Martins, 1999), confirmed by the features of the formation of Covelo do Monte. About 11000 BP a new climatic crisis must have occurred (Cordeiro, A. R. , 1990; Guillien *et al.*, 1978; Garmendia, 1984); it would have led not only to the occurrence of processes related to the action of the ice but also to generalised solifluctions which may have caused the remixing of deposits formed by prior processes.

It is possible to find a great heterogeneity in the Tardiglacial deposits, which depends on the exposure of the slopes, on their rock substratum and on their inclination (Pedrosa, A., 1994b; Martins, 1999); but the fundamental factor must have been the snowfall during a part of the year and its thawing in the warmer period, which was probably the time of the heaviest rainfall. The most important processes must have been the solifluctions which were responsible for the regularisation of a great part of the slopes as well as the occurrence of slides especially extensive debris flows, whose marks can still be traced on the bottoms of the valleys (Photo 3).

However, it is not possible to find mature soils; the majority are entisols and are quickly affected by small climatic changes. A new warming seems to have reached its peak by 8000 BP as it was possible to find in the Marão some palaeosols which are contemporary with this period known as Holocene climatic optimum.

Photo 3 – Tardiglacial deposit regularising great part of the slopes of the Serra do Marão.

Around 5000 BP when the sub-Boreal period began (Goudie, 1979) an increase in erosion must have taken place; this increase is probably connected with a drop in temperature as well as with some human activities, especially the burning of land to renew the vegetation and obtain new pastureland, which would increase the power of such erosion processes as runoff and splash (Pedrosa, A., 1993). Solifluctions must also have occurred in some parts of the slopes, above all in higher places facing north. In the Marão the best example of this period is the formation of Lameira.

Gravity slumping associated with a massive congelifraction of rocks may correspond to different generations of these forms or, at least, to the existence of different periods which activated their formation and evolution. In the Marão they are generally found at heights superior to 700m and are sometimes associated with steep inclines, especially on shady slopes. An important phase in the origin of these forms may have been the short glacial age, which occurred in the 17th and 18th centuries (Ladurie, 1983). This process is still active nowadays in places situated on shady slopes where the bare rock appears on the surface without any soil or vegetation covering it (Pedrosa, A.,1993).

The importance of slope deposits for the present slope morphodynamics

The geomorphologic dynamics of the mountain ranges of northern Portugal is very complex since both the factors and the intervening agents as well as their interaction are diverse. Even if only the natural agents are taken into account, there is still the interaction of several factors whose relative importance varies from region to region or even from place to place, making the active morphogenetic processes different. It is indispensable to understand the behaviour of the fundamental climatic elements – precipitation and temperature – to explain the action of the processes which are responsible for the present evolution of the slopes, but it is also necessary to take into account factors such as the lithology, the morphology, the biogeography and the surface formations.

The importance of the formation of gullies

In these areas the formation of gullies is clearly conditioned by the existence of a slope deposit, which works as a regulator because there are no trees or quite often because man has acted on this terrain.

The examples that will now be given show clearly what has just been said.

In July 1992, on a slope near the village of Paradela do Monte (municipality of Santa Marta de Penaguião) there was a very heavy shower. Unfortunately, it is not recorded, owing to the small geographic extension of the area on which it rained and the non-existence of pluviometres, but it is estimated to have reached values very nearly 30 mm while it lasted (about 1 hour); in consequence, two big gullies appeared (Photo 4).

Photo 4 – Gullying in the area of Paradela do Monte.

In July 1991 there had been a fire which had completely destroyed the vegetation covering that slope. Due to the altitude and the inclination of the slope (30º), the growth of new vegetation is rather slow. The whole slope is regularised by a deposit which in some places is more than 2 meters thick. More or less in the middle of the slope two tracks were opened on the slopes to lay a system of waterpipes. This was the background in which the slope gullying began. At first the runoff flowed along one of the tracks and formed gullies. Later the drainage stopped flowing along the tracks, turned in the direction of the steeper incline and formed two gullies whose depth is clearly conditioned by the depth of the deposit which regularises the slope. As soon as the water reached the schists in situ the gully thalweg could not become deeper; it became wider and the water transported the slope material which was not well consolidated. One of them deepened a pre-existing gully while the other developed at first parallel to a small valley that existed on the slope, later using only its final part; as a consequence, its thalweg became deeper.

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In order to calculate the quantity of material transported, the length, the width and depth of the two gullies, they were measured in different sections. The results of these measurements were as follows: in one of the gullies the volume of material transported was about 465 m^3 while in the other it was a bit more: about 570 m^3 (Chart 1). All this material must have been transported only in the short period of time during which the rain poured down; one of the gullies has a cone of dejection just above the road (Photo 5), formed by the coarser materials, while the material transported by the other crossed the road and ran down the slope into the main brook.

Chart 1- Dimension and Volume of material transported by the gullies.

	Length	Width		Depth		Volume of transported material
	(m)	*max.* (m)	*min.* (m)	*max.* (m)	*min.* (m)	(m^3)
Gully 1	160,7	2,6	0,3	2,5	0,1	465,8
Gully 1	120,9	7,7	1	3	0,8	570,2

Photo 5 – Detail of the material deposited in the slope after gullying.

The importance of mass movements

Mass movements can have a greater or smaller complexity because they can be the result of different processes which can only be identified by an analysis of each individual case. Roughly speaking, they can go from the moving of small individual particles to the fall of big stones and slow or fast flows.

However, these movements cannot be explained only by adverse meteorological conditions, as neither heavy rainfalls nor all the long periods of precipitation always give rise to soil movements. Therefore, it is necessary to look for other factors which acting together make it possible to explain the onset of the initial movement which causes the earth-flow .

In several recent studies different authors (Rebelo, 2001; Pedrosa, 1993, 1994a, 1994b, 2001; Pedrosa, Lourenço, Felgueiras, 2001; Pedrosa, Martins, 2001; Pedrosa, Bateira, Soares,1995; Pedrosa, Marques, 1994) have tried to systematise the factors that are of greater importance for the onset of these processes in northern Portugal. Natural factors that can influence the occurrence of debris flows and mass movements have been considered up to this moment. Nevertheless, factors related to human interference are more and more frequent. Some are connected with the subdividing of estates into plots for the building of houses, others with the building of roads and railways which imply extensive back filling (*aterro*) and excavation (*desaterro*) of land; these alter the conditions of equilibrium on the slope and are responsible for the occurrence or, at least, for starting the initial process.

Humankind has been a geomorphological agent for a long time and in this role is becoming more and more important. Human influence creates "humanised landscapes" which do not always safeguard the operation of the natural processes and thus contribute to situations which, left to nature, might eventually happen but much, much later.

It is unquestionable that many of these movements (not only the individualised ones such as landslides, earth falls, mudflows, and so on, but also those that act together) almost always happen after periods of heavy rainfall which leave the soil, the alteration mantles (*mantos de alteração*) and the slope deposits saturated or near saturation, so creating conditions to initiate the earth flow.

Besides, the infiltration resulting from the rainwater activates the underground circulation which sometimes respects former palaeotopographies, *i.e.*, former small river valleys fossilised by slope deposits. The water manages to trickle between the rock, little or not altered, and the overlying deposits. When these underground flows are strong and are associated with the water infiltrated directly from the rainfall, they can contribute to the fluidity of the overlying deposits and, in doing so, to create conditions for their starting a movement which often extends downstream through flows containing a higher or smaller quantity of mud.

Besides the hydroclimatic conditions, structural aspects both lithological and tectonic are sometimes fundamental factors, often playing an important part in that they condition the type of movement, its size and the evolution of the area affected.

Quite often it is the net of faults and fractures that contributes to facilitate the alteration of the rocks and allows a more efficient infiltration of water which reaches progressively deeper levels and ends up by making the surface mass movements easier.

The geomorphological factors are the most varied and those that have more significant repercussions when connected with other factors – natural and human.

The steepness of the slope is another morphological factor of great importance for the onset of mass movements. The above mentioned authors speak of steep inclines almost always superior to 30% as being one of the morphological factors decisive for the fast evolution of the slopes and it is one of the criteria that may provide important elements for the definition of areas of potential risk.

Breaks in the slope, above all when they contribute to the increase of the incline downstream, are a local factor responsible for the worsening of the conditions of the occurrence of movements; because of that, they deserve a special reference.

Besides the incline, the form of the slope also plays an important part in the creation of conditions favourable to the development of processes of slope evolution.

Slope regulation by surface formations is undoubtedly one of the factors that may contribute in a more decisive way to the development of these mass movements, which according to their characteristics can lead to movements sometimes slow sometimes fast. Thus, when the surface formation corresponds to deep alteration mantles, capable of absorbing large quantities of water, it can lead to extensive mass movements. In fact, the great thickness of the alteration mantle or of the deposit favours the water infiltration; the saturation point can then be reached and the soil may begin to collapse. The great absorption power may slow down the beginning of the movement and bring about its development in stages over the course of several days.

Another frequent situation has to do with the thin slope deposits of the Quaternary, rich in argillaceous material with a great capacity to absorb water, lying on rocks which are little altered and which quite often act as an efficient sliding surface. In the schist and quartzite areas of the mountain ranges in northern Portugal, this is one of the most efficient natural processes of slope evolution. In fact, when heavy rain falls for long periods of time on steep slopes regularised by slope deposits, mass movements such as debris flows happen frequently.

Debris flows in the Serra do Marão

Debris flows are a frequent occurrence on the slopes of the Marão. They are related to the quantity of rainfall, the steep inclination of the slopes and above all to the regularisation of the schist slopes by the deposits of the Quaternary which have already been mentioned in the first part of this paper. In fact, it is on the discontinuity surface which coincides with the contact between the slope deposits and the bedrock that the failure occurs and the debris flow begins.

In fact, surface formations constituted by the slope deposits of the Quaternary allow the infiltration of the rainwater that then flows through the deposit materials but above all in the surface of contact between them and the metasedimentary rocks, which owing to their impermeability, lead to the accumulation and flow of the infiltrated water. Thus, when the period of rainfall is long, the fluidity of the overlying deposits may increase, causing the rupture.

In 1992 several debris flows occurred in consequence of a long period of precipitation (A. Pedrosa, 1993); they happened near the villages of Montes e Póvoa da Serra, whose slopes are steep and covered with trees; but the fundamental reason was the fact that they were regularised by deposits (Photos 6 and 7).

Photo 7 – Another detail of the debris flow in Póvoa da Serra.

Photo 6 – Characteristics of the debris flow of Póvoa da Serra.

Later, in 1997, after a few very rainy days, some more debris flows occurred in slopes with the same characteristics as those already described. This is the case of Portal da Freita (Photo 8) and of Carvalhada de Baixo (Photo 9) both near the village of Montes.

Again in 2001, after a long period of rainfall, there were debris flows down several slopes; all of them had the same characteristics: a steep inclination and the presence of a surface formation with a thickness of 1.5 / 2 metres which regularises the slopes. In that same year, besides the occurrence of debris flows in new places, there were also new movements in the locations of previous flows, such as the ones in Póvoa da Serra or in Montes.

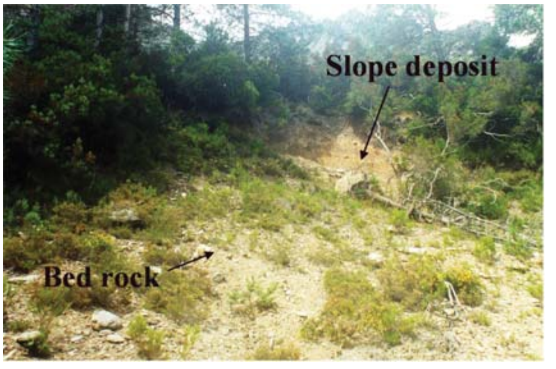

Photo 8 – Detail of the place where the debris flow of Portal da Freita began, whose failure is clearly related with the contact of the deposit with the bedrock.

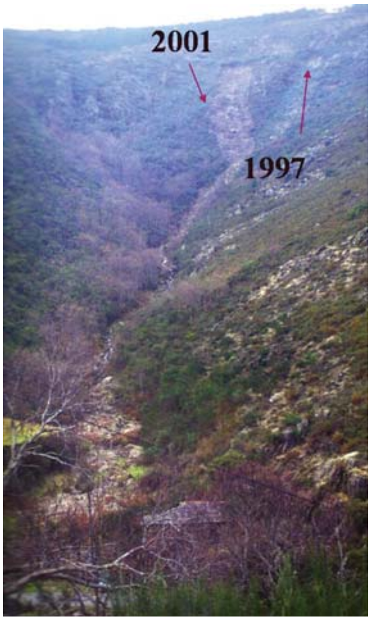

Photo 9 – Debris flow in Carvalhal de Baixo where it is possible to observe that the place of the flow began coincides with slope are regularised by deposit.

The one that had the most serious consequences happened place near Mesão Frio (Volta Grande) (Photo 10). It reached road no N101 (Amarante – Peso da Régua), dragging two cars that were driving along it and causing the death of one of the drivers. This example shows clearly the risk of building roads on the foot of slopes with the characteristics that have been described because processes of rapid change in the characteristics of the slopes often occur in these circumstances, leading to a greater instability of the regolith materials that regularise the slope.

Photo 10 – Location of the occurrence of the debris flow of Volta Grande which affected road N101 and dragged two cars causing one death among the car occupants.

Conclusion

The behaviour of climatic elements is important for the understanding of the morphogenetic processes. The analysis of such elements cannot confine itself to the mean values because it is important to know their variation, not only during one year but also over a larger number of years, especially on account of the consequences that that variation may have on the morphogenetic processes (Rebelo, 1983; Bryant,1991; Faugères, 1991).

Mass movements do not always coincide with the day of the heaviest rainfall; quite often they occur on days on which the precipitation is scarce or even non-existent. So it is indispensable to observe the pluviometric values of periods further from the day on which the movement occurred. Although there may be a relationship between the occurrence of very heavy rainfall and the occurrence of movements the prolonging of heavy rain over many days causes soil saturation (Flageollet, 1989). Thus, in areas with large quantities of argillaceous material the relationship of heavy rainfall to earthflow movement is not so direct, because its water absorption capacity is very high, which retards the occurrence of the slip.

Another important factor in the dynamics of the morphogenetic processes is morphology. Thus, when one goes from steeper slopes to gentler ones, one may observe the deceleration of the erosion processes in favour of processes of accumulation of materials (Young, 1969).

Slope inclinations have great influence on the dynamics of any present-day morphogenetic process; therefore, it is an ever present factor in the analysis and understanding of the morphogenetic processes and their action.

On the slopes on which these flows occurred the mean inclination varies between 30º and 40º which is an important element in the onset of the whole process. In some places the gradient is even higher: for example, near Póvoa da Serra the mean slope inclination is over 40º. However, near the scars in the place where the debris flow began the angle is over 60º.

But on the slopes of the Marão it is the fact that they are regularised by slope deposits that are very different in size that facilitates the infiltration of rainwater even on steep slopes. The water reaches quickly the plane of contact with the bedrock, which is relatively impermeable. That is where the rupture occurs which allows the debris flow to begin.

The study of the present morphogenetic processes may contribute to knowledge about the natural hazards (Martin, 1987; Rebelo, 1991b, 1994; Bryant, 1991). Knowing the elements that interact on the slopes is fundamental; they must be understood from a dynamic point of view, distinguishing between the major and the minor factors.

The geomorphologist must know as deeply as possible the combinations and ways in which these factors act. But although it is possible to map areas where landslides may take place, the forecast of the occurrence of such phenomena is based merely on a probability and not on a precise indication both in time and in space.

However, the study of a growing number of cases related to specific morphogenetic processes makes it possible to get a deeper insight into the way these processes operate, which will enable the authorities to mitigate their harmful consequences, to establish a scale of risks and draw maps showing the vulnerable areas in the landscape.

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