Impact of terrain instability on the infrastructure and human habitat of Dambovita County, Romania: Determination and classification of the risk

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Abstract: Situated at the contact between the Carpathian side and the plain area, the territory of Dambovita County, Romania, is shaped by a series of phenomena and processes whose dynamics have seriously increased during the last two decades, and whose effect is the triggering of different forms of terrain instability. The impact is quite high, especially in the Sub-Carpathian area, where there is a high density of habitation and infrastructure. These phenomena, however, affect large areas of terrain having other uses (agriculture, forest, grazing fields and even arable areas). Such forms of instability belong to the category of hazards and, due to their complexity, there is a low level of knowledge about them. The purpose of this research is to increase the level of knowledge by delimiting the natural factors, and, quite frequently, the human ones, that contribute to the activation of the terrain instability processes and phenomena. By delimiting the factors that contribute to the appearance of the terrain instability processes and phenomena, and by evaluating their impact on the environment, it is possible to classify the forms of instability, which would result in a categorization of the level of hazard or emergency. Based on this classification, one could develop a strategy to deal with these problems, which would make it possible to limit the effects of terrain instability particularly on the human habitation and on the environment, in general. The correlation of the external instability factors with the geological, hydrogeological, etc. structure would even allow for the determination of the scenario of evolution, which would make it possible to adopt some preventive actions in order to limit such processes, which in turn would entail lower costs.

Résumé:Le territoire du département de Dambovita, situé là où se rencontre la chaine des Carpates et la zone de plaine, est marqué par toute une série de phénomènes et de processus dont la dynamique s'est particulièrement accentuée lors des deux dernières décennies et qui ont pour conséquence le déclanchement de différentes formes d'instabilité du sol. L'impact est assez fort, surtout dans la zone des Sous-Carpates, où l'on constate une grande densité des localités et des travaux d'infrastructure. Mais ceux-ci affectent des grandes surfaces prises sur les terrains ayant d'autres destinations (agricole, forestier, paturage et même arable). De telles formes d'instabilité sont classées dans la catégorie des hasards, vu leur complexité, ce qui suppose qu'un degré réduit de connaissance. Le but de cette recherche est de remédier à cette ignorance en délimitant les facteurs naturels et, dans beaucoup de cas, des facteurs anthropiques qui contribuent au déclanchement des formes d'instabilité du terrain. La délimitation des facteurs qui contribuent à l'apparition des processus et des phénomènes d'instabilité du terrain, ainsi que l'évaluation de la gravité de l'impact sur l'environnement permettraient une classification des formes d'instabilité qui précise le degré de dangerosité ou d'urgence. Suivant ceux-ci, on pourrait élaborer une stratégie pour cette problématique qui conduise à la limitation des effets sur l'habitat humain en particulier et sur l'environnement en général. La corrélation des facteurs d'instabilité externes et de la structure géologique, hydrogéologique permettrait même l'élaboration d'un pronostic d'évolution qui permettrait l'adoption de mesures préventives de limitation de tels processus, ce qui conduira à un moindre coût.

Keywords: case studies, environmental impact, infrastructure, classification, plasticity, sedimentary rocks

During the last few decades the terrain instability phenomena in Dambovita County have become increasingly intense, having a particular impact on the socio-economic environment. Their extension has increased year on year due to the reactivation of some older areas and to the appearing of new ones. The problems tend to become acute, especially as no remedial measures have been taken or, where such measures were taken, they have been inadequate or inappropriate to the respective situation. In order to find satisfactory solutions it is necessary to know the factors that contribute to the occurrence of such phenomena, by means of research concerned not only with their qualitative evaluation, but also to their quantitative assessment. The delimitation of the dominant factor/factors in the different areas under analysis would allow for a classification of the types of instability phenomena from the viewpoint of their genesis, dynamics, development, etc. At the same time, their quantitative determination would allow for a correct evaluation of the risk to a certain area and even behavior prognoses could result, so that, with the use of appropriate remedial measures, it may become possible to minimize or even prevent their effects for as much time as possible.

This area is part of a larger region, superposed on the external geostructural units of the Carpathian arc, where such phenomena are frequent and have a relatively high dynamics. The instability of the slopes represents a continuous process of natural relief modeling, being the result of the action of factors associated with the geological and tectonic structure of the Earth's crust and with the action of the external geospheres. To these should be added the action of the human factors, which are increasingly present and generally unfavorable, and which accelerate the terrain degradation processes.

The geostructural units of the region in which the most frequent instability phenomena occur are the ones belonging to the flysch and to the internal Avanfosa of the Oriental Carpathians, because of their lithologic structure and the intense tectonic manifestations of the geological formations. The specific feature of the Oriental Carpathians is the existence of a large flysch area whose geotectonic structure comprises layers of alluvial deposits, covering one another from the west to the east. The area of flysch includes layers of Cretaceous tectogenesis, like the layer of Ceahlau, the layer of Teleajan and the layer of Macla, and with lower Miocene tectogenesis, like the layer of Tarcau. Those of Cretaceous tectogenesis form the area of the internal flysch, while the one of Miocene tectogenesis belongs to the external flysch. The south-western sector of the layer of Teleajan and of Macla has undergone deformation until the lower Miocene finished with the formation of the post-tectonic synclinal Slanic-Breaza-Bezded-Raul Alb.

In the area of the Carpathian Flysch from the interfluve of Ialomita and Prahova, the instability phenomena manifest themselves by means of very diverse terrain slides, whose structure and extent can be connected to the petrographic and tectonic structure.

From the viewpoint of their volume and of their particular arrangement, the slides occur at the level of:

- the actual Quaternary deposits that make up the alteration layer (alluvial, deluvial and colluvial deposits) of the old geological formations;
- pre-Quaternary geological formations, which are made of clays and marls, or of the formations with tougher rocks with intercalations of the clay and marl type;
- the Quaternary and pre-Quaternary deposits, the sliding plans being situated in the latter ones.
- From the viewpoint of the speed at which the instability phenomenon occurs, the slides can be:
- very slow, manifesting themselves by means of creeping and solifluxion phenomena, where the sliding process develops over long periods; months or years;
- slow, the instability phenomenon occurring taking weeks or months;
- rapid, when the instability phenomenon takes a few days;
- very rapid, when the phenomenon takes just a few hours in all, mud flows being included here.

In the sub-unit or layer of Ceahlau, the lithofacies that favor the occurrence of the instability phenomena are the following:

- the layers of Sinaia, the lower horizon, made up mainly of argillaceous schists and argillaceous-marly schists, marls and mixtures of marls and calcareous rocks;
- the layers of Comarnic, which represent a marly-calcareous flysch to which fine calcareous grit stones and mixtures of marls and calcareous rock are associated;
- the layers of Piscu cu brazi, or the reddish flysch, formed marls and clay with no schistosity, with rhythmic intercalations of fine calcareous grit stones, with limonitic alterations, which give the reddish color to this facies.
- the marly-argillaceous Vraconian-Cenomanian facies;
- the post-tectonic marly facies from the level of the Senonian.

A special structure is that of the instability phenomena from the upper basin of Ialomicioara de Jos (of Glod), which affects the southern slope of Dichiu Mountain and especially the south-western slope of Paduchiosu Mountain, almost up to the confluence with Carpinis Valley. The phenomenon occurs in the level of the lower Sinaia layers, on significant depths, of over 20m. In this zone, partial stabilization of the road from Targoviste to Sinaia has been achieved using Benotto pillars, tangential and even transversal, however the problem has not been solved completely. That is why for this zone another factor must also be taken into account, specifically the tectonic factor. First of all, we should note that in this area the layers of Sinaia form an anticline, largely opened in the area of its axis by the erosion of Ialomicioara Valley. The slopes of the valley are formed from the medium and upper Layers of Sinaia and of the Barremian-Aptian grit stone facies. This structure creates the premises for the action of the tectonic factor by means of two types of forces: The lithostatic force of the formations from the slopes of Ialomicioara Valley, and the compression force, given by the pushing of this sector to the east by the intramoesic fault of the Wallachian platform. Consequently, the zone is still active from a tectonic viewpoint, undergoing deformations and even rising up, a thing that undermines the slopes' gravitational balance.

The layers of Comarnic appear at the surface to a large extent in the flanks of the anticlines of Ialomicioara and Moroieni, which also create large zones of instability. In this area numerous older slides that have been partially reactivated are known, affecting a large area of the territory of Moroieni and Pietrosita Communes. They are located in the flanks of the Ialomicioara de Jos anticline, affecting the slopes without trees. Thus, such phenomena appear along the river courses within the Ialomita Valley, like: Glava and Rusetului Valley of the area of Moreni Commune; Lupului Valley, of the area of Pietrosita Commune. Otherwise, the right slope of Ialomita River has been affected on a large area of paleo-sliding, which shows, at the present time, numerous reactivations, from superficial slides to deep slides.

The Vraconian-Turonian deposits appear in the Talea-Petrosita-Runcu synclinal, formed of marls and grey sandy marls, weakly stratified, with intense tectonic phenomena, are one of the reasons of the existence of the palaeo-slides and recent slides in the areas of Pietrosita and Runcu. The instability phenomena of the zone of Pietrosita occur especially in the area of the locality Dealu Frumos (which is part of Pietrosita Commune) and in the lower course of Tata Rivulet.

The Senonian deposits in the facies of the red marls of the Gura Beliei-type have a post-tectonic character, developing regionally in the axis of the same synclinal, from the front of Ceahlau layer, namely: Runcu area, Dealu Frumos area, the eastern zone of Pietrosita Commune, and Talea region. Many processes of instability occur in the area of Runcu commune (The villages: Siliste, Ferestre and Brebu), which concern the Senonian deposits and alluvial layer. Sometimes the sliding bed is formed of the Vraconian-Turonian deposits.

Teleajan sub-unit or layer appears east of Fieni, being a continuous zone in the interval from Ialomita to Bizdidel. The instability phenomena are associated with the Vraconian-Turonian marly flysch (the Fieni Series) and marly flysch (marls of Boncu). They are determined by the presence of the paleo-slides and recent slides from the middle course of Bizdidel Rivulet, from the locality called Magura, downstream of the confluence with Valea Leurzii. The recent slides concern both the alluvial deposits and the Vraconian-Turonian rock below.

Macla sub-unit or layer appears as a narrow stripe, starting approximately from the upper basin of Vulcana Rivulet and continuing in the Ialomita-Prahova interfluve. The instability phenomena are present both in the alluvial deposits and in the Turonian-Vraconian formations, in the facies of the Macla series, which is represented by a schistic flysch with clay and grit stones and at other times only with clay, being colored gray, black and red (the facies of the clays in stripes). Such phenomena affect the territory of Cucuteni locality (the basin of Vulcanita Rivulet) and the territory of Magura locality of Bizdidelului Valley.

Tarcau sub-unit or layer is the geological and tectonic structure of the area in between the alignment south Fieni-Breaza and the alignment Pucioasa-Campina, where the instability phenomena cover large areas and manifest themselves actively, through recent slides. The frequency of the active slides is relatively higher in the area of the external flysch if we compare it to that of the slides in the internal Flysch. The body of the Tarcau layer is made up of Oligocene deposits:

- layers of Pucioasa: marly schistic flysch with intercalations of mars and calcareous stones;
- grit stone of Fusaru – calcareous grit stone with rough granulations;
- schistic Flysch with levels of tuffs and bentonites – Vinetisu layers;
- disodilic schists with intercalations of tuffs and bentonites dating from the lower Oligocene-Miocene.

The instability phenomena are present especially in the levels of alluvial-colluvial deposits, which have rock of the layers of Pucioasa for a base. The superficial deposits are generally thick, due to the weathering of the argillaceous-marly formations that are part of the lithofacies of Pucioasa.

The slides cover large areas in Vulcana Bai Commune, especially in the slopes of Vulcana, Vulcanita and Cainelui Rivulets. The same phenomena deeply affect the right slope of Ialomita River between Motaieni Commune and Pucioasa Town. But the more spectacular and at the same time the most complex sliding phenomena are situated in Bizdidel-Provita interfluve, on the alignment of the localities Niculesti-Carlanesti-Visinesti, and in the interfluve Provita-Prahova, on the alignment Provita-Podu Vadului-Cornu. Ample phenomena are known in the zones: Carlanesti, Ulmetu, the right slope of Suvita Rivulet, Varfuri, Visinesti, Ursei, Provita de Sus and Provita de Jos. The slides are of the slow and rapid type, in the latter case the phenomenon being triggered by the accumulation of several favoring factors.

Similar phenomena to those of the area of Tarcau layer appear in the zone of the post-tectonic synclinal of the final structures of the Laramic orogenesis stage (the layer of Ceahlau and the layer of Teleajan) Slanic-Breaza-Bezdead-Raul Alb, whose filling is made up of the formations of the Paleocene and lower Miocene. The structure of the facies of Sotrile and that of Valea Leurzii, which is predominantly argillaceous-marly, represents one of the main factors that determine the formation of a thick layer of alteration, at the level of which the slope instability phenomena occur. These slides are similar to those developed in the area of the layer of Tarcau. Sometimes the slides take place both in the alluvial layer and at the level of the Paleocene and lower Miocene rocks, as they occupy large areas in the basin of Ialomicioara de Jos Rivulet, in the area of Runcu Commune (Badeni zone), in the slopes of Ilaomita (the area of Buciumeni-Valea Leurzii, north Fieni, Valea Caselor, Bezdead), in the basin of Rau Alb Valey and of Barbuletu and in the slopes of Prahova Valley (Breaza area).

An important role in the starting of the terrain slides or in the predicted evolution of the slopes is caused by mineralogical changes; the way in which the pre-Quaternary rocks are transformed during the alteration processes. The mineralogy of the deposits from the alteration layer is determined by the increase in the content of montmorillonite under the influence of the underground waters and the continuous feeding of the argillaceous and marly deposits with alkaline cations in a chemical environment with a high pH (alkaline environment). On the other hand the deliverance of the anions of K^+, Ca^{2+} makes the free valences occupied by hydroxyl ions specific to the bonds of the montmorillonite. Some replacements of the Si^{4+} by Al^{3+} determine the appearing of free negative valences that are partially occupied by Ca^{2+} and Na^+, which accentuates the enrichment in water and increases the occurrence of the swelling phenomenon. These profound transformations and especially the adding of water lead to a reduction of the shearing resistance, through the decrease of the friction and cohesion forces from among the argillaceous particles. The reduction of the shear strength parameters is due partly to the fact that calcium carbonate becomes soluble, and is usually leached from the upper strata of the alteration layer to a deeper level. By comparison to the argillaceous-marly deposits that usually make up the *in situ* rock of the alteration layer a slight chemical change can be noted. Thus, a decrease of the concentration of potassium and sometimes of calcium can be observed, and at the same time an enrichment in aluminum.

The increase of the degree of the montmorillonitization of the pellitic deposits from the alteration layer is reflected in the physical parameters of these deposits and especially in those connected to the water. A growth of the pellitic fraction of less than 2 μ is reflected in the substantial growth of the humidity limit for flowing Wc and implicitly of the plasticity index *Ip*. The connection between these parameters and the mineralogical structure was made in the 1970s, so that it is possible to describe the type of clay just by knowing some of their physico-mechanical parameters.

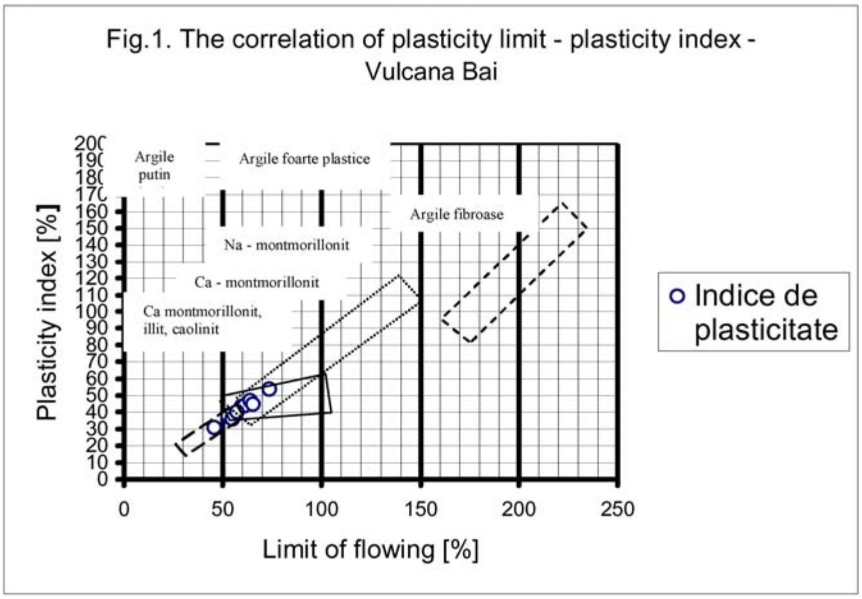
Of the multitude of instability processes that manifest themselves by sliding of the alteration layer, we will present only four cases situated in the area of the layer of Tarcau, in the zone of Vulcana Bai Commune, and in the area of the internal avanfosa, the point Sultanu from the zone of the localities Visinesti-Valea Lunga, Laculete and Glodeni.

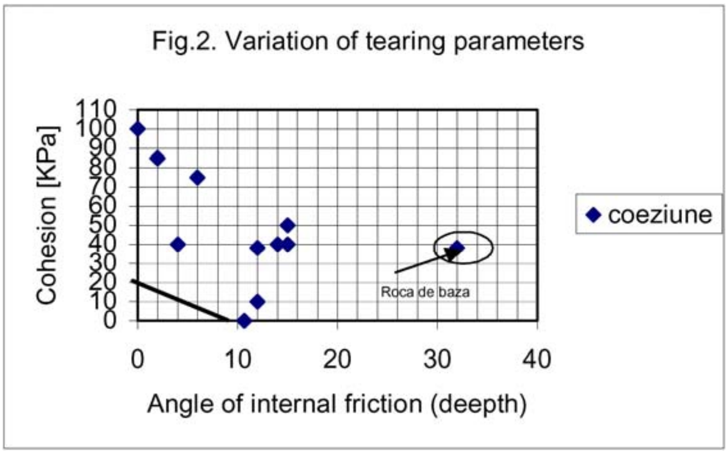
One of these analyses was made on a slope with an inclination of 10-12^o situated in Vulcana Bai Commune, unaffected by instability phenomena, where some public and private buildings were to be built.

Vulcana Bai Commune is situated at the heart of the external flysch represented here by the layer of Tarcau made up of the Oligocene succession in the facies of the strata of Pucioasa, which is a schistic argillaceous-marly facies, with thin intercalations of marls and limes, marly grit stones, and grit-stony marls deposited in a strongly euxinic environment. That is why the marls and clays have impregnations of bitumine and efflorescences of sulphur. The major structure of the Oligocene is given by an ample anticline oriented ENE-WSW, in which the secondary synclinal folds contain, in their axis, deposits of the lower Miocene.

The slope under analysis is situated in the southern flank of the megastructure, where the alteration layer reaches depths of 8-12m, while in the lower part there is underground water situated in the level of the argillaceous deposits.

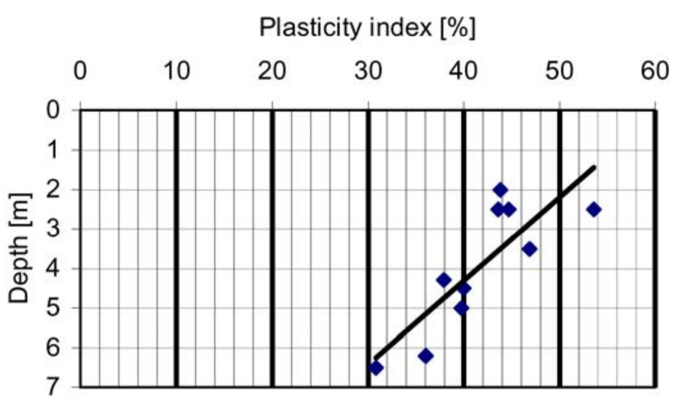
The laboratory analyses undertaken on the borehole samples place the clays, from a geomechanical viewpoint, in the domain of the fat clays, which supposes a high percentage of montmorillonite. The correlation of the limit of flowing with the plasticity index places the clays from the alteration layer at the passage limit from illite to montmorillonite (Figure 1), which explains the low value of the shearing parameters, that is the angle of internal friction φ and the cohesion *c* (Figure 2).





The residual values of the shearing parameters are represented by means of a straight line with the coordinates (9^o, 20 kPa), resulting both from the laboratory tests and from the calculation of the stability limit of the slope. By examining them we notice easily that a series of values are situated near the high risk-limit in respect of the stability of the slope. From the distribution of the plasticity index with the depth we find the distribution of the variation of the degree of montmorillonitization, which increases towards the surface (Figure 3), in respect of the increase of the degree of alteration of the argillaceous deposits.

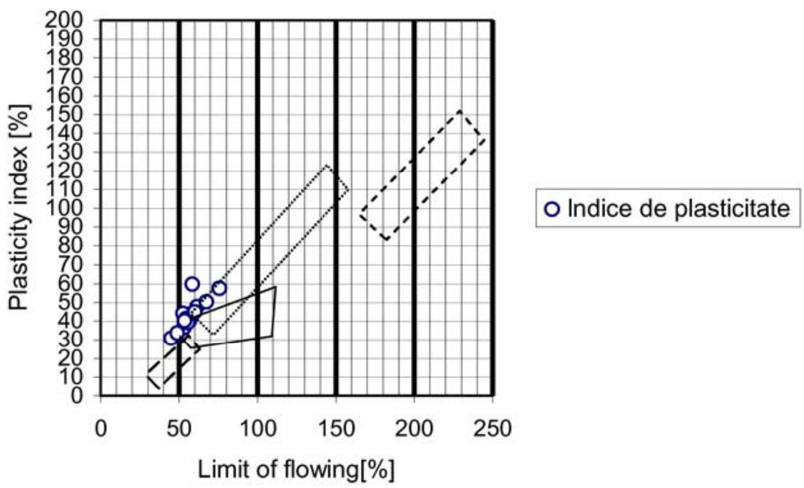
Fig.3.Variation of the plasticity index with the depth Vulcana Bai



The acceleration of the alteration processes is also favored by the substantial mineralization of the underground waters, as they are deposit waters, a fact that influences the chemistry of the underground waters. The presence of different salts, especially of sodium, determines the increase of the montmorillonitic fraction in the deposits from the alteration layer. This may explain the fact that the critical depths of the alteration layer are rapidly reached, which in turn triggers the phenomena of terrain instability.

On the northern flank of the post-tectonic syncline of the layer of Teleajen, whose filling is made up of the deposits of the Paleocene and of the Lower Miocene, the bed of the sliding is formed from the strata of the Eocene and of the Oligocene at the boundary with the Lower Miocene. The Eocene is present under the form of facies of flysch in which the rhythms are formed of clays and schistic marls, calcareous clays, grit-stony clays and violet marly clays. The Oligocene also has the character of a flysch mainly with marls and clays, and also with siliceous rocks from the category of the mylonite and disodilic schists, with impregnation of bitumen and sulphur. To these should be added the influence of the deposits of gypsum and sometimes of rock salt at the level of the lower Miocene deposits. The presence of the sulphur and of sulphates creates a strongly acid environment that leads to the removal of the carbonates and the enrichment in clay. The correlation between the limit of flowing and the plasticity index of the clays from the alteration layer indicates the same tendency of enrichment in clay, in the domain of the passage from the illite to montmorillonite (Figure 4).

Fig.4.Correlation between the limit of flowing and the plasticity index Buciumeni



The fact that the process of montmorillonitization is mainly caused by the acid environment is also reflected in the variation of the plasticity index with the depth (Figure 5).

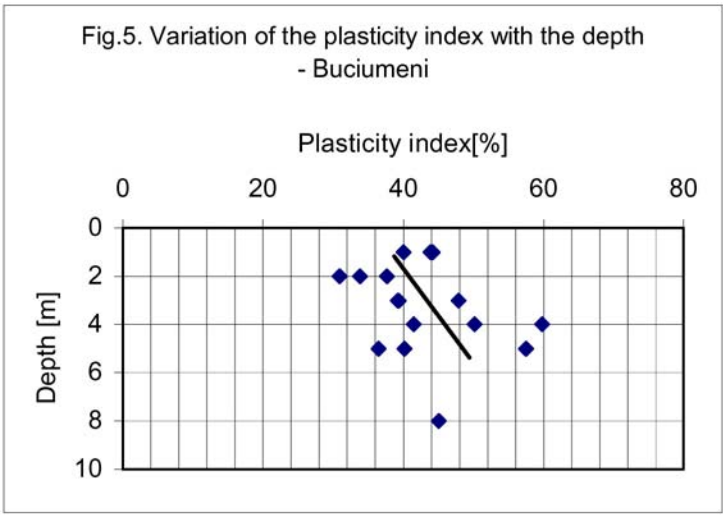


Fig.5. Variation of the plasticity index with the depth - Buciumeni

In this case the clay's plasticity increases with depth especially in the interval 3-5 m; the total depth of the deposits being of 6-8m. The sliding of the deposits occurred at an inclination of 20°-30°, sometimes even lower. The value of the shearing parameters are similarly decreased, particularly the angle of internal friction, which decreases sometimes from values of 20-30° (high values because of the increase of the sand and even gravel fraction) at the upper level, to 2-7° at depths greater than 4m.

Another case that was analyzed is situated on the territory of the localities Valea Lunga-Visinesti from the internal avanfosa of the oriental Carpathians, at the boundary with the layer of Tarcau, in the point called Sultanu. Here sliding of the superficial deposits occurs at a slope of less than 10°, with an apparent depth of 6-8m, seriously affecting the access way to the localities mentioned above. The bed of the sliding is made up of Pontian deposits in a facies of clays and marls.

The clays from the alteration layer are of the fat-clay type, characterized by high values of the plasticity index. As in the former cases the clays are situated at the boundary between the illite and montmorillonite (Figure 6), indicating an increase of the fine pelitic fraction towards the surface (Figure 7).

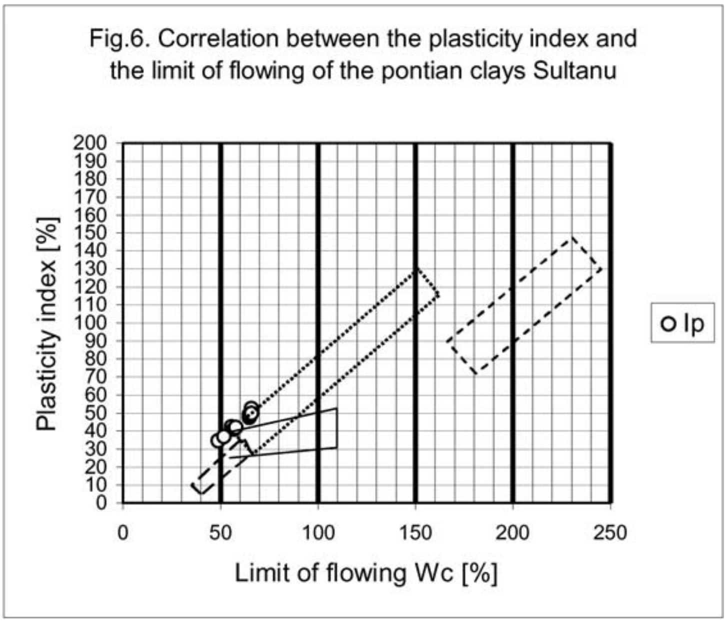


Fig.6. Correlation between the plasticity index and the limit of flowing of the pontian clays Sultanu

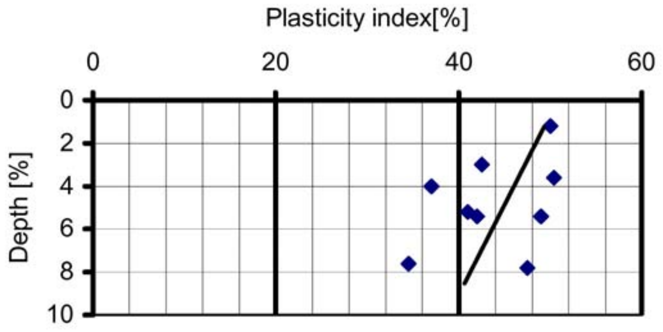


Fig.7.Variation of the plasticity index with the depth - Sultanu

These results indicate the biggest influence on the accentuation of the alteration processes is provided by the external factors, particularly to the direct infiltration of the precipitations through the system of fissures and micro-fissures. If we compare it to other cases, we note the similarity in respect of the value of the shearing parameters (Figure 8). At the same time, the relatively low values of these parameters explain the low resistance to instability, with the slides moving at low slope inclinations. The high values of the shearing parameters, especially of the cohesion are specific to the slightly altered Pontian rock, at the contact with the slope's Quaternary deposits.

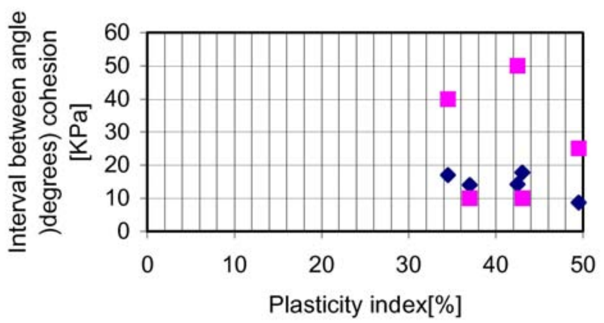


Fig.8. The correlation of the plasticity index with the angle of internal friction and cohesion

CONCLUSIONS

The analyses undertaken on several cases of terrain instability manifested under the form of soil slides show the importance of the mineralogical factor in the classification and determination of the degree of risk. The alteration of the rocks occurs differently according to the lithological structure of the substratum and the chemical environment created there. Thus we note that the process of montmorillonitization of the rocks in the alteration process occurs differently. We observe that for the deposits in the area of flysch the alteration processes are more profound by comparison to the one from the area of the internal Avanfosa. In the flysch area the plasticity of the clays is higher, varying between 44-54% and 40-60% respectively, while in the internal Avanfosa the variation limits are between 40-50%. we also notice a differentiation in the evolution of the alteration with the depth, frequently this being more accentuated towards the surface of the superficial deposits. In other cases the process is the other way round, depending on the mineralogical structure of the base rock and on the chemistry of the underground waters. Thus, when the chemical environment is relatively normal this process becomes more accentuated towards the surface of the deposits, indicating the influence of the exogenous factors. In other cases the process is the other way round, when the chemical environment from the underground is very acid and determines the rapid removal of the carbonates and the intensification of the ionic exchange. The excess of calcium that appears and the enrichment in sodium create a favorable environment to the processes of alteration. The growth of the degree of montmorillonitization leads to the decrease of the friction and cohesion forces, with massive water absorption, which explains the instability of some slopes with low inclinations. In other cases the alteration speed prevails with respect to the growth of the depth of the Quaternary deposits. There is a clear correlation between the depth of the alteration layer and the frequency of the terrain slides; and thus a "critical depth" can be established for each area with a certain lithological structure and with a certain make-up of the chemical environment of reaction of the different mineralogical compounds. The mineralogical study of the clays in correlation to the physico-chemical parameters can allow for the prediction of the behavior of the slopes, so that, by means of the remedial measures taken, it may become possible to limit the instability processes.

Therefore, in the evaluation of some terrains, the mineralogical factor plays an important role, which together with the other instability factors allows for a more rigorous assessment of the degree of risk and for the determination of a classification of the instability phenomena.

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REFERENCES

BANCILA, I. 1980. *Geologie inginereasca,* vol. **II**. Editura tehnica.
FLOREA, M.N. 1977 *Alunecari de teren si taluze* .Editura Tehnica.
ISTRATE, A. 1997. *Elemente de prognoza a evolutiei versantilor* Simpozionul - Schimbul de experienta al laboratoarelor din constructii, SELC X,Constanta.
ISTRATE, A. 1998. *Comportarea in timp a terenului de fundare-* Simpozionul - Schimbul de experienta al laboratoarelor din constructii, SELC XI,Calimanesti.
MATEI, L. 1983. *Argilele panoniene din Transilvania*, Ed. Academiei Romaniei,Bucuresti.