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GEOHARZARDS TRAPS ENCOUNTERED ON THE ROUTE OF THE HIGHWAY PITEŞTI-SIBIU, ROMANIA

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Abstract

The architecture of the geological structure is very often an intricate composition of structural rock and soil masses, affected by divers and independently or simultaneously discontinuities syn, or post genetic, which sustain one or more local and regional aquifers, and is continuously submitted to gravitational, and seismically hazardous actions. Usually, all large infrastructure projects invariable pass through one or more complex areas in which objectives are affected by geohazards at various scales. This is also the case of the route of the highway Pitesti-Sibiu, Romania, which was investigated in several field campaigns to decrypt the complex geological and hydrogeological structure. The paper elaborates and details, one by one, all enounced geohazards, which were studied by diverse and numerous investigation methods: geological, geotechnical, hydrogeological, and geophysical, by a multidisciplinary team.

Key words

Landslides, faults, expansive soils, erosional process, geohazard.

1 Geologic and tectonic frame

Along 50km sections of the route, the highway steps over four large geologic structures (from South-East to North -West): Getic Depression, Subcarpathian thrust belt, and Post-tectonic Cover of South Carpathians, and effectively cut up a stratigraphic column starting from Palaeocene sandstones and claystone, up to Quaternary alluvial, deluvial or terrace deposits. All structures, which are situated less than 150 km from the Vrancea Seismic Zone, are affected by a few deep intra-Moesical faults and more recent and superficial thrust faults which turn into blocky fractured shapes in the upper deposits.

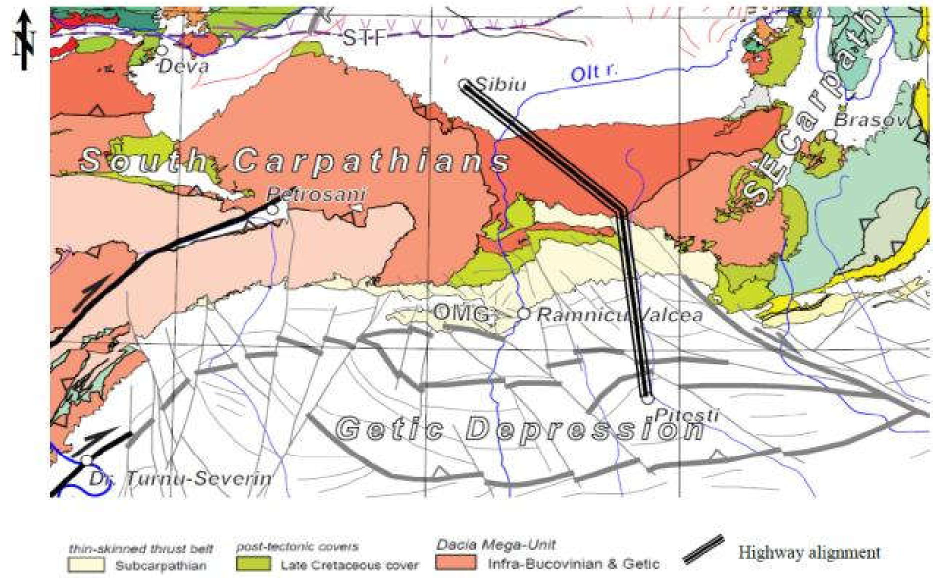

Figure 1. Geologic frame of the project (RGI, 2023)

2. Investigations

The field investigation program at the current stage of the study included geotechnical drilling, standard drilling penetration tests (*SPT*), heavy dynamic penetration tests (*DPH*), ~~and,~~ static cone penetration tests (*CPT*), *ERT* electrical resistivity tomographies and *MASW* seismic measurements. On the route of the studied highway section, a total of 208 boreholes with a total length of 4525 m was executed.

3. The Northern area

3.1. Geological frame of the Northern area

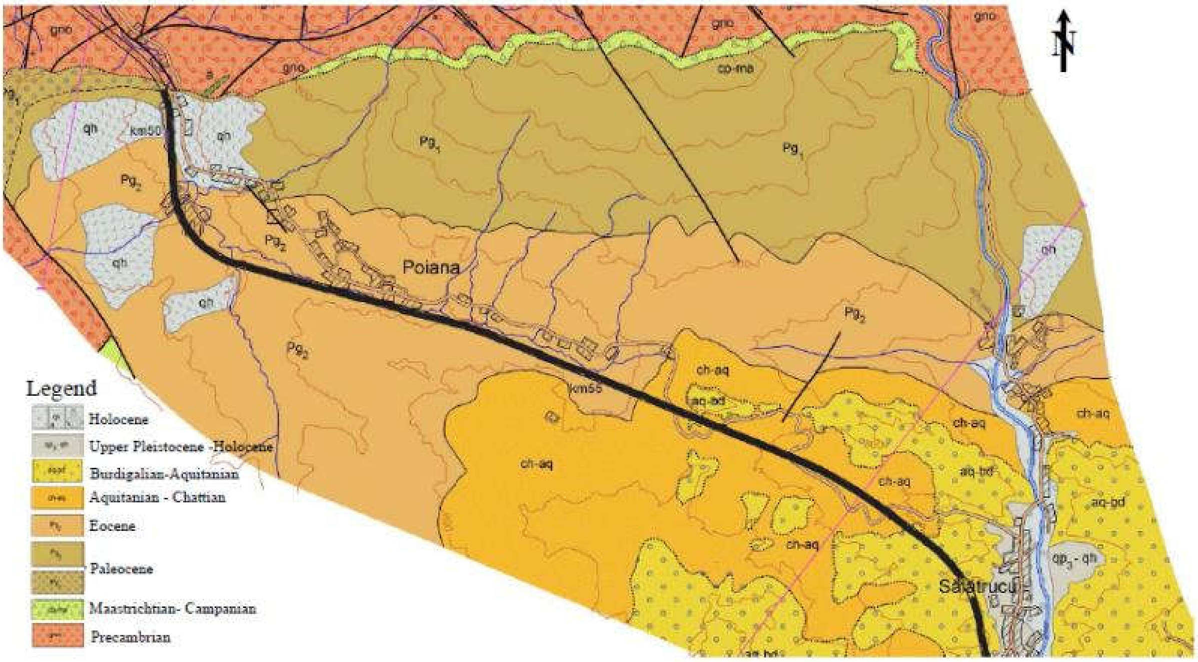

Figure 2. Geologic frame of the Northern area (RGI, 2021)

The oldest bedrock we encountered in the Northern area of investigation is Lower Paleocene (Pg_1) which are represented by polymictic conglomerates, or by grey and reddish marls with sandstones. This package appears at the surface on the extreme Northern frame of the investigated area, but is uncovered in all torrential valleys encountered in the highway alignment.
The Eocene deposits (Pg_2) are very extended at the surface in this area, and have large thicknesses what exceeds 100m. The basic level is represented by polygenic conglomerates containing crystalline shale, Jurassic limestone and coarse sandstone, followed by marls and sandstones.
The next layer is represented by the specific Pucioasa formation (*ch-aq*) consisting in dark-grey clays and thin layers of fine sand.
The newest bedrock we encountered in the area is the aquitanian-burdigal deposits (*aq-bd*) which are lithologically constituted of „*erratic*" polygenic conglomerates, sometimes poorly cemented by a sandy clay matrix, which includes elements from the most varied formations (crystalline shales, mesozoic rocks, etc, eocene organogenic limestones, as well as soft buckets of oligocene rocks), gravels and sands that comprise frequent intercalations of gray marl.
The shallow formations are mainly composed in thick, unconsolidate deluvial deposits (qp_3-*qh*) as in extended sliding masses of debris or landslides, both being predominantly constituted by elements coming from submerged deposits.

3.2. Geohazard traps encountered in the Northern area

3.2.1. Geomorphological hazards

As the topographical alignment of the highway, it's opening up on the top of the hills, between 800m and 700m height, it passes over numerous torrential valleys and ravines. All of them are thus open to erosional processes due to superficial spillage of rainfalls, which may attain 130mm/month in winter or 200mm/month in summer. In consequence, most of them (more than 15 positions) are found in various stages of evolution manifested by the presence of frequent faces of detachment and various stages of instability. Considering all above, the geomorphological hazard present in this area derives from the fragmentation of the general slope by torrential erosion of the water from surface runoff in the context of a predominantly non-cohesive substrate of the bedrock and of shallow deposits.

3.2.2. Hydrogeological hazards

In the Northern part of the Northen area, due to the high position of the site, the groundwater was intercepted at depths ranging from 1 m to 9 m, usually as an aquifer with a free level cantoned in the non-cohesive levels of the complex of quaternary deluvial deposits. Due to the lithological variability of the deluvial structure (is recognized that the existence of a minimum percentage of 20% of fine fractions <0.063mm, transforms a granular layer from aquifer into aquitard), it was frequently encountered the situation in which the cohesive levels from the surface of the land, locally bring the aquifer under pressure, fact demonstrated by the presence in several drillings of a piezometric level in a completely cohesive quaternary sequence.
In the Southern part of the Northen area, the groundwater was sporadically intercepted on the investigated route, only in 20% of executed boreholes, as a partial free-level aquifer, partial under pressure, located at depths ranging from 0 m to 22 m, either in the deluvial deposits or in non-cohesive layers of the base rock. Likewise, deluvial deposits, the non-cohesive deposits of the base rock have variable percentages of fine fractions, creating the premises that they become locally aquitard, and thus delimiting multiple discontinuous "*suspended*" aquifers, feed from precipitation.
Overlaid over the general regional aquifer situated at deeper depths, these local "*suspended*" aquifers are non-permanent, but temporary, during periods of strong rainfalls when they can enter under pressure, generating (also temporarily) the loss of internal resistance of non-cohesive deposits.

3.2.3. Geological and geomechanical hazards

From geologic point of view, hazards that may occur in this part of the project is related both on the bedrock formations and on the shallow deposits, as we describe below.
The bedrock formations, regardless of petrography / lithology or age, is found in boreholes with the specific characteristics of an overconsolidated rock, intensely fragmented by relaxation and sometimes with one or more intense shearing intervals. This situation may explain by the fact that in this specified area, all bedrocks formations were and still are subject to the following fields of efforts (Figure 2 a, b, c):

- Overall tectonic stress applied to the entire sedimentary structure, which manifests in long term (compressions and shears with extremely low deformation speeds occurring in geological time, but which by summing up the effects can generate such deformations);
- actual and local stresses, due to sliding forces acting in time at a perceptible human scale; in the preliminary phases of sliding phenomena, the entire sliding forces generate plastic or brittle deformations (depending on the degree of saturation of the clays / degree of cementation of sandstones or conglomerates) which are not (yet) generalized along a unique sliding surface to facilitate the movement of a large mass of rocks, or in final stages assembled on a proper shear surface which allows displacements of the upper deposits on limited distances to a position with lower potential energy.

Figure 3. Aspects of hazadous geologic characteristics of cohesive bedrock:
(a) undisturbed; (b) sheared ; (c) intensely fragmented by relaxation Pucioasa formations(*ch-aq*);

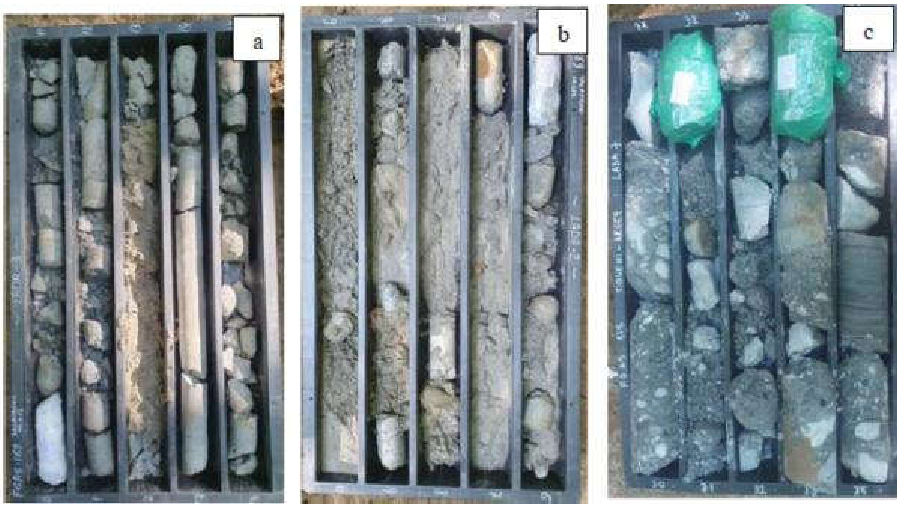

Figure 4. Aspects of hazadous geologic characteristics of un-cohesive bedrock:
(a) Variable degree of cementation of sandstone; (b) immersed sands and fragments of Eocene sanstone (Pg_2);
(c)) „*erratic*" polygenic conglomerates with variable degree of cementation *(aq-bd)*

Most of the time, the non-cohesive bedrock deposits are either fine and very homogeneous or coarse and extremely inhomogeneous, containing numerous rock fragments of various sizes and petrographic types. In many positions the fine - non-cohesive deposits are found in a partially/apparently cemented state (Figure 4, a), generating levels of sandstone with cementing levels ranging from uncementing to very well cemented. But there are also situations where these deposits contain intercalations of conglomerates, core samples with lengths >0.50m of compact rocks or fragments of hard rocks which are more or less ~~desegregated~~ (disaggregated?) (Figure 4, c).

The shallow formations in this part of the project are exclusively Holocene deluvial type (*qh*) which are always unconsolidated and consists either of weakly cohesive matrix (in soft or very soft plastic state) mixed with elements of the bedrock, or more frequently they are made up mainly of non-cohesive soils, is loose state.

Even that the uncohesive bedrock formations or shallow deposits are found in predominantly dry state, another hazard that may affect these soils is related to the genetic or postgenetic hererogenity of these deposits which promote the formation of temporary, discontinuous "*suspended*" aquifers, that we described above, during or after every strong precipitation. In consequence, in short time sequences, the entrapped areas of uncohesive deposits may develop temporary excessive water pressures which destroy the natural sedimentary structure and leave the volume of the affected slope with near nul shear resistance. As mark of this geomechanical process, we found in boreholes, in both formations frequently “immersed sands”, as presented in Figure 4. b.

Due to the limited and discontinuous extensions of these suspended aquifers, displacements do not generate a well-defined area of yielding, however, it is very likely that this fact is one of the primary causes of multiple lithological disturbances and discontinuities of the non-cohesive deposits that subject the slopes constantly and continuously to some "incremental" displacement downstream, over short distances. These cumulative manifestations over time, or amplified by seismic events (that may generate even local liquefaction areas) can lead to significant instability as is confirmed by geophysical investigations executed in these areas, two of them being presented in Figure 5.

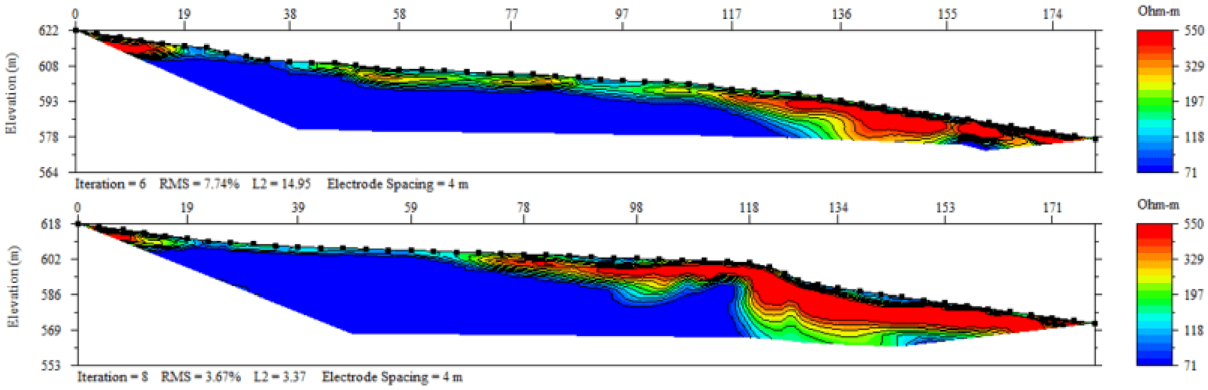

Figure 5. Geophysical investigations (*ERT*) wich confirm the instability of deluvial shallow deposits (Geotesting C.I, 2023)

4. The Southern area

4.1. Geological frame of the Southern area

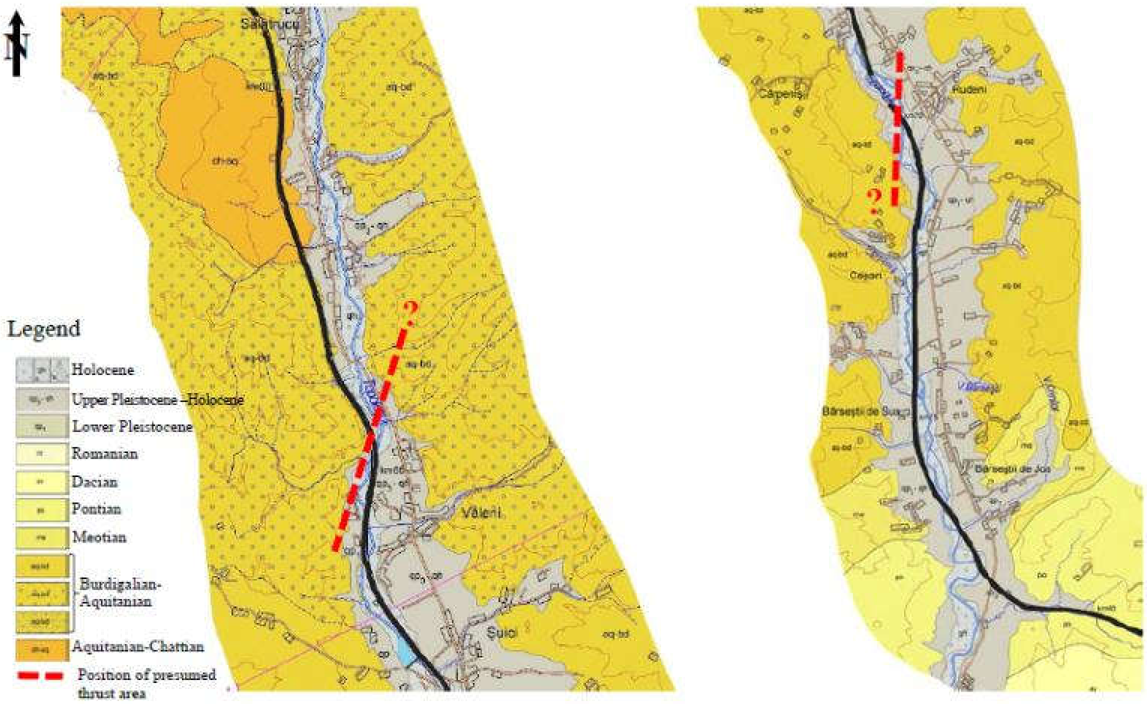

Figure 6. Geologic frame of the Southern area (RGI, 2021)

The oldest bedrock we encountered in the Southern area of investigation is Pucioasa formation (*ch-aq*) consisting in dark-grey clays and thin layers of fine sand, which is exposed at the surface in the North part of the Southern area, but is spread in depth in all the rest of the project.
It is covered by a thick package of aquitanian-burdigal deposits (*aq-bd*) which were mainly described in the previous section 3.2., but here a new member completes the succession, respectively a reddish layer of clays or marls.
The next lithologic complex is attributed to Miocene epoch and is composed mainly by marls (*me, po, ro*) or marls alternated with sands (*dc*).
The shallow formations are mainly composed in alluvial gravels which are regionally spread, namely Cândeşti Strata (qp_1), followed by unconsolidated deluvial deposits (qp_3-*qh*) and actual alluvial sediments (*qh*).

4.2. Geohazard traps encountered in the Southern area

4.2.1. Geomorphological and anthropic hazards

In this Southern part of the project, the route alternately crosses the both banks of the Topolog river.

On the right side of the river, which have a limited extension, the route traverses both the terrace and the meadow units, encountering the following geomorphologic features which generate hazardous aspects that may affect the embankment:

- The position on the highway is often situated on the first level of the terrace, in the area of connection with the base of the hill slope, which reach higher altitudes between 550m and 750m, and are cut by numerous torrential valleys and ravines. Locally, in several positions it approaches very close to the slopes, which in some places already manifests instability phenomena under various stages of development;
- these critical positions favors also the temporary the accumulation of the flows from surface runoff of precipitation, which are prevented from infiltration in deep by the presence of impermeable river bed, or the accumulations of permanent springs that emerges at the base of the slopes, and are obstructed from discharge in river by the embankment itself;
- Also, on this side of the river the phenomena of instability of the connection between the terrace deposits (3m-15m height) and lower alluvial banks, as of the erosional processes of the latter, are quasi permanent presented;
- finally, we mention here, as an important anthropic hazard, the presence of the exploitation career of sand and gravel in Salatrucu, Arges County, which is subjected to continuous regressive erosion processes under the action of rainwater, accentuated on the background of poor cementing of conglomerate formations (Figure 7).

Figure 7. Aspects of the perimeter of the exploitation of sand and gravel quarry in Salatrucu

On the left side of the Topologu river, mainly extend the alluvial plain on 2km-3km wide and in consequence the embankment will encounter only:

- erosional processes of alluvial banks, which is active along the entire length (Figure 8);
- fewer torrential valleys affluents on the left that discharges the waters coming from the surface of the terrain and water leakages on the forehead of the alluvial plain. In one position, namely Vãleni location, it develops a limited area of terraced deposits that are shattered by an important left affluent;
- some instability phenomena at the level of connection between the minor and the major riverbed;
- finally, an important anthropic hazard on this side represents the presence of numerous and extensive bumps (positive and negative) due to chaotic exploitation of alluvial deposits or landfills, as the presence of a small concrete dam.

Figure 8. Undisturbed (left) and instable deposits (right) of riverbanks

4.2.2. Hydrogeological hazard

In this Southern part of the project, we encounter two superficial aquifers located on both sides of the Topolog river:

- on the right side, the phreatic aquifers develop according to the morphological unit in which they are quartered. These aquifers are located in terraces and deluvial deposits that are generally coarse, consisting of sands, gravels and boulders;
- on the left side, the meadow of Topolog has between 2 km and 3 km wide, and the groundwater level is situated between 0.5 m-2 m deep, in aluvial porous permeable layer deposits which are covered by a thin waterproof roof. During periods of intense rainfall, the regime of flow can temporarily enter under pressure and under high hydraulic load, the aquifer can become artesian at the base of the embankment. In the discharge sections of this aquifer, due to temporary rise of hydraulic gradient of water flow, pipping and internal regressive errosions may occur, causing extensive landslides as is the case of above mentioned Vãleni area.

Bellow all these phreatic aquifers lays a huge structure, namely the "Cândeşti Layer". From hydrogeological perspective, it is defined as a large multistat-aquifer structure characterized by hydraulic conductivity of up to 100m/day and transmissivity of less than 1000m^2/day, with a thin supply front in the North, which ends at contact with the Carpathian chain and the main directions of groundwater flow from North to South (Palcu et. al., 2008).

This regional hydrogeological configuration is in hydraulic contact with deeper regional aquifers and can develop water pressures on the coatings up to 40 Barr. The entire package of multilayer aquifers (from the Jurassic to the Upper Pleistocene) operates under a pressure regime that becomes uneven artesian. These deep (regional) aquifer horizons defined as the "Dacian Artesian Basin", is located under the erosion base and is supplied by infiltration of the surface waters of the main valleys and atmospheric precipitation through the border areas of these formations, which sometimes are situated far away. In consequence, all these structures are therefore in hydraulic communication with the groundwater levels generating vertical drainage phenomena when the developmental pressures are high (Figure 9).

Figure 9. Artezian well and swamping areas created by vertical ascensional drainage of Cândeşti aquifer

4.2.3. Presence of expansive soils

On this Southern part of the project, the foundation ground consists mainly of weakly consolidated or normally consolidated alluvial quaternary formations (maximum 15m thick), followed in depth by bedrock formations which include alternations of cohesive and non-cohesive complexes (Figure 10). The main risk factor is the quasi-continuous presence of soils with large swelling and contractions, both in the case of bedrock formations framed in the cohesive complex and sporadically in the fine-cohesive levels of the quaternary deposits. An extensive study of these swelling formations was based on more than 660 samples that have been tested both mineralogical and geotechnical.

Figure 10. Cohesive bedrock in the Sothern part of the project

From mineralogic point of view, these swelling soils are made mainly of hydrous phyllosilicate, especially of smectite clays (60%-80%), followed by illite (20%-30%) and subordinate kaolinite and chlorite. The main geotechnical characteristics include the predominance of fine granulometric composition (*Cl* and *siCl* in proportion >72%), of high and very high plasticity (I_p >20% in the proportion 95%). In the purpose of a better interpretations, the results have been divided into three classes according to the plasticity index and range values of swelling pressure (p_u), as presented in Table 1.

Table 1. Classification system according to plasticity indices and swelling pressures results

Class of swelling pressures		C1 No	C1 [%]	C2 No	C2 [%]	C3 No	C3 [%]	Total number of samples	[%]
(I)	p_u<200kPa	28	100	203	91	254	62	485	73
(II)	200≤ p_u<400kPa	-	-	16	7	114	28	130	20
(III)	$p_u \geq$400kPa	-	-	4	2	44	11	48	7

Figure 11 presents the variation in depth of the swelling pressure as the corresponding distribution of differences between inflation pressures and geological load at the level of sampling of the respective sample (p_u-s_g).
We appreciate that these values must to be regarded as estimative but expressing a real geotechnical risk that can manifest both in the areas specified by this investigation, as well as in the syngenetic areas that have not been tested yet, especially due to the intricate occurrence of these soils in the vicinity or inside the Cândeşti Strata.

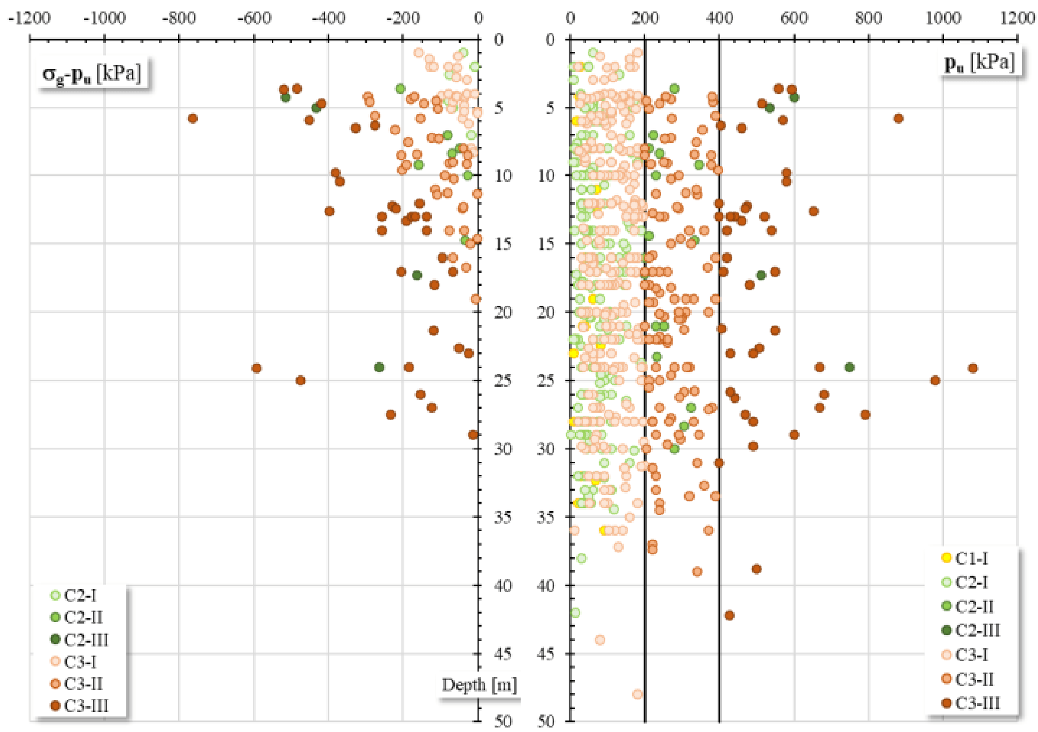

Figure 11. The variation in depth of p_u (right) and of the potential heave of Cândeşti Layers (left).

4.2.4. Tectonic hazard

In this Southern area, we found some geomorphological aspects that suggests that the entire geological structure is possibly affected by tectonic disturbances. More precisely, in at least two locations in this area, the river suffers a sudden change of the course direction, both dextro-roughing, with displacements of about 100m (Fig.6). These aspects are consistent with the tectonic compression frame of this sector where other systems of parallel fault with NE-SV direction are already pointed out. In these two locations, these presumptions are also sustained by the findings in the cores of the boreholes situated on both sides of the presumed fractures, mainly by the following aspects whose explanation can only be one of tectonic nature:

- in the areas of the roughest of the river, the continuity of the geologic and hydrogeologic structure is broken on short distances, by the development of different members of the bedrock (cohesive/noncohesive) respectively, by the disappearance of the underground water table level on several meters distances;
- usually, the non-cohesive complex of the bedrock consists of fine to coarse granular deposits, which often also contain significant percentages of fine fractions, which are found in a partially/apparently cemented state, generating levels of soft rocks. In the positions we mention above, these deposits contain many intercalations or fragments of hard rocks, allogeneic as marbles, gneiss, or tuffs;
- the same situation is encountered also in cohesive complex of the bedrock, which usually contains levels of fine particles, generally in the stiff state, but the areas we reffer too these deposits contains frequently hard allogeneic rock fragments imbedded, and the soil matrix was found in a soft consistency.

5 Conclusion

The complex investigations – geomorphologic, hydrogeologic, geologic, mineralogic and geophysical-performed on the alignment of about 20km length between Poiana and Tigveni, part of Piteşti-Sibiu highway, revealed several natural and anthropic aspects that may become truly traps for the further large project.
Geomorphologically, in the Northern part, the route is situated on the slopes and alternately crosses climbs, promontories and torrential valleys, with west-east orientation. Here, instability phenomena are already manifested in various stages of evolution, most of them along torrential valleys which fragmented the continuity of the slope and eroded the base thereof, constituting preliminary factors of the instability re-appearances. In the Southern part, the route is situated on the terrace level and on the alluvial plain of the main watercourse Topolog, and the main geomorphologic traps consist in the development of the erosional processes both of the river at the base of the terrace as of runoff precipitations on very neighbouring slopes.
From hydrogeological perspective, in the highlands of the Northern part, heterogeneity of deluvial deposits favo~~u~~rs the formation of non-permanent suspended aquifers, which temporarily during periods of precipitation, may enter under pressure, generating loss of internal resistance of non-cohesive deposits. Consequently, these are subject to downstream "incremental" displacements on short distances, in a process that occurs without the formation of a well-defined area of disposal, but are uncovered by superficial deformations. In the Southern part, hydrogeological traps refer to the artesian manifestation of both superficial (alluvial) and regional (Cândeşti) aquifers that may induce pipping and internal regressive erosions in foundation terrains, or the wetting of the base of the future embankment.
The specific geological features consist, in the Northern part, in the prevalence in the foundation terrains of the over-consolidated rocks which have been affected by tectonic and neo-tectonic processes of folding, cutting or even bending over other formations, and now during the project excavation, may be easier affected by sliding processes due to relaxation deformations. In the Southern part, the main geologic trap is the presence and the discontinuous spreading of expansive soils, with a very hight content of smectite minerals (60%-80%). Here, the recorded values of the swelling pressures are also sometimes exceptional ($p_u<1080kPa$), and are associated with very high free swelling values ($U_L<600\%$). This feature is even more hazardous, as these layers are prone to wetting by ascensional vertical drainage phenomena of the regional Cândeşti aquifer.
Apart from the major seismic hazard which derives from the vicinity with one of the strongest seismic epicentral areas of Europe (less than 160 km from Vrancea), the tectonic network of main and secondary faults has been proved denser than the official tectonic architecture, some of them being revealed by newest investigations and still pending for geophysical seismic endorsement.

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