GEOLOGICAL VULNERABILITY OF THE A1 HIGHWAY. CASE STUDY ON THE ACILIU SECTOR (SIBIU COUNTY)

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Abstract. This paper examines the connections between the regional geological context and the local geological conditions on the Aciliu sector of the A1 highway, in order to identify the geological vulnerability factors of the construction works made in this sector. We refer to the cutting on the southern side of the Bucium Hill and to the Aciliu Viaduct, affected by landslides, deep gallies and major malfunctions after the opening of highway traffic. On this occasion, the necessity of geological studies on both regional and local scale in choosing the optimal route of roads is emphasized.

Keywords: geological vulnerability, A1 highway, Aciliu Viaduct.

Rezumat. Vulnerabilitatea geologică a autostrăzii A1. Studiu de caz pe sectorul Aciliu (județul Sibiu). În lucrare sunt analizate conexiunile dintre contextul geologic regional şi condiţiile geologice locale din sectorul Aciliu al autostrăzii A1, pentru identificarea factorilor geologici de vulnerabilitate ale lucrărilor de construcţii executate în acest sector. Ne referim la debleul de pe versantul sudic Dealul Bucium şi la viaductul Aciliu, afectate de alunecări de teren, ogaşe adânci şi defecţiuni majore după deschiderea circulației publice pe autostradă. Cu această ocazie, este subliniată necesitatea studiilor geologice la scară regională şi locală în alegerea traseului optim al căilor rutiere.

Cuvinte cheie: vulnerabilitate geologică, autostrada A1, viaductul Aciliu.

INTRODUCTION

The deteriorations that have occurred on the Sibiu-Orăştie section of the A1 highway after the traffic opening, especially on the Aciliu sector, are of public notoriety. Partially, these problems are the result of insufficient knowledge of the geological structure of the ground, superficially treated in the pre-construction geotechnical studies. Anyway, such studies have a local character, and the local geological data cannot be correctly interpreted outside of a wider geological context, especially the structural and the tectonic data.

The geological vulnerability of a road appears more clearly if is first analyzed on a regional scale. Such an analysis should take into account three geological factors of vulnerability: lithological, structural and tectonic. We will also use the phrase “geological structure of the ground” in this text, as a synonym for all three factors of vulnerability.

The lithological factor is important for sedimentary terrains consisting of weakly consolidated rocks, such as sands, clays or marls. It is the case of Neogene sedimentary formations on the orogen border and from the intramontane depressions. Frequently, permeable and impermeable rocks alternate in their lithological constitution. Large open excavations in such geological formations represent new ways of infiltration of water in the permeable sequences to their waterproof substrate, which softens by favouring the sliding of the overlying rock layers.

The lithological vulnerability is lower for magmatic and metamorphic terrains, made up of rocks much stronger than the sedimentary ones. The boundaries between the formations with contrasting lithologies from mechanical and rheological point of view may be vulnerable in the metamorphic terrains. These boundaries may become locally unstable due to seismic movements and to the permanent vibrations caused by road traffic.

The structural vulnerability factor is important for sedimentary and metamorphic terrains, especially for those wich are weakly metamorphosed. For example, a cutting that is excavated parallel with the strike of a monoclinal structure can produce landslides on the cutting slope inclined according to the monoclin. The same thing happens by severing the limb of an anticlinal parallel with its axial plane, as the rocks in the fold hinge tending to slide into the excavation. In both situations, lithological and tectonic factors can aggravate the landslides. A local geological study can not reveal a regional geological structure.

Tectonic vulnerability exists in all geological types of terrains. The faults weaken the cohesion of rocks and increase their permeability, facilitating the water infiltration in the subsurface, on the crossed structural discontinuities and the permeable rock layers severed by tectonic planes. Crustal earthquakes frequently occur along the major active faults increasing the terrain instability. Most of the time, the characteristics of a tectonic plane cannot be understood on a local scale, especially in sedimentary formations with non-cohesive and monotone lithologies which do not preserve the faults traces and the movement markers.

This study tries to show how the regional geological context is reflected at a local scale as well as the consequences of ignoring the context on the A1 highway, with reference to the Aciliu sector. The biggest construction on the highway route was erected here, i.e. the Aciliu Viaduct, as well as the largest anthropic intervention in the geological environment, i.e. the Aciliu cutting, excavated on the southern side of the Bucium Hill, near the Aciliu Village, and on the northern foot of the Furcilor Hill, very close to the Sibiu-Sebeş railway.

LITHOLOGICAL AND STRUCTURAL DATA

The geological formations in the studied region belong to the metamorphic basement (Getic Crystalline) of the Cibin Mountains from their north-eastern edge, and to the sedimentary deposits of the Transylvanian Depression from its south-western border.

Metamorphic formations. The metamorphic basement of the Cibin Mountains in this region mainly consists of gneissic rocks representing the lower complex of the Getic Crystalline (Fig. 1). This includes two metamorphic formations, one of micaceous gneisses with lenses of amphibolites and pegmatites, at the top, and one of augen gneisses with remnants of undeformed coarse-grained granitoids, at the bottom. Micaschists and quartzo-feldspathic gneisses from the upper complex appear only on small areas. A diverse range of fine-grained mylonitic schists, mainly chlorite and feldspathic schists, with interlayered marbles and amphibolites outcrop along a major tectonic lineament corresponding to the Răşinari Shear Zone.

The Hercynian structure of the Getic Crystalline is tabular and subhorizontal at a regional scale, but in the north-eastern part of the Cibin Mountains it was weakly folded during the Late-Alpine orogenesis. On the contact with the Transylvanian Depression the basement is cut by vertical dip-slip faults, N-S and NE-SW trended, the tectonic blocks in the Tilişca, Sălişte-Sibiel and Orlat areas being moved downward. The entire basement gradually sinks under the sedimentary cover on normal faults parallel with the orogen, reaching depths of over 1,000 meters in the Sibiu Town area (e.g. GHEORGHIAN et al., 1975).

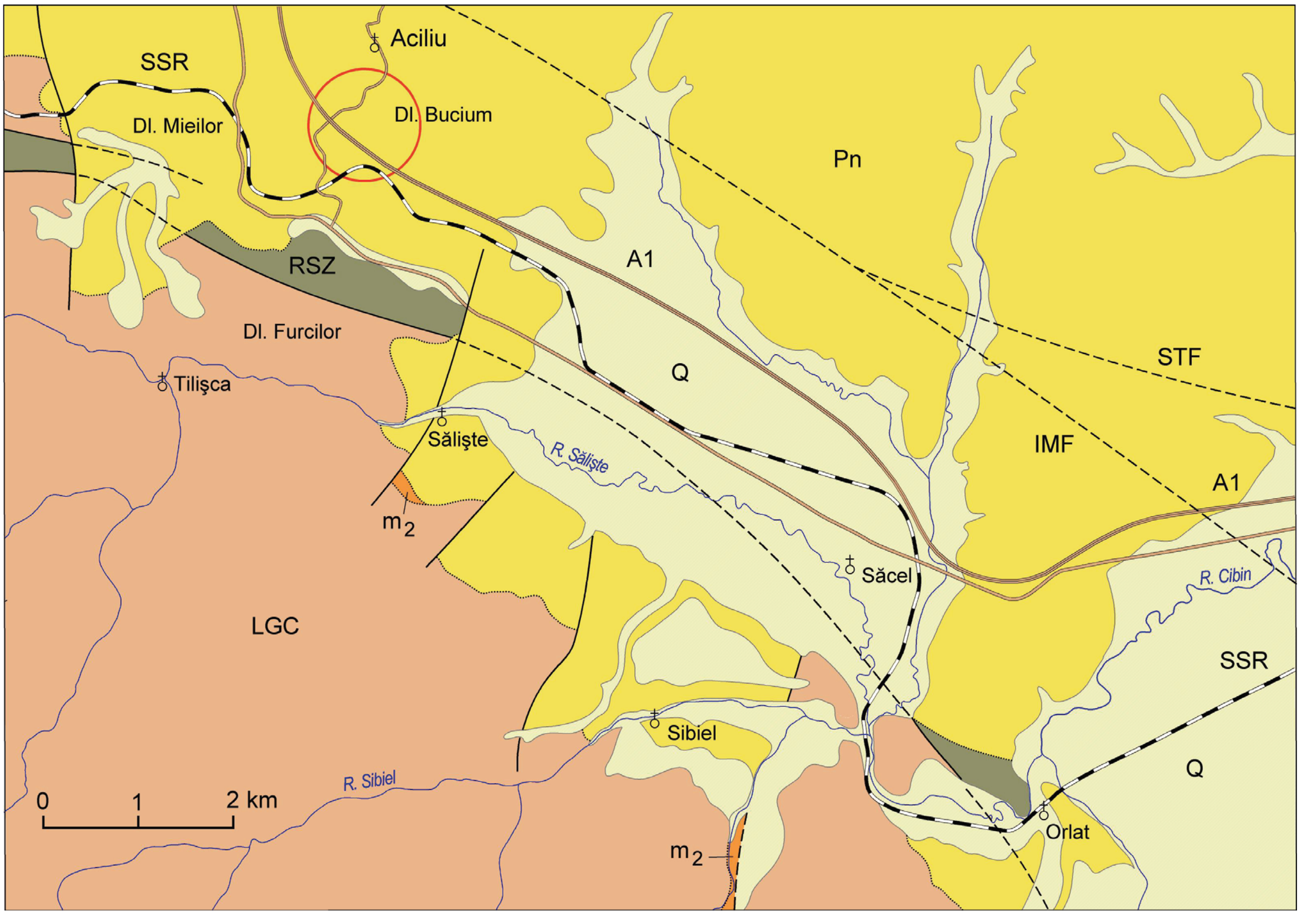

Figure 1. Simplified geological map in the Aciliu area (after STELEA & SĂNDULESCU, 1993). Legend: Q-Quaternary deposits; Pn-Panonian formations; m_2- Badenian formations; LGC-Lower Getic Complex; RSZ-Răşinari Shear Zone; IMF-Intramoesian Fault; STF- South Transylvanian Fault; A1-A1 highway; SSR-Sibiu-Sebeş railway; Red circle- Location of the photos in Figs. 2 and 3. Details in text.

Sedimentary formations. The sedimentary deposits of the Transylvanian Depression are made up of Upper Cretaceous-Lower Miocene sequences, representing the post-tectonic cover of the orogenic structures, and of Mid to Upper Miocene sequences, representing the depression molasse fill (SĂNDULESCU, 1984). The stack thickness generally increases from the orogen to the central part of the basin, but the drilling data show that the stratigraphic terms of the pile have neither constant thickness nor continuous areal development. For example, in the drilling near Daia, a village situated 14 km east of Sibiu, the Badenian lies on the Eocene, intercepted at the meter 940. In the drilling near the Ilimbav Village, situated 30 km east-northeast of Sibiu, the Sarmatian lies directly on the metamorphic basement, met at 1,355 meters deep (VANCEA, 1960).

At the topographic surface, the Pannonian formations develop on large areas in this region (Fig. 1), while Badenian and Sarmatian formations outcrop on small areas, only on the basement margin (STELEA & SĂNDULESCU, 1993). The Badenian is represented by dacitic tuffs and tuffites with rare intercalations of marls, sometimes marls and clays. The Sarmatian is represented by calcareous sandstones, sands and gravels with intercalations of marls. The Pannonian deposits consist of thick sequences of sands and clayey sands with thin lenses of gravels, and marls with thin intercalations of unconsolidated sandstones.

Details in the Aciliu area. The total thickness of the Pannonian deposits exposed in outcrops is about 300 meters in the Aciliu sector of the A1 highway. The general strike of the beds varies from NNW-SSE to NNE-SSW, with dip of 2-5 degrees towards the ENE and ESE respectively.

A succession of marls and sands with decimetric levels of fine gravels outcrops on the northern side of the Bucium Hill. On its southern side, reddish clays outcrop in the eastern part of the highway cutting slope, severely affected by landslides with gullied scarps of 1-4 meters high (Figs. 2a, b). Yellow-reddish clayey sands with decimetric levels of sands and gravels outcrop in the western part of the cutting slope, affected by a branched system of 2-3 meters deep gullies exposing the marls beneath (Fig. 2c). The same marls outcrop on the western side of the hill, under the Aciliu Viaduct (Fig. 2d). Yellow-reddish clayey sands also outcrop on the opposite cutting slope, affected by parallel gullies following the line of greatest slope.

Figure 2. Outcrop photographs in the Bucium Hill area (original, September 2017). a, b) Landslides in the clays from the eastern part of the cutting slope; destroyed drenaige works and textile net are seen. c) Gullies in the clayey sands from the western part of the cutting slope, with marls (m) on the bottom of the deep gullies. d) Sistematically fissures on NW-SE direction in the Pannonian marls under the Aciliu Viaduct (detail).

REGIONAL TECTONICS

Four major tectonic lineaments join on the south-western border of the Transylvanian Depression, without taking into consideration the presumed Oltului Fault, insufficiently documented. These are the Intramoesian Fault, on NW-SE direction, the South Transylvanian Fault, on E-W direction, the Răşinari Shear Zone, on the NW-SE direction in this region, and the Sadu Fault, on the WSW-ENE direction. The first three faults cross the Aciliu area, their trace being buried under the Pannonian sedimentary deposits (Fig. 1). Only the Intramoesian Fault is active, but the frequent seismic movements along it could cause local reactivations on the other faults, most likely on the South Transylvanian Fault, parallel to the European road, Sibiu-Braşov.

These faults also favoured the emergence of mud volcanoes (locally named *gloduri*) in this region, on the Alba Iulia-Sibiu and Sibiu-Făgăraş alignments (CIUPAGEA et al., 1970). On the A1 highway route are mentioned mud vulcanoes at the Sibiu Town (Guşteriţa district) and the Apoldu de Jos Village, 10 km north-northwest of Aciliu.

The Intramoesian Fault. The well-known crustal earthquakes in the Făgăraş Mountains area are related to the Intramoesian Fault, with dextral strike-slip movement on the alignment Sibiu-Câmpulung Muscel. The fault crosscut the metamorphic basement as well as the pre-Pliocene terms of its sedimentary cover. The geological trace is partly coincidental with the geophysical trace of the tectonic line Oradea-Cumpăna, gravimetrically highlighted at the level of the Moho discontinuity (SOCOLESCU et al., 1964).

In its western compartment, the Intramoesian Fault is accompanied by secondary faults with the same general direction, representing the expression at the topographic surface of a deep structure, asymmetrically branched (STELEA, 2017). Consequently, the related seismic activity is asymmetric with respect to the main tectonic plane, chiefly affecting the western fault compartment, from Târgovişte to Sibiu (VISARION et al., 1988).

The South Transylvanian Fault. This fault was active with dextral strike-slip movement during the Cretaceuos, allowing the eastward translation of the Intracarpathian crustal block and thus the synchronous nappes emplacement in the East Carpathians (SĂNDULESCU, 1984). In the Sibiu region, the South Transylvanian Fault was subsequently intersected by the Intramoesian Fault and dextral displaced on the Apoldu de Jos-Sibiu alignment. On the fault segment east of the Intramoesian Fault, the metamorphic basement of the Făgăraş Mountains is 500 meters moved downward under the sedimentary deposits of the Transylvanian Depression (CIUPAGEA et al., 1970).

The Răşinari Shear Zone. This tectonic lineament crosscut the entire northern margin of the Sebeş-Cibin Massif from the Streiului Valley to the Lotrului Valley, on an arcuate trace with the length of 150 km. It is a Hercynian fault with dip-slip movement which accommodated the differential up-lift of the getic metamorphic pile, with higher rates in the axial area of the orogen than on its northern margin. The fault was intermittently reactivated with sinistral strike-slip movement during the Early-Mid Alpine orogeneses, when the medium-grade mylonites inside the shear zone as well as the adjacent host rocks were dynamically retrogressed. Usually, the fault zone segment south of Răşinari is considered as thrust plane of the Supragetic Nappe.

Between the localities Sălişte and Cisnădioara, the shear zone is covered by the sedimentary deposits of the Transylvanian Depression, starting with Cenomanian conglomerates (GHEORGHIAN et al., 1975). Very likely, secondary faults from the western compartment of the Intramoesian Faults overlap over the shear zone in this area.

The Sadu Fault. It is a Tertiary fault with sinistral strike-slip movement which displaced *en echelon* the Răşinari Shear Zone between the localities Râul Sadu and Sadu; the fault plane is subvertical at present. Toward WSW, the fault crosscut the left side of the Sadu Valley then follows the Frumoasei Valley and reaches the basin of the Eastern Jiu River. It is possible that this fault may have contributed to the formation of the sedimentary Petroşani Basin, in tandem with the Cerna-Jiu Fault, with dextral strike-slip movement during the Eocene and dip-slip movement during the Oligocene and the Miocene (BERZA & DRĂGĂNESCU, 1988). Toward ENE, the Sadu Fault is covered by the Mid Miocene sedimentary deposits from the Cisnădie-Boiţa area and probably stops in the Intramoesian Fault.

Details in the Aciliu area. In the outcrops of marls on the western side of the Bucium Hill, under the Aciliu Viaduct, have been measured a set of equally spaced fissures, NW-SE oriented (Fig. 2c), and a set of joints NNE-SSW oriented. Joints with NW-SE and NNE-SSW orientations also occur in the marls on the northern side of the hill. In the marls levels that occur in the sands on the eastern side of the Mieilor Hill, on the other side of the A1 highway, have been measured NW-SE and N-S oriented joints, with calcite efflorescences.

One thing draws attention, namely the systematic character of the joints and fissures with NW-SE orientation. These appear on both sides of the highway on a distance of at least 2000 meters, from the Bucium Hill to the Mieilor Hill, indicating the existence of a tectonically controlled joint corridor along the highway. We also note that the joints occurring under the viaduct are open and that the joints occurring on the northern side of the Bucium Hill sometimes coincide with the slide surface of some old landslides. These field data suggest that the joint set with NW-SE orientation is active, which is why we associate it with the tectonic movemens along the Intramoesian Fault, the only active fault în this region.

IMPACT ON THE HIGHWAY IN SEPTEMBER 2017

In September 2017, all the drainage works made in the Aciliu cutting slope on the Bucium Hill (drainage channels, pipes and collecting channels), as well as the textile net for soil protection, were practically destroyed by still active landslides and gullies (Figs. 2a, b; 3a). Water is gathering and a hydrophilic vegetation grow behind the sliding mass (Fig. 2a). The landscape is desolated. We mention that there were no landslides on the southern side of the hill prior to the cutting excavation.

Gullies of 1-4 meters deep appeared at the heads of the Aciliu viaduct, between the abutments and the downstream pilots (Figs. 3b, c), especially at the north-western head, toward Apoldu de Jos, where the works at the abutment were affected; the drainage channels were broken and the concrete slabs for the embankment protection were cracked and dislocated (Figs. 3c, d). The two abutments have already fallen once, the north-western one in 2015, and the south-eastern one, toward Sălişte, in 2016. Although these have been repaired, the problems appeared again. Considering the geological structure of the ground and the vibrations caused by the road traffic, correlated with the effects of atmospheric precipitation, we anticipate that these damages will increase in the future.

Figure 3. Photographs of the highway construction works (original, September 2017). a) Broken collecting channel on the cutting slope (Bucium Hill). b) Gullies at the pilots down the eastern head of the Aciliu Viaduct. c) Broken collecting chanel and the subsequent gully at the western head of the Aciliu Viaduct. e) Cracked and dislocated concrete slabs at the western head abutment.

CONCLUSIONS

The Pannonian formations outcrop at 450 meters elevation under the Aciliu Viaduct, and at 315 meters elevation in the banks of the Secaş River near Apoldu de Jos. Therefore, the thickness of the sands, clayey sands and marls deposits in this sector of the A1 highway is of 100-130 meters. This means that the viaduct pilots, buried 40 meters deep, are fixed in the Pannonian soft rocks noway in hard rocks, term geologically equivalent with magmatic and metamorphic rocks. Evidence is the stability problems which appeared and continue to appear at the viaduct heads.

The technical solution for crossing through cutting the Bucium Hill did not consider the geological structure of the ground. Cannot stop with textile nets the sliding of a high hill of 613 meters excavated down to the highway elevation which is 550 meters in this sector. Above the highway there are over 50 meters of sedimentary formations with alternation of permeable and waterproof lithologies, systematically fissured on NW-SE direction, parallel to the highway in the Aciliu sector, but intersecting the highway in the Apoldu de Jos sector. The hill will continue to slide until it reaches the natural slope of the rocks from which it is constituted and the drainage works will be permanently destroyed. It is possible that the railway above the opposite cutting slope to be also affected.

The geotechnical studies for the roads and highways construction, in general for civil and industrial construction, must be done with utmost responsibility and must be preceded by geological studies at regional scale and even at detailed scale if the geological structure of the ground requires this.

And last but not least, we must never forget that "civilization exists by geological consent, subject to change without notice" (DURANT, 1946).

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