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THE IMPACT OF EXPLOITING NATURAL SUBSOIL RESOURCES ON THE SUBCARPATHIAN RELIEF (ROMANIA)

ABSTRACT: CIOACĂ A. & DINU M., *The impact of exploiting natural subsoil resources on the Subcarpathian relief (Romania).* (IT ISSN 0391-9838, 2000).

This hilly unit, which makes the transition from the mountain to the platform regions of Romania, is particularly well-individualised between the Moldova and the Motru valleys. The Subcarpathian region, formed at the external margin of the Carpathian geosyncline, is the youngest mountain unit in Romania. This «new Carpathian wave» represents one more trait that distinguishes the Carpathians from the other sectors of the Alpine - Himalayan system. The string of hills and depressions, standing more or less parallel to the mountains, but situated at their periphery, has a distinct morphostructure that shapes out three big units: The Moldavian Subcarpathians, the Bend Subcarpathians and the Getic Subcarpathians.

The varied rates of present-day weathering, with significant local and annual differences, call for detailed studies whenever man intends to act upon the landscape. The extraction of raw materials in the Subcarpathians had a negative impact on natural modelling, leading gradually either to a new, man-made landscape, or to some complementary geomorphological processes. The hilly zones where lignite is mined are fragile ecosystems, very vulnerable to environmental changes. Human activity-induced relief degradation has far-reaching and long-term effects on the other components of the environment: water, air, vegetation, soils and settlements.

KEY WORDS: Natural subsoil resources, Anthropic relief, Subcarpathians, Romania.

REZUMAT: CIOACĂ A. & DINU M., *Impactul exploatarii resurselor naturale de subsol asupra reliefului Subcarpatic (Romania).* (IT ISSN 0391-9838, 2000).

Această unitate de relief care face tranziţia dintre regiunile montane, şi cele de platformă ale României, este bine individualizată între văile Moldovei şi Motrului. Regiunea subcarpatică formată la marginea externă a geosinclinalului carpatic, este cea mai tânără unitate montană din România. Acest «nou val carpatic» reprezintă o particularitate în plus care diferenţiază Carpaţii faţă de alte sectoare ale sistemului Alpino-Himalaian. Şirurile de dealuri şi depresiuni, mai mult sau mai puţin paralele cu bordura montană, dar situate la exteriorul acesteia, au o structură specifică care pune în evidenţă trei mari subunităţi: Subcarpaţii Moldovei, Subcarpaţii Curburii şi Subcarpaţii Getici.

Ritmul şi intensitatea proceselor geomorfologice actuale de modelare, cu diferenţieri locale şi anuale, necesită studii amănunţite, inclusiv efectele acţiunii omului asupra mediului. Extracţia resurselor naturale în Subcarpaţi a avut un impact negativ asupra modelării naturale a reliefului, conducând gradat la un nou peisaj, cel antropizat, sau la declanşarea unor procese geomorfologice. Regiunea deluroasă de extracţie a lignitului a devenit un ecosistem fragil, foarte vulnerabil la schimbările mediului. Activitatea antropică a dus la degradarea reliefului în moduri nebănuite, cu efecte pe termen lung asupra celorlalte componente ale mediului: apa, aer, vegetaţie, soluri şi aşezări.

CUVINTE CHEIE: Resurse naturale de subsol, Relief antropic, Subcarpaţi.

INTRODUCTION

The 150-year-old severe exploitation of the natural resources is an indication that human pressure had a lasting impact on the environment. In the beginning, environmental changes had a local character, spreading, in time, throughout the region and altering the characteristic features of the whole natural Subcarpathian realm. Of all the factors which have been affected, it is the relief that has suffered the most persistent and radical modifications. Human activity is responsible for the development of new landforms (both positive and negative) through the mining of lignite and the extraction of building materials; when crude-oil and salt started being exploited, the rate of geomorphic processes was accelerated (Brundsden, 1996). The size and extent of local modifications of the landscape are quite spectacular. Despite attempts to consolidate the waste dumps and rehabilitate the land such as it had been before the mining of lignite started, results were only partly successful. Studies on the local geographical environment suggest that the implementation of ecological rehabilitation programmes capable of equilibrating the natural components in quite a short time span is a must. It is the only chance of bringing the landscape as close as possible to its initial state (Cioacă & Dinu, 1996).

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GEOGRAPHICAL PARTICULARITIES OF THE SUBCARPATHIANS

Original aspects of morphostructure and morpholithology. The Subcarpathians (fig. 1) as a whole make up a distinct geomorphological unit. The landscape, governed by a tectonic and structure-controlled relief, shows a wide diversity of forms due to a remarkable variety of rocks. Although the area undergoes severe erosion, yet its morphogenesis is primarily related to the tectonic activity. For comparison's sake, let's say that the Prealps (resembling the Subcarpathians only as far as position in the vicinity of the mountains is concerned) are formed of a folded sedimentary cover that has not evolved within a geosyncline, so that the pattern of folds depends rather on the mechanical properties of rocks and inter-strata relations than on tectonics. Therefore, the Prealps unit is dominated by an inverted relief, while the Subcarpathians feature by conformable primary landforms developed on the latest folded structures.

The different relations between lithology and structure, on the one hand, and landforms, on the other, are detectable in two distinct morphostructural units: the Subcarpathian hills and depressions underlain by folded Mio-Pliocene structures and the Romanian - Quaternary monocline piedmont (fig. 2).

The folded Mio-Pliocene unit shows marked tectonisation (anticline and syncline folds, diapir folds, scale-like sheets, etc.) due to distinct tectonic mobility, of maximum intensity in the Bend area (positive movements of 2-3 mm/year). These particularities have individualised two subunits:

– *the highly folded and tectonised Mio-Pliocene structure, dominated by conformable primary forms*; its synclines and anticlines correspond to depressions and hills, respectively. There is also an inverted relief shaped by active erosion. This inverted relief is developed on a strip of land at the edge of the mountains. It is represented mainly by an almost continuous depressionary corridor, closed up towards the inside by a string of high hills. The main valleys are transversal to morphostructure lines (most of them have perpendicular sectors, but some, eg. in Moldavia, are oblique). Therefore, along transversal valleys one sees alternations of narrow channel sectors with steep sides and severely eroded slopes where the valleys pass through anticlines and broadened sectors governed by alluviation, into synclines or axial sinking areas.

– *the Pliocene structure* with simple, large and slightly faulted or monocline folds, built from low erosion-resistant marls, clays and alternations of sands, corresponds to the outer Subcarpathian side. The dominant relief is adapted

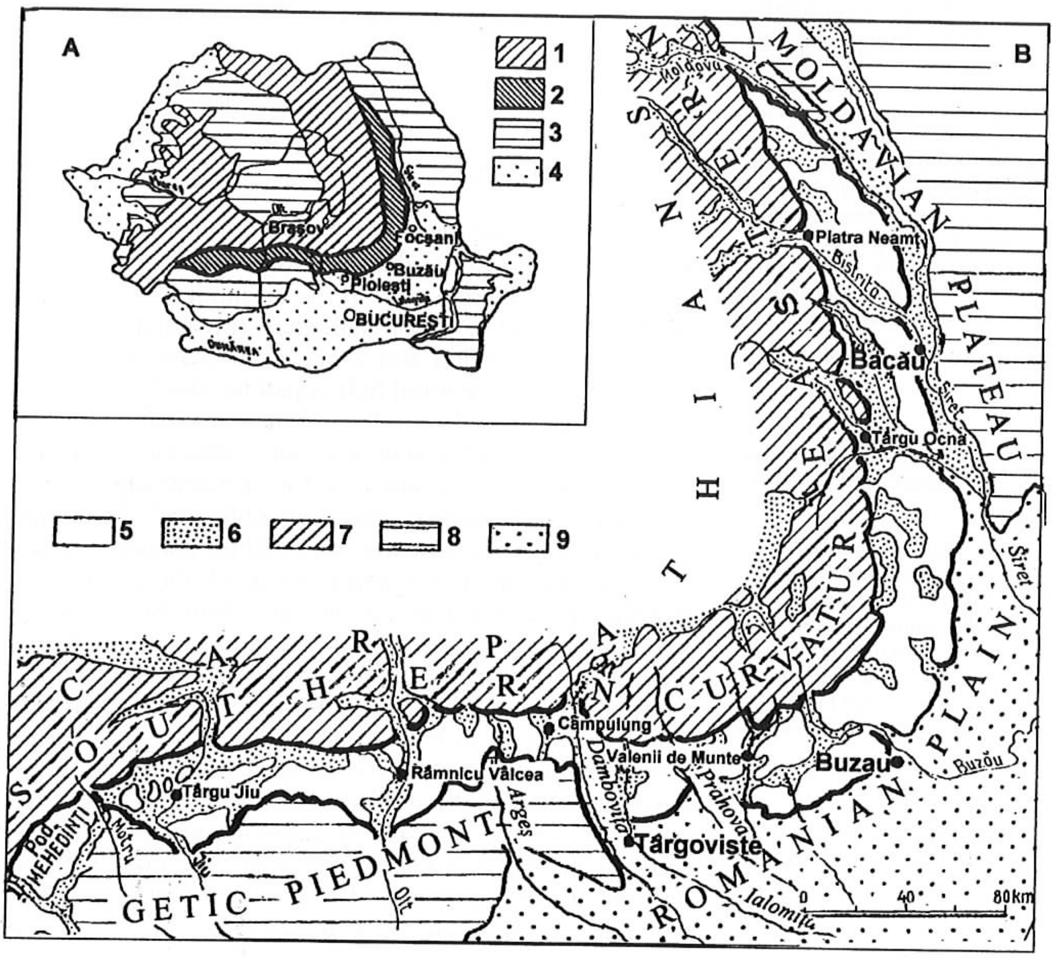

FIG. 1 - The Subcarpathians, a transition unit between the Carpathian Mts. located in the central part of Romania and the eastern and southern hills and plains: A, Location of the Subcarpathians within Romania's relief levels: 1, Carpathians; 2, Subcarpathians; 3, hills and plateaus; 4, plains, B, The Subcarpathians and the adjacent geographical units; 5, Subcarpathian hills; 6, depressionary area; 7, mountain units; 8, piedmont and tableland units; 9, lowland units.

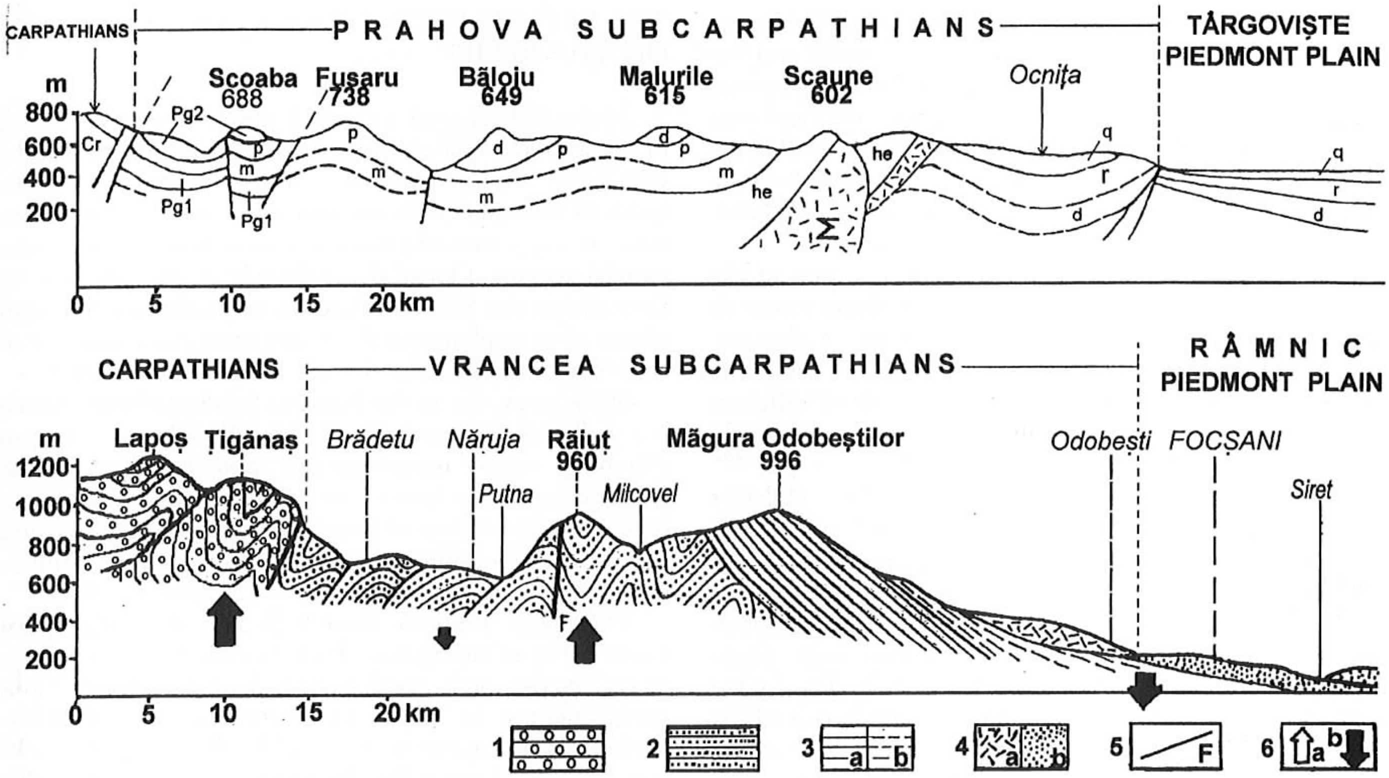

FIG. 2 - Geomorphological profiles of the Subcarpathians: A, Prahova Subcarpathians: q, Pleistocene; r, Romanian; d, Dacian; m, Meotian; p, Pontian; he, Helvetian; Pgl, Upper Paleogene; Pg2, Lower Paleogene; Cr, Upper Cretaceous; Σ, salt; B, Vrancea Subcarpathians: 1, Folded Paleogene flysch; 2, Miocene molasses and folded Pliocene formations; 3, Pliocene (a) and Pleistocene (b) piedmont formations; 4, piedmont (a) and fluvial-lacustrine (b) formations; 5, faults; 6, areas subjected to uplift (a) and sinking (b) movements.

to the diversified rock structure; some inverted relief forms occur as well (Ocnele Mari and Berca buttonholes, Bucovel syncline hill). The monocline structure is widely developed towards the outside, both on the large anticline slopes and on the more recent, mildly tilting formations. In this way, cuestas are facing the mountain whereas the structure-controlled surfaces slope smoothly down towards the outside.

The monocline unit is formed of a piedmont glacis of variable extension fragmented by a transversal valley network circumscribed to large corridors that delimit monocline asymmetrical hills.

A characteristic feature of the Subcarpathians is the presence side by side of salt, lignite, crude-oil and building materials. The evolution of the molasse facies peculiar to this unit passed through several phases: marine (Burdigalian-Baddenian), salmastrian-dulcicolous (Meotian-Pontian), and dulcicolous (Romanian), which accounts for the economic value of its rocks. The crude-oil, salt and coal formations connected with the above facies (crude-oil occurs at the contact with Paleogene flysch deposits or beyond them under the molasse formations) constitute one of the riches of the subsoil and explains why the region is so densely populated.

The presence of salt in the Subcarpathians is a basic element of the definition given by geologists to this peripheral Carpathian unit (Boué, 1874) even before the notion of Subcarpathians was used in the curent acceptation (de Martonne, 1906; Mrazec, 1899; Teisseyre, 1905; Murgoci, 1917). As a matter of fact, with the exception of building rocks, salt had been known and exploited long before the other natural subsoil resources were, which explains why the earliest geological investigations targeted it. Out of the multitude of salt outcrops (Bălţătşti, Borlşti, Tazlău, Valea Sării, Mânzălşti, Slănic, Ocnele Mari, Govora), only a few are being exploited (Târgu Ocna, Slănic Prahova, Ocnele Mari). Besides, there are potassium salts and gypsum exploitations at Târgu Ocna-Gălean, and Ceraşu, Mâneciu Ungureni, Poiana Vărbilău, and Stăneşti-Corbeni, respectively.

Information about the existence of crude-oil and lignite deposits date back to the 14^{th}-15^{th} centuries. The crude-oil from Oligocene formations under the Subcarpathian cover is drilled out at Zemş and Buştenari, and pumped from Helvetian strata at Tescani, Câmpeni, Runcu-Mislea, Gura Ocniţei, Răzvad, Moreni, Teiş, Băbeni and in the western extremity at Bălteni-Ţicleni, and Brădiceni sites. The highest outputs are obtained from Meotian deposits at Berca-

Arbănaşi, Urlaţi, Boldeşti, Ţintea, Băicoi and Ochiuri in the area of diapir folds. Lignite lies in the Dacian and Romanian horizons of the Trotuş Valley, and as far as beyond the Jiu Valley. However only in the Buzău Valley and west of it are they exploited at Ceptura, Filipeştii de Pădure, Şotânga, -Doiceşti, Berevoieşti, Glodeni, Aninoasa, Goleşti, Berbeşti, Albeni, Cuceşti, Armăşeşti, Cerna, Panga, Bustuchin, Ruget, Seciuri, Rovinari, Tismana, Roşia etc.

The great many Mio-Pliocene rocks are used in the manufacturing of glassware and in the building materials industry: Sarmatian limestone (on the edge of the mountain); quartzose sands (Văleni de Munte); diatomite (Pătârlagele); clays, marls, and lots of gravels of different origin and grain-size found in the numerous mountain river beds.

A hilly relief interspersed with depressions. Hillsides (400-800 m up to 1,000 m alt.) occupy 70-80% of the Subcarpathian relief because the large depressions of the Moldavian Subcarpathians are themselves hill land.

Other depressions look like valley corridors (200-300 m alt.) widening and branching out in junction areas. Târgu Jiu depression alone is kind of a large plain. The folded structure builds a widely varied relief, either curved, or with vertical strata (diapirs) yielding a combination of impressive steep and mild slopes, narrow, gorge-like valleys and valleys lined with floodplains and extremely broad terraces (Mihăilescu, 1966, p. 24). Human activity, in its turn, had both an indirect contribution to the building of a microrelief of gullies, of areas with the top soil washed off and of alluvial fans, and a direct contribution by creating coal-strip mines and dumps. Because of the previously mentioned environmental factors the rate of change in the Subcarpathians is faster than elsewhere.

A shelter climate is characteristic of depressions, where winter days are calm and snowstorms are absent (fast travel of the north-east polar front). In other parts of the Subcarpathians temperatures are higher (Getic area), Foehn winds blow (Bend area), or gushes are channelled to major valleys (Moldavia). As the Bend Subcarpathians stand in the vicinity of the Bend Carpathian orographic barrage they face the retrograde Mediterranean cyclones. The impact between the two triggers violent precipitations of short duration (Bordei-Ion, 1988), sometimes limited to a small catchment alone. All in all, they fall into the category of hilly climate with favourable temperatures and sufficient amounts of precipitation (500-800 mm/year).

The relief unit with the densest population in Romania. Owing to the positive environmental factors of this region relief, shelter climate, forests with rich subsoil, lands fit for the growth of fruit-trees and vine, pastures for grazing the livestock, people would settle here in great numbers. With the increase of population (to about 10% of Romania's in 1988) and of settlements at densities higher than elsewhere in this country (136 inhab./sq. km and 12.2 settlm/100 sq. km as against the national average of 6 settlm/sq. km) pressure on the environment kept growing steadily.

THE EXPLOITATION OF SALT AND ITS EFFECTS ON THE RELIEF

In the Subcarpathians, salt deposits begin right north of the Moldova Valley[1] and continue as far as beyond the Olt Valley. Many chronicles and historical documents speak of its exploitation ever since the Ancient Times, because it was a valuable trading item of a flourishing commercial activitiy. Out of the multitude of salt-rich sites we have chosen the Slănic Prahova mines, following the relief effects of its exploitation for nearly forty years now (Cioacă, 1967, Dinu & Cioacă, 1998, Cioacă & Dinu, 1999).

Slănic town lies in the Prahova Subcarpathians, which is a well individualised sector of the Bend area. It has an extremely varied morphogenetic potential due to the chemical and mechanical diversity of the sedimentary rocks, the association of forms and the structured layout, responding in a different manner to the action of sculptural agents (Badea & Niculescu, 1964; Niculescu, 1971).

The Slănic Prahova Basin falls into the category of forms cut in an alternation of soft Eocene-Oligocene rocks (clays, marls) with loosley bound rocks (gravels and sands), pierced by diapir cores consisting of soluble formations (salts, gypsum) associated with compact rocks (salt breccia). Against this background dissolution is distinctively different from one sector to the other, in salt (Muntele de Sare, Baia Roşie, Baia Verde etc), and in gypsum (Groşeni). Clay and marl horizons of various thickness present in the complexes of monocline rock on anticline flanks or diapir folds, create a huge diversity of forms of manifestation of the geomorphic processes. Although dissolution and piping are undoubtedly dominant processes, landslides, mudflows and gullying, holding a different share on each slope, or even in every sector of one and the same slope, could not be overlooked. That makes the dominant morphogenetic processes themselves widely varied over a small area.

THE EXPLOITATION OF BUILDING ROCKS AND ITS EFFECTS ON THE RELIEF

While exploitation of gravels from the ballast pits of the Subcarpathian river beds does not induce notable changes in the relief (frequent flooding rebuilding the thalweg with gravels carried from the foot of slopes), the quarries opened to exploit limestone, gypsum, sandstones and marls, so widespread in the Subcarpathians, create a manmade relief pretty visible in the landscape.

An illustration of this reality is Dealul Pietrei (fig. 3) in Prahova county. This elevation, emerging from a Subcarpathian summit (Dealul Vitioarei, 472 m) and cut in

[1] The presence of Cacica salt beyond the Moldova Valley was an argument in support of the extension of the Subcarpathian area north of the valley.

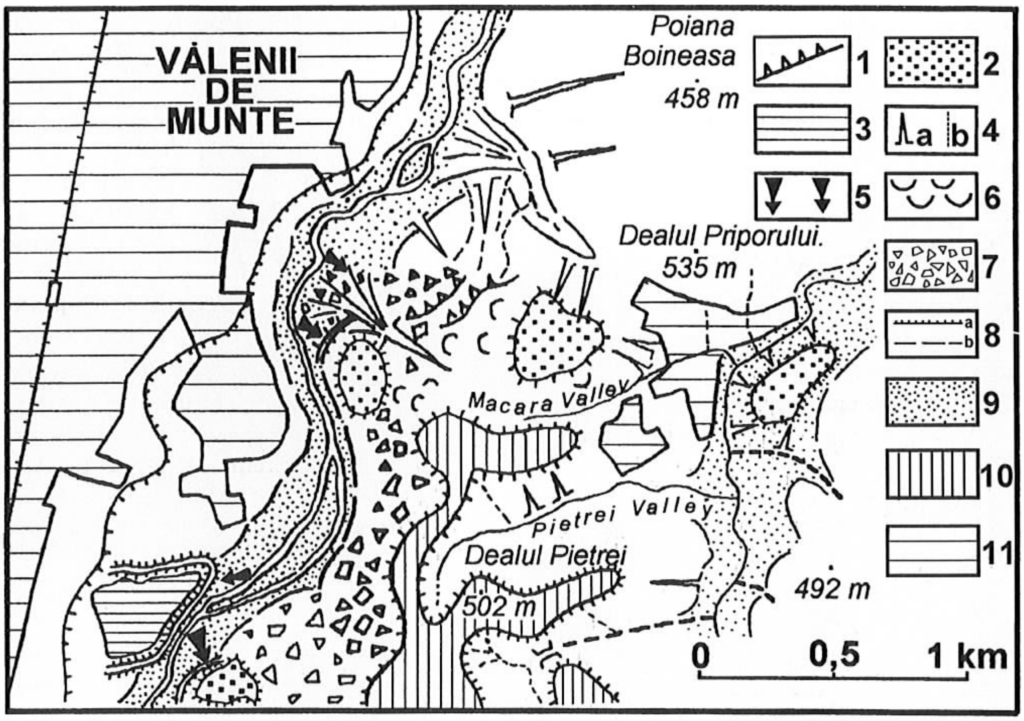

FIG. 3 - Vălenii de Munte. Exploitation of quartziferous sands from loosely-cemented sandstones: 1, sandstones-strip-mine front; 2, wastedump; 3, decanting apparatus; 4, ravenes on dump; 5, dump sector with rockfalls due to the Teleajen River sideway erosion; 6, reactivated slides; 7, gravels dislodged from the 40 m-high terrace; 8, terrace scarp (a), and floodplain boundary (b); 9, floodplain deposits; 10, the 40 m-high terrace; 11, residential area.

loosely-cemented sandstones, is a site of quartziferous sand extraction for the near-by glassware manufacture (Boldeşti-Scăieni).

The slope facing the Teleajen Valley shows a delevelling of 160 m; the road running at its base and heading to the quarry is protected against the overflows of the Teleajen River by a 2.1 km-long embankment. In the north, the quarry can be reached through the Macaralei Valley. Because of the high rate of exploitation and speed of advancement, these two quarry sectors are very much exposed to the modelling of a new man-made relief that inevitably imbalances the slope.

At first, the wastes stockpiled in the Macaralei Valley helped strengthening the foot of the slope close to the quarry. However, as work kept moving forward, the space left between the work front and the waste dump favoured the emergence of deep gullying processes. So, as slope declivity declines, a mass of nearly 200 cu.m of crushed sandstones is very likely to collapse any time in the future.

The second slope at risk from sinking lies in the northwestern margin of the hill towering the Teleajen Valley. Here, water jetting desquamation of sandstones technique, together with the undercutting of the slope base by the river have contributed to the occurrence of minor downsaggings. The conjugated action of these two slope-destabilising factors might enlarge the sinking-prone area.

Recent geomorphological evolutions of the man-made landforms have brought about major changes in the relief and environment surrounding Vălenii de Munte town. It is only natural relief modelling of the mined hilly area that could heal the fast-sinking movement.

THE EXPLOITATION OF CRUDE-OIL AND ITS EFFECTS ON THE RELIEF

Effects are connected with the transition from a natural modelling regime to one partly modified by drillings, loss of viscous residue and, moreover, the construction of a dense network of roads and pipelines. A characteristic exemple of the impact of crude-oil exploitation is the oil--field. Before works begun, rilling had affected a few very steep surfaces only, afterwards it kept extending and occurring more frequently, so that the soil layer was either soaked, which accelerated erosion, or strips of soil along the slope were removed and the vegetation lost its growth support. Along the roads, crossed by heavy trucks and heavy equipment, deep traces have been left so that rilling processes have become a dominant feature of the relief. Stockpiling wastes that slide downslope and gather in some old gullies creates a protective blanket against erosion during mild rains, but under heavy rainfall sideway erosion enhances and gullies grow deeper. At the same time, the mechanical action of various works (digging pipe ditches, small excavation etc.) fissuring the slope surface, favour the infiltration of water, thereby stimulating sheet slides or solifluctions. Management works to stabilise the slope loaded with derricks and oil pipes halted the expansion of sideway erosion (eg. concrete slabs laid on the access roads, ditches dug out on the roadside to drain the rain water) temporarily depleting the process of erosion (fig. 4).

And yet, sheet erosion on the surface of terraces intensified, even tending to be replaced by forms of transition to gullying on the summit that towers the oil field, and in

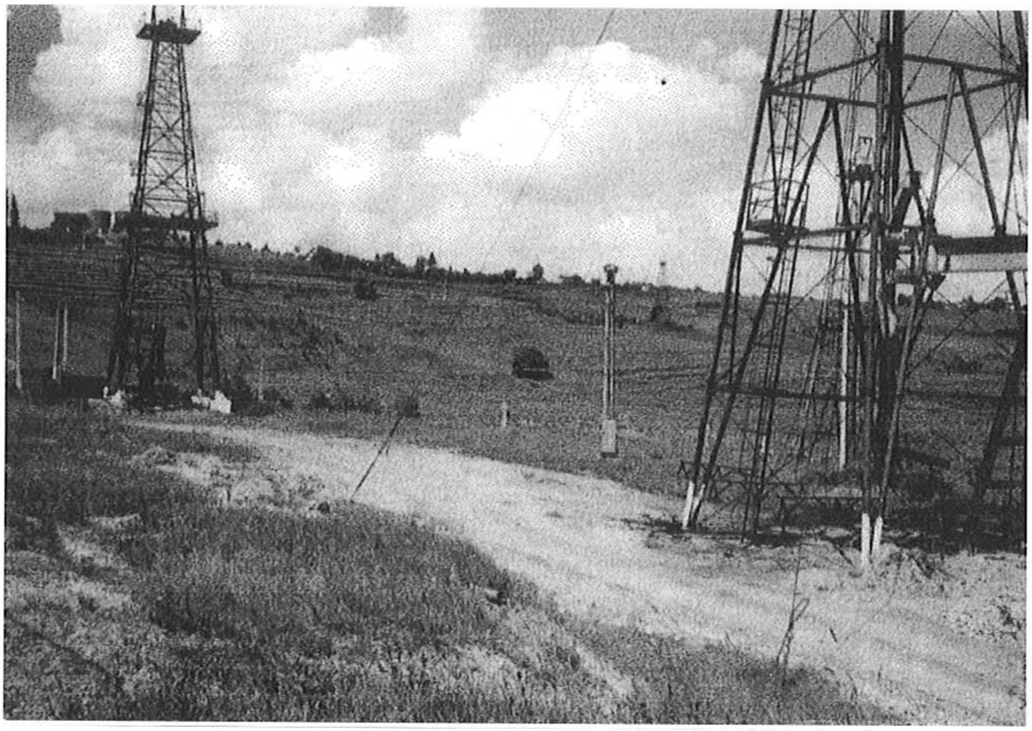

FIG. 4 - Crude-oil exploitation in Bucovel Hill, Prahova Subcarpathians. Intensification of gully formation on access roades to drilling sites (front plane). Formation of sheet-wash-induced local little glacis, attenuating terrace scarps (back plane).

the direction of Teleajen and Bucovel valleys. The main visible changes in the relief of Bucovel Hill, are due to the accumulation of materials transported downslope and stocked at its foot in the form of thin glacis.

THE EXPLOITATION OF LIGNITE AND ITS EFFECTS ON THE RELIEF

In the old Subcarpathian centres lignite mining has become particularly intense over the past fifty years, simultaneously with the opening of new pits to satisfy the energy demand of the country's industrialisation drive. Both intensive and extensive practices, involving new excavations and the creation of waste dumps, induced vast changes in the Subcarpathian relief. The emergence and development of man-made landforms has long been a focus of interest for us. We shall present a singular case-study, with diverse forms of manifestation and impact on the relief extent prior to the opening of the exploitation. Mining works began in the Campulung Muscel area in the early 20th century (pit mining), but got momentum after the year 1950. At Aninoasa, in the source area of the Rugeanca Brook (fig. 5) there are seven dump steps in the coal-strip mine, those on

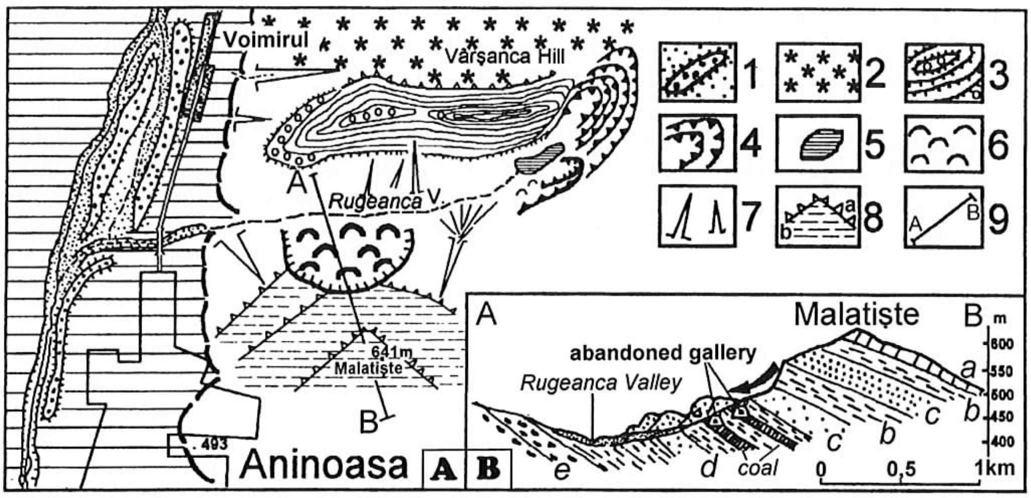

FIG. 5 - Map of Aninoasa modified relief (A): 1, old external waste dump in Bratia floodplain; 2, external waste dump on the slope used as orchard; 3, present internal waste dump in construction (7 steps); 4, present coal stripmine; 5, lake developed in the old mine excavation area; 6, landslide triggered by the collapse of abandoned mine galleries; 7, ravenes; 8, cuesta scarpe (a) and structure - controlled surface (b); 9, profile outline. B, profile of slided area due to the collapse of abandoned gallery: a, Quaternary lake deposits; b, Romanian clay-marls; c, loosley-cemented Pontian sandstones; d, alternation of Dacian marls with lignite; e, Meotian-microconglomerates.

the eastern side being in a steady process of formation. The external dump is now stabilised and used as orchard. However, because the waste is brittle, management works could not prevent ditches and gutters from appearing and criss-crossing the orchard. The main natural modelling processes have suffered serious changes so that man-induced geomorphic processes are presently developing, rilling in particular, on a new local base level (see Ghilan Hill). They also occur on the waste dumps irrrespective of their age and degree of fixation. At the base of the old dumps in the Bratia floodplain, but also of the external one on Vârşanca Hill, partly grass-covered, steps have formed. The last ones represent a link between the base of the dump and the slope. Another modelling process is sliding, which though not very extended, has notably changed the aspect of the Rugeanca Valley. Here, on the northern slope of Podul Hodăii («pod»-English «bridge»), a very significant name for the smooth surfaces of piedmont hills, a gallery had stood rather close to the surface of the slope, causing the ceiling to colapse, fact that undercut the slope triggering an over 690 m-long landslide that affected 75-100 m of slope. Despite the marked dynamic of this slide that fashioned the left slope to a significant extent, the stabilisation of its lower third is underway.

CONCLUSIONS

Repeated investigations conducted by us over a long period of time have pointed out the impact of the exploitation of subsoil resources in a very vulnerable area like the Subcarpathians. Correlating these observations with some of our older concerns to estimate geomorphic risk grades in the Subcarpathians (Cioacă & Dinu, 1996) has revealed that many areas are symptomatic for a more or less critical environment. The findings indicate that the rate of sheet and linear erosion, as well as slope and channel-bed processes were enhanced over the past three decades because the forcible industrialisation drive often ignored the natural regeneration capacity of environmental factors, in principal. The present study does not provide solutions for the rehabilitation of these grounds but offers specialists a series of data on the environmental components that need be addressed insofar as activities connected with putting subsoil resources to account permit it.

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