# GEOLOGICAL INVESTIGATIONS AND MAPPING IN THE BUZĂU LAND GEOPARK: STATE OF THE ART

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**Abstract.** This paper presents the detailed geological investigations, *i.e.*, lithological, sedimentological and paleontological ones, carried out in the territory of the Buzău Land Geopark, aiming to produce a Geological Map of this area at the scale 1:100,000. Along with new data, previously published results have been used. Eventually, the GIS map of the Buzău Land Geopark has been accomplished, representing an unique attempt in Romania.

**Key words:** Eastern Carpathians; Buzău River basin; geology; GIS; maps.

## 1. INTRODUCTION

The geology of the Buzău Land Geopark (BLG) territory, placed in the southern part of the Eastern Carpathians, is quite intricate, showing a structure of nappes involved in two main tectonic phases, *i.e.*, Late Cretaceous (Laramian tectonic movement) and Early Miocene (Burdigalian), according to Săndulescu (1984). The nappes that occur in the area of BLG belong exclusively to the Outer Moldavian nappe system, represented by the Tarcău Nappe (towards West) and the Subcarpathian Nappe (towards East). The former nappe is exposed on a limited area of the BLG, only in the W and NW parts, while the units of the latter nappe crop out on larger areas, in the central, southern, eastern and north-eastern parts of the geopark. Besides, towards E, the deposits of the Foredeep occur.

The oldest geological maps comprising the territory of the BLG have been published in the 6$^{th}$ decade of the 20$^{th}$ century, *i.e.*, the Covasna Sheet, scale 1:100,000 by Popescu and Mutihac (1960) and the Buzău Sheet, scale 1:100,000, compiled by Dragoş (1959). Both geological maps have been published by the Geological Institute of Romania.

By using mainly the data acquired in the middle part of the last century, two geological maps at the scale 1: 200,000 were published by the Geological Institute of Romania: Covasna Sheet (Dumitrescu *et al.*, 1968) that covers the main part of BLG and the Ploieşti Sheet (Motaş *et al.*, 1967), including the southern end of the geopark. The western part of BLG was studied in detail and the obtained data represented the base of the published Nehoiu Sheet, at the scale 1:50,000 (Ştefănescu *et al.*, 1993), so far the only published map at this scale.

The main aim of this paper is to present the achievements of the geological investigations and mapping carried out in BLG, in the framework of the SEE Romanian-Norway Project GeoSust "*Applied research for sustainable development and economic growth following the principles of geoconservation: Supporting the Buzău Land UNESCO Geopark initiative*". The investigations were carried out over three years on the whole BLG territory (Fig. 1), including mapping at the scale 1:100,000. Besides, a detailed study of various aspects concerning the geology and paleontology, along with the completion of the inventory regarding the protected sites, especially the geological and paleontological ones have been performed. Former published data have been also used, together with the newly acquired ones.

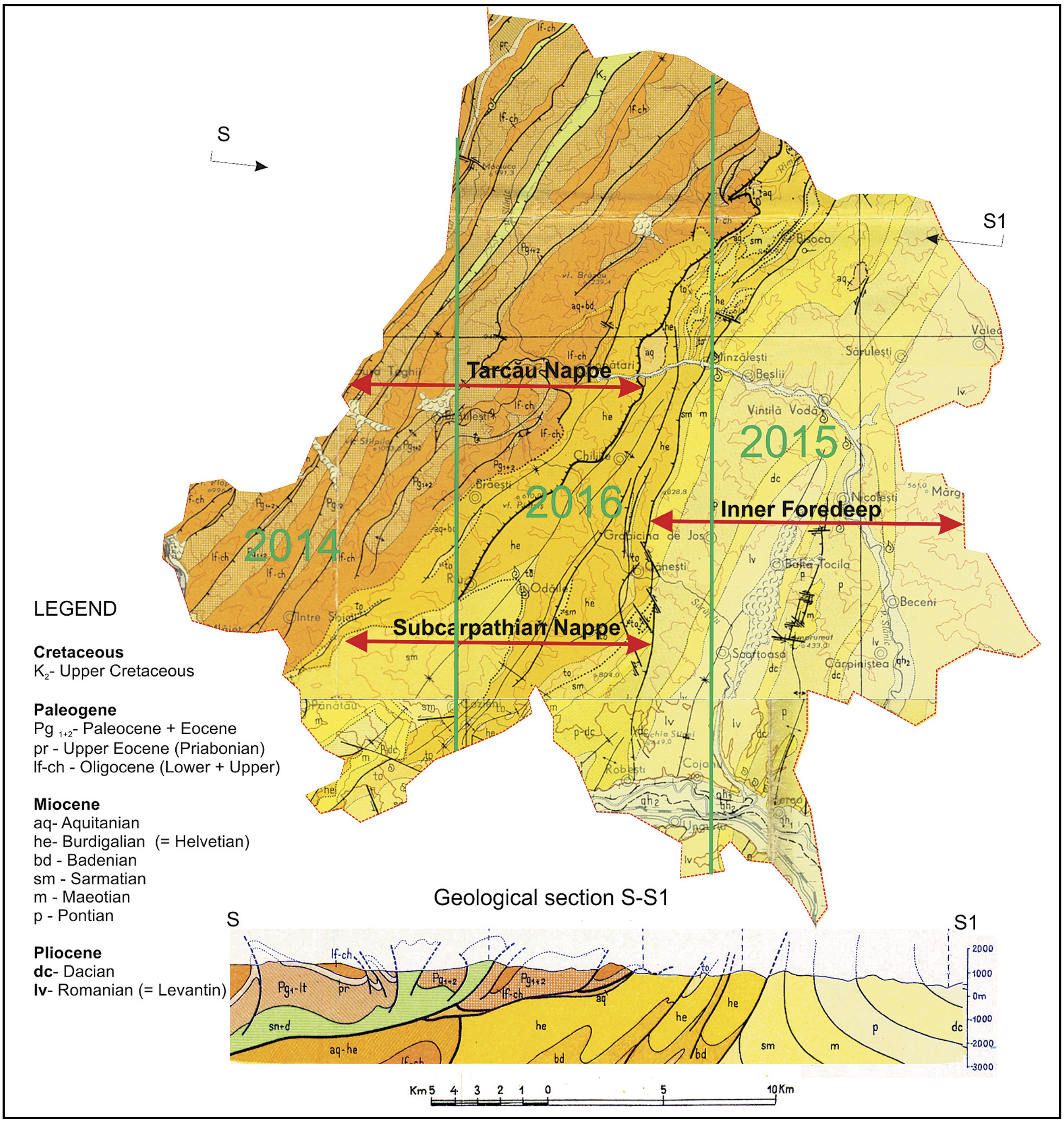


**Fig. 1.** Geological map of the BLG, scale 1:200,000 published by the Geological Institute of Romania (Covasna Sheet – Dumitrescu *et al.*, 1968; Ploiești Sheet – Motaș *et al.*, 1967); the Geological Section S-S1 from the Covasna Sheet – Dumitrescu *et al.*, 1968. The mapping of the BLG territory at the scale 1:100,000 presented in this paper was achieved as follows: (**1**) the western part – in 2014, (**2**) the eastern part – in 2015 and (**3**) the central part – in 2016.

## 2. HISTORICAL DATA ON THE GEOLOGY OF THE BLG TERRITORY

In the BLG region, the geological investigations started in the 19th Century with the publication of Coquand (1867) that firstly described the Mud Volcanoes from Berca. Cobălcescu (1883) published the first comprehensive monograph on the Romanian Tertiary sediments including Miocene and Pliocene rocks of the western BLG area. Fuchs (1894) & Teisseyre (1897) investigated the Tertiary deposits and Richard (1897) published data about the Paleogene including the amber occurrences from Colți.

A special attention was given to the Miocene and Pliocene deposits that crop out in the Buzău Valley basin, the results being published by Porn & Murgoci (1910), Protescu (1923), Rabischon (1924), Ciocârdel (1949) and Oncescu (1944); the aforementioned authors gave also a special attention to the oil potential of the region.

Filipescu (1940) brought significant geological contributions, by identifying the boundary between several Middle Miocene up to Pliocene Paratethyan stages, such as Sarmatian, Maeotian, Pontian, Dacian and Levantine (the latter updated as the Romanian), between Pănătău, Berca and Arbănaşi localities. The Paleogene deposits from Sibiciu Valley were investigated by Stoica (1945) and Olteanu (1951) that analysed the salt occurrences from the BLG, such as salt breccias and salt massifs.

The geology of the Buzău River upper basin, between Crasna and Nehoiaşu localities, was included by Băncilă (1958) in a comprehensive book on the geology of the Eastern Carpathians including the lithostratigraphy and the tectonics of the Tarcău Nappe. A significant advancement in the knowledge of the flysch zones, including the Buzău River basin, was brought by Murgeanu *et al.* (1961).

The Foredeep situated in the BLG was subjected to detailed investigations of Macarovici (1961) that focused on the Lower Pliocene deposits belonging to the Eastern Paratethyan Dacian stage, from the Arbănaşi-Berca region. Pană (1966) analysed the Miocene and Pliocene sediments that crop out in SW extremity of the BLG and also published a geological map of this area.

Important contributions in the Buzău basin region, including the part where Paleogene and Neogene deposits crop out (NW part of the Geopark), were brought in the 1988 - 1992 interval by the scientists of the Geological Institute of Romania. Several lithological markers, such as: tuffs, bentonites, laminitic coccolithic limestones and evaporites, *i.e*., gypsum and salt, have been identified in the Paleogene and Miocene sediments of BLG (Ştefănescu *et al.*, 1989; Brustur and Alexandrescu, 1989). These lithological markers allow correlation not only along the Eastern Carpathian bend, but also with other Carpathian segments situated in Ukraine, Poland and Slovakia. Based on data acquired during the mapping work, several papers were published on the lithology and biostratigraphy of the region, on the Oligocene/Miocene boundary exposed in the Buzău Valley (Melinte, 1988; 2005), as well as on the Eocene/Oligocene boundary from the same region (Ştefănescu & Melinte, 1992). Paleogene paleoenvironmental changes mirrored by variation in the paleoichnologic content were published by Brustur (2016) and Buatois *et al.* (2001).

Comprehensive macropaleontological studies concerning the Miocene and Pliocene faunas from the Buzău region, including the BLG territory, were published by Pană (1968; 1971), which described many mollusc genera, including endemic taxa of Paratethys, and used them for an accurate biostratigraphy. Rich Miocene and Pliocene paleontological assemblages mainly composed of bivalves and gastropods, along with their biostratigraphic significance, were described from the Eastern and Central Subcarpathian regions, including the BLG territory, by Papaianopol & Macaleţ (1994; 2006) and Macaleţ (2005).

The Miocene evaporitic deposits of the Eastern Carpathian southern part, including the Buzău Valley, were studied in detail by Frunzescu (2002). Recently, Frunzescu & Brănoiu (2004) included in a geological monograph of the Buzău River basin several outcrops located in the W and SW parts of BLG, such as the Salt Breccias exposed around the Bădila locality, the Mud Volcanoes from Berca, as well as the Valea Lupului Quarry of the Miocene diatomites.

Significant advancements in understanding the paleodepositional features characterizing the BLG territory and the paleogeography of this area, included in the Dacian Basin, since Middle Miocene times up to the Present, were published by Jipa *et al.* (2006), Olteanu & Jipa (2006) and Jipa & Olariu (2013). Papers on biostratigraphical aspects combined with magnetostratigraphy revealed new aspects on the paleoenvironmental modifications that took place during the Late Miocene-Pleistocene interval on the BLG territory (Stoica *et al.*, 2013; Van Baak *et al.*, 2015). Recently, Brustur *et al.* (2015), Brustur (2016), Popa *et al.* (2016), Macaleţ *et al.* (2016), Popa *et al.* (2017) and Melinte-Dobrinescu *et al.* (2017) published various aspects linked to the main geological and paleontological sites of the BLG.

## 3. GEOLOGICAL DATA AND MAPPING

The BLG area displays complete successions of the Late Cretaceous, Paleogene, Miocene, Pliocene and Pleistocene intervals. For the Cretaceous and Eocene intervals, as for the entire Romanian Carpathian area, the global stages are used. The Paleogene tectonic movements in the Alpine chain led to the separation of the Tethys Realm into two domains, *i.e*., the Mediterranean and the Paratethys, periodically disconnected and reconnected since the Oligocene (Papp *et al.*, 1974; Piller *et al.*, 2007, among many others).

Hence, since the Oligocene, the BLG region was part of the Paratethys, but for the Oligocene-Early Miocene interval, the global stages, *i.e*., Rupelian, Chattian, Aquitanian and Burdigalian, are used. Since the upper part of the Middle Miocene, upwards the Sarmatian in term of the regional stages, the extra-Carpathian area was part of the Eastern Paratethys (Popov *et al.*, 2004). Therefore, in the BLG, as for the whole Eastern Carpathians, the regional stages of the Eastern Paratethys are in use.

In the BLG territory three tectonic units (from the western to the eastern part) occur: the Tarcău Nappe, the Subcarpathian Nappe and the Inner Foreland (Dumitrescu *et al.*, 1968; Motaş *et al.,* 1967). The western part of the Geopark, delimited to the east by the localities (from N towards S) Lopătari, Brăeşti and the region comprised between the villages Între Sibicii and Pănătău is mainly composed of Paleogene, *i.e*., Eocene and Oligocene, sediments.

The Eocene is largely made by arenites, belonging to the Tarcău Sandstone Formation (*i.e*., massive calcareous sandstones), while the Oligocene mainly comprises massive siliceous sandstones of the Lower Kliwa Formation (Fig. 2). Subordinately, the pelites that crop out are represented by Oligocene bituminous marls and menilites – silicolites and bituminous clays (called dysodiles, as in the whole Carpathian bend). On large areas, Eocene turbiditic successions, made by rhythmic alternating thin dm-thick sandstones, clays and marls crop out (Ştefănescu & Melinte, 1992; Melinte, 2005).

In the Tarcău Nappe, the Oligocene-Miocene deposits from Colţi area, displaying a bituminous facies with Kliwa sandstones, belong to small folds directionally developed over few kilometers length. In this location, the Lower Kliwa Sandstone Formation may reach 400 m in thickness, forming metric beds often intensely folded and faulted (Fig. 3a, b). In places, massive, horizontally quartzous sandstones crop out (Fig. 3c). They display frequently interbeds of bituminous shales (*i.e*., dysodiles) and grey-blackish argillaceous sandstones (Fig. 3d).

In the NW extremity of the BLG, Upper Cretaceous deposits, the oldest ones in the Geopark territory, are exposed (Fig. 4). In previous publications, these sediments are indicated to have in general a Late Cretaceous age. Our studies, including biostratigraphical ones, proved that their age is Santonian - early Campanian. The age is argued by the calcareous nannofossil assemblages identified that contain the nannofossils *Arkhangelskiella cymbiformis*, *Broinsonia parca constricta*, *Eiffellithus eximius*, *Reinhardtites anthophorus* and *Reinhardtites levis*, among other taxa that have no biostratigraphical values for this interval. The Santonian - lower Campanian sediments are represented by turbidites composed of rhythmically alternating dm-thick grey-whitish calcareous sandstones and grey claystones.

The central and eastern parts of the BLG belonging to the Subcarpathian Nappe and the Inner Foreland of the Eastern Carpathians are characterized by the deposition of much younger sediments than the western part (Fig. 4). Hence, the Miocene, Pliocene and Pleistocene deposits are mostly sandstones, sands, clays and salt, all of them having a big potential for the occurrence of landslides.

The western part of the BLG, where the Tarcău Nappe is exposed, shows a 'classical' tectonic style of the Alpine-Carpathian chain. Therefore, faulted axial anticlines and

**Fig. 2.** 'The Giant Wall' from Nucu; vertical beds of massive siliceous fissured Oligocene Kliwa sandstones at Bozioru (Photo: Adrian Gherghe, September 2015).

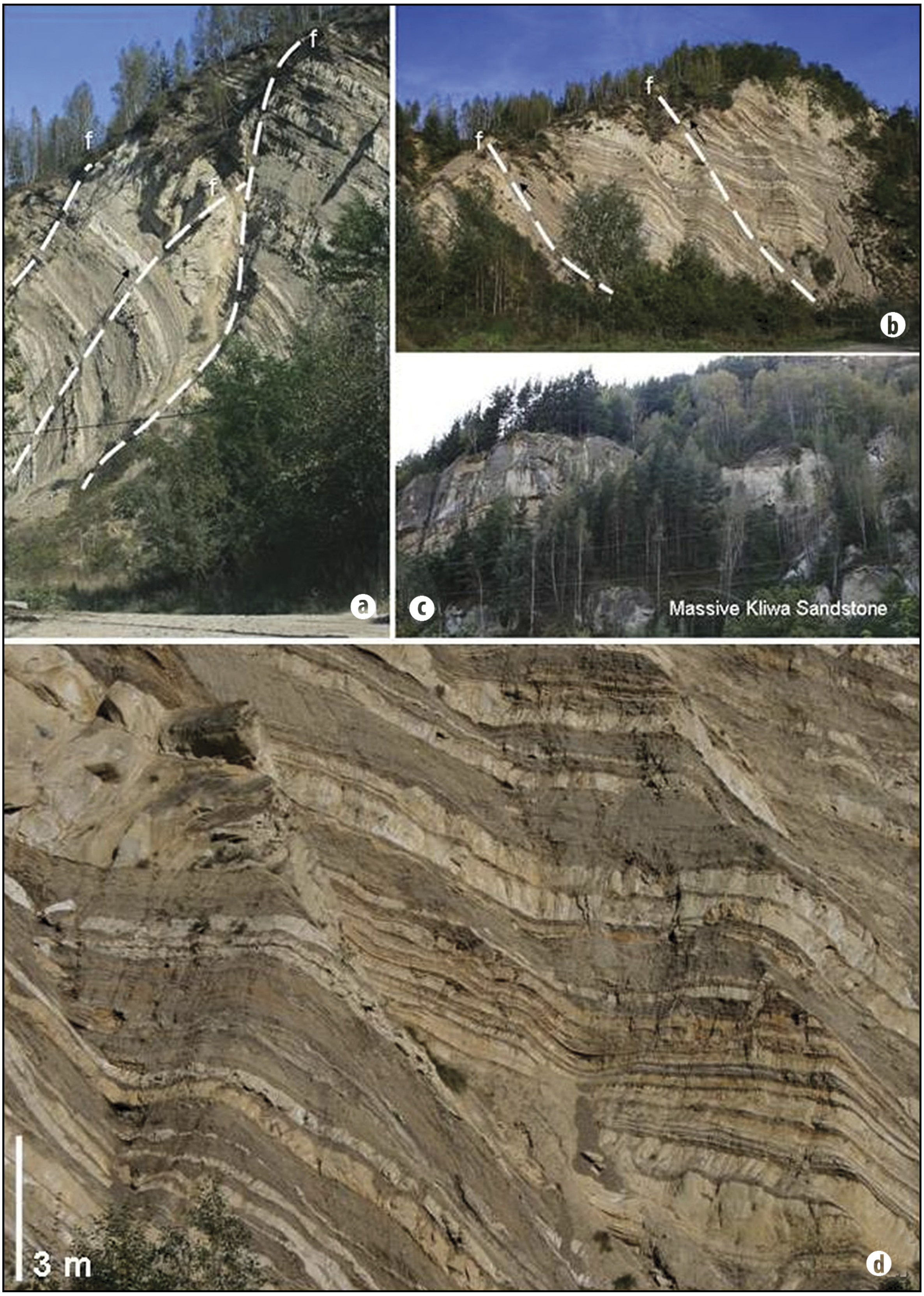


**Fig. 3.** Tectonical and lithological features of the Lower Kliwa Sandstone Formation of the Tarcău Nappe; **a-b**: outcrop of the Kliwa sandstones with intraformational faults in the Sibiciu Valley, N of the Colţi locality, towards Colţii de Jos village; **c**: outcrop of massive Kliwa Sanstones, NE from Colţi, towards Aluniş; **d**: detail of b, showing dm sandstone beds rhythmically alternating with bituminous claystones (Photo: Titus Brustur, August 2014).

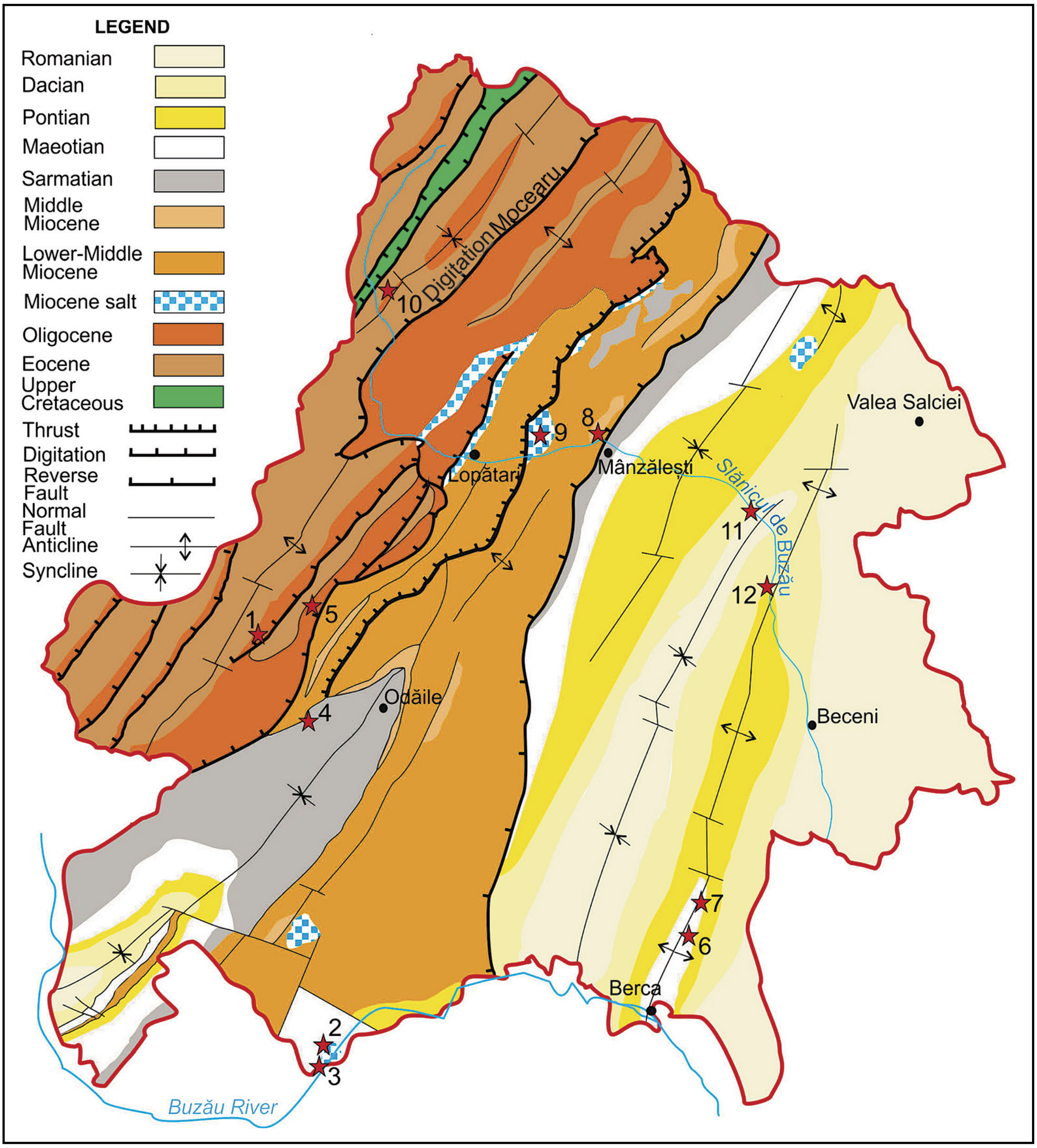


**Fig. 4.** The geological map of Buzău Land Geopark with locations of geological and paleontological sites (after Melinte-Dobrinescu *et al.*, 2017 and herein). The data obtained by us have been ploted on topographic maps, scale 1:100,000. The stars indicate the geological and paleontological patrimony: **IUCN Protected sites:** (**2**) The Limestone blocks from Bădila; (**3**) The Buzău's Salt; (**5**) The Buzău Amber; (**6**) The Mud volcano Pâclele Mari; (**7**) The Mud volcano Pâclele Mici; (**8**) The White Stone "La Grunj"; (**9**) The Meledic Plateau; (**10**) Focul Viu – Lopătari; **Unprotected sites**: (**1**) The Mineral springs of Fișici; (**4**) The Old Ladies from Ulmet; (**11**) The Dacian Stage Stratotype; (**12**) The Romanian Stage Stratotype. The mapping data have been inserted on the topographic map scale 1:100,000.

synclines, with a NW-SE direction have been identified. Several digitations with a NW to SE vergence occur also in the Paleogene deposits. The most developed digitation is the Mocearu Digitation, situated towards the eastern (external) part of the Tarcău Nappe; this digitation developed up to the contact with the Subcarpathian Nappe.

The central part of the BLG, where the deposits of the Subcarpathian Nappe crop out, is characterised, as in the western part, by a complicate tectonics, *i.e.*, anticlines and synclines axial faulted and many transversal and longitudinal faults. Additionally, salt deposits are also present in this nappe (Fig. 4). The lithological features, combined with tectonical ones, make from the central part of BLG an area which could be the most affected by landslides. Recent subsurface faults, activated by climate processes (intervals with high rainfalls alternating with intense and prolonged drought) combined with the effect of subcrustal earthquakes from Vrancea region, caused frequent landslides (the best known one is located at the Răteşti Monastery, 5 km NW from Berca) (Fig. 5).

Due to the presence of many Miocene salt breccia outcrops, located in the geopark central-eastern part, there is a high risk of landslides and rockfall in connection with the surface exposure of salt breccia. Notably, some of the landslides and debris flow are already affecting the geological sites from the central region of the BLG.

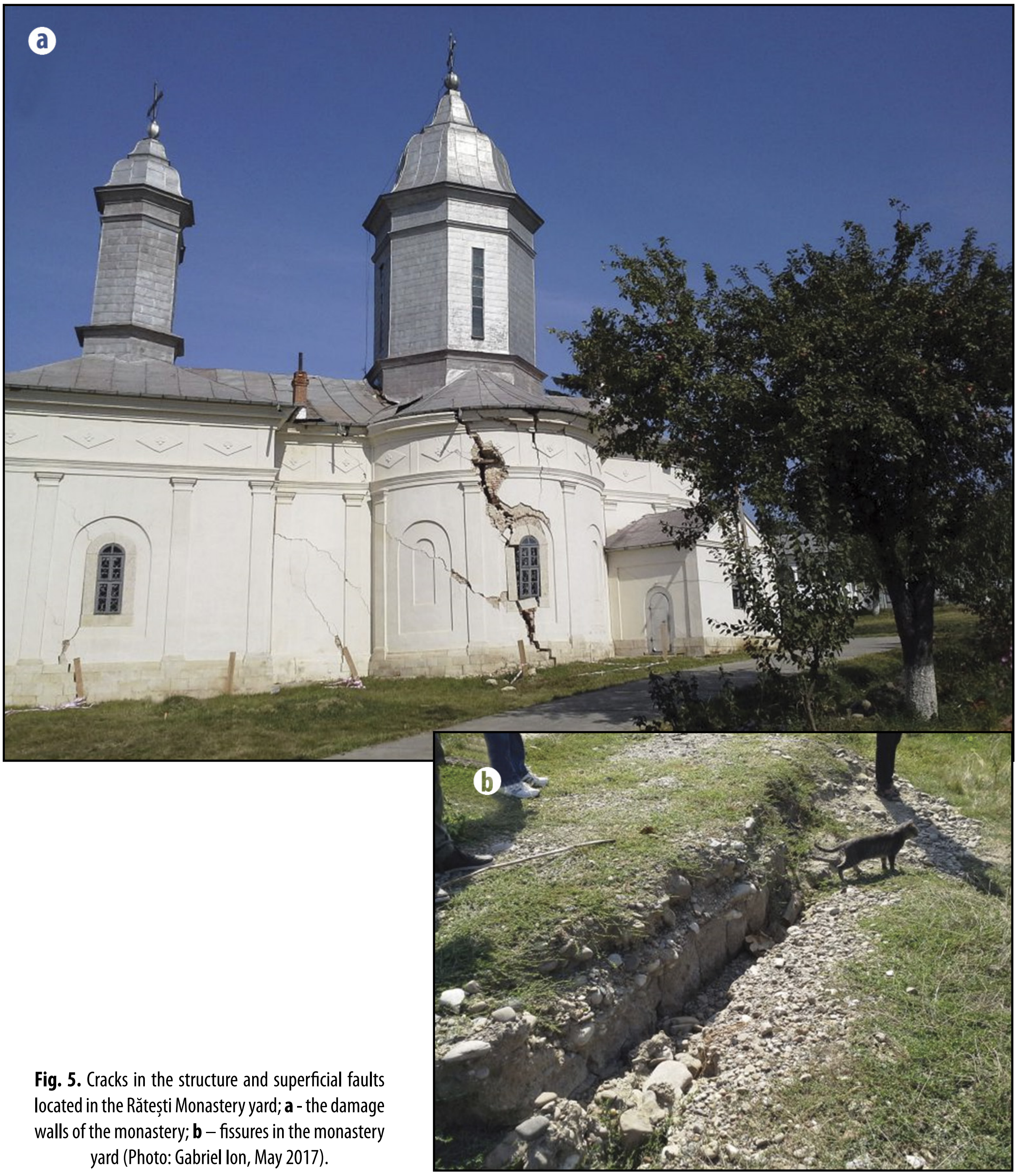


**Fig. 5.** Cracks in the structure and superficial faults located in the Răteşti Monastery yard; **a** - the damage walls of the monastery; **b** – fissures in the monastery yard (Photo: Gabriel Ion, May 2017).

Hence, in one important geosite that has also a great touristic potential, "Babele de la Ulmet" (= The Old Ladies from Ulmet), made by concretions of Middle Miocene (Sarmatian) rock, this phenomenon could be observed. As these concretions are situated on a crest, the erosion due to the wind action, combined with the activity of torrents during the rainy seasons, are already affecting this site; therefore, large amounts of debris consisting of these sandstones are present at the base of the outcrop (Fig. 6).

Last but not least, the eastern region of the BLG, where mainly the Inner Foreland of the Eastern Carpathians is exposed, is also affected by landslides. There, the alpine tectonics is poorly expressed, but the occurrence of many weak consolidated deposits determined the occurrence of recent subsurface faults, activated also during the numerous earthquakes linked to the well known highly seismic zone Vrancea.

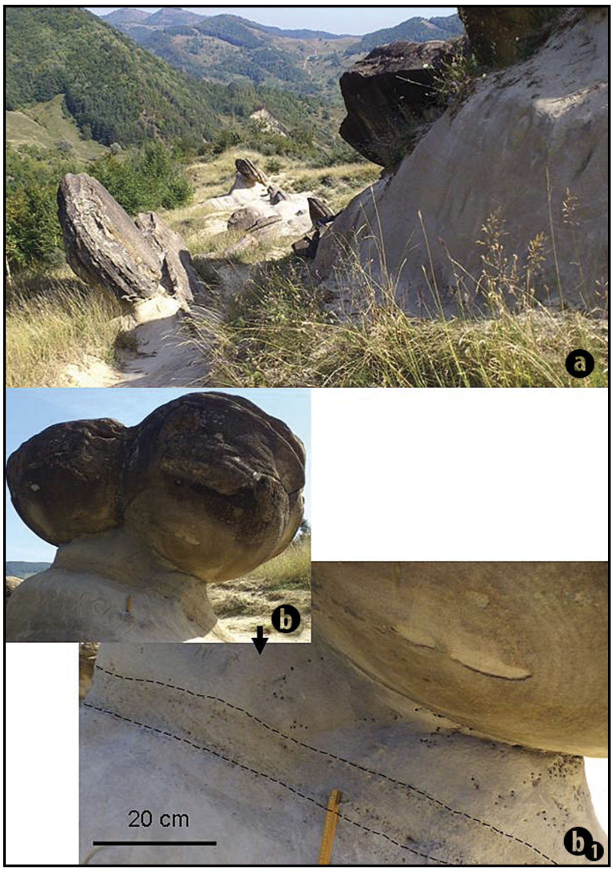


**Fig. 6. Left**: **a,b**: features of the Concretions from Ulmet; **b$_1$**: detail of **b**, at the base of the concretions.
**Right**: a concretion crashed at the base of the slope
(Photo: M. Melinte-Dobrinescu, June, 2016)

## 4. GIS MAP OF THE GEOPARK

We have developed the state-of-the-art geological map based on the latest known data and newly collected data, all of them being integrated in the GIS platform. The area that had to be mapped is quite large, more than 1,000 km$^2$.

As aforementioned, for this territory there were available only maps from the 1960s at a scale of 1:200,000 and a single map of 1:50,000 (Ştefănescu *et al.*, 1994 – Nehoiu Sheet; the later map covers a small area in the NW extremity of the Geopark. Therefore, intensive field campaigns were conducted in the years 2014, 2015, 2016 and 2017 to map at the scale of 1:100,000 the whole Geopark territory; the data sets were incorporated in topographical maps at 1:100,000 scale.

The geological maps 1:100,000 obtained for the Geopark were georeferenced and then digitized. The digitization process has been accomplished in ESRI ArcMap, first as polylines and then converted to polygons, for the tectonic elements such as faults, anticlines, synclines, and thrusts, as well as the lithostratigraphic units (formations) to correspond to the polygons limits (Fig. 7).

The GIS geological map of BLG can be accessed at the link: https://drive.google.com/open?id=1xFJGKt92kJpFA49dUL01oeakpRs&usp=sharing. The map is interactive; hence, each time a geological formation is selected (in the bellow image the blue one with white line around) the age of that specific formation is displayed, together with the area and perimeter values, in metric system of units.

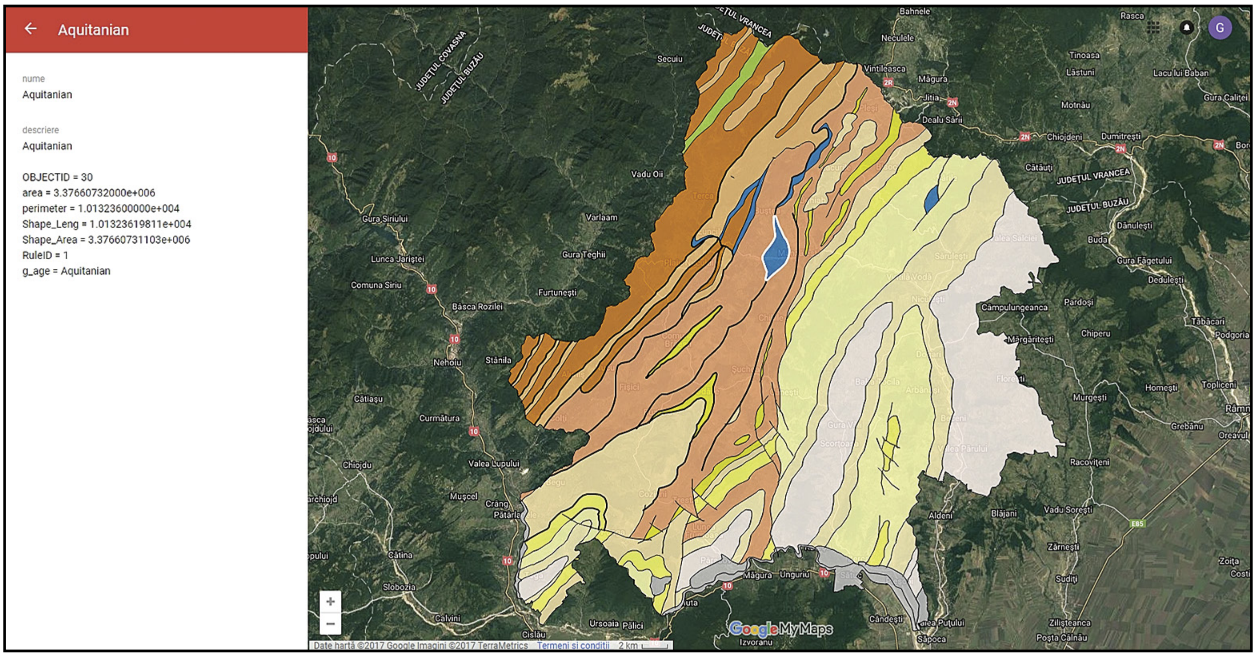


**Fig. 7.** The GIS map of the Buzău Land Geopark plotted on googlemaps.

Additionally, two areas that are nature reserves, Bădila Limestones (detailed presented in Popa *et al.*, 2016) and Pâclele Mari Mud Volcano (Figs. 8 and 9) have been photo-mapped using a quadcopter drone. By using the geotagged photos obtained with the drone, we have been able to produce two photo-mosaics that bring new insights regarding the geological processes.

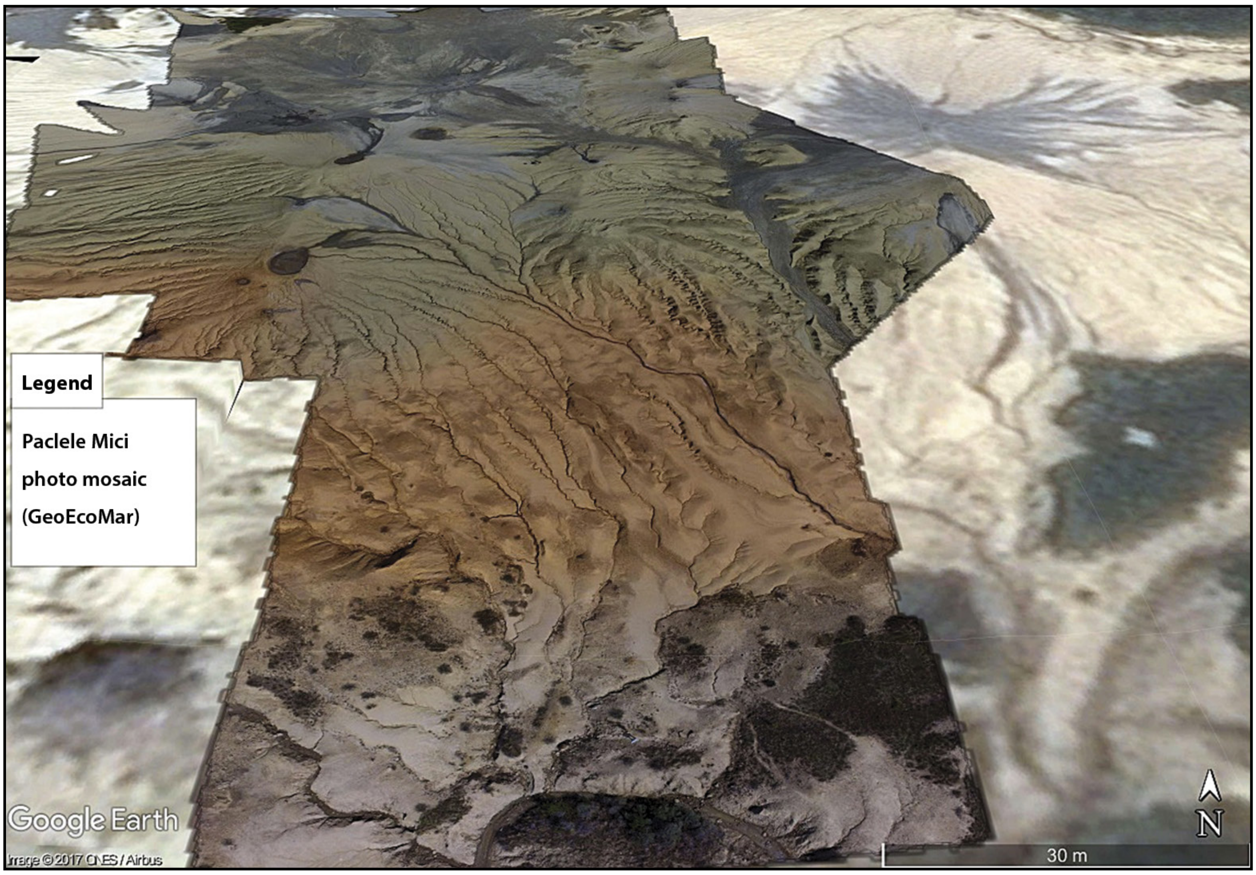


**Fig. 8.** Photo-mosaic of Pâclele Mici Mud Volcano (noted in the List of the Nature Reserves of the Buzău County as Pâclele Mari). The base of the map is from Google Earth.

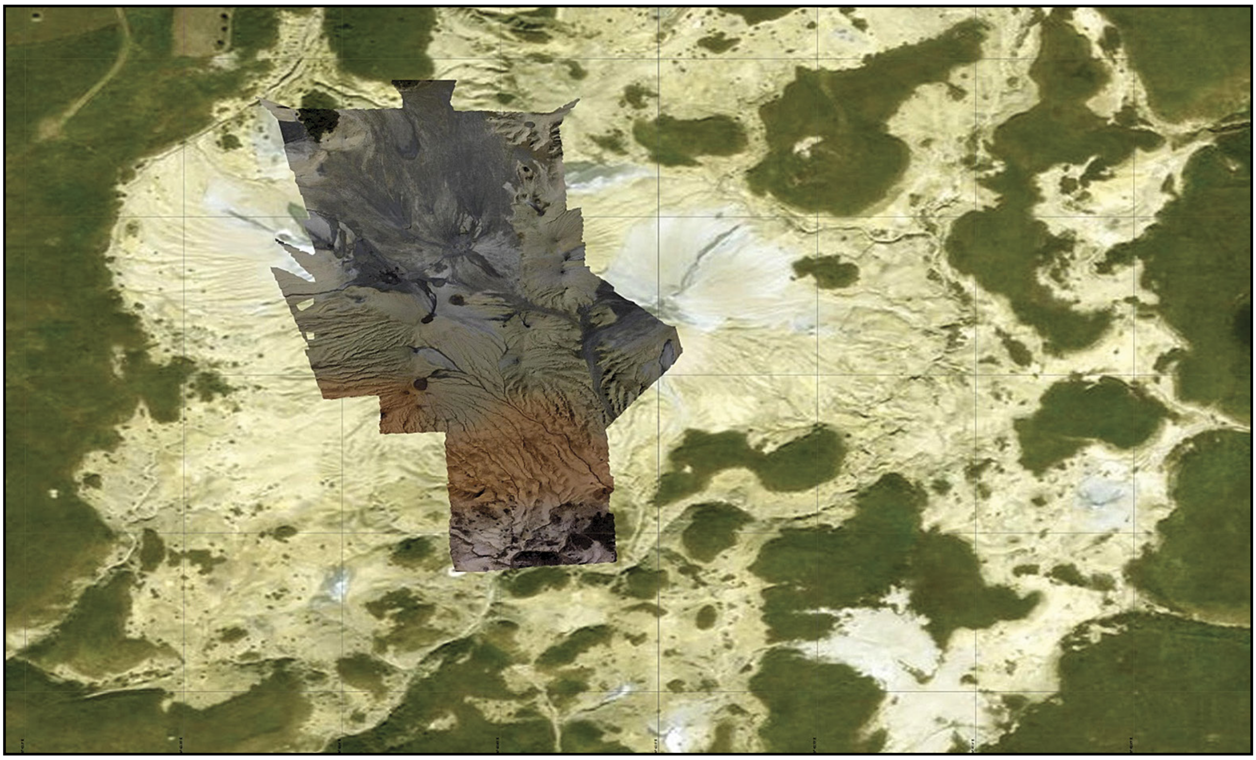

**Fig. 9.** Photo-mosaic of the Pâclele Mici reserve area (noted in the List of the Nature Reserves of the Buzău County as Pâclele Mari). The base of the map is from www.googleearth.

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