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 6th decade of the 20th 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 Dragos (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 Ploiești Sheet (Motaș 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 (Ștefănescu 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.
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
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 Pânătău, Berca and Arbănași 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 masses.

The geology of the Buzău River upper basin, between Crasna and Nehoiu localities, was included by Bâncilă (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 Arbănași-Berca region. Pană (1986) 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 lithostratigraphic 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 (Ștefănescu et al., 1989; Brustur and Alexandrescu, 1989). These lithostratigraphic 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 (Ștefănescu & Melinte, 1992). Paleogene paleoenvironmental changes mirrored by variation in the paleoichnologic content were published by Brustur (2016) and Butoițoi 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 & Macalet (1994; 2006) and Macalet (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 & Oliariu (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), Macalet 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; Motaș et al., 1967). The western part of the Geopark, delimited to the east by the localities (from N towards S) Lopătări, Braești and the region comprised between the villages Între Sibicii and Pânătău 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 (Ștefănescu & Melinte, 1992; Melinte, 2005).

In the Tarcău Nappe, the Oligocene-Miocene deposits from Colți 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. 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 Sibiuciu Valley, N of the Colți locality, towards Colții de Jos village; c: outcrop of massive Kliwa Sandstones, NE from Colți, towards Aluniș; d: detail of b, showing dm sandstone beds rhythmically alternating with bituminous claystones (Photo: Titus Brustur, August 2014).
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 Rătești 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.

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**Fig. 5.** Cracks in the structure and superficial faults located in the Rătești 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.

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 km².

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 (Ștefănescu 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.
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.
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