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The occurrence of the armored mud balls during the flash flood phases of the streams from the Meledic Plateau – the Curvature Subcarpathians, Romania

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Abstract

Armored mud balls that form in fluvial environments were observed on the river bed of two small streams from South-East Subcarpathians Bend, in the area of Miocene deposits with salt dia-pirs. Pieces of well-rounded clay mate-rial but with coarse surface were found on the gravel banks as well as partially submerged into stream channel and embedded in soft sediments of stream banks. The surfaces of mud balls, nearly spherical and ranging from 5 cm to 17 cm in diameter, were studded with sand grains and gravel that collected during flash floods as a result of bedload transport. The main source material of the armored mud balls consists of dark clay material detached from the cap rock of the salt massif that is crossed by the two streams. The newly formed armored mud balls, which were found among the gravels on the stream bed following the summer flash flood event from June 2019, supports the fact that these particular sedimentary features form during exceptional floods when pieces of clay material are rolled by the high-energy water flow, which results in acquiring of their spherical shape and the pebble shell. This paper represents the first report on the occurrence of modern armored mud balls formed in a fluvial environment, located in the Curvature Subcarpathians, Romania.

Keywords: *armored mud balls, Meledic Plateau, salt diapire, ephemeral fluvial flood, temperate climate*

Rezumat. Formarea ”bilelor de argilă ghintuite”(”amored mud balls”) în condiții de scurgere torențială a pâraielor din Platoul Meledic - Subcarpații de Curbură, România

În lungul a două văi cu caracter torențial, formate în depozitele Mio-cene de sare din cadrul pânzei subcar-patice de Sud-Est, au fost identificate formațiuni geologice descrise în litera-tura geologică și geomorfologică inter-națională sub numele de armored mud balls (bile de argilă armate/ghintuite). Formațiunile argiloase rotunjite, dar cu suprafața rugoasă, care au fost identifi-cate în albia pâraielor, erau parțial sub-merse, ori prinse într-o matrice de sed-imente fine. Suprafața bilelor de argilă, cu diametrul cuprins între 5 și 17 cm, era armată cu nisip grosier, pietriș și fragmente angulare de rocă, colectatate în timpul scurgerii turbulente care apare doar la debitele extraordinare cauzate de ploi torențiale. Sursa pri-mară a materialului din care sunt for-mate bilele de argilă este cuvertura sedimentară a masivului de sare, frag-mentat de văile în care s-au format acestea. Bilele de argilă care au fost identificate în albia unei văi, imediat după inundația din iunie 2019, con-firmă faptul că aceste structuri sedi-mentare particulare se formează exclu-siv în timpul debitelor extraordinare ale unor cursuri mici de apă. Atunci când bucățile angulare de argilă, de dimensi-uni caracteristice, ajung în albia râului, ele sunt preluate ca parte a debiuluit solid de scurgerea turbulentă a apei, timp în care sunt rulate și rotunjite, asigurînd totodată și aderarea fragmen-telor de rocă și nisip la suprafața plas-tică a acestora din care rezultă din care se formează armura. Această lucrare semnalează pentru prima dată for-marea bilelor de argilă armate în mediu fluvial actual aflat în Subcarpații de Curbură, România.

Cuvinte-cheie: *bile de argilă armate, Platoul Meledic, cută diapiră, curgere torențială, climă temperat continentală*

Introduction

An armored mud ball is described as an rounded, unusual clastic sedimentary structure, consisting of piece of clay material eroded from a muddy bank or detached from a streambed and rolled along the river bottom, shore bed, sea bed by the strong currents or waves and coated with sand grains and pebbles of different origins, even organic debris (Bell, 1940; Picard & High Jr., 1973; Tanner, 1996; Goudie, 2013; Gutierrez & Gutierrez, 2016).

The term armored mud balls (AMBs) was coined by Bell (1940) and since then it is widely used in geological literature, both for fossil and modern specimens. In his seminal paper and comprehensive study, Bell pleaded for his proposed term as being "truly descriptive" one for the highly spherical mass-es of clay studded with pebbles. In earlier papers these geological structures were referred to as "clay galls" (Jones & King, 1875). "Pudding balls", "mud pebbles", and "mud cobbles" are other synonymous terms (Little, 1982), but Prokopovich & Isom (1985) suggest

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that "armored clay balls" is preferable to the widely used term AMBs.

AMBs are commonly formed during bedload transport of floods events in small streams, temporary streams, torrents, and gullies from semiarid and arid climate regions (Bell, 1940; Karcz, 1969; Karcz, 1972; Prokopovich & Isom, 1985; Martin Penela & Barragan, 1993; Sholokhov & Tiunov, 2002; Mather, Stokes, Pirrie, & Hartley, 2008; Desir & Marín, 2008; Desir & Marín, 2009; Marín & Desir, 2010). Also, fluvial contemporary AMBs have been identified and described in streams from temperate regions (Bescós Roy, 1991), including within Outer Carpathian flysch from Poland (Baluk & Radwanski, 1962; Glazek & Radwanski, 1962; Jońca, 1981; Krzyszton, 1984; Gebica & Sokolowski, 2001) and Slovakia (Bóna, Kováčik, & Kobulský, 2005). Recently they have been document-ed in humid climate regions that record tremendous floods have (Bachmann, 2014).

Besides, the occurrence of AMBs has also been reported on the shorelines of the lacustrine environments (Haas, 1927; Dickas & Lunking, 1968), on marine beaches (Tanner, 1996; Baptista Neto & Martins da Silva, 2001; Martins, Martins, & Tabajara, 2003; Ghandour, Al-Washmi, & Haredy, 2003), barrier islands (Hall & Fritz, 1984), intertidal environments (Stanley, 1969; Jindrich, 1969; van Diggelen, 1983), and in the deep marine environment within sandy turbidity currents (Stanley, 1964; Hizzet, Summer, Cartigny, & Clare, 2020). Although it is generally assumed that AMBs have a transitory existence, they are common features in many sedimentary rocks that developed in various environments, including salt deposits (Lang, 1963), ranging in age from the Late Pre-Cambrian until the Holocene (Leney & Leney, 1957; Bull, 1964; Dickas & Lunking, 1968; Wayne, 1981; Little, 1982; Diffendal, 1984; Sen & Sit, 1998; Felix et al., 2009; Rybar et al., 2015; Mleczak & Pisarska-Jamroży, 2019). However, the armoring process of the mud balls is not a sine qua non to assure their fossilization, but their occurrence within stratigraphic sequences record high hydro energetic conditions in any particular environment as well as the suitable sources of pieces of clay material (Unrug, 1963).

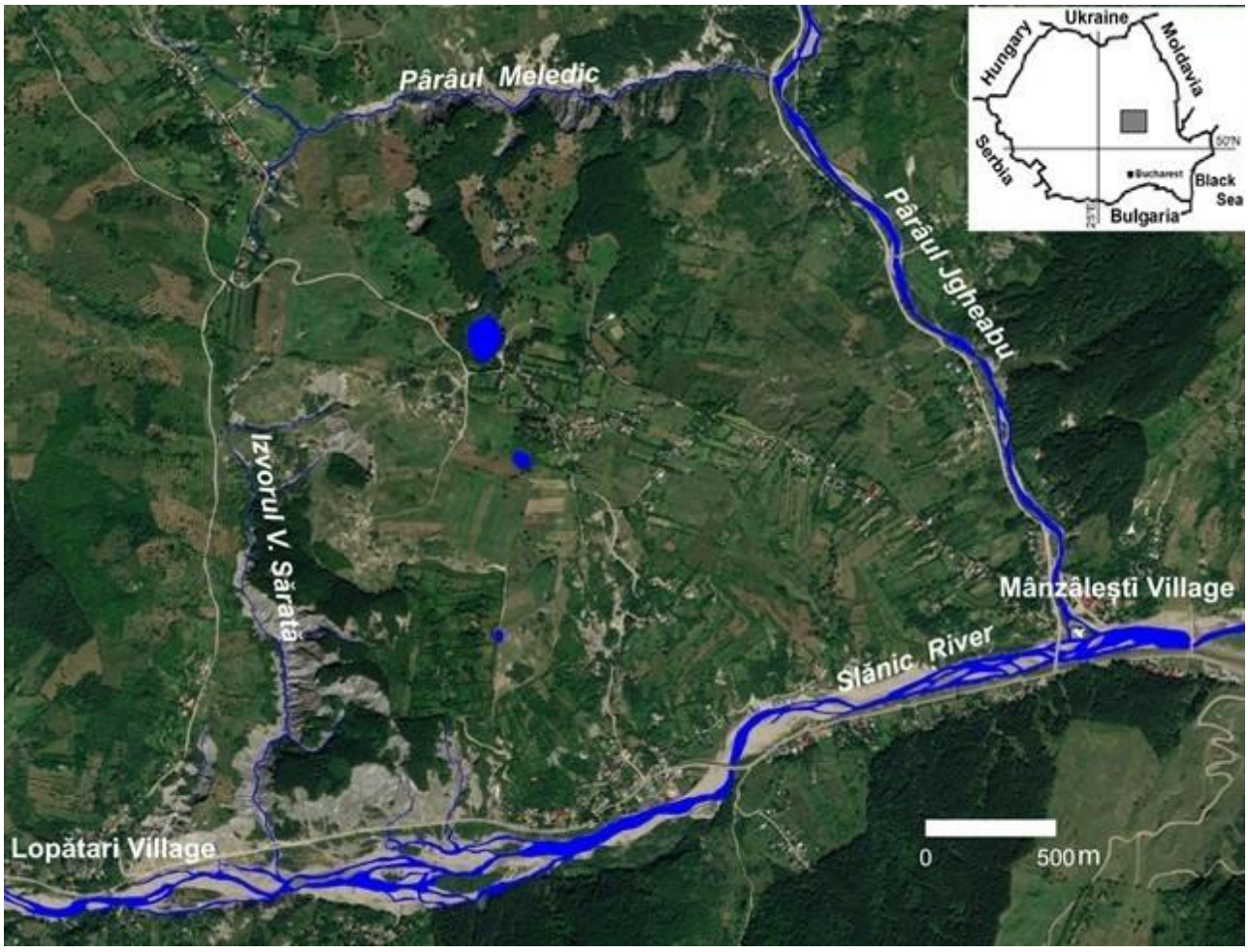

Fig. 1: Location of the Meledic Plateau in Romania

The formation of AMBs in the fluvial environ-ments is a physical process due to high energy de-veloped during flood events. Their occurrence is related to the discharge characteristics of river, and their shape and size reveal the competence of the rivers. They form when large pieces of hard and dry clay material or mud fell into a stream from slopes and river banks (Bell, 1940). Then, during the flood events, as a result of bedload transport within fluvial river systems, the angular pieces of rock tumble in the fast water currents (Bell, 1940; Mather, Stokes, Pirrie, & Hartley, 2008). Consequently, these angular pieces of rock become rounded as well as sufficiently soft and sticky on the outside for embedding of the streambed pebbles and coarse grains sand in their soft exterior. In this way, the armor of the mud balls is formed. The armor defines the final size of the mud balls. Soon after the energy of the flash runoff decreases, the AMBs remain scattered along the transport path. Further, the newly created AMBs might be preserved and recorded as sedimentary evidence only if they are buried and sealed by fine sediments during the flood events. Within temper-ate climate areas AMBs occur during summer floods that are caused by torrential rains; they were not found after winter floods induced by thawing (Krzyszton, 1984).

After Bell (1940) performed a thorough study of clay ball genesis in a ravine subject to strong flooding, several experiments were undertaken to investigate the origin and morphological development of these kinds of mud aggregates (Smith, 1972; Mather, Stokes, Pirrie, & Hartley, 2008). The sphericity and roundness are the main criteria for the morphological description of AMBs (Bell, 1940; Mather, Stokes, Pirrie, & Hartley, 2008; Li, Shengli, Shan, Gong, & Yu, 2017) and as well as parameters that may be used to estimate the length of clay clasts and the velocity of streams which transported them (Bell, 1940; Diffendal, 1984; Faimon & Nehyba, 2004). However, regardless of the environment in which they are formed, common to AMBs is that they are made by two distinct materials (a rounded clay core, and debris elements that compose the armor) and are shaped by turbulent water currents and waves.

In this paper we report the occurrence of AMBs along two stream valleys that drain a salt massif located in southeastern Subcarpathians Bend, Vrancea Hills, Romania. Morphological and morphometric characteristics of AMBs as well as the environment conducive to their genesis are discussed based on successive field observations.

Methods

The study area - Geological and geomorphological setting

The two salt streams with low-flow regime, Meledic and Izvorul Sărat, wherein have been formed the armored mud balls, belong to the Subcarpathians section of the Slănicul de Buzău River drainage basin, Vrancea Subcarpathians hilly region. The area corresponds to the anticline structure that has developed in Miocene deposits of the Sub Carpathian Nappe (Săndulescu, 1984). Both streams drain an Aquitanian buried salt dome diapir that belongs to Mânzălești salt formation (Dumitrescu, Săndulescu, Bandrabur, & Săndulescu, 1970).

The sedimentary cover of diapir consists of Aquitanian salt breccia (reddish and grey clays, silty interbeds, clasts of green schist, fragments of marl and sandstone up to cobbles, and boulders) and Burdigalian age deposits that consist in grey marls, calcareous sandstones, an discontinuous gypsum strata (Dumitrescu, Săndulescu, Bandrabur, & Săndulescu, 1970). The salt breccia deposits are the main source of the heterogeneous stream bed material.

The sedimentary succession on top of the salt massive is near horizontal, but the contact plane with the salt rock is corrugated, both due to recent local folding caused by diapir (Stoica, Andrășanu, Palcu, & Popa, 2017) and sub erosion processes. The sub erosion of the salt massif at the contact with its cap rock, driven by the infiltrated meteoric water, leads to the subsidence of overlying sediments and continuous readjustment of the topographic surface. Sub erosion processes in the upper part of the salt diapir are marked by a darker residual layer of cap rock.

Fig. 2: General view of the Pârâul Meledic valley

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The physiographic expression of this salt massif is a plateau landform, the Meledic Plateau, resembling a trapezium which is delineated by river valleys (fig. 1) and a thrust fault on the west side. It is located between 45°29'3" and 45°30'13 North latitude, and 26°36'25"and 26°32'19" East longitude, covering an area of 3.12 km2 with an average altitude of around 500 m. The Meledic Plateau is sharply confined by steep slopes and escarpments where salt rock outcrops, both as a result of faulting process and fluvial erosion. Numerous karst features like dolines and sinkholes, are scattered on its surface (Strat, 2016; Móga et al. 2018). Some former dolines have evolved into doline valleys, gullies and ravines.

According to Köppen classification, the region has a humid continental climate, warm summer subtype. Based on the 1961-2000 data period, the yearly mean air temperature is around 8.7 °C. The multiannual average precipitations amount is around 650 mm, unevenly distributed throughout the year. Nearly two thirds of annual precipitations fall during the warm semester, May-July recording the annual pluvial maximum and heavy rains events. Precipitations amount recorded in June 2019 was 140 mm, of which about 80 mm were recorded in the first four days of the month and 37 mm fell on June 4th 2019, which caused a flash flood in the area.

Due to its geological, geomorphological and biodiversity value, most of the Meledic Plateau, including the above-mentioned two salty streams, it was designed natural protected area and also it belongs to Buzău Land Geopark (Anonymous, 2000, 2008; Andrășanu, 2010).

Field survey and data gathering

Fig. 3: General view of the Izvorul Sărat stream valley in the lower course, upstream to its debouche in the Slănic River. Picture taken on June 7th 2019, after the flash flood event

During a field trip carried out in August 2014 several well rounded, rougly spheroidal mud clasts coated by various size mineral debris were found partial immersed in water as well as stranded on the river bank along the Pârâul Meledic valley (Meledic Stream) located in the Meledic Pateau that belongs to Subcarpathians section of the Slănicul de Buzău River drainage basin. These unusual fluvial sedi-mentary features, never seen before, were identified as armored mud balls. In the following years, exten-sive surveys of the stream valleys from Meledic Pateau allowed to discover more AMBs specimens, to identify the sediment supply (suitable aggregates as mud ball seeds), the mud ball factory zone of stream valleys.

Also, geomorphology of the stream valleys was exanimated. Taking advantage of the flood event from 4th June 2019, the stream valleys were explored on 7th June 2019. Newly formed armored mud balls were found and exanimated on the river bed of the second stream, Izvorul Sărat, also. Along the two stream valleys that have been subject of our observations, AMBs were randomly collected in order to examine their clay core material, size, shape, roundness, type of armor, and degree of preservation. To find if our findings are supported by other pub-lished studies, the literature review on AMBs subject was made.

Results and Discussions

The stream valleys – the environment of formation of AMB

The Pârâul Meledic delineates northern side of the Meledic Plateau (Fig. 1). This stream flows in eastern directions along around 1.5 km and debouches into Jhiabului River that is the left-bank tributary of the Slănic River as well as the eastern boundary of the Meledic Plateau. The valley of Pârâul Meledic is fairly straight, deep and narrow "V-shaped", with unstable steep sides, over 45°, where the salt rock outcrops. The upper part of slopes exhibit badland features as a result of erosion of friable and loose sedimentary material (Fig. 2). Superficial landslides and mudflows are mobilized on springs when the clay material reaches its plastic limit and can slide due to heavy rains. During dry periods, because of sodium chloride, this material is affected by desic-cation cracks and popcorn structures.

On the salt outcrops surface runoff shapes sharp rillen-karren patterns that then evolve into planar solution surfaces. The remaining residue of rock salt is carried downslope by runoff and deposited on sub-horizontal portions of the slopes which, accord-ing to its thickness and areal distribution, become a protective layer of salt from further dissolution. Due to a sandstone sequence in the eastern part of the

salt dome, close to its confluence with Jhiabului River, the Meledic valley has a short a gorge section with knick point and waterfall, where the valley does not exceed 2 meter wide.

The main tributary of the Pârâul Meledic drains a doline and salt cave system from Meledic Plateau, which includes one of the longest salt caves in the world (Giurgiu, 1987). Several other brine springs that drain salt massif feed the stream on the right-bank.

Izvorul Sărat, which is almost a 2 km long stream, has developed its catchment in the western part of the Meledic Plateau (Fig. 1). It flows in north-south direction and is a left-bank tributary of the Slănic River. The Izvorul Sărat valley is a relatively straight channel, deeply incised into salt diapir, with very steep slopes, especially in the midle and lower course section that is named „Salt Canyon" (Fig. 3) where it overlaps on a thrust fault (Ponta, 2019).

Fig. 4: Salt outcrop and earth pyramids formed in cap rock material on the steep slopes of the Izvorul Sărat stream valley

The evolution of the salt escarpments delineated by streams is controlled by runoff, dissolution and gravitational mass-movement. Over time, the erosion has been disintegrated slopes and generated peculiar features as a result of the overlap of two different geological materials: salt rock and its cap rock. In the cover material, with stone blocks and enough large sandstone and mudstone debris, formations resembling something between the classic earth pyramids and tulin are formed, while in the more homogenous material only ravines and ridges are shaped. When the salt rock outcrops, water rain dissolves the exposed salt, detaching salt columns with more or less pyramidal breccia material cover (Fig. 4).

The span life of these salt pyramids is shorter than that of classical earth pyramids and most probably weathering processes are involved in their evolution. It is not uncommon for the columns of salt to break off and collapse under the weight of their covering material. Materials derived from sed-imentary cover of salt rock are the source of the talus cones as well as of the river bed pavement. The stream Izvorul Sărat is fed by many small salty springs that emerge from both sides of the valley. These springs play a critical role in the salt content of the stream during dry period times.

Both streams, Pârâul Meledic and Izvorul Sărat, are very shallow. Their water discharges show monthly variability, being directly linked to rainfall regime. Toward the end of the summer the water discharge is very low and streams are affected by drying up processes. Drought periods lead to evaporation of high mineralized water from streams and their hyporheic zones and efflorescence of sodium chloride that results in the white crusts on the river bed sediments (Fig. 5). Thus, the stream bed becomes partially covered by salt crust and halite crystals, resembling frozen water and hoarfrost. Clay materials on the steep slopes of both stream valleys alternately desiccate/crack and erode during hot dry and rainy seasons.

Armored mud balls – morphology, genesis and deposition

Along two stream valleys, which are deeply incised in a salt Miocene formation from southeastern Subcarpathians, Romania, have been found particular rounded sedimentary structures whose already enshrined name is armored mud balls. Their distribution along the valleys was irregular, being preponderantly in the middle course of Pârâul Meledic and in the lower course of Izvorul Sărat stream, which, morphologically, mainly corresponds to its canyon-like valley section, just before of its debouche.

The density of AMBs along the Pârâul Meledic ranged from 0.6 to 1.4 per m2 across the area in which they occurred. They were lying in the stream channel, partial immersed, as well as on the stream bank, and among rock debris (Fig. 6, 7). Also, AMBs were identified embedded in sediments of stream bed that were exposed by fluvial erosion (Fig. 7). Few AMBs, only partially embedded in a loose sandy loam matrix, were thoroughly coated by white halite crystals. Several of AMBs that were completely subaerial exposed were partially disintegrated, most probably due to desiccation and weathering, which means that they are never preserved unless completely covered at the time of the flood by soft alluvium (Bell, 1940; Mather, Stokes, Pirrie, & Hartley, 2008).

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Fig. 5: AMBs immersed in water stream in a low velocity section of the Pârâul Meledic channel and surrounded by Enteromor-pha intestinalis thali. The size of AMB may be noted in comparison to the alga thallus, which range from 0.5 to 1.5 cm wide. In insert, a close up of an AMB spec-imen. Noteworthy is the heterogeneous armor of the mud ball, whitish appear-ance of its subaerial exposed part caused by salts precipitations, and thalli of ma-rine alga Enteromorpha, which is an un-common species in rivers but whose its occurrence is supported by the high salin-ity of stream water

Fig. 6: AMBs immersed in water stream in a low velocity section of the Pârâul Meledic channel and surrounded by Enteromor-pha intestinalis thali. The size of AMB may be noted in comparison to the alga thallus, which range from 0.5 to 1.5 cm wide. In insert, a close up of an AMB spec-imen. Noteworthy is the heterogeneous armor of the mud ball, whitish appear-ance of its subaerial exposed part caused by salts precipitations, and thalli of marine alga Enteromorpha, which is an uncommon species in rivers but whose its occurrence is supported by the high salin-ity of stream water.

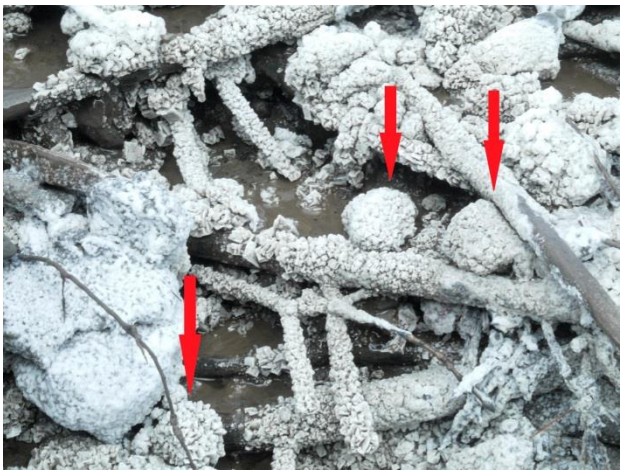

Fig. 7: AMBs immersed in water stream in a low velocity section of the Pârâul Meledic channel and surrounded by Enteromorpha intestinalis thali. The size of AMB may be noted in comparison to the alga thallus, which range from 0.5 to 1.5 cm wide. A close up of an AMB specimen. Noteworthy is the heterogeneous armor of the mud ball, whitish appearance of its subaerial exposed part caused by salts precipita-tions, and thalli of marine alga Entero-morpha, which is an uncommon species in rivers but whose its occurrence is support-ed by the high salinity of stream water

Based on measurements of 57 specimens randomly sampled the AMBs ranged in size from 5 to 17 cm in diameter, with an average diameter of 9 cm, but few specimens which was not part of the sample, were larger. The AMBs were dark grey and brownish yellow, nearly perfect spheres in shape (Fig. 6, 7, 8). They were generally uniformly armored and the armor was variable in composition and size, ranging from coarse grains sand to pebble. The pebbles were firmly inserted into clay and well pressed in, so the surfaces of AMBs were fairly smooth (Fig. 7, 8). AMBs specimens that have collected from the Izvorul Sărat stream soon after the flood event were soft, malleable and sticky but with a dry core.

The armored nature of the mud balls that were found was confirmed by slicing several open. The interior of each mud ball consisted of clay material with few small pebbles and the exterior was coated by a layer of coarse sand grains to pebble – size clasts, more diverse as origin (sandstone, marl, green

schist, limestone), up to 30-35 mm in diame-ter. Clasts were irregular, with varying degrees of rounding, from unrounded to well-rounded. Some of AMBs were well rounded and spherical but incomplete varnished by armor.

The core material of AMBs that have been found in the study area has two sources. The main source consists of clay material that composes the cap rock of salt massif that has evolved in badland slopes. It is about by detached blocks from the upper part of slopes as a result of rock falling, which break up and reach the river channel, pieces of clay material detached by cracking from slopes affected by mass movement, popcorn structures, as well the colluvi-um material that produced talus slopes. The second source core of AMBs is the fine mud material deposited along the stream bed and then exposed. The desiccation cracking process that is enhanced by the crust of sodium chloride generates irregular clasts of cohesive clay material. From the resulted mass of unsorted pieces of clay material by various sizes, some of them suitable aggregates to become AMBs. S-o called mud ball 'seeds", if the energy of currents during time of floods is strong enough, are transported as bedload or lifted in the water column, being suitable to be rounded by turbulence flow. Then, if they are enough soft and sticky, the armor is added to the core as the sand and gravel grains press into soft exterior while they are rolling downstream.

Fig. 8: Close up of AMBs specimens collected from the Izvorul Sărat valley following the flash flood event fom June 4th 2019

However, based on observations carried on the two valleys it was noticed a larger number and a higher frequency of occurrence of AMBs along the Pârâul Meledic than in the Izvorul Sărat valley, althought the lithology and climate are identical in both cathments. The diffrence in their ability to generate mudballs consists in topographic configu-ration of the valleys and extension of the salt out-crops within the slopes in relation to clay material cover of the salt rock. Althought in the most of the previous reported cases of AMBs in fluvial alluvial systems there is a direct and strong connection be-tween steep slopes that supply the source of suitable aggragates and generation of AMBs, the Izvorul Sărat reveals a weak connection in this regard com-pared to the other stream. The slopes of the Pârâul Meledic are less steep than those of the Izvorul Sărat, but they are covered by bare clay material, seasonaly affected by active mass movements and runoff. Besides the salt soluble content of this mate-rial enhances desiccation cracking and popcorn stucture formation. Consequently, these slopes are constant, direct and suitable source of mud ball seeds to the stream.

Fig. 9: Mud clasts produced by mud craking are the second source of the 'seeds' of AMBs. The dessication craking process is inten-sified by the sodium chloride content of clay material

The slopes of Izvorul Sărat valley, even though they are very steep, they are rather point sources of clay into stream. Most part of slopes consists of exposed salt rock and clayey material comes from their upper part, mainly as large blocks of material which fall at the foot slope, building the talus. Then,

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subsequently these blocks might become source aggregates for the mudballs by wethering and fluvial erosion (Fig. 3,4,10) evolving in suitable mud ball seeds in term of size or might be disintegrated by rains.

The AMBs that were found on the Izvorul Sărat valley were close to the mouth of stream, where the valley has a wide and flat floor, paved with gravels, cobbles, and even erratic boulders. The density of AMBs (ranging in size from 6 cm to 11 cm) in the area was 0.2 per m2, but they had a high degree of roundness and sphericity. These findings are in accord-ance to Bell (1940) who pointed out that size of balls record facts about the stream which made them; in a stream with bed composed mainly of stones, if the pieces of clay that reach stream bed are not large enough, then they would be crushed and smashed to bits by the heavier elements of the load during high water and hight velocities. The high degree of roundness and sphericity of AMBs, may sugests another interpretation, sensu Bell (1940): the AMBs increass in sphericity and armoring shell with the distance from source material, which is upstream to „Salt Canyon" area, the place where they occured.

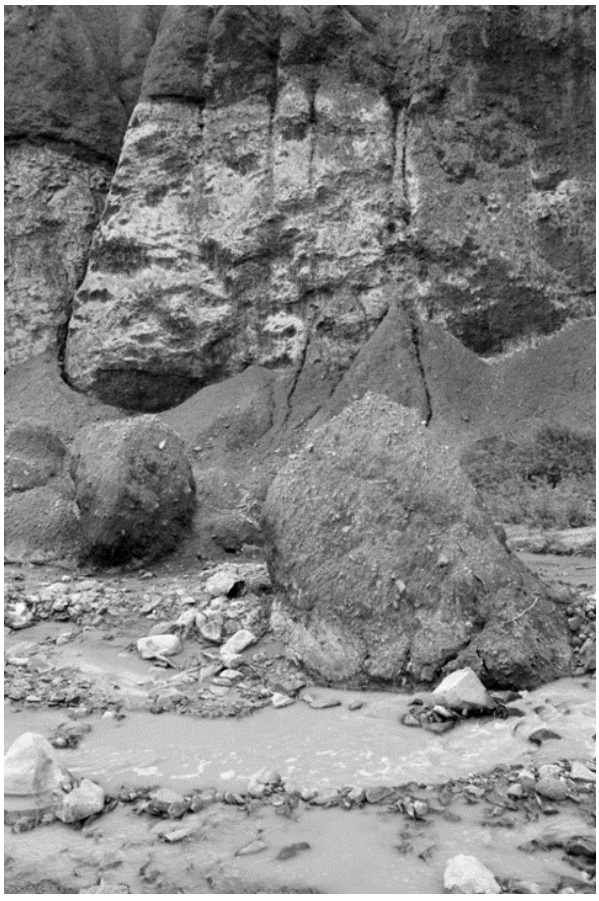

Fig. 10: Cayley blocks in the stream bed rounded by flow of stream, source of mud ball "seeds"

As opposed to Pârâul Meledic valley, where AMBs were present in considerable numbers, including embedded in riverbank sediments (Fig. 11) there is the possibility that the Izvorul Sărat stream does not produce commonly AMBs during the flash floods. Rounded mud clasts with various sizes as well as some disintegrated specimen of AMBs were noticed in the river bed during the surveys of valley, well-defined AMBs was spotted only once, immediately after the flood event from June 2019. However, the possibility of their genesis in similar circumstances cannot be excluded. Taking into account AMBs have poor preservation potential, even though they are produced because remain exposed on the stream bank and gravel bars, then they are disaggregated in the meantime. Perhaps the most important explanation of the scarce occurrence of AMBs on Izvorul Sărat valley may be that there are not suitable clay pieces or mud ball "seeds" (Mather et al., 2008) in the "mudball "factory" (Bell 1940) for production of AMBs during each flood event, the optimum condi-tions for mud balls generation are not met regularly. Also, it may be speculated that the scantiness of AMBs along this valley is that they are delivered to the mainstem as a sediment load because before of it confluence there is not enough flow decrease to cause their deposition.

Fig. 11: AMBs embedded in the layered Pârâul Meledic stream bank of the Pârâul Meledic. The erosive section of the stream bank shows successive fluvial deposits that preserve AMBs formed during previous flood events. Some of the mud balls, rested on the current river bed, both armored and unarmored, may have been exhumed from their matrix by ero-sion during high waters and reintroduced into active river system as bedload. Also, the lightly armored balls found in the water may have been new, unfinished mud balls, formed during the most recent flood event, or older AMBs that were peeled off by corrosion

Fluvial erosive sections through several point bars of the Pârâul Meledic have revealed buried AMBs formed during discrete flood events that were preserved in the subsurface (Fig. 11). This fact support idea that in similar valleys nearby study site and other salt areas from Subcarpathians AMBs may be occurring, but not necessarily. However, if they are not covered by a thick layer of gravel, sand or clay, almost certainly they will be disintegrated and washed out by the next flood, as it was stated and experimentally confirmed (Haas, 1927; Bell, 1940; Mather et al., 2008).

The occurrence of AMBs in the area of the Meledic Plateau represent a new natural element that enhances the already its known scientific (geo-logical, geomorphological) and educational value (Giurgiu, 1995; Mărunțeanu & Ioane, 2010; An-drășanu, 2010; Strat, 2016; Stoica, Andrășanu, Palcu, & Popa, 2017; Melinte-Dobrinescu, et al., 2017; Moga et al., 2018). Taking into account that AMBs, as geo-logical formations, have not been documented in the Romanian geological or geographical literature, and neither in vernacular language, we suggest two Romanian versions of the accepted term by the international scientific community. The first one is "bilă de argilă armată", and it is the literal transla-tion without any change of meaning of the English term "armored mud ball". The other one,"bilă de lut ghintuită", is closer to normally spoken Romanian language, informally.

Conclusions

Modern fluvial armored mud balls developed in the salt Miocene formations that belong to South-East Subcarpathians, Romania, are reported for the first time. The geological, climatic and hydrogeomorphologic conditions are suitable for genesis of AMBs along two small stream valleys that are deeply incised in a salt diapire formations over which overlaps the geomorphological unit called the Meledic Plateau.

The occurrence of centimeter-sized mud aggregates coated by sand grains and various pebbles and rock clasts is associated with high energy of water during flash floods episodes following dry period times. The badland catchments and the steep slopes of the stream valleys supply the weathered blocks of clay material to the stream bed that are the main mud ball seeds within the "mud ball factory". The second source of AMBs consists in more homoge-nous pieces of polygonal shape of clay detached from stream banks as a result of mud cracking and erosion. The AMBs that were found along the stream valleys from the Meledic Plateau, Vrancea Subcarpa-thians, are nearly spherical, with an average diame-ter of 9 cm.

The observations made from this study show that these streams represent an exceptional opportunity to study contemporary fluvial AMBs formed in a hilly region with temperate climate. The occurrence of these particular sedimentary structures represent a physical proof of extreme floods episodes caused by summer heavy rain episodes following a dry long period time, similar to semi-arid regions when AMBs were initially studied, but more detailed stud-ies are needed. In addition, AMBs can be regarded as a new natural element that enhances the scientific and educational value of the Meledic Plateau, which was designed as natural protected area and part of the Buzău Land Geopark.

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Author contribution

Both authors contributed equally to this manuscript.

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