PATRULIUS OLISTOLITH – A LARGE JURASSIC LIMESTONE BLOCK IN ALBIAN CONGLOMERATES OF THE BUCEGI MOUNTAINS, SOUTHEAST CARPATHIANS, ROMANIA

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Abstract. The paper introduces and describes the *Patrulius Olistolith*, one of the largest exotic blocks (218 m long, 110 m wide and 55 m thick) embedded in Albian conglomerates from the Carpathian Bend area (southern part of Eastern Carpathians, Romania).
The Albian conglomerates embedding the Patrulius Olistolith are deposits with homogeneous internal structure and poor sorting, features typical of debris flow sediments. Based on this character, it is considered that the Patrulius Olistolith transport was a gravitational collapse process and that it was transported as a very large clast within the mass flow conglomerates.
The olistolith-embedding conglomerates also have sedimentary features (small matrix amount, normal grading and some internal sedimentary structures) not typically produced by mass transport process, which points out the special nature of the transport and sedimentation processes responsible for the deposition of the conglomerates and embedded olistoliths, and calls for further sedimentological investigations. Like the other Albian Bucegi olistoliths, the Patrulius Olistolith was subjected to an estimated 10 km marine transfer, its transportation taking place in shallow waters.

Key words: exotic blocks, mass transport, debris flow conglomerates, olistolith transport

1. INTRODUCTION

The Lower Cretaceous deposits of the Bucegi Mountains include numerous allochtonous, or exotic blocks also referred to as olistoliths (Flores, 1959; Patrulius, 1969, Abbate *et al.*, 1970). Most of the olistolith blocks are made of Jurassic limestone and only a few smaller metamorphic rock olistoliths occur. The olistoliths are included in different stages of Lower Cretaceous deposits, starting with the Valanginian stage. Olistolith size varies from a few meters to more than 200 m, and exceptionally to more than 1000 m (Patrulius, 1969).

The objective of this paper is to present one of the largest olistoliths of the Bucegi area, describe its stratigraphic position, the conglomerate deposits that incorporate the limestone block, and the sedimentological contacts between the block and the bed(s) that incorporate it.

The Jurassic olistolith that we describe in detail has not been previously discussed in the literature, nor has it been identified with a given name. Here we propose to call this block "*Patrulius Olistolith*", to honor Dr. Dan Patrulius, an extraordinary, accomplished Romanian geologist of the 20th century, the first scientist who identified, mapped and interpreted the olistoliths from the Bucegi area. The Patrulius Olistolith name in relation to the large limestone block was first mentioned by Jipa and Olariu (2018).

The research area of this study is located in the northern part of the Bucegi Mountains, in the Carpathian Bend zone (Fig. 1). The area is positioned at the boundary between the Eastern and the Southern Carpathians.

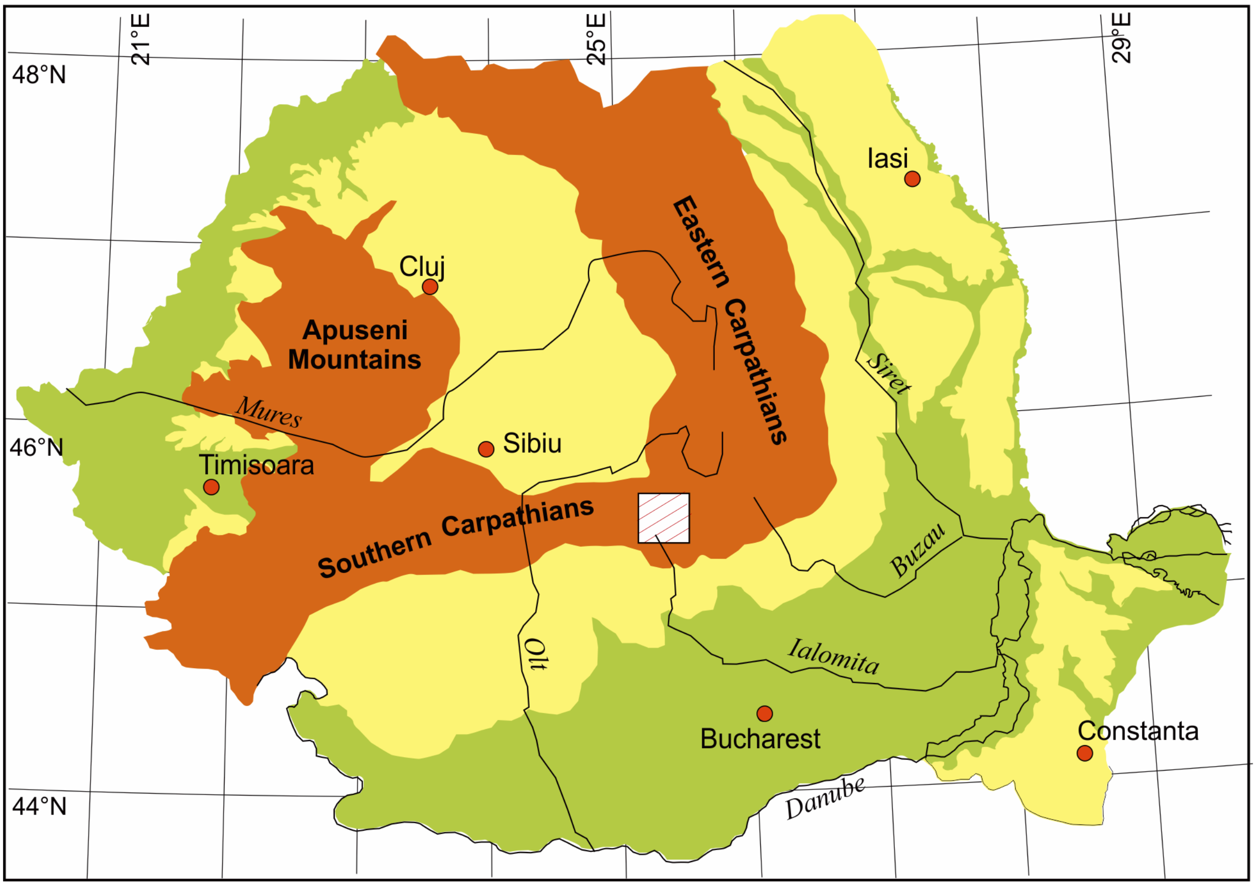

Fig. 1. Geomorphological map of Romania showing plains (green), hills (yellow) and mountains (orange/brown). Study area, Bucegi Mountains, is indicated by the white square.

2. MATERIAL AND METHODS

Research was carried out by direct observations through geological field work combined with utilizing remote data obtained from satellite images. Detailed geological examination (grain size, bedding structure, bed contacts, and clast composition) focused on the study of the olistolith basal surface and of the deposits occurring underneath and lateral to the olistolith. Geological observation provided data regarding the Patrulius Olistolith in relationship with the underlying and overlying conglomerate deposits. Satellite Google Earth and Microsoft Bin images supplied important data regarding the olistolith location within the overall stratigraphy, its morphology, and overall dimensions. The interpretations of the data also used information regarding features of the conglomerates within which the Patrulius Olistolith is embedded.

3. GEOLOGICAL SETTING

One of the earliest geological studies of the Bucegi Mountains (Jekelius, 1928) considered that the exotic blocks included in the Lower Cretaceous deposits are tectonic blocks that mark a thrust plane. The tectonic interpretation related to all the Bucegi Jurassic limestone block occurrences was challenged by Oncescu (1945), who proposed that the limestone blocks come from an older relief and have been incorporated into the conglomerates. As already mentioned above, Patrulius (1969) is the first visionary geologist to understand and correctly interpret, in modern terms, the sedimentary significance of the limestone blocks cropping out in the Bucegi Mountains.

Individual olistoliths associated with the Albian conglomerates have been mapped in remarkable detail (Fig. 2). Approximately 100 exotic blocks are marked (the location and approximate dimension) on the Bucegi Mountains geological map (Patrulius, 1969) and also added on the 1:50,000 scale Geological Map of Romania (Patrulius *et al.*, 1971).

3.1. Litho-stratigraphy of the Albian deposits in the Bucegi Mountains

The Albian conglomeratic deposits of the Bucegi Mountains show two important lithostratigraphic units: a conglomerate unit and a predominantly sandstone unit. The Bucegi Conglomerates is the most important unit of the Albian sedimentary succession (Fig. 3). The conglomerates reach a thickness of about 1300 m in the north part of the Bucegi Mountains and thin significantly and pinch out southward over a 10 to 15 km distance.

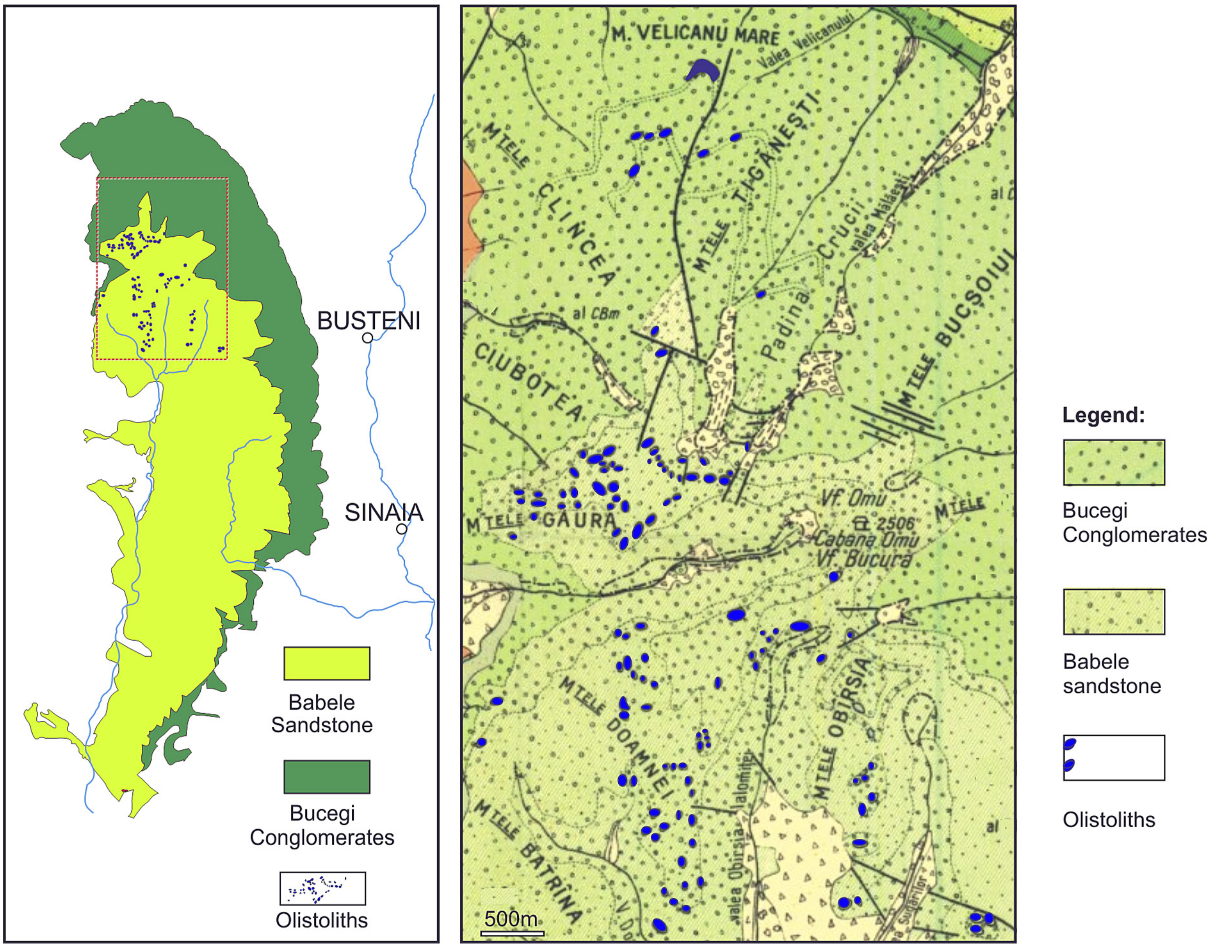

Fig. 2. Olistoliths in Albian deposits on the Patrulius map of the Bucegi Mountains. On the left, the distribution of the two main units of the Bucegi Mountains (Bucegi Conglomerates and Babele Sandstone) (simplified from Patrulius, 1969). On the right, mapped Albian olistoliths on the Geological Map of Romania, scale 1:50,000 (Patrulius *et al.*, 1971).

Murgeanu and Patrulius (1963) divided the Bucegi Conglomerates succession into three subunits (Lower, Middle and Upper Bucegi Conglomerates). Our investigations indicated that these subdivisions are not genetically significant and there are common depositional elements to all three units.

The Bucegi Conglomerates are overlain by the dominantly arenaceous deposits of the Babele Sandstone unit (Patrulius, 1969) (Fig. 3). Patrulius (1969) and Jipa *et al.* (2013) revealed the presence of an extensive rudaceous facies of the Babele Sandstone unit, in places discontinuous, but presenting similar bedding and depositional styles as the underlying Bucegi Conglomerates.

Based on pebble imbrications measurement, Panin *et al.* (1963), Mihailescu *et al.* (1967) and Patrulius *et al.* (1967) mapped the paleocurent directions in all the Albian conglomerates from the Carpathian Bending area. As suggested by the radial dispersal distribution of the measured paleocurrents, Murgeanu *et al.* (1963) interpreted the deposits of the Bucegi Conglomerates as a submarine fan with the main apex, or source, area located in the northwest area of the present Bucegi Mountains. Stanley and Hall (1978) proposed the deep sea fan setting and compared it to modern deposits of the Southern Alps to Mediterranean Sea system. The deposits were more recently interpreted by Jipa and Olariu (2018) as a slope fan.

The Babele Sandstone deposits have a sedimentation origin different from the Bucegi Conglomerates. Based on the variable orientation of the paleocurrents and presence of some pelitic and arenaceous intervals, the Babele Sandstone deposits are considered by Olariu *et al.* (2014) to represent sediment accumulation on a narrow shelf within a highly energetic (strong currents) environment. The Babele Sandstone represents the shallow water margin of an elongated deep water, trench-like basin extending at least 25 km westward from the Bucegi Mountains (Jipa and Olariu, 2018) (see Fig. 10).

3.2. Olistolith litho-stratigraphic distribution

The olistoliths mapped by Patrulius (1969) (Fig. 2), as well as other blocks that cannot be depicted on the geolog-

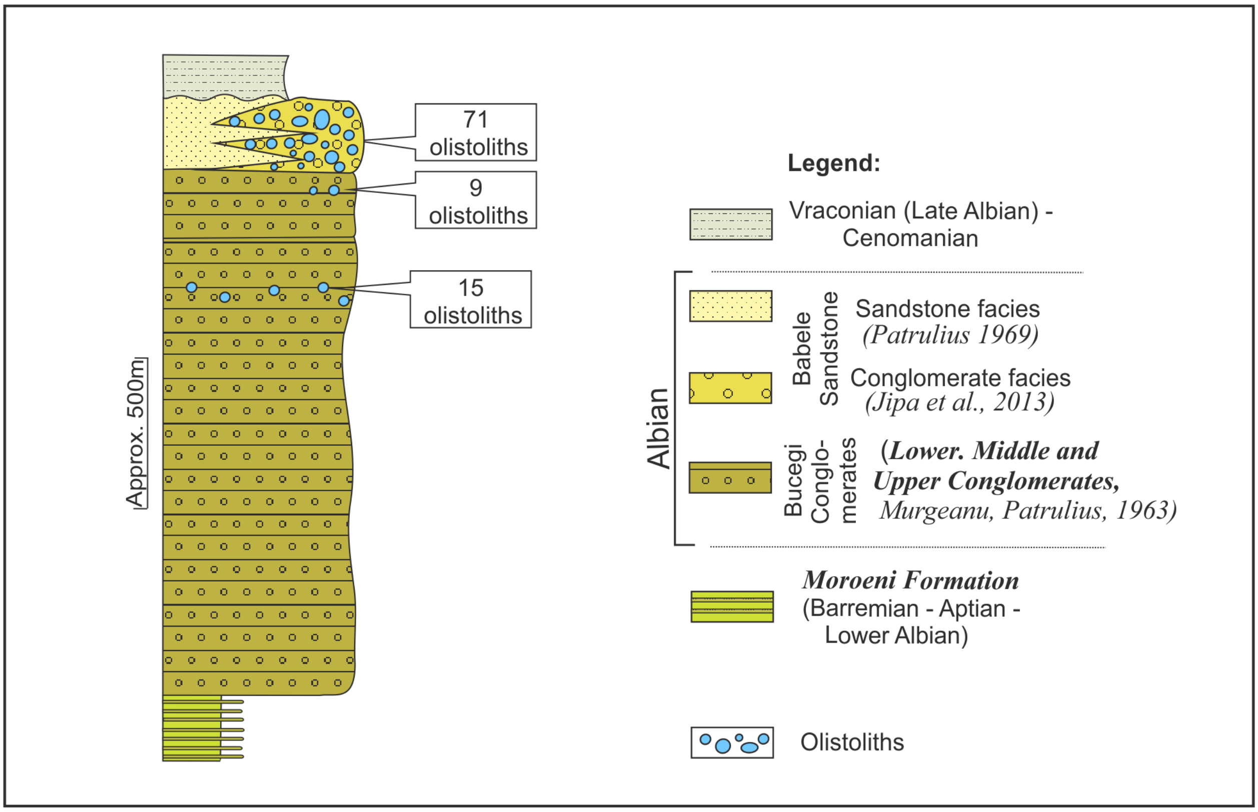

Fig. 3. Lithostratigraphy of the Albian conglomerates and the stratigraphic distribution of the olistoliths. Modified after Jipa and Olariu (2018). The number of olistoliths mapped (Patrulius, 1969) at different stratigraphic levels is also shown.

ical map, are scattered and appear irregularly distributed on the map as well as stratigraphically in the upper part of the litho-stratigraphic column of the Albian conglomerates (Fig. 3). Considering only the mapped exotic blocks, it appears that most of them (more than 80%) occur in the deposits of the Babele Sandstone conglomeratic facies. A small number of olistoliths (less than 20%) occur in the upper part of the underlying Bucegi Conglomerates (Fig. 3). Most of the olistoliths embedded in Albian conglomerates are limestone blocks, with similar lithology.

4. PRESENTATION OF DATA

4.1. Patrulius Olistolith location

The Upper Jurassic exotic block, named in this paper "*Patrulius Olistolith*", occurs in the highest area of the alpine zone in the Bucegi Mountains. The olistolith is located about 1.2 km west of the highest peak (Omu Peak), in a saddle between the Bucura and Doamnele peaks (Fig. 4). The topographic point corresponding to the location of the Patrulius Olistolith is called Găvanele (2479 m elevation), with 45°26´23.38˝N and 25°26´48.89˝E coordinates.

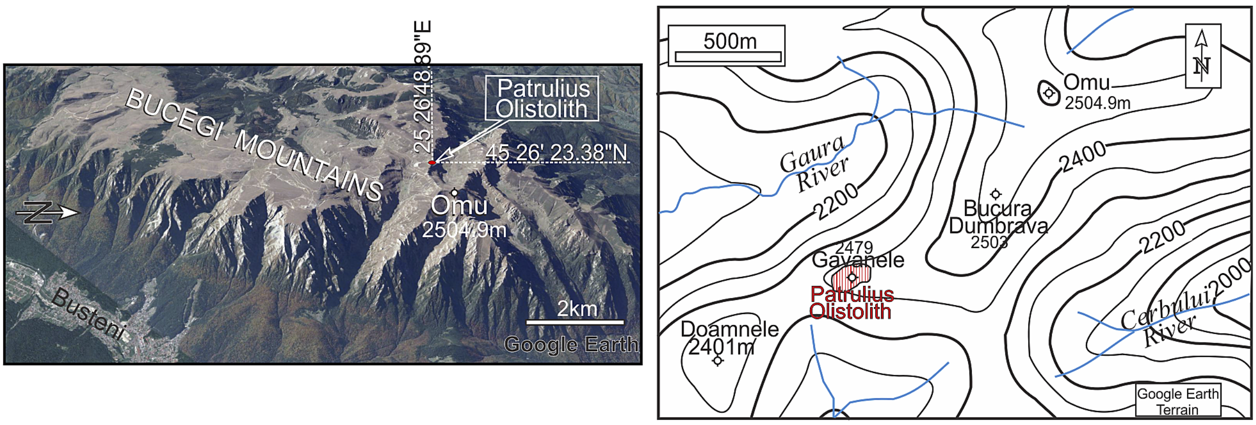

Fig. 4. Patrulius Olistolith location. Satellite image from Google Earth (left) and topography (right) from Google Earth Terrain.

Patrulius Olistolith appears in the center of the field where Albian olistoliths are cropping out in the Bucegi Mountains plateau area (Figs. 2 and 5). Taking into consideration only the largest (over 100 m) exotic blocks, the Patrulius Olistolith occurs southward from the Velicanul Mare Olistolith and in close vicinity to the Mecetul Turcesc Olistolith (Fig. 5)

4.2. Morphology of the Patrulius Olistolith

Being located on top of a narrow mountain crest and having a light color with strong contrast to the surrounding, the Patrulius Olistolith is clearly visible in horizontal plan on Google Earth and Bing satellite images (Fig. 6A) as well as in vertical plan in a large outcrop (Fig. 6B). In the horizontal section, the shape of the exotic block is slightly elongated (Fig 6A). The contour line of the olistolith surface is rather smooth, but irregular.

In the vertical plan the limestone block is relatively symmetrical, thickest (about 55 m) in the central part (Fig. 6B) and decreasing to about 25 m at the sides. The upper surface, presently exposed to weathering, is unevenly undulated. The basal surface of the olistolith is more irregular and its contour line describes a large undulation, discordant to the bedding of the underlying deposits (Fig. 6 B).

Measured on a satellite image, the olistolith have a maximum exposed length of 218 m and reaches a width of 110 m (Fig. 6A). The thickness of the limestone block in the existing, rather marginal natural vertical section is 55 m (Fig. 6B).

4.3. Patrulius Olistolith in the Babele Sandstone sedimentary succession

The entire sedimentary succession that incorporates the Patrulius Olistolith is visible from the south-east slope of the Gaura River (Fig. 7). The limestone block occurs in conglomer-

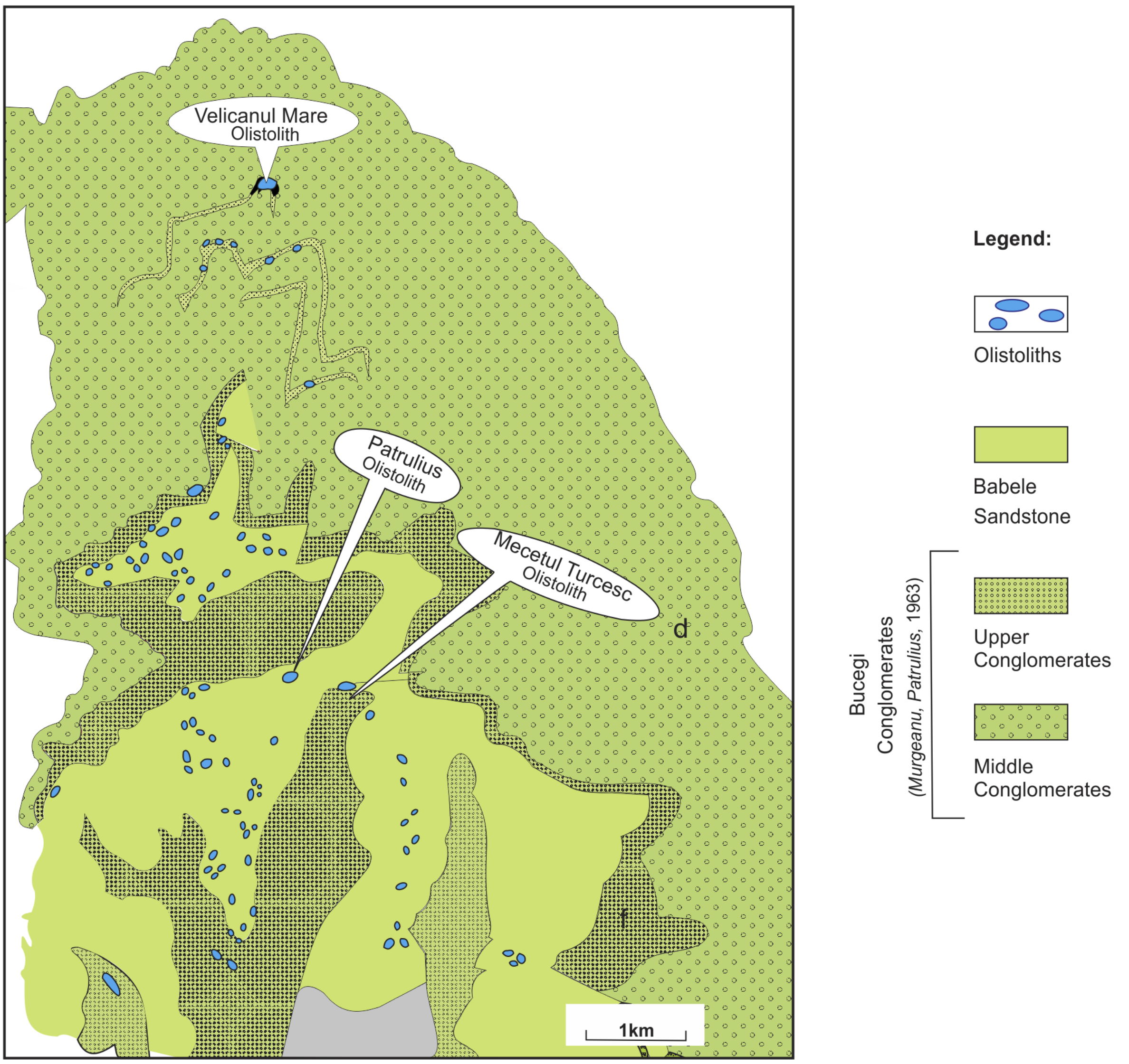

Fig. 5. Patrulius Olistolith location in the Bucegi Mountains. The Patrulius is located in the middle of the Albian olistoliths outcrop field. Note that most of the olistoliths are incorporated in the Babele Sandstone conglomeratic facies. Geological map from Patrulius (1969).

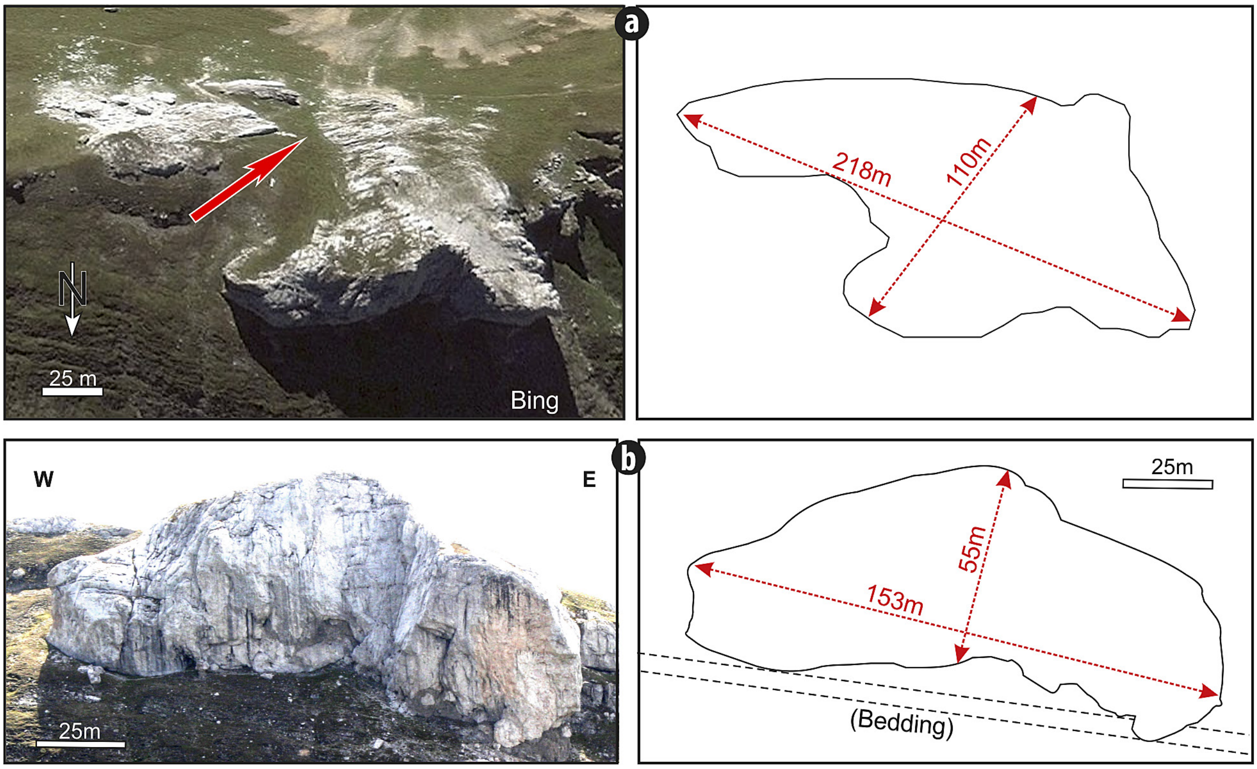

Fig. 6. Patrulius Olistolith shape and size, as seen on Bing satellite images (A) and telephoto images (B). **A.** Top view, horizontal image. Red arrow shows the regional paleocurrent trend (from Panin *et al.*,1963) (see also Fig. 10). **B.** Lateral image as seen in a south-facing natural vertical exposure.

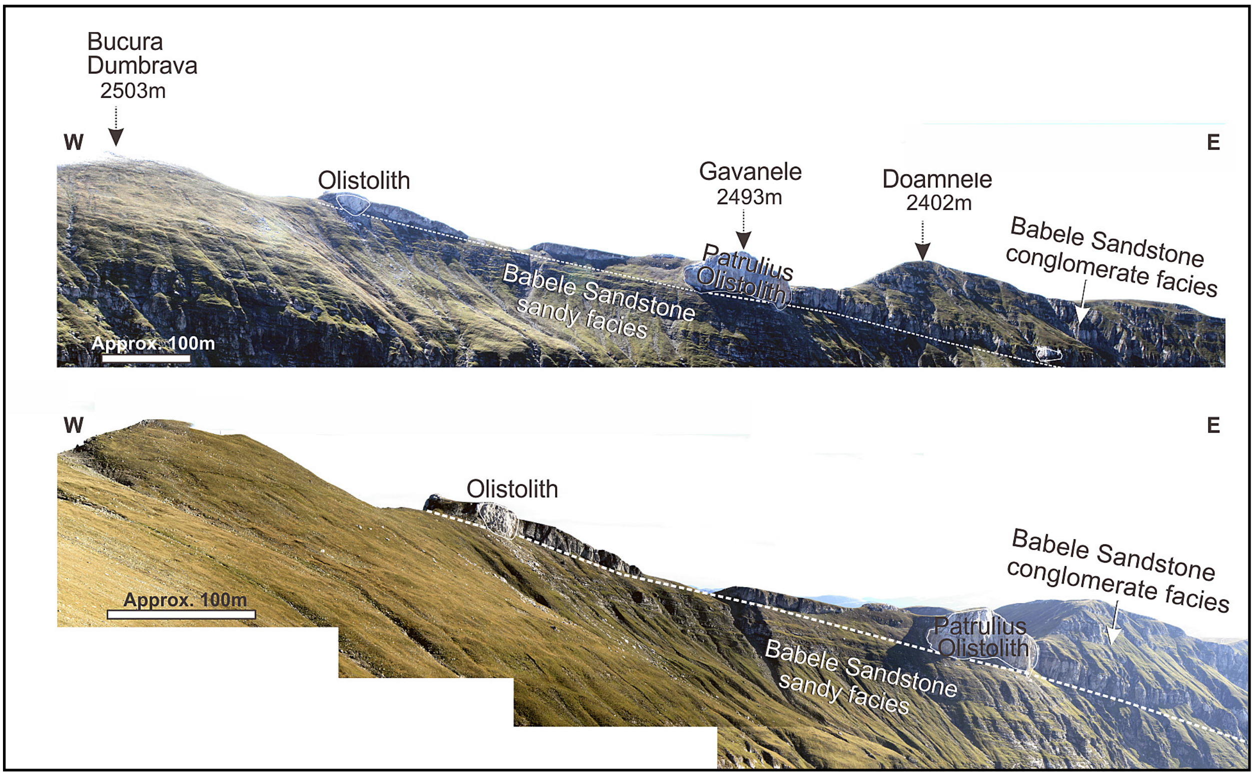

Fig. 7. The Patrulius Olistolith in the Albian conglomerate beds of the Babele Sandstone. Two photo panoramas taken from different locations.

ate beds that belong to the conglomeratic facies of the Babele Sandstone unit (Fig. 3). The conglomerates on the western side of the Patrulius Olistolith have been affected by recent erosion and presently, only 20 to 40 m of conglomerates is exposed in the outcrops. From the olistolith towards the east, the conglomerates are thicker, measuring about 100 m in the Doamnele Peak area (Fig. 7). The bottom part of the Patrulius exotic block is very close to the basal boundary of the conglomerate beds.

Under the interval with the conglomerate beds, a well-bedded sandstone series occurs (Fig. 7). Stratigraphically, the sandstones represent the lower part of the Babele Sandstone arenaceous facies, within the lateral transition between the northern rudaceous facies and the southern arenaceous facies (Jipa *et al.*, 2013). The Babele sandstone interval is at least 100 m thick in this locality.

Rudites belonging to the Bucegi Conglomerates crop out underneath the arenites of the Babele Sandstone.

4.4. Characteristics of the conglomerates embedding the Patrulius Olistolith

As mentioned in the previous section, the Patrulius Olistolith is embedded in conglomerates from the rudaceous facies of the Babele Sandstone. Conglomerates crop out both under and sideward of the olistolith (Fig 8 A and B). The top side of the olistolith is subaerially exposed (Fig. 6 and 7). The entire cropping out area of the Babele Sandstone conglomerates was examined. No consistent facies variation was revealed between the rudites around the Patrulius Olistolith and the other synchronous conglomerates in the northern Bucegi Mountains.

The embedding conglomerates have limestone and metamorphic rock clasts, with diameters varying from several centimeters (granules and pebbles) to several tens of centimeters (cobbles and boulders) (Fig. 8 C and D). Megaclasts (sometimes more than 1 m in diameter) are frequent. The grain-size sorting of the conglomerates is quite poor, a feature especially noticeable in the coarse conglomerate intervals.

The conglomerate matrix is arenaceous. Clasts make up most of the conglomerate deposit, with the sandy matrix constituting a smaller percentage (less than 30%) of the rock.

The degree of roundness of the large conglomerate clasts varies from rounded to subrounded. The larger clasts (more than 5 to 10 cm in lengths) are better rounded (Fig 8).

Normal grading occurs frequently in the rudaceous Babele Sandstone beds. Graded beds occur in both the conglomerates under the Patrulius Olistolith (Fig. 9 A and B) and those aside the olistolith (Fig. 9 C and D). The normal grading develops from coarse- or medium-grained conglomerate at the base, to coarse-grained sandstones at the top of the graded unit. Some of the top sandstones are well bedded (Fig. 9 E).

The Albian conglomerate beds associated (below, side and above) with the Patrulius Olistolith are distinguished by the absence of the internal sedimentary structures within beds. The homogeneous, disorganized aspect of these conglomerates is characteristic of the coarse-grained conglomerates found in the lower part of the graded units and, at least partly, in the finer grained conglomerates higher up in the graded beds (Fig. 9). The bedded aspect and internal structures become visible in the upper part of the normal-graded units (Fig. 9 E). The coarse-grained, homogeneous and poorly sorted conglomerate type seems to be prevalent in and characteristic to the Albian, Babele Sandstone ruditic facies.

5. INTERPRETATION OF DATA

5.1. The Patrulius limestone block defined as olistolith

The olistolith nature of large blocks with allochtonous origin is suggested by the occurrence of an older, exotic block within a younger deposit. But the same situation could be present when younger sediments cover a high relief surface of older sediments. The most convincing situation for an olistolith interpretation would be when the exotic block is visibly embedded by younger sediments.

The exotic block status of the Jurassic-age Patrulius Olistolith is fairly well proven, especially by the occurrence of Albian conglomerates below and laterally to the limestone blocks (Figs. 8 A and 9). Although the top of the limestone block is aerially exposed (Fig. 6 A), geological structure considerations indicate that Patrulius Olistolith is also covered by Albian conglomerates (Figs. 5 and 7).

The geological studies of Oncescu (1945) and Patrulius (1963) concluded that there are no valid arguments to regard the exotic limestone blocks occurring in the Albian conglomerates as resulting from thrust tectonics, as presumed by Jekelius (1928).

5.2. Sedimentogenetic contradictions of the embedding conglomerates

Several characteristics with sedimentogenetic significance emerge from the examination of the conglomerate beds embedding the Patrulius Olistolith. The most noteworthy characteristics of the beds are the absence of organized internal sedimentary structures and the very poor grain-size sorting of the beds associated with the olistolith. These features imply that the transport of the rudaceous material was not made through a particle-to-particle transport process. The lack of a clast-organized arrangement, by size or bedding structures, indicates that the detrital material was mass transported (a debris flow sediment), and that gravity was the triggering transport factor.

Major (2013) considers debris flows to be fluid-clast mixtures with fluid flow properties. This is why the predominance, or at least abundance, of matrix is considered a characteristic of debrites. The Albian conglomerates with encased

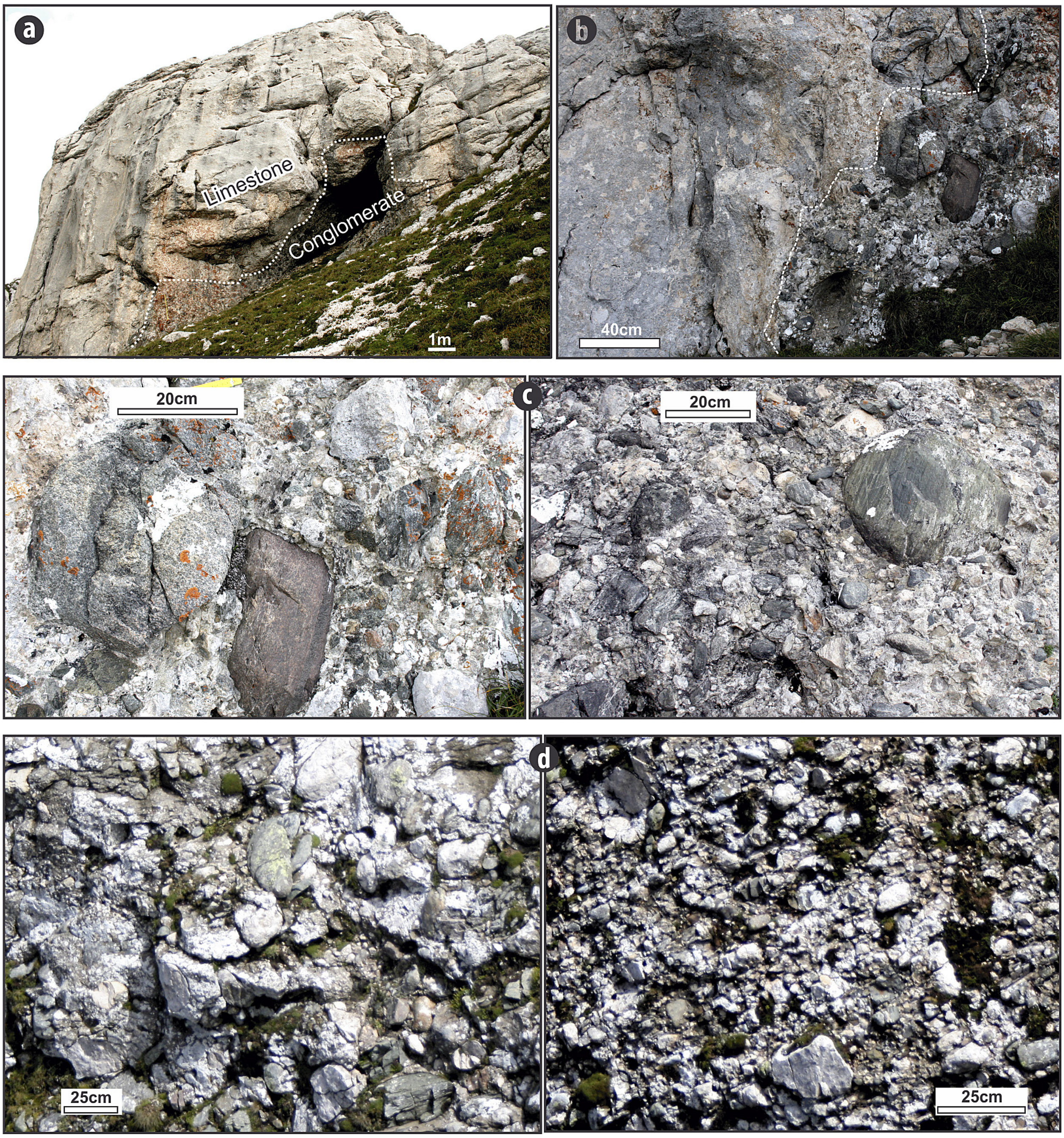

Fig. 8. Conglomerates below the Patrulius Olistolith. **A** and **B**. Poorly sorted conglomerates cropping out under the olistolith base. Note the irregular limestone – conglomerate boundary. **C**. Detailed view of the conglomerates occurring at the base of the olistolith. **D**. Conglomerates occurring aside the limestone block, between the Găvanele and Doamnele points.

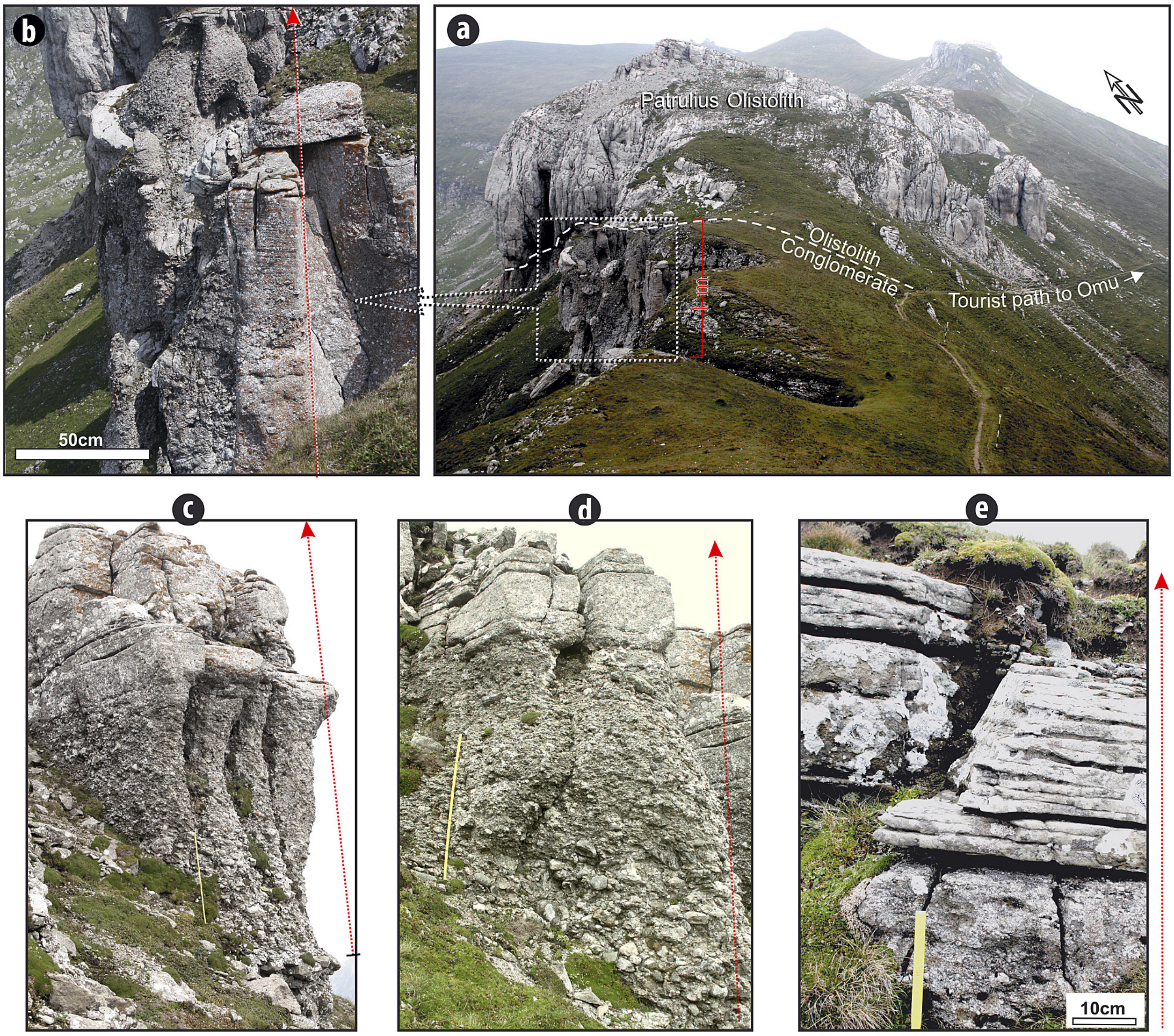

Fig. 9. Normal grading in the conglomerates embedding the Patrulius Olistolith. **A** and **B**. Normal-graded conglomerates below the olistolith. **C** and **D**. Fining-upward conglomerates located at the margin of the olistolith. **E**. Well-bedded sandstone from the top of the graded unit shown in D. The red dotted lines point out the grading trend. Length of the scale ruler in C and D images is 1 m.

olistoliths, however, show a small amount of matrix, and the matrix is not lutitic but arenitic or possibly coarser grained. This difference from characteristics typical of debris flow deposits—that is, the small amount and coarseness of the matrix—therefore contradicts the mass-transport process inferred for the Albian conglomerates.

Normal grading is a sedimentary aspect not associated with the debris flow connotation but rather with turbulent flows. The frequent normal grading of the conglomerates embedding the Patrulius Olistolith is the second important differentiation from the debris flow deposits model for the conglomerate beds. An Albian conglomerate normally-graded succession usually shows the debris flow facies (poor sorting, internal homogeneity) in the lower part. In the upper part of the succession grain-size sorting is better, internal sedimentary structures occur (bedding, imbrications and others), and the facies is rather of the turbulent flow type. In light of, and despite, these contradicting sedimentogenetic characteristics reveal the fact that the transport and accumulation process of the Albian rudites surrounding the Patrulius Olistolith was actually a special sedimentary process, implying both mass-flow (debris flows) and turbulent flow.

5.3. On the Patrulius Olistolith transport

One of the conclusions of this study is that the Patrulius Olistolith is embedded in Albian conglomerates from the Babele Sandstone lithogenetic unit and therefore likely has a similar origin as the conglomerates. As the conglomerates around the olistolith display mass transport characteristics (even though there is clear indication of some turbulent flow behavior), we infer that the olistolith was transported gravitationally together with the rudites. The data we presently have (discussed in the previous section) suggest the olistolith was transported as a very large block, and was moving with the downslope-flowing rudaceous material.

Because of the large size of the Patrulius Olistolith, additional studies and more clarification is required in regard to the assumption of its involvement in mass flow transport. According to outcrop observations, the Patrulius Olistolith is associated with several meters-thick conglomerate units. This suggests that the debris flow events responsible for these conglomerate units were relative small-scale processes, and likely could not explain the displacement of a 55 m thick block on the upper part of the flows. In synchronous conglomerates occurring immediately southward from the Patrulius Olistolith location, Jipa *et al.* (2013) described a conglomeratic mega-bed (a single sedimentary unit) 26 m thick, with multiple embedded olistoliths. Therefore, during the Babele Sandstone time volumetrically large debris flow individual events likely took place. This makes it easier to imagine the transport of a 200 m long limestone block embedded in rudaceous sediments. However, the at least 55 m thick Patrulius Olistolith could have been only partially included in the mass flowing material, with the olistolith top protruding above the gravitational detrital flow body.

5.4. Patrulius Olistolith sedimentary environment

The Bucegi Albian olistoliths, including the Patrulius Olistolith, are associated with conglomerates belonging to two main sedimentary systems. The olistolith-embedding Albian Bucegi Conglomerates are considered sediments of a deep sea fan (Fig. 10) from the Carpathian Bend area (Murgeanu *et al.*, 1963; Panin *et al.*, 1963; Mihailescu *et al.*, 1967; Patrulius *et al.*, 1967; Stanley and Hall, 1978). According to Jipa and Olariu (2018) this Albian submarine cone is a slope fan (Allen and Allen, 2005), its sediments covering not only the base-of-slope zone, but the entire continental slope from the shallow water upper part to the deep sea.

Olariu *et al.* (2014) pointed out that the Babele Sandstone sediments have been laid down in a narrow shelf environment. The Babele Sandstone and synchronous, associated deposits represent a sedimentary system different from the Bucegi Conglomerates. Westward, toward the Ialomița and Dâmbovița rivers area, the deposits of this system, including the bulk of the olistolith-wrapping conglomerates, laterally developed in a trench-like deep sea basin (Fig. 10). The Babele Sandstone deposits represent the shelf facies of this basin.

The olistoliths embedded in the Albian conglomerates are concentrated within a small area in the northern part of the Bucegi Mountains (Figs. 2 and 5). Most of these exotic blocks are included in the rudaceous deposits of the Babele Sandstone unit, considered shallow water shelf deposits by Olariu *et al.* (2014). Some of the olistoliths, incorporated in the Bucegi Conglomerates, occur in the shallow water area of the Albian submarine fan, at the edge of the source area (Jipa and Olariu, 2018) (Fig. 10). Consequently, the olistoliths from both sedimentary systems of the Bucegi Mountains Albian conglomerates, including the Patrulius Olistolith, have been deposited in a marine shallow water environment, located in a zone near the non-marine source area (Fig. 10).

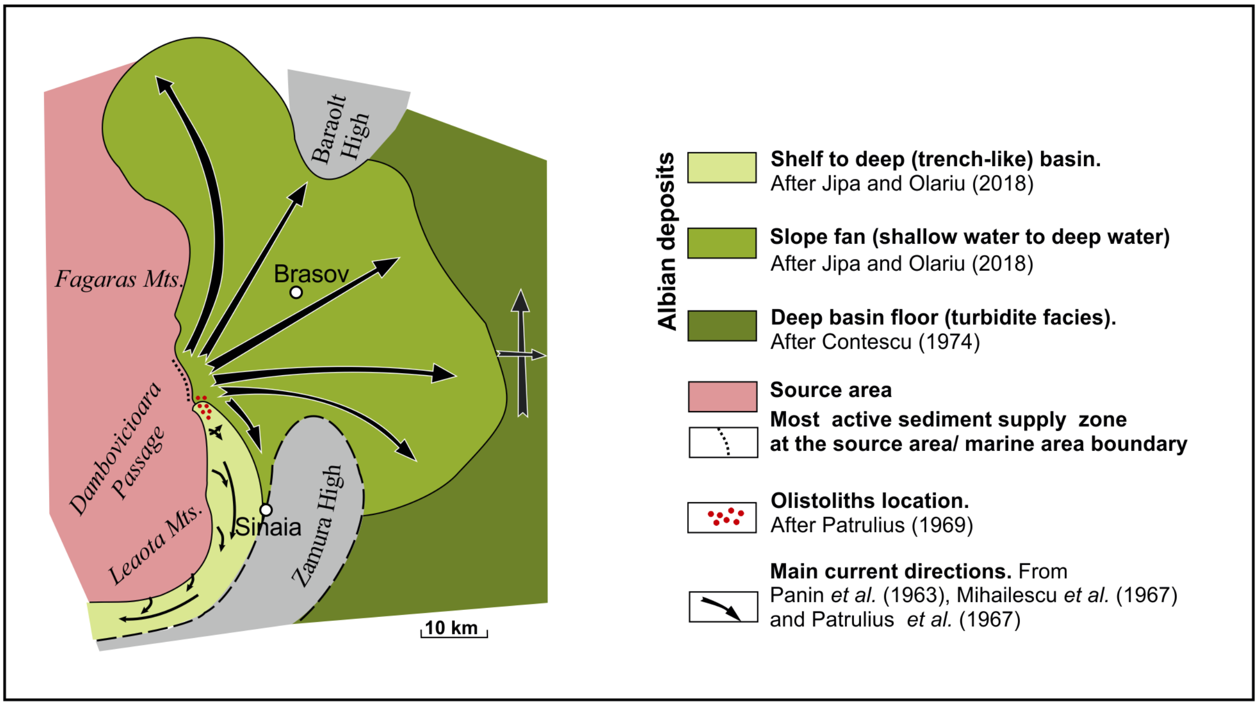

Fig. 10. Sedimentary environment of the olistoliths embedded in Albian conglomerates from the Carpathian Bend area

According to the regional paleocurrent pattern, the most active Albian sediment-supply zone is at the boundary between the northeastern margin of the Dambovicioara Passage and the marine area northward from the Bucegi Mountains (Fig. 10). Considering this boundary as a reference line, it appears that the marine transport distance of the olistoliths embedded in Albian conglomerates (Patrulius Olistolith included) was not greater than 10 km.

6. CONCLUSIONS

The Patrulius Olistolith, one of the largest exotic blocks embedded in Albian conglomerates, is here formally named and described. The olistolith, as exposed, is 218 m long, 110 m wide and 55 m thick.

The Patrulius Olistolith is encased in Albian conglomerates. According to their main characteristics (homogeneous internal structure and poor sorting) the Albian conglomerates are regarded as debris flow sediments. Based on this character, it is considered that the Patrulius Olistolith transport was a gravitational collapse process, the exotic block behaving as a very large clast travelling within the debris flow deposits. The olistolith-embedding conglomerates also have sedimentary features (small amount of matrix, normal grading and some internal structures) not generated by the mass transport process, which points out the special nature of the transport and sedimentation processes involved in the deposition of the ruditic beds. Further study is required to determine the origin of these features, normally considered turbulent flow indicators, within these debris flow deposits

Like all the Albian Bucegi olistoliths, the Patrulius Olistolith was subjected to an estimated 10 km marine transfer, its transportation taking place in shallow waters.

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