SALT DIAPIR EXOTIC BLOCKS FROM BĂDILA NATURE RESERVE (BUZĂU LAND GEOPARK, ROMANIA). A DRONE-BASED TEXTURAL EVALUATION

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Abstract. The Nature Reserve „Bădila Limestone Blocks", located on the Buzău River in the Buzău Land Geopark (Romania), is known for the occurrence of exotic limestone blocks (Tithonian) included in the Badenian Salt Breccia Horizon. An investigation of the Reserve area using an unmanned aerial vehicle was carried out. The drone-based study of the Bădila Geological Reserve generated a high resolution digital image of the exotic blocks distribution. A small number of large blocks (12 blocks with diameters ranging from 4 to 20 m) occur together with a large number of smaller blocks (414 blocks with diameters from 0.1 to 4 m). The Bădila exotic limestone blocks were resedimented by fluvial currents, suffered a size-sorting and their frequency diminished downstreamward.

Key words: Unmanned aerial vehicle, salt breccia, fluvial resedimentation, nature reserve, Eastern Carpathians

1. INTRODUCTION

The exotic blocks occurring in the Buzău River channel area represent a scientific, as well as a tourist attraction. In the year 2000, the block area was declared a geological and paleontological nature reserve of national interest, named „Bădila Limestone Blocks". The reserve belongs to the protected areas of the IUCN category III.

At the Bădila reserve site, there are limestone blocks of various sizes. Several limestone blocks are large enough to be clearly visible on Google Earth aerial images. Other smaller blocks are underwater when the Buzău River is at high water level (Fig. 1a). Taking advantage of a short low water level period, when the smaller limestone blocks became exposed to sight, we carried out an unmanned aerial vehicle (UAV) inspection of the Bădila Reserve area. The acquired imagery led to the most comprehensive information so far available regarding the Bădila limestone blocks.

The purpose of the present paper is to analyze the areal distribution of the Bădila exotic limestone blocks and to evaluate the textural features of the block assemblage. This investigation is regarded by the authors of this paper as an accumulation of descriptive characteristics before approaching the genetic significance study of the Bădila Reserve exotic blocks.

The study area is confined to the Subcarpathian hilly area of the Carpathian Bend, in the upper watercourse of the Buzău River, 35 km away from the Buzău Town (Fig. 2). From an administrative viewpoint, the investigation area belongs to the Buzău County, located between the Pârscov and Vipereşti communes, or more exactly, flanked by the Bădila and Palici villages.

Method. The project investigation relied on the use of a low-flying unmanned aerial vehicle (UAV) for acquiring images of the study area, subsequently processed *via* specialized GIS software. In addition, field observations and terrestrial photographs were made to supplement the aerial imagery.

Twelve megapixel photos were captured with a DJI Phantom-3 drone, flying 30 - 40 m high. Some of the acquired images (35 photos) were assembled using the Adobe Photoshop software, to carry out a detailed photogrammetric representation of the study area. A very detailed final image resulted with a 152 Mp final resolution, one pixel corresponding to 13 - 15 mm on the field.

Fig 1. Limestone blocks in the western Bădila Nature Reserve. Most part of the year many smaller blocks are underwater (left side photograph). The study presented in this paper was carried out during a period of low water level (right side photograph).

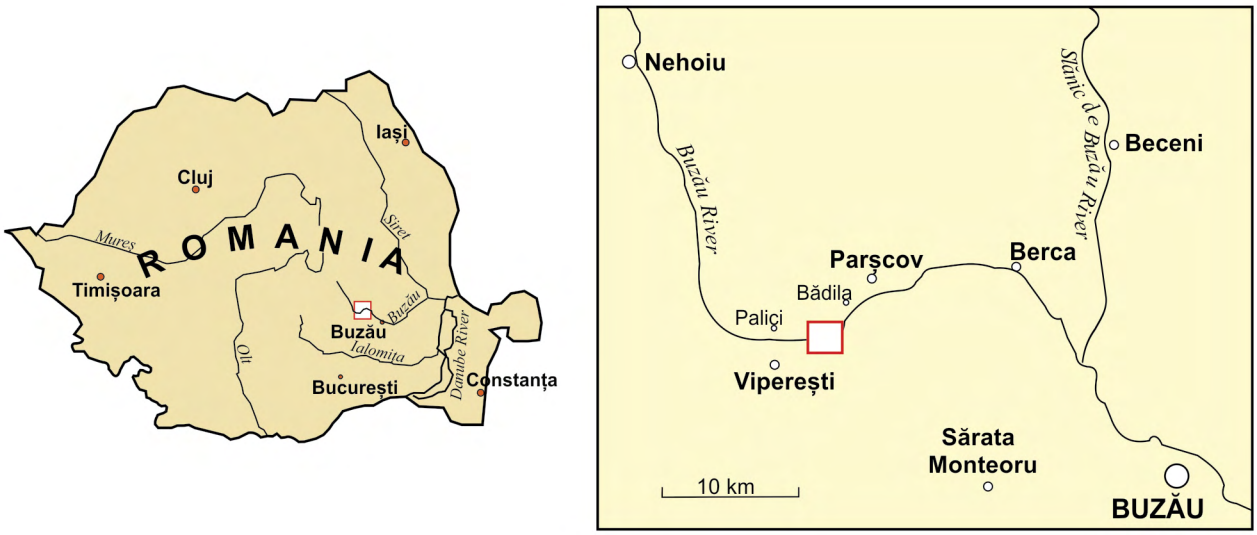


Fig. 2. Study area location in Romania (left) and in the northern Buzău County (right).

The study area image was imported and referenced in the Global Mapper software, using data from nine GPS points marked in the drone fly over zone. The accurate outline of the exotic limestone blocks was traced, and 426 blocks were evidenced. A list of every block was generated (Table 1), showing their projection area and the perimeter lengths. A shape file was exported in the QGIS software, where a script was created to deliver the maximal diameter for every limestone block.

2. GEOLOGICAL SETTING

The Bădila limestone blocks existence was recognized by Filipescu (1938). Previously, Protescu (1926, 1928) mentioned the presence of conglomerate and limestone blocks at the confluence of the Unghiului and Nişcov rivers, their occurrence being similar to the Bădila limestone blocks stratigraphic position.

The area where the Bădila limestone blocks occur is part of the folded, inner Carpathian Foredeep (Motaş *et al*., 1967), known as the Diapir Folds Zone, in the southern part of the Eastern Carpathians (Fig. 3). According to Frunzescu and Brănoiu (2004) and Frunzescu (2013), the limestone blocks are included within the deposits of the Badenian lithostratigraphic unit named by Popescu (1951) and Olteanu (1951) the "Horizon of the Salt Brecia with Salt Massifs". The Lapoş - Bădila anticline (Fig. 3) is the tectonic structure hosting the deposits with the limestone blocks from Bădila.

The paleontologic content of the Bădila limestones was first studied by Filipescu (1938). This study reveals the presence of corals remains, plates of echinoderms, brachiopods and mollusk fragments, as well as nodules of coralline red algae. Due to the presence of the *Calpionella alpina, Nerinea* and *Perisphinctes* species, the Late Jurassic age was assigned to the Bădila limestone blocks. Commonly, the faunas comprise corals, echinids, brachiopods, mollusks (mainly, *Nerina* and *Perisphinctes*) and red algal nodules. Microfaunal content is represented by foraminifera (*i.e*., *Miliolida*, *Textularia* and

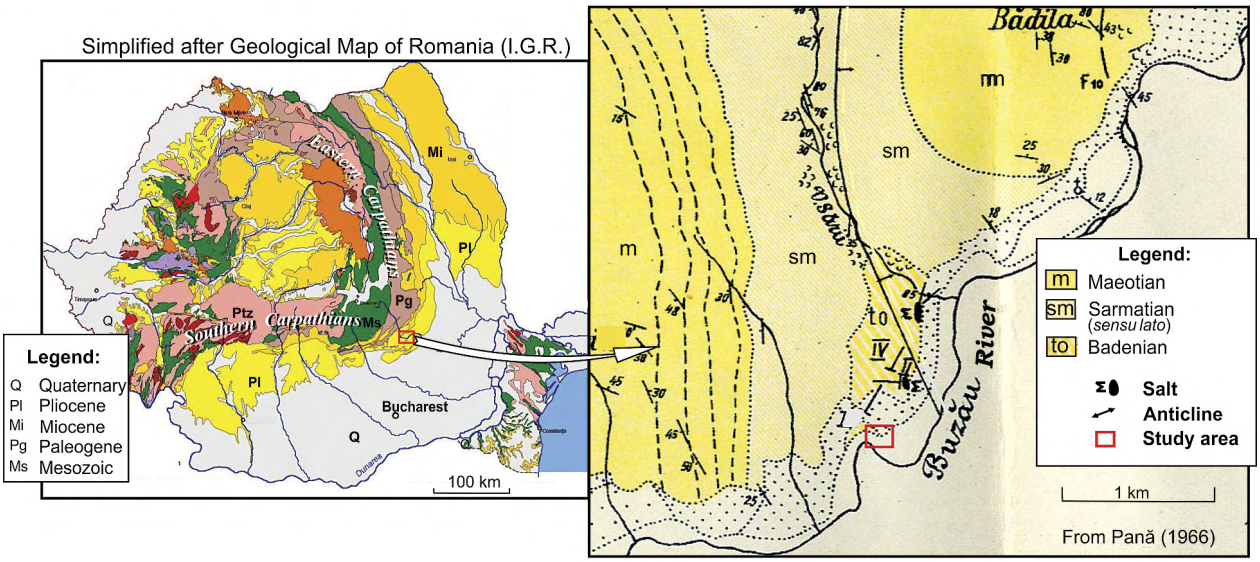


Fig. 3. Study area location on the geological maps.

Rotalia), calcified radiolarians (*Spumellaria* and *Nasselaria* genera), ostracods and bryozoans, as well as uppermost Jurassic to lowermost Cretaceous calpionellids, *i.e. Calpionella alpina* (Pană and Nimigean, 1982). Rare cephalopod (ammonite) species, mainly belonging to the genus *Perisphinctes*, were recently observed (Melinte-Dobrinescu *et al.,* 2017).

Significant data on the Bădila limestone blocks were published by Pană and Nimigean (1981 and 1982). The first map showing the distribution of the Bădila limestone blocks is one issue of this investigation (Fig. 4). Pană and Nimigean (1981) also carried out a microfacies study which reveals the reefal, coralgal, reef-slope and lagoonal features of the Bădila limestones.

Filipescu (1938) pointed out the exotic character of the Bădila limestone blocks, mentioning their provenance from the deep part of the Carpathian geological architecture. This statement is confirmed by Pană and Nimigean (1981), with the specification that similar uppermost Jurassic limestones were identified by deep drillings in the eastern part of the Moesian Platform.

Besides the limestone blocks in the Bădila Reserve area, a large conglomerate block occurs in the upstream zone, and a sandstone block in the downstream zone, marked on the exotic block map of Pană and Nimigean (1981). The petrographic composition of the conglomerate block was investigated by Frunzescu *et al.* (2009).

The Bădila zone was declared natural geological and paleontological reserve in the year 2000. The tourist presentations of the reserve refer to 40 limestone blocks dispersed on 1 ha area.

So far, no study of the Bădila exotic blocks genetic significance has been undertaken. Filipescu (1938) speculates on the blocks provenance from the disaggregation of some crests from the Miocene Carpathian Foredeep basin. The tectonic origin of the Bădila blocks is advocated by Pană and Nimigean (1981). Frunzescu *et al.* (2009) use the term olistolith for the conglomerate block from the Bădila Reserve.

Considering the geological information presently accumulated, the idea of the Bădila exotic blocks provenance in association with the diapir salt movement is taking shape (Melinte-Dobrinescu *et al*., 2017). In fact, Filipescu (1938) mentioned that these blocks are lying directly on the salt massif.

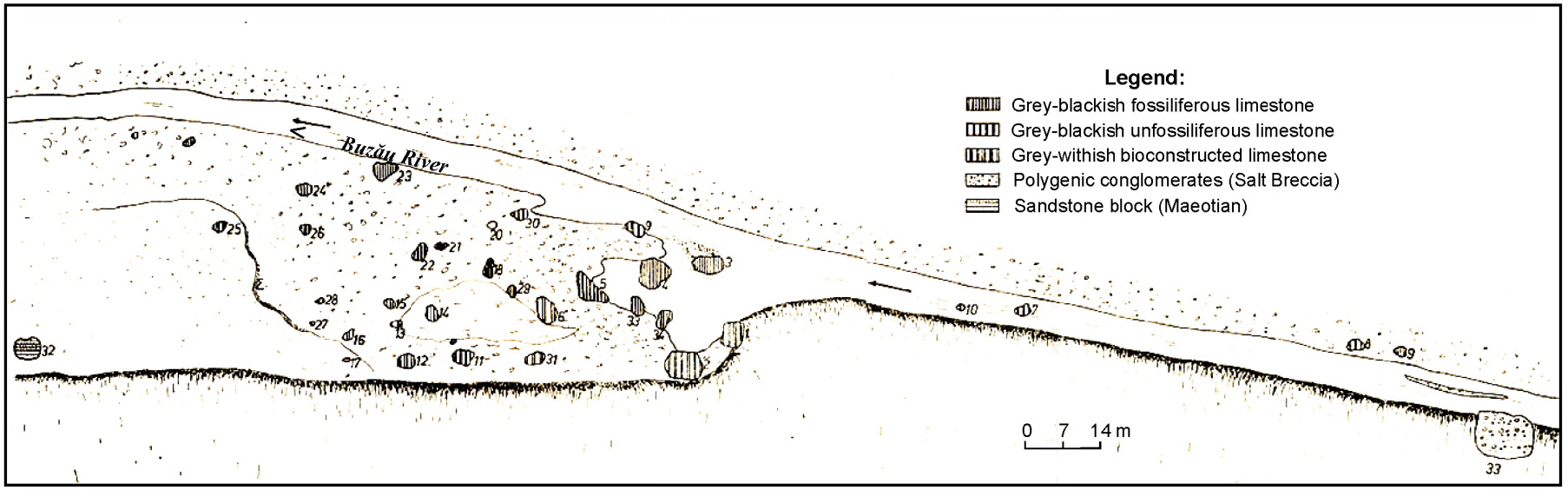
3. PRESENTATION OF DATA

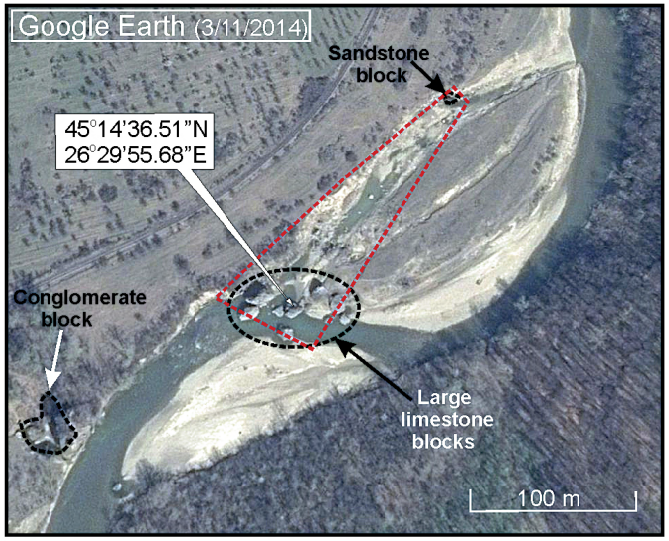
3.1. Exotic blocks in the drone fly over area

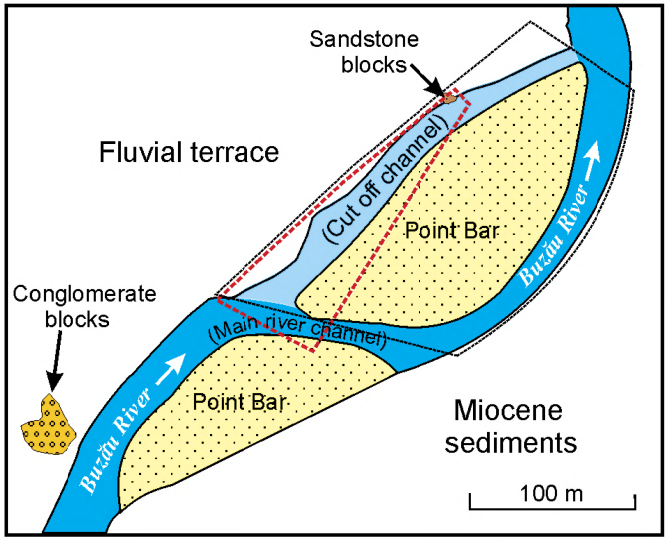
Geomorphology of the limestone blocks area. In the limestone blocks occurrence area, the Buzău River has a sinuous watercourse, forming a low amplitude meander (Fig. 5). One of the meander loops is initiated at the river channel contact with the concentration of the large size limestone blocks (Fig. 5). It seems possible the resistance generated by the group of blocks contributed to the meander configuration.

In the course of the Bădila Reserve meanders evolution, by outer bank erosion and accumulation on the opposite bank, two pointbars developed. The majority of the Bădila limestone blocks are located in the area of the left bank pointbar. The pointbar sediments covered the relatively small exotic limestone blocks, probably the ones with less than about two meters height.

After the Bădila Reserve pointbar was built, a secondary cut off fluvial channel formed (Fig. 5). The cut off channel eroded the pointbar sediments and uncovered the small limestone blocks along its waterway. This secondary channel could be of very recent origin, taking into consideration that it is not outlined on the Pană and Nimigean (1981) map. Presently, when the Buzău River is at high water level, the left bank Bădila pointbar appears as a fluvial island.







Bădila Geological Reserve area

Drone fly over perimeter

▲ **Fig.** 4. Sketch map of the Bădila Nature exotic blocks locations. Reproduced from Pană and Nimigean (1981).

◀ **Fig.** 5. Geomorphology features of the Bădila Nature Reserve area.

The drone-surveyed Bădila limestone blocks. The unmanned aerial vehicle fly over area covered the main Bădila Reserve zone, extending along the cut off river channel and on the northern part of the left bank pointbar (Fig. 6). On the drone imagery, 426 limestone blocks and several sandstone blocks were identified.

The size of the limestone blocks varies in the range of 0.16 m (block no. 58 in Table 1) - 19.5 m (block no. 1 in Table 1). The large limestone blocks, over 4 m in diameter, represent little more than 3 % of the total number of the blocks marked on the drone imagery, but they represent two thirds of the total horizontal projection area of the blocks (Tables 1 and 2). The medium size blocks (2 to 4 m diameter) make up 37.7 %, and the small blocks (less than 1 m in diameter) stand for almost 60 % of the all investigated limestone blocks.

Table 1. Dimensions of the exotic limestone blocks occurring in the Bădila Nature Reserve (Buzău County, Romania). Values derived from the drone-based imagery. H.sec.area = horizontal section area.

Limestone block no.	H. sect. area (sq. m.)	Block diameter (m)	Limestone block no.	H. sect. area (sq.m.)	Block diameter (m)	Limestone block no.	H. sect. area (sq.m.)	Block diameter (m)	Limestone block no.	H. sect. area (sq.m.)	Block diameter (m)
1	242.31	19.55	106	0.30	0.82	213	0.65	1.13	319	0.11	0.49
2	3.02	2.46	107	1.45	1.54	214	0.96	1.39	320	0.33	0.82
3	146.83	15.69	108	3.65	2.94	215	1.88	1.75	321	0.15	0.54
4	98.10	14.11	109	0.48	0.93	216	0.09	0.46	322	0.18	0.65
5	0.70	1.56	110	0.26	0.68	217	0.18	0.59	323	0.16	0.52
6	46.00	9.77	111	0.09	0.51	218	0.44	1.04	324	0.09	0.51
7	126.04	15.40	112	0.38	0.79	219	0.20	0.67	325	6.24	3.33
8	15.52	6.19	113	1.10	1.46	220	0.16	0.54	326	0.24	0.83
9	115.65	16.26	114	0.37	0.82	221	0.33	0.79	327	0.31	0.76
10	12.27	5.09	115	0.34	0.95	222	0.50	1.00	328	0.15	0.54
11	37.22	9.07	116	0.12	0.54	223	2.23	2.78	329	0.11	0.68
12	8.30	4.17	117	0.16	0.57	224	0.53	1.00	330	0.36	0.92
13	1.59	2.48	118	0.88	1.39	225	0.41	0.95	331	0.28	0.79
14	0.69	1.25	119	0.64	0.99	226	0.16	0.74	332	0.43	1.05
14b	1.33	1.97	120	0.33	0.87	227	0.33	0.82	333	0.39	0.86
15	0.98	1.75	121	1.61	1.60	228	0.06	0.37	334	0.58	1.02
15b	1.21	1.83	122	0.54	0.97	229	1.53	1.70	335	0.16	0.51
16	0.20	0.65	123	0.22	0.67	230	0.15	0.50	336	0.13	0.61
17	0.90	1.49	124	1.79	1.71	231	0.56	1.13	338	0.38	1.32
18	1.66	1.78	125	0.40	0.86	232	0.15	0.56	339	0.29	0.74
19	12.65	4.62	126	2.67	2.24	233	0.32	0.69	340	0.24	0.62
20	0.89	1.26	127	0.33	0.77	234	0.21	0.69	341	0.26	0.74
21	0.54	1.16	128	0.34	1.03	235	0.15	0.56	342	0.11	0.46
22	1.52	1.92	129	5.33	3.21	236	0.13	0.63	343	0.18	0.71
23	1.12	1.85	130	1.20	1.57	237	0.20	0.59	344	0.15	0.48
24	0.62	0.99	131	1.24	1.65	238	2.96	2.50	347	0.16	0.50
25	1.98	2.04	132	0.54	0.98	239	2.72	2.39	348	0.12	0.55
26	0.37	0.78	133	0.95	1.46	240	0.73	1.13	349	0.15	0.58
27	4.28	2.77	134	0.21	0.72	241	3.52	2.81	350	0.11	0.48
28	0.72	1.21	135	0.28	0.77	242	0.22	0.64	351	0.09	0.52
29	0.15	0.54	136	0.41	1.12	243	2.33	2.30	352	0.05	0.32

Table 1 (continuing)

Lime-stone block no.	H. sect. area (sq. m.)	Block diame-ter (m)	Lime-stone block no.	H. sect. area (sq.m.)	Block diame-ter (m)	Lime-stone block no.	H. sect. area (sq.m.)	Block diame-ter (m)	Lime-stone block no.	H. sect. area (sq.m.)	Block di-ameter (m)
30	1.85	1.88	137	1.06	1.79	244	0.66	1.11	353	0.20	0.58
31	0.08	0.45	138	1.77	1.70	245	0.93	1.33	354	0.09	0.47
32	0.05	0.30	139	0.14	0.49	246	0.84	1.31	355	0.21	0.66
33	0.04	0.33	140	0.19	0.65	247	0.35	0.83	356	0.20	0.60
34	0.09	0.39	141	0.28	0.71	248	0.29	0.76	357	0.12	0.44
35	0.45	1.17	142	2.39	2.11	249	0.21	0.60	358	0.23	0.62
36	0.14	0.53	143	0.12	0.58	250	0.17	0.74	359	0.08	0.42
37	1.02	1.58	144	0.18	0.59	251	0.11	0.48	360	0.57	1.10
38	0.93	1.85	145	1.09	1.46	252	0.24	0.78	361	0.65	1.08
39	1.05	1.35	146	0.18	0.60	253	0.78	1.52	362	0.11	0.52
40	5.08	2.96	147	0.47	1.09	254	0.53	0.96	362b	0.86	1.13
41	0.32	0.72	148	0.23	0.61	255	0.31	0.73	363	0.20	0.58
42	4.86	3.24	149	0.24	0.66	256	0.36	0.85	364	0.31	0.79
43	1.55	2.00	150	0.28	0.68	257	0.47	0.85	365	0.16	0.55
44	0.73	1.09	151	0.65	1.15	258	0.77	1.30	365b	0.19	0.54
45	0.07	0.32	152	0.38	1.08	259	0.07	0.35	366	0.14	0.49
46	0.04	0.30	153	0.14	0.53	260	1.43	1.71	367	0.54	1.01
47	0.04	0.26	154	1.00	1.35	261	0.03	0.30	368	0.14	0.56
48	0.11	0.47	155	1.35	1.67	262	0.24	0.73	369	0.11	0.46
49	0.03	0.27	156	2.90	2.19	263	1.37	1.72	370	0.16	0.56
50	0.13	0.63	157	0.62	1.24	264	1.09	2.06	371	0.11	0.42
51	0.07	0.43	158	1.07	1.38	265	0.11	0.47	372	0.14	0.49
52	0.05	0.49	159	5.07	3.23	266	0.38	0.85	373	0.25	0.65
53	0.11	0.45	160	0.17	0.68	267	0.66	1.17	374	0.34	0.87
54	0.01	0.16	161	2.10	2.22	268	0.12	0.50	375	0.16	0.52
55	0.03	0.31	162	0.17	0.54	269	0.30	0.72	376	0.31	0.75
56	0.09	0.43	163	0.48	0.99	270	0.50	0.98	377	0.29	0.76
57	0.03	0.31	164	0.38	0.80	271	0.14	0.51	378	1.20	1.49
58	0.18	0.71	165	0.63	1.16	272	0.46	0.98	379	0.45	0.94
59	1.63	1.88	166	0.16	0.57	272b	0.71	1.04	380	1.12	1.42
60	0.19	0.65	167	0.11	0.50	273	0.08	0.42	381	1.55	1.75
61	0.09	0.42	168	0.25	0.82	274	0.18	0.64	382	0.18	0.59
62	1.09	1.55	169	0.66	1.14	275	0.42	0.82	383	0.10	0.39
63	0.43	0.87	170	1.96	2.61	276	2.47	2.33	384	0.14	0.53
64	0.31	1.06	171	0.43	0.85	277	0.67	1.62	385	0.07	0.32
65	3.09	2.39	172	0.31	0.75	278	0.50	1.23	386	0.05	0.29
66	0.18	0.60	173	11.31	6.05	279	0.30	0.81	387	0.05	0.29
67	1.93	1.97	174	0.65	1.12	280	0.72	1.24	388	0.12	0.52

Table 1 (continuing)

Lime-stone block no.	H. sect. area (sq. m.)	Block diame-ter (m)	Lime-stone block no.	H. sect. area (sq.m.)	Block diame-ter (m)	Lime-stone block no.	H. sect. area (sq.m.)	Block diame-ter (m)	Lime-stone block no.	H. sect. area (sq.m.)	Block di-ameter (m)
68	3.33	3.27	175	0.14	0.50	281	0.23	0.75	389	0.12	0.47
69	0.59	1.04	176	0.16	0.75	282	0.13	0.50	390	0.09	0.37
70	3.66	3.30	177	0.25	0.86	283	0.09	0.43	391	0.08	0.38
71	0.13	0.50	178	0.36	0.81	284	0.18	0.59	392	1.10	1.38
72	2.50	2.38	179	0.32	0.85	285	0.06	0.37	393	0.05	0.31
73	0.15	0.65	180	0.42	0.94	286	0.22	0.64	394	0.10	0.42
74	1.10	2.16	181	0.19	0.58	287	0.06	0.31	395	1.99	1.94
75	1.53	1.96	182	0.20	0.60	288	2.48	2.09	396	1.66	1.89
76	1.29	1.64	183	0.28	0.75	289	0.07	0.39	397	0.56	1.17
77	1.07	1.59	184	0.28	0.75	290	0.11	0.44	398	0.53	1.25
78	0.38	0.83	185	0.83	1.45	291	0.19	0.59	399	0.04	0.34
79	0.40	0.84	186	0.35	0.93	292	0.74	1.42	400	0.13	0.55
80	0.22	0.80	187	0.31	0.93	293	0.88	1.47	401	0.17	0.57
81	0.47	1.05	188	0.23	0.70	294	0.72	1.25	402	0.08	0.39
82	1.34	1.54	189	0.39	0.96	295	0.11	0.50	403	0.12	0.53
83	0.34	0.90	190	1.30	1.84	296	0.14	0.52	404	0.14	0.70
84	0.79	1.18	191	0.92	1.32	297	0.31	0.81	405	0.09	0.48
85	2.12	1.96	192	0.18	0.61	298	0.39	0.85	406	0.07	0.47
86	1.15	1.65	193	0.68	1.20	299	0.27	0.76	407	0.11	0.49
87	2.44	1.99	194	0.43	0.89	300	0.09	0.52	408	1.95	1.94
88	2.06	1.97	195	0.26	0.88	301	0.13	0.47	409	0.59	1.14
89	1.76	2.16	196	0.26	0.73	302	0.24	0.67	410	0.41	0.91
90	1.70	2.08	197	0.64	1.07	303	0.30	0.77	411	0.17	0.54
91	1.33	1.99	198	0.29	0.72	304	0.57	1.16	412	0.12	0.44
92	1.09	1.54	199	0.06	0.36	305	0.35	1.12	413	0.44	0.97
93	0.10	0.46	200	1.16	1.65	306	0.60	1.14	414	0.09	0.44
94	2.23	1.93	201	1.10	1.36	307	2.52	2.14	415	0.24	0.85
95	1.05	1.65	202	0.22	0.67	308	1.26	1.57	416	0.56	1.07
96	2.08	2.10	203	0.06	0.39	309	0.20	0.64	418	0.30	0.78
97	3.60	3.03	204	2.23	2.05	310	0.15	0.59	419	0.45	0.92
98	10.82	4.82	205	0.53	1.05	311	0.92	1.30	420	0.51	0.99
99	0.50	0.97	206	0.36	1.01	312	0.33	0.80	421	0.19	0.61
100	0.62	1.27	207	0.67	1.24	313	0.48	1.28	422	0.08	0.38
101	0.63	1.09	208	1.89	2.16	314	9.48	4.08	423	0.07	0.38
102	4.86	3.59	209	0.14	0.55	315	2.99	2.65	424	0.14	0.48
103	2.04	2.27	210	0.20	0.65	316	0.16	0.56	425	0.37	0.86
104	1.53	1.87	211	0.06	0.40	317	0.15	0.58			
105	0.68	1.05	212	0.06	0.39	318	0.29	0.93			

Table 2. Size distribution of the exotic limestone blocks from the Bădila Nature Reserve. Zones 1, 2 and 3 are displayed in the figures 7, 9 and 10.

Limestone block diameter (m)	Number of limestone blocks			
	Entire drone fly over area	Zone 1 (partialy underwater)	Zone 2	Zone 3
32 - 16	2 (0.5%)	2		
16 - 8	5 (1.2%)	5		
8 - 4	7 (1.6%)	4	3	
4 - 2	39 (9.2%)	12	27	
2 - 1	122 (28.5%)	33	74	15
1 - 0.5	180 (42.3%)	16	135	29
0.5 - 0.1	71 (16.7%)	18	29	24
Total number	**426**	**90**	**268**	**68**

Block size areal variation. The size distribution of the Bădila limestone blocks was investigated in four zones situated along the 300 m long cut off channel from the Bădila Reserve.

The most representative zone of the Bădila Reserve includes the largest limestone blocks (Figs. 7, 8 and 11a). Five limestone blocks have more than 10 m diameters (1, 3, 4, 7, and 9 in Table 1) and four of them are larger than 15 m. The largest is the limestone block no. 1 (19.5 m diameter). Smaller blocks also occur in this zone, the size distribution extending between the 16 – 32 m grain size class and the 0.1 - 0.5 class (Fig. 11a).

Downstream, in the second and the third zones (Fig. 11b and c), the blocks with larger than 8 m diameter are absent from the size distribution. Further downstream, the blocks with the diameter larger than 2 m are not anymore components of the size distribution in the zone 4 (Fig. 11d).

Limestone blocks frequency variation. From the visual examination of the Bădila drone imagery it appears that the number of the limestone blocks is decreasing downstream, along the cut off channel (Fig. 6). For this analysis we are not taking into consideration the large blocks zone which is partly underwater or covered by alluvial sediments. The number of identified blocks diminishes lengthwise the cut off channel from 20 blocks/100 sq. m. in the upstream zone (Figs. 9 and 11b) to 5 blocks/100 sq. m. in the central zone (Fig. 11c), and to 2 blocks/100 sq. m. in the downstream zone (Figs. 10 and 11d).

Limestone blocks sphericity and roundness. Using the drone imagery data, the shape of the Bădila Reserve limestone blocks was evaluated by visual comparison with standard images charts. Terrestrial photographs were also used for the enhancement of the shape analysis.

Some of the large Bădila limestone blocks, with equidimensional transversal section, have a relatively high degree of sphericity (block no. 4 in Figs. 7 and 12a). Other large blocks are elongated (1 and 3 in Figs. 7 and 12a), or show sharp excrescences, indicating a lower degree of sphericity (6 and 8 in Figs. 7 and 12a).

The same morphology is characteristic for the smaller limestone blocks from the upstream or central zones of the Bădila cut off fluvial channel (Fig. 12b, c, d). They show variable sphericity, with equidimensional (65 and 42 in Fig. 7; 121, 155, 239 in Fig. 9) or elongated (70, 59, 19 in Fig. 7; 129, 170, 173 in Fig. 9) horizontal sections. These features extend also to the downstream zones (Fig. 12e, f), but their shape characteristics are more difficult to be evaluated due to the small size of the blocks.

The roundness degree of the limestone blocks is best estimated for the large limestone blocks. The outline traced on the aerial imagery reveals slightly rounded irregularities (blocks 1, 3, 4, 9 and 11 in Figs. 9 and 12a), characteristic for the subrounded grains (Powers, 1953). According to the observations on terrestrial photographs, the large limestone blocks roundness is, in fact, subangular, as indicated by frequent rather sharp small crests (Figs. 8 and 13a, b).

The field shape inspection of the smaller Bădila blocks from the upstream zone indicates frequent minor irregularities with sharp or slightly rounded corners (Fig. 13c). Their roundness degree is subangular to subrounded.

A low roundness grade, but with rounded crests, is also shown by the small limestone blocks from the downstream zones (Fig. 10a).

The sandstone blocks. Close to the downstream margin of the drone fly over area, at the edge of the fluvial terrace, a large sandstone block (9 m diameter) occurs (Fig. 14). Around it there are several smaller sandstone blocks, 2 to 4 m large.

The large sandstone block was not rounded at all (Fig. 14a). Some of the smaller sandstone blocks are subrounded.

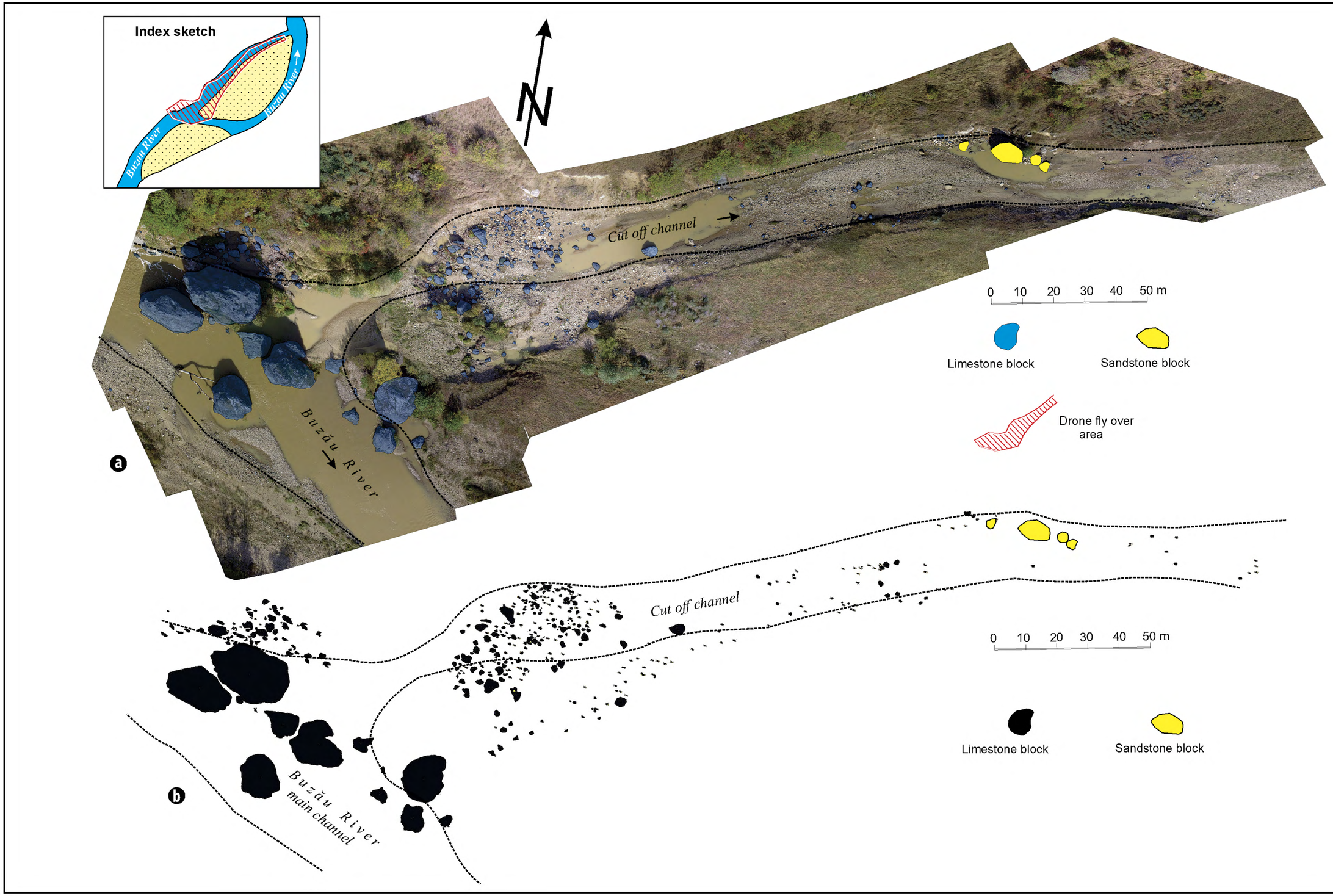


Fig. 6. Bădila exotic blocks areal distribution. Processed drone-acquired imagery. **a**. Exotic blocks distribution on the drone-based photogrametric image of the investigated area. **b**. Sketch of the exotic blocks distribution.

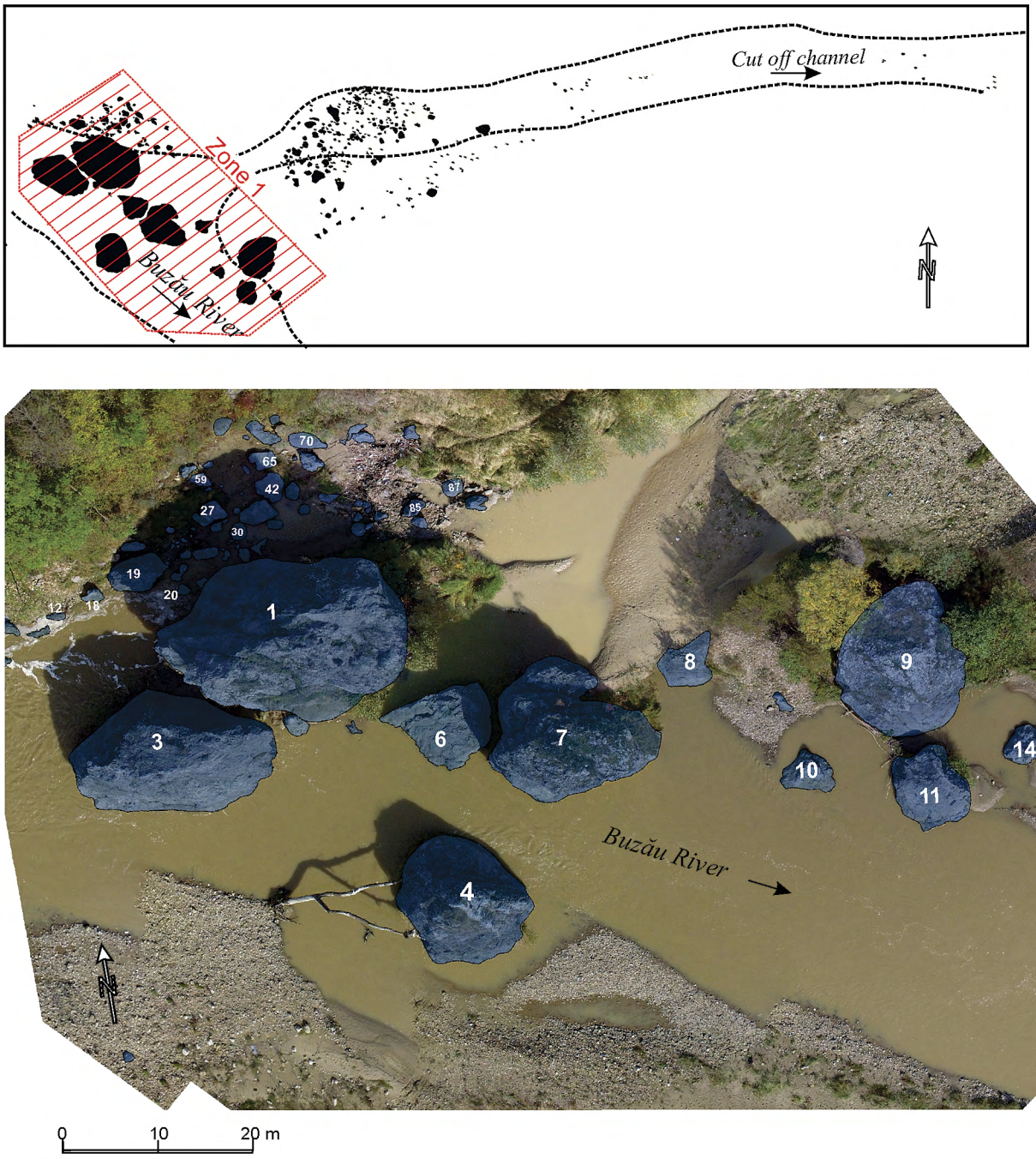


Fig. 7. The western part of the Bădila Nature Reserve area, on the River Buzău. The largest limestone blocks are concentrated in this zone. Drone-acquired imagery.

3.2. Exotic blocks outside the drone fly over perimeter

The drone fly over area does not include the entire Bădila exotic blocks occurrence zone. A large block made of conglomerate and several middle size limestone blocks are located upstream the large blocks group.

At about 150 m upstream, the Bădila large limestone blocks area, on the left bank of the Buzău River, a large conglomerate block is located (Fig. 15). The visible height of the block is 11 m and its width is over 10 m. Presently, the conglomerate block is in a heavily forested area and only its southern half is visible. However, this block seems to be even larger than the exotic limestone blocks in the northern Bădila Nature Reserve. The green schist clasts are important petrographic characteristics of the conglomerate block (Filipescu, 1938, Dragoş, 1970, Frunzescu *et al*., 2009).

Between the conglomerate block site and the large Bădila limestone blocks zone, four limestone blocks with 2 - 4 m diameter are mentioned by Pană and Nimigean (1981).

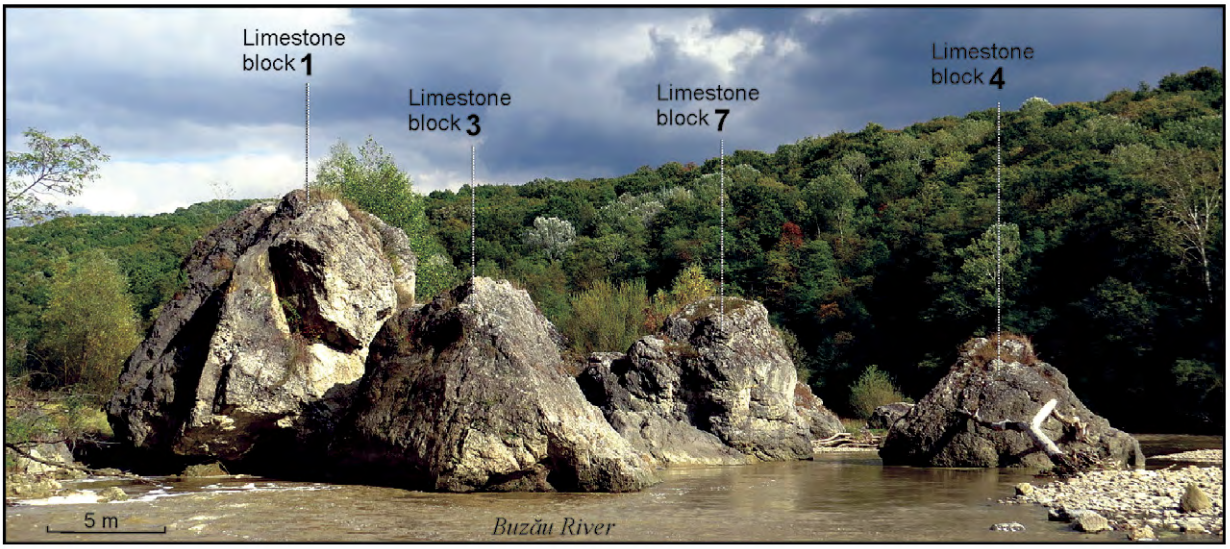


Fig. 8. Some of the largest, Upper Jurassic exotic limestone blocks, in the western part of the Bădila Nature Reserve.

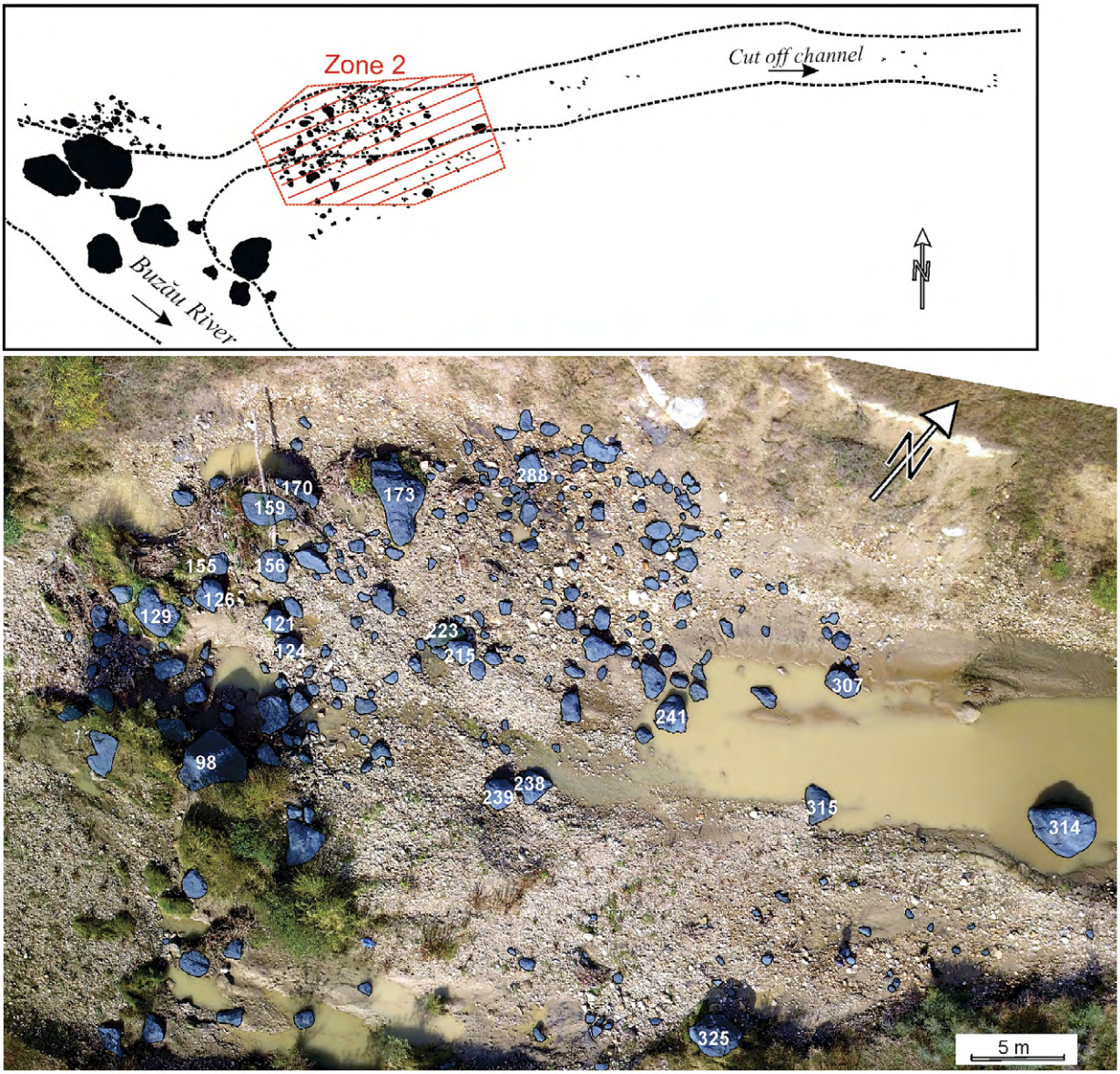


Fig. 9. Exotic limestone blocks in the middle part of the Bădila Reserve, upstream the cut off river channel. Drone-acquired imagery.

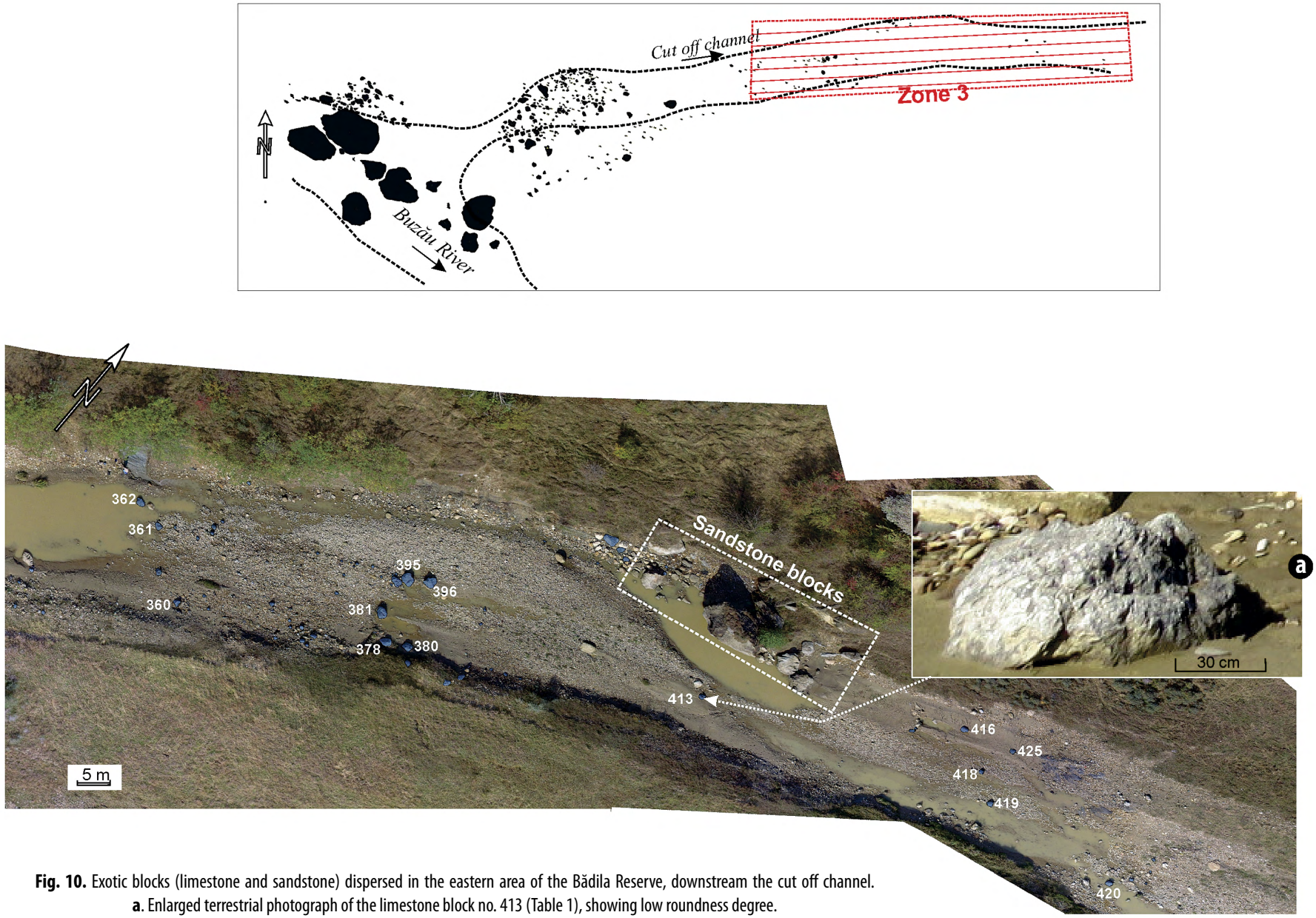


Fig. 10. Exotic blocks (limestone and sandstone) dispersed in the eastern area of the Bădila Reserve, downstream the cut off channel.
a. Enlarged terrestrial photograph of the limestone block no. 413 (Table 1), showing low roundness degree.

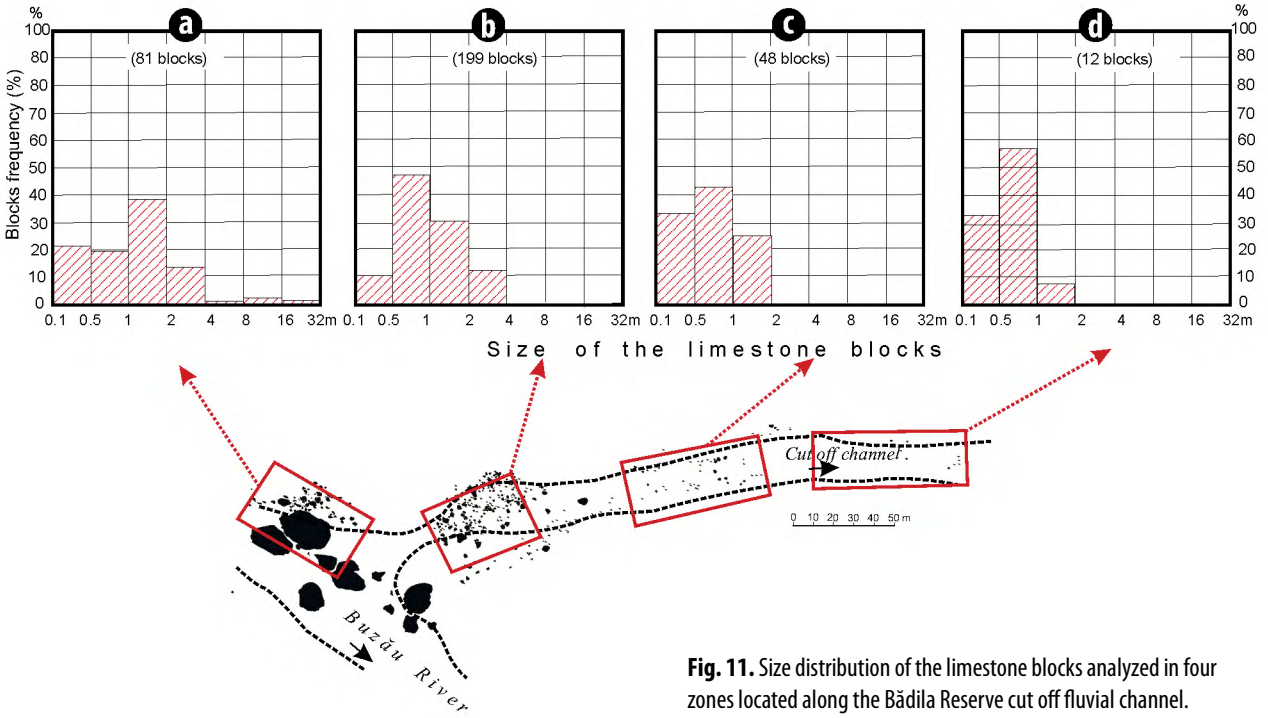


Fig. 11. Size distribution of the limestone blocks analyzed in four zones located along the Bădila Reserve cut off fluvial channel.

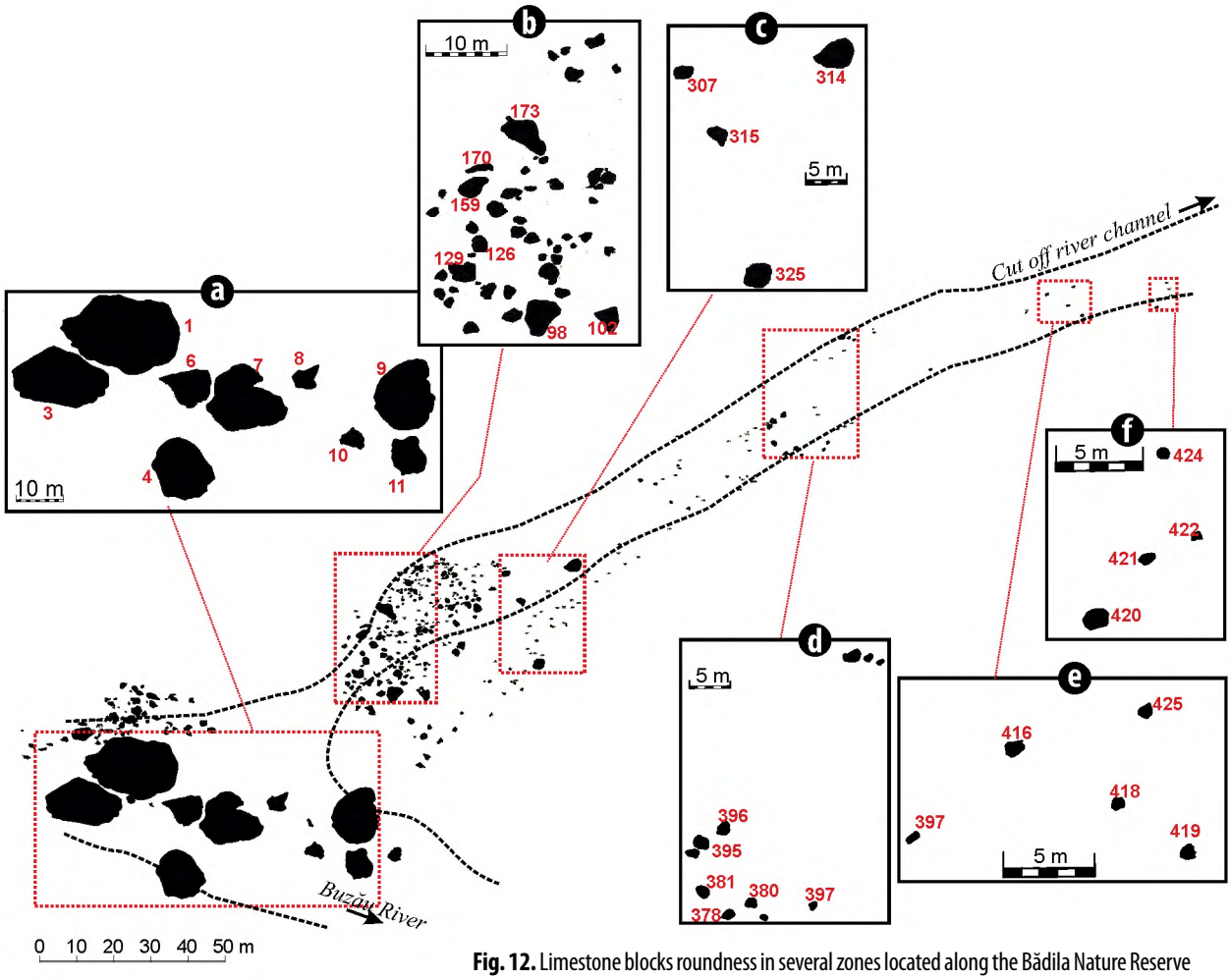


Fig. 12. Limestone blocks roundness in several zones located along the Bădila Nature Reserve cut off channel. The horizontal block sections are displayed for roundness evaluation.

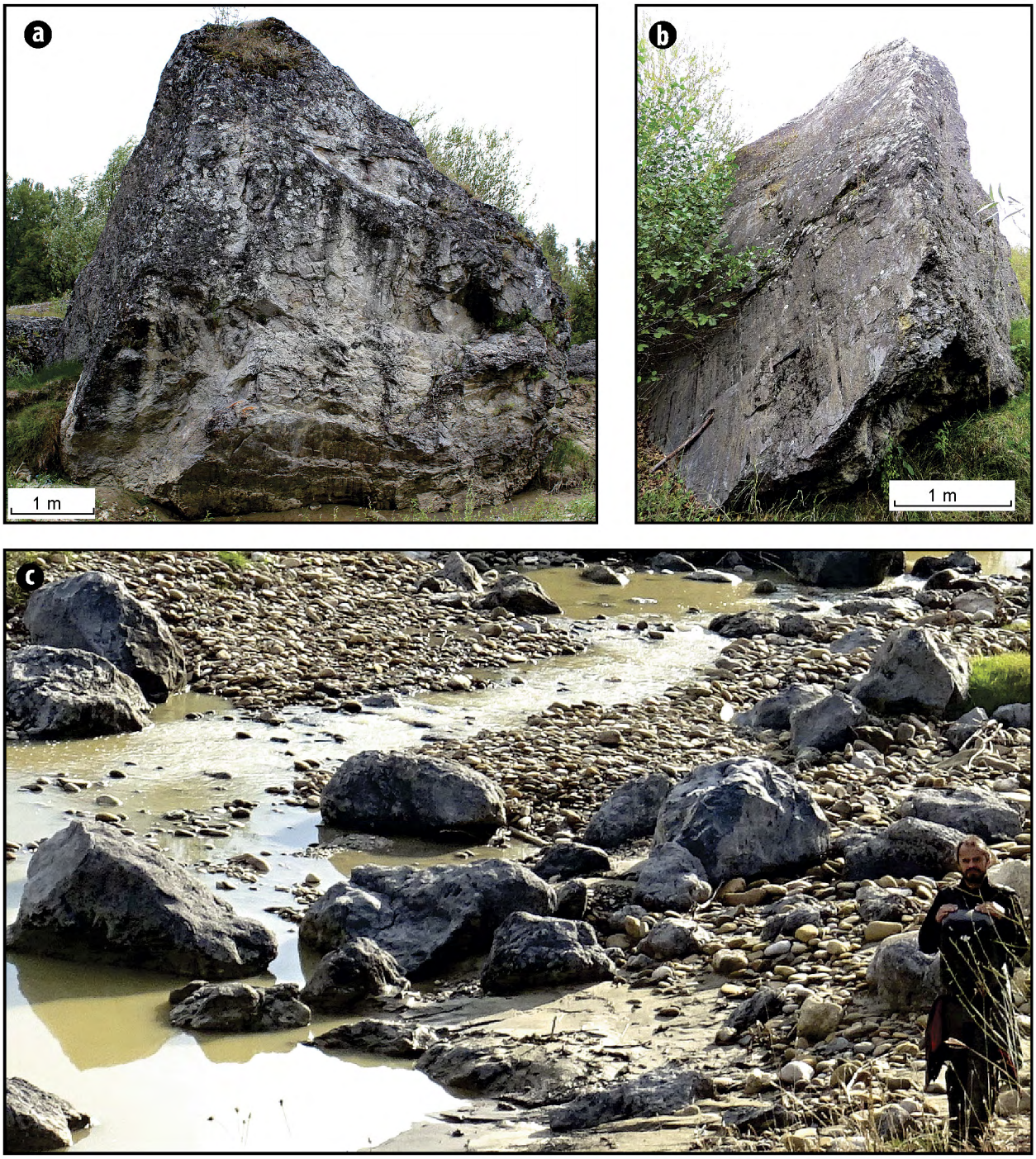


Fig. 13. Terrestrial photographs showing larger and smaller exotic limestone blocks in the western part of the Bădila Reserve study area (zone 1 in Fig. 7).

4. DISCUSSION OF DATA

The use of an unmanned aerial vehicle to investigate the Bădila Reserve proved the high potential for the accurate, rapid and low cost study of the exotic blocks areal distribution and for the textural investigation. The investigation enhancement with the use of terrestrial photographs provided more accuracy and efficiency for some textural aspects analysis.

The geomorphological features of the fluvial zone of the Bădila Reserve (Fig. 5) indicate that the exotic blocks distribution presented in this paper shows only what was exhumed out of the alluvial sediment cover by the Buzău River. The erosion exerted by the Bădila cut off channel uncovered a multitude of limestone blocks previously unknown and that are not marked on the Pană and Nimigean (1981) map (Fig. 4). The study took advantage of a seasonal drop of the Buzău River water level, in October 2016, that allowed the observation of a large number of limestone blocks, otherwise hidden underwater (Fig. 1).

The most important fact evidenced by the present study is the large number of relatively small exotic blocks (less than 4 m in diameter) associated with a small number of large limestone blocks (4 to 20 m diameter) (Table 1).

The investigation reported in this paper proved that the large majority of the exotic blocks consist of Upper Jurassic limestones (Filipescu, 1938). The Lower Miocene (Burdigalian) conglomerate block (maybe divided in several pieces) was identified in one point only (Fig. 15). In contrast, many conglomerate blocks occur at the confluence of the Unghiului and Nişcov rivers (Protescu, 1926, 1928).

Just as the Bădila conglomerate block, the sandstone blocks (Fig. 14) are located in only one site in the Bădila Reserve area. Pană and Nimigean (1981) believe the sandstones are Upper Miocene (Maeotian) in age. In our opinion, the sandstone blocks are of the same facies as the Middle Miocene (Sarmatian *s. l.*) sandstones cropping out close to the Reserve area. However, there are decimeter-large sandstone clasts in the Salt Breccia exposed along the Buzău River banks. Consequently, the exotic characteristic of the Bădila sandstone blocks cannot be excluded, and their age is not clearly known.

The genetic relationship between the large Bădila limestone blocks and the associated relatively small limestone blocks is ambiguous. One viewpoint considers the provenance and the primary transport were the same for all the limestone blocks irrespective of their size. Without *pro/con* arguments the smaller blocks could be viewed as products of the large blocks disaggregation.

The drone revealed distribution of the Bădila Reserve limestone blocks points to the resedimentation process inflicted by the fluvial Buzău River dynamics. As evidenced by the drone-based inspection, the fluvial-generated changes suffered by the limestone blocks took place along a distance of 300 m only (the lengths of the Bădila Reserve cut off channel). Both the processed drone-imagery picture (Fig. 6) and the size analysis (Fig. 11) emphasize the downstream-directed transport and the selection of the Bădila limestone blocks. Along the Bădila cut off channel the grain size sorting improves as a result of the smaller limestone blocks preferential transport (Fig. 11; Table 2). The larger blocks successively disappear downstreamward, because their transport requires currents of higher competency. Following the same trend, the limestone blocks frequency in the alluvial sediments decreas-

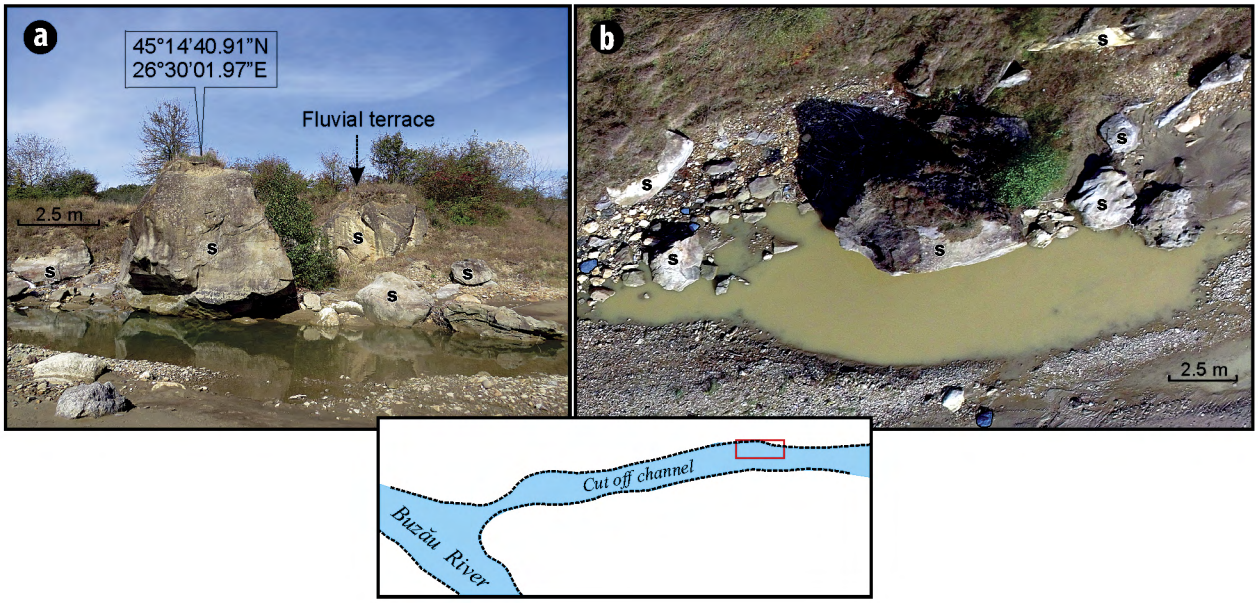


Fig. 14. Sandstone blocks in the downstream part of the Bădila Reserve cut off channel. **a**. Terrestrial photograph. **b**. Aerial, drone-acquired imagery. **s** - sandstone blocks.

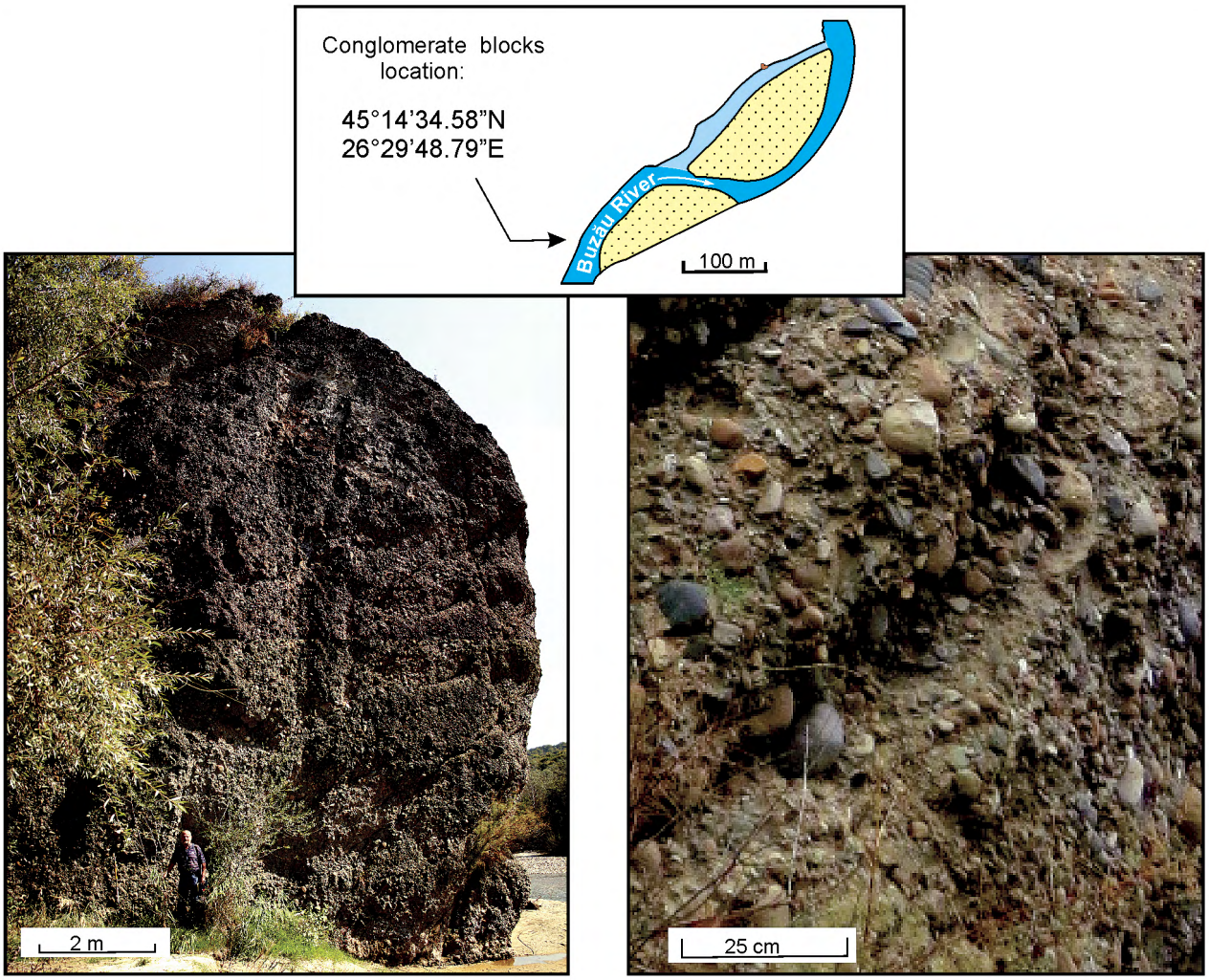


Fig. 15. Large exotic conglomerate block on the left bank of the Buzău River, Bădila Nature Reserve.

es, due to the selection made by the fluvial transport (Table 2). The dominant subangular roundness of the limestone blocks was not modified by the fluvial-controlled changes (Figs. 8 and 10a), a consequence of the short distance aquatic transport.

It is to be noticed that the sandstone blocks are not size-sorted, all of them (with diameters between 2 and 9 m) emerging in the same site. This means that the sandstone blocks have been not subjected to the fluvial transport, an argument for the different provenance of the limestone *versus* sandstone blocks.

5. CONCLUSIONS

The drone-based study of the Bădila Geological Reservation (Buzău River, Buzău County, Romania) generated a high resolution digital image of the exotic blocks areal distribution.

A large number of limestone blocks (426) have been pointed out in the Bădila Reserve area, a definite improvement of the information, which previously referred to 33 - 40 blocks.

The Bădila exotic limestone block assemblage includes a small number of large blocks (12 blocks with 4 to 20 m diameter) associated with a large number of smaller blocks (414 blocks with 0.1 to 4 m diameter).

Irrespective of size, the limestone blocks from the Bădila Geological Reserve show a sphericity degree expressed by equidimentional to elongated horizontal section surface, and a roundness of subangular to subrounded grades.

Sandstone blocks of variable size (2 to 9 m in diameter) occur in one site only, located on the eastern part of the Bădila Reserve.

The surface distribution of the Bădila exotic limestone blocks was postdepositionally modified through fluvial transport. On a distance of about 300 m, along a cut off fluvial channel, the blocks are size-sorted and their frequency diminishes.

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