Modal composition and morphometric characteristics of gravels in exploration field “Abesinija” (Otok Svibovski; SE from Zagreb, Croatia)

Sremac, Jasenka; Velić, Josipa; Bošnjak, Marija; Velić, Ivo; Malvić, Tomislav; Fotović, Daniel; Drempetić, Renato

Mathematical methods and terminology in geology 2020
(*Matematičke metode i nazivlje u geologiji 2020*)

Original scientific paper

Modal composition and morphometric characteristics of gravels in exploration field "Abesinija" (Otok Svibovski; SE from Zagreb, Croatia)

Jasenka Sremac[1]; Josipa Velić[2]; Marija Bošnjak[3]; Ivo Velić[4]; Tomislav Malvić[2]; Daniel Fotović[5]; Renato Drempetić[6]

[1] Faculty of Science, Department of Geology, University of Zagreb, 10000 Zagreb, Croatia; http://orcid.org/0000-0002-4736-7497
[2] Faculty of Mining, Geology and Petroleum Engineering, University of Zagreb, 10000 Zagreb, Croatia; http://orcid.org/0000-0002-5810-2187; http://orcid.org/0000-0003-2072-9539
[3] Croatian Natural History Museum, 10000 Zagreb, Croatia; http://orcid.org/0000-0002-1851-1031
[4] Croatian Summer School, Pančićeva 5, 10000 Zagreb, Croatia
[5] IGM šljunčara Trstenik d.o.o., 10370 Dugo Selo, Croatia
[6] 10000 Dalmatinska 12, 10000 Zagreb, Croatia

Abstract

Gravels exploited from the gravel pit in Trstenik area, in the Sava River floodplain SE from Zagreb, are variegated and of complex composition. All together 1399 clasts from the bulk (gross sample) and 606 from the fraction >32 mm were measured (x, y and z axes) and their lithology, shape and roundness were carefully studied. Numerical analyses were done through the Microsoft Excel program. The Zingg-shape analyses and flatness calculations were also applied. Gravels proved to be polymictic, composed of carbonate, clastic, igneous and metamorphic rocks. Size of measured clasts in bulk sample varies from 6.8 till 110.25 mm along the longest axis (x) and such value exhibits normal distribution. Carbonate, well rounded, disc-shaped clasts prevail. Sporadically, cross sections of red and green algae and macrofossils are visible on pebble surfaces, enabling the determination of stratigraphic age of some pebbles/source rocks. The second abundant group is composed of variegated sandstones, of red, green, grey, brown and yellow colour. Coarse-grained clastic rocks form less rounded clasts, similarly as green diabases. Angular quartz and chert clasts appear in all fractions, but they are more common among small-sized clasts. Modal composition, size and shape point to the important transport route from the Medvednica Mt., by combination of glacial, alluvial and lacustrine processes.

Keywords: gravels, lithology, morphometrics, Sava River, Croatia

1. Introduction

Polymictic gravels occur all along the River Sava Valley, attracting attention of several authors (e.g., **Marić et al., 1954**; **Crnković and Bušić, 1970**; **Šimunić and Basch, 1975**; **Velić and Saftić, 1996**; **Velić et al., 1999**; **Barudžija et al., 2020**, and references therein). They are exploited for various construction and industrial purposes. During this study, geological investigations were carried out at a gravel exploration field "Abesinija", between Otok Svibovski and Strugara (SE from Zagreb) (**Figure 1**), carried out by the Company IGM šljunčara Trstenik. Research area is presented on the Basic Geological Map, sheet L 33-81, Ivanić-Grad (**Basch, 1983 a,b**). The main goal of the research team was to recognize the lithotypes, morphometric characteristics and clast shape, in order to find out the possible source of gravel material and presume the most probable transport processes.

Jasenka Sremac
jsremac@geol.pmf.hr

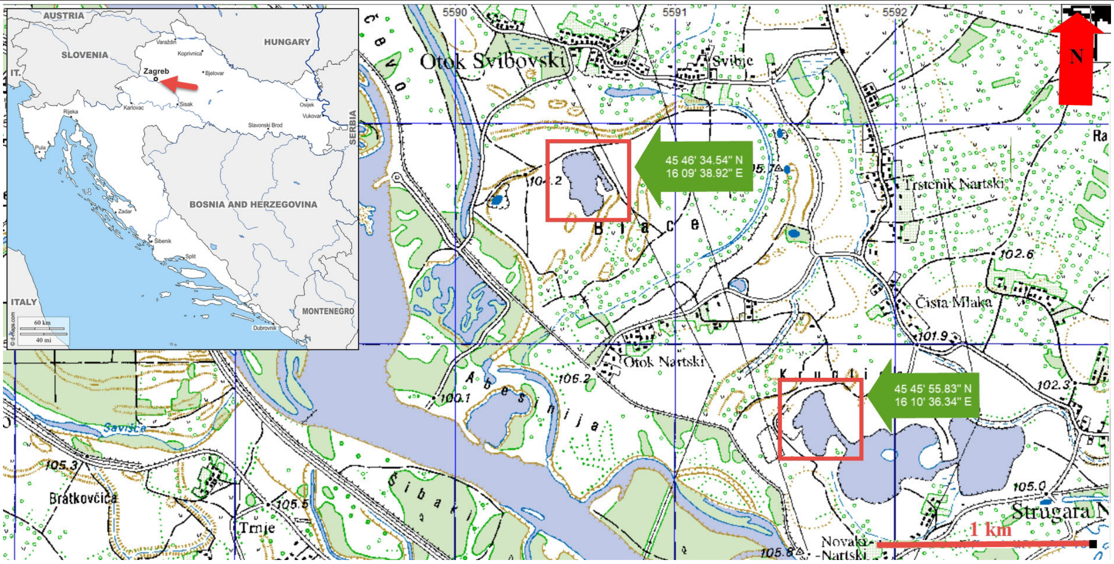


Figure 1: Geographic position of the research areas "Abesinija" (SE from Otok Svibovski) and "Trstenik" (ESE from Otok Nartski, marked by red rectangles (Map of Croatia from **d-maps.com**, assessed in August 2020)

2. Materials and methods

This study was performed on gravels from the gravel pit "Abesinija" by complex study methods, partly in the field and partly in laboratory and in cabinets.

2.1. Field work

Field work took place from March to July 2020 in gravel pit "Abesinija" (**Figures 1** and **2**). Fraction > 32 mm was collected at the position: 45°46'34.54"N; 16° 09'38.92. It was first sorted by colour (**Figure 3**), and then according to the lithology into limestones, sandstones, breccias/conglomerates, diabases, pyroclastics and quartz/chert grains. 22 subcategories were further distinguished by using field magnifier 10 x (**Figure 3; Table I**). All together 606 clasts were measured in the field by a digital caliper, taking care that at least 30 clasts of each category are measured (**Figure 3**).

Figure 2: Sampling and measuring in gravel pit "Abesinija" in March 2020

Figure 3: Bulk sample of gravels (a) and clast sorted into categories: (b) – carbonates; (c) – red sandstones; d) – green sandstones; (e) – quartz(ites) and cherts. Collected in gravel pit "Abesinija" in March 2020.

Table I: Initial classification of clast categories distinguished in the field

FIELD MARK	LITHOLOGY
Z	GREEN, VARIOUS LITHOLOGIES
Z1	Fine-grained sandstone
Z2	Laminated micaceous sandstone
Z3	Dark green siltite
Z4	*Pietra verde* pyroclastite
Z5	Strongly laminated sandstone
Z6	Green microbreccia
Z7	Coarse-grained sandstones with diabase fragments
	RED TO BROWN, CLASTITES
C1	Coarse grained sandstone/microbreccia
C2	Vine-red sandstone
C3	Rusty sandstone
C4	Siltite
	GREYISH SANDSTONES
P1	Micaceous, laminated
P2	Coarse-grained
P3	Light grey, perforated
P4	Yellowish-grey
P5	Dark grey
	CARBONATES
V1	Grey limestone
V2	White dolostone
V3	Black calcarenite
BKG	BRECCIA, CONGLOMERATE
E	EFFUSIVE/DIABASE
Q	QUARTZ(ITE)
R	CHERT
O	OTHER/UNCLASSIFIED

Gross gravelly material was collected at 45°46'31.74"N; 16°10'1.58"E and taken to the laboratory to be sorted and measured. Additional material for further study was collected at the nearby pit "Trstenik", at the position 44°45'55.83"N; 16°10'36.34"E (**Figure 1**).

2.2. Laboratory preparations and photography

Gross gravel sample weighing ca. 5 kilograms was taken to the laboratory. Pebbles/clasts (1399 in number) were separated into categories, clasts larger than 5 mm (371 clasts) counted and measured (longest: x, intermediate: y, shortest: z axes) by a digital caliper. Thin sections were prepared from pebbles of different lithologies in the Wet laboratory of the Department of Geology, Faculty of Science.

Field photographs and macrophotographs of pebbles were taken by a Cannon COOLPIX P900 V1.5 camera.

2.3. Numerical analyses

2.3.1. Excel sheets and graphics

All measured dimensions (axes x, y and z) were presented in Microsoft Excel sheets, enabling the graphic presentation of their relations in form of different diagrams. Relations between the axes are presented as pies and line-charts.

2.3.2. Zingg diagrams

To define a shape classification form, **Zingg (1935)** developed a classification scheme using the relation of the measures of the three orthogonal axes. We calculated relations between the shortest and intermediate axis (z/y or c/b) and the relation between the intermediate and the longest axis (y/x or b/a) for the Zingg diagram, and graphically defined the distribution of the four form pebbles categories for each lithotype and sublithotype: spheroids, discoids, rods and blades (**Table II**).

Table II: Pebble shape categories according to **Zingg (1935)**

Category	b/a (=y/x)	c/b (=z/y)	Shape
I	> 2/3	< 2/3	disc
II	> 2/3	> 2/3	sphere
III	< 2/3	< 2/3	blade
IV	< 2/3	> 2/3	rod

2.3.3. Granulometric analyses

Granulometric analyses were done for the purposes of regular material control for the Company IGM Šljunčara Trstenik in their own laboratory using sieve sizes set shown on **Figure 11**.

The grading of the aggregate was determined in accordance with the Croatian Standards Institute, document EN 933-1 (Tests for geometrical properties of aggregates — Part 1: Determination of particle size distribution — Sieving method).

2.3.4. Gaussian curves

Distribution of frequencies (f_i) of most of the natural, technical and social categories can be represented by a continuous curve. Curve height is controlled by the concentration of data in each point. Curve *f(x)* appears in a typical bell-shaped form (**Figure 4**):

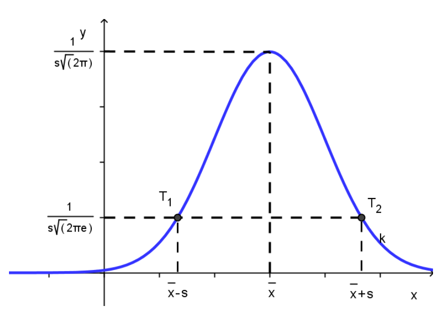


Figure 4: Theoretical bell-shaped Gaussian Curve representing normal distribution

Theoretical normal distribution represents a base of the applied statistics, especially parametric. In geology, the many phenomenon and belonging variables could be mostly described with Gaussian (normal) distribution (e.g., **Malvić and Medunić, 2015**)

2.3.5. Flatness

We calculated the flatness ratio of the pebbles to assume the original sedimentary environments of the pebbles. The flatness ratio is defined by Equation **(1)**:

$$F = (a + b)/2c \tag{1}$$

Where:
F = flatness ratio;
a = the longest axis;
b = the intermediate axis and
c = the shortest axis.

The flatness ratio for each lithotype was defined and compared to the possible environment origin according to the **Table III**.

Table III: Flatness in different sedimentary environments (after: **Cailleux, 1952** and **Müller, 1967**, from **Barudžija et al., 2020**)

Depositional environment	**Flatness**
Potholes in river channels	1.2 – 1.6
Ground moraine	1.6 – 1-8
Fluvioglacial	1.7 – 2.0
Beach (marine)	2.3 – 3.8
Beach (lacustrine)	2.3 – 4-4
Frost river	2.0 – 3.1
Rivers in moderately warm climate	2.5 – 3.5

3. Results

Results of analyses have shown the size span and size distribution of clasts, abundance of different lithologies, shape and sphericity through lithological classes. Lithological features and fossils in limestone pebbles indicate the age and the probable source of clasts.

3.1. Clast number and modal composition

Clasts number and size were studied from fractions larger than 32 mm and 16-32 mm for comparison, but clasts were particularly detailed measured and counted in a gross sample. Size and shape vary within various lithological categories (**Tables II** and **IV**). Clasts from the gross sample were taken to the laboratory and visually separated in a coarse- and fine-grained fraction. Clasts with x-axis smaller than 5 mm were divided into lithological categories and counted (**Table IV**). Coarse-grained pebbles, larger than 5 mm along the longest axis, were also sorted by lithology, and their dimensions (x, y, z) were measured by a digital caliper (**Tables V–VII**). The most abundant in both categories are calcareous pebbles, particularly white and grey micritic carbonate rocks (**Figure 3b; Table IV; Figure 5; Figure 6a,b**).

Coralgal and marly limestones appear in a small number of pebbles (**Tables IV** and **V, Figures 5** and **6c**). Among sandstones, green sandstone (**Figure 3d**) prevails in fine fraction, while red sandstone (**Figures 3c** and **6d**) is the most abundant in coarse fraction (**Table IV**). Silicate rocks (quartz grains, cherts) (**Figures 3e** and **6 h,i**) and volcanic diabases are far more abundant in a fine-grained fraction, than among larger clasts (**Table IV**), and they can be clearly recognized by their sharply-rectangular shape (**Figures 3e** and **6h**). Pyroclastites of *pietra verde* type can be easily recognized for their bluish-green colour, but they are rather scarce (**Table IV**). Quite a large number of small clasts remained unclassified (**Tables II** and **IV**).

Table IV: Number of clasts of different lithologies in bulk sample

				BULKSAMPLE-COARSE FRACTION		BULK SAMPLE-FINE FRACTION	
ROUNDNESS	**LITHOLOGY**	**FIELD MARK**	**LITHOL. CATEGORY**	**CLAST NUMBER**		**CLAST NUMBER**	
ANGULAR	QUARTZITE	Q	SILICATE ROCKS	28	44	93	124
	CHERT	R		16		31	
	DIABASE	E	VOLCANICS	15	19	144	147
ROUNDED	PYROCLASTIC	Z 4		4		3	
	GREEN SANDSTONE/SILTITE	Z 1, Z 2, Z 3, Z 5 Z6, Z7	SANDSTONES/SILTITES	34	76	44	124
	RED SANDSTONE/SILTITE	C 1, C 2, C 4		12		57	
	BROWN SANDSTONE	C 3		7		2	
	YELLOW SANDSTONE	P 4		15		21	
	GREY SANDSTONE	P 1, P 2, P 3, P 5		8		0	
	CORALGAL BIOCLASTIC LIMESTONE		CARBONATES	12	173	28	309
	WHITE MICRITIC LIMESTONE	V 2		75		181	
	GREY MICRITIC LIMESTONE	V 1		52		66	
	DARK-GREY CALCARENITE	V 3		28		34	
	MARLY LIMESTONE			6		0	
INTERMEDIATE	BRECCIA/CONGLOMERATE	BKG	OTHER	12	67	316	316
	UNCLASSIFIED / OTHER	O		55			
				379	379	1020	1020

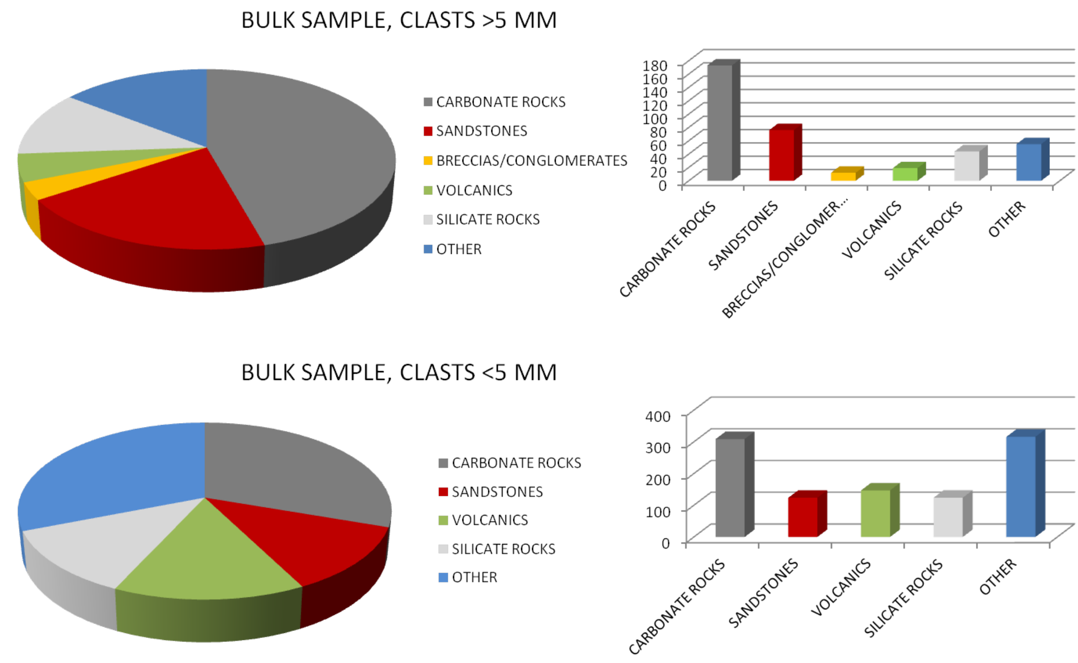


Figure 5: Modal composition and distribution of main clast groups from a bulk sample collected in gravel pit "Abesinija" in March 2020, divided in two size groups (larger and smaller than 5 mm) and presented as pies and histograms (Microsoft Excel Program)

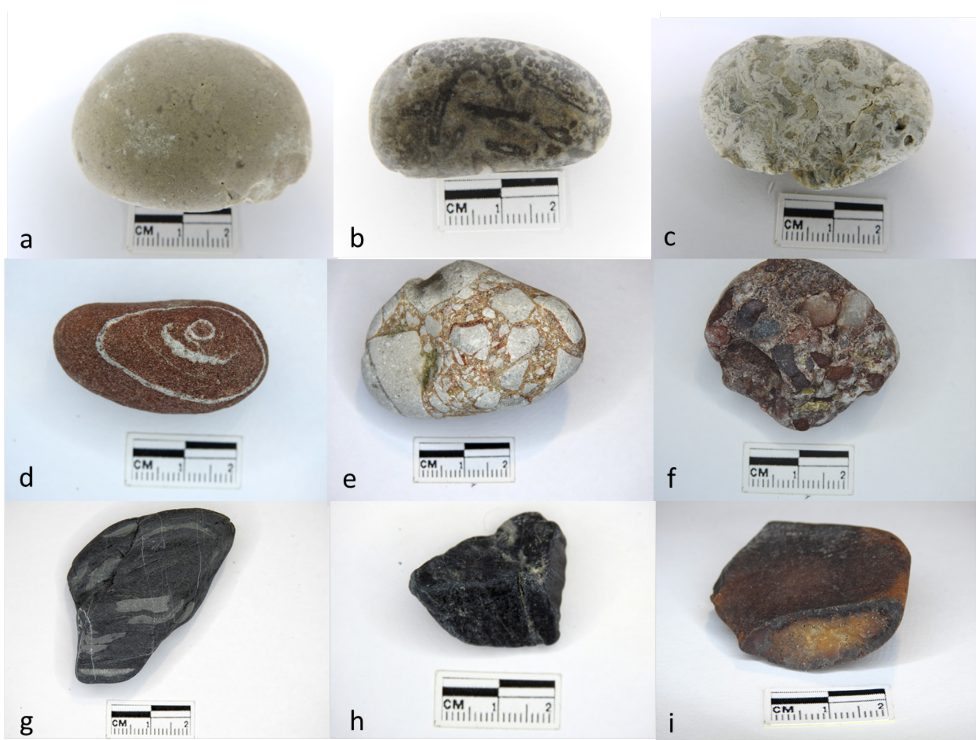


Figure 6: Common types of pebbles from "Abesinija" Gravel Pit: (a) – white micritic limestone; (b) – grey micritic limestone with dasyclad algae; (c) –bioclastic limestone with coralline algae; (d) – red laminated sandstone; (e) – carbonate breccias; (f) – polymictic conglomerate; (g) – bioturbated grey sandstone; (h) – black chert; (i) – chert nodule

3.2. Clast size, shape and distribution

Carbonate clasts are the most common both in gross sample and in fraction larger than 16 mm (**Tables IV** and **V**). Their size is variable, and, among the measured clasts, varies between 6.8 and 62.1 mm along the longest (x) axis.

Table V: Dimensions of measured carbonate pebbles from the bulk sample

WHITE CARBONATES		
x	y	z
10,0	7.9	5.1
12.5	13.9	8.2
14.0	9.0	6.3
15.0	10.6	5.2
15.0	12.9	9.0
15.1	14.1	7.1
15.5	11.5	5.5
15.6	12.7	6.9
15.8	13.9	6.9
16.1	11.9	7.3
16.7	14.1	11.0
17.0	13.6	10.2
17.2	15.9	7.8
17.3	9.5	5.9
17.9	13.6	9.8
17.9	15.8	10.1
18.0	11.1	6.4
18.2	17.9	16.5
18.3	14.3	12.9
19.3	16.0	12.5
19.5	16.2	10.4
19.9	14.3	6.9
20.2	15.2	14.1
21.3	15.1	11.3
21.5	14.9	11.0
21.6	11.4	9.5
22.5	15.5	13.5
22.6	15.0	8.6
22.6	18.2	9.7
22.8	19.1	17.3
22.9	14.2	12.2
22.9	18.5	6.5
23.0	15.2	9.0
23.2	9.5	8.5
23.5	20.0	11.6
24.2	14.9	10.1
25.2	17.2	10.5
25.8	15.9	11.8
26.1	20.4	12.8
26.1	22.5	12.0
27.0	19.1	7.5
27.0	19.3	13.4
27.4	18.2	17.9
27.6	17.3	17.0
28.1	24.5	13.6
28.3	22.9	13.5
28.4	18.7	12.9
29.4	28.3	10.2
31.1	20.2	8.7
31.1	22.8	14.2
33.3	22.4	12.6
33.5	22.2	13.5
34.1	25.0	11.7

GREY CARBONATES		
x	y	z
12.2	11.0	6.5
12.4	11.2	8.5
14.7	10.2	4.1
15.0	8.5	4.1
16.5	12.7	7.1
18.0	11.9	9.2
18.4	12.0	7.8
18.7	16.3	7.6
19.1	17.2	13.1
19.2	15.7	9.4
19.4	17.1	6.0
19.6	20.4	7.7
19.9	15.4	10.2
20.0	13.3	4.4
20.1	11.8	6.4
21.5	16.4	13.4
23.2	17.2	12.1
23.2	18.5	11.5
23.2	19.9	8.8
24.2	21.2	12.4
24.3	18.1	10.2
25.5	21.8	15.5
25.8	22.1	9.7
26.1	23.8	16.6
26.6	17.6	8.4
27.2	15.2	15.1
27.3	23.0	12.2
28.2	18.8	9.4
28.8	20.4	11.5
29.3	26.3	15.2
30.2	18.7	11.8
30.4	25.3	18.6
30.5	15.6	9.7
31.2	31.0	11.5
32.0	27.5	11.6
32.4	26.7	11.5
35.3	21.6	15.1
36.6	28.7	18.7
37.7	31.2	12.4
38.1	26.6	18.3
40.0	27.3	19.1
40.7	22.2	17.5
41.4	26.3	20.0

BLACK CALCARENITES		
x	y	z
15.4	13.0	10.0
17.5	16.3	10.9
17.7	12.0	7.3
18.3	14.0	8.6
18.6	14.8	7.8
20.1	11.2	9.6
21.7	21.5	11.0
23.2	23.2	17.4
23.4	18.0	7.6
24.5	17.3	5.7
25.3	20.9	11.1
27.2	16.6	14.2
28.4	18.8	11.5
28.4	22.0	10.2
31.9	20.4	20.1
32.2	25.0	9.4
32.3	16.4	15.5
32.5	26.7	20.3
33.8	22.7	11.5
35.4	15.0	9.3
36.5	25.2	18.0
38.2	27.8	19.1
38.4	18.4	11.3
41.5	31.8	17.4
41.5	33.7	12.4
43.1	33.1	27.5
46.4	33.5	19.5
50.3	33.7	27.4

MARLY LIMESTONES		
x	y	z
15.2	12.2	8.1
19.7	9.4	9.2
25.8	16.3	13.3
27.8	25.3	7.4
35.1	15.3	12.8
38.1	20.6	12.1
38.2	29.2	23.1
46.3	27.7	19.2

BIOCALCARENITES		
x	y	z
6.8	5.0	3.5
11.2	8.9	4.9
15.0	11.5	4.7
23.8	11.5	9.6
25.4	17.0	16.0
43.5	24.8	20.0

OTHER CARBONATES		
x	y	z
41.4	37.9	23.2
47.3	34.2	26.5

34.3	33.7	14.2
34.8	16.2	13.5
36.8	24.4	17.4
36.8	25.5	12.3
36.9	34.3	8.3
37.4	32.7	12.5
38.5	33.6	12.5
40.5	36.2	15.3
41.6	25.5	20.7
42.4	33.5	16.4
42.9	30.0	14.8
44.3	30.7	20.4
44.5	28.2	20.6
62.1	30.4	21.7

51.3	26.2	20.8

Relationship between the measured x, y and z axes of carbonate clasts from the bulk gravel sample are presented on **Figure 7**.

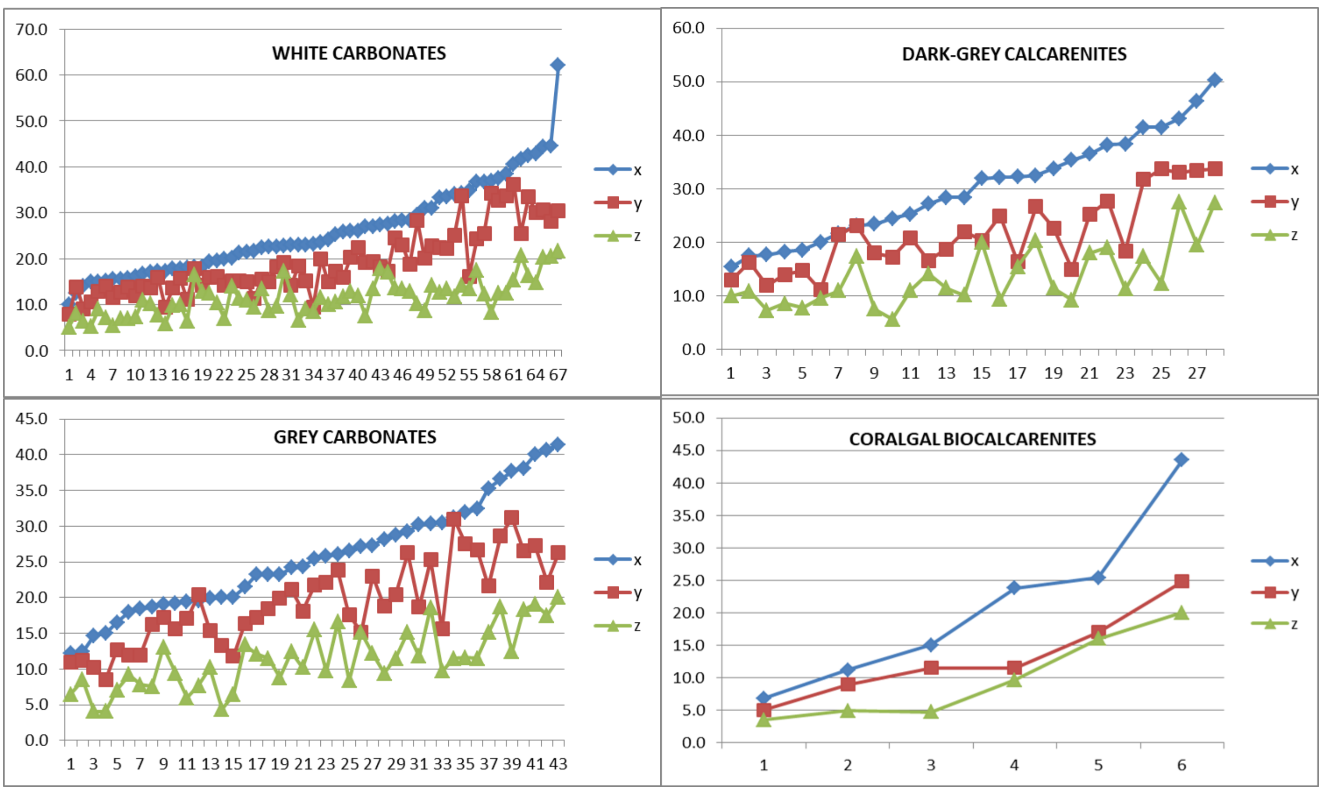


Figure 7: Size distribution of different types of carbonate pebbles obtained from the Microsoft Excel Programme

Sandstone pebbles are clearly visible in the field, very common in bulk and fractionated gravels (**Figure 3a**), and often present in striking colours. Green and red sandstones are equally abundant (**Tables IV** and **V**), while grey (**Figure 6g**) and brown sandstone clasts occur in small numbers (**Tables IV** and **V**). Lamination occurs in all sandstone categories (**Table I, Figures 6 d,g**).

Table VI: Dimensions of measured sandstone pebbles from the bulk gravel sample

GREEN SANDSTONES			RED SANDSTONES			YELLOW SANDSTONES			GREY SANDSTONES		
x	y	z	x	y	z	x	y	z	x	y	z
12.8	8.4	6.0	9.0	5.2	3.0	15.5	12.5	8.6	8.2	4.2	4.0
16.0	12.9	11.0	12.5	8.4	6.5	16.6	15.2	4.2	15.5	11.9	6.5
16.5	13.3	8.9	26.5	12.2	11.7	17.4	14.0	12.0	17.4	11.0	7.9
17.9	15.5	5.8	27.2	22.9	9.1	18.9	13.1	9.5	21.6	14.2	7.9
18.5	10.9	8.9	27.3	20.9	15.5	20.2	14.7	17.9	22.5	17.4	13.5

19.6	12.2	4.1
20.0	15.9	13.6
21.4	19.1	6.3
22.6	14.6	10.1
23.4	16.5	7.4
25.0	17.4	14.1
25.6	13.5	9.1
25.8	15.8	9.9
26.5	14.2	12.0
27.9	18.6	11.9
27.9	23.5	12.9
29.0	23.5	8.3
30.0	24.8	17.2
30.5	17.5	13.5
30.6	26.4	13.3
30.8	21.3	10.0
36.8	23.1	16.0
36.8	25.7	14.9
37.2	32.6	19.0
40.8	15.0	14.9
41.2	24.5	16.9

27.5	17.9	8.0
29.0	20.5	11.2
29.2	20.9	18.0
29.4	20.6	18.4
30.0	28.8	14.0
36.6	31.2	18.8
38.5	20.5	10.2
42.3	23.7	12.7
43.1	21.4	13.5
45.5	23.0	15.5
46.0	24.1	14.6

RED COARSE SANDSTONES		
x	y	z
18.1	12.8	11.0
19.4	14.8	10.0
22.5	14.1	12.4
26.5	12.3	11.9
28.9	22.5	18.4
32.4	25.6	25.3
39.0	19.5	10.6
50.1	35.5	24.8

20.5	17.1	7.2
21.5	15.9	5.5
22.8	16.5	9.4
28.9	19.1	14.1
29.5	24.0	13.5
31.3	22.8	16.4
32.5	16.2	6.9
50.8	25.1	10.0

BROWN SANDSTONES		
x	y	z
25.5	21,2	12.4
31.9	24.4	18.8
32.1	22.1	20.5
33.2	24.0	16.2
33.2	26.4	16.4
45.8	30.7	15.8

25.1	13.3	8.0
47.5	28.9	13.1
53.0	35.5	21.2

Relationships between the measured x, y and z axes of sandstone clasts from the bulk gravel sample are presented on **Figure 8**. They are rather homogenized in yellow and brown sandstones (**Figure 8**), although they are represented by rather small numbers (**Table VI**). Green micaceous sandstones are of variable shape and red micaceous sandstones present a different pattern (**Figure 8**). Medium-sized clasts seem to be unified, while larger clasts show somewhat different pattern (**Figure 8**).

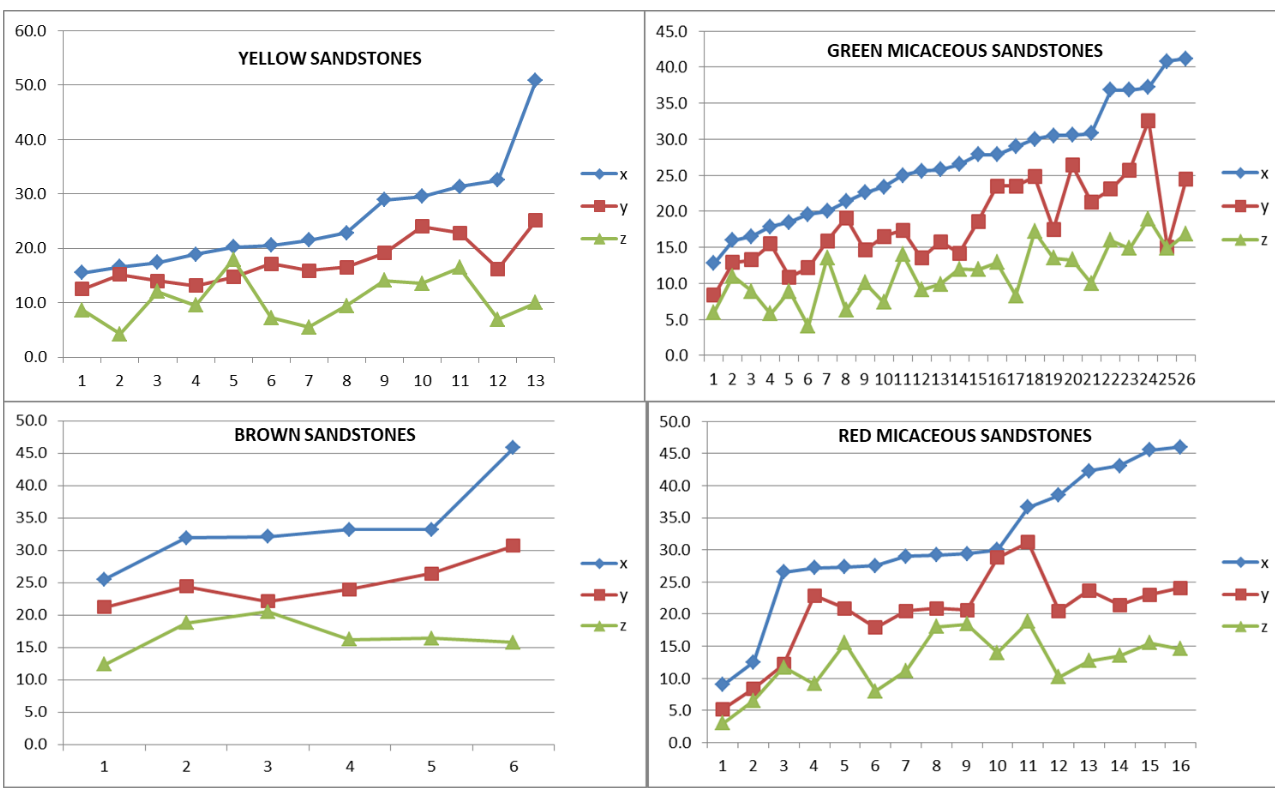


Figure 8: Size distribution of sandstones obtained from the Microsoft Excel Programme

Table VII: Dimensions of measured other pebbles from the bulk gravel sample

QUARTZ(ITE)		
x	y	z
9.8	6.6	4.5
11.5	8.0	7.5
12.8	11.2	6.2
13.5	8.6	8.5
14.0	9.5	7.1
15.0	12.0	8.5
15.0	12.0	10.0
15.3	8.3	8.2
15.9	8.5	5.5
16.1	11.4	8.0
16.1	11.5	10.1
16.4	11.4	10.6
16.5	12.9	6.2
18.2	13.4	11.8
18.4	13.9	12.4
18.5	13.9	9.3
19.6	10.3	9.9
19.6	13.8	11.9
21.3	18.3	9.0
21.9	17.2	15.1
22.4	15.4	15.2
23.2	19.3	18.0
24.2	16.7	10.0
24.5	22.5	12.0
25.5	19.3	11.3
26.5	16.9	15.5
27.5	20.5	18.2
30.5	21.5	16.3
31.0	19.9	17.3
32.3	31.7	15.5
33.4	17.8	11.0
34.8	23.1	16.5
39.8	15.0	9.8

CHERT		
x	y	z
14.4	10.2	7.0
15.0	14.0	8.2
18.0	12.0	7.3
18.7	14.5	8.4
20.2	12.5	6.8
20.5	14.0	7.5
20.7	17.9	10.5
22.9	14.7	13.5
24.5	12.0	10.4
25.0	14.1	10.5
25.0	15.0	11.5
25.0	20.2	17.7
25.7	12.2	9.6
29.8	20.1	12.8

EFFUSIVES		
x	y	z
12.2	10.5	7.2
19.3	13.6	10.0
21.3	14.7	14.5
29.2	28.4	15.1
35.8	33.9	13.8
53.8	43.2	16.8
61.1	38.3	13.8

Breccias and conglomerates occur in small numbers, but they can be easily spotted for their colourful appearance, both in breccias with reddish matrix (e.g., **Figure 6e**), or polymodal conglomerates with clasts of different colours (e.g., **Figure 6f**). Their shape and roundness depend on the hardness, structure and texture of clasts (**Figure 9**).

Quartz(ite), chert and diabase clasts differ from carbonate and sandstone pebbles in size (they are generally smaller) and angular shape (**Figures 3e** and **6h**). They are more common in finer, than in coarser fractions (**Table IV**). Their size distribution is presented on **Figure 9**. Quartz grains are white in colour, while quartzites and cherts display different colours, usually brownish to black. Some chert grains are angular (e.g., **Figure 6h**), while others, lense-shaped, represent nodules extracted from sedimentary rocks (e.g., **Figure 6i**). The **Figure 10** clearly showed that Gaussian distribution can be obtained for number of samples data measured for all three analysed axes (x, y, z, **Figure 10a-c**). Also, if the samples are grouped according the length of the x axis, the same curve could be approximated over the histogram with classes wide 6.3 mm (automatically selected by software algorithm).

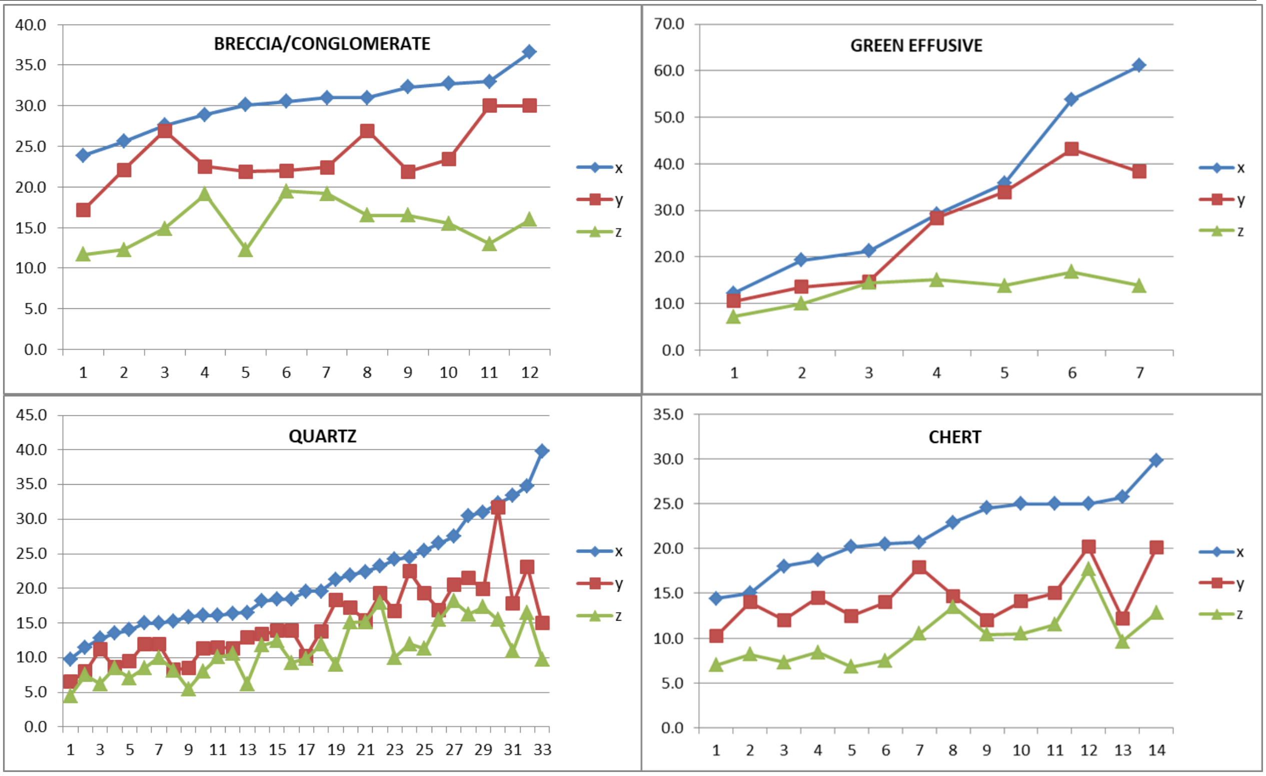


Figure 9: Size distribution of coarse-grained clastites, diabases, quartz and chert grains obtained from the Microsoft Excel Programme

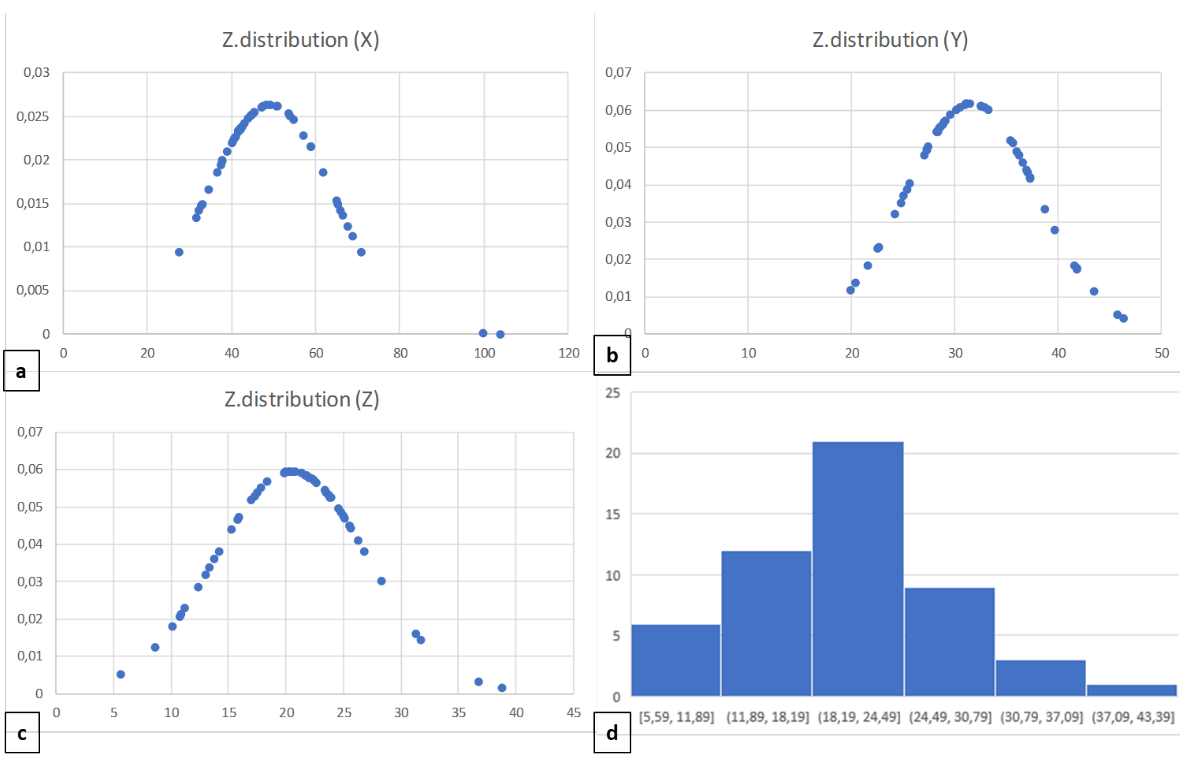
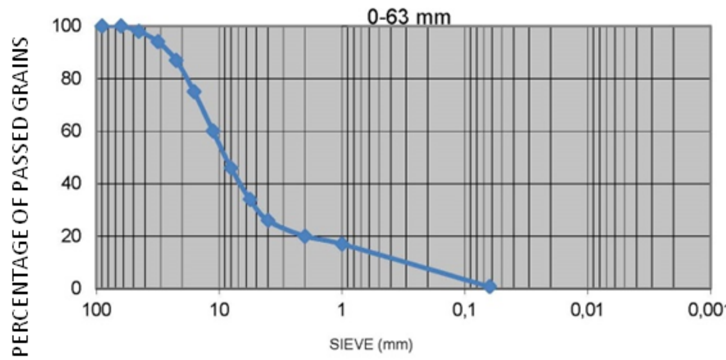


Figure 10: Normal distribution of size of bulk pebbles (x, y and z axes) in a Gaussian curve and histogram

CUMMULATIVE PASSAGE OF CLASTS THROUGH THE SIEVE, 1ST LAYER

SIEVE (mm)	0,063	1	2	4	5,6	8	11,2	16	22,4	31,5	45	63	90
PASSAGE (%)	0,80	17	20	26	34	46	60	75	87	94	98	100	100



CUMMULATIVE PASSAGE OF CLASTS THROUGH THE SIEVE, 2ND LAYER

SIEVE (mm)	0,063	1	2	4	5,6	8	11,2	16	22,4	31,5	45	63	90
PASSAGE (%)	1,40	16	20	27	34	44	56	70	83	92	97	100	100

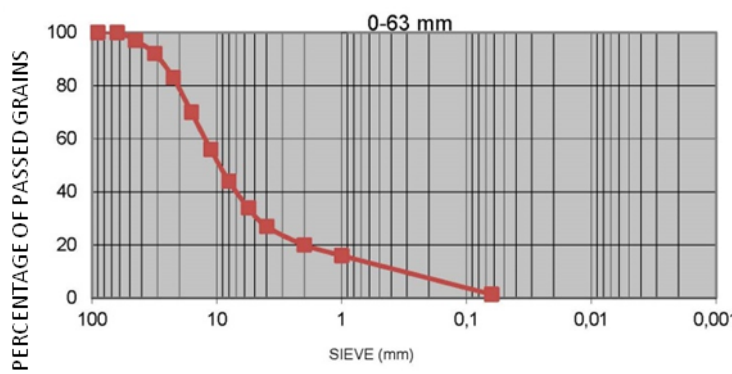


Figure 11: Results of granulometric analyses of pebbles from younger (1st layer, Trstenik) and older (2nd layer, Abesinija) stratigraphic horizons (February, 2020)

Granulometric analyses, done in IGM Šljuncara Trstenik laboratory for the purposes of regular material control of gravels, gave us insight into slight differences between the younger 1st layer, 5-10 m thick (exploited in "Trstenik" pit, **Figure 1**, **Figure 11**, blue curve) and older, 2nd layer, >20 m thick which is now under exploitation in the "Abesinija" Pit (**Figure 1, Figure 11**, red curve). Gravel layers are separated by a 2.5-4.5 m thick argillaceous-peat coal layer. Curves support the normal distribution, as seen in **Figure 10**, with minor deviation in the finest fraction of the younger, 1st horizon (**Figure 11**, blue curve). Comparison between the two layers is in our plan for further research.

Shape analyses of fractioned and bulk gravel sample were done in order to recognize the shape characteristic for different types of clasts, and, if possible presume the modes of their transport, according to **Zingg (1935)**. Results are presented in form of diagrams (**Figures 12, 13, 15, 16, 18** and **20**), while the comparison of Zingg data for pebbles from bulk and fractioned gravels (fraction > 32 mm) are shown on **Figures 17, 19** and **21**. Among the most common white and grey limestones, discoidal pebbles prevail both in bulk and fractioned gravels (**Figures 12, 13** and **14**). Distribution of blade and rod shapes seems similar, with slight differences in percentage of rod-shaped clasts. The most pronounced difference is in percentage of spheroidal clasts, which occur in much larger numbers in the bulk gravel sample (**Figure 14b**).

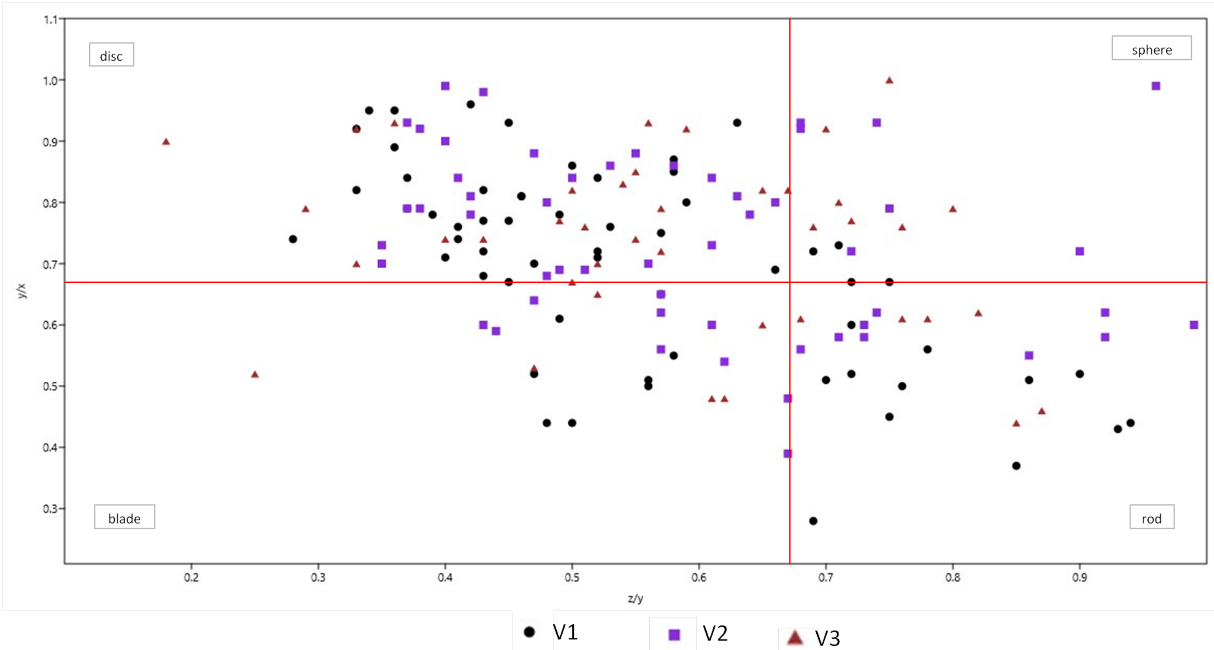


Figure 12: Zingg's diagrams for 146 measured carbonate pebbles from the gravel fraction > 32 mm: (a) the most common carbonate pebbles (white and grey micritic carbonates, black calcarenites). V1 – grey limestone; v2 – white limestone; v3 – black calcarenite.

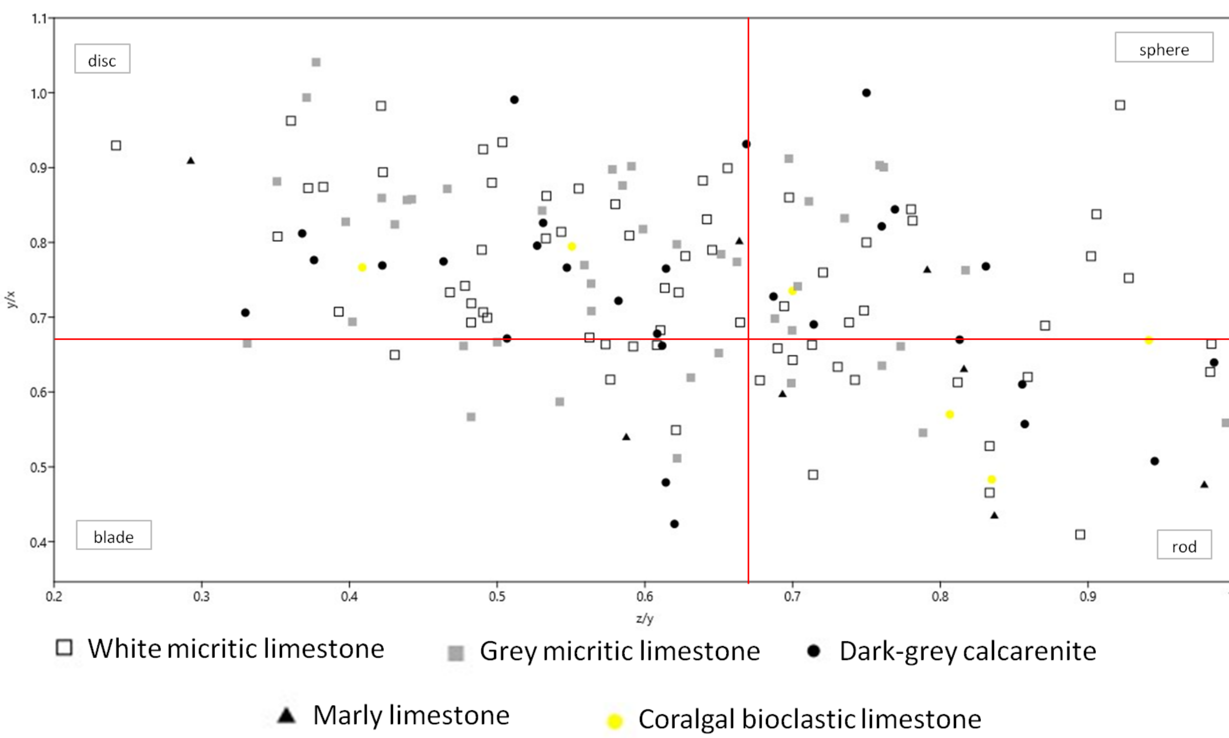


Figure 13: Zingg's diagram for carbonate pebbles from the bulk gravel sample, with *x*-axis larger than 5 mm

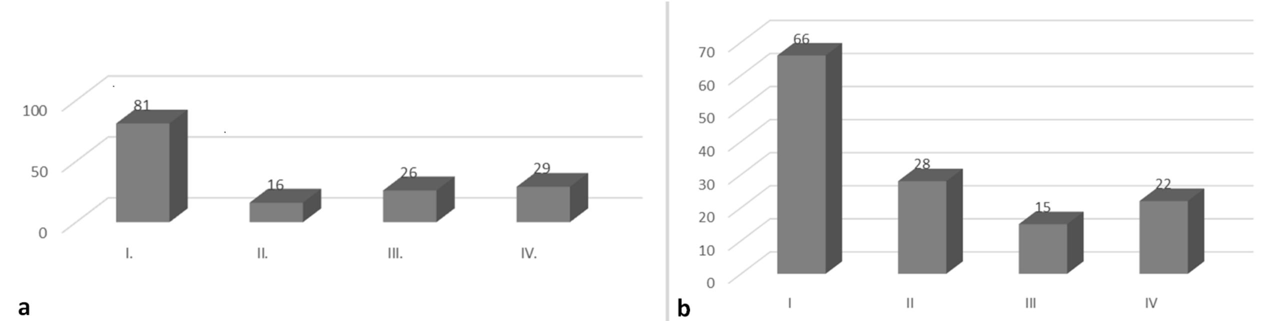


Figure 14: Comparison of Zingg's data for the most abundant carbonate pebbles (v1, v2, v3) from the: (a) fraction >32 mm and (b) bulk sample, without pebbles with 0.67 ratio. Categories: I. disc; II. sphere; III. blade; IV. rod.

Study of sandstone pebbles shows a variety of results, again with slight domination of discoidal pebbles in bulk sample (**Figure 15**).

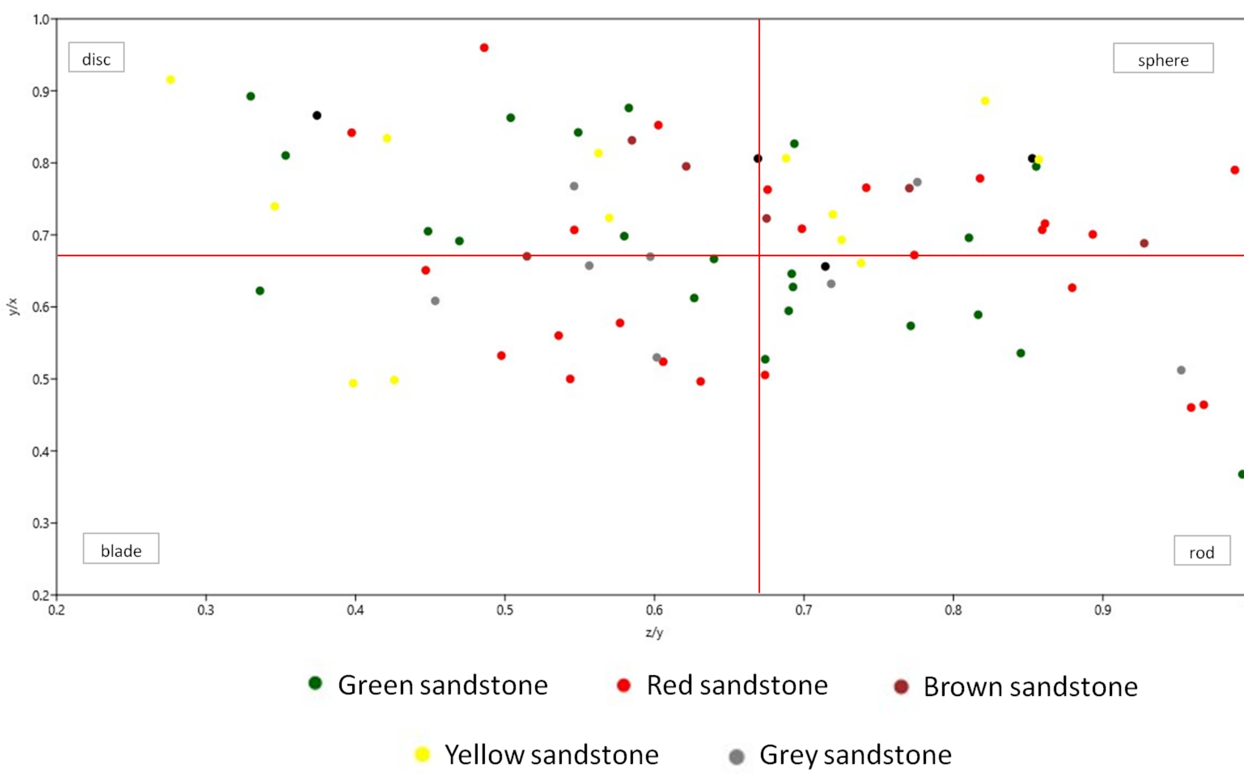


Figure 15: Zingg's diagram for 76 sandstone pebbles with *x*-axis larger than 5 mm, from the bulk gravel sample

Results are slightly different, when different types of sandstones are studied separately from the fractioned gravel larger than 32 mm (**Figures 16, 18** and **20**). Green sandstones are the most common both in bulk and sieved groups (**Tables IV** and **VI, Figure 5**). Their Zingg diagram looks extremely dispersed (**Figure 16**). Comparison of a fraction larger than 32 mm with bulk sample shows significant differences (**Figure 17**). In fractionated material almost all shapes are equally abundant, except blades (**Figure 17a**), while in the bulk gravel discoidal and rod-shaped clasts prevail (**Figure 17b**).

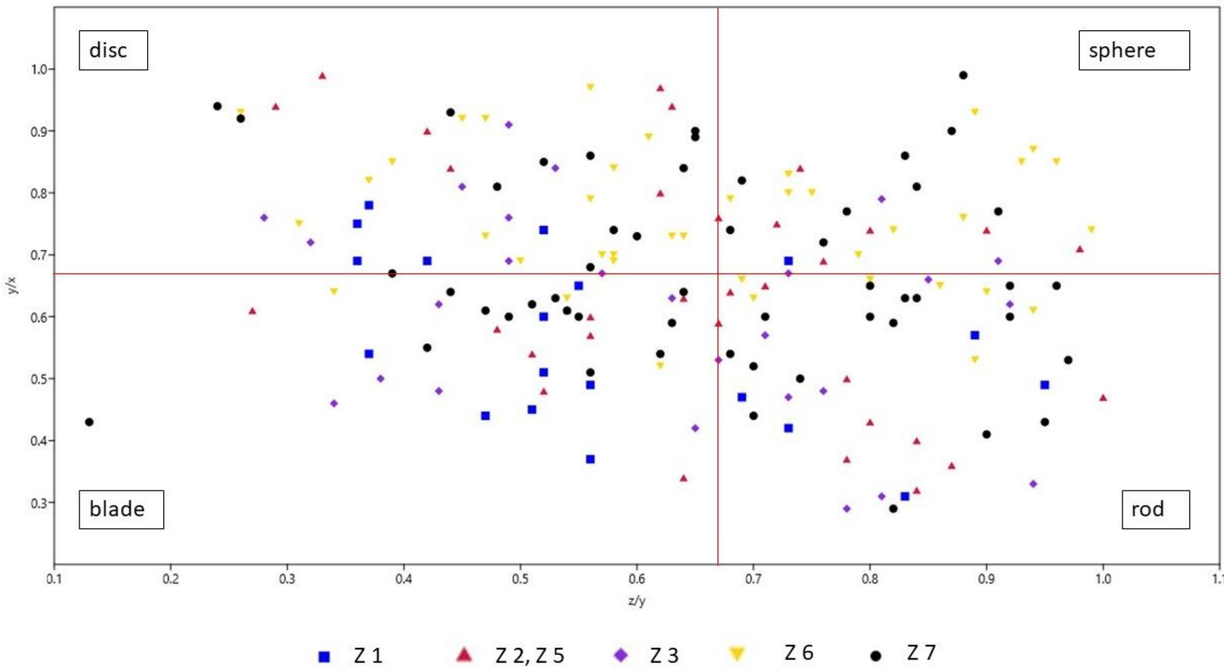


Figure 16: Zingg's diagram for green sandstone pebbles from the gravel fraction > 32 mm (See **Table I** for explanation of categories)

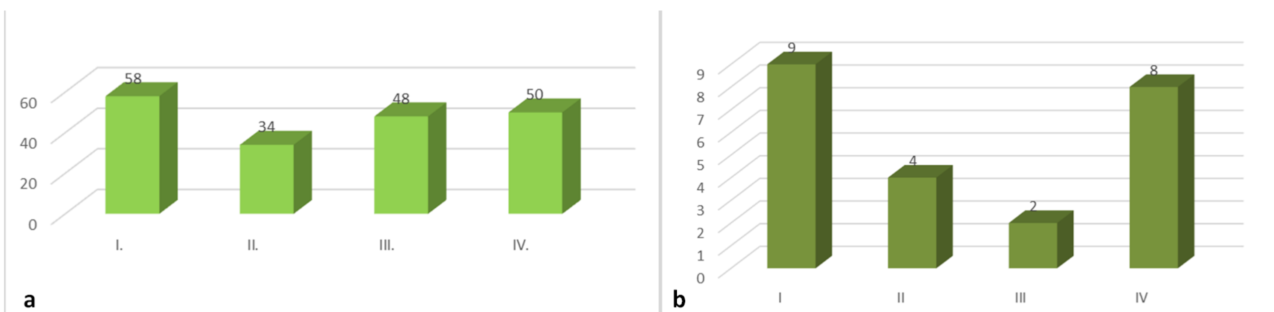


Figure 17: Comparison of Zingg's data for green sandstone pebbles from the: (a) fraction >32 mm and (b) bulk gravel sample, without pebbles with 0.67 ratio. Categories: I. disc; II. sphere; III. blade; IV. rod.

Within the red sandstones, discoidal shapes are the most common (**Figure 18**). In fractionated coarse material almost all shapes are equally abundant, except blades (**Figure 17a**), while in the bulk gravel discoidal and rod-shaped clasts dominate (**Figure 17b**), which is very different than in green sandstone group.

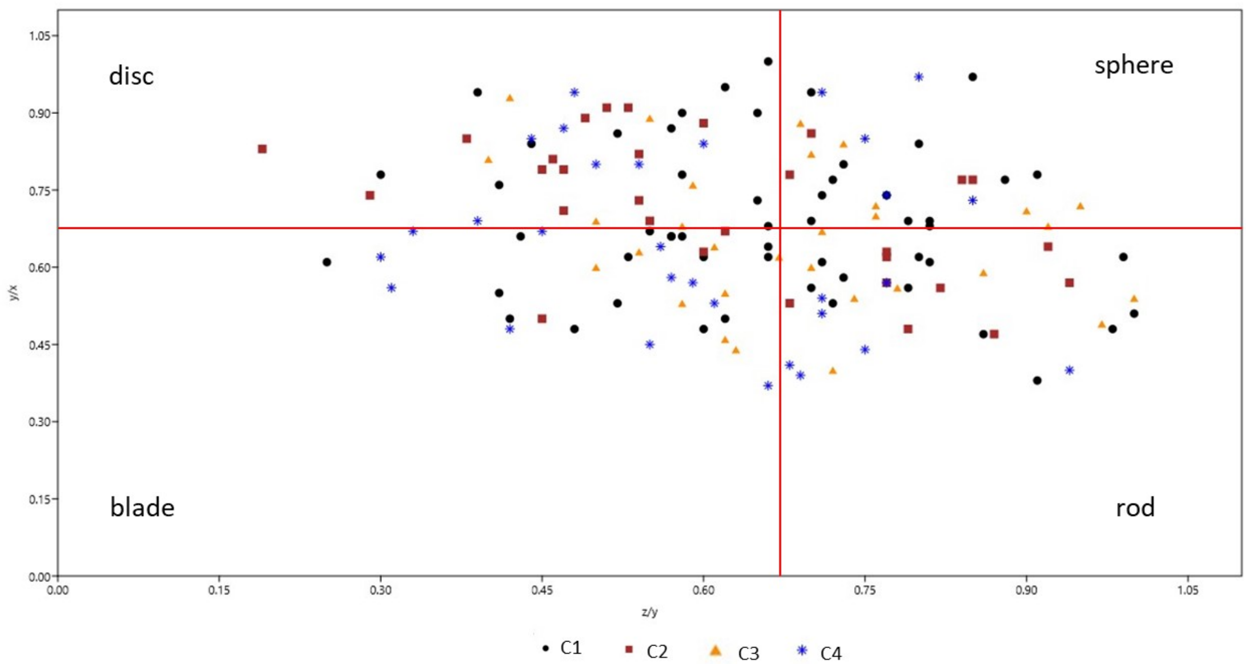


Figure 18: Zingg's diagram for red sandstone pebbles from the gravel fraction > 32 mm (See **Table I** for explanation of categories). C1 – coarse-grained sandstones; C2 – vine-red sandstone; C3 – rusty-coloured sandstone; C4 – fine-grained sandstone/siltite.

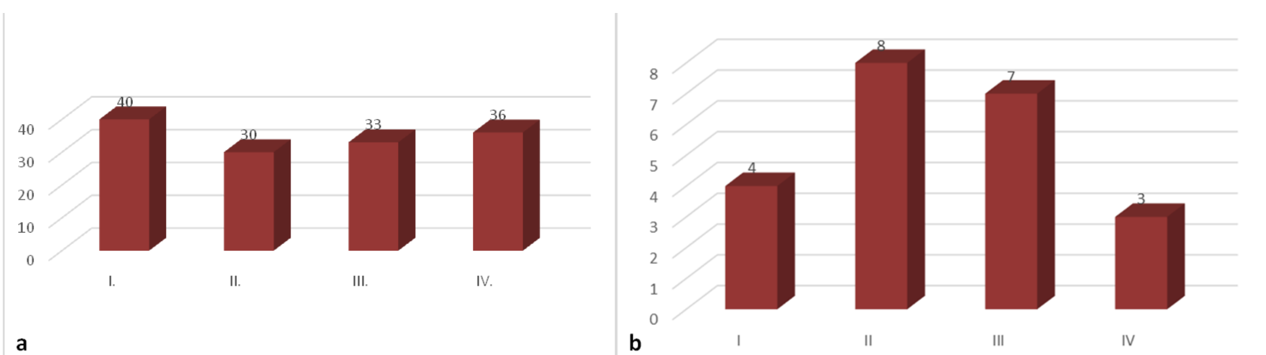


Figure 19: Comparison of Zingg's data for the red sandstone pebbles (C1, C2, C4) from the: (a) fraction >32 mm and (b) bulk gravel sample, without pebbles with 0.67 ratio. Categories: I. disc; II. sphere; III. blade; IV. rod.

Conglomerates and breccias are the only group of clastic rocks clasts with high percentage of spheroidal forms (**Figures 20** and **21**). They are represented with smaller number in gross sample, and their shape analyses were only done on coarse fractions.

Eruptives are represented with tuffs and diabases, also too scarce in bulk sample, and presented only from the coarse fraction (**Figures 20** and **21**). In both groups discoidal forms slightly prevail, while blades are very rare (**Figures 20** and **21**). Group of angular quartz grains and quartzites are present in all forms except blades. They are much more common in fine fractions of the bulk sample, but only small number was counted from the fraction larger than 5 mm.

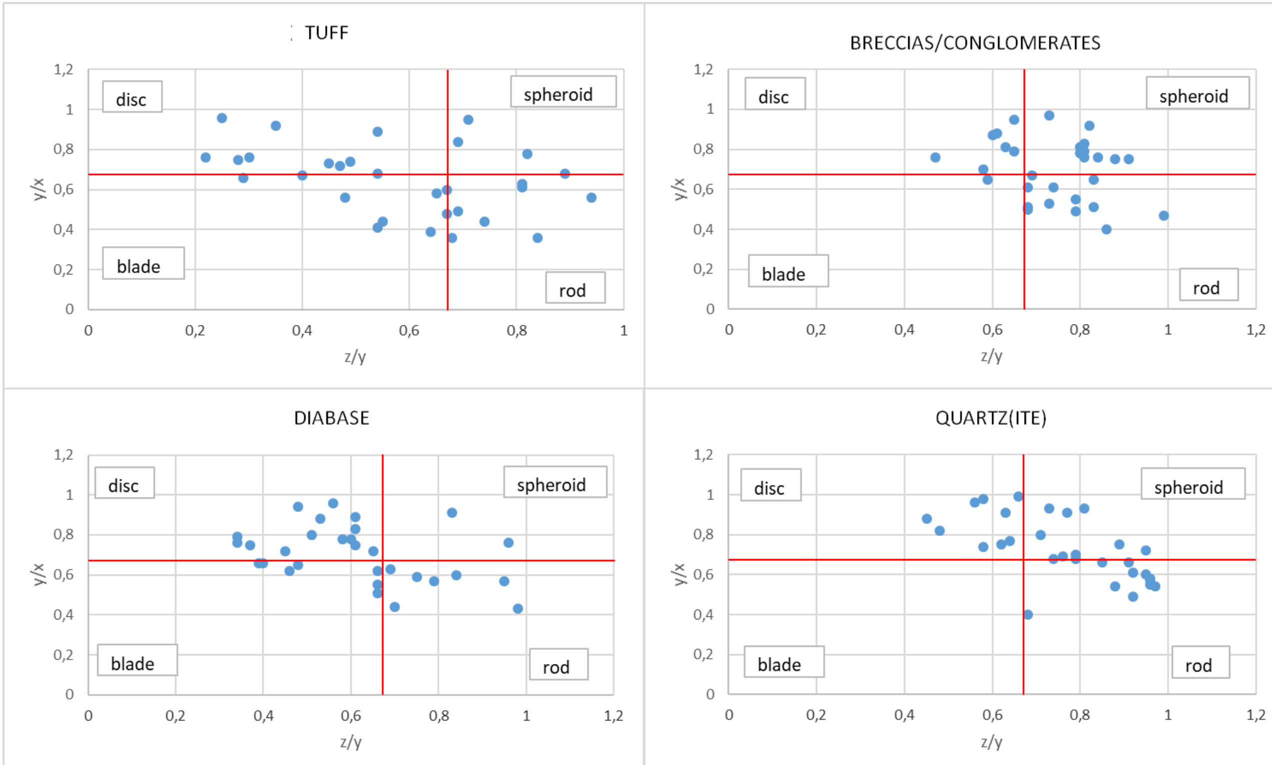


Figure 20: Zingg's diagram for less common pebbles from the gravel fraction >32 mm. These pebbles were not represented with statistically satisfactory numbers in bulk sample.

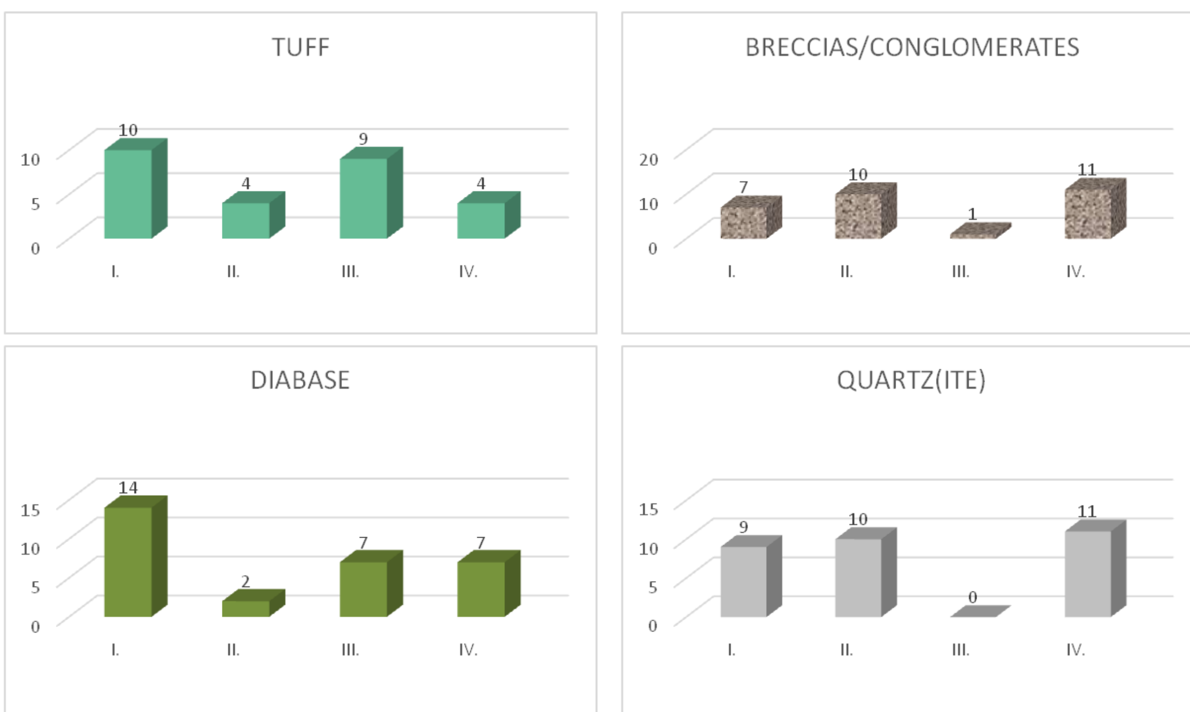


Figure 21: Histograms presenting Zingg's data for less common pebbles from the gravel fraction >32 mm, without pebbles with 0.67 ratio. These clasts were not represented with statistically satisfactory numbers in bulk sample larger than 5 mm. Categories: I. disc; II. sphere; III. blade; IV. rod.

Flatness ratio (after **Cailleux, 1952** and **Müller, 1967**) for all measured clasts from the bulk sample varies between 1.6 and 2.1 (**Table VIII**). The most common clasts, carbonates and sandstones, have flatness ratio of 1.9.

Table VIII: Flatness ratio for pebbles of different lithologies in a bulk gravel sample (calculated after: **Cailleux, 1952** and **Müller, 1967**)

LITHOTYPE	FLATNESS RATIO
SANDSTONE	1.9
LIMESTONE	1.9
BRECCIA/CONGLOMERATE	1.7
DIABASE	2.1
QUARTZ(ITE)	1.6
CHERT	1.7

4. Discussion

Since the beginning of this research, we were focused on two main goals: recognizing the source rocks contributing to the formation of gravels and trying to understand the mode of their transport. This study offers some interesting initial results and represents a good foundation for further research of these topics.

4.1. Modal composition of "Abesinija" pit gravels and possible source area(s)

Study of the coarse-grained gravels (clasts larger than 32 mm) from gravel pit "Abesinija" enabled the first insight in different lithologies present in the studied gravels. Results could be well compared with published data from the neighbouring areas (**Marić et al., 1954; Crnković and Bušić, 1970; Šimunić et al., 1975; Velić and Saftić. 1996; Velić et al., 1999; Barudžija et al., 2020, and references therein**).

Carbonate and sandstone clasts predominate in the studied samples. The most expressed difference between the fraction > 5 mm and finer fraction of the bulk gravel sample is the amount of silicate clasts of quartz(ites) and cherts, which are far more abundant in finer fractions, similar to the samples analysed by **Crnković and Bušić (1970)**. Similar distribution has been observed for the diabase clasts (**Table IV, Figure 5**). Such modal distribution points to the two possible reasons: either these smaller clasts were transported from more distant source rocks, or they were eroded from older rocks in the wider area. Amount of clasts with sharp edges within this lithological group is very high, therefore the long transport is not likely, and extraction from older clastic rocks, not very far from the depositional basin, seems more probable. Shape of carbonate clasts is dominantly discoidal, but shape charts for grey micritic limestones and dark-grey calcarenites (**Figure 7**) leave the possibility of existence of more than one source area, or different transport mechanisms. Distribution of green and red clastic rocks (microbreccias, sandstones and siltstones) display rather scattered shape data (**Figure 8**), which depends on lithological varieties within this category. Nevertheless, it is interesting that green clastites are more common in the finer fraction, while red-coloured clastic rocks are more abundant in the coarser fraction, when counted in the bulk sample (**Table IV**). The explanation can be like in quartz, chert and diabase clasts. It is possible that red clasts originate from a source area closer to the depositional basin, or green sandstones passed through more than one cycle of redeposition.

Carbonate clasts rarely comprise cross sections of macrofossils, which can hardly be determined. In some pebbles foraminiferal remnants are visible, and they will be further studied to determine the age of source rocks. Axial sections of diploporacean dasyclad algae can be recognized in several grey limestone pebbles (e.g., **Figure 5b**), pointing to the middle Triassic age. Coralline algae are visible in some bioclastic limestone pebbles (**Figure 5c**). The most probable age of these clasts is the Middle Miocene (Badenian). Red sandstones, particularly those with micas, are the typical lithotype of the Early Triassic. Green sandstones seem to be the product of weathering of diabases, which point to the Upper Jurassic to earliest Cretaceous melange on the Medvednica Mt. Scarce *pietra verde* clasts could have also been derived from the northern slopes of the Medvednica Mt. A more detailed study of clasts is necessary for further discussions and conclusions.

4.2. Morphometric features and transport mechanisms

Shapes calculated from three pebble axes by **Zingg (1935)** method exhibit some interesting patterns (**Figures 12-21**). In some cases they are influenced by rock textures (e.g., lamination in sandstones, character of lithoclasts in breccias/conglomerates), but in many cases they reflect the principal mode of transport. Discoidal shape seems to prevail in all sedimentary rocks categories. Among the most common white and grey limestones (**Figures 12, 13** and **14**), distribution of blade and rod shapes seem similar, while some differences appear in percentage of rod-shaped clasts. Spheroidal clasts occur in much larger numbers in the gross sample, than in selected coarse fraction (**Figure 14b**). The Zingg diagram of sandstones is much more dispersed (**Figure 16**), due to the various lithological subcategories included in this group. In coarse fraction (>32 mm) of the fractioned material almost all shapes are equally abundant, except blades (**Figure 17a**), while in the gross sample discoidal and rod-shaped clasts prevail (**Figure 17b**), which might simply be the result of separation processes. In fractioned coarse material almost all shapes of red sandstones are equally represented, except blades (**Figure 19a**), while in the gross sample discoidal and rod-shaped clasts dominate (**Figure 19b**), which is very different pattern than in green sandstone group. The difference between the fractioned and bulk sample, can be again explained by separation processes, during which blade- and rod-shaped clasts are partly crushed. The flatness ratio for the most abundant pebbles of sedimentary rocks, sandstones and carbonates (1.9, **Table VIII**) points to the fluvio-glacial transport (**Table III**) (**Cailleux, 1952** and **Müller, 1967**, from **Barudžija et al., 2020)**. Other lithological categories also fit into glacial/periglacial transport patterns, e.g., coarse-grained clasts (breccias, conglomerates), with flatness 1.7 (**Table VIII**) can be also the product of fluvio-glacial transport. Flatness result for quartz/quartzite grains of 1.6 fits into the ground moraine category (**Tables III** and **VIII**). Diabases have the highest value of 2.1, which can relate to a frost river (**Tables III** and **VIII**). Final touch in formation of these gravels might relate to a paleo-lake formed in this area after the melting of ice at the end of the Ice age. Further research will be focused on main transport modes and routes, taking into the consideration the different weathering rates for various clast categories.

5. Conclusions

- Gravels exploited from the gravel pits "Abesinija" and "Trstenik" in the Sava River flood-plain are polymictic and composed of dominantly carbonate pebbles, with rather common sandstones and less abundant quartz, quartzite, chert, diabase and coarse-grained clastic rocks.
- Carbonate and sandstone pebbles are dominantly discoidal in shape, with well-rounded surfaces. Quartz(ite) and chert clasts are often sharp-edged and much more abundant in smaller than in coarser fractions, as well as the semi-angular diabase clasts.
- Clast sizes indicate a normal distribution, while their shape and flatness ratio point to the important role of fluvio-glacial processes in their formation.
- The first results indicate the Medvednica Mt. as the possible important source area, and further research will be focused to reveal the source rocks and their transport routes.

6. References

Barudžija, U., Velić, J., Malvić, T., Trenc, N. and Matovinović-Božinović, N. (2020): Morphometric Characteristics, Shapes and Provenance of Holocene Pebbles from the Sava River Gravels (Zagreb, Croatia). Geosciences 2020, 10, 92; doi:10.3390/geosciences10030092

Basch, O. (1983a): Osnovna geološka karta SFRJ (*Basic Geological Map of SFR Yugoslavia*), 1:100000, Ivanić-Grad sheet, L33-81; Federal Geol. Institute: Belgrade, Serbia, 1983.

Basch, O. (1983b): Osnovna geološka karta SFRJ (*Basic Geological Map of SFR Yugoslavia*) 1:100000, Explanatory notes for sheet Ivanić-Grad, L33-81; Federal Geol. Institute: Belgrade, Serbia, 1983; pp. 66. (*in Croatian*)

Cailleux, A. (1952): Morphoskopische Analyse der Geschiebe und Sandkörner und Ihre Bedeutung für die Paläoklimatologie. Acta Diabetol., 40, 11–19.

Crnković, B. and Bušić, M. (1970): Mineraloško-petrografski sastav nanosa rijeke Save (*Mineralogical-petrological composition of the Sava River sediment*). Proceedings of 30th anniversary of the RGN Faculty (1939–1969*)*, Zagreb, Croatia, pp. 133–140. (*in Croatian*)

Malvić, T. and Medunić, G. (2015): Statistika u geologiji (*Statistics in Geology*), Sveučilište u Zagrebu, Rudarsko-geološko-naftni fakultet, Prirodoslovno-matematički fakultet, 88+VI str. (*in Croatian*)

Marić, L., Bogojević, D. and Majer, V. (1954): Petrografski spektar vučenog nanosa u koritu rijeke Save (*Petrographic spectrum of dragged sediment in the Sava riverbed*). Građevinar, VI/6, 201/5. (*in Croatian*)

Müller, G. (1967): Methods in Sedimentary Petrology. Schweizerbart: Stuttgart, Germany, 283 p.

Šimunić, A., and Basch, O. (1975): Stratigrafija kvartarnih sedimenata Zagrebačkog Posavlja (*The stratigraphy of Quaternary sediments in the Zagrebačko Posavlje – in Croatian with French summary*). Geološki vjesnik, 28, 153–164.

Velić, J. and Saftić, T. (1996): Dubinskogeološki odnosi područja smetlišta "Jakuševec"–čimbenik sanacije (*Deep geological relations of the "Jakuševec" Waste Depository area – remediation factor*). ZGO Gospodarenje otpadom IVth International symposium, Zagreb, 197-205. (*in Croatian*)

Velić, J., Saftić, B. and Malvić, T. (1999): Lithologic Composition and Stratigraphy of Quaternary Sediments in the Area of the "Jakuševec" Waste Depository (Zagreb, Northern Croatia). Geologia Croatica, 52, 2, 119-130.

Zingg, Th. (1935): Beiträge zur Schotteranalyse. Min. Petrog. Mitt. Schweiz., 15, 39-140.

Internet sources:

URL 1: d-maps.com
URL 2: McLeod, S. A. (2019): Introduction to the normal distribution (bell curve). Simply psychology: https://www.simplypsychology.org/normal-distribution.html

SAŽETAK

Modalni sastav i morfometrijske značajke šljunka iz eksploatacijskog polja „Abesinija" (Otok Svibovski; JI od Zagreba, Hrvatska)

Šljunci koji se eksploatiraju u šljunčarama na širem području Trstenika u poplavnoj ravnici rijeke Save jugoistočno od Zagreba, već su na prvi pogled šaroliki i različitoga litološkog sastava. Ukupno je proučen 1399 klast iz prirodnog (nesortiranog) uzorka i 302 klasta iz krupne prosijane frakcije, veće od 32 mm. Mjerene su najduža (x), srednja (y) i najkraća (z) os, valutice su sortirane po litotipovima te je proučen njihov oblik i stupanj zaobljenosti. Numeričke analize načinjene su uz pomoć Microsoft Excel programa, a primijenjene su i Zinggove analize oblika klasta te izračuni plosnatosti. Šljunci su polimiktni i sastoje se od valutica/klasta sedimentnih (karbonatne stijene, pješčenjaci, breče i konglomerati), eruptivnih (dijabazi), piroklastičnih (tufovi) i metamorfnih (kvarciti) stijena, a dobro su zastupljena i kvarcna zrna te rožnjaci. Veličina mjerenih klasta po dužoj osi varira između 6,8 i 110,25 mm, a klasti pokazuju normalnu distribuciju. Dominiraju dobro zaobljene, diskoidalne karbonatne valutice. U nekima od njih vidljivi su presjeci zelenih i crvenih algi i makrofosila. Sljedeću najbrojniju litološku skupinu čine pješčenjaci različitih boja (zeleni, crveni, sivi, smeđi i žućkasti). Krupnozrnasti klastiti i dijabazi slabije su zaobljeni, dok su zrna kvarca i klasti kvarcita i rožnjaka često uglati i češći su u sitnijoj frakciji, nego među krupnijim šljuncima. Modalni sastav, veličina i oblik klasta upućuju na razmjerno kratak transport, vjerojatno s padina Medvednice, kombinacijom glacijalnih, fluvijalnih i lakustričkih procesa.

Ključne riječi: šljunci, litologija, morfometrija, rijeka Sava, Hrvatska

Acknowledgment

Authors are grateful to the University Support „Mathematical methods in geology V“ (leader: Tomislav Malvić) and University Support 107-F19-00005 (leader: Alan Moro) for their financial support in field work and analyses.

Author's contribution

Jasenka Sremac (1) (Dr.sc., Full Professor, geology, palaeontology, palaeoenvironment) provided the field work, palaeontological analyses, palaeoenvironmental interpretations and presentation of the results. **Josipa Velić (2)** (Dr.sc., Professor Emerita, Quaternary geology, petroleum geology, geomathematics) provided the field work, analyses of statistics results, geological settings and comparison and interpretation with the surrounding Quaternary deposits. **Marija Bošnjak (3)** (Dr.sc., senior curator, palaeontology, geomathematics) provided the field work, numerical analyses and methodological data. **Ivo Velić (4)** (Dr.sc., Meritorious Scientist, geology, stratigraphy) participated in field work, collected and determined Mesozoic microfossils from pebbles. **Tomislav Malvić (5)** (Dr.sc., Full Professor, geology, geomathematics) contributed with geomathematical methods and presentation of results. **Daniel Fotović (6)** (mining engineer), contributed with field work and provided relevant analytical data on exploited gravels for comparison. **Renato Drempetić (7)** (electrotechnics engineer), contributed with field work, field- and macrophotography, measuring pebbles from bulk sample and preparation of computer tables and graphics.