GEOL. CROAT.	47/2	167 - 179	3 Figs.	1 Tab.	2 Pls.	ZAGREB 1994

The Detrital Versus Authigenic Origin and Provenance of Mineral Particles in Mesozoic Carbonates of Central Croatian Karst Area

Marta **CRNJAKOVIĆ**

Key words: Insoluble residue, Carbonate rocks, Authigenic minerals, Detrital minerals, Karst, Croatia

Abstract

In 1911, Tućan studied the insoluble residue of limestones and dolomites from the Croatian karst realm, and compared it to the composition of terra rossa and bauxite. He concluded that the insoluble residue represented the source material for terra rossa and bauxite, and that these materials in carbonates are authigenic in origin. The provenance study of non-carbonate minerals and other particles based on TUĆAN's (1911) analytical material, stored in Croatian Natural History museum in Zagreb, suggests that they are partly detrital, and partly authigenic in origin.

1. INTRODUCTION

The provenance and character of the parent material for the origin of karst bauxites and terra rossa have been discussed for many years and still deserves scientific interest. The origin and composition of the parent material for bauxite has been considered by VALETON (1972) as one of the five questions in the field of study of karst bauxites, that await solution. It is generally thought that provenance may vary depending on local conditions, and may include both detrital and residual material (VALETON, 1972; BARDOSSY, 1982). For terra rossa it is thought to be partly residual, and largely aeolian in origin (ESTEBAN & KLAPPA, 1983). However, there are few data on the associations and provenance of minerals and other grains occurring in carbonates, from which non-carbonate material would have been released.

Studies of thick Dinaric carbonate successions may be relevant to the discussion on the origin and fate of insoluble residue in platform carbonates. Eighty years ago TUĆAN (1911) additionally studied the insoluble residue of 185 samples of predominantly platform carbonates, derived from the Croatian outer Dinaric karst realm (Fig. 1), spanning the ages from the late Palaeozoic to the Tertiary, and compared the results to the composition of terra rossa and bauxite. He concluded that (1) the source material for terra rossa and bauxite represented the insoluble residue of carbonate sediments, and that (2) the noncarbonate components in carbonate rocks were authigenic in origin. Furthermore, TUĆAN (1911, 1912), and KIŠPATIĆ (1912) stated that (A) Al-oxides and Al-hydroxides are the dominant mineral components in terra rossa and bauxite, originating from "clayey material" which was found by them to represent the dominant non-carbonate component of the insoluble residue of carbonates, and (B) numerous non-carbonate mineral species found in carbonates (TUĆAN, 1911) are identical to those occurring in terra rossa and bauxite, suggesting their concentration following the dissolution of carbonates. At this time the topic was amply discussed by well known geologists. Some of them presented similar opinion (e.g. Zippe, Lipold, Tietze, Neumayr, Fuchs, Taramelli, Graf zu Leiningen), while others opposed the theory (Stache, Kramer, Walther) fide TUĆAN (1911). However, TUĆAN (1911, 1912), and KIŠPATIĆ (1912) were the first to provide abundant analytical data to support their conclusions.

Later works, dealing with heavy minerals from several horizons within thick Dinaric platform carbonates and interstratified bauxites, suggested that the heavy mineral association is mostly detrital in origin (ŠUŠNJARA & ŠĆAVNIČAR, 1977, 1978). The parent material for bauxites may have been negligibly to predominantly influenced by carbonate-derived material, according to various conditions and authors (ŠINKOVEC, 1970; ŠUŠNJARA & ŠĆAVNIČAR, 1978; MARIĆ, 1965; ŠUŠNJARA et al., 1990).

The purpose of this work is to present results of a provenance study of non-carbonate minerals and other grains in Dinaric carbonate rocks, based on TUĆAN's (1911) analytical material. The character of these grains suggests that they are partly detrital, and partly authigenic in origin. As the geological literature appears to contain scarce data on this aspect of the composition of "pure" shallow-water carbonates, a large amount of samples from carbonates of different ages may provide information about the overall character of the insoluble residue of shallow-marine carbonates. The data presented may be relevant to the understanding of the provenance of parent material for bauxite and terra rossa in the Dinaric realm.

Croatian Natural History Museum, Demetrova 1, 41000 Zagreb, Croatia.

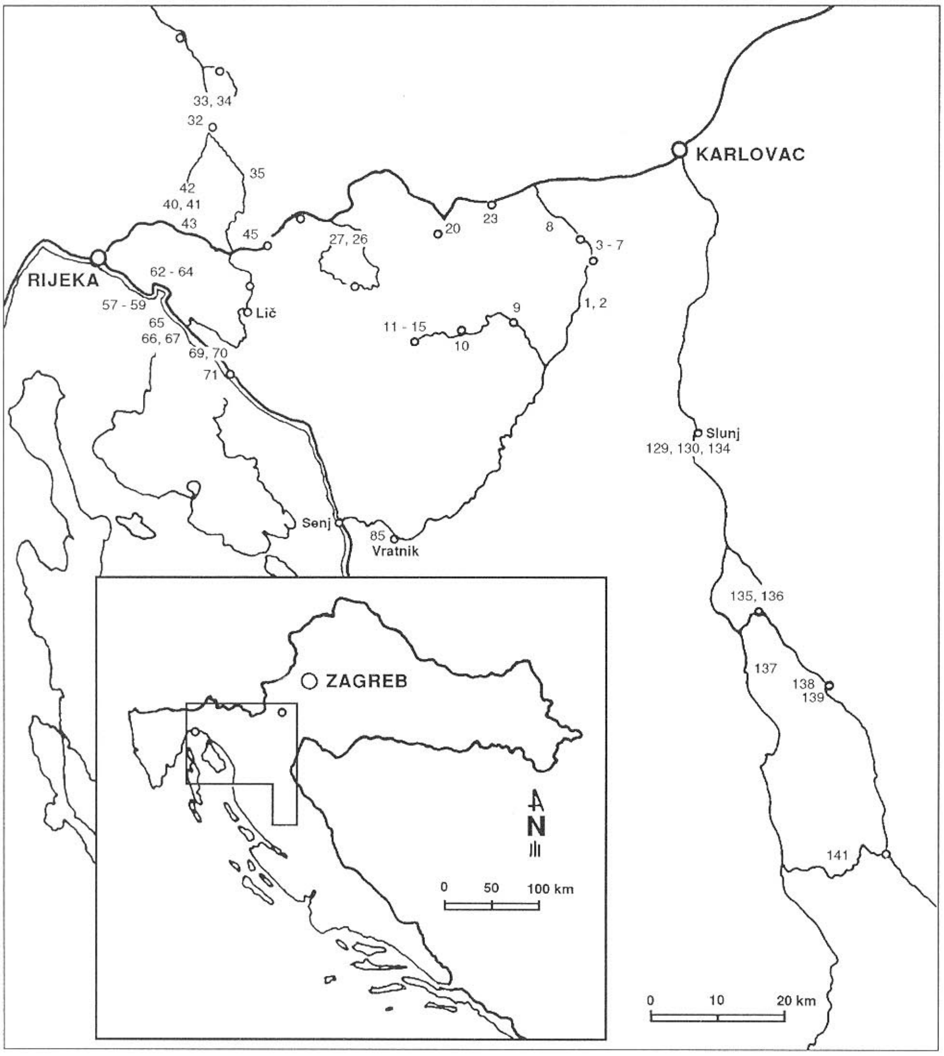


Fig. 1. Location map with geographical position of analysed samples.

2. ANALYTICAL MATERIAL AND METHODS

TUĆAN's (1911) original analytical material is stored in the collections of the Croatian Natural History Museum in Zagreb. It contains 72 microscopic slides of insoluble residue of limestones and dolostones (collection numbers -600: ZAG; 1 MP2 to 600: ZAG; 72 MP2). The slides represent a portion of the original 185 slides studied by TUĆAN (1911). The samples derive predominantly from platform carbonate sequences ranging in age from the Late Palaeozoic to the Tertiary, cropping out in Dinaric karst areas of Gorski Kotar, Lika and Hrvatsko primorje (Fig. 1). Tućan dissolved samples "in dilute hydrochloric acid". Besides mineral grains the residues contain rock particles, fish teeth, and "clayey material". "Clayey material" is a term used by TUĆAN (1911) for flaky material, whose composition is not identifiable microscopically. The grains were of fine sand to silt size, and were studied using standard optical methods.

3. MINERAL GRAINS AND OTHER PARTICLES

Quantitative data related to mineral grains and other particles occurring in insoluble residues of 51 samples are shown in Table 1, which contains all identifiable grains (i.e. grains larger than about 0.01 mm).

3.1. QUARTZ

Description. Quartz occurs in 88% of the slides, and in many of them it is the most common constituent. Quartz grains are either anhedral (72%), or euhedral to hypidiomorphic (55%).

Anhedral quartz is mostly of silt size, but some grains exceptionally may reach 1.02 mm. Most grains are irregular, subangular to slightly rounded. Sharp ended "shards" resembling pyroclastic quartz occur in a few slides. Quartz grains may be inclusion-free except for a few fluid, dark "dusty" or mineral inclusions. The later may be rutile, or other, mostly acicular minerals. Two slides (No. 112 and 130) show irregular quartz grains, crowded with inclusions of carbonate mineral (calcite or dolomite).

Euhedral quartz crystals vary from 0.005 to 0.3 mm in length, and most of them are less than 0.05 mm (Fig. 2). Measurement of 280 crystals (about 20 in each of 14 slides) shows that the elongation (length/width ratio) may vary from 1 to 5 (Pl. I, Figs. 1, 2, 3, 4, 6 and 7), but short prismatic forms with elongation less than 3 are most common (Pl. I, Figs. 1, 2 and 7; Text Fig. 2).

Most crystals are single, prismatic, and doubly-terminated (Pl. II, Fig. 3). In two slides prismatic crystals are observed to form aggregate of two or more individuals. Most crystals are very regular and sharply angular, commonly showing a slight rounding of their corners. Occasionally, crystals have a "zigzag" outline (Pl. I, Fig. 8). In four slides small crystals appear consisting of doubly-terminated hexagonal bipyramids, either lacking prism faces, or very narrowly developed face, and "pseudocubic" crystals consisting of one rombohedron only (Pl. I, Figs. 3 and 7). TUĆAN (1911) noted this type of crystals in 11 of his 185 slides. One slide contained very irregular authigenic quartz grains crowded with inclusions of carbonate minerals as commonly shown by most euhedral quartz grains. Inclusions may be either scattered (Pl. I, Figs. 1, 3, 6 and 7), concentrated in the core (Pl. I, Figs. 2 and 5), zoned (Pl. I, Fig. 4), or fill the entire grain except for a thin margin (Pl. I, Figs. 3, 6 and 7). Inclusions of pyrite and haematite (Pl. I, Fig. 1), or gypsum and anhydrite, are less common.

In some slides (No. 12, 13, 14, 62 and 137), detrital grains are overgrown by secondary quartz forming a regenerated quartz crystal. In one of these slides (No. 14) only the regenerated part contains inclusions of carbonate mineral.

TUĆAN (1911) described "sphaerocrystal aggregate" in four slides and he supposed that they are chalcedonic. Some of them showed a transition to quartz toward the edges. In the present study chalcedony was observed in only a few slides (No. 26, 68, 127, 133 and 144) and in Table 1 it is counted with authigenic quartz. Several slides contain fine-grained quartz aggregates, that mostly show very irregular forms.

Interpretation. *Anhedral* grains (some of them slightly rounded), and the grains with liquid, gaseous, and dark dusty inclusions of acicular minerals are detrital. Some of them originated from older sediments, and others were probably derived from pyroclastic rocks. In contrast to TUĆAN's (1911) general conclusion about the authigenic origin of all non-carbonate constituents, Table 1 shows that detrital quartz appears in almost all slides, and in some of them, may be predominant.

Euhedral quartz crystals, almost without exception contain inclusions of the host rock minerals (calcite or dolomite), and less common iron-oxide, gypsum and anhydrite, growing in situ. Chalcedony sphaerulites, lacking traces of mechanical abrasion, are also authigenic.

Authigenic quartz in sediments is mostly of late-diagenetic origin (FÜCHTBAUER, 1974), but bipyramidal grains, common in anhydrite, halite, and carbonate rocks, may also form during early diagenetic processes (GRIMM, 1964). Short-prismatic, euhedral crystals with elongation less than 5 - the most common type in TUĆAN's (1911) material (Fig. 2), are considered to indicate the influence of saline solutions (GRIMM, 1962, 1964; ADAMS, 1971). "Pseudocubic" crystals consisting of only one rombohedron, similar to those shown in Pl. I, Fig. 7, formed first. Afterwards, crystals

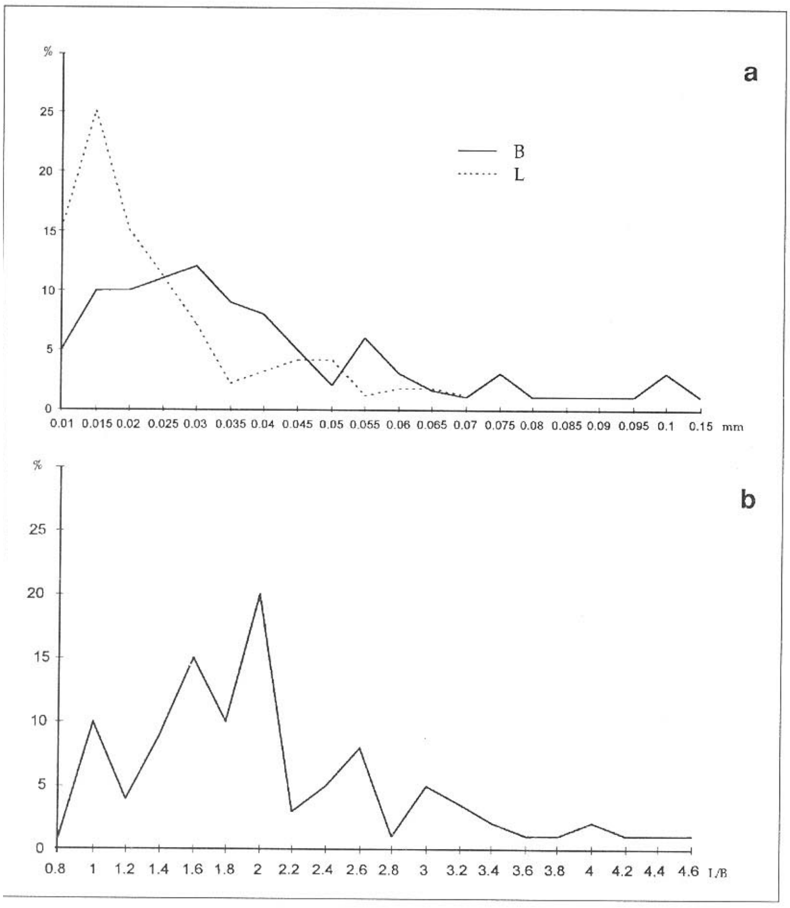


Fig. 2: Morphological features of authigenic quartz (based on measuring of 200 grains). a) Frequency distribution of length (L) and breadth (B) measurments; b) Frequency distribution of length/breadth (L)/(B) ratios.

Locality	Rp/Mg=100% Rp	Mg	Mineral grains (detrital/authigenic)=100% Hem.	Py.	Anh.	Gy.	Flu.	Brk.	Glkn	Ant	Ti.	Q	Ms.	Tu.	Zr.	Ru.	Fel.	Ep.g.	Am.	Chl.	Co.	Gr.	Ap.	Sp.	Oth.
1. Gen. Stol L.	5/0	95	0/1		0/2	0/1						36/4	49/0	+/+	1/+	+/+	1/0	1/0		5/0	+/0	+/0			
2. Gen. Stol D.	0/11	89		0/55			0/2					28/5	7/0	2/0			1/0								
4. Top. Lešće L.	7/51	42	0/76									2/1	20/0	+/0											
5. Top. Lešće L.	2/0	98	0/90									4/0	4/0	1/0											
6. Top. Lešće L.	0/99	1	0/34			0/51		0/2					11/0	1/0	1/0										
7. Top. Lešće D.	0/88	12	0/26		0/1	0/44						3/0	26/0	0/1											
8. Bosiljevo D.	7/0	93	0/4			0/7		0/2				69/10	5/0	+/+	1/0	1/0	1/0								
9. Ogulin L.	11/0	89	0/26	0/1	0/1	0/1						11/56	1/0	0/1			0/1							+/0	
10. Musul. pot. D..	5/0	95	0/10	0/10				0/2				20/5	3/0			1/0	43/3		1/0	2/0					
11. Klek D.	0/9	81	0/16		0/35							4/43	2/0	+/+											
12. vrh Kleka L.		100	0/1									0/98				1/+									
13. vrh Kleka L.	0/1	99	0/6		0/1			0/1				0/92		+/+											
14. vrh Kleka L.	5/6	89	0/6			0/21		0/1				6/31					21/13								
15 Klek L.	0/67	33	0/1	0/11	0/1			2/1			0/+	40/5	18/0	2/0	2/0		6/+	+/0	6/0	1/0	+/0		3/0		
20. Severin Stubica L.	0/44	56				0/2						0/98													
23. Stubica Vrbovsko L.	1/32	67	0/65			0/3	0/3			0/1		9/5	14/0	+/0											
26. Kupjak Ravna g. D.	+/82	18	0/48				0/10	0/3				+/0	33/0	2/1			1/2								
27. Zalesina D.	6/0	94	0/5								0/2	1/0	89/+	+/0		1/0	1/0						1/0		
32. izv. Gerovčice L.	8/0	92	0/21	0/12		0/35			0/1			11/0	15/0	2/0		+/0				2/0					
33. Kupari L.	1/3	96	0/8	0/76								10/2	1/0	+/0		1/0	1/0			1/0					
34. Kupari D.	0/85	15	0/83						0/1		1/2		12/0	+/+						1/0					
35. izvor Kupe L.	0/34	66			0/96							+/0	2/0	1/0	+/0			+/0							
40. Šegine D.- L.	6/0	94	0/23	0/3	0/20							13/24	16/0	+/0				+/0				+/0			
41. Lazac - Risnjak L.		100	0/8			0/+	0/+					0/91	1/0			+/0									
42. Risnjak /vrh/ L.	62/0	38	0/2					2/0				3/2	85/+	3/0	2/0	2/0									
43. Jelenje L.	0/9	81		0/57		0/2				0/+		0/21	20/+												
45. Lokve D.	37/0	63						0/+				9/2		+/0	2/0	+/0	87/0								
48. Lič - Fuž ine D. - L.	41/0	59	0/35	0/3				0/+					59/0	2/0	+/0										
57. Srščica L.	4/0	96	0/49		0/35			0/2					12/+	1/0	+/0										
58. Bakar L.		100		0/55								0/43	2/0												
59. Bakar - Bakarac L.	+/0	100	0/31		0/32			0/+					35/0												
61. Bakar - Bakarac L.	24/0	76			0/49							9/0	33/+	4/0		2/0				2/0					
62. Krasica L.	37/0	63	0/6	0/4				0/+		0/+		5/65	2/0				16/0								
63. Meja calc. -D.	0/23	77	0/88		0/3			0/+					6/0	3/0		+/0						1/0	+/0		
64. Hreljin L.	0/20	80	0/57		0/27							1/0	12/0				1/0								
65. Kraljevica L.	0/3	97		0/93				0/1				1/0	4/0	+/0	+/0					1/0					
66. Is. Sv. Marko L.	3/0	97		0/94					0/+			3/0	1/0							1/0		1/0			f.t.
67. Is. Sv. Marko L.	0/27	73		0/62					0/8			14/3	8/0		1/0	1/0	3/0								
68. Šmrika L.	0/11	89	0/18	0/21	0/57								3/0												
70. Sv. Jelena L.	0/99	1	0/89	0/5	0/1																				
71. Crikvenica L.		100		0/5	0/70		0/2	0/3				6/0	6/0	3/0	3/0	2/0	+/0								
85. Vratnik D.	8/0	92	0/33				0/1	0/+				9/0	51/0	1/0	1/0	+/0	1/0		+/0	+/0	2/0				
112. Mrkvište D.	0/86	14	0/36					0/1				11/44	6/0	0/+		+/0				1/0	1/0				
129. Popovac g. D.	0/+	99	0/44					0/1				3/0	42/1	+/4						5/0					
130. Popovac g. D.	2/0	98	0/39					0/1				8/48	3/0	+/0	+/0	+/0	1/0	+/0							
134. izv. Slunjčice D.	0/34	66	0/59	0/17			0/1					7/0	13/0	0/1							1/0		2/0		
135. Petrovo selo L.	0/70	30	0/14	0/3			0/1	0/1			0/1	27/5	23/0	2/+	+/0	1/1	10/4	2/0		5/0					
137. Baljevac D.	0/44	56		0/41		0/32		0/+				17/7	2/0	0/+	+/0	+/0				1/0					
138. Zavalje - D.Lapac L.	32/0	68	0/2					+/0				28/0	42/0	1/0		1/0	10/1		1/0	9/0				Bt.	
139. Zavalje - D.Lapac L.	0/86	14	0/18					+/0		0/1		13/3	34/0	1/0	1/0	1/0	16/10		1/0	1/0	1/0				
141. vrh Ozeblina D.	0/75	25	0/76		0/12		0/1					1/0	5/0			1/0	0/1			3/0					

with two equally developed rombohedrons, with or without very narrow prism faces, may form (GRIMM, 1962). Similar crystal types in TUĆAN's (1911) slides (Pl. I, Fig. 3) might therefore result from the short-term influence of saline solutions during crystallisation. Crystals with rounded edges, and those shoving zig-zag outlines (Pl. I, Fig. 8) could result from dissolution after the supply of electrolites ceased (GRIMM, 1962). Irregular shapes of quartz aggregates possibly reflect the shapes of former intersticies in a carbonate rock.

3.2. TOURMALINE

Description. Tourmaline is present in most slides, but is very sparsely represented (Table 1, Fig. 3). Most grains are short prismatic, hypidiomorphic, and more or less rounded. Grain size varies from 0.095x0.09 mm, to 0.14x0.13 mm. Broken grains are common, with sharp (Pl. II, Fig. 5), or rounded margins. Tourmaline displays a great variety of colors, and light green, blue green, or yellowish grains prevail. Dark green and brown grains with dark dusty inclusions also occur.

Some rounded or irregular pleochroic grains have a very light green, or almost colourless authigenic rim (noticed also by TUĆAN, 1911), or small colourless prismatic overgrowths (Pl. II, Fig. 4). Euhedral crystals (most frequently mentioned by TUĆAN, 1911), are extremly small (0.045x0.025 to 0.07x0.03 mm), but some of them also show at least slightly rounded margins. One slide (No. 129), shows extremly elongated, colourless tourmaline crystals, some with forked ends, not described from these sediments.

Interpretation. Most tourmaline grains are more or less mechanically abraded, that is they are detrital. Dark coloured varieties, and brown grains with dark inclusions were derived from low-grade metamorphic rocks (TRÖGER, 1967). Well rounded grains are probably recycled from older sediments, and small unworn tourmaline euhedra might be of pyroclastic origin. Colourless, needle-like tourmaline, lacking signs of mechanical abrasion are authigenic. Similar authigenic tourmaline crystals in carbonate rocks have been described by VALETON (1955) and FÜCHTBAUER (1974). Minute tourmaline euhedra may also be authigenic, but dark coloured, and slightly rounded grains are possibly detrital, likely transported by wind.

3.3. HAEMATITE AND PYRITE

Haematite appears in most slides, and can constitute as much as 90% of the mineral grains (Table 1, Fig. 3). As TUĆAN (1911) already noted, haematite appears as globular grains about 0.025 mm in diameter, cubic forms (0.015 mm), or platy grains with hexagonal outline (0.012 mm). The similarity in form and size of most haematite and pyrite grains suggests alteration of pyrite.

Pyrite occurs as cubes (Pl. II, Fig. 1), botryoidal grains, or irregular masses of minute crystals. Many grains are partly altered to haematite or limonite. As TUĆAN (1911) stated, the entire pyrite population is probably authigenic.

3.4. ANHYDRITE AND GYPSUM

Most anhydrite grains are curved and bent fibrous agregates (0.04x0.01 mm to 0.08x0.02 mm), bladed crystals being rare. Anhydrite and gypsum may appear in the same slide.

Gypsum is usually represented by minute euhedral crystals (0.02x0.01 mm to 0.03x0.02 mm), some of them twinned. Somewhat larger grains may explain irregular, probably anhydrite core. As TUĆAN (1911) already concluded, both minerals are authigenic.

3.5. THE MICA GROUP

Description. In TUĆAN's (1911) material, muscovite is the most common mica, appearing in almost 90% of examined slides (Table 1; Fig. 3). Biotite grains are rare, TUĆAN (1911) additionally reported phlogopite.

Larger muscovite flakes (0.13 mm to 0.15 mm) are irregular and sharp-ended, but in some slides (No. 35, 38, 57 and 137), well-rounded flakes have been observed. Only occasionally, "dusty" material and acicular inclusions of rutile and zircon are present.

In a few slides (TUĆAN, 1911, reported two slides, which were lost), very regular six-sided muscovite has been observed.

Interpretation. In most slides muscovite displays features indicating a detrital origin: (irregular, or well rounded platelets). It is also the most common, although not the most abundant detrital mineral (Fig. 3; Table 1). Only regular six-sided muscovite platelets may be authigenic. Similar pictures of muscovite have been considered by TOPKAYA (1950) (fide FÜCHTBAUER, 1974) to represent "presumed" authigenic muscovite.

3.6. ZIRCON

Description. Zircon has been observed in one third of the slides although the number of grains are very small. Most grains are short, prismatic, and more or less rounded (0.024x0.01 mm to 0.07x0.01 mm). Some

Table 1: Content of minerals and rock particles in insoluble residue of limestones (L) and dolomites (D) from TUĆAN's (1911) slides. Locations of samples (after TUĆAN, 1911) in Fig. 1. Legend: L - limestone; D - dolomite; Rp - rock particles (d/a - detrital/authigenic); Mg - mineral grains (d/a - detrital/authigenic); Hem - haematite; Py - pyrite; Anh - anhydrite; Gy - gypsum; Flu - fluorite; Brk - brookite; Glkn - glauconite; Ant - anatase; Ti - titanite; Q - quartz; Ms - muscovite; Tu - tourmaline; Zr - zircon; Ru - rutile; Fel - feldspars; Ep.g. - epidote group; Am - amphibole; Chl - chlorite; Co - corundum; Gr - garnet; Ap - apatite; Sp - spinel; Oth - others; f.t. - fish teeth; Bt - biotite; ± traces (less than 1%).

grains display a very uneven, pitted surface. Broken grains with rounded, broken ends, as well as perfectly rounded grains, also occur (Pl. II, Fig. 3). Euhedral crystals, or only very slightly abraded grains (0.025x0.015 mm to 0.11x0.03 mm), appear in 10% of the slides (Pl. II, Fig. 2). Long-prismatic crystals, also showing slightly rounded edges have been observed in only one slide (No. 15). Some grains are zoned (noticed also by TUĆAN, 1911). Most minute zircon grains are colourless, and in some slides hypidiomorphic, somewhat rounded grains were yellowish or light brown.

Interpretation. Almost all zircon grains are pretty well rounded, and even very small crystals show some degree of rounding. Therefore zircon is considered as entirely a detrital mineral.

3.7. RUTILE

Description. Rutile appears in 41% of the slides, and is represented by partly to very well rounded grains, and short, broken, rounded or sharp-ended prisms. Rare knee-shaped twins also occur. Most rutile grains are very small (0.05x0.025 mm), and only the smallest grains are very regular euhedral crystals (8% of slides).

Interpretation. Based on morphology, most rutile grains are detrital, and have likely been derived from older sediments for the most part, or from metamorphic rocks. Only the smallest euhedra may be of authigenic origin.

3.8. BROOKITE

Description. Brookite appears in 47% of the slides but only as a few grains in each. TUĆAN (1911) did not mentioned brookite. Most grains are irregular, angular, or slightly rounded (0.04x0.019 mm to 0.07x0.04 mm). Only one hypidiomorphic bladed grain has been observed.

Interpretation. According to TRÖGER (1967) brookite in sediments is likely authigenic for the most part, and the same is probably true for TUĆAN's material. Some rounded grains might be detrital in origin.

3.9. FELDSPARS

Description. Feldspar appears in 43% of the slides (Fig. 3), but the content is very low, exept for two slides (No. 45 and 10; Table 1). Most grains are of the plagioclase group, exhibiting some degree of rounding, and varying degrees of alteration. Additionally, few fresh microcline grains have been observed, and TUĆAN (1911) also found orthoclase. Most feldspar grains are irregular, a few grains are slightly rounded, or hypidiomorphic, varying in size from 0.03x0.03 mm to 0.1x0.09 mm. Most feldspars have a dusty appearance due to alteration. Clear hypidiomorphic grains, (0.052x0.033 mm) sometimes exibiting a small altered (probably detrital core), are rare. In slide No. 45 (Table 1), where feldspars predominate, TUĆAN (1911) determined albite and andezine grains. In the same slide numerous lithic grains containing feldspar microphenocrysts occur. Similar, small plagioclases, but without lithic grains, occur in another slide (No. 10). One twin resembling the Roc Tourné type has been found in slide No. 41.

Interpretation. TUĆAN (1911) emphasized idiomorphic and hypidiomorphic unworn grains, as evidence of the authigenic formation of feldspars. Such grains are the least abundant in the preserved slides, and some of them are detrital showing secondary overgrowth. Only the twinned grain of the Roc Tourné type indicates any authigenic origin for the plagioclases in carbonate rocks (FÜCHTBAUER, 1948). Volcanic lithoclasts containing feldspar phenocrysts suggest a detrital origin for at least a part of plagioclase grains. Besides, TUĆAN (1911) reported the presence of a plagioclase group ranging in composition from albite to anorthite, while authigenic feldspars in sediments are nearly always pure alkaline members (VAN STRAATEN, 1948). Irregular limpid microcline grains are also probably detrital. Therefore feldspar grains in insoluble residues examined are predominantly detrital (Table 1; Fig. 3).

3.10. FLUORITE

Description. Fluorite is present as minute violet euhedra (up to 0.01 mm) in 18% of the slides. The crystals are cubic, or a combination of a cube and octahedron (Pl. II, Fig. 6). Somewhat larger grains are colourless and irregular.

Interpretation. As TUĆAN (1911) already stated, fluorite is of authigenic origin, and most probably of biogenic origin. This is suggested by fluorite found in the insoluble residue of a rudist shell (TUĆAN, 1911; No. 177), and by fluorine in phosphorites of Ervenik in Dalmatia, which is also of biogenic origin (TUĆAN, 1932, 1933). He has also cited works (ANDREE, 1909), which atribute fluorite in sediments to plant or animal remains.

3.11. OTHER MINERAL GRAINS

A series of minerals: chlorite, amphibole, garnet, minerals of the epidote group, corundum, kyanite, staurolite, apatite, titanite, chromite, glauconite, and anatase (TUĆAN, 1911, additionally stated - chloritoid, periclase, brucite, "kopite"), occurs in 1 to 33% of the slides but only as a few grains with the exception of chlorite, and glauconite grains (Table 1; Fig. 3). Except for one euhedral corundum grain, and a few hypidiomorphic garnets, all other minerals are irregular. Most of these grains originate from metamorphic source rocks, mafics or ultramafics (chromite), with the exception of glauconite, which may be authigenic.

3.12. ROCK PARTICLES

Description. Rock fragments are very scarce, which is understandable owing to their very small dimensions.

Most lithic grains are of the "microquartzite" type (0.04 mm to 0.07 mm), then schistose grains (0.096x0.024 mm to 0.43x0.14 mm), lithoclasts of phyllitic rocks consisting of quartz and some phyllosilicate minerals, chlorite schist fragments, and exceptional sericite-schist grains. In slide No. 45 (Table 1) volcanic rock fragments with plagioclase phenocrysts are abundant.

Interpretation. Rock particles obviously represent a detrital component. TUĆAN (1911) did not mention them but he did find "sericite aggregates", here interpreted as sericite shists. The presence of rock particles indicates not only the detrital character of these grains, but also supports the interpretation of the detrital character of an important portion of the mineral grains, that could have derived from subaerially exposed rocks.

3.13. FISH TEETH

Fish teeth have been observed in two of the slides.

4. DISCUSSION

4.1. DETRITAL VERSUS AUTHIGENIC ORIGIN OF PARTICLES STUDIED

The results presented above and summarized in Table 1 suggest a detrital origin for an important portion of the mineral and other non-carbonate grains. The mineral species can be segregated accoding to their authigenic versus detrital origin:

(1) A group of mineral species are exclusively authigenic in origin (Fig. 3). This group includes haematite, pyrite, anhydrite, gypsum, glauconite and fluorite.

(2) Quartz and tourmaline are partly authigenic and partly detrital.

(3) The third group includes feldspar, rutile, muscovite, and brookite. These are mostly detrital, but some of them are, or may be partly authigenic.

(4) The fourth group includes mineral species only represented by detrital grains; including zircon, chlorite, biotite, corundum, garnet, epidote group, amphibole, and chromite. Kyanite is found only in one sample (No. 153), which was probably taken from the Promina Beds (see TUĆAN, 1911), which are terrigeneous carbonate-clastics, and not platform carbonates as in all other samples, and it is therefore excluded from further discussion.

(5) Insoluble residues also contain rock particles that, besides being detrital themselves, suggest by default the possibility of a detrital origin for same of the mineral grains.

The results differ considerably from TUĆAN's (1911) opinion, on the authigenic origin of all mineral

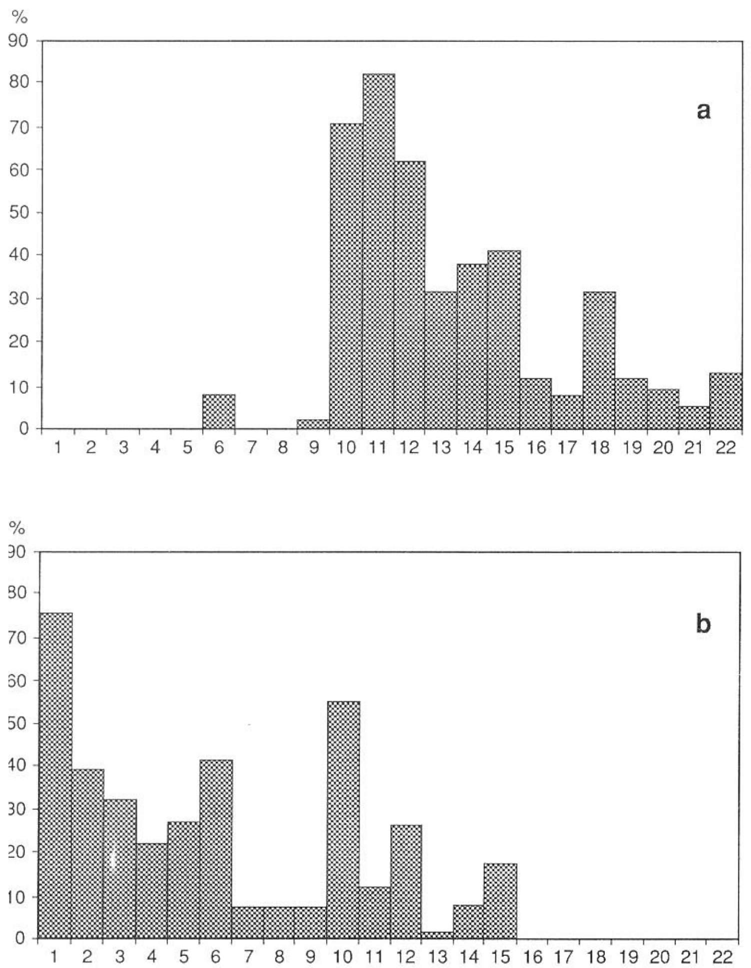


Fig. 3: The percent ratio of the number of slides containing a) detrital, and b) authigenic minerals (based on 51 slides). Legend: 1) Haematite; 2) Pyrite; 3) Anhydrite; 4) Gypsum; 5) Fluorite; 6) Brookite; 7) Glauconite; 8) Anatase; 9) Titanite; 10) Quartz; 11) Muscovite; 12) Tourmaline; 13) Zircon; 14) Rutile; 15) Feldspar; 16) Epidote group; 17) Amphibole; 18) Chlorite; 19) Corundum; 20) Garnet; 21) Apatite; 22) Chromite.

grains occurring in insoluble residues, despite the fact that the present work is based on the same, although not entire collection of analytical material. Besides, several mineral species and other grain types, not mentioned by TUĆAN (1911), have been identified in the present investigation: brookite, anatase, glauconite, chromite, rock particles and fish teeth (Table 1). Several minerals (e.g. staurolite and chloritoid) found by TUĆAN (1911) have not been identified during this work, but his original descriptions also suggest a detrital origin for these grains.

MARIĆ (1965) has already stated that all minerals reported by TUĆAN (1911) can not be of authigenic origin. He also reported detrital grains of various mineral species occcurring in three carbonate samples. Heavy mineral associations from several horizons of Late Cretaceous and Palaeogene carbonates in the coastal Dinaric karst realm have been inferred by ŠUŠNJARA & ŠĆAVNIČAR (1977, 1978) to be mostly detrital in character. The inference has been based on transparent heavy minerals. Data on insoluble residues presented here (Fig. 3) confirm that opinion. On the other hand, the rest of minerals studied suggest a different picture, which includes both authigenic and detrital grains (Table 1).

Another difference between TUĆAN's (1911) data, and the results presented here concerns the distribution of mineral species in samples. In contrast to TUĆAN's (1911) statement on the uniform distribution of all minerals in all carbonate rocks, his own slides show different distributions, as also seen in Table 1, and Fig. 3. Accordingly, TUĆAN's (1911) opinion, that the uniformity of mineral distribution suggests their authigenic origin, is not founded. On the contrary, the data presented here illustrates extremely contrasting compositions, and an important detrital component.

As TUĆAN's (1911) slides were sampled from various stratigraphic horizons within a large time-span ranging from the Palaeozoic to the Tertiary, they represent an "average" composition of the insoluble residue of limestones and dolomites of Dinaric, predominantly shallow-marine carbonates. If so, an important quantity of detrital mineral grains might be a common feature of these platform carbonates.

4.2. PROVENANCE AND TRANSPORT OF DETRITAL GRAINS

Rounded mineral particles of stable minerals, such as zircon, tourmaline and rutile, are quite common, and indicate older sediments as important source rocks, which may have also yielded rounded quartz grains. Other mineral particles may have different provenances including igneous, metamorphic, and sedimentary source rocks, and contemporaneous volcanic ash particles, e. g. epidote, brown turmaline, and amphibole which have mostly been derived from metamorphic rocks, and some feldspar grains derived from acid/neutral igneous rocks. ŠUŠNJARA & ŠĆAVNIČAR (1977, 1978), who have analysed heavy mineral associations from several carbonate horizons in Dalmatia, suggested mafic igneous rocks, and partly also methamorphics, and older sediments as source rocks. The importance of mafic igneous and metamorphic rocks contrasts with the results presented here, with the exception of samples probably taken from the terrigenous Promina Beds (No. 153), which otherwise contain a large spectrum and quantity of minerals (ZUPANIČ, 1969), in contrast to "common" Dinaric platform carbonates.

When possible, transport mechanisms for the grains are considered, then a general "clear-water" depositional environment on successive, large Dinaric carbonate platforms must be taken into account. The supply of non-carbonate, predominantly silt-grade detritus to such settings may have been performed by wind, and exceptionally by storm currents, which were able to bring detritus from distant areas. Some other specific mechanisms, like transfer by organisms, might be only of negligible importance.

4.3. INSOLUBLE RESIDUE OF CARBONATES VERSUS PARENT MATERIAL FOR KARST BAUXITES AND TERRA ROSSA

Tućan-Kišpatić's theory of carbonate-derived parent material for karst bauxites and terra rossa has already been modified based on later investigations. It has been concluded that some Dinaric bauxite deposits did originate predominantly from the insoluble residue of carbonates (ŠINKOVEC, 1973; ŠINKOVEC & SAKAČ, 1981; ŠUŠNJARA et al., 1990), which is consistent with TUĆAN's (1911, 1912) and KIŠPATIĆ's (1912) opinion concerning karst bauxites in general. Other Dinaric bauxites originated from parent material derived from non-carbonate sources (ŠINKOVEC, 1970; ŠUŠNJARA & ŠĆAVNIČAR, 1977, 1978), and still others from combined sources (ŠINKOVEC, 1974; ŠUŠNJARA et al., 1990). Several bauxite deposits, e.g. those within Sinj environs, and those on the Northern Adriatic Islands, have been interpreted in two contrasting ways as to source rocks (e.g. (1) ŠUŠNJARA & ŠĆAVNIČAR, 1977, 1978, in contrast to ŠUŠNJARA et al., 1990, and (2) ŠINKOVEC & SAKAČ, 1981 in contrast to ŠUŠNJARA & ŠĆAVNIČAR, 1977, 1978). This reflects difficulties concerning diagnostic criteria. These works mostly used heavy mineral associations in bauxites, comparisons between heavy mineral associations in carbonates and bauxites, and comparisons between clay minerals in bauxites and footwall carbonates. The results of the present work suggest, that specific aspects of the light mineral associations, including important physiographic features, might be helpful in tracing the provenance of bauxite parent material.

In cases where heavy minerals in the underlying carbonates and bauxites are small in number, they are of little use for determining provenance, and light minerals may provide more information. In particular, the physiography of quartz grains may be indicative, because authigenic quartz, which is common in the studied material, may survive bauxitisation. It is suggested that quartz from the insoluble residues of carbonates should be studied, as well as quartz in overlying, possibly related bauxite/terra rossa.

The insoluble residues studied, which represent an "average" platform carbonate, contained a number of mineral species and their physiographies, that may have been available for accumulation in later bauxite deposits. Therefore, minerals found in bauxite, and identified as detrital, should carefully be considered as to their residual (carbonate-derived), or allogenic provenance. Namely, their detrital character in bauxite/terra rossa does not simply imply an allogenic (non-carbonate) provenance, as an important portion of carbonate-derived minerals may have already been present in possible carbonate source rocks as detrital grains.

5. CONCLUSIONS

1. The insoluble residue of the "average Dinaric platform carbonate" contains both detrital as well as authigenic mineral grains. Some mineral species are detrital, others are authigenic, and still others are represented by both grain types. Most mineral assamblages in TUĆAN's (1911) slides are dominated by detrital grains. Heavy minerals are mostly detrital in origin, while others are both detrital, and authigenic.

2. Detrital grains in the Dinaric platform carbonates studied have come from various sources, predominantly from sedimentary rocks.

3. The study of minerals and other particles in insoluble residues of carbonates, as well as the study of heavy mineral associations must include the physiography of grains, and not only listings of mineral species. Furthermore, the study of all minerals is adventageous to heavy mineral study alone. When investigating the possible provenance of parent material for bauxite and terra rossa from underlying carbonates, "light" minerals, especially quartz grains may provide additional information. The detrital character of mineral grains found in bauxite/terra rossa need not imply a provenance from non-carbonate sources, because many detrital grains may have already been present in potential carbonate source rocks.

Acknowledgements

I would like to thank Dr. Ljubomir BABIĆ for his very helpful advice, and for help in preparing the English manuscript. Dragan BUKOVAC provided editorial aid. This investigation was supported by the Ministry of Science of the Republic of Croatia through project No. 1 - 08 - 203.

6. REFERENCES

ADAMS, J.E. (1944): Upper Permian Ochoa series of the Delaware basin, West Texas and Southwestern New Mexico.- Am. Assoc. Petrol. Geol., 28/11, 1596-1625.

ANDREE, K. (1909): Über einige Vorkomen von Flusspat in Sedimenten.- Tschermaks mineralogische und petrographische Mitteilungen, 28, 535-556, Wien.

BARDOSSY, G. (1982): Karst Bauxites.- Developments in Economic Geology, 14, Elsevier, 1-441, Amsterdam.

ESTEBAN, M. & KLAPPA, C.F. (1983): Subaerial exposure environment.- In: SCHOLLE, P.A., BEBOUT, D.G. & MOORE, C.H. (eds.): Carbonate Depositional Environments. Mem. Am. Assoc. Petrol. Geol., 33, 1-63.

FÜCHTBAUER, H. (1948): Einige beobachtungen an authigenichen Albiten.- Schweiz. Miner. Petr. Mitt., 28, 709-716.

FÜCHTBAUER, H. (1958): Die petrographische Unterscheidung der Zechsteindolomite im Emsland durch ihren Saureruckstand.- Erdöl u. Kohle, 11, 689-693.

FÜCHTBAUER, H. (1974): Sediments and Sedimentary Rocks.- Sedimentary Petrology, Part II, Schweizerbart, 464 p., Stuttgart.

GRIMM, W.D. (1962): Idiomorphe Quartze als Leitmineralien fur salinare Fazies.- Erdôl und Kohle, 15, 880-887.

GRIMM, W.D. (1964): Ausfallung von Kieselsauere in salinar beeinflusten Sedimenten.- Z. dt. geol. Ges., 114, 590-619.

KIŠPATIĆ, M. (1912): Bauxite des kroatischen Karstes und ihre Entstehung.- Neues Jahrb. Mineral.Geol. Paleont., 34, 513-552.

MARIĆ, L. (1965): Terra rossa u karstu Jugoslavije (Terra rossa dans le karst de Yougoslavie).- Prirodosl. istr., 34 (Acta Geol., 4), 19-54, Zagreb.

ŠINKOVEC, B. (1970): Geology of Triassic bauxites of Lika, Yugoslavia. (Geologija trijaskih bokista područja Like).- Prirodosl. istraž., 39, (Acta geol., 7/1), 5-70, Zagreb.

ŠINKOVEC, B. (1973): The origin of early palaeogene bauxites of Istria, Yougoslavia.- 3. Intern. Congres for the study of Bauxites, Alumina and aluminium ICSOBA, 151-164, Nice.

ŠINKOVEC, B. (1974): Jurski glinoviti boksiti Zapadne Istre (Jurassic clayey bauxites of western Istria).- Geol. vjesnik, 27, 217-226.

ŠINKOVEC, B. & SAKAČ, K. (1981): Boksiti starijeg paleogene na otocima sjevernog Jadrana (The early

Paleogene Bauxites of the North Adriatic Islands).- Geol. vjesnik, 33, 213-225.

ŠUŠNJARA, A. & ŠĆAVNIČAR, B. (1977): Akcesorni teški minerali u boksitima i karbonatnim stijenama podine boksita u SR Hrvatskoj (Accesory heavy minerals in the bauxites and underlying carbonate rocks in Croatia).- IV jugosl. simp. istraž. eksploat. boksita, 53-66, Hercegnovi.

ŠUŠNJARA, A. & ŠĆAVNIČAR, B. (1978): Heavy minerals as provenance indices of tertiary bauxites in Dalmatia (Yugoslavia).- 4th Intern. Congres for the study of Bauxites, Alumina and aluminium ICSOBA, 822-837, Athens.

ŠUŠNJARA, A., SAKAČ, K., GABRIĆ, A. & ŠINKOVEC, B. (1990): Boksiti područja Sinja u srednjoj Dalmaciji (Bauxites of the Sinj area in Middle Dalmatia).- Geol. vjesnik, 43, 169-179.

TRÖGER, W.E. (1967): Optische Bestimmung der gesteinsbildenden Minerale. Teil 2, Text-Band.- Schweizerbartische Verlagsbuchhandlung, 822 p., Stuttgart.

TUĆAN, F. (1911): Die Kalksteine und Dolomite des kroatischen Karstgebietes.- Geol. anali Balk. poluostrva, 6/2, 609-813, Beograd.

TUĆAN, F. (1912): Terra rossa, deren Natur und Entstehung.- Neues Jahrbuch Min. Geol. Paleont., 34, 401-430.

TUĆAN, F. (1932): Fosforiti od Ervenika u Dalmaciji.- Rad Jugosl. akad. znan. umjetn., 244, 1-12, Zagreb.

TUĆAN, F. (1933): Pogledi na geokemiju dinarskog krša.- Rad Jugosl. akad. znan. umjetn., 246 (Matem. prir. razr., 76), 37-108, Zagreb.

VALETON, I. (1955): Veränderungen an Zircon und Turmalin in Buntsandstein und Keuper.- Heidelb. Beitr. Mineral. Petrogr., 5, 100-104.

VALETON, I. (1972): Bauxites.- Developments in Soil Science, VII, Elsevier, 226 p., Amsterdam.

VAN STRAATEN, L. M. J. U. (1948): Note on the occurence of authigenic feldspar in non-metamorphic sediments.- Am. Jour. Science, 246, 569-572.

ZUPANIČ, J. (1969): Promina naslage planine Promine (Promina formation of the Promina mountain).- Geol. vjesnik, 22 (1968), 477-498.

Manuscript received March 5, 1992.
Revised manuscript accepted November 7, 1994.

PLATE I

1. Authigenic quartz with inclusions of calcite and haematite. Insoluble residue of limestones (No. 41).
2. Short-prismatic authigenic quartz with inclusions of carbonate minerals concentrated in the core. Insoluble residue of limestone (No. 12).
3. Quartz "dihexahedron" with calcite inclusions. Insoluble residue of limestone (No. 43).
4. Zoned hypidiomorphyc quartz with euhedral core. Insoluble residue of limestone (No. 20).
5. Xenomorphic grain of authigenic quartz with inclusions of carbonate minerals. Insoluble residue of limestone (No. 62).
6. Long-prismatic authigenic quartz containing carbonate mineral inclusions. Insoluble residue of limestones (No. 43).
7. Quartz "dihexahedron", and barrel-shaped type of authigenic quartz. Insoluble residue of limestone (No. 43).
8. Authigenic quartz with saw-shaped borders, explained by TUĆAN (1911) as hindering during the crystal formation. Insoluble residue of limestone (No. 58).

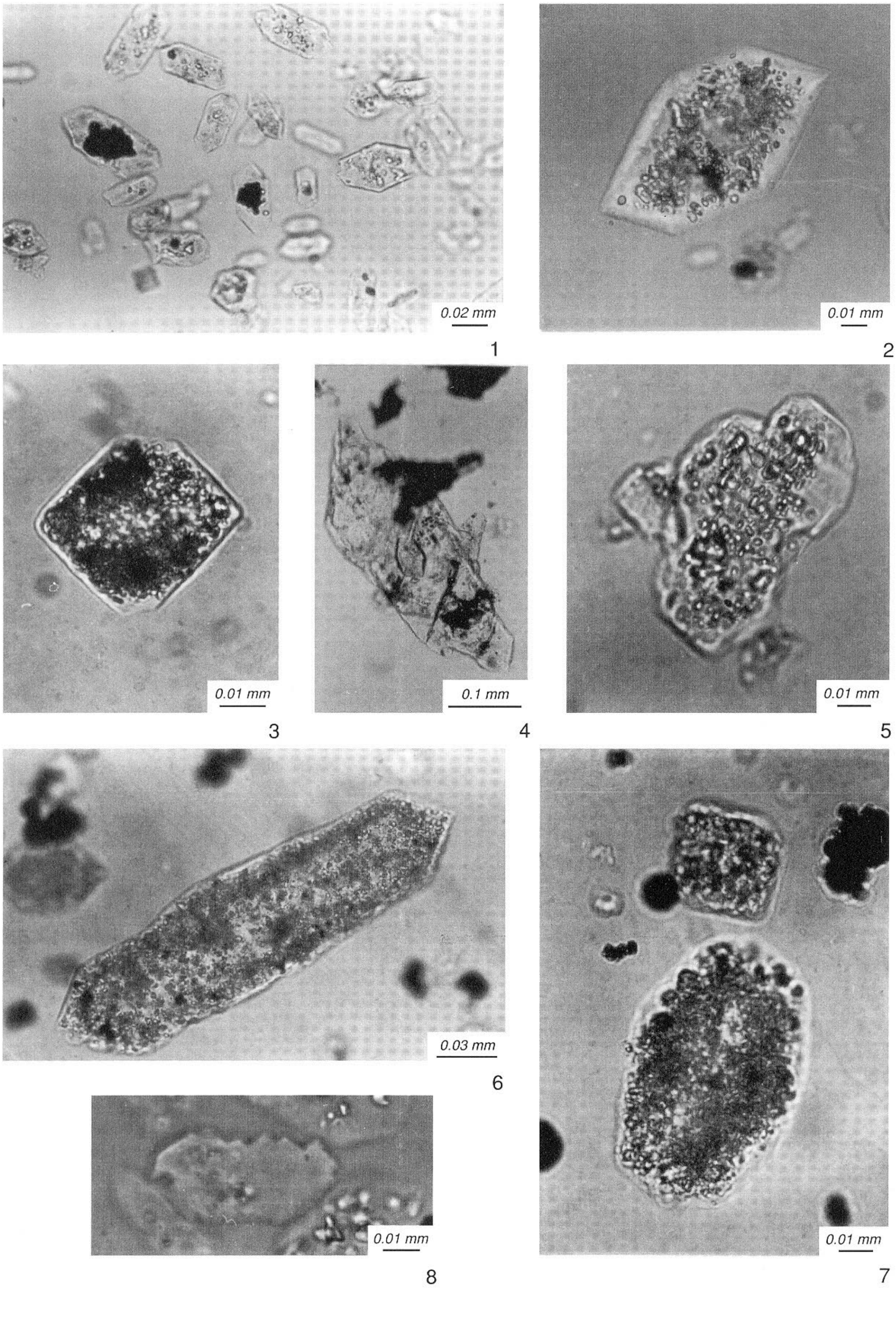
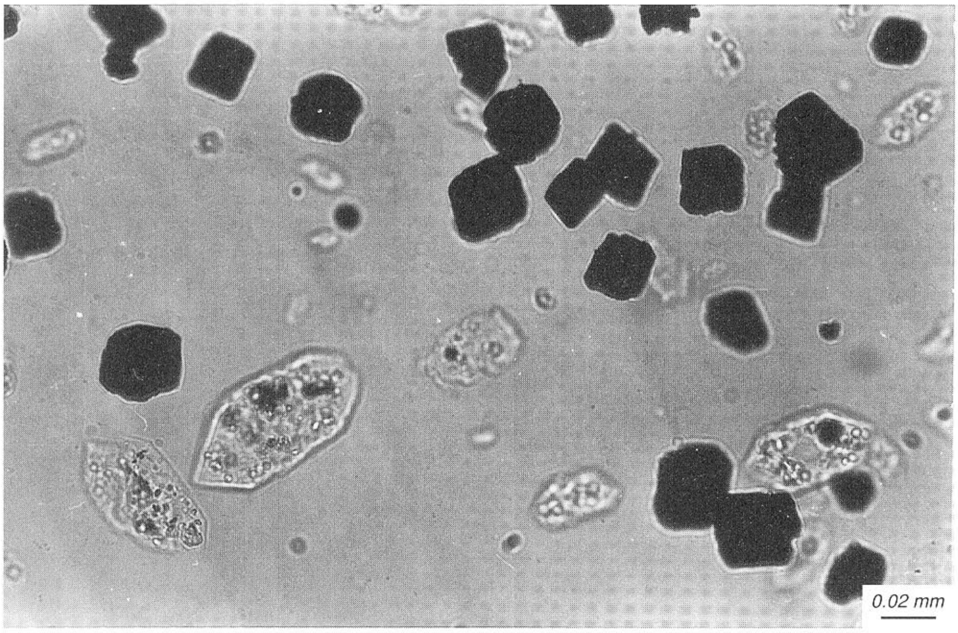
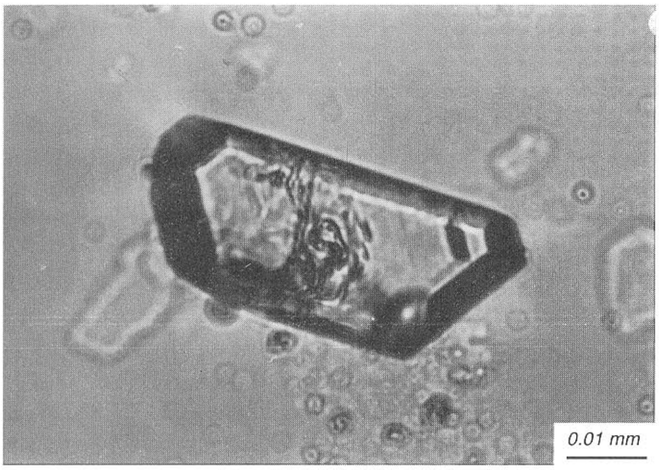

0.02 mm
1
0.01 mm
2
0.01 mm
3
0.1 mm
4
0.01 mm
5
0.03 mm
6
0.01 mm
7
0.01 mm
8

PLATE II

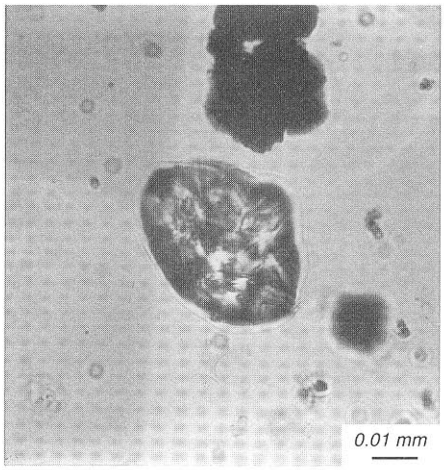
1. Authigenic quartz overgrowth with calcite inclusions, on an inclusion-free detrital core. Insoluble residue of limestone (No. 58).
2. Euhedral zircon with slightly abraded edges. Insoluble residue of dolomite (No. 27).
3. Rounded detrital zircon. Insoluble residue from limestone (No. 33).
4. Detrital tourmaline with minute authigenic overgrowths. Insoluble residue of limestone (No. 15).
5. Broken grain of detrital tourmaline with slightly abraded broken end. Insoluble residue of limestone (No. 15).
6. Idiomorphic fluorite crystal. Insoluble residue of limestones (No. 33).



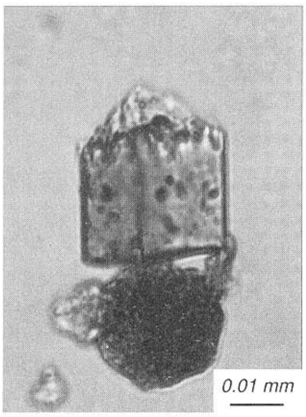
1



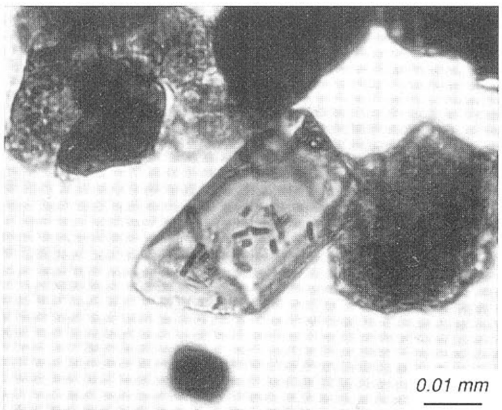
2



3



4



5

6