Geologia Croatica | 64/2 | 121–132 | 6 Figs. | 1 Tab. | Zagreb 2011

Composition and provenance of Neogene sedimentary rocks of Dilj gora Mt. (south Pannonian Basin, Croatia)

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doi: 104154/gc.2011.10

Geologia Croatica

ABSTRACT

The petrographic composition and transport direction of medium and coarse-grained clastic material of Dilj gora Mt. which is located in the south Pannonian basin, shows that this area experienced several changes in provenance of the detritus through the Neogene. Detritus for the oldest Lower Miocene (Ravan unit) was generally transported from the south and most probably derived from clastic and carbonate sediments and metamorphic rocks of the Internal Dinarides. Detritus of the Lower–Middle Miocene (Tuk unit) probably originated by weathering of acid magmatic and metamorphic rocks, with significant input of materials from local sources, primarily from the Internal Dinarides and from Požeška gora and Dilj gora Mts. During the entire Middle Miocene (Zdenci, Dubovik and Glogovica units), and through the older part of the Late Miocene (Croatica and Pavlovci unit), the deposition of siliciclastic gravel and sandy detritus was less significant. Only the Middle Miocene deposits (Kasonja unit) contain clastic detritus derived from granitoids, metamorphic and sedimentary rocks of the hinterland. The source area of this detritus was most probably in the Slavonian Mts. (Papuk, Psunj, Požeška gora Mt.) or the mountains of northern Bosnia (Motajica Mt.). At late Upper Miocene times (Andraševec and Nova Gradiška units), detritus was derived from different metamorphic and older sedimentary rocks. The structural and mineralogical maturity of these sediments, and their transport directions, indicates an Alpine-Carpathian provenance of the material. Most of the detritus of the Pliocene sediments (Cernik unit) also belong to an Alpine-Carpathian provenance, however a small part of it is of local origin and came from uplifted and mainly sedimentary rocks.

Various textural characteristics and diverse modal compositions were determined, and the provenance of Neogene clastic material of Dilj gora Mt. can be attributed to differing source rock compositions and locations of source areas. However, they are also the product of different controls on sedimentation, including different rates of subsidence and extension of the Pannonian Basin (PB) interrupted by compressional events, basin water-level fluctuations connected with global sea-level changes and infilling of PB by delta progradation.

Keywords: Pannonian Basin, Dilj gora Mt., Neogene sediments, detritus composition, clastic material source

1. INTRODUCTION

Dilj gora Mt. is one of the Slavonian Mountains located in eastern Croatia (Fig. 1), belonging to the south Pannonian Basin (PB). It consists of Neogene and Quaternary sediments with rare occurrences of magmatic rocks (ŠPARICA & CRNKO, 1973; ŠPARICA et al., 1980a,b; 1987a,b, ŠPARICA et al., 1988). The origin of Neogene sediments of Dilj gora Mt. is related to the development of the PB and its surrounding uplifted areas. Namely, the PB is a sedimentary area surrounded by the Alps, Carpathians and Dinarides, and is composed of several smaller depressions separated by shallow

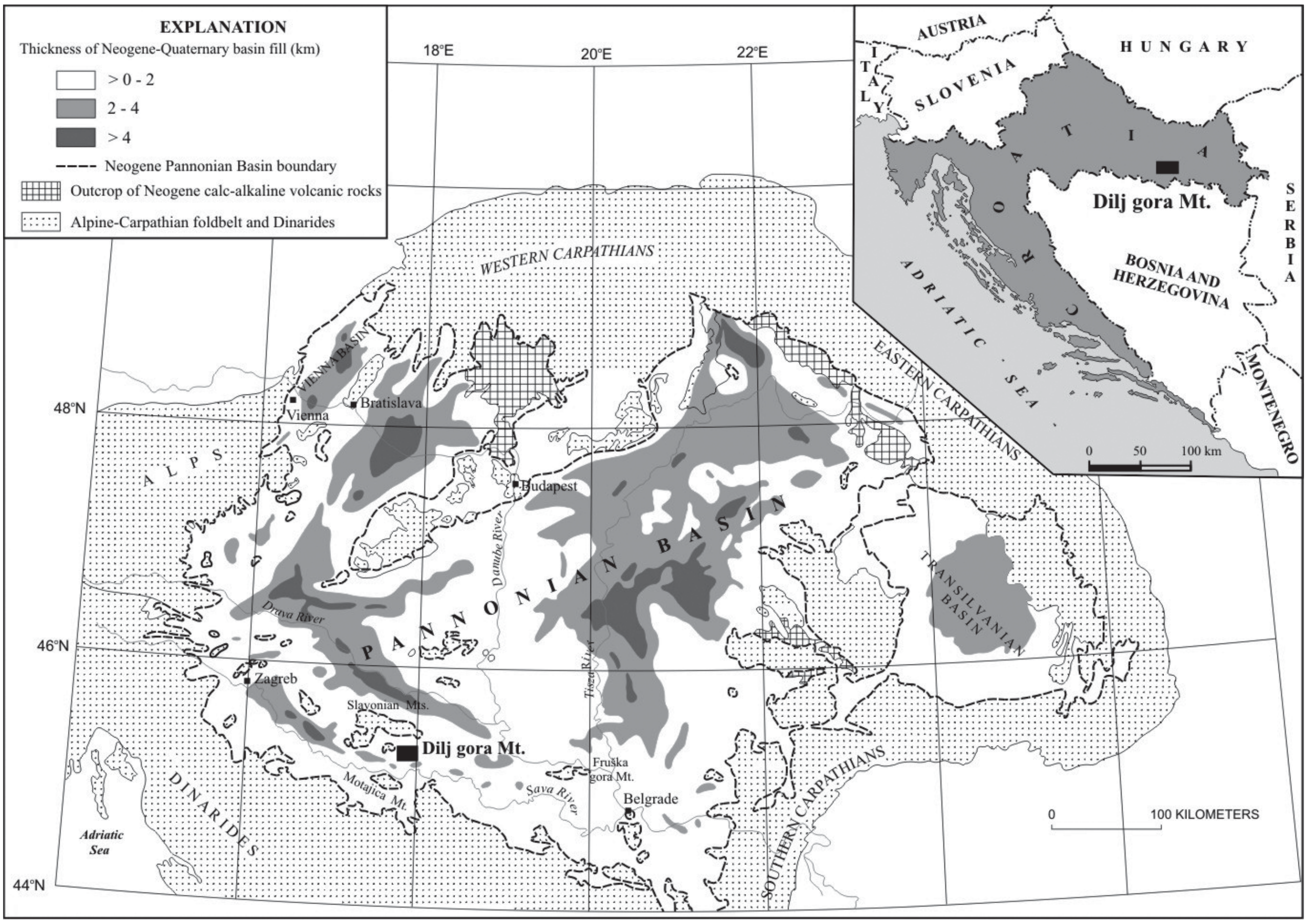

Figure 1: Map of the Neogene Pannonian Basin, showing depocentres of the sub-basins, with location of Dilj gora Mt. Thickness of the Neogene–Quaternary sedimentary rocks in the Pannonian Basin, compiled by HORVÁTH in ROYDEN & HORVÁTH (1988).

lying basement rocks (Fig. 1). Since its formation in the Early Miocene, a huge amount of clastic material has been transported with varying intensity into and within the PB (MATTICK et al., 1988; JUHÁSZ, 1991; JUHÁSZ & MAGYAR, 1992; VAKARCS et al., 1994; MAGYAR et al., 1999; THAMÓ-BOSZÓ & JUHÁSZ, 2002; SAFTIĆ et al., 2003; KOVAČIĆ et al., 2004; THAMÓNÉ BOSZÓ et al., 2006; THAMÓ BOSZÓ & KOVÁCS, 2007). Deposition of this material in the PB formed a sequence of sediments reaching several thousand meters in thickness in some depressions (SAFTIĆ et al., 2003). Six boreholes from the nearby area drilled into Quaternary and Neogene sediments for about 2000 m depth. Four of them reached the crystalline basement: Tekić-I (northwest from Dilj gora Mt.) ended in gneiss-phyllonite (NAJDENOVSKI, 1988), Visoka Greda-1 in biotite-amphibole granite and Visoka Greda-2 in amphibole schist (amphibolite?) west of Dilj gora Mt. (PIKIJA, 2004) and Djakovačka Breznica-1 (ŠPARICA, 1985) in mica schist to the northeast. Another two boreholes Nova Kapela-1 and Garčin-1 ended in Lower Miocene conglomerates (PIKIJA, 2004).

Source areas for this huge amount of material in the PB were primarily related to the surrounding mountain chains of the Dinarides, Alps, and Carpathians, which were uplifted before and during the formation of the PB. However, part of the material was also derived from locally uplifted mountains within the basin (KOVAČIĆ & GRIZELJ, 2006).

Dilj gora Mt. is located in the southern PB near the northern margin of the Dinarides but the Dinaridic provenance has been determined only for the youngest Quaternary sediments (MUTIĆ, 1993). Previous investigations determined an origin of the material in the distant north Alpine-Carpathian sources for Pleistocene loess sediments (MUTIĆ, 1990) and Upper Miocene sediments (KOVAČIĆ et al., 2004; KOVAČIĆ & GRIZELJ, 2006). The origin of clastic material of Lower and Middle Miocene deposits has not yet been studied in detail.

The main goal of this study is to determine the composition of clastic sedimentary rocks and reconstruct the origin of clastic material supplying the sediments of Dilj gora Mt. during the Neogene by integrating sedimentological and petrographic data. Furthermore, data is used to reconstruct changes in transport directions or intensity of sedimentation in the study area during the Miocene.

2. GEOLOGICAL SETTING

The PB is a back-arc type of basin (ROYDEN, 1988; KOVÁČ et al., 1998). Its formation began in the Early Miocene due to the subduction and continental collision of the Euro-

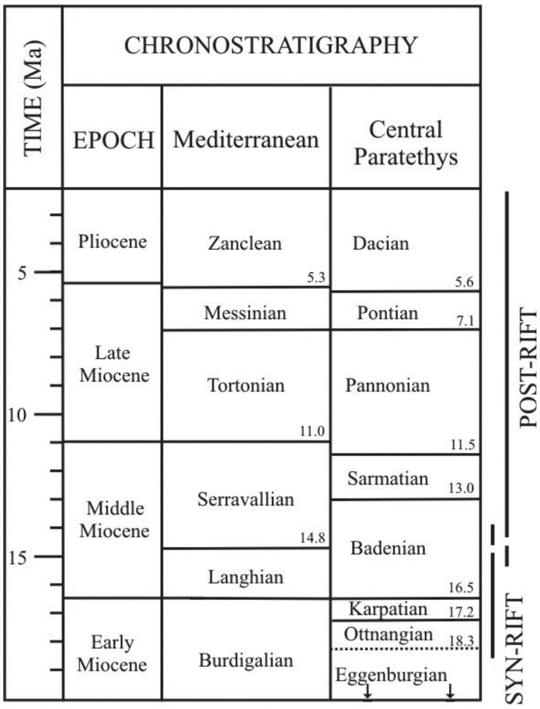

Figure 2a: Chronostratigraphic correlation of the Mediterranean and Central Paratethys (after RÖGL, 1996).

pean Plate under the Apulian plate. The first phase of basin development (until the Middle Badenian), was characterised by tectonic thinning of the crust and isostatic subsidence (syn-rift), while the second phase (from the Middle Badenian to the Quaternary) was marked by cessation of rifting and subsidence caused by cooling of the lithosphere (post-rift).

The PB is surrounded by the Alps, Carpathians and Dinarides, and palaeogeographically belongs to the area and bioprovince of Central Paratethys. During the Miocene, sea-level oscillations strongly controlled sedimentation because a connection of Central Paratethys with the Mediterranean and Indo-Pacific Ocean was established and closed several times (STEININGER et al., 1988, RÖGL, 1996). Marine transgressions did not flood the entire basin. Therefore, the basement was disconformably covered by deposits ranging in age from Early to Late Miocene, formed in marine, brackish and fresh-water environments, while some parts of basin were characterised by temporary emersions. The final isolation of Central Paratethys began some 10.5 Ma ago (STEININGER et al., 1988, RÖGL, 1996). The nature of the evolution of Central Paratethys and occurrences of endemic faunas has necessitated the establishment of local Miocene stages (Fig. 2a).

Recent investigations of Neogene sediments for the 1:50000 Geological map of Croatia revealed eleven informal lithostratigraphic units of Dilj gora Mt. The basic characteristics of these units and their vertical and lateral relationships are shown in a compiled geological column in Figure 2b. These units constitute two transgressive – regressive cycles. The first cycle consists of the Ravan, Tuk, Zdenci, Dubovik,

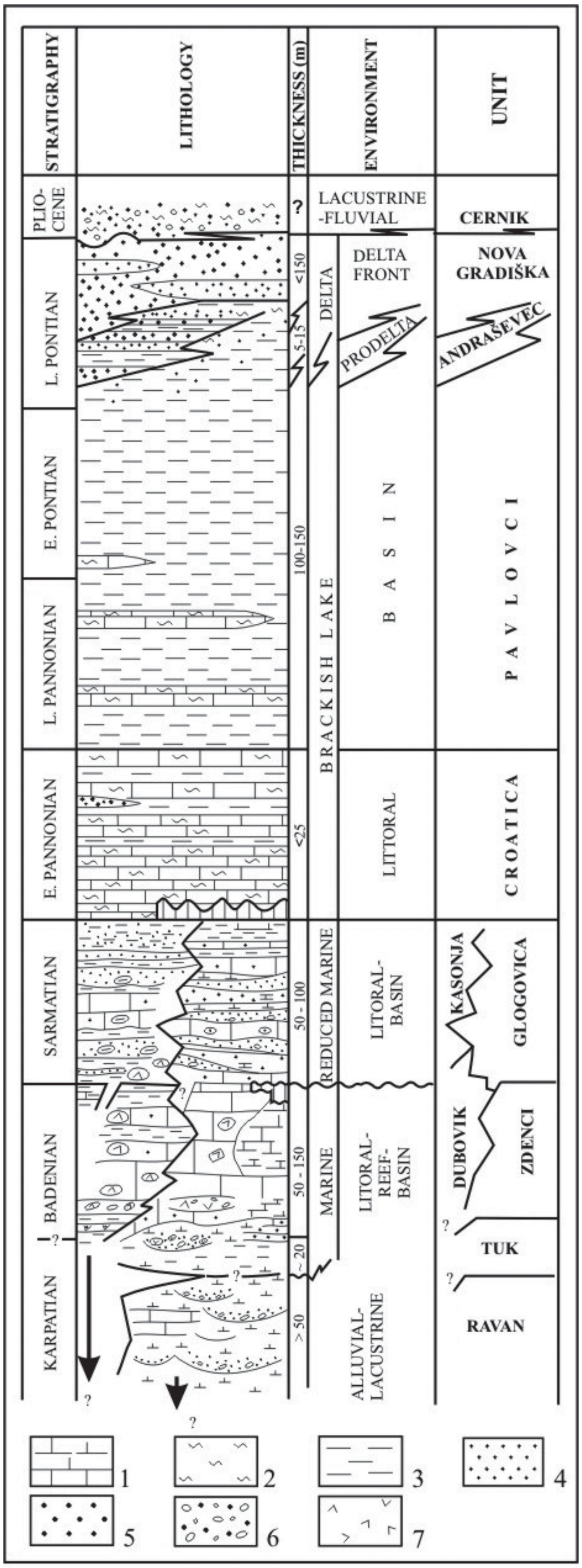

Figure 2b: Compiled geological column of the Neogene succession of Dilj gora Mt. after PIKIJA et al. (2005) and KOVAČIĆ et al. (2005). Legend: 1 – limestone; 2 – clay; 3 – marl; 4 – silt; 5 – sand; 6 – gravel, conglomerates, sandstone; 7 – volcanic fragments.

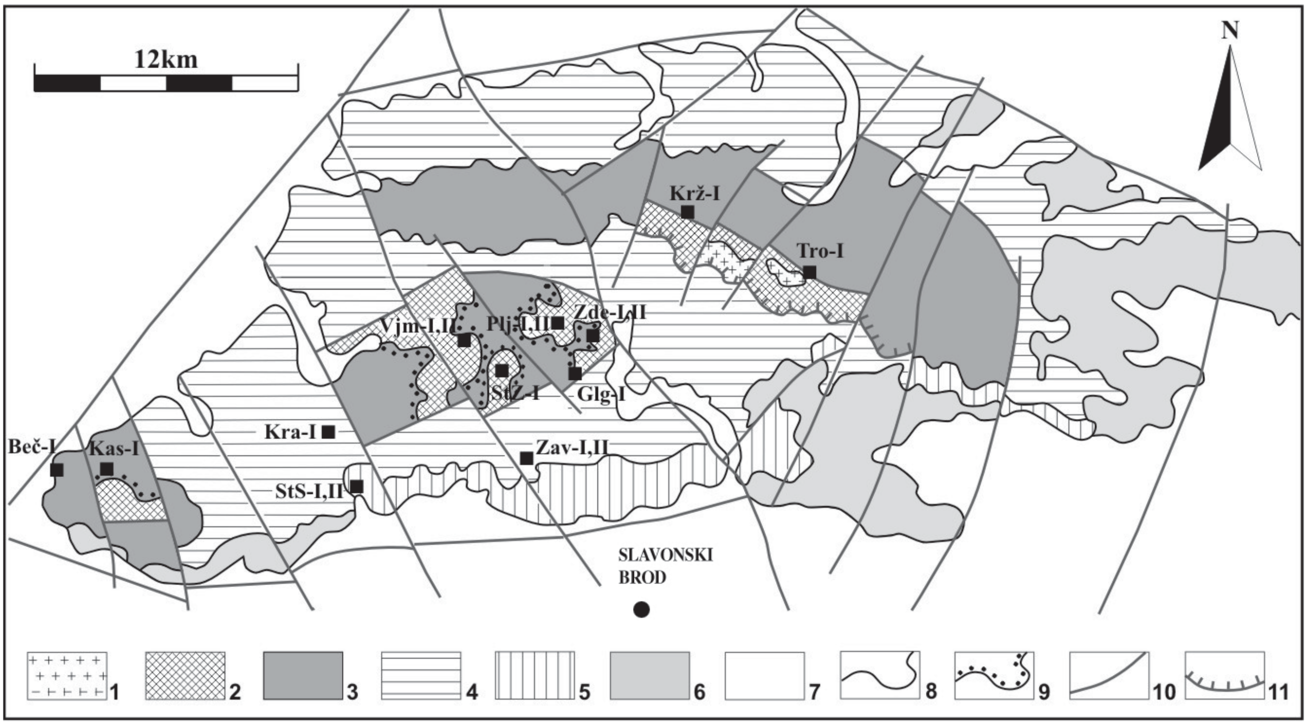

Figure 3: Geological sketch map of Dilj gora Mt. (simplified from the Basic Geological Map of Croatia 1:300000; CROATIAN GEOLOGICAL SURVEY, 2009) with locations of the studied sections. Legend: 1 – magmatic rocks; 2 – Badenian; 3 – Sarmatian + Pannonian; 4 – Pontian; 5 – Pliocene; 6 – Pleistocene; 7 – Holocene; 8 – normal boundary; 9 – transgressive boundary; 10 – fault; 11 – thrust.

Kasonja and Glogovica units which include ?Lower–Middle Miocene sedimentary rocks (PIKIJA et al., 2005), while the second cycle includes the Upper Miocene sediments of the Croatica, Pavlovci, Andraševec, Nova Gradiška units as well as the Cernik unit, of Pliocene age (KOVAČIĆ et al., 2005). These cycles generally correspond to the first and second sedimentary megacycle described by SAFTIĆ et al. (2003) in the Southern PB.

3. MATERIALS AND METHODS

Seventeen geological columns were investigated (Fig. 3) in the field: Staro Završje-I (StZ-I), Vučje jame-I (Vjm-I), Vučje jame-II (Vjm-II), Pljuskara-I (Plj-I), Pljuskara-II (Plj-II), Križ-I (Krž-I), Završje-I (Zav-I), Završje-II (Zav-II), Tromeđa-I (Tro-I), Kasonja-I (Kas-I), Bečic-I (Beč-I), Krajačići-I (Kra-I), Stari Slatinik-I (StS-I), Stari Slatinik-II (StS-II), Glogovica-I (Glg-I), Zdenci-I (Zde-I) and Zdenci-II (Zde-II). At some localities, where it was possible, imbrications, cross bedding and cross lamination were measured in order to reconstruct sediment palaeotransport directions in the depositional basin.

Samples for petrographic analysis of clastic sedimentary rocks were collected in order to cover the entire study area, as well as, the entire time span of the Neogene deposits. The composition of gravel, conglomerate and sandstones was determined by analyzing 50 thin sections using a polarizing microscope. Compositional analysis of the unconsolidated sand-silt sediments was performed in the 0.09–0.16 mm calcite-free fraction. Heavy and light mineral fractions (HMF and LMF, respectively), were separated by bromoform liquid ($CHBr_3$; δ=2.84 gcm^{-3}). Qualitative and quantitative analysis of HMF and LMF for 32 samples were performed by identifying 300–400 grains per sample using the ribbon counting method (MANGE & MAURER, 1992).

4. RESULTS

4.1. Ravan unit

Siliciclastic sediments of the Ravan unit are mostly composed of poorly sorted sandy silts, sands and gravels deposited in an alluvial-lacustrine environment (Fig. 2b). They are the oldest deposits on the Dilj gora Mt. with a Badenian age according to ŠPARICA et al. (1980a,b; 1987a,b) and a Karpatian age according to PIKIJA et al. (2005).

Sands, studied at the Staro Završje (StZ-I) and Vučje jame (Vjm-I, II) localities (Fig. 3) are characterized by their mineralogical immaturity. Forty five percent or more, of their composition consists of rock fragments and feldspars (Tab. 1). Among the rock fragments, particles of unstable rocks such as quartz-sericite schist, quartz-chlorite schist, slate and phyllite are most abundant. In addition, particles of quartzite, quartz schist and sandstone are ubiquitous. Among the feldspars, the kaolinised alkali feldspars prevail, while acid plagioclase with polysynthetic lamellae is very rare. There is some difference in the composition of the HMF among the localities. Sands at the StZ-I locality contain more opaque minerals and chlorite than transparent heavy minerals (THM). At the Vjm-I locality, they are also rich in opaque minerals,

Table 1: Modal composition of heavy and light mineral fractions of Neogene sands from the Dilj gora Mt. Abbreviations: op – opaque min., ch – chlorite, b – biotite, do – dolomite, thm – translucent heavy minerals, tu – tourmaline, zr – zircon, rt –routile, ap – apatite, am – amphibole, py – pyroxene, ep – epidote, g – garnet, ky – kyanite, st – staurolite, ti – titanite, csp – chromespinel, oth – other translucent heavy minerals, q – quartz, f – feldspar, l – lithic fragments, ms – muscovite, + – minerals with occurrence <1%. And* – Andraševec unit, M_3-Karpatian, M_4-Badenian, M_5-Sarmatian, M_7^{2}- Upper Pontian, Pl-Pliocene

Sample	Unit	Age	Heavy minerals (%)					Translucent heavy minerals (THM) (%)													Light minerals (%)			
			op	ch	b	do	thm	tu	zr	rt	ap	am	py	ep	g	ky	st	ti	csp	oth	q	f	l	ms
StZ-I 1/1	Ravan	M_3	65	22		+	13	32	3	1	3	5		27	19		5	3		2	33	13	54	
4/1		M_3	73	4		2	21	13	10	11		10		34	20		1			1	37	14	49	
8/1		M_3	61	2			37	10	7	1		6		44	22		3	5		2	40	15	45	
Vjm-I 3		M_3	90			+	10	9	14	8		17		26	24		+		+	1	55	18	27	
4		M_3	87			+	13	10	11	5		16		27	28		1			2	51	19	30	
Vjm-II 1/1		M_3	23	+	+		76	9	+	3	3	38	+	19	13	+	2	6		5	46	28	26	
2/1		M_3	33		+		66	4	3	1	1	42	+	25	16		2	2		3	49	20	31	
7/2		M_3	34	1	1		64	11	1	2		19	+	27	31	1	3	3		2	52	23	25	
Plj-II 1/2	Tuk	M_3	22	10	7		61	15	7	3	2	17		46		+	2			7	30	13	56	1
2/2		M_3	38		16		46	16	7	5	2	11		53			2			4	26	13	58	3
3/3		M_3	38				62	24	2	3	4	23		34	3	+	3	1		2	45	21	33	1
Kas-I 1/1	Kasonja	M_5	36				64	28	2	3		2		10	30		19	3		3	49	41	9	1
7/1		M_5	46				54	39		5		+		5	20		11	13		6	52	41	7	
15/1		M_5	31				69	20	3	7				24	24		11	5		6	49	44	6	1
19/1		M_5	56		1		43	20	2	4	2			26	18		11	13		4	57	38	5	
Beč-I 14/1		M_5	28	1		1	70	33		5				22	16		16	3		5	32	53	15	
17/2		M_5	21				79	21	+	3				32	21		8	8		6	24	69	7	
24/1		M_5	24	1			75	25	1	3				32	16		11	7		5	43	43	13	1
Kra-I 3/2	And*	M_7^{2}	5	13		38	38	4	3	4	+	16	+	17	37	6	5	+		6	49	11	10	30
Kra-I 6/1	Nova Gradiška	M_7^{2}	13	2			85	6	1	3		3	+	60	3	8	11	+		4	50	10	36	4
Zav-I 1/1		M_7^{2}	18	32			50	1	+	3		13		28	33	4	11			6	37	12	15	36
4/2		M_7^{2}	11	4		+	85	4	1	2	+	12		20	44	3	10	1		3	50	17	29	4
4/2A		M_7^{2}	6	4		4	86	5	+	+	2	24		22	22	7	13	+		4	54	18	20	8
5/2		M_7^{2}	10				90	2	+	3		24		21	27	5	12	2		3	48	14	24	14
Zav-II 4/1		M_7^{2}	10	2		5	83	2		1	1	19		24	36	5	9	+		2	67	17	14	2
7/1		M_7^{2}	12				88	2		3		21		24	26	7	14	1		2	60	11	24	5
StS-I 1/1	Cernik	Pl	39	+	+	28	32	12		3		19	1	24	18	10	9			4	55	4	41	
5/1		Pl	44	6			50	14	7	5		7		28	13	4	13	1		8	48	6	44	2
5/2		Pl	37	3			60	10	3	4	+	9	1	26	25	7	9			5	58	5	37	
StS-II 1/1		Pl	28	+			71	8	2	5		5		17	45	2	12	+		3	53	12	35	
2/1		Pl	53				47	3	2	2		10		59	12	3	7			2	18	10	72	
5/2		Pl	18			52	30	9		2	+	5	+	19	40	8	14			2	62	5	33	

opposed to the Vjm-II sands, which are rich in THM. In the THM association, epidote, tourmaline, garnet and amphibole are most common. Glaucophane is regularly present among the amphiboles.

Gravels, studied at Staro Završje (StZ-I) and Vučje jame (Vjm-I) (Fig. 3), have a polymictic composition with pebbles averaging 10 cm in size with blocks up to a maximum of 40 cm diameter. Sandstone, siltstone, and limestone pebbles (Figs. 4A,B) are most common. Sandstone types are arkosic arenite, subarkose, sublitharenite and in the case where the intergranular carbonate content increases they belong to the greywackes. Some of the sandstones can be described as metasandstones. Siltstones also carry a significant amount of $CaCO_3$ and are classified as calcitic siltstones. Limestones are mainly represented by micritic facies, but with sandy and recrystallised limestone types, too. Their Cretaceous age has been proven by FUČEK (in PIKIJA, 2004). Polymictic clast-supported and matrix-supported breccias are rare, but fragments of anchimetamorphic rocks composed of slightly metamorphosed carbonate and marl laminae, and low grade metamorphic rocks in the range of slate and phyllite, are common (Fig. 4C). Marble and amphibole schists are significant, while granite and rhyolite pebbles are present in small amounts (Fig. 4D).

The direction of imbricated platy pebbles in column StZ-I, measured in two horizons (Figs. 5A, B, see page 128) clearly indicates transport of material from the south-southeast. Measurements in section Vjm-I (Fig. 5C) show higher data scattering, but suggest that the material came from the south-southwest.

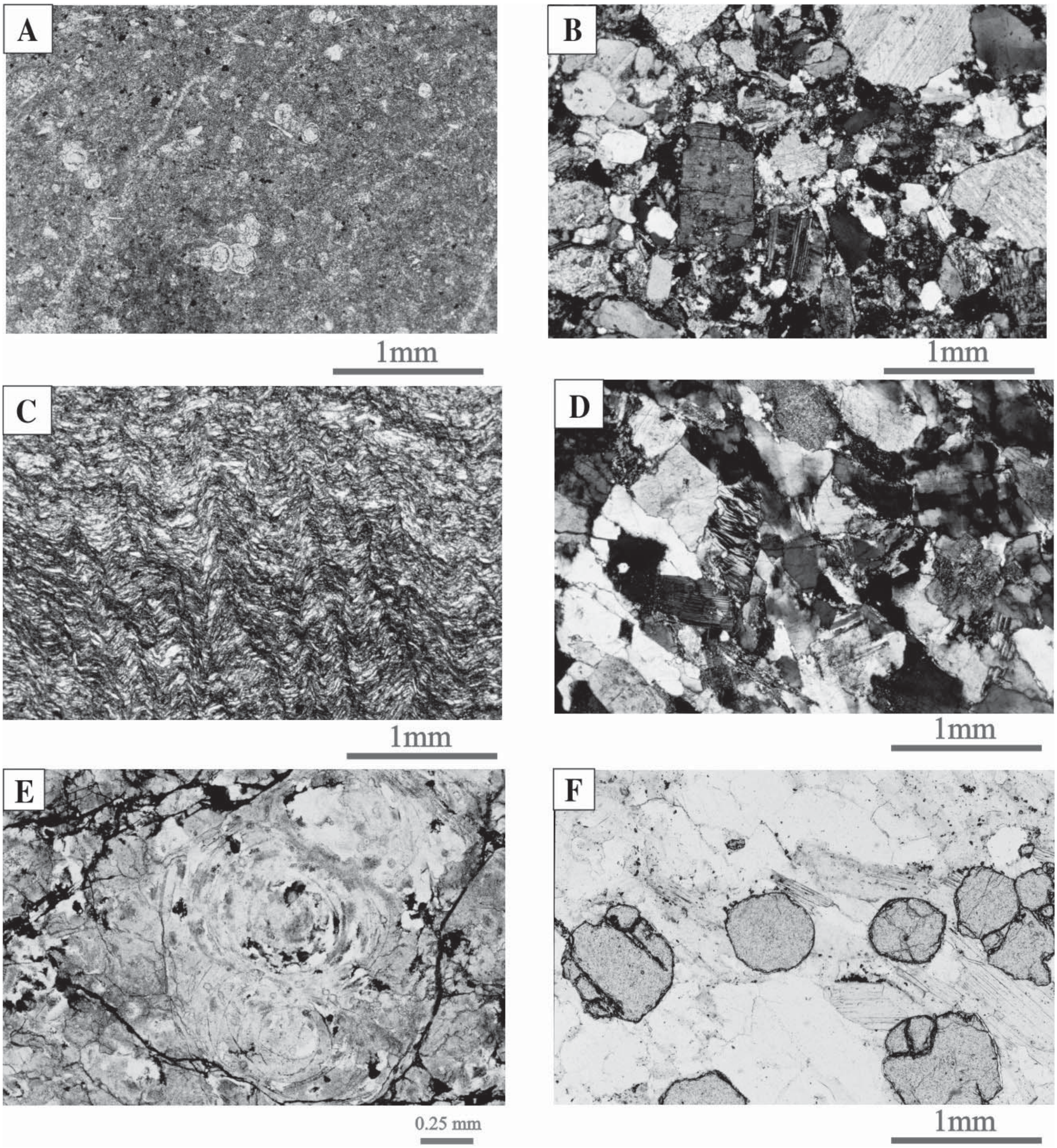

Figure 4: Photomicrographs of different kinds of pebbles and fragments of coarse clastic sediments of Dilj gora Mt. (A-D) Staro Završje-I locality (Ravan unit); (E) Križ-I locality (Dubovik unit) and (F) Kasonja-I locality (Kasonja unit). (A) limestone sample StZ-I 1/3f (B) sandstone sample StZ-I 1/3a (C) slate/phyllite sample StZ-I 9/1B (D) granite sample StZ-I 9/1C (E) acid volcanic glass (perlite) sample Krž-I 2/1 (F) garnet-muscovite gneiss sample Kas-I 8/2C.

4.2. Tuk unit

Siliciclastic sediments of the Tuk unit are poorly sorted. They are deposited during the Karpatian and the Lower Badenian in a marine environment (Fig. 2b). In this unit, clayey-sandy silts dominate, while sands, sandstones and gravels appear as lenses.

Sands studied at Pljuskara (Plj-II, Fig. 3) are composed of acid volcanic rock particles. Besides them, particles of quartzite, chert, slate and phyllite are present. Quartz grains are fresh with uniform extinction. Some of the feldspar grains are kaolinised, but others are fresh. The composition of the HMF is similar to that of the Ravan unit sands, apart from the presence here of fresh biotite (Tab. 1).

Gravels at Pljuskara (Plj-I; Fig. 3), are composed exclusively of pebbles of acid volcanic rocks; alkali feldspar rhyolites, and rhyolitic tuffs up to 3 cm in diameter.

4.3. The Zdenci, Dubovik and Glogovica units

The basic feature of these units is the predominance of carbonate sediments in relation to siliciclastics. Sediments of the Zdenci and the lower part of the Dubovik unit were deposited during the Badenian in a marine environment, while sediments of the upper part of the Dubovik unit and sediments of the Glogovica unit were deposited during the Sarmatian in a reduced marine environment (Fig. 2b). In the Zdenci and Glogovica units (Zde-I, Glg-I; Fig. 3), which are composed mainly of bioclastic limestone, the siliciclastic component is almost completely absent. BELAK at al. (1991) described the appearance of Badenian volcaniclastic sediments of rhyolitic composition at the Zdenci locality.

In the Dubovik unit (Tro-I, Krž-I; Fig. 3) silty marls, calcsiltstones, and calcarenites, apart from the resedimented fossiliferous carbonate material, contain very small amounts of siliciclastic detritus. This siliciclastic material is essentially composed of fresh quartz and feldspar grains. In addition, altered feldspars (alkali feldspar and plagioclase) and rock fragments including quartzite, quartz-sericite schist, chert, acid intrusive rocks, slates and phyllite are also present.

Furthermore, at the Krž-I section, blocks and fragments of acid volcanic rocks: rhyolite, trachyrhyolite, perlite, and devitrificated volcanic glass were observed (Fig. 4E).

4.4. Kasonja unit

Clastic sediments of the Kasonja unit (Kas-I, Beč-I; Fig. 3) were deposited during the Sarmatian in a reduced marine environment (Fig. 2b). They are composed of siliciclastic and carbonate material. Sandy, silty sediments prevail over gravels that only occur sporadically.

Sands and sandstones are poorly to very poorly sorted, composed of very poorly rounded siliciclastic and carbonate material. Among the siliciclastic material fresh quartz and alkali feldspar grains are most abundant, while alterated feldspars, rock fragments (acid volcanic, chert and quartzite) and muscovite flakes are rare. In the HMF, THM are more abundant than opaque minerals. Tourmaline, epidote and garnet are the most abundant transparent phases, while staurolite and titanite are significant (Tab. 1). Carbonate particles are represented by redeposited fossiliferous material.

The gravel (Kas-I; Fig. 3) is composed of several types of rock fragments. The most common are represented by granite, garnet-muscovite gneiss (Fig. 4F), quartzite and quartz sandstone pebbles.

4.5. Croatica and Pavlovci units

The sediments of the Croatica unit were deposited during the Early Pannonian in a littoral brackish lake environment, while sediments of the Pavlovci unit were deposited during the Late Pannonian and Early Pontian in a brackish lake basin (Fig. 2b) (Zde-II; Fig. 3). They are built up of limestone and marl containing rare siliciclastic material with grains no larger than silt size. Only within the Croatica limestones centimetre thick layers of biocalcarenite composed of redeposited middle Miocene fossil debris occur.

4.6. Andraševec and Nova Gradiška units

Clastic material of the Late Pontian Andraševec and Nova Gradiška units (Kra-I, Zav-I, Zav-II; Figs. 2b and 3) is mostly composed of well sorted sand and silt deposited in prodelta and delta front environments. The main characteristic of the material is the predominance of siliciclastic detritus. Quartz is most frequent, followed by rock fragments, feldspar and muscovite (Tab. 1). Quartz grains are subrounded, while well rounded and poorly rounded grains are very rare. Among the rock fragments, quartzite is significant, while chert fragments are notable as well. Quartz-chlorite schist, quartz-sericite schist, slate, phyllite and quartz-feldspar bearing rock fragments are rare. Feldspars are altered. The most abundant feldspar is orthoclase, while microcline and plagioclase with polysynthetic lamella occur very rarely. THM are dominant in the HMF. Garnet and epidote are the most common. Amphibole, staurolite, tourmaline, rutile and kyanite are also significant (Tab. 1). Rutile and tourmaline are well rounded. In these units the amphibole is hornblende (KOVAČIĆ, 2004).

4.7. Cernik unit

The clastic material of the Cernik unit (StS-I, StS-II; Fig. 3) was deposited during the Pliocene in a lacustrine-fluvial environment (Fig. 2b). It is mostly composed of sandy and silty material with a clay component and small gravel lenses. The sorting of the material varies from poor to very good. Its modal composition is similar to the composition of the Andraševec and Nova Gradiška units (Tab. 1). However, there are some differences. Sands of the Cernik unit sporadically contain dolomite, and in most cases higher amounts of opaque minerals (predominantly limonite) tourmaline and rock fragments, and less feldspar than those of the Andraševec and Nova Gradiška units.

5. DISCUSSION

The poorly sorted sediments with gravel pebbles and blocks up to 40 cm in size in the Ravan unit, indicate short transport distances of the clastic material. The dominance of unstable rock fragments in the sandy material also implies short transport distances. Measurement of imbrication in gravels suggest a general palaeotransport direction for clastic material from the south (Fig. 5, Fig. 6A,B). The dominance of sandstones, siltstones, micritic and sparitic limestones among the pebbles and sand composition with lithoclasts of sandstones, partly abraded quartz grains and altered feldspars, point to the conclusion that the older sedimentary rocks had the most important role as a source for the clastic material. Furthermore, pebbles of anchimetamorphic rocks, marble and amphibole schist, as well as lithoclasts of slate-phyllite, quartz-sericite schist, quartz-chlorite schists, quartzite and epidote, garnet and amphibole in sands, show that part of the detritic material originated from weathering of different metamorphic rocks. The dominance of glaucophane in the sandy fraction is very interesting and suggests blue schists as the source rock for part of the material. Granitic and rhyolitic pebbles as well as tourmaline, zircon and rutile also indicate an acid

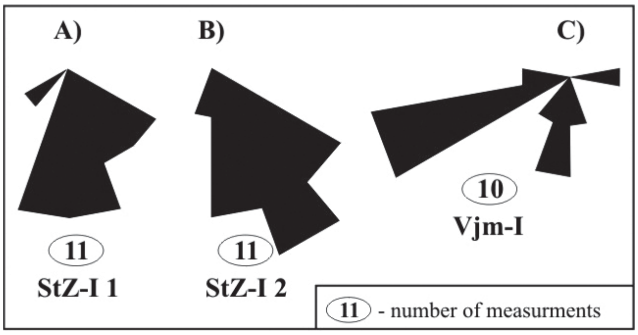

Figure 5: Rose diagrams of clast imbrication show palaeotransport of clastic materials in the Ravan unit from the south – south-east at StZ-I section (A, B) and from south – south-west at Vjm-I column (C).

magmatic source for the studied clastic deposits of the Ravan unit. These results suggest the conclusion that the source area for the clastic material of the Ravan unit was composed of various lithologies, mostly older sediments and metamorphic rocks, and was situated relatively close by, most probably south of Dilj gora Mt. (Fig. 6A).

PAVELIĆ & KOVAČIĆ (1999) have reported on material transport from the south for the oldest Miocene sediments of nearby Požeška gora Mt. South of the Dilj gora and Požeška gora Mts. lie the mountains of northern Bosnia. Intensive erosion of these uplifted mountains could provide clastic material which was then transported short distances to the north. Motajica, a mountain located 10 km south/southwest of Dilj gora Mt. in northern Bosnia, is a possible source. Namely, all rock types found among the gravels and sandy detrital material of the Ravan unit can be found at present on Motajica Mt. at the surface (VARIĆAK, 1966; ŠPARICA et al., 1980a,b; MUTIĆ & DMITROVIĆ, 1991).

The detritus of the Tuk unit is similar to that of the Ravan unit. However, the predominance of acid effusive rock fragments and fresh biotite in the sandy fraction, suggest that acid magmatic rocks had the leading role in material production. Those rocks are also present at the surface of Mt. Motajica (VARIĆAK, 1966; ŠPARICA et al., 1980a,b) but also at the surface of Požeška gora Mt. and Dilj gora Mt. This indicates the conclusion that part of the detritus of the Tuk unit could be local in origin like that of the overlying units (Fig. 2b).

The composition, transport directions and depositional environments of clastic detritus of the Ravan and Tuk units could be related to tectonic events in the southern part of the PB during the early Miocene. Prior to and during the older Miocene, the Internal Dinarides were uplifted south of Dilj gora Mt. (PAMIĆ et al., 2002). Simultaneously, along the southern margin of the PB, in the early syn-rift phase of its development, WNW-SSE elongated depressions were formed (PAVELIĆ, 2001; MARTON et al., 2002). Intensive weathering and erosion of the uplifted blocks, primarily of the Internal Dinarides in the area of northern Bosnia, and partly blocks within the PB, produced large amounts of clastic detritus which was deposited in these depressions. Changes in the depositional environment from terrestrial-lake (Ravan unit) to marine (Tuk unit) is an indicator that subsidence of the basin and an increase in accommodation space was faster than the rate of sediment supply. Similarly, the reduction of grain size of detritus in the Tuk unit in relation to the Ravan unit probably was the result of the removal of source areas to the south. It was a consequence of normal faulting occurring along the active southern margin of the PB during that time (JAMIČIĆ, 1995; PAVELIĆ & KOVAČIĆ, 1999).

Fossil carbonate debris, which is dominant in the Zdenci, Dubovik and Glogovica units, indicates the leading role of different marine organisms in the production of clastic material. The unaltered character of siliciclastic detritus from the insoluble residue of calcsiltites of the Dubovik unit indicates short transport distances, while the mineral composition and rock fragments suggests its origin mainly from acid igneous rocks, and subordinately from metamorphic rocks.

The absence of middle and coarse siliciclastic detritus within clastic detritus of these units indicates that during the Middle Miocene, most of the Dilj gora Mt. as opposed to other Slavonian Mts. including Psunj, Papuk and Krndija (PAVELIĆ et al., 1998) was out of range of siliciclastic detritus input. At that time Dilj gora Mt. area belonged to the southern part of Central Paratethys. In the shallower parts of the sea during the Badenian, fossil carbonate detritus was produced (Zdenci unit). Part of this detritus was resedimented into deeper basinal areas (Dubovik unit). The remainder, after falling sea level due to partial isolation of the basin in the early Sarmatian (STEININGER et al., 1988, RÖGL, 1996), was eroded and resedimented in the Glogovica unit. The origin of acid volcanic detritus of the Dubovik unit may be linked to pre-Badenian (PIKIJA et al., 2005), and possible Badenian (BELAK et. al., 1991) volcanism in Dilj gora Mt. area.

The presence of gravel and siliciclastic material in the sands of the Kasonja unit, beside fossil carbonate debris points to the fact that the western part of Dilj gora Mt. during the Sarmatian, was strongly influenced by clastic sedimentation material delivery. Textural immaturity of the sandy fraction as well as the significant presence of fresh alkali feldspars, suggests short transport distances. The composition of the material indicates different rock types as sources. Pebbles of granite, quartz grains with uniform extinction, particles of acid effusive rocks, alkali feldspars, tourmaline and titanite originated from acid magmatic rocks. Garnet-muscovite gneiss, quartzite pebbles and muscovite, garnet, epidote and staurolite originated from metamorphic rocks, while quartz sandstone pebbles and chert particles originated from the same type of sedimentary rock.

According to the results it can be presumed that the clastic material of the Kasonja unit is of local origin, but it is not possible to determine the exact location of the source area. This detritus may have come from the south, from the mountains of northern Bosnia, but could also have arrived from the nearby Slavonian Mts. (Požeška gora Mt., Papuk or Psunj Mts.) (Fig. 6A), which are also composed of the aforementioned rocks (JAMIČIĆ & BRKIĆ, 1987; JAMIČIĆ et al., 1987; KOROLIJA & JAMIČIĆ, 1989; ŠPARICA et al., 1980a,b, 1987a,b).

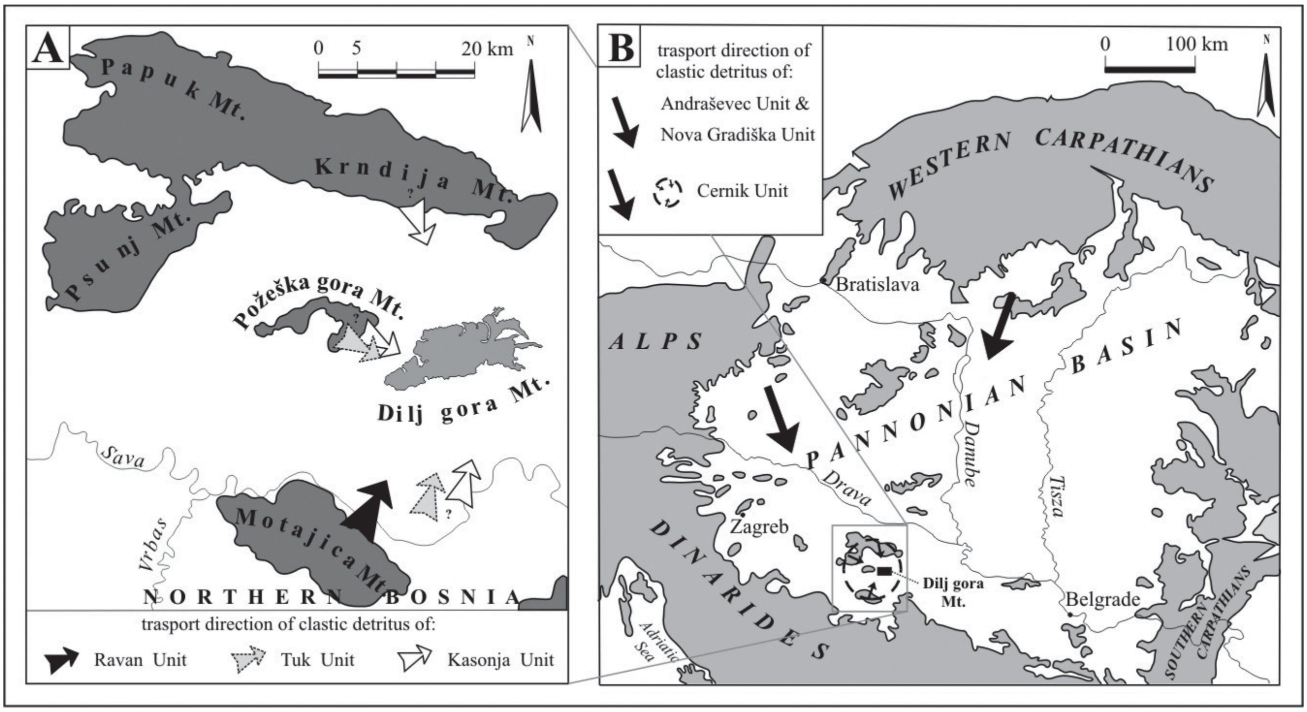

Figure 6: Sketch map of the Pannonian Basin System and its surroundings (B) simplified after ROYDEN (1988). (A) Enlarged part of the studied area and neighbouring mountains. Transport directions and source areas for the clastic detritus of older Miocene (A) and younger Miocene and Pliocene (B) sediments of Dilj gora Mt.

The absence of siliciclastic material in the Croatica and Pavlovci units shows that during the early Late Miocene, the area of Dilj gora Mt. was not under the significant influence of clastic material. The only evidence of clastic material input is centimetre thick biocalcarenite layers in the Croatica unit composed of resedimented middle Miocene fossil debris. Poor sorting and low roundness of the detritus suggests short transport distances, most probably from small local uplifts within the southern part of the Pannonian Basin. These blocks are uplifted due to inversion of the basin and falling sea level at the end of the Sarmatian (CSONTOS, 1995; HORVÁTH, 1995). Coarse and poorly sorted contemporaneous sediments from northern Bosnia, south of Dilj gora Mt. (STEVANOVIĆ & EREMIJA, 1977; ŠPARICA et al., 1980a,b), as well as thick sequences of clastic deposits in fresh-water basins within the Dinarides (PAVELIĆ, 2002), show that during the Late Miocene, the Dinarides produced huge amounts of clastic detritus which was deposited near the mountain chain or within the internal depression. Alternatively, material carried by prograding clastic systems from the Alps and Carpathians were deposited northern of the studied area (MAGYAR et al., 1999; KOVAČIĆ et al., 2004; KOVAČIĆ & GRIZELJ, 2006).

The well sorted and relatively well rounded particles in the Andraševec and Nova Gradiška units indicate its textural maturity, while the dominance of quartz and highly resistant rock particles prove their mineral maturity. Such a mature material could have been produced by lengthy transport or by multiple recycling. Measurements of cross stratification and cross lamination (PAVELIĆ, 2001; KOVAČIĆ & GRIZELJ, 2006) in sandy sediments imply transport of material from the north. The roundness of the quartz, tourmaline and rutile grains, together with the altered feldspars and the dominance of resistant THM in the HMF suggest that part of the detritus came from older sediments. The particles of low metamorphic rocks, quartz with undulatory extinction, heavy minerals like chlorite, epidote, garnet, kyanite and staurolite indicate different metamorphic rocks as additional sources of material. The presence of hornblende suggests that part of the material could have magmatic origin. Such composition of Late Miocene detritus was determined in the wider area of the south-western part of the PB (ŠIMUNIĆ & ŠIMUNIĆ, 1987; KOVAČIĆ & GRIZELJ, 2006).

The modal composition, textural maturity and transport directions of the detritus of the Upper Miocene Andraševec and Nova Gradiška units indicates that this material was derived from the weathering of different, predominantly sedimentary and metamorphic rocks, from sources situated relatively far to the north of Dilj gora Mt. (Fig. 6B). These results are consistent with investigations of provenance of clastic detritus deposited during the Late Miocene in the south-western (KOVAČIĆ & GRIZELJ, 2006; KOVAČIĆ et al., 2009) and central parts of the PB (THAMÓNÉ BOSZÓ et al., 2006). Their results suggested the conclusion that this material originated from the Alps and the Carpathians, and was delivered into the PB by prograding clastic systems. The progradation of clastic systems, shallowing and final infilling of the basin may be attributed to reduced subsidence rates in the latest part of post-rift phase of basin development (PAVELIĆ, 2001).

Beside the differences a notable similarity in modal composition among sands of the Cernik unit and underlying Andraševec and Nova Gradiška units indicates their common

(Alpine-Carpathian) provenance. However, the presence of gravel, sporadic poorer sorting of detritus and occurrence of carbonate detritus (dolomite), suggests that part of the detritus did not undergo significant transport, and is of local origin. Namely, some blocks in the southwest part of the PB were uplifted as a result of compression at the end of the Miocene, a process which intensified later in the Pliocene when the Cernik unit was deposited (JAMIČIĆ, 1995; TOMLJENOVIĆ & CSONTOS, 2001; MÁRTON et al., 2002). The erosion of these uplifted blocks, together with material arriving from the Alps and Carpathians, produced detritus for the Cernik unit (Fig. 6B). This is a prelude to the formation of new sources from the south at the end of the Pliocene(?) and during the Quaternary, evidenced by chert pebbles at the top of the Završje-I and Završje-II sections.

The investigation showed that the clastic material deposited during the Neogene in the area of Dilj gora Mt. has various textural characteristics and diverse modal compositions and provenance. These differences can not only be attributed to differing source rock compositions and locations of source areas, but are also the product of different controls on sedimentation. The most important controls were varying rates of subsidence and extension of the PB interrupted by compressional events, water-level changes in the PB connected with global sea-level changes and infilling by delta progradation.

6. CONCLUSIONS

The detritus of the oldest, Lower Miocene Ravan unit is mineralogically and texturally immature, brought dominantly from the south, and derived by weathering of sedimentary and metamorphic rocks from the Internal Dinarides. Motajica Mt. located southwest of Dilj gora Mt. in northern Bosnia, is the most logical source area since it is composed of all the rock varieties found in the clastic detritus of the Ravan unit.

Detritus of the Lower–Middle Miocene Tuk unit is mineralogically and texturally immature and originated by the weathering of acid magmatic and metamorphic rocks. Most probably it is a mixture of material from the Internal Dinarides, and material of local origin (Požeška gora and Dilj gora Mts.).

The origin of clastic material of the Ravan and Tuk units could be related to uplift of the Internal Dinarides before and during the Early Miocene, and to the formation of elongated depressions along the southern margin of the PB, in their early syn-rift phase. In most parts of Dilj gora Mt. during the Middle Miocene (Zdenci, Dubovik and Glogovica units) carbonate clastic detritus was deposited. This detritus formed by the accumulation of the remains of fossil marine organisms in the southern, marginal parts of Central Paratethys. The appearance of acid volcanic detritus in the Dubovik unit may be linked to the pre-Badenian and Badenian volcanism in Dilj gora Mt. area. Only in the Kasonja unit, in the western part of Dilj gora Mt., was deposition of clastic detritus significant. This detritus was derived from granitoids, metamorphic and sedimentary rocks. The sources of this material were most probably the PB basement rocks of the neighbouring Slavonian Mts. (Mts. Papuk, Krndija, Psunj, Požeška gora) or the Internal Dinarides of northern Bosnia (Motajica Mt.).

The older part of the Late Miocene area of Dilj gora Mt. (Croatica and Pavlovci units) composed of limestone and marl was not under the significant influence of clastic material. Rare carbonate clastic detritus most probably originated from the local hinterland, uplifted during compression at the end of the Sarmatian in the post rift phase of basin development.

The detritus of younger Late Miocene (the Andraševec and Nova Gradiška units) is of uniform composition, and is mineralogically and texturally mature. It was derived by weathering of different metamorphic rocks and older sedimentary rocks of the Alps and Carpathians. This material was transported into the southern part of the PB as a consequence of the progradation of clastic systems caused by reduction of subsidence rates of the PB in late post-rift phase of its development.

Most of the detritus of the Pliocene Cernik unit has the same Alpine-Carpathian provenance as the detritus of the Andraševec and Nova Gradiška units. Only a small part of the detritus was formed by weathering of sedimentary rocks from local blocks uplifted at the end of the Miocene as a result of a new compression phase in the PB.

ACKNOWLEDGMENT

This study was supported by the Ministry of Science, Education and Sports, project no. 181-1811096-1093 "Basic Geological map of Republic Croatia 1:50 000" and project no. 119-1191155-1159 "Evolutionary Changes of the Dinarides from Subduction to Modern Adriatic Beaches". We thank all members of the "Pannonian team", that worked on Dilj gora Mt. between 2004 and 2006. We are particularly grateful to Ivo SUŠA (Croatian Geological Survey) for help with drawings and Borna LUŽAR-OBERITER (Faculty of Science, University of Zagreb) for language editing. The authors acknowledge THAMÓ-BOZSÓ Edit (Geological Institute of Hungary, Budapest) and to an Anonymous Reviewer for their useful comments and suggestions which substantially improved the submitted manuscript.

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Manuscript received December 08, 2010
Revised manuscript accepted March 24, 2011
Available online June 09, 2011