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PLEISTOCENE GLACIAL AND PERIGLACIAL SEDIMENTS OF KVARNER, NORTHERN DALMATIA AND SOUTHERN VELEBIT Mt. - EVIDENCE OF DINARIC GLACIATION

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Doctoral Thesis

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LJERKA MARJANAC

Thesis completed in: Croatian Academy of Sciences and Arts, Institute of Quaternary Paleontology and Geology, 10000 Zagreb, Ante Kovačića 5, Croatia

Abstract

The research comprised field study of Quaternary sediments on Krk, Rab and Pag Islands, Senjska Draga, Jablanac, South Velebit, the coast of Velebit Channel, and Northern Dalmatia (Novigrad Sea, Karin Sea, Obrovac, Paljuv and Smilčić), detailed logging, outcrop mapping and radiometric dating, and the sedimentological data confirmed glacigenic interpretation of the studied sediments, namelly: Glacial sediments, tills or tillites form ground, medial or lateral moraines, and their main characteristics are clasts with glacial striae, ice-shaped (faceted, bullet-shape and conical) and ice-shattered clasts. Glacifluvial sediments comprise glacial outwash deposits of braided streams and flood plains, and fluvial deposits of meandering rivers. The glacigenic origin is based on their occurrence with tills or tillites, and glacially-derived debris. Glacilacustrine sediments comprise clay-silt sediments with classic varves, and varve-like calcisiltites with drop-stones. Glacideltaic sediments are conglomerates, calcarenites and calcisiltites in alternation. Ice-striated clasts, and their association with glacilacustrine sediments, document their glacigenic origin.

The following depositional paleoenvironments were reconstructed: a) glacial environment is documented by ground and lateral moraines. The ground moraines are indentified as Rujno, Paklenica and Novigrad members and two tentative members are Sklopine and Raduč. The Paklenica member, found also on Krk and Rab Islands, documents the furthest extent of glaciation. Another characteristic landform of ice-contact zone are kame terraces well preserved on the Krk and Pag Islands. b) proglacial environment influenced by melting ice and glacial outwash processes is widespread in Northern Dalmatia, and proglacial lacustrine sediments of ždrilo, Seline and Novigrad. c) periglacial environment, is recognized in sediments of Novigrad section, were ice-wedge casts and kettle-forms occur, which indicate freezing and thawing of sediment.

The sedimentological data proved far seawards extention of the Dinaric glaciation which at the most advanced phase reached islands of Krk, Rab and Pag, a large part of Northern Dalmatia, and the whole Velebit Channel. Chronostratigraphic correlation of sediments is based on allostratigraphy and ^{14}C and U-series ages of sediments, which allowed attribution of the Middle Pleistocene age to most of the studied sediments.

Keywords: Middle Pleistocene, sediments, glacial, periglacial, Dinaric glaciation, Adriatic, Velebit
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PLEISTOCENSKE GLACIJALNE I PERIGLACIJALNE NASLAGE KVARNERA, SJEVERNE DALMACIJE I JUžNOG VELEBITA - DOKAZ DINARIDSKE GLACIJACIJE

LJERKA MARJANAC

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Sažetak:

Ovaj rad obuhvaća terensko istraživanje kvartarnih sedimenata na Krku, Rabu i Pagu, u Senjskoj dragi, Jablancu, na južnom Velebitu, duž obale Velebitskog kanala i u sjevernoj Dalmaciji (Novigradsko more, Karinsko more, Obrovac, Paljuv i Smilčić), snimanje detaljnih sedimentoloških stupova, kartiranje izdanaka i radiometrijsko datiranje. Sedimentološki podatci su potvrdili glacigenu interpretaciju istraženih sedimenata, i to: glacijalnih sedimenata, tilova i tilita koji tvore podinske, središnje i bočne morene, a njihova su glavna karakteristika klasti s ledenjačkim strijama, ledom oblikovani klasti (fasetirani, konični i kopljasti) i raspuknuti klasti, glaciofluvijalnih sedimenata koji obuhvaćaju sedimente ispiranja, istaložene u prepletenim koritima i poplavnim ravnicama, te sedimente meandrirajućih rijeka koji su pridruženi tilovima i tilitima, a sadrže ledom doneseni detritus, glaciolakustrinskih sedimenatai koji obuhvaćaju glinovito-siltne sedimente s klasičnim varvama i varvama slične siltite s ledenjačkim utruscima, te glaciodeltaičnih sedimenata zastupljenih konglomeratima, kalkarenitima i kalcisiltitima u izmjeni, na čije ledenjačko porijeklo ukazuju klasti sa strijama i njihovo pojavljivanje u zajednici s glaciolakustrinskim sedimentima. Rekonstruirani su sljedeći taložni okoliši: a) glacijalni koji obuhvaćaju podinske, središnje i bočne morene. Podinske morene su izdvojene kao alo-članovi Rujno, Paklenica i Novigrad, te dva moguća člana Sklopine i Raduč. Paklenica-član dokumentira najdalji doseg leda. U zoni kontakta s ledom razvijene su kame-terase na otoku Krku i Pagu, b) proglacijalni okoliš pod utjecajem lada koji se topio i glacijalnog spiranja a koji je rasprostranjen u sjevernoj Dalmaciji s jezerskim sedimentima kod ždrila, Selina i Novigrada, i c) periglacijalni okoliš koji se nalazi u Novigradskom području i obuhvaća ledenjačke klinove i kotlaste forme koje ukazuju na višekratno smrzavnaje i taljenje sedimenata i tla. Sedimentološki podatci potvrdili su daleko prostiranje Dinaridske glacijacije koja je u najintenzivnijem razdoblju zahvatila Krk, Rab i Pag te velik dio sjeverne Dalmacije i Velebitski kanal. Kronostratigrafska korelacija sedimenata zasniva se na alostratigrafiji i datiranju po 14C i U-seriji, što je omogućilo određivanje srednje pleistocenske starosti za većinu istraženih sedimenata.

Ključne riječi:Srednji pleistocen, sedimenti, glacijalni, periglacijalni, Dinaric glaciation, Adriatic, Velebit
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CONTENTS

1. INTRODUCTION

Quaternary deposits, especially those of Pleistocene age, attract today special attention of geologists and other scientists because they contain information about significant climatic changes during the past 2.6 million years, particularly the period of the appearance of mankind. In spite of this fact, the Quaternary has not been given adequate significance in terms of geological investigation throughout Croatia.

Since Quaternary deposits in the offshore Northern Adriatic are known gas-reservoirs, a strong need for correlation with Quaternary onshore deposits arose. Therefore, already in 1988, began the exploration of Quaternary deposits of the eastern Adriatic, namely the islands and the coastal area, as a long-term project of INA-Naftaplin, the Croatian petroleum company, and executed within the research unit of INA-Projekt.

Firstly as a collaborator and later as project leader of this research, I began my investigations on the Quaternary deposits in 1989, which in time became the major object of research as part of the project "Sedimentologic and stratigraphic exploration of Neogene and Quaternary of External Dinarides" conducted in INA-Projekt, a satellite company of INA-Naftaplin. The primary task was to describe the Pleistocene age sedimentary facies, define sedimentary processes, sedimentary environments and systems, and to interpret their mutual relationship and chronostratigraphy. In a very short time, the results obtained by preliminary explorations indicated on glacial and periglacial origin of majority of Pleistocene sediments in the studied area of the coastal Dinarides and some Adriatic islands. The results supported the working hypothesis that older Pleistocene glaciations affected larger coastal Adriatic area, and that glaciers reached beyond the modern sea level, all of which provided a completely knew perspective on paleogeographic reconstruction of the coastal Dinarides and adjacent areas. The thinking of my collaborator and life-partner T. Marjanac about glaciated Adriatic lowlands (today Adriatic islands, mainland coast and hinterlands of Zadar) and Velebit mountain, became reality and provoked lively discussions at the 3 km long Novigrad Sea coastal section, which we began to study in 1989.

Starting in 1990, these rather revolutionary results were brought to public through scientific and popular-scientific lectures (1990 - 2010), popular-scientific papers (1991, 2001, 2009), scientific publications (Marjanac et al., 1990, Marjanac & Marjanac, 2004), many conference abstracts and presentations (IAS 1991, Carpatho-Balkan Assoc. Mtg. 1992, IAS 1994, INQUA 1999, Pancardi 2000, ADRIA 2006, INQUA-SEQS 2006, ProGEO 2007, Postojna 2008, INQUA-SEQS 2008) and several field excursion guide books (Geotrip 1999, IAS Lecture Tour 2000, 32. International geological congress 2004, ADRIA 2006, OUGSME 2007, ProGEO 2008) (see Chapter 16.).

It obviously took many years of convincing the international geological society to acknowledge Adriatic (Dinaric) glaciation. Further research is now towards an international approval of Dinaric glaciation as one of major middle Pleistocene glaciations of the Mediterranean.

It is worthy to note that the earliest ideas on glaciation of the Velebit Mt. date from the 19th Century, and were fostered by geomorphologists. Milojević (1922) was the first to ascribe clastics in Velika Paklenica canyon to glacial deposits, in other words he was the first to mention sediments, while the ideas of his predecessors (Penck, 1900, Hranilović 1901, Gavazzi 1903a, 1903b) were based solely on geomorphological observations. Review on previous research is presented in Chapter 2.

Thus, generally insufficient knowledge about Quaternary deposits additionally motivated further research with aim to interpret the sedimentary processes and reconstruct palaeo environments. In order to obtain satisfactory data base for reconstruction of the Pleistocene palaeo environments in the Adriatic, the Pleistocene deposits were studied at many outcrops within the study regions of Kvarner, Southern Velebit Mt. and Northern Dalmatia (Figure 3.1.). Although the exploration covered very large area, this Thesis presents and explains only the most important localities, which were studied in detail, and which document the extent of the Pleistocene glaciations in the studied region. Several new study locations (like Kalifront and Krklant on Rab Island, Stinica near Jablanac, Ždrilo, Kusača, Maslenica and Modrič related to Starigrad-Paklenica) under preliminary observation are also included in the Thesis, because of supporting evidence and obvious necessity of further research. The aim of this Thesis was also to provide a fundamental data base and context for future interdisciplinary and regionally more extensive research of the Dinaric glaciation.

This twenty years long research of the Pleistocene deposits along the eastern Adriatic islands and the mainland coast, Southern Velebit mountain, and North Dalmatia is presented in 12 chapters of the thesis. Such a long-term study was interrupted by the Croatian War of Independence (1990-1995), which predominantly affected field work options. The mine fields, which remained after the war, still make many key areas inaccessible.

For all these years field work was conducted more or less continuously, which provided more and more supporting evidence. After closing of INA-Naftaplin project in 1991 due to the war conditions, my further research as well as elaboration of this doctoral thesis based on the

working-hypotheses of a very extensive glaciation of the Adriatic during the older Pleistocene, became part of the national research projects financially supported by the Croatian Ministry of Science, Education and Sports: “*Evolution of Cenozoic basins and genesis of clastics in Adriatic region*” (119303) conducted by T. Marjanac (University of Zagreb) in the period 1997 - 2000, “*Paleontology of vertebrates and chronostratigraphy of Quaternary*” conducted by late M. Paunović (Croatian Academy of Sciences) in the period 1990 - 1996, “*Geologic effects of bolide impacts*” (0119401) conducted by T. Marjanac in the period 2002 - 2006 and “*Impacts and associated geological events in evolution of Dinarides"* (119-000000-1164) also conducted by T. Marjanac in the period 2007-2011. The results achieved in the period from 1988 until 1992 when I was a researcher in INA-Projekt, were the basis for doctoral thesis with permission of the investor INA-Naftaplin.

Radiocarbon dating of five samples was undertaken in the laboratory at the Institute "Ruđer Bošković" in Zagreb, and was financially supported by the above mentioned research project conducted in INA-Projekt.

Uranium series dating of moraines was obtained through the collaborative research project "*Timing of extensive ice cap glaciation in the northeast Adriatic mountains, Croatia: implications for moisture supply and cyclogenesis in the Mediterranean basin"* conducted by Ph. Hughes (University of Manchester) and financially supported by the UK Natural Environment Research Council (NERC Grant 2009).

Besides the fact that such a long-term research yielded a large amount of data on genetically various Quaternary sediments, this Thesis emphasizes the sediments of glacial origin (tills and tillites) described in the Chapter 5.1, and related glacial landforms (moraines, kame-terraces) described in the

Chapter 6.1. Associated sediments of proglacial and periglacial environments are presented in the Chapter 5.2 .and related geomorphological features in the Chapter 6.2., while the pre-glacial and post-glacial sediments are presented in general in order to express an overall complexity and diversity of the Pleistocene environments and events recognized in the study area, which are as well relevant for broader region of Dinaric Alps (the Dinarides).

In order to better present the nature of the studied outcrops that are commonly isolated locations with no possibility of lateral correlation, the Chapter 3 is organized as a catalogue of sites giving detail description of the site regarding geographical data, axcessibility, morphology, geology and interpretation by previous authors, and general new results. At the same time this review of Quaternary sites should provide data for later evaluation of potential geohritage sites of regional/international importance.

2.
PREVIOUS RESEARCH OF PLEISTOCENE DEPOSITS IN EASTERN ADRIATIC AND COASTAL DINARIDES, A REVIEW

The Quaternary deposits of the studied area have been first described by Alberto Fortis in his book about travels in Dalmatia published in 1774 (translated in Croatian by Bratulić 1984).

Quaternary relief was studied by Hranilović (1901), Gavazzi (1903 a, b), Gregory (1915), Roglić (1949, 1963, 1969), Šegota (1960, 1968, 1982), Nikler (1973), Riđanović (1964), Marković-Marjanović (1976), Belij (1985), and Perica (1993).

First comprehensive geological study of the Quaternary sediments was carried out during mapping for Austro-Hungarian geological maps of Kvarner and Dalmatia (Waagen 1905, 1911, 1913, 1914, 1916; Schubert & Waagen, 1913). The authors very precisely determined outcrops of Quaternary sediments as "*Altquartäre Sande und Lehme*" ('Old Quaternary sands and clays') or only "*Altquartär*" ('Old Quaternary') and younger Quaternary deposits, namely "*Diluvium, Gehängeschutt, quartär Breccien und Sande"* ('diluvium, slope talus, Quaternary breccia and sands'). These sediments are described in detail in Chapters 5 and 6 in relation to particular studied sites.

Regional explorations related to geological mapping for *Osnovna geološka karta Jugoslavije* (General Geological Map of Yugoslavia) in scale 1:100.000 were performed in 1960-es to 1980-es. During that period, Quaternary deposits were locally studied in detail, but mostly could not be distinguished and outlined in many sections of the General Geological Map due to limited extent of outcrops, as well as the map scale. *Tumač Osnovne geološke karte Jugoslavije* (Explanation book of General Geological Map) contains usually only short descriptions, and in spite of the data based on the maps in scale 1:25.000, a limited number of papers about Quaternary in Croatia, based on this database, was published later on.

The Quaternary deposits of the studied area have been basically treated as a subordinate topic, and in many papers they are mentioned only in a short description: Fritz & Pavičić (1982), Fritz (1967, 1972, 1977), Blašković (1983), and others. On the contrary, Malez spent most of his scientific career on Quaternary geology of Yugoslavia, giving emphasis on cave sediments and fossil fauna found in those sediments. He published more than hundred and fifty papers regarding Quaternary of southwest Croatia, visited more than four hundred caves, conducted long-term excavations at several significant sites (Šandalja, Vindija, Veternica, Velika Pećina etc) and collected numerous fossil remains of the Pleistocene fauna, and later his collaborators continued palaeontological research of the Pleistocene fauna in the Adriatic region reviewd by Herak et al. (2005). Several contributions about Pleistocene gastropods were written by Poje (1990), Štamol & Poje (1998), Marjanac et al. (1992/93) and about ostracods from lacustrine deposits by Ana Sokač (1975), Malez & Sokač (1968) and Malez et al. (1969). Šimunić (1971) presented in his Master Thesis the Quaternary sediments of Kninsko polje (adjacent to the study area of North Dalmatia (ND)). Kastmüller (1989) studied in detail the Pliocene-Pleistocene sedimentary succession exposed in then active clay-pit in Strmica near Knin and presented results in his Master Thesis.

However, the Pleistocene sediments of the Adriatic region have already been observed by naturalists and described more than 200 years ago. In 1774 Fortis (Bratulić, 1984) described Quaternary sediments of Susak Island. Later on, Quaternary was studied by geologists and geomorphologists Schubert (1909), Salmojraghi (1907), Roglić (1949, 1963, 1969), Blašković (1983), Bognar (1978, 1979, 1986, 1989) and Cremaschi (1990). Milojević (1927, 1933) nicely described outcrops of Quaternary sediments on the Adriatic islands and Dinaric coast, and also described traces of glaciers on the Velebit Mt.

It is important to note that Cvijić (1917) described the glaciation of southern parts of the Dinarides already at the beginning of the 20th century, but at elevations higher than 1000 m a.s.l. It is interesting that even before Cvijić, English geographer Gregory (1915) described various relief forms in Dalmatia, as well as glacial features of Montenegro. Although the Dalmatian relief appeared to him as of glacial origin, he was reluctant to attribute them as such, but chose to call them "pseudo glacial features".

The idea that at least the highest peaks of Croatian External Dinarides were glaciated dates back to 1899 and Albrecht Penck's journey through Dinarides. Hranilović (1901), Gavazzi (1903 a, b) and Schubert (1909) also promoted the idea of glaciation on the Velebit Mountain, but it was not accepted by other researchers (i.e. Gorjanović, 1902). Later on, geomorphologist Milojević (1922) described what he interpreted as glacial deposits in the Paklenica canyon on the Velebit Mountain, and so did also Bauer (1934/35) and Degen (1936). However, their ideas were rejected by J. Poljak (1947) who regarded all of the evidence quoted by previous authors as misinterpretations, and he favored fluvial origin of extremely coarse-grained sediments first described by Milojević (1922) and herein illustrated in Figures 3.62 to 3.64. Malez (1968) made a general statement that the mountain tops of the coastal Dinarides, including the Velebit Mountain, were glaciated during Pleistocene, but provided no documentation. Nikler (1973) first described well preserved "terminal" moraine ridge on the Velebit Mountain, located at 920 m a.s.l. (for details see Chapter 6). More complex geomorphological study of the same part of the Velebit Mountain was conducted by Belij (1985) who reconstructed the path and extent of the corresponding valley glacier. During the past ten years new evidence about glaciation of the Northern Velebit Mt. were presented by Roglić (1963), Faivre (1991), Bognar & Prugovečki (1997), Bognar & Faivre (2006) and Velić et al. (2011), but ascribing all evidence to Würm glaciation.

The first idea ever that even Mediterranean (and consequently the Adriatic Sea as the most northern epicontinental sea) was affected by Pleistocene glaciation has been briefly expressed by Louis Agassiz (1840), who unfortunately provided no supporting evidence. Later in 1907 a paper by Prister was presented at the 25th Annual Convention ALPI GIULIE describing in detail the traces of glaciation of the Trieste karst region and glaciers that descended from Nanos Mountain all the way to the gulf of Trieste (Prister, 1907).

The first supporting data to glaciation hypothesis are glacial sediments recognized at several locations of coastal Adriatic (Marjanac et al. 1990, Marjanac T. & Marjanac Lj., 1991). An overview of glaciation of the Adriatic islands and coast (including southern Velebit Mt. and a part of northern Dalmatia) published in 2004 by Marjanac & Marjanac finally attracted the international geological community for further joint studies, and in 2006 the authors proposed that the "Dinaric glaciation" should be recognized as a model for glaciation of the Dinaric Alps as part of the Mediterranean region especially because of its importance in origin of Dinaric karst (Marjanac & Marjanac, 2008).

Since 2007 several papers written by Hughes and coauthors (2006 a, 2006 b, 2007, 2010) brought new evidence of Middle Pleistocene glaciation in the Mediterranean, Pindus Mountains in Greece and Orjen in Montenegro, respectively. Hughes et al (2011) also reconstructed the glacial history of the Dinaric Alps in central Montenegro. Recently, Stepišnik et al (2010) mapped glacial features in the area of Lovčen Mt. in Montenegro. They atributed all features and moraines to the last glacial maximum, including moraines found in Kotor Bay at sea level.

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3.
STUDY AREA AND ITS GEOLOGICAL FRAMEWORK

The studied area comprises regions of Kvarner (northern Adriatic islands of Kvarner Bay), Southern Velebit Mountain and Northern Dalmatia (Figure 3.1.). Studied sites are located within range between modern sea-level and elevations up to 1000 m above sea-level.

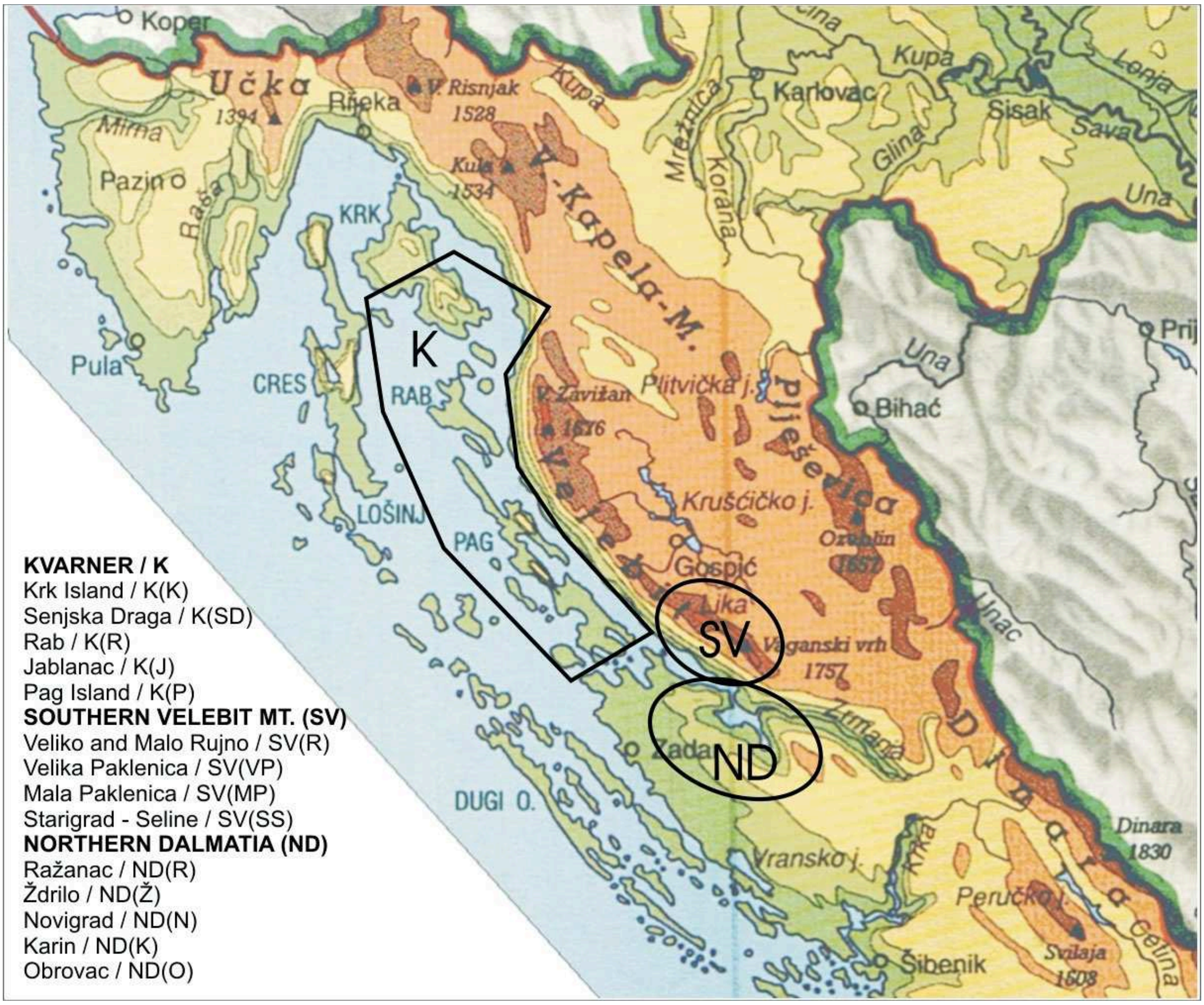


Figure 3.1. Study regions (bold) and study zones presented in this Thesis, and abbreviations (in parentheses) used in text.

Slika 3.1. Istražne regije (masna slova) i istražne zone opisane u ovoj dizertaciji, i kratice (u zagradama) korištene u tekstu.

Although the exploration was carried out in very large area, this Thesis presents and explains only the most important localities which were studied in detail and which document the extent of Pleistocene glaciations in the southwest Croatia, and were the basis for reconstruction of palaeo-environments. The study area is divided in three study regions, each comprising several study zones (Fig. 3.1.) with a number of observation stops, which are presented in this chapter.

The studied Pleistocene deposits occur in various geological settings. The Pleistocene deposits include a variety of lithologies of different origin and sedimentary environments. Due to such diversity, including variability of bedrock, geological setting will be explained for each study region, zone or location in the following text. Table 3.1. shows the coverage of the study area by General Geological Maps in scale 1:100.000 published by the Federal Geological Institute of former Yugoslavia.

Table 3.1. Sheets of the General Geological Map used for geological framework explanation of the study zones.
Tablica 3.1. Listovi Osnovne geološke karte korišteni za opis geološke građe istraživanih područja.

GENERAL GEOLOGICAL MAP, Sheet Osnovna geološka karta Jugoslavije, list	**STUDY ZONE COVERAGE** Pokriva istražnu zonu	**EXPLANATION BOOK** Tumač lista
CRIKVENICA (Šušnjar et al., 1970)	Krk island	Šušnjar et al., 1973
RAB (Mamužić et al., 1969)	Krk, Senj, Prvić, Rab, Pag	Mamužić et al., 1973
GOSPIĆ (Sokač et al.., 1974)	Pag, Rujno	Sokač et al., 1976
SILBA (Mamužić et al., 1970)	Pag	Mamužić et al., 1973
ZADAR (Majcen et al., 1970)	Pag, Starigrad, Seline	Majcen et al., 1973
UDBINA (Šušnjar et al., 1973)	Velika and Mala Paklenica	Sokač et al., 1976
OBROVAC (Ivanović et al., 1973)	Ždrilo, Ravni Kotari, Bukovica	Ivanović et al., 1979

Table 3.2. Review of studied sites in the Kvarner study region and site coding in the text.

Tablica 3.2. Pregled istražnih lokacija u istražnoj regiji Kvarner, te oznaka u daljnjem tekstu.

KVARNER STUDY REGION - K				
Study zone	*Code*	*Name of study site*	*Study site code*	*Sediment log code*
KRK ISLAND	**K(K)**	Baba	K(K)-1	
		Suha Ričina	K(K)-2	
		Jurandvor	K(K)-3/1	
			K(K)-3/2	
			K(K)-3/3	
			K(K)-3/4	
			K(K)-3/5	
			K(K)-3/6	
			K(K)-3/7	
		Batomalj	K(K)-4	
		Baška Gajevi	K(K)-5/1	K(K)-5-L1
			K(K)-5/2	
			K(K)-5/3	
			K(K)-5/4	
		Baška Žarok	K(K)-6/1	K(K)-6-L1 to -L9
			K(K)-6/2	
			K(K)-6/3	
		Stara Baška	K(K)-7	
		Prvić Island	K(K)-8/1	
			K(K)-8/2	
SENJSKA DRAGA	**K(SD)**	Senjska Draga	K(SD)-9	
		Vratnik	K(SD)-10	
RAB ISLAND	**K(R)**	Pudarica	K(R)-11	
		Mišnjak	K(R)-12	
		Mag	K(R)-13	
		Krklant	K(R)-14	
		Lopar	K(R)-15	
		Supetarska Draga	K(R)-16	
		Kalifront	K(R)-17	
		Sv. Grgur	K(K)-18	
JABLANAC	**K(J)**	Jablanac	K(J)-19/1	K(J)-19-L1
			K(J)-19/2	K(J)-19-L2
			K(J)-19/3	
		Stinica	K(J)-20/1	
			K(J)-20/2	
PAG ISLAND	**K(P)**	Metajna	K(P)-21/1	
			K(P)-21/2	
			K(P)-21/3	
			K(P)-21/4	
		Crnika	K(P)-22/1	K(P)-22-L1, -L2
			K(P)-22/2	
			K(P)-22/3	
			K(P)-22/4	
		Bošane	K(P)-23	K(P)-23-L1, -L2, -L3, -L4
		Gradac	K(P)-24/1	
			K(P)-24/2	
			K(P)-24/3	
		Gorica	K(P)-25	

Table 3.3. Review and coding of studied locations in the Southern Velebit study region.

Tablica 3.3. Pregled istražnih lokacija i oznaka u istražnoj regiji Južni Velebit.

SOUTHERN VELEBIT STUDY REGION SV				
VELIKO I MALO RUJNO	SV(R)	Veliko Rujno	SV(R)-1	
			SV(R)-2	
			SV(R)-3	
			SV(R)-4	
		Rujanska Kosa	SV(R)-5	
			SV(R)-6	
		Pričetrnja	SV(R)-7	
		Zavrata	SV(R)-8	
VELIKA PAKLENICA	SV(VP)	Vaganac	SV(VP)-9	
		Bezimenjača	SV(VP)-10	
		Sklopine	SV(VP)-11	
		Kneževići	SV(VP)-12	
		Mokrača	SV(VP)-13	
		Crno Vrilo	SV(VP)-14	
		Velika Paklenica	SV(VP)-15	
			SV(VP)-16	
		Borisov Dom	SV(VP)-17	
			SV(VP)-18	
		Velika Paklenica	SV(VP)-19	
			SV(VP)-20	
			SV(VP)-21	
		Anića Luka	SV(VP)-22	
		Velika Paklenica	SV(VP)-23	
			SV(VP)-24	
			SV(VP)-25	
			SV(VP)-26	
MALA PAKLENICA	SV(MP)	Mala Paklenica	SV(MP)-27	
			SV(MP)-28	
			SV(MP)-29	
STARIGRAD - SELINE	SV(SS)	Veliki Ravnik	SV(SS)-30	
		Uvala Kusača	SV(SS)-31	
		Tribanjska Draga	SV(SS)-32	
		Dokoze	SV(SS)-33	
		Starigrad	SV(SS)-34	
			SV(SS)-35	
		Seline	SV(SS)-36	
			SV(SS)-37	SV(SS)-37-L1
		Provalija	SV(SS)-38/1	
			SV(SS)-38/2	
			SV(SS)-38/3	
		Zečica	SV(SS)-39/1	
			SV(SS)-39/2	
			SV(SS)-39/3	
			SV(SS)-39/4	
		Modrič	SV(SS)-40/1	
			SV(SS)-40/2	
			SV(SS)-40/3	
			SV(SS)-40/4	
LIKA	SV(L)	Raduč	SV(L)-42	
		Zir	SV(L)-42	

Table 3.4. Review of studied locations in the Northern Dalmatia study region with indicated coding of locations.
Tablica 3.4. Pregled istražnih lokacija u istražnoj regiji Sjeverna Dalmacija i prikaz oznaka lokacija.

NORTHERN DALMATIA STUDY REGION ND				
RAŽANAC	ND(R)	Uvala Radanovica	ND(R)-1	
		Uvala Jabučarica	ND(R)-2	
		Crvena pećina	ND(R)-3	
ŽDRILO	ND(Z)	Uvala Kusača	ND(Z)-4	
		Uvala Porat	ND(Z)-5	
		Uvala Poljice	ND(Z)-6	
		Uvala Gaunarica	ND(Z)-7	
NOVIGRAD	ND(N)	Maslenica	ND(P)-8	
		Posedarje	ND(N)-9	
		Novigrad Sea coast	ND(N)-10	ND(N)-10-L1 to -L7
		Paljuv	ND(N)-11	
		Smilčić	ND(N)-12	
KARIN	ND(K)	Karin	ND(K)-13/1	
			ND(K)-13/2	
OBROVAC	ND(O)	Obrovac	ND(O)-14	

3.1. KVARNER (K)

Kvarner is the bay area in the northern Adriatic Sea, located between the Istra peninsula and the northern Croatian coast. The main islands in Kvarner bay are Cres, Krk, Pag, Rab and Lošinj. Senj and Jablanac are included in this region because they are very close to studied islands Krk and Rab, although located on the mainland coast.

3.1.1. KRK ISLAND / K(K)

The Krk Island is the largest Adriatic island with area of 410 km^2. Its largest part is built of carbonate rocks: Cretaceous limestones and dolomites, Eocene Foraminiferal limestones, Eocene Flysch (siliciclastic sediments), Eocene-Oligocene carbonate coarse-clastic breccia, and Quaternary breccias and sands and gravels (Šušnjar et al., 1963; Mamužić et al., 1969). Newer explorations revealed an asteroid-impact origin of the Post-Eocene coarse-clastic breccia (Marjanac et al, 2002, 2003, 2006).

Pleistocene sediments cover various parts of the island restricted to rather small areas. Nevertheless, some exposures are exceptionally good, especially in the southeast section of Krk island (the area of Baščanska Draga valley, Fig.3.2.).

Waagen (1911) wrote about the outcrops of horizontally bedded carbonate sands eastwards of the Dobrinj village near Šilo, on the northeast side of Krk Island. He defined these deposits as *"Altquartärer Sand"* ('Old Quaternary sand') of reddish color, filling a depression, overlain by poorly to well cemented limestone breccias or sandstones. The 'Old Quaternary sands' cover about 2 km^2 and are 4-6 m thick, and comprise fossil gastropod fauna, similar to fauna of the middle European "diluvial" loess. Schubert (1909) determined the following gastropod species: *Helix (Xerophila) striata*, *Helix (Vallonia) pulchella* and *Pupa (Pupilla) muscorum* indicating older Quaternary age of those deposits. Šušnjar et al. (1963) described sediments near Šilo as "*yellow-brown well-stratified sands and gravels, possibly of lacustrine origin*". Marjanac et al. (1992/93) described Šilo sediments and sedimentary facies in detail and revealed upper Pleistocene (Würm interstadial) based on *Striata fauna* studied by late M. Poje and presented in the same paper. Mamužić et al. (1969) mapped the sediments in Baščanska Draga (Baška valley) as "*deluvial deposits consisting of sands, gravels and slope talus*". The Krk study zone (Fig. 3.2.) comprises three sub-zones studied in detail (Stara Baška, Baška-Gajevi and Baška-Žarok) where 11 sediment logs were made. The other three are observation stops (Baba, Suha Ričina, Batomalj).

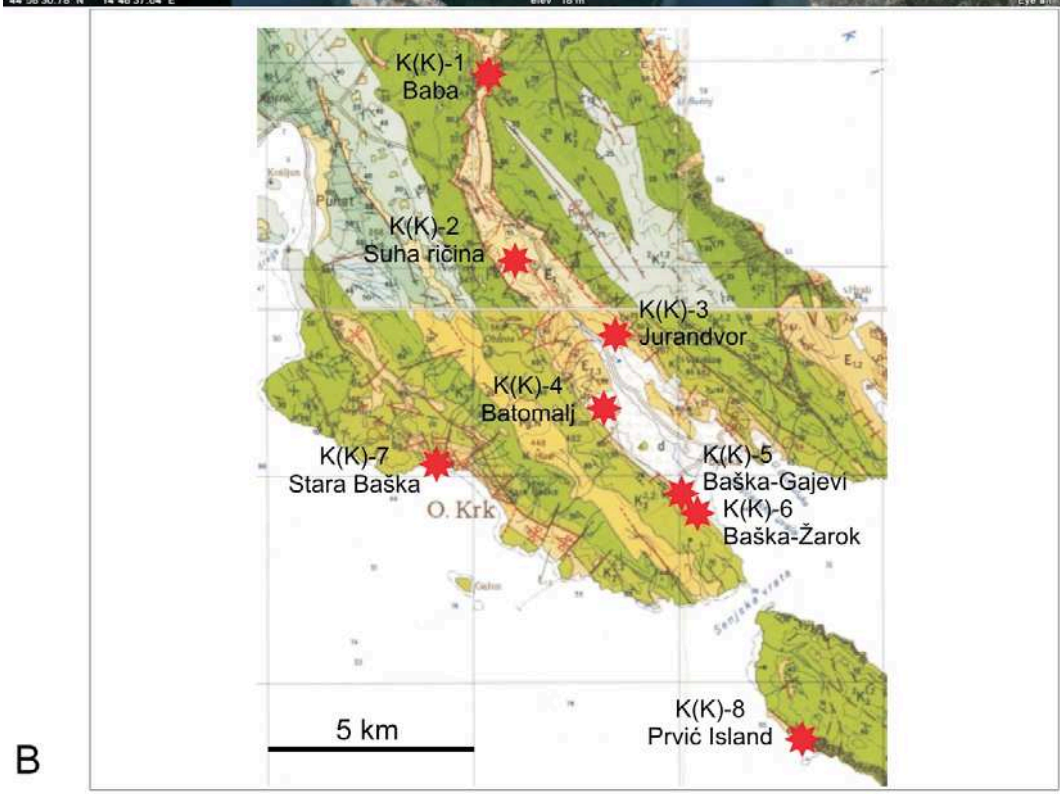


Figure 3.2. A - Study zone Krk island (K) with study sites. Google Earth image 2011. B - Geological framework of the Krk island study zone (General Geological Map 1:100.000, Sheets Crikvenica (Šušnjar et al., 1970) and Rab (Mamužić et al., 1969).

Slika 3.2. A - Istražna zona Otok Krk (K) s istražnim lokacijama. Google Earth snimak 2011. B - Geološka karta područja (Osnovna geološka karta 1:100.000, listovi Crikvenica (Šušnjar et al., 1970) i Rab (Mamužić et al., 1969).

3.1.1.1. Krk - Baba / K(K)-1

The studied site Baba is located at the northern end of Baščanska Draga valley (Fig. 3.3. A) where the outcrop is an isolated, tooth-like occurrence of breccia, standing in the middle of the valley (Fig. 3.4). This Pleistocene breccia lays on Eocene clastics (Fig. 3.3. B), but the contact is not clearly visible.

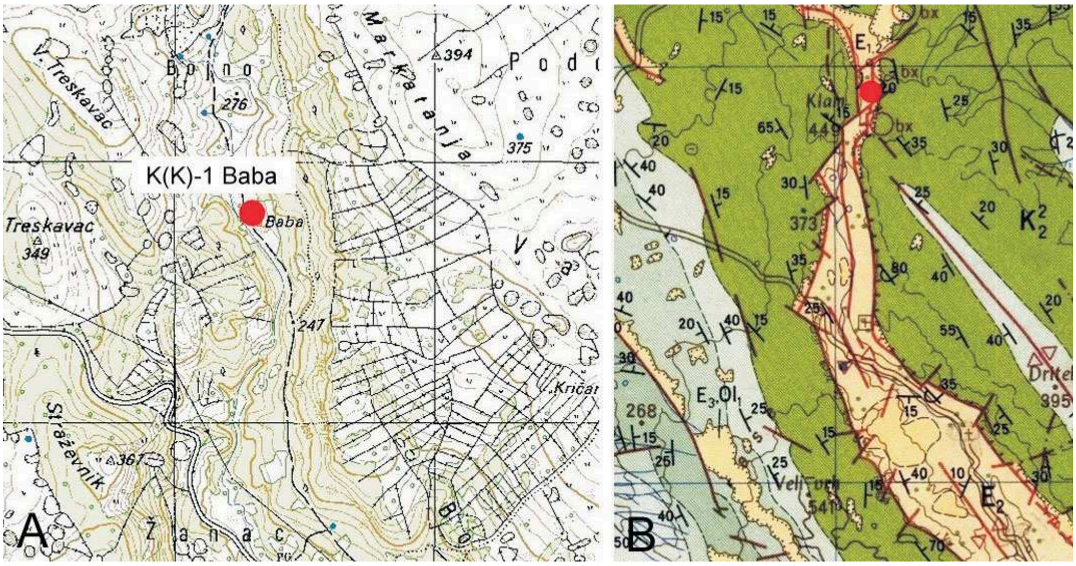


Figure 3.3. A - Location of Baba site. B - Geological setting (General Geological Map 1:100.000, Sheet Crikvenica (Šušnjar et al, 1970).

Slika 3.3. A - Lokacija točke Baba. B - Geološka karta područja (Osnovna geološka karta 1:100.000, list Crikvenica (Šušnjar et al., 1970).

Figure 3.4. Erosional remnant of the Pleistocene breccia in the middle of the valley at the Baba site (K(K)-1). Photo taken in 2005.

Slika 3.4. Erozijski ostatak pleistocenskih breča u sredini doline na lokalitetu Baba (K(K)-1). Snimljeno 2005.

3.1.1.2. Krk-Suha Ričina / K(K)-2

The study location Suha Ričina (Dry River) is an outcrop of the Pleistocene breccia-conglomerate located on the right bank of the Suha Ričina brook (160 m a.s.l.) in the vicinity of the main road Krk - Baška (Fig. 3.5. A). The outcrop is at least 15 m high, covered with shrub vegetation (Fig. 3.6.). Collapsed meter-sized clasts are found in its surrounding. There are Eocene clastics laying beneath, although the contact with breccia is not exposed (Mamužić et al. 1965). They are not marked on the General Geological Map (Fig. 3.5. B).

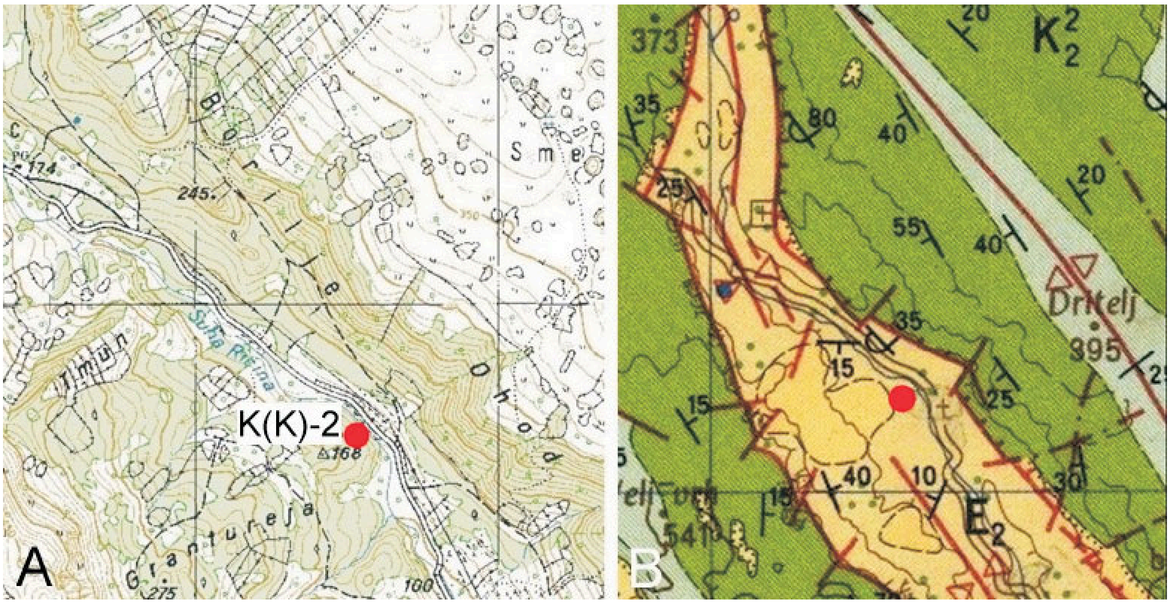


Figure 3.5. A - Location of Suha Ričina site. B - Geological setting (General Geological Map 1:100.000, Sheet Crikvenica, Šušnjar et al., 1970).

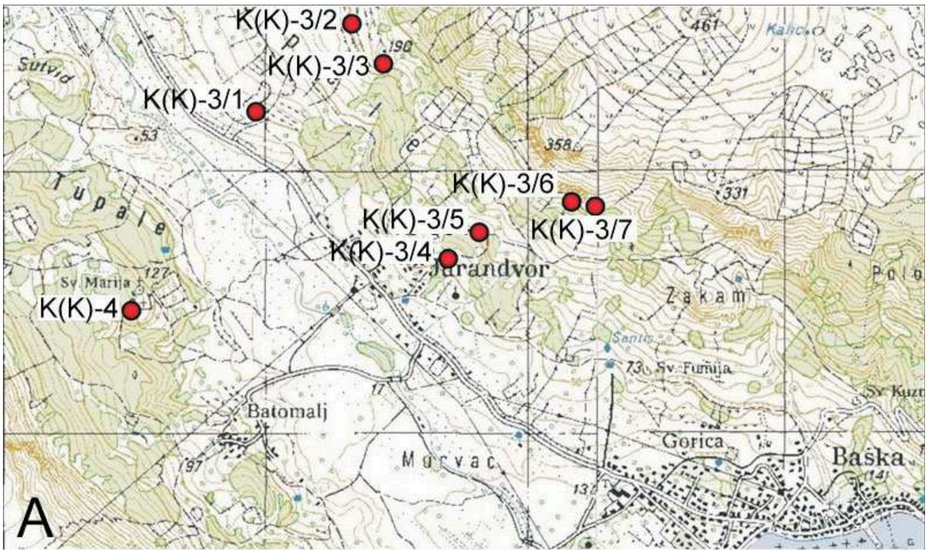
Slika 3.5. A - Položaj točke Suha Ričina. B - Geološka karta područja (Osnovna geološka karta 1:100.000, list Crikvenika, Šušnjar et al., 1970)

Figure 3.6. Pleistocene breccia-conglomerate on the right bank of the Suha Ričina brook. This nearly 10 m high rock is mostly hidden in vegetation. Photo taken in 1989.

Slika 3.6. Pleistocenska breča na desnoj obali potoka Suha Ričina. Stijena visoka desetak metara većim je dijelom obrasla vegetacijom. Snimljeno 1989.

3.1.1.3. Krk - Jurandvor / K(K)-3

The studied zone Jurandvor (Fig. 3.7. A) comprises six observation sites (K(K)-3/1, 2, 3, 4, 5, 6, 7). Northwards and northwestwards of the Jurandvor village, on the northeast slope of the Baščanska Draga (Šupele area) there is a stratified breccia that forms an extensive terrace with horizontal top surface and steep front wall (Fig. 3.8.). The terrace is located between 150 and 190 m a.s.l. and extends for about 100 m along the slope. The visible thickness is more than 40 m. Downslope from this terrace there is a sand pit exposing stratigraphically younger Pleistocene gravel and sand (Fig. 3.9.). Breccia and sand-gravel deposits partly overlie the Upper Cretaceous limestones and partly Eocene clastics (Mamužić et al. 1969; Fig. 3.7. B).



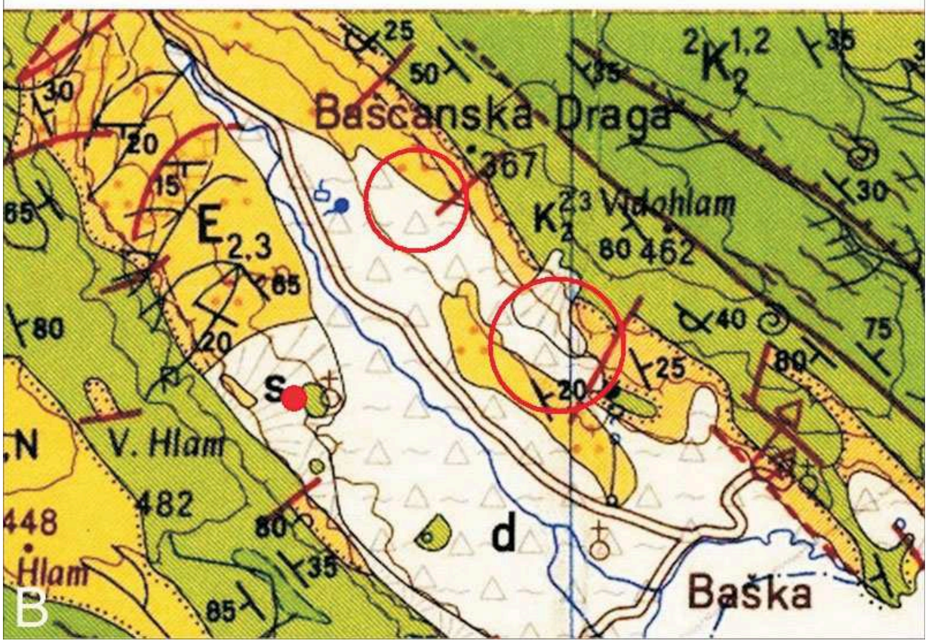


Figure 3.7. A - Locations of observation stops in the study zone Jurandvor (K-K-Ju) and Batomalj (K-K-Bt). B - Geologic setting (General Geological Map 1:100.000, Sheet Rab, Mamužić et al, 1969).

Slika 3.7. A - Položaj točaka opažanja u istražnoj zoni Jurandvor (K-K-Ju) i Batomalj (K-K-Bt) na otoku Krku. B - Geološka karta područja (Osnovna geološka karta 1:100.000, list Rab, Mamužić et al., 1969).

Figure 3.8. The NE side of the Baščanska Draga valley showing the Jurandvor study zone where alluvial (in frame 1, see Chapter 5.3.2.) and glacial deposits of a kama-terrace (in frame 2, see Chapter 6.1.2.) were studied. Photo taken in 2005.

Slika 3.8. Sjeveroistočna strana doline Baščanske Drage gdje se nalazi istražna zona Jurandvor, gdje su istraživani alivijalni sedimenti (u okviru 1, vidi Poglavlje 5.3.2.) i glacijalni sedimenti kama-terase (u okviru 2, vidi Poglavlje 6.1.2.). Snimak iz 2005.

Associated to terraces occur mega-blocks found at several locations along the NE slope of Baščanska Draga valley (Fig. 3.9.).

Figure 3.9. The megablocks found in Jurandvor study zone, interpreted as erratic blocks (see Chapter 6.1.4.). Photo taken in 2008.

Slika 3.9. Megablokovi u istražnoj zoni Jurandvor, interpretirani kao eratički blokovi (vidi Poglavlje 6.1.4.). Snimak iz 2008.

3.1.1.4. Krk - Batomalj / K(K)-4

The Batomalj site (K-K-BT-126) is located northwestwards of the Batomalj village, on the southwest slope of Baščanska Draga (Baška Valley), opposite of Jurandvor study zone (Fig. 3.7. A). A relatively large outcrop of coarse clastic sediments is located at 127 m a.s.l. Those are Pleistocene massive and stratified limestone breccias, which form a vertical walled terrace about 20 m high, so the outcrop is not easily accessible (Fig. 3.10). The breccia is also visible along the local road Batomalj - Sv. Marija church. Direct contact with the bedrock is not visible, but it is in one part the Upper Cretaceous limestone and in another the Eocene clastics (Fig. 3.9. B). The area is fully vegetated with shrubs, which make access more difficult.

The Quaternary sediments of the Baščanska Draga valley are marked on the General Geological Map in scale 1:100.000 (Mamužić et al., 1969) as slope talus deposits (Batomalj terrace) and deluvial sands and gravel in the rest of the area, as seen in Figure 3.7. B.

Figure 3.10. Batomalj terrace (study site K(K)-4, Fig. 3.7. A) is visible in the middle Sheet of the photograph. It is built of slopeward-dipping stratified breccias and interpreted as a kame-terrace (see.Chapter 6.1.2.). Sv. Marija church is built on the terrace (middle right). Photo taken in 2007.

Slika 3.10. Terasa Batomalj (točka K(K)-4, Sl. 3.7. A) na jugozapadnoj strani doline Baščanska Draga. Građena je od koso uslojenih breča nagnutih prema padini, a interpretirana je kao kama-terasa (vidi Poglavlje 6.1.2.). Na stijenama terase sagrađena je crkva Sv. Marije (desno u sredini). Snimljeno 2007.

3.1.1.5. Krk - Baška - Gajevi / K(K)-5

The studied zone Baška-Gajevi is located on the southwest slope of the Baščanska Draga (Baška valley) above coast of the Baška bay, and comprises four observation sites (K(K)-5/1, 2, 3, 4) and a sediment logging site K(K)-5-L1 (Fig. 3.11. A). That is an extensive outcrop of coarse clastic deposits in the vicinity of a small coastal town Baška in the Baščanska Draga. These Pleistocene coarse clastic deposits extend from ca. 70 m a.s.l. up to ca. 200 m a.s.l. Nearly 55 m of the sediment succession is visible. The outcrop is more than 50 m wide in its lower part (Fig. 3.12). At the Baška - Gajevi site, 54 m of deposits were logged (see Chapter 5.2.1.).

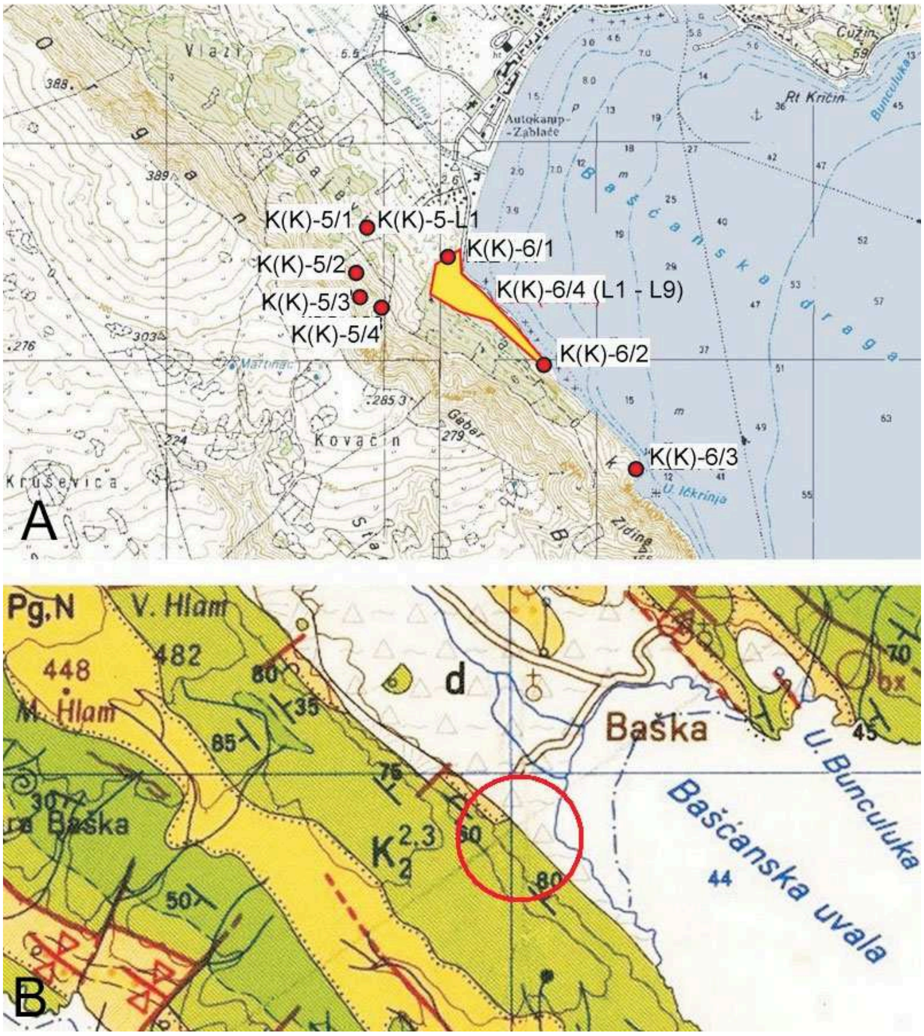


Figure 3.11. A - Locations of studied sites in the Baška-Gajevi study zone (K(K)-5/1, 2, 3, 4, L1) and Baška-Žarok study zone (K(K)-6/1, 2, 3, 4(L1 to L9). B - Geologic setting (General Geological Map 1:100.000, Sheet Rab, Mamužić et al, 1969).

Slika 3.11. A - Položaj točaka u istražnoj zoni Baška-Gajevi (K(K)-5/1, 2, 3, 4, L1) i Baška-Žarok (K(K)-6/1, 2, 3, 4(L1 to L9). B - Geološka karta područja (Osnovna geološka karta 1:100.000, list Rab, Mamužić et al., 1969).

Within the Baška -Gajevi zone there are coarse-clastic sediments comprising massive diamicts and stratified breccias (Fig. 3.12.) interpreted as glacigenic deposits constructing a kame-terrace. The contact with bedrock at location K(K)-5/1 is unexposed, but according to Mamužić et al. (1965) these deposits in one part overlie the Eocene clastics and in the other the Upper Cretaceous limestones (Fig. 3.11. B), which is visible at the upper section of Baška-Gajevi (locations K(K)-5/3, 5/4).

Figure 3.12. The upper section of the Lower Gajevi terrace, interpreted as a kame-terrace (see Chapter 6.1.2.), is built of predominantly slopeward-dipping stratified breccia (location K(K)-5/1, Fig. 3.11. A). Photo taken in 2004.

Slika 3.12. Donja Gajevi-terasa, interpretirana kao kama-terasa (vidi Poglavlje 6.1.2.), građena je od uslojenih breča uglavnom nagnutih prema padini (lokacija K(K)-5/1, Fig. 3.11. A). Snimljeno 2004.

Figure 3.13. The Upper Gajevi terrace preserved at 200 m above sea level (location K(K)-5/3, -5/4, Fig. 3.11. A). It is built of stratified breccias that are visible as a slightly brownish zone extending left-right in the middle of the photograph. Photo taken in 2007.

Slika 3.13. Gornja Gajevi-terasa na nadmorskoj visini od 200 m (lokacija K(K)-5/3, -5/4, Fig. 3.11. A). Građena je od uslojenih breča koje se u središnjem dijelu slije vide kao zona smeđaste boje. Snimljeno 2007.

3.1.1.6. Krk - Baška - Žarok / K(K)-6

The studied zone Baška - Žarok comprises three observation sites K(K)-6/1, 6/2 and 6/3 (Fig. 3.11. A) and zone in between where nine sediment logs were measured (K(K)-6-L1 to L9, Fig. 3.15.). The Baška-Žarok zone consists of three outcrop sections, one right on the coast and two above the coast , where sand is occasionally exploited. This extensive outcrop is In the vicinity of the small coastal town Baška in the Baščanska Draga valley. The Pleistocene deposits form coastal cliffs about 500 m long (Fig. 3.14. and 3.15.). Maximum thickness of exposed deposits is nearly 60 m. Although most of the outcrop are vertical and poorly accessible coastal cliffs, nine detailed logs were measured in scale 1:50 (Fig. 3.15.) and the whole outcrop was mapped in scale 1:200 (see Chapter 5.2.). They are also partly exposed in a sand pit where the access was easier for detailed sediment logging and mapping.

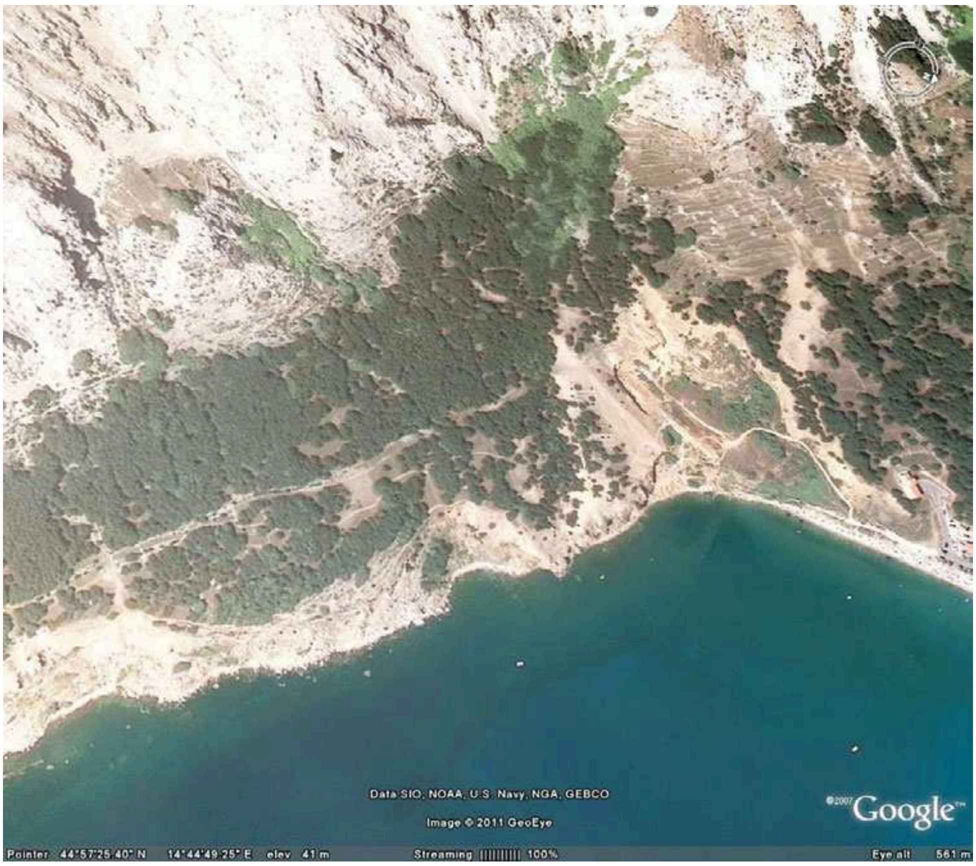


Figure 3.14. The zone of coastal outcrops of the Pleistocene sediments on the SW side of Baška Bay. They occur up to more than 200 m above sea level. The Pleistocene sediments contrast in color with white colored limestones of the bedrock. Google Earth image 2011.

Slika 3.14. Pleistocenski sedimenti otkriveni u obalnoj zoni jugozapadne strane Baškog zaljeva. Nalaze se do nadmorske visine i više od 200 m. Pleistocenski sedimenti izdvajaju se smeđastom bojom od izrazito bijelih vapnenaca podloge. Google Earth image 2011.

Figure 3.15. The coastal outcrop of Pleistocene sediments on the SW side of Baška Bay with marked locations (1 to 9) of detailed sediment logging. Photo taken in 1989.

Slika 3.15. Obalni izdanak pleistocenskih sedimenata na jugozapadnoj strani Baškog zaljeva s pozicijama detaljnog snimanja sedimentoloških stupova (1 do 9). Snimljeno 1989.

Pleistocene clastics overlie steeply inclined Eocene clastics (Figs. 3.11. B and 3.16.) with pronounced angular unconformity (Fig. 3.16.). Mamužić et al. (1965) mapped these sediments as "*Quaternary deluvial sands and gravels*".

Figure 3.16. The unconformable contact of Pleistocene clastics and Eocene clastics (in the footwall) exposed at Baška-Žarok study site K(K)-6/3 (Fig. 3.11.). Photo taken in 1989.

Slika 3.16. Diskordantni kontakt pleistocenskih klastita i eocenskih klastita (u podlozi) vidljiv na lokaciji Baška-Žarok K(K)-11 (Sl. 3.11.). Snimljeno 1989.

3.1.1.7. Krk-Stara Baška / K(K)-7

The studied site Krk-Stara Baška is located at the coast of Stara Baška Bay on the southwest of Krk Island (Fig. 3.17. A). Pleistocene sediments are visible in the surroundings of a small settlement Stara Baška. The sediments are stratified, partly cemented limestone breccias (Fig. 3.18.). Bedrock of Pleistocene sediments are Cretaceous limestones and Neogene clastics (Fig. 3.17. B).

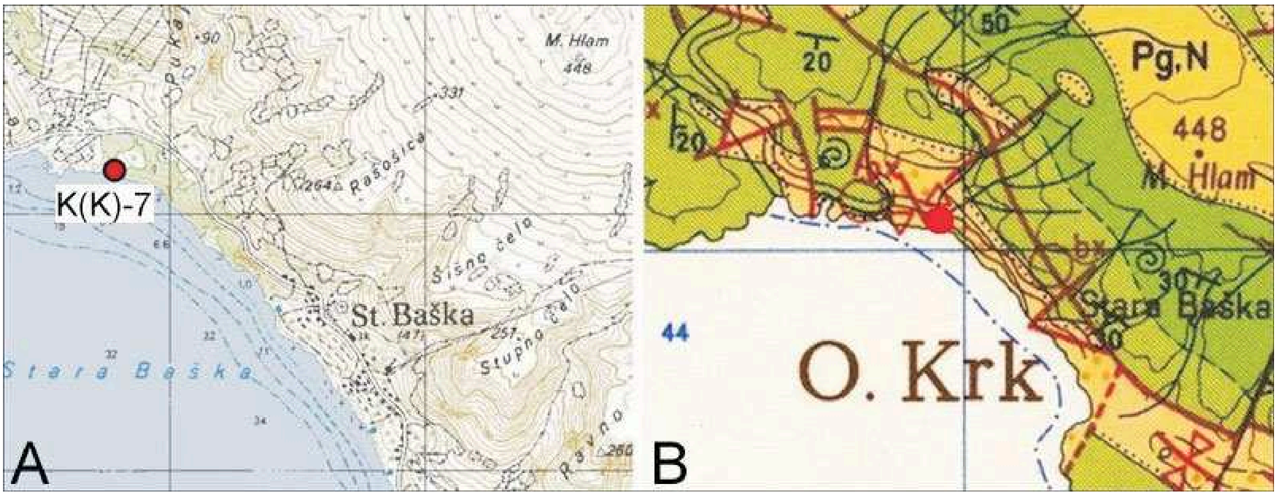


Figure 3.17. A - Location of Stara Baška site. B - Geological setting (General Geological Map 1:100.000, Sheet Crikvenica, Šušnjar et al, 1970).

Slika 3.17. A - Lokacija točke Stara Baška. B - Geološka karta područja, (Osnovna geološka karta 1:100.000, list Crikvenica, Šušnjar et al., 1970).

Figure 3.18. Coastal outcrop of Pleistocene coarse-clastic sediments in Stara Baška. Photo in 1990.

Slika 3.18. Obalni profil krupno-klastičnih pleistocenskih naslaga kod Stare Baške. Snimljeno 1990.

3.1.1.8. Prvić Island / K(K)-8

An outcrop of Pleistocene coarse clastics is located at the Pipa Point on the southwest coast of the Island (Fig. 3.19. A). The outcrop is 20 m high and ca. 100 m long and forms an expressed terrace with horizontal top surface and steep slopes (Fig. 3.20). The deposits are uncemented stratified boulder gravels and cemented massive breccia cropping out from the shallow sea as seen on the right side in Figure 3.20. These Pleistocene deposits are not identified on the Basic Geological Map by Mamužić et al. (1969) (Fig. 3.19. B).

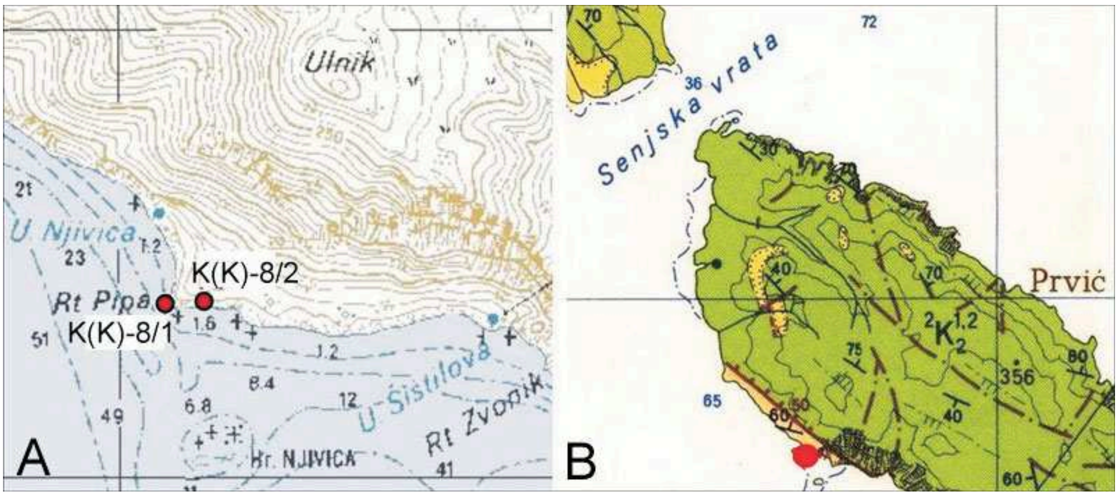


Figure 3.19. A - Location of studied site Pipa on Prvić Island. B - Geologic setting (General Geological Map 1:100.000, Sheet Rab, Mamužić et al, 1969).

Slika 3.19. A - Položaj točaka na Rtu Pipa na otoku Prviću. B - Geološka karta područja (Osnovna geološka karta 1:100.000, list Rab, Mamužić et al., 1969).

Figure 3.20. Pipa Point terrace built of Pleistocene cross-stratified gravels. Emerged Pleistocene cemented massive breccia is visible on the right. Photo taken in 1989.

Slika 3.20. Terasa Rt Pipa građena od pleistocenskih koso uslojenih nevezanih breča. U desnom kutu se vide cementirane pleistocenske breče koje vire iz mora. Snimljeno1989.

3.1.2. SENJSKA DRAGA / K(SD)

Senjska Draga is the valley extending from the Vratnik saddle on the Northern Velebit Mt. westwards to small coastal town Senj. Pleistocene sediments are preserved and exposed at several locations along the valley and two of those sites were studied, one in the uppermost part of the valley and the other in the lower part of the valley, next to the Senj graveyard (Fig. 3.21. A).

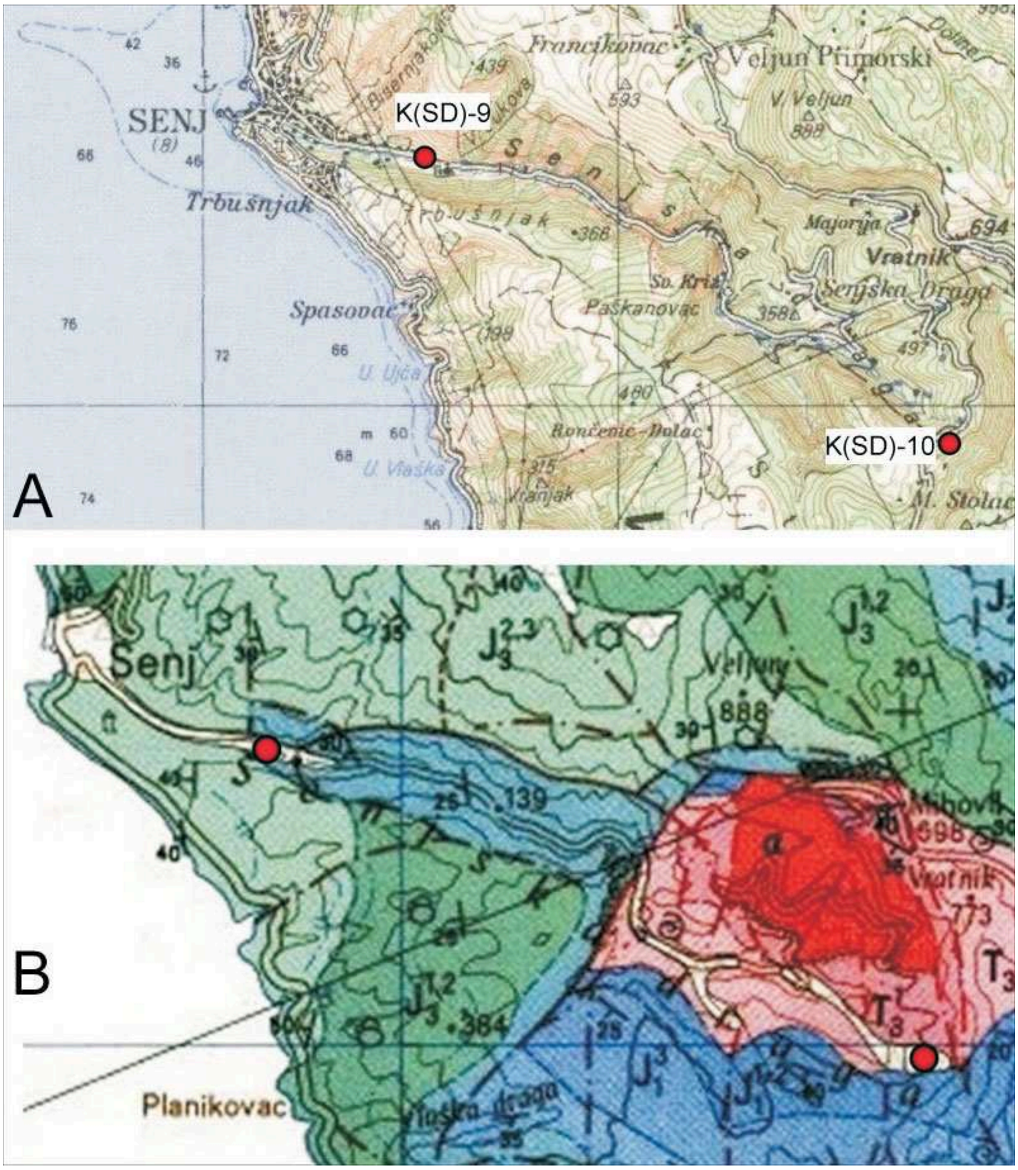


Figure 3.21. A - Location of studied sites in Senjska Draga. B - Geological setting (General Geological Map 1:100.000, Sheet Rab, Mamužić et al, 1969).

Slika 3.21. A - Položaj točaka promatranja u dolini Senjske Drage. B - Geološka karta područja (Osnovna geološka karta 1:100.000, list Rab, Mamužić et al., 1969).

At the Vratnik observation site K(SD)-10 the Pleistocene sediments are represented by stratified fine and coarse gravel with cobbles and scarce boulders (Fig. 3.22), which overlie Middle Triassic limestones associated with andesite (Fig. 3.21. B).

Figure 3.22. Pleistocene stratified coarse to fine gravels exposed in a gravel pit near Vratnik K(SD)-10. Photo taken in 2008.

Slika 3.22. Pleistocenske stratificirane naslage krupnozrnog šljunka u napuštenom kopu nedaleko Vratnika K(SD)-10. Snimljeno 2008.

At the Senj observation site K(SD)-9 there are matrix-supported cobble and boulder conglomerates exposed that overlie tectonized Jurassic limestones (Fig. 3.23.). These conglomerates are overlain by stratified gravel-size conglomerate or stratified breccia. Mamužić et al. (1969) distinguished these deposits as “Quaternary deluvial sand and gravel”.

Figure 3.23. Pleistocene conglomerate, interpreted as reworked basal moraine, exposed at the north side of the road to Senj from Senjska Draga valley (K(SD)-9). Photo taken in 2008.

Slika 3.23. Izdanak pleistocenskog konglomerata na sjevernoj strani ceste prije ulaza u grad Senj iz doline Senjske Drage (K(SD)-9). Konglomerat je interpretiran kao prerađena podinska morena. Snimljeno 2008.

3.1.3. RAB ISLAND (K(R)) AND JABLANAC (K(J))

Three sites were studied on the Rab island (Pudarica, Mišnjak and Mag) as possible correlative to the Jablanac deposits (Fig. 3.24. A). Quaternary deposits of the Rab Island were identified on the General Geological Map (Mamuž et al, 1969) as "*Quaternary redishbrown sands*" occurring in northwest part of the Rab Island and "*Quaternary deluvium*" composed of gravelly sands and slope talus breccia that occurs in the southeast part of the island (Mamužić et al. 1969) (Fig. 3.24. B).

Waagen (1911, 1914) has described the above mentioned deposits as "*Altquartärer Sand*" ('Old Quaternary sand'). In the southeast part of the Rab Island he described horizontal- and cross-bedded loose reddish-colored coarse-grained carbonate sands, and compared them with those near Dobrinj on the Krk island as very similar. The same are visible along the road Rab-Lopar.

Figure 3.24. A - Locations of study sites on the Rab Island, Sv. Grgur Island and around Jablanac at the mainland coast below Velebit Mt..

Slika 3.24. A - Položaj istražnih lokacija na otoku Rabu, otoku Sv. Grgur i u okolici Jablanca uz obalu podno Velebita.

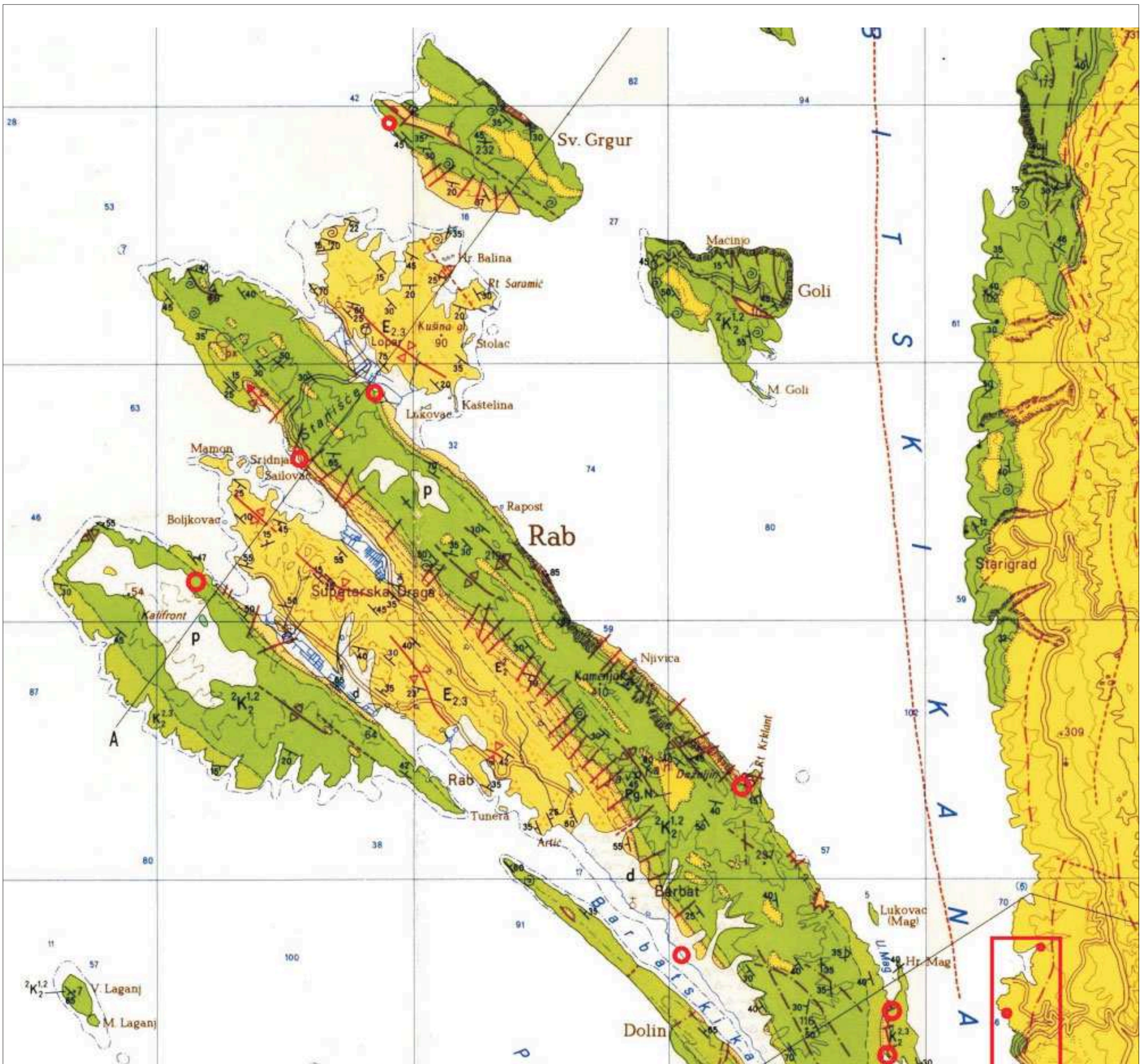


Figure 3.24. B - Geological setting (General Geological Map 1:100.000, Sheet Rab, Mamužić et al, 1969). Cretaceous carbonate deposits in green shades and Tertiary clastics in yellow, white for Quaternary deposits.

Slika 3.24. B - Geološka karta područja (Osnovna geološka karta 1:100.000, list Rab, Mamužić et al., 1969). Kredne karbonatne naslage u zelenim tonovima, tercijarni klastiti žute boje i kvartarne naslage bijela polja.

3.1.3.1. Rab - Pudarica / K(R)-11

The site Pudarica is located on the southwest coast of the Rab Island in the old ferry port Pudarica (Fig. 3.25.). Pleistocene deposits are represented by stratified sand and fine gravel which form coastal cliffs and are well exposed in a sand pit (Fig. 3.26). Maximum visible thickness of Pleistocene sediments is 10 to 12 m and their characteristics are persistent along the strike.

Figure 3.25. Location of Pudarica.
Slika 3.25. Položaj točke Pudarica.

Sediments exposed at Pudarica are part of a large alluvial fan whose cross-section extends northwest- -wards and southeastwards along the coast. A contact with bedrock is not visible, but according to Mamužić et al. (1969) the Pleistocene deposits lay over Upper Cretaceous limestones (Fig. 3.24. B).

Figure 3.26. Pleistocene stratified sand and gravel exposed in Pudarica abandoned sand pit. Photo taken in 2006.

Slika 3.26. Pleistocenski stratificirani pijesak I šljunak u napuštenom pjeskokopu Pudarica. Snimljeno 2006.

3.1.3.2. Rab - Mišnjak (K(R)-12) and Mag (K(R)-13)

At the east coast of the Mag cove there is a large outcrop of Pleistocene stratified gravels and sands, which overlay the Upper Cretaceous limestones and in one part Eocene clastics (Fig. 3.24. B). Maximum visible thickness of sediments is 8 to 10 metres. There are well cemented massive breccias on the top of the sand-gravel succession. The Pleistocene sediments were logged in scale 1:50 at Mag site. Those Quaternary deposits are not marked on the General Geological Map (Fig. 3.24. B).

On the east slope of a valley which connects Mišnjak and Mag coves, there is an erosional remnant of Pleistocene deposits represented by horizontally stratified cobbley to bouldery gravel, more-or-less cemented which overlay the Upper Cretaceous limestones (Fig. 3.29). The outcrop is about 100 m long and sediments are about 10 m thick.

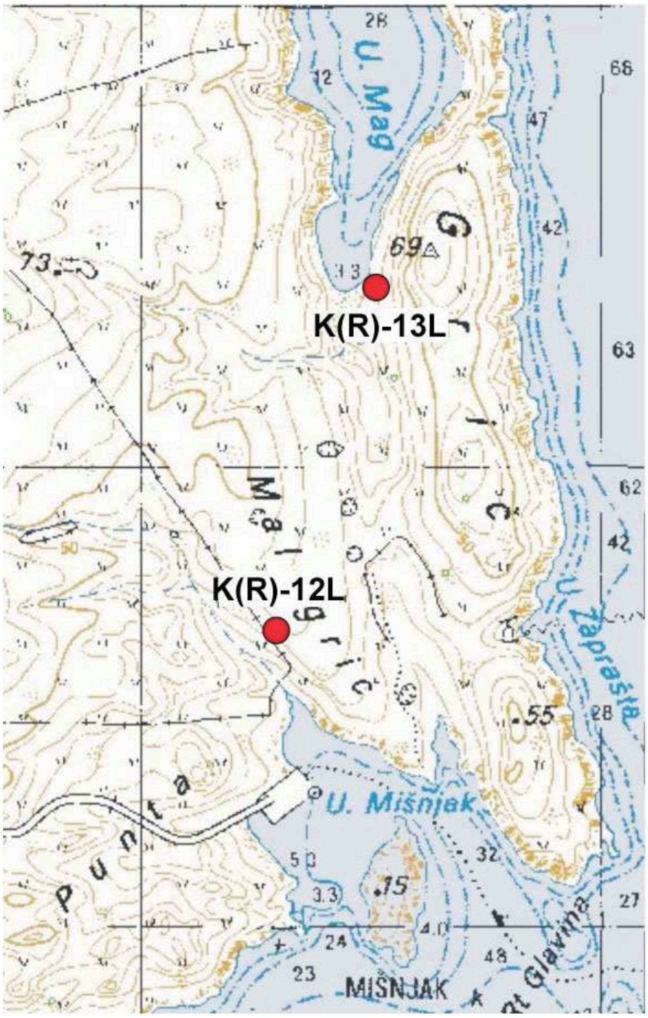


Figure 3.27. Location of study sites Mag (K(R)-13) and Mišnjak (K(R)-12).

Slika 3.27. Položaj točaka Mag (K(R)-13) i Mišnjak (K(R)-12).

Figure 3.28. Pleistocene stratified sand and gravel in the Mag Cove (location K(R)-13). This is an erosional remnant of an extensive alluvial fan. Photo taken in 2006.

Slika 3.28. Pleistocenski stratificirani pijesak I šljunak u uvali Mag (lokacija K(R)-13). To je erozijski ostatak nekada velike aluvijalne lepeze. Snimljeno 2006.

Figure 3.29. Erosional remnant of Pleistocene alluvial sediments (stratified sand and gravel) exposed in a small valley entering the Mišnjak cove (location K(R)-12). Photo taken in 2006.

Slika 3.29. Erozijski ostatak Pleistocenskih aluvijalnih naslaga (stratificirani šljunak i pijesak) sačuvan na sjeveroistočnoj strani uske doline koja ulazi u uvalu Mišnjak (lokacija K(R)-12). Snimljeno 2006.

3.1.3.3. Rab sites in preliminary study

There are five recently located sites where preliminary observations were done regarding general macroscopic characteristics of sediment textures and structures, and possible origin. Four sites (Krklant K(R)-14, Lopar K(R)-15, Supetarska Draga K(R)-16, Kalifront K(R)-17) located on the Rab Island and one site on the island of Sv. Grgur (K(R)-18) are shown in Figure 3.24. A.

Figure 3.30. Krklant study site (K(R)-14 in Fig. 3.24.) on the northeast coast of Rab Island. Quaternary clastics overlie partly the Upper Cretaceous limestones and partly the Eocene clastics and limestones (see Fig. 3.24. B). Slopeward diping deposits are visible in the middle. They are an erosional remnant of an extensive kame-terrace (see Chapter 6.1.). Photo taken in 2011.

Slika 3.30. Lokacija Krklant (K(R)-14 in Fig. 3.24.) na sjeveroistočnoj obali otoka Raba. Kvartarni klastiti leže dijelom na gornjokrednim vapnencima i dijelom na eocenskim klastitima i vapnencima (vidi Sl. 3.24. B). Naslage nagnute prema padini vidljive su u središnjem dijelu. Ti su sedimenti erozijski ostatak velike kama-terase (vidi Poglavlje 6.1.). Snimljeno 2011.

Figure 3.31. Supetarska Draga study site (K(R)-16, Fig. 3.24. A) on the northeast coast of the Supetarska Draga bay. The outcrop is very much degraded by human influence, but still many striated boulders are found in earthy matrix and therefore this diamict is interpreted as moraine. Contact with bedrock is not visible but below are Eocene clastics (see Fig. 3.24. B). Photo taken in 2011.

Slika 3.31. Lokacija Supetarska Draga (K(R)-16, Fig. 3.24. A) na sjeveroistočnoj obali zaljeva Supetarske Drage. Izdanak je dosta degradiran ljudskim uticajem, ali se još uvijek nalaze blokovi sa strijama u zemljastom matriksu pa je ovaj dijamikt interpretiran kao morena. Kontakt s podlogom nije vidljiv ali se ispod nalaze Eocenski klastiti (vidi Sl. 3.24. B). Snimljeno 2011.

Diamicts (mega-breccia) were recognized at all sites and are interpreted as tills and tillites according to many striated clasts present at every site (see Chapter 5.1.). Neither of the observed sites with Quaternary sediments is shown on the Basic Geological Map (Fig. 3.24. B), nor corresponds to any occurance of Quaternary marked on the map. These sites are presented in the Thesis because of their importance for documenting Dinaric glaciation.

Figure 3.32. Kalifront study site (K(R)-17, Fig. 3.24. A) located on the west side of the Rab Island - the Kalifront peninsula. A small quarry exposed a diamict with many striated clasts, therefore interpreted as moraine (see Chapter 5.1.). They overlay Upper Cretaceous rudist limestones (Fig. 3.24. B). Photo taken in 2011.

Slika 3.32. Lokacija Kalifront (K(R)-17, Fig. 3.24. A) nalazi se na zapadnom dijelu otoka Raba - poluotoku Kalifrontu. U malom kamenolomu vidi se dijamikt s brojnim klastima sa strijama, te je interpretiran kao morena (vidi Poglavlje 5.1.). Dijamikt leži na gornjokrednim rudistnim vapnencima (Sl. 3.24. B). Snimljeno 2011.

Figure 3.33. Grgur study site (K(R)-18, Fig. 3.24. A) is at the southwest coast of the island Sv. Grgur. The coastal outcrop exposed a diamict (a mega-breccia) that contains many striated boulders and therefore is considered a moraine (see Chapter 5.1.). They lie over Upper Cretaceous limestones with dolomite lenses (Fig. 3.24. B). Photo taken in 2010.

Slika 3.33. Lokacija Grgur (K(R)-18, Fig. 3.24. A) nalazi se na jugozapadnoj obali otoka Sv. Grgur. Na obalnom izdanku vidi se dijamikt (mega-breča) koji sadrži brojne klaste sa strijama te se zbog toga smatra morenom (vidi Poglavlje 5.1.). Leži na gornjokrednim vapnencima s lećama dolomita (Sl. 3.24. B). Snimljeno 2010.

3.1.3.4. Jablanac / K(J)-19

The Jablanac study area comprises two sites where sediments were logged (K(J)-19-L1, -L2) or just observed (K(J)-19/1, 2; Fig. 3.34.). In the area of Jablanac cove occur Pleistocene stratified breccias, which Koch (1929) identified as "*older deluvial deposits*". He wrote that they are horizontally bedded in the central part and inclined slopewards elsewhere because of postdiluvial dislocati- -ons (Koch 1929, p. 27). He also found bone fragments of mammals. Mamužić et al. (1965) described these deposits as "*deluvial gravel and slope talus breccia*". According to the General Geological Map the Pleistocene deposits overlay the Eocene-Oligocene Jelar-breccia (Fig. 3.24. B) but at the outcrop shown in Figure 3.35. there is a clear contact with underlying thick bedded Cretaceous limestones.

Figure 3.34. Locations of studied sites in Jablanac area.
Slika 3.34. Položja točaka u istražnom području Jablanac.

Figure 3.35. Pleistocene bedded breccia on the NW side of Jablanac (K(J)-19-L2), laying over Cretaceous limestones. Photo taken in 1989.

Slika 3.35. Pleistocenske uslojene breče na sjeverozapadnoj strani Jablanca (K(J)-19-L2), koje leže na krednim vapnencima. Snimljeno 1989.

Figure 3.36. Horizontally bedded sand and gravel deposits with few paleosol intervals, exposed in the central part of Jablanac (K(J)-19/2). Photo taken in 2006.

Slika 3.36. Horizontalno uslojeni pijesci i šljunci s nekoliko intervala paleotla, nalaze se u centralnom dijelu Jablanca (K(J)-19/2). Snimljeno 2006.

Figure 3.37. Pleistocene alluvial deposits (stratified breccia) exposed at the Jablanac ferry port (K(J)-19-L1). Photo taken in 2006.

Slika 3.37. Pleistocenske aluvijalne naslage (stratificirane breče) otkrivene uz cestu kod trajektne luke u Jablancu (K(J)-19-L1). Snimljeno 2006.

3.1.3.5. Rab - Stinica / K(J)-20

The Pleistocene deposits were studied at outcrops along the coast northwards of Jablanac (location Stinica K(J)-20/1; Fig. 3.38. and 3.39.) and in the valley of Jadrelić Draga northeast of Stinica (location Stinica K(J)-20/2) (Fig. 3.38.). The outcrops of breccia and breccia-conglomerate were subjected only to field diagnostics and sediment characteristics were recorded. The field observations were significant for interpretation (see Chapter 5.1.) and future study. The sediments at the location Stinica 20/1 are recognized as deluvial deposits on the General Geological Map by Mamužić et al. (1969) (Fig. 3.24. B), while sediments observed at the location Stinica 20/2 are in place of the Eocene-Oligocene Jelar-breccia (Fig. 3.24. B), and were not marked as Quaternary deposits on the map by Mamužić et al. (1969). The outcrop in Jadrelić Draga is very similar to those in Velika Paklenica and constitute a morphological terrace about 10 m high and about 50 m in length. It is interpreted as erosional remnant of reworked moraine (see Chapter 5.1.). The coastal outcrop Stinica 1 is about 0.5 km long exposure of coarse-grained breccia with large blocks, locally stratified and graded. These Pleistocene deposits lie over Cretaceous bedded limestone, while in Jadrelić Draga the bedrock are Jelar-breccia (Fig. 3.24. B).

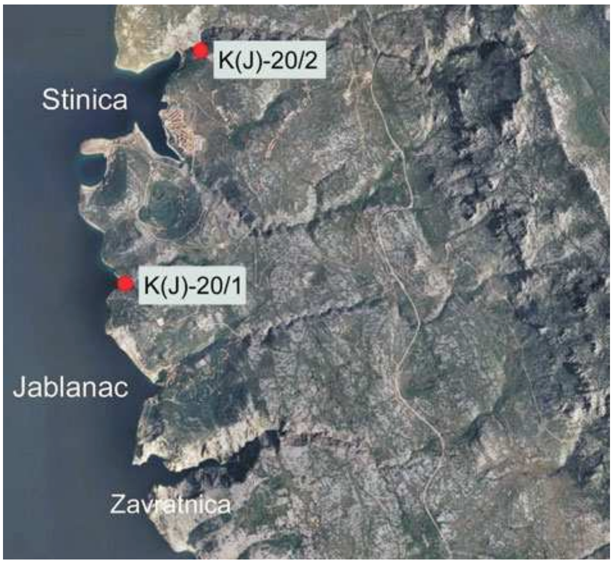


Figure 3.38. Location of study sites Stinica north of Jablanac. Section from ARKOD image (www.arkod.hr).

Slika 3.38. Položaj istražnih lokacija Stinica sjeverno od Jablanca. Isječak ARKOD snimka

Figure 3.39. Pleistocene breccia coastal exposure northwards of Jablanac (location K(J)-20/1). The breccia lie over Cretaceous bedded limestones visible at right side of the outcrop. Photo taken in 2010.

Slika 3.39. Pleistocenske breče otkrivene duž obale sjeverno od Jablanca. Kredni uslojeni vapnenci podloge vide se na desnom kraju izdanka. Snimljeno 2010.

3.1.4. PAG ISLAND / K(P)

The Pag island is an island of 284 km^2 extending NW-SE. Its highest mount is 345 m located northwestwards of Pag town. The strike of the island and its valleys and ridges follow geological structures (Fig. 3.40.).

Pleistocene sediments were studied within four main areas as shown in Figure 3.40.: Metajna K(P)-21, Crnika K(P)-22, Bošane K(P)-23 and Pag K(P)-24. Location Gorica K(P)-25 is an observation site. The sediments were studied in detail at Crnika, Bošana and Pag location. Sediment logging in scale 1:50 or 1:20 was performed at these locations. In further text each study location is described separately including the geological framework of the area.

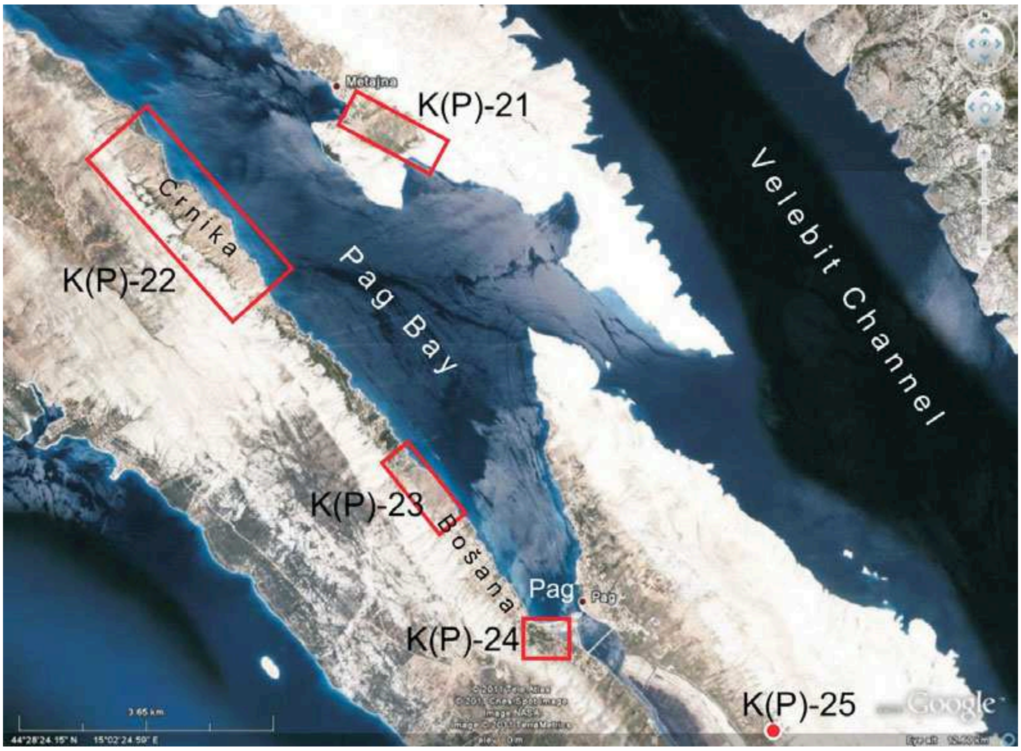


Figure 3.40. A - Study areas on Pag Island. Each area marked contains several observation or logging locations shown in detail in further text. Google Earth image 2011.

Slika 3.40. A - Istražna područja na otoku Pagu. Svako označeno područje sadrži dvije ili više lokacija na kojima su sedimenti promatrani ili je snimljen detaljni stup, a prikazane su u daljnjem tekstu. Google Earth podloga 2011.

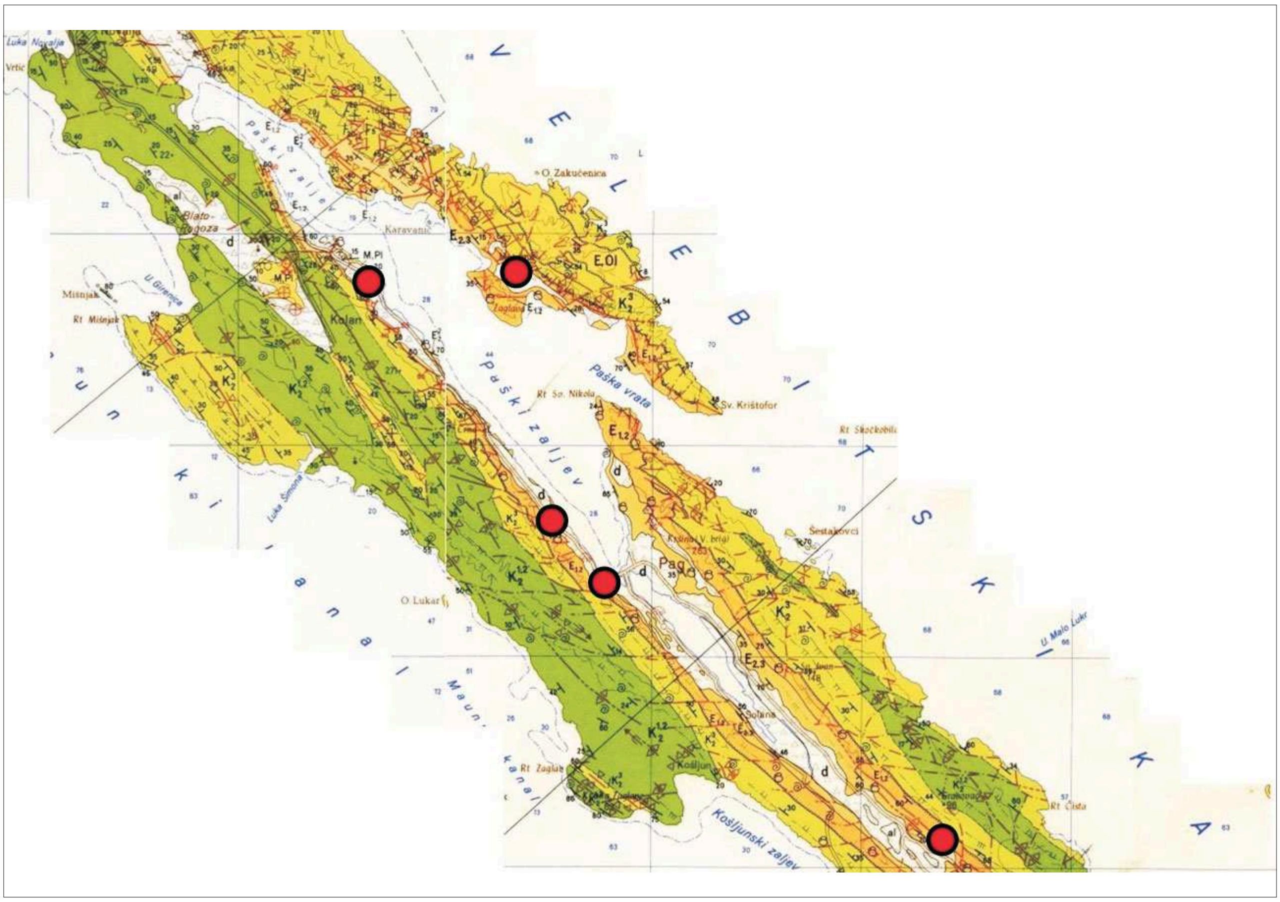


Figure 3.40. B - Geological setting of studied sites on Pag Island (General Geological Maps in scale 1:100.000, Sheet Rab, Mamužić et al, 1969; Sheet Gospić, Sokač et al, 1974; Sheet Zadar, Majcen et al, 1970; Sheet Silba, Mamužić et al, 1970). Cretaceous carbonate rocks in green shades and Tertiary clastics in yellow shades.

Slika 3.40. B - Geološka karta područja (Osnovna geološka karta 1:100.000, list Rab, Mamužić et al., 1969; list Gospić, Sokač et al., 1974; list Zadar, Majcen et al., 1970; list Silba, Mamužić et al., 1970). Kredne karbonatne stijen u zelenim bojama i tercijarni klastiti u žutim bojama.

3.1.4.1. Pag - Metajna / K(P)-21

In hinterland of the Metajna village occur outcrops of Pleistocene deposits (observation sites K(P)-21/1, 2, 3, 4) on a saddle between two coves and further southeastwards along a steep slope of the Panos hill (Fig. 3.41. A). Those are stratified cemented breccias, dipping slopewards at angle of 25°. Their maximum thickness reaches 20 m. The Pleistocene sediments overlay Eocene Foraminiferal limestones and were determined as "*Upper Pleistocene diluvium*" by Sokač et al. (1974) (Fig. 3.41. B).

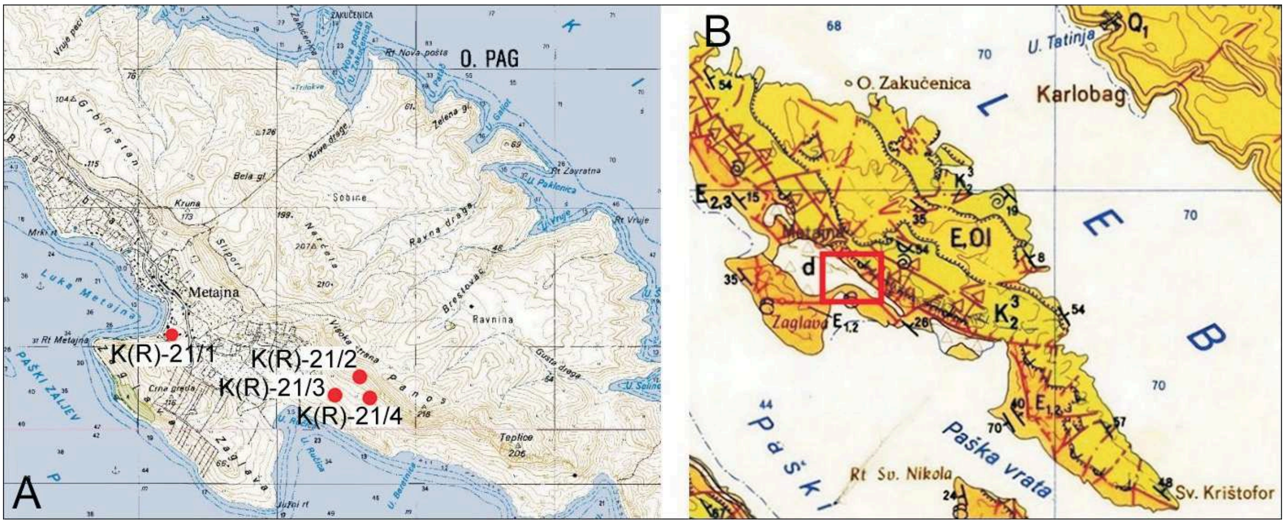


Figure 3.41. A - Location of observation sites in the surroundings of Metajna. B - Geological setting (General Geological Map 1:100.000, Sheet Gospić (Sokač et al, 1974).

Slika 3.41. A - Položaj točaka u istražnom području Metajna. B - Geološka karta područja. Isječak Osnovne geološke karte 1:100.000, list Gospić (Sokač et al., 1974).

Figure 3.42. Pleistocene stratified breccia in the hinterland of Metajna village are remnant of a kama-terrace. Breccia is on the left side and grass-land are Tertiary clastics. Photo taken in 1992.

Slika 3.42. Pleistocenske uslojene breče u zaleđu sela Metajna ostatak su kama-terase. Breče se vide na lijevoj strani, a travnato područje su tercijarni klastiti. Snimljeno 1992.

3.1.4.2. Pag - Crnika / K(P)-22

Crnika is a part of coastal zone along the old road Pag - Novalja. Pleistocene sediments are exposed at several locations (Fig. 3.43. A), and overlie either Cretaceous limestones or Eocene foraminiferal limestones and clastics (Fig. 3.43. B). At location K(P)-22/1 the Pleistocene deposits overlie Miocene-Pliocene lacustrine deposits.

On the hill side along the Novalja - Pag road there are several large sand/gravel-pits (Fig. 3.44.) opened one after another by local people for exploitation during my research, providing good quality outcrops. The vertical cuts left by exploitation exposed about 20 m of sediments and some sections were mapped (K(P)-22/1; see Chapter 5.2.). Seawards, there is a vertical cliff near the Hanzina Point exposing about 10 m thick sediment succession with a complex paleosol (K(P)-22/3). These deposits were defined as *Upper Pleistocene deluvium* by Mamužić et al. (1970) (Fig. 3.43. B).

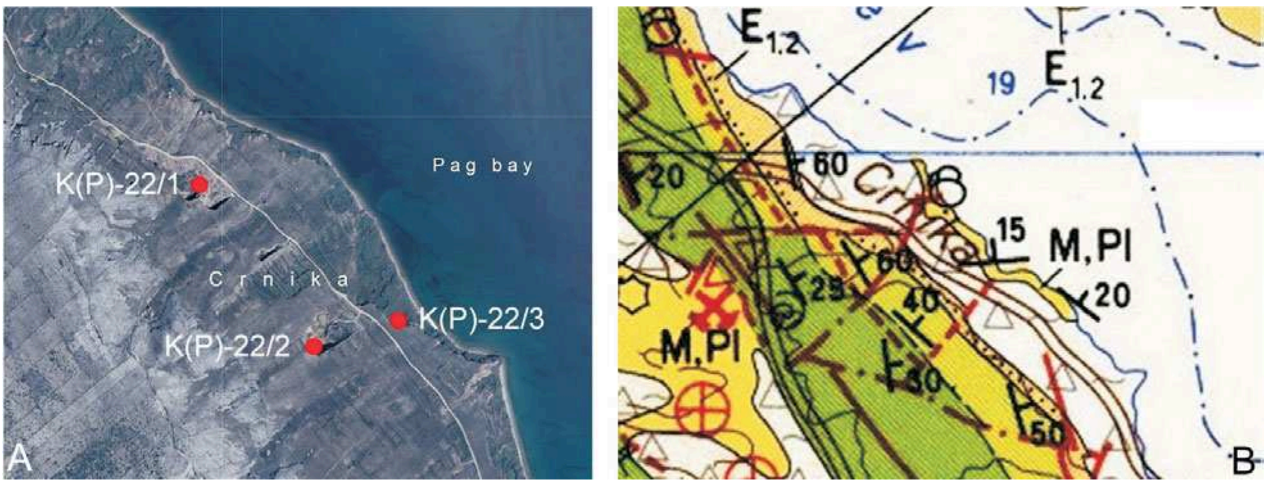


Figure 3.43. Locations of studied sites in Crnika study area. B - Geological setting (General Geological Map 1:100.000, Sheet Silba, Mamužić et al, 1970).

Slika 3.43. A - Položaj točaka u istražnom području Crnika. B - Geološka karta područja (Osnovna geološka karta 1:100.000, list Silba, Mamužić et al., 1970).

Figure 3.44. Pleistocene sands and gravels exposed in a gravel pit (location K(P)-22/1), interpreted as glaciofluvial deposits of a kama-terrace. Photo-mosaic taken in 2008.

Slika 3.44. leistocenski sedimenti (pijesak i šljunak) u djelomično napuštenom pjeskokopu (lokacija K(P)-22/1), interpretirani kao glaciofluvijalne naslage kama-terase. Foto-mozaik snimljen 2008.

3.1.4.3. Pag - Bošana / K(P)-23

The studied Bošana zone in the middle part of Pag Island comprises two study sites, one on the hill side of the Novalja - Pag road (the sand/gravel pit at location K(P)-23/1 and the other beneath the road along the coast (observation site K(P)-23/2) shown in Figure 3.45.A).

The first site is a very large gravel/sand-pit (Fig. 3.46.), which was in exploitation at the time of study, so the outcrops were very good for detailed sediment logging in scale 1:50 (K(P)-23-L1, -L2, -L3, -L4), including details logged in scale 1:10 (see Chapter 5.2.). The exposed Pleistocene sediments are stratified gravels and sands, which were deposited over steep sloped paleorelief (ca 50°) formed in Cretaceous limestones. The sediments exposed in the pit are extension of the sand-gravel zone described at Crnika locations (Fig. 3.43.). The second site is a nearly 1000 m long coastal cliff exposing ca 20 m of stratified gravels and sands (Fig. 3.47.), which overlie folded Eocene clastics (Fig. 3.48.) and represent alluvial fan deposits.

Schubert and Waagen (1913), and Koch (1929) mentioned "*Older deluvial deposits*" composed of "finer grained limestone debris with red cement" which occur along the central Pag syncline. Sokač et al. (1976) identified these sediments as "*Upper Pleistocene deluvial deposits*", namely slope talus breccia.

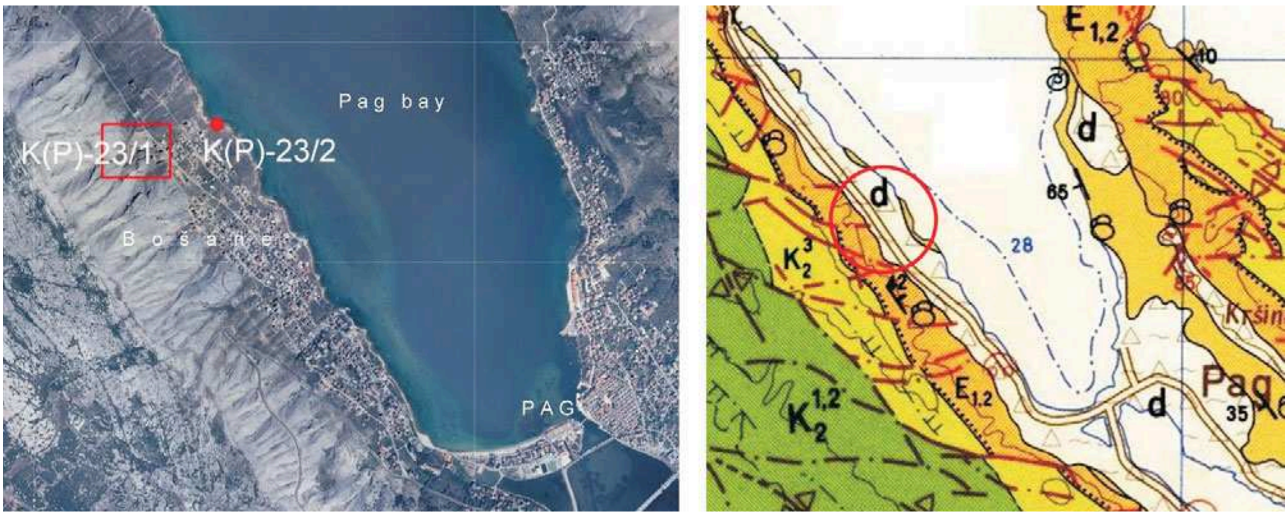


Figure 3.45. A - Location of studied sites in Bošana zone . B - Geological setting (General Geological Map 1:100.000, Sheet Gospić, Sokač et al, 1974).

Slika 3.45. A - Položaj istražnog područja Pag-Bošana. B - Geološka karta područja (Osnovna geološka karta 1:100.000, list Gospić, Sokač et al., 1974).

Figure 3.46. The abandoned Bošana gravel pit exposing Pleistocene sediments interpreted as glaciofluvial kame-terrace deposits. Photo taken in 2006.

Slika 3.46. Napušteni pjeskokop Bošana gdje su dobro otkriveni Pleistocenski sedimenti interpretirani kao glaciofluvijalni sedimenti kama-terase. Snimljeno 2006.

Figure 3.47. The NW side of the abandoned sand-gravel pit where kama-terrace glaciofluvial and alluvial sediments were studied. Photo-mosaic taken in 2005.

Slika 3.47. Sjeverozapadna strana napuštenog pjeskokopa Bošana gdje su istraživani sedimenti *kame*-terase. Foto-mozaik snimljen 2005.

Figure 3.48. The NW side of the abandoned sand-gravel pit where kama-terrace glaciofluvial and alluvial sediments were studied. Photo taken in 2005.

Slika 3.48. Sjeverozapadna strana napuštenog pjeskokopa Bošana gdje su istraživani sedimenti *kame*-terase. Snimljeno 2005.

3.1.4.4. Pag - Pag / K(P)-24

The Pag zone comprises sites where Pleistocene deposits were observed (Fig. 3.49.). Morphologically distinctive terrace (Gradac in Fig. 3.49.) built of cemented stratified breccias is located above the main road southwest of the Pag town. These slope-dipping breccias (Fig. 3.50.) extend between 30 and 100 m a.s.l. Below occur fine-grained sediments with paleosol (Fig. 3.51.). Pleistocene sediments overlay Cretaceous and Eocene limestones (Fig. 3.45. B) with clear unconformity between steep slope of carbonate ridge and the slope-dipping breccias (Fig. 3.52.). Southeastwards, where the slope becomes gently inclined, occur horizontally stratified breccia and laminated sand, which are exposed in thickness of ca 15 m (Fig 3.52). The laminated sand is exposed in a horizontal cave (20 m wide, 9 m deep and 2-3 m high) developed within the breccia.

The Pleistocene sediments, studied in the Pag zone, overlie the Eocene Foraminiferal limestones and clastics, but contact with the Cretaceous limestones is also visible. On the General Geological Map of Sokač et al. (1974) these Pleistocene deposits are identified as "*Upper Pleistocene deluvial deposits*" (Fig. 3.45. B).

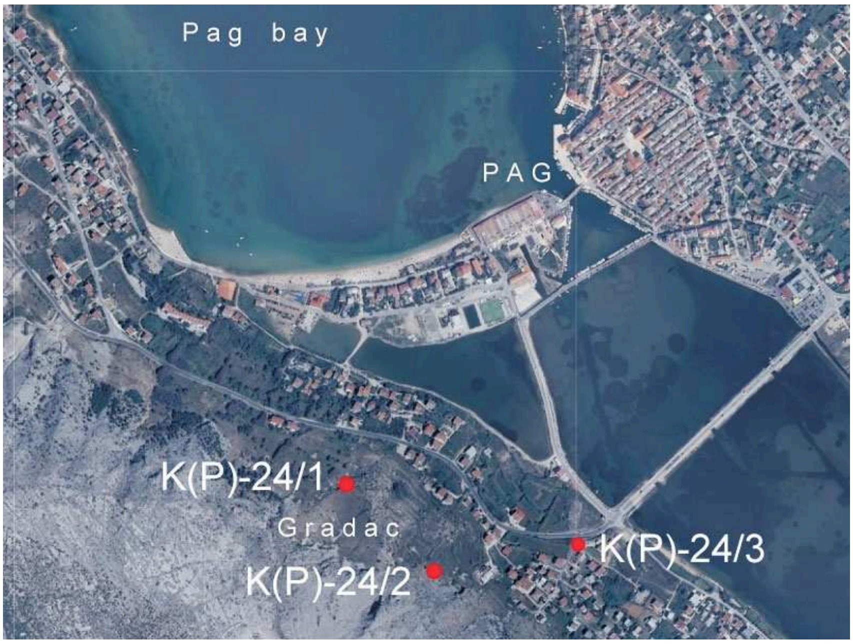


Figure 3.49. A - Locations of studied sites in Pag zone in the vicinity of Pag town. B - Geological setting (General Geological Map 1:100.000, Sheet Gospić, Sokač et al, 1974).

Slika 3.49. A - Položaj točaka u istražnom području Pag u bližoj okolici grada Paga. B - Geološka karta područja (Osnovna geološka karta 1:100.000, list Gospić (Sokač et al., 1974).

Figure 3.50.Pleistocene sediments near Pag town interpreted as kame-terrace deposits (location K(P)-24/1). Note slope-dipping beds. Photo taken in 1991.

Slika 3.50. Pleistocenski sedimenti ponad grada Paga, interpretirani kao naslage kama-terase (točka K(P)-24/1). Naslage su nagnute prema padini. Snimljeno 1991.

Figure 3.51. Pleistocene sediments with paleosols (location K(P)-24/2). Photo taken in 1991.

Slika 3.51. Pleistocenski sedimenti s paleosolom (fosilnim tlom). Lokacija K(P)-24/2. Snimljeno 1991.

Figure 3.52. Pleistocene stratified breccia. There is a small cave beneath the top of the terrace where laminated sands are exposed (location K(P)-24/3). Photo taken in 1991.

Slika 3.52. Pleistocenske uslojene breče. U brečama je mala špilja u kojoj su otkriveni laminirani pijesci (točka K(P)-24/3). Snimljeno 1991.

3.1.4.5. Pag - Gorica / K(P)-25

The Gorica observation site is located behind the Gorica village, between 70 and 80 m a. s. l. (Fig. 3.53. A). The Quaternary sediments are identified as "deluvial breccias" on the General Geological Map of Sokač et al. (1974) (Fig. 3.53. B). It is an outcrop of slope-dipping, cross-bedded Pleistocene breccia, a remnant of a formerly distinctive terrace (Fig. 3.54.).

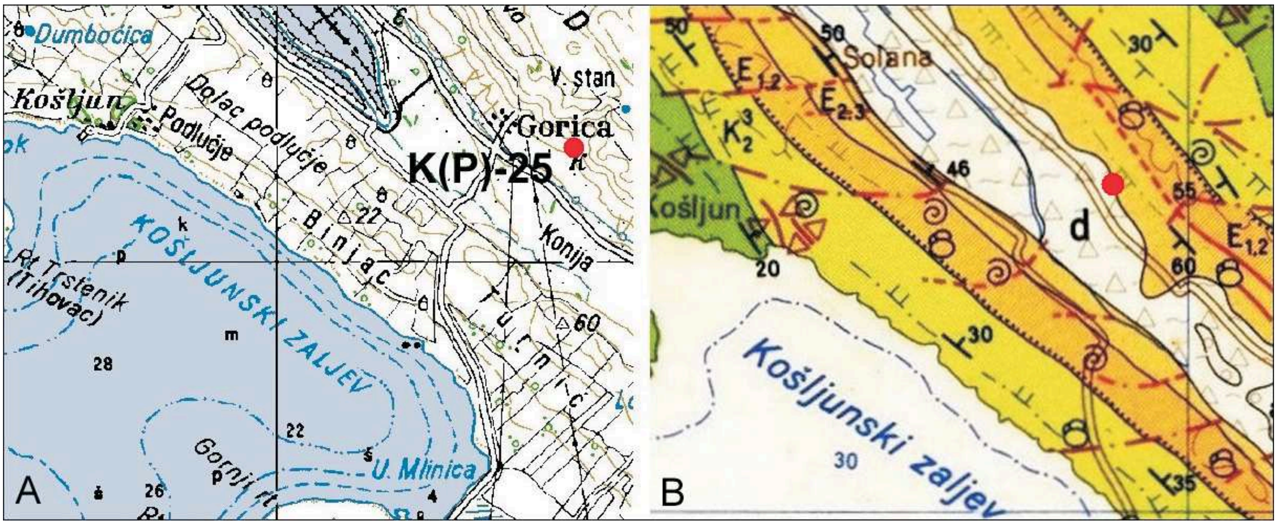


Figure 3.53. A - Location of studied site Gorica. B - Geological setting (General Geological Map 1:100.000, Sheet Gospić, Sokač et al, 1974).

Slika 3.53. A - Položja točke Gorica. B - Geološka karta područja (Osnovna geološka karta 1:100.000, list Gospić, Sokač et al., 1974).

Figure 3.54. Slope-dipping Pleistocene stratified breccia, interpreted as remnant of a kame-terrace. Photo taken in 1989.

Slika 3.54. Pleistocenske uslojene breča nagnute prema padini, interpretirane kao dio kama-terase. Snimljeno 1989.

3.2. SOUTH VELEBIT MOUNTAIN (SV)

The Southern Velebit study region (Fig. 3.55.) covers four study zones where field observations and detailed sediment logging were concentrated: Veliko and Malo Rujno and their surroundings (SV(R)), Velika Paklenica and Bezimenjača (SV(VP), Mala Paklenica (SV(MP)), Starigrad - Seline (SV(SS)) and Lika (SV(L)) which includes two locations on the NE side of Southern Velebit Mt.. Observations were recorded at more than 150 sites but Figures 3.56., 3.57., 3.58. and 3.59. show selected study locations. Detailed sediment logs were measured in Velika Paklenica canyon and in Seline along the coastal exposure.

The studied Pleistocene sediments are generally more widespread than illustrated on the General Geological maps of the area (Sheets Gospić, Zadar, Udbina and Obrovac) (Fig. 3.55. B). Quaternary deposits outlined on these maps are *"Upper Pleistocene fluvioglacial conglomerates"* at Veliko and Malo Rujno and *"slope talus breccia"* in the upper Paklenica Canyon (Sokač et al. 1974, Šušnjar et al. 1973). Nikler (1973) re-interpreted deposits on Veliko Rujno in terms of "terminal moraine" ridge. Earlier, on the geological map 1:75000, Schubert (1907) diferentiated them as *"Altquartäre konglomerate"* in the area of Rujno, Pričetrnja, Zavrata, valley of Velika Paklenica brook and in Seline area.

Figure 3.55. A - The realm of study region South Velebit including five study zones of which two are remote in Lika (two locations in square on the northeast side. Google Earth image 2011.

Slika 3.55. A - Područje istražne regije Južni Velebit, koja obuhvaća i dva lokaliteta u Lici (uokvirene lokacije na sjeveroistočnoj strani. Google Earth snimak 2011.

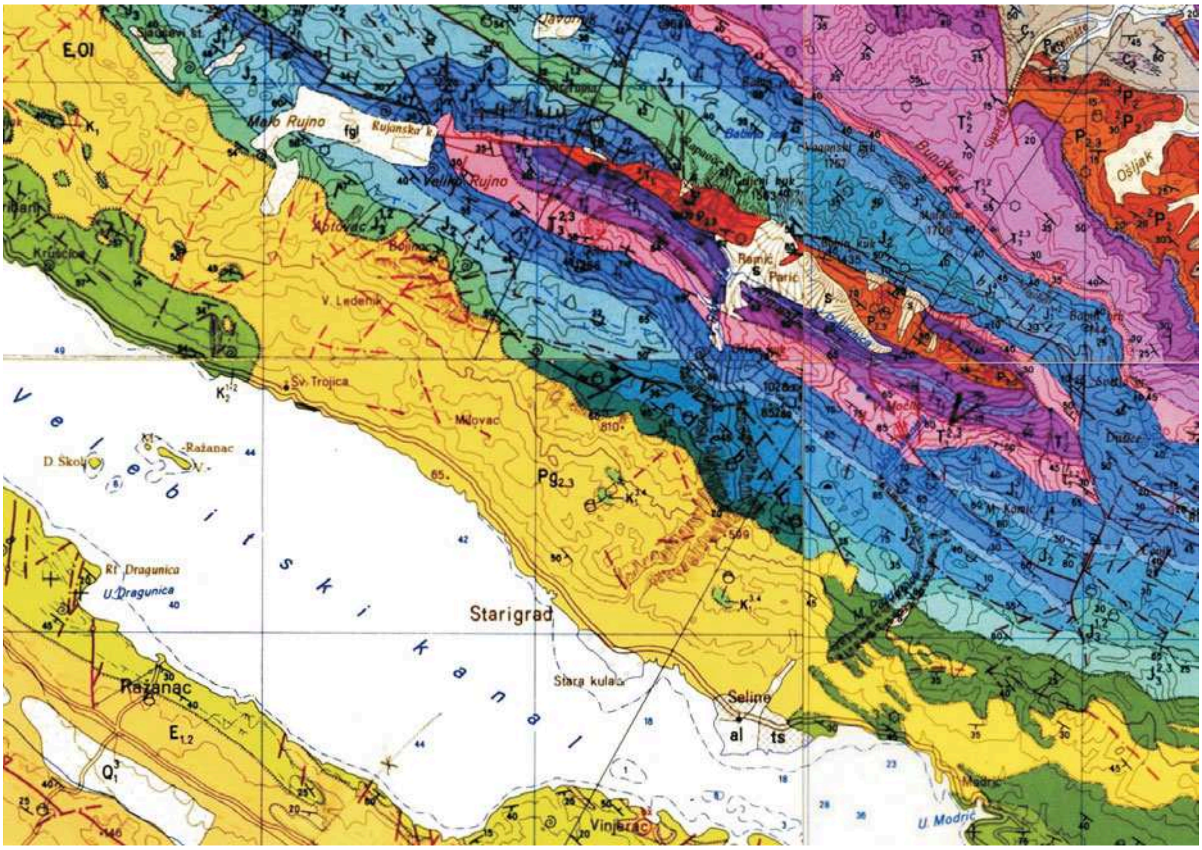


Figure 3.55. B - Geological map of the Southern Velebit study region. General Geological Map composit of Sheet Gospić (Sokač et al., 1974), Udbina (Šušnjar et al., 1973), Zadar (Majcen et al., 1970) and Obrovac (Ivanović et al., 1973).

Slika 3.55. B - Geološka karta istražne regije Južni Velebit. Kompozit Osnvne geološke karte: listovi Gospić (Sokač et al., 1974), Udbina (Šušnjar et al., 1973), Zadar (Majcen et al., 1970) i Obrovac (Ivanović et al., 1973).

Figure 56. Study locations in western part of Southern Velebit region. Google Earth image 2011.

Slika 56. Istražne lokacije u zapadnom dijelu istražne regije Južni Velebit. Google Earth snimak 2011.

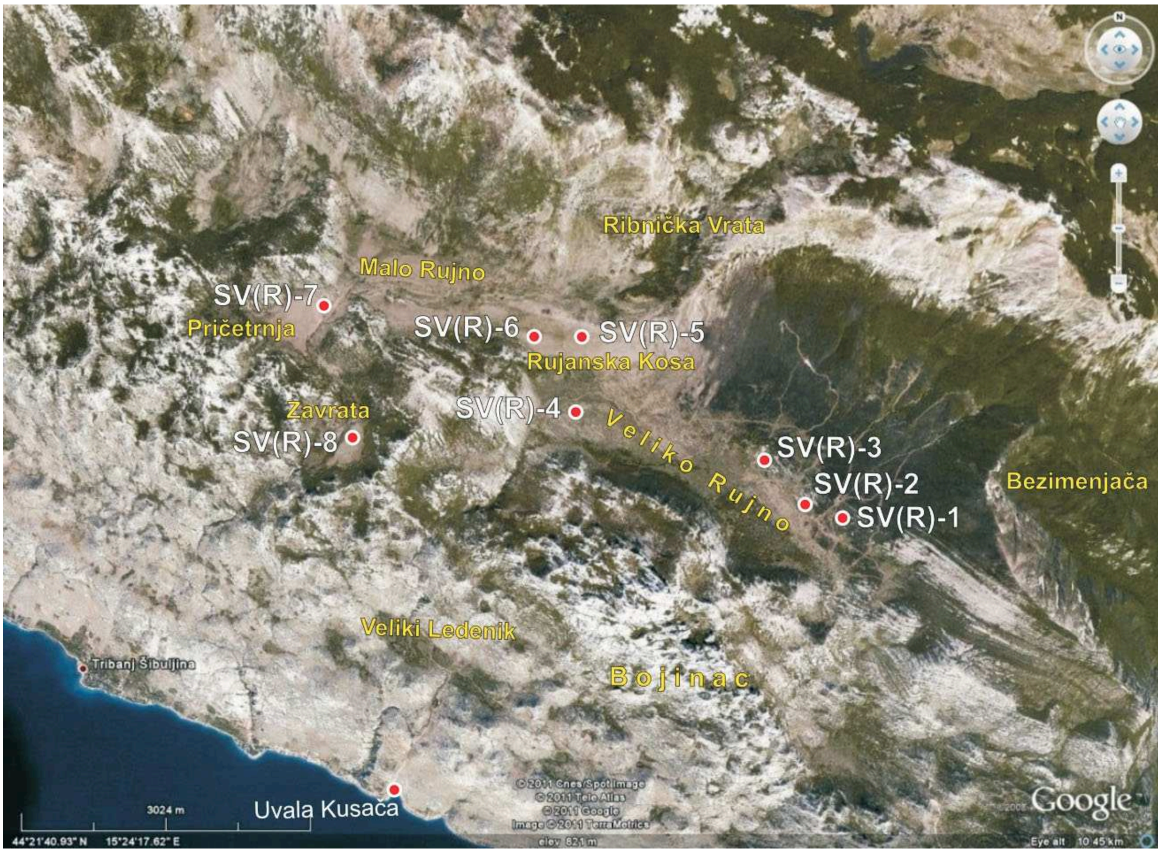


Figure 3.57. Study locations in Veliko and Malo Rujno study zone. Google Earth image 2011.

Slika 3.57. Istražne lokacije u istražnoj zoni Veliko i Malo Rujno. Google Earth snimak 2011.

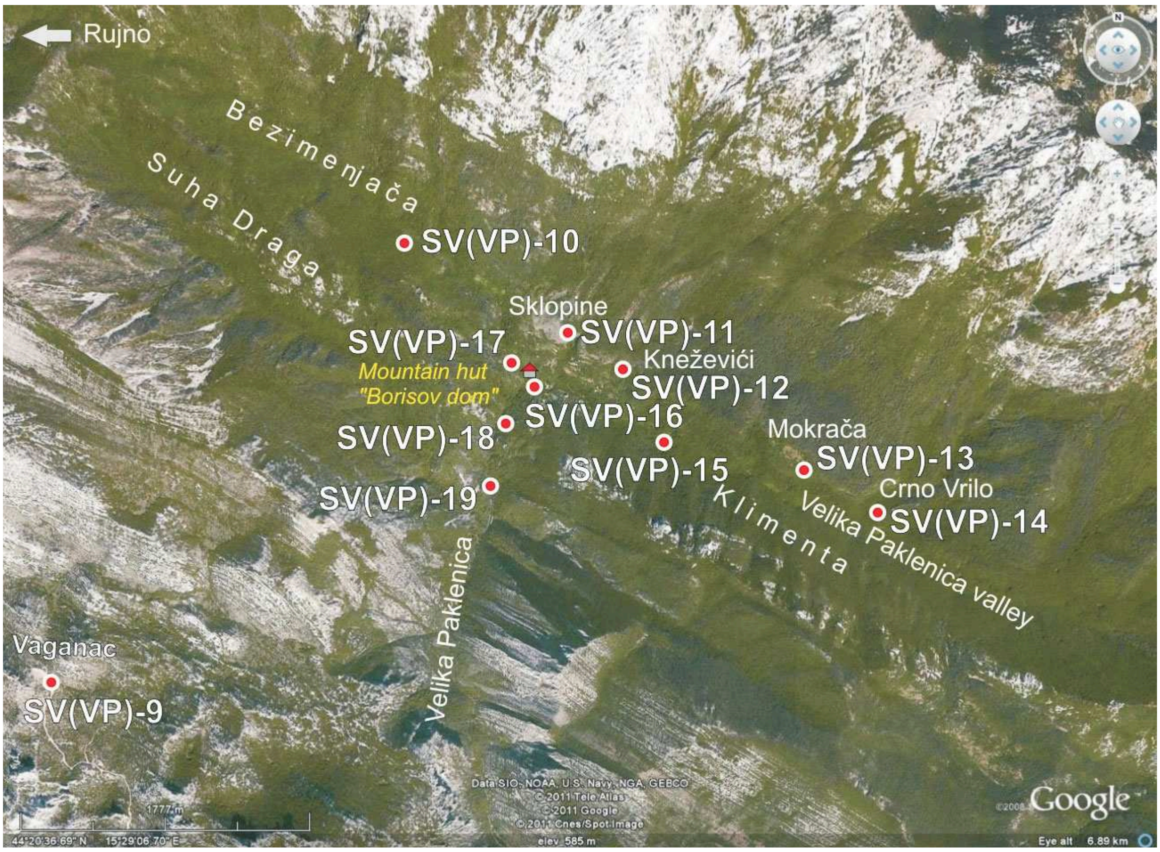


Figure 3.58. Study sites in upper section of the Velika Paklenica. Google Earth image 2011.

Slika 3.58. Lokacije u gornjem dijelu istražne zone Velika Paklenica. Google Earth snimak 2011.

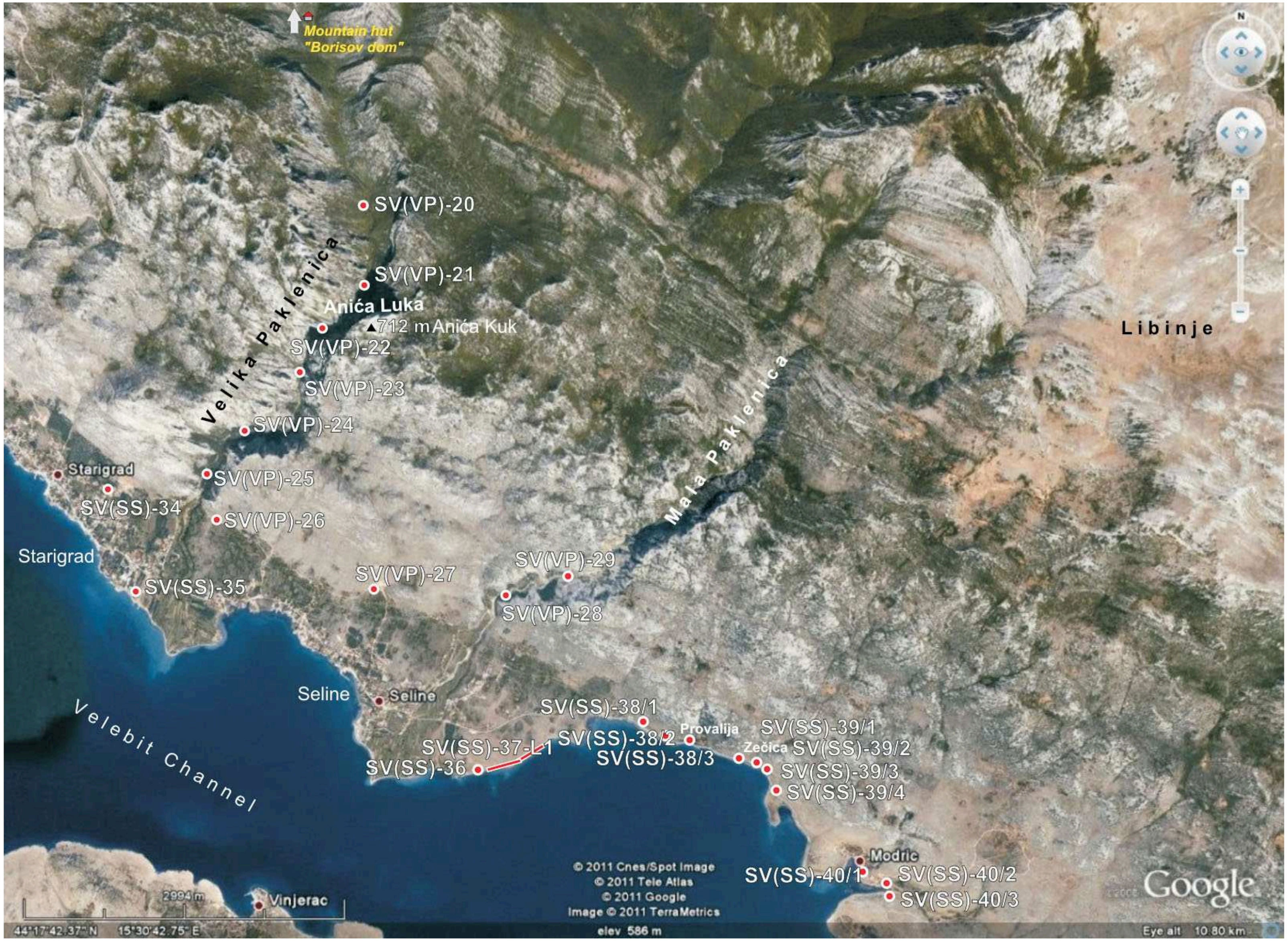


Figure 3.59. Study locations in the central part of the Southern Velebit study region.. Google Earth image 2011.

Slika 3.59. Istražne lokacije u središnjem dijelu istražne regije Južni Velebit; istražne zone. Google Earth snimak 2011.

3.2.1. VELIKO AND MALO RUJNO / SV(R)

The Veliko and Malo Rujno study zone covers the area of a mountain valley of about 6 km^2 (0.5 - 1 km wide and 6 km long). This valley is divided in two parts, Veliko Rujno located at altitude between 800 and 860 m a.s.l. and Malo Rujno between 760 and 800 m a.s.l. That divide is a morphological barrier - the Rujanska kosa moraine ridge (800 - 980 m a.s.l.), as recognized by Nikler (1973), which extends diagonally across the valley in NE-SW direction (Fig. 3.60. A, Fig. 3.61.). Veliko and Malo Rujno valleys are developed in the Lower and Middle Jurassic well bedded limestones which steeply (40°- 55°) dip southwestwards (Sokač et al., 1976), and in Veliko Rujno they are even steeper (70°- 85°). Both Veliko and Malo Rujno have distinctive wide and flat bottom surface (Fig. 3.61.) very gently inclined eastwards.

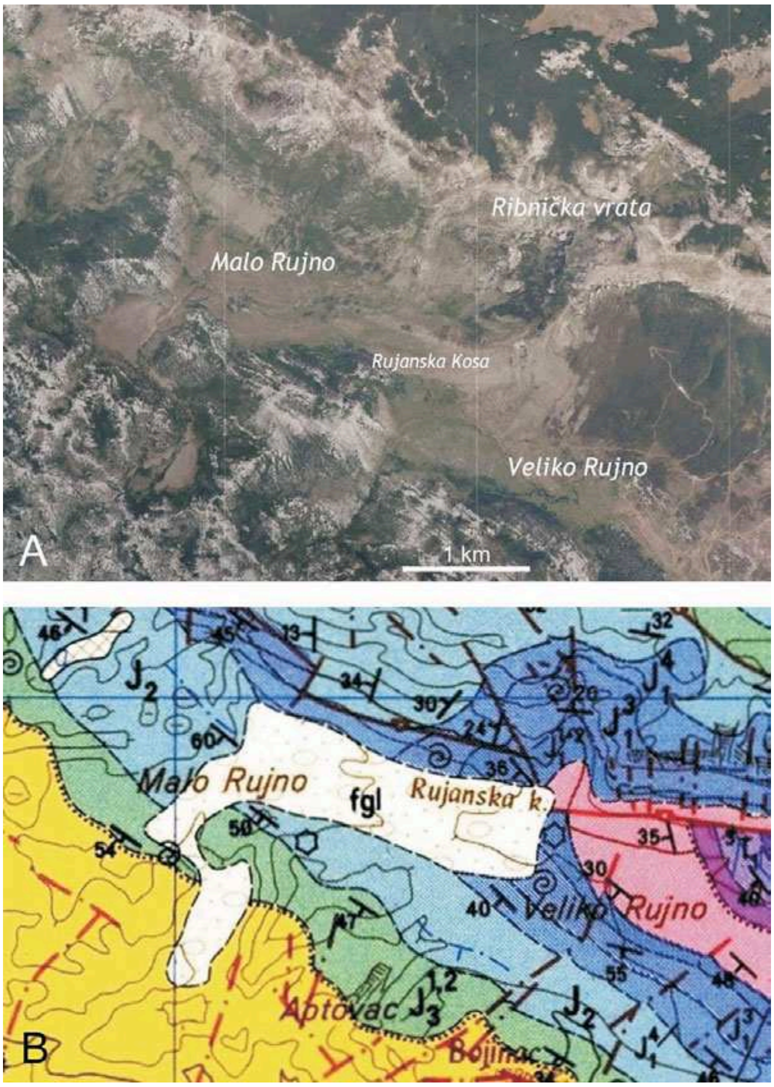


Figure 3.60. A - Satellite image of VelikoRujno and Malo Rujno with Rujanska Kosa in the middle, dividing the two valleys. Scale is 5 km. (GoogleEarth image). B - Geological setting of Veliko and Malo Rujno study zone (General Geological Map 1:100.000, Sheet Gospić, Sokač et al, 1974).

Slika 3.60. A - Satelitski snimak Velikog I Malog Rujna, te Rujanske kose između dvije doline. Mjerilo je 5 km. (GoogleEarth snimak). B - Geološka karta istražne zone Veliko I Malo Rujno (Osnovna geološka karta 1:100.000, list Gospić, Sokač et al., 1974).

Malo Rujno is completely covered with Pleistocene sediments herein interpreted as till and glaciofluvial conglomerates, but the sediment cover of the Veliko Rujno is much thinner and preserved only patchy, represented by till and reworked till, respectively. This study included the Rujno valley and adjacent areas south and southwest of Rujno, while northern areas were not studied due to mine fields still active at the time of research, and most are not cleared yet.

The Pleistocene sediments of Rujno area were interpreted as Upper Pleistocene fluvioglacial conglomerates by Sokač et al. (1974) as geological map of the area shows (Fig. 3.60. B). Schubert (1907) diferentiated them as *"Altquartäre konglomerate"* on the geological map 1:75.000. Nikler (1973) interpreted the Rujanska Kosa moraine ridge (Fig. 3.62.) as terminal moraine of last glacial.

Figure 3.61. The northwest part of Veliko Rujno valley and Rujanska Kosa in the back below the Southern Velebit peaks. The flat surface of Rujno valley is covered with thin soil and partially till. Photo taken in 2010.

Slika 3.61. Sjeverozapadni dio Velikog Rujna i Rujanska Kosa u pozadini podno vrhova Južnog Velebita. Ravna površina rujanske doline pokrivena je tankim tlom i djelomično tilom. Snimljeno 2010.

Figure 3.62. The southwest side of Rujanska Kosa moraine ridge (location SV(R)-6, Fig. 3.58.) built of till that is exposed in a small pit. Photo taken in 2009.

Slika 3.62. Jugozapadni dio morenskog grebena Rujanske Kose (lokacija SV(R)-6, Sl. 3.58.) izgrađenog od tila, koji izdanjuje u malom kopu. Snimljeno 2009.

3.2.2. VELIKA PAKLENICA / SV(VP)

Figure 3.63. GoogleEarth satellite image shows the Velika Paklenica study zone.

Slika 3.63. Google Earth satelitski snimak prikazuje istražnu zonu Velike Paklenice.

The Velika Paklenica study zone comprises the area of a deep valley of Velika Paklenica brook, which extends for ca 3,5 km northwestwards from its spring area at 900 m a.s.l., and then turns southwards and after ca 8 km ends in alluvial fan in the vicinity of Starigrad-Paklenica town (Fig. 3.63.). Pleistocene sediments are exposed all the way through the upper valley of Velika Paklenica, striking SE-NW, and the lower valley of N-S strike. The sediments were studied at 60 sites including two sites which were logged in detail.

The generally NE-SW oriented canyon of Velika Paklenica (Fig. 3.64.) is developed in Jelar-breccia in the lower part and Jurassic limestones and dolomites in the upper part (Majcen et al. 1970). Its NW-SE tributary is developed partly in Jurassic carbonates and partly in Lower Triassic clastics and Middle Triassic carbonates (Šušnjar et al. 1973). Pleistocene sediments are, thus, in contact with various lithostratigraphic units, and are represented by clast-supported to matrix-supported diamicts locally characterized by outsized clasts (megablocks) of various lithologies. These sediments are herein interpreted as of glacial origin (till and reworked till) and stratified conglomerates of glaciofluvial origin (see Chapter 5). By former researchers (see Chapter 2) these clastic sediments are interpreted as slope talus and fluvial accumulations. Only Milojević (1922) recognized them as of glacial origin. Pleistocene sediments in the Velika Paklenica were studied by detailed logging (location SV(VP)-23, Fig. 3.59.), outcrop mapping (location SV(VP)-24, Fig. 3.59.) and data recording at more than 100 observation stops but only selected are shown in Figure 3.59. Some of the most important study sites are shown in Figures 3.65. to 3.70.

Figure 3.64. Velika Paklenica canyon viewed from the sea.

Slika 3.64. Pogled s mora na kanjon Velike Paklenice.

Figure 3.65. Proglacial and glacial sediments at study site SV(VP)-25/2 (Fig. 3.59.) in the lower part of the Velika Paklenica canyon. Photo taken in 2005.

Slika 3.65. Proglacijalni i glacijalni sedimenti u donjem dijelu kanjona Velike Paklenice na lokaciji SV(VP)-25/2 (Sl. 3.59.). Snimljeno 2005.

Figure 3.66. Proglacial and glacial sediments at study site SV(VP)-24 (Fig. 3.59.) in the lower section of the Velika Paklenica canyon, where outcrop mapping was done (see Chapter 5). Photo taken in 2005.

Slika 3.66. Proglacijalni i glacijalni sedimenti na lokaciji SV(VP)-24 (Sl. 3.59.) u donjem dijelu kanjona Velika Paklenica gdje je izvršeno kartiranje izdanka (vidi Pogl. 5). Snimljeno 2005.

Figure 3.67. Study site SV(VP)-23 (Fig. 3.59.) in the lower section of the Velika Paklenica canyon where glaciofluvial and glacial deposits were logged in detail (see Chapter 5). Photo taken in 2005.

Slika 3.67. Lokacija SV(VP)-23 (Sl. 3.59.) u donjem dijelu kanjona Velike Paklenice gdje su detaljno snimljeni glaciofluvialni i glacijalni sedimenti (vidi Pogl. 5). Snimljeno 2005.

Figure 3.68. Glacial deposits below Anića Luka in the middle section of the Velika Paklenica canyon (location SV(VP)-22, Fig. 3.59.). Photo taken in 2007.

Slika 3.68. Glacijalni sedimenti ispred Anića Luke u srednjem dijelu kanjona Velike Paklenice (lokacija SV(VP)-22, Fig. 3.59.). Snimljeno 2007.

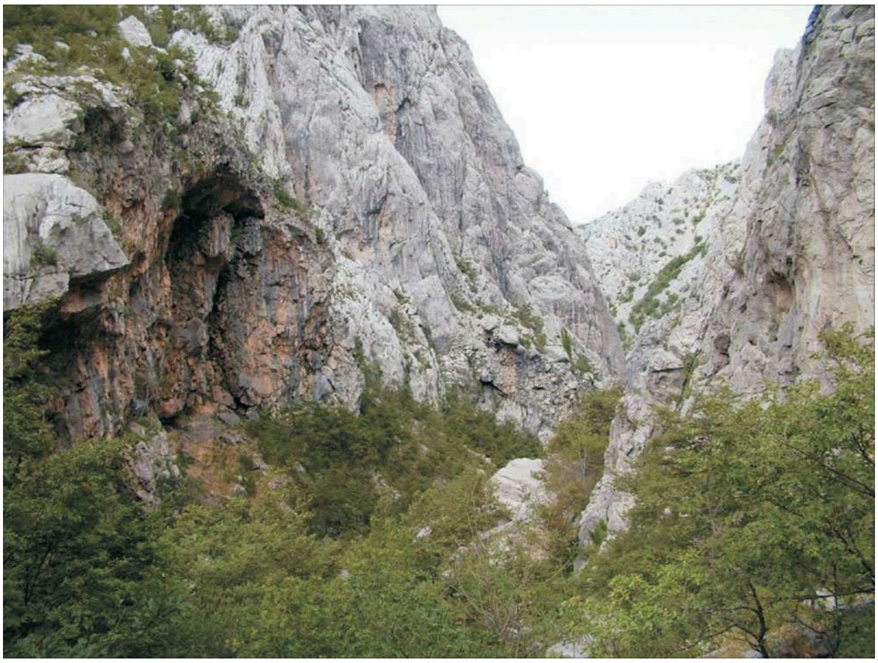


Figure 3.69. The upper valley of the Velika Paklenica brook extending SE-NW, where glacial and proglacial deposits are found. Photo taken in 2005.

Slika 3.69. Gornja dolina potoka Velika Paklenica pružanja JI-SZ, gdje se nalaze glacijalni i proglacijalni sedimenti. Snimljeno 2005.

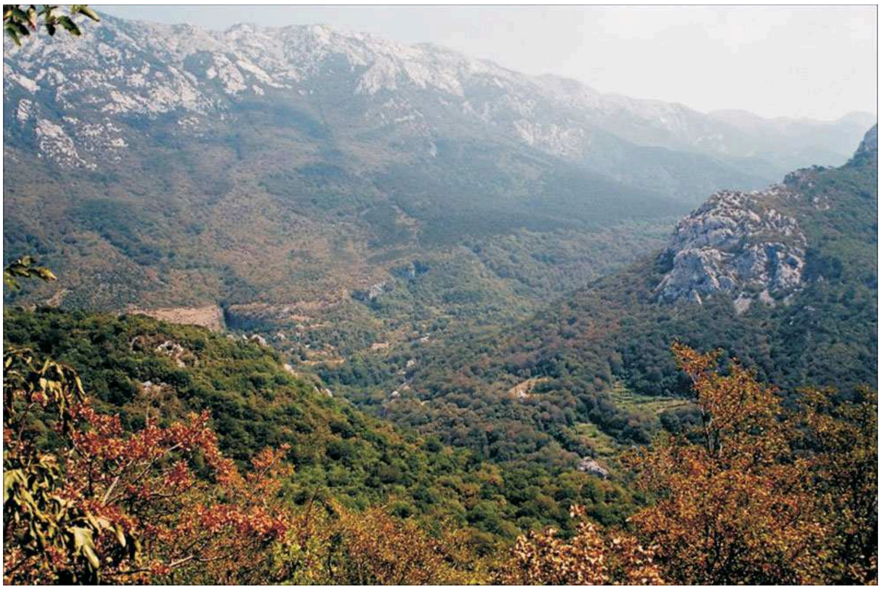


Figure 3.70. An outcrop of stratified breccia interpreted as a kame-terrace, located at the NE slope of the upper Paklenica valley (location SV(VP)-13, Fig. 3.59.). Photo taken in 2003.

Slika 3.70. Izdanak uslojenih breča koje su interpretirane kao kame-terasa (lokacija SV(VP)-13, Fig. 3.57.). Snimljeno 2003.

3.2.3. MALA PAKLENICA / SV(MP)

This zone regards to only the lowermost part of the Mala Paklenica canyon because Pleistocene sediments are preserved and exposed only in front of the canyon. A general extension of Mala Paklenica is NE-SW (Fig. 3.63.). Its middle part is a narrow gorge (Fig. 3.71.) and then it widens into a v-shaped valley turning northwestwards and again northeastwards towards the spring area of the Mala Paklenica brook (Fig. 3.63). Detailed outcrop mapping in scale 1:50 was performed at location SV(MP)-28 (Fig. 3.59.). Those deposits are marked on the General Geological Map, Sheet Zadar (Majcen et al., 1970) (Fig. 3.55. B), as *"alluvial gravel deposits"*.

Figure 3.71. A gorge in the lower section of the Mala Paklenica canyon. An arrow points at mega-breccia (location SV(MP)-29, Fig. 3.59.) interpreted as tillite (see Cpt. 5). There is a person in red circle for scale. Photo taken in 2006.

Slika 3.71. Klanac u donjem dijelu Male Paklenice. Strelica pokazuje sačuvane mega-breče (lokacija SV(MP)-29 (Sl. 3.59.) interpretirane kao tilit (vidi Pogl. 5). Osoba u crvenom krugu za mjerilo. Snimljeno 2006.

Figure 3.72. Study site SV(MP)-28 in the valley before the george of Mala Paklenica where glaciofluvial deposits are preserved. Photo taken in 2005.

Slika 3.72. Istražna lokacija SV(MP)-29 u dolini ispred kanjona Male Paklenice gdje su sačuvane glaciofluvijalne naslage. Snimljeno 2005.

3.2.4. STARIGRAD - SELINE / SV(SS)

The Starigrad - Seline study zone covers the area from the Kusača cove 10 km north of Starigrad, then Starigrad-Paklenica, Seline village and its surroundings located in front of Mala Paklenica, and the costal area from Seline to Rovanjska (Fig. 3.56. and 3.59.).

Quaternary deposits found in the study zone are not completely presented on the General Geological Maps produced by Majcen et al. (1970) and Ivanović et al. (1973). Those recognized on the geological map (Fig. 3.55. B) are the Pleistocene *"terra rossa"* and the Holocene *"alluvial sediments"* and lay over Paleogene limestone breccias and partly over Cretaceous limestones in the area of Seline (Majcen et al., 1973; Ivanović et al., 1976). They are distinguished as *"Altquartäre konglomerate"* on the geological map by Schubert (1907). These conglomerates were logged at Seline coastal section (location SV(SS)-36 and -37; see Chapter 6) are herein interpreted as glaciodeltaic deposits. Other then mentioned deposits are mega-diamicts and mega-breccias found in Kusača cove and in the coastal zone from Seline to Rovanjska, interpeted as moraines (see Chapter 5), and fine-grained sediments also logged at Seline section are interpreted as glaciolacustrine (see Chapter 6).

The mentioned mega-diamicts and mega-breccias that were recently recognized but not studied in detail, and located along the road between Seline and Rovanjska (locations SV(SS)-38, -39, -40; Fig.3.59.) are included in the thesis because of their importance for paleoenvironmental reconstruction, but are considered as preliminary study sites within this Chapter.

3.2.4.1. Uvala Kusača (SV(SS)-26) and Starigrad (SV(SS)-27)

There is a road-cut exposure all along the Kusača cove (Fig. 3.73.) where just preliminary observations were done, and samples taken. The outcrop is up to 10 m high. Both lacustrine and glacial sediments are exposed, e.g. silty/sandy marls and diamicts.

Quaternary sediments of Kusača are not marked on the General Geological Map of Ivanović et al. (1973) (Fig. 3.55. B).

Alluvial deposits of Starigrad (Fig. 3.74.) are traceable along the coast and towards the Velika Paklenica Canyon, and are interpreted as Pleistocene alluvial fan deposits of proglacial zone (see Chapter 6).

Figure 3.73. The road-side exposure of Pleistocene glacial and glaciolacustrine sediments (location SV(SS)-31, Fig. 3.57.). Photo taken in 2010.

Slika 3.73. Pleistocenske glacijalne i glaciolakustrinske naslage vidljive na profilu na sjeveroistočnoj strani ceste Starigrad - Tribanj (lokacija SV(SS)-31, Sl. 3.57.). Snimljeno 2010.

Figure 3.74. Pleistocene alluvial fan conglomerates on the coast of Starigrad - Paklenica (location SV(SS)-35, Fig. 3.59.). Photo taken in 2008.

Slika 3.74. Pleistocenski konglomerati aluvijalne lepeze otkriveni uz obalu Starigrada - Paklenice (lokacija SV(SS)-35, Sl. 3.59.). Snimljeno 2008.

3.2.4.2. Seline / SV(SS)-29

Pleistocene sediments of Seline were studied along ca 1 km long coastal exposure (Fig. 3.75). The sediments are well exposed and succession nearly 100 m thick was logged along the coast and observations recorded in the surrounding area (Fig. 3.59.)

The Pleistocene sediments of Seline are glaciolacustrine siltstones (Fig. 3.76.) and stratified alluvial fan and deltaic conglomerates (Fig. 3.77.). Majcen et al. (1970) distinguished in the Seline area the "*Holocene alluvial deposits*" and "*Late Pleistocene terra rossa*", while Schubert (1907) recognized them as *"Altquartäre konglomerate"* (Old Quaternary conglomerates).

Fossil plants were found in several intervals of lacustrine deposits, as well as numerous molds of fossil terrestrial gastropods and fresh-water bivalves (Fig. 3.78. and 3.79.) which are described in Chapter 5.

Figure 3.75. Coastal exposure of glaciolacustrine sediments near Seline (locations SV-SS-Se-215, -216). Mala Paklenica canyon is in the background. Photo taken in 2005.

Slika 3.75. Obalni izdanak glaciolakustrinskih sedimenata kod Selina (lokacije SV-SS-Se-215, -216). Mala Paklenica vidi se u pozadini. Snimljeno 2005.

Figure 3.76. Pleistocene glaciolacustrine deposits near Seline. Photo taken in 2005.

Slika 3.76. Pleistocenski glaciolakustrinski sedimenti blizu Selina. Snimljeno 2005.

Figure 3.77. Coastal exposure of glaciodeltaic conglomerates within Seline section (location SV(SS)-37, Fig. 3.59.). Photo taken in 2009.

Slika 3.77. Obalni profil s otkrivenim glaciodeltaičnim konglomeratima unutar profila Seline (lokacija SV(SS)-37, Sl. 3.59.). Snimljeno 2009.

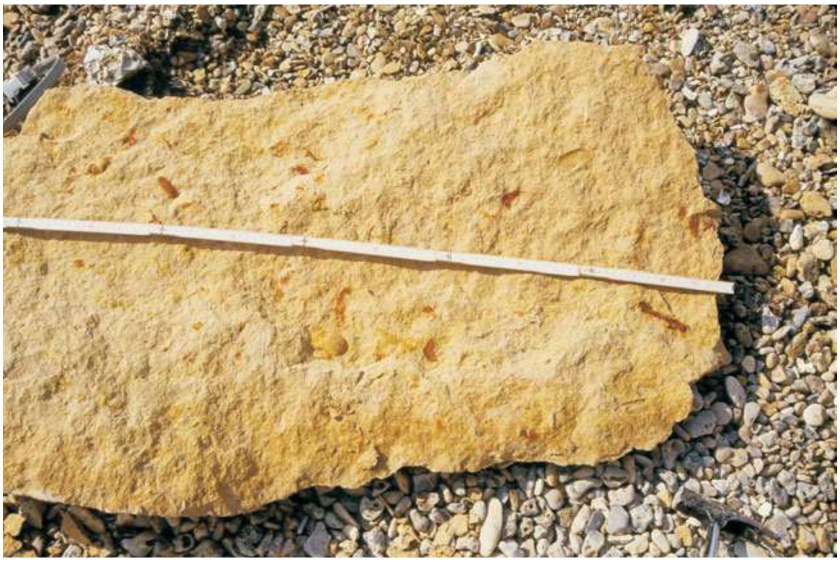


Figure 3.78. Pleistocene lacustrine calcareous marls with fossil plant debris and molds of fossil terrestrial gastropods. Scale is 1 m long. Photo taken in 2008.

Slika 3.78. Pleistocenski jezerski lapor s mnogo ostataka fosilnog bilja i jezgrama kopnenih puževa. Mjerilo je dužine 1 m. Snimljeno 2008.

Figure 3.79. A mold of Pleistocene terrestrial gastropod found in Seline lacustrine interval. Photo taken in 2008.

Slika 3.79. Kamena jezgra pleistocenskog kopnenog puža u sedimentu jezerskog intervala na profilu Seline. Snimljeno 2008.

3.2.4.3. Starigrad - Seline sites in preliminary study

During the most recent field study several roadside locations were observed and basic data on sediment characteristics were colleted. Mega-diamicts and locally mega-breccias were recognized. The key characteristic are many striated boulders, megablocks and smaller clasts. Therefore, although not studied in detail, these sites are included in this theses as important for glacial interpretation and paleoenvironment reconstruction.

These outcrops are neither marked on the General Geological Map (Fig. 3.55. B) nor described in the relevant Explanation book. Though, Milojević (1933) mentioned that in Provalija village exist lacustrine marls of Pliocene age. These marls, herein interpreted as glaciolacustrine, were found at location SV(SS)-38/1 (Fig. 3.59.) underlaying a mega-diamict.

Figure 3.80. Exposure of mega--diamict along the northeast side of the road Seline - Rovanjska (location SV(SS)-34/1, Fig. 3.59.). Photo taken in 2011.

Slika 3.80. Mega-diamikt na sjeveroistočnom profilu duž ceste Seline - Rovanjska (lokacija SV(SS)-34/1, Sl. 3.59.). Snimljeno 2011.

Figure 3.81. A road-side exposure of a mega-diamict close to Modrič village (location SV(SS)-40/4, Fig. 3.59.) that is interpreted as ground moraine. Photo taken in 2011.

Slika 3.81. Izdanak mega-dijamikta uz cestu blizu sela Modrič (lokacija SV(SS)-40/4, Sl. 3.59.) koji je interpretiran kao podinska morena. Snimljeno 2011.

3.3. NORTHERN DALMATIA (ND)

The study region, herein named Northern Dalmatia, covers just the northern part of the Northern Dalmatia, which includes the coastal zone at the southeast end of the Velebit Channel, Bukovica district (location Obrovac), and Ravni Kotari district (Novigradsko More, Karin, Smilčić, Paljuv) (Fig. 3.82. A).

The Pleistocene sediments of Northern Dalmatia are partly presented (depending on size of occurrence) on the General Geological Maps, Sheets Zadar (Majcen et al., 1970) and Obrovac (Ivanović et al., 1973) (Fig. 3.82. B). On the contrary, the Austro-Hungarian geological maps in scale 1:75.000 (Sheet "Novigrad und Benkovac", Hauer et Stache, 1906) show all registered Pleistocene deposits, which are recognized as "*Altquartär Sande und Lehme*" (*Old Quaternary sands and marls*) and "*Alluvium*" (*Alluvial deposits*).

Figure 3.82. A - Study zones in the Northern Dalmatia study region. Google Earth image 2011.

Slika 3.82. A - Istražne zone u istražnoj regiji Sjeverna Dalmacija.

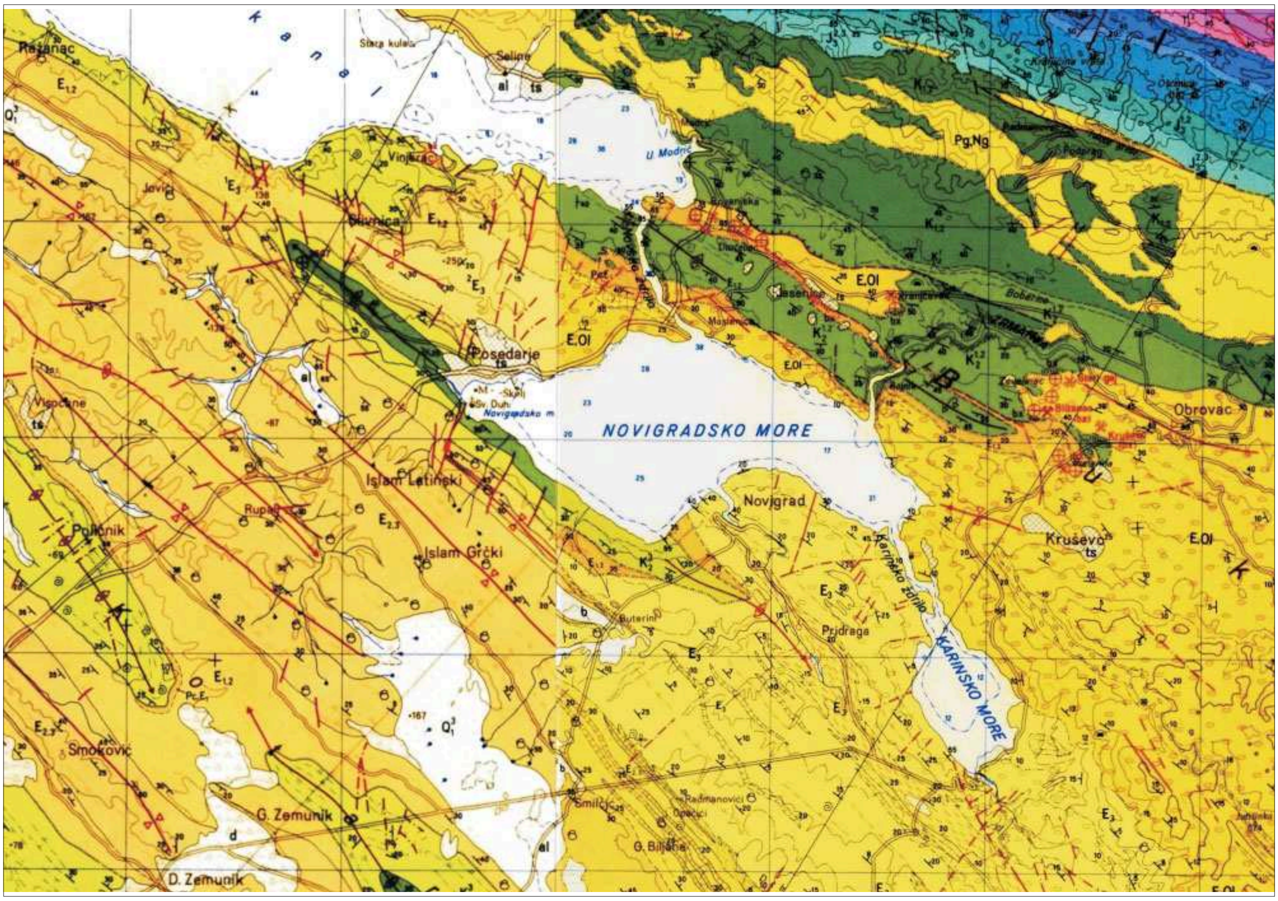


Figure 3.82. B - Geological setting of the study region (General Geological Map 1:100.000, Sheets Zadar, Majcen et al., 1970) and Obrovac (Ivanović et al., 1973). Triassic - violet, Jurassic - blue shades, Cretaceous - green shades, Teertiary - yellow shades, Quaternary - white.

Slika 3.82. B - Geološka karta istražne regije (Osnovna geološka karta 1:100.000, listovi Zadar, Majcen et al., 1970; Obrovac, Ivanović et al., 1973). Trijas - ljubičasto, jura - plavi tonovi, kreda - zeleni tonovi, tercijar - žuti tonovi, kvartar - bijelo.

3.3.1. NOVIGRADSKO MORE / ND(N)

The Novigrad study zone is the southwest coastal zone of Novigradsko More (Novigrad Sea), characterized by mainly cliffs and otherwise low coast (Fig. 3.83. A) where Pleistocene deposits are exposed in length of 3 km. Their thickness varies between 2 and 15 meters.

The sediments were logged in detail at seven locations and the complete 3 km long outcrop was mapped based on digital photo mosaic (App. II). Successive photographing of the outcrop was done from a boat. Photo-profile was produced by stitching 73 photographs using AutoStich software, and then it was used as background for reconstruction of lateral and vertical facies relation and interpretation with help of field data (App. III-A to III-D).

These deposits are not marked on the General Geological Map 1:100.000, Sheet Zadar (Majcen et al., 1970) (Fig. 3.82. B) but were recognized by Hauer and Schubert and distinguished as "*Altquartärer Sand*" (Old Quaternary sand) on the Austro-Hungarian geological map in scale 1:75.000, Sheet "*Novigrad und Benkovac*" (Schubert, 1907). These deposits lay mainly over Cretaceous limestones, but also over Paleogene clastics on the southeast side of the study zone. Contact with the bedrock can be traced all the way, although it is locally covered with soil.

The main objects of study at Novigrad section were glaciolacustrine deposits (Fig. 3.84.) and various diamicts interpreted as moraine (Fig. 3.85). Glaciofluvial sand and gravel deposits (Fig. 3.86.) also occur at several locations along the studied section.

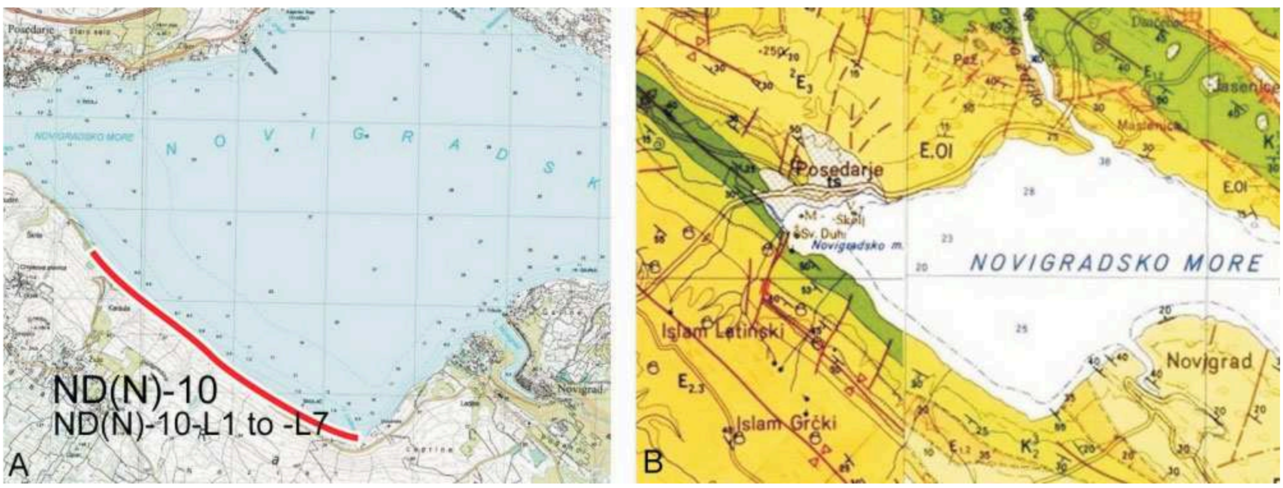


Figure 3.83. A - Studied zone along the SW coast of Novigradsko More. B - Geological setting (General Geological Map 1:100.000, Sheet Zadar, Majcen et al., 1970; Sheet Obrovac, Ivanović et al., 1973).

Slika 3.83. A - Istražna zona duž JZ obale Novigradskog mora. B - Geološka karta područja (Osnovna geološka karta 1:100.000, list Zadar, Majcen et al., 1970; i Obrovac, Ivanović et al., 1973).

Figure 3.84. Pleistocene glaciolacustrine deposits exposed along the SW coast of Novigradsko More. Photo taken in 2008.

Slika 3.84. Pleistocenske glaciolakustrinske naslage otkrivene duž JZ obale Novigradskog mora. Snimak iz 2008.

Figure 3.85. Coarse-clastic deposits on the coast of Novigradsko More, interpreted as basal moraine (see Chapter 5). Photo taken in 2008.

Slika 3.85. Krupno-klastične naslage na obali Novigradskog mora, interpretirane kao podinska morena (vidi Pogl. 5). Snimak iz 2008.

Figure 3.86. Gravel and sand deposits exposed along SW Novigrad Sea coast, are interpreted as glaciofluvial. They were deposited over Novigrad older moraine (see Chapter 5.2.). Photo taken in 2008.

Slika 3.86. Naslage šljunka i pijeska otkrivene duž JZ obale Novigradskog mora interpretirane kao glaciofluvijalne. Istaložene se na starijoj moreni (vidi Pogl. 5.2.). Snimljeno 2008.

3.3.2. KARINSKO MORE / ND(K)

The site with exposed Pleistocene sediments is located at the SE coast of the Karinsko more in the zone of small town Karin (Fig. 3.87. A). These are lacustrine sediments and conglomerates in total thickness of 2 to 3 m. The lacustrine sediments at one location form an erosional mound nearly 3 m high covered with tuffa and are marked on the Austro-Hungarian geological map by Schubert (1908), Sheet "*Novigrad und Benkovac*" (Schubert, 1908). About a hundred meters away, lacustrine sediments are exposed along the coast and are much thinner and overlain by diamicts. These sediments have limited extent and are covered by Holocene organogenic swamp deposits (Ivanović et al. 1973).

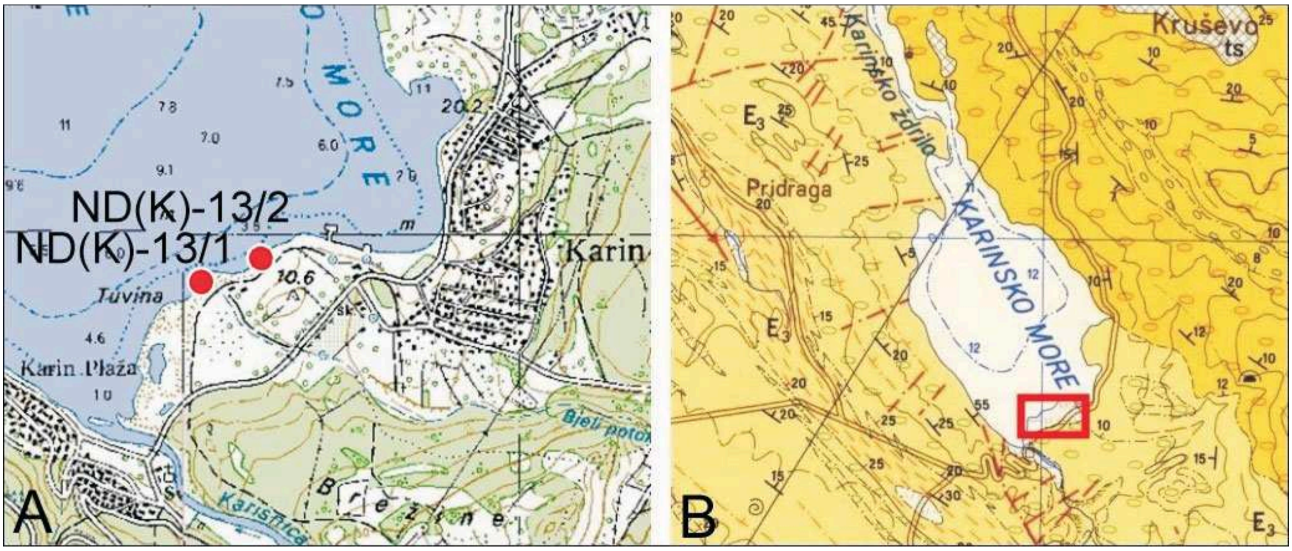


Figure 3.87. A - Study sites Karinsko More coast. B - Geological setting (General Geological Map 1:100.000, Sheet Obrovac, Ivanović et al., 1973.)

Slika 3.87. A - Istražne točke na obali Karinskog mora. B - Geološka karta područja (Osnovna geološka karta 1:100.000, list Obrovac, Ivanović et al., 1973).

Figure 3.88. Pleistocene sediments exposed along the SE coast of Karinsko more. (Location ND(K)-8/1). Photo taken in 2006.

Slika 3.88. Pleistocenski sedimenti otkriveni duž JI obale Karinskog mora (lokacija ND(K)-8/1). Snimljeno 2006.

3.3.3. SMILČIĆ AND PALJUV / ND(N)

Study sites Smilčić (ND(N)-12) and Paljuv (ND(N)-11) are located on the southwest of the Novigradsko More study zone (Fig. 3.89.). The Smilčić site is an abandoned sand/gravel pit (Fig. 3.90.) with up to 3 m thick stratified gravel and sand was exposed. There is dark colored clay underlying, at least 1 m thick.

These Pleistocene deposits were determined as "*Altquartärer Sand*" ('Old Quaternary sand') by Schubert (1908). The Paljuv site is another small sand/gravel pit located closer to Novigradsko More.

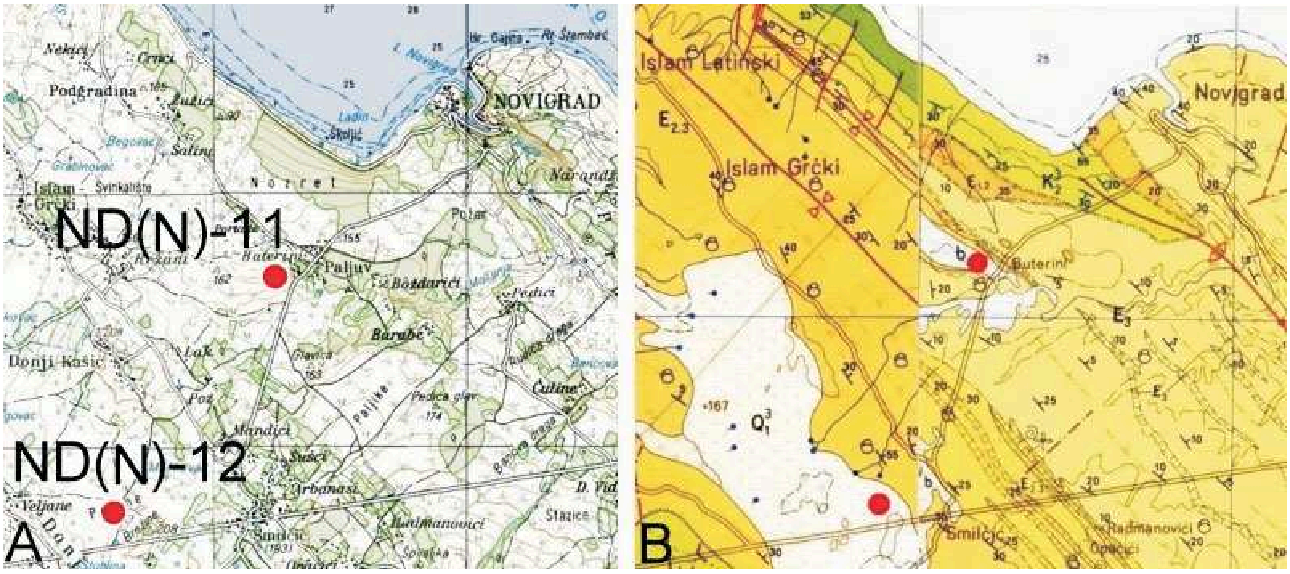


Figure 3.89. A - Study sites Smilčić and Paljuv. B - Geological setting(General Geological Map 1:100.000, Sheet Obrovac (Ivanović et al., 1973.)

Slika 3.89. A - Istražne točke Smilčić i Paljuv. B - Geološka karta područja. Isječak Osnovne geološke karte 1:100.000, list Obrovac (Ivanović et al., 1973).

Figure 3.90. Exposure of the Pleistocene sand and gravel deposits, in a sand pit near Smilčić village (location ND(K)-12). Photo taken in 1989.

Slika 3.90. Pleistocenski sedimenti u pjeskokopu blizi sela Smilčić (lokacija ND(K)-12). Snimljeno 1989.

3.3.4. OBROVAC / ND(O)

Obrovac site is located at the road curve on the SE bank of Zrmanja river in the vicinity of Obrovac town (Figures 3.91. and 3.92.). The outcrop is a road-cut exposure, about 10 m high. There occurs Pleistocene coarse breccia-conglomerate (a diamict), which is in contact with well bedded conglomerates of Eocene-Oligocene age (Ivanović et al. 1967). The Pleistocene sediment is not marked on the General Geological Map (Fig. 3.91. B) by Ivanović et al. (1967).

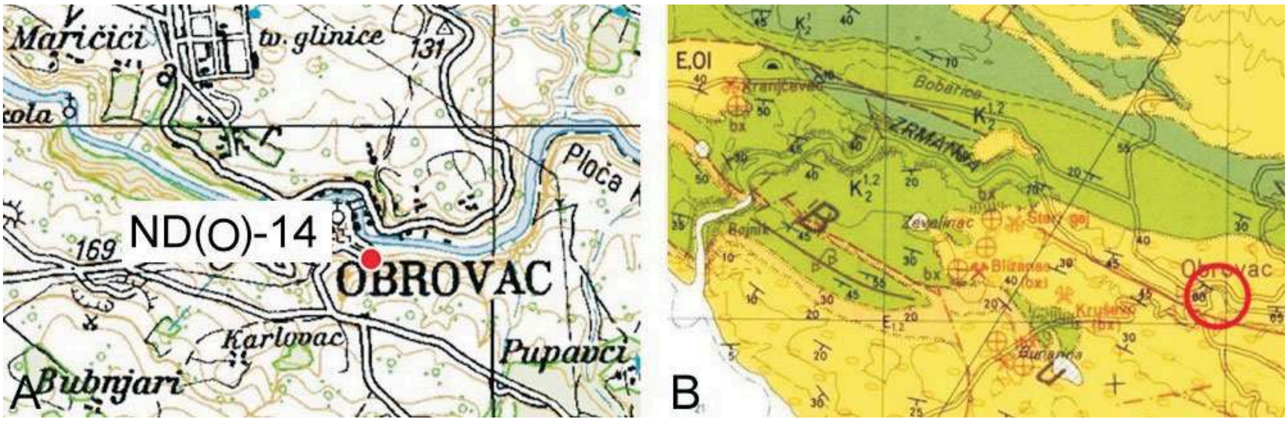


Figure 3.91. A - Location of study site Obrovac (ND-Ob-...). B - Geological setting (General Geological Map 1:100.000, list Obrovac, Ivanović et al., 1973).

Slika 3.91. A - Položaj točke Obrovac. B - Geološka karta područja (Osnovna geološka karta 1:100.000, list Obrovac, Ivanović et al., 1973).

Figure 3.92. Road-cut exposure of Pleistocene coarse-clastic deposits near Obrovac town (location ND(K)-14) Photo taken in 2006.

Slika 3.92. Izdanak pleistocenskih krupno-klastičnih sedimenata u blizini Obrovca (lokacija ND(K)-14). Snimak iz 2006.

3.3.5. NORTHERN DALMATIA SITES IN PRELIMINARY STUDY

Ždrilo site is located on the southwest coast of the Velebit Channel (Fig. 3.82.) north of the Ždrilo village. Pleistocene sediments are preserved in four coves. Only glaciolacustrine sediments in Poljica cove (ND(Z)-6, Fig. 3.82.A), both glaciolacustrine and glacial deposits (moraines) in two coves, one westwards (ND(Z)-5, Fig. 3.82. A) and another eastwards (ND(Z)-7, Fig. 3.82. A). Due to their very restricted occurrence, they are not marked on the General Geological Map by Majcen et al. (1970), but Milojević (1933) recognized lacustrine sediments as of Pliocene age.

Figure 3.93. A coastal exposure of Pleistocene glaciolacustrine sediments preserved in a cove near Ždrilo village (location ND(Z)-6, Fig. 3.82. A). Photo taken in 2009.

Slika 3.93. Obalni izdanak pleistocenski glacio-jezerskih sedimenata sačuvanih u maloj uvali blizu sela Ždrilo (lokacija ND(Z)-6, Sl. 3.82. A). Snimljeno 2009.

Figure 3.94. A coastal exposure of Pleistocene coarse-clastic deposits (mega-breccia) interpreted as basal moraine (location ND(Z)-5, Fig. 3.82. A). Photo taken in 2009.

Slika 3.94. Obalni izdanak pleistocenskih krupno-klastični sedimenata (mega-breča) interpretiranih kao podinska morena (lokacija ND(Z)-5, Sl. 3.82. A). Snimak iz 2009.

Figure 3.95. Pleistocene diamict (mega-breccia) exposed in Kusača cove (location ND(Z)-4, Fig. 3.82.A). Photo taken in 2011.

Slika 3.95. Pleistocenski diamikt (mega-breča) otkriven u uvali Kusača (lokacija ND(Z)-4, Sl. 3.82. A). Snimljeno 2011.

Figure 3.96. Pleistocene diamict (mega-breccia) at Crvena Pećina (location ND(R)-3, Fig. 3.82. A). Photo taken in 2011.

Slika 3.96. Pleistocenski diamikt (mega-breča) kod Crvene pećine (lkacija ND(R)-3, Sl. 3.82. A). Snimljeno 2011.

Figure 3.97. Pleistocene diamict (mega-breccia) exposed along the coast at Radanovica cove (location ND(R)-1, Fig. 3.82. A). Photo taken in 2011.

Slika 3.97. Pleistocenski diamikt (mega-breča) otkriven duž obale kod uvale Radanovica (lokacija ND(R)-1, Sl. 3.82. A). Snimljeno 2011.

4. RESEARCH METHODS

The research comprised field investigations, laboratory sample preparation and analyses of both consolidated and unconsolidated sediments, radiocarbon and U-series dating, analyses of air born photographs, Landsat and ASTER satelite images, Google Earth images in additional search for outcrops, for estimation of their extension and morphology, and other geomorphological features.

The utilized field methods described in section 4.1. included field observations, detailed sediment logging and outcrop mapping, sampling, particle-size analysis, analysis of shape of gravel to boulder size particles, lithological analysis of gravel to boulder size particles, and on-site statistical processing of particle characteristics.

Laboratory methods described in section 4.2. comprised particle analyses and statistical processing of measurements, structure and texture observation on solid rock samples, and dating of number of samples using carbon and U-series isotopes.

Graphic and photo presentation of the results was obtained using the following software: Corel Draw, PaintShop Pro, Harward Graphics for DOS and WIN98, QuatroPro 9 and Corel VENTURA 8 publishing software. Sections of high-resolution satelite images of Croatia, available at free site www.arkod.hr, were used to present certain type of data, like location data and various reconstructions of paleoenvironments.

4.1. FIELD METHODS

The outcrops for detailed study of Pleistocene sediments were chosen during the field inspection of the Adriatic islands and mainland coast from Rijeka to Zadar. Those sufficiently extensive and exposing sufficiently thick sediment succession, were considered for detailed analyses of sediment characteristics, lithofacies and their relations.

Detailed sediment logging was carried out at sites where sediments are exposed in significant area and where succession of sediments was suitably thick, 2 m at least. At sites with extensive outcrops and distinct lateral facies diversity the whole outcrop was mapped. All other sites which were not suitable for detailed logging or mapping were taken as observation/sampling sites.

At chosen sites, detailed sediment logs were made in scale 1:50, or 1:20 for details within the sediment succession. Four sites with very extensive outcrops were mapped in the scale 1:100. Regarding the fact that most of the outcrops have very steep faces, even vertical cuts, it was necessary to use ladders to access otherwise inaccessible parts of the section. The sites with restricted outcrops were only observation and sampling points.

Since Quaternary sediments are predominantly loose or poorly cemented, it was necessary first to clean the outcrop by removing few centimeters of weathered surface or moss which obscured observation of primary structures of sediments. In addition to detailed sediment logs measured directly in the field, notes were taken about grain size and shape, sorting, sedimentary structures and textures, layer thickness, particle (gravel to boulder size) organization and sediment color (for paleosols according to Munsell Color Chart).

For field determination of grain size and sorting I used field grain size comparator. For study of coarse-grained sediments I utilized two field methods: a) measurement of largest diameter of ten largest particles along the length of 1 m or in a square meter, depending on layer thickness, b) measuring diameter of all particles along the length of 1 m and calculating the mean value of the grain size.

Samples were taken for granulometrical, petrographical, sedimentological and palaeontological analysis, and radiometric dating. Sampling of sediments composed of sand and fine gravel was done by collecting 1 liter volume of sediment. Separately, matrix and clasts were sampled in coarse-grained sediments.

Mapping of large outcrops in scale was not an easy task because most of them are vertical cliffs or very steep slopes and are located at the shoreline

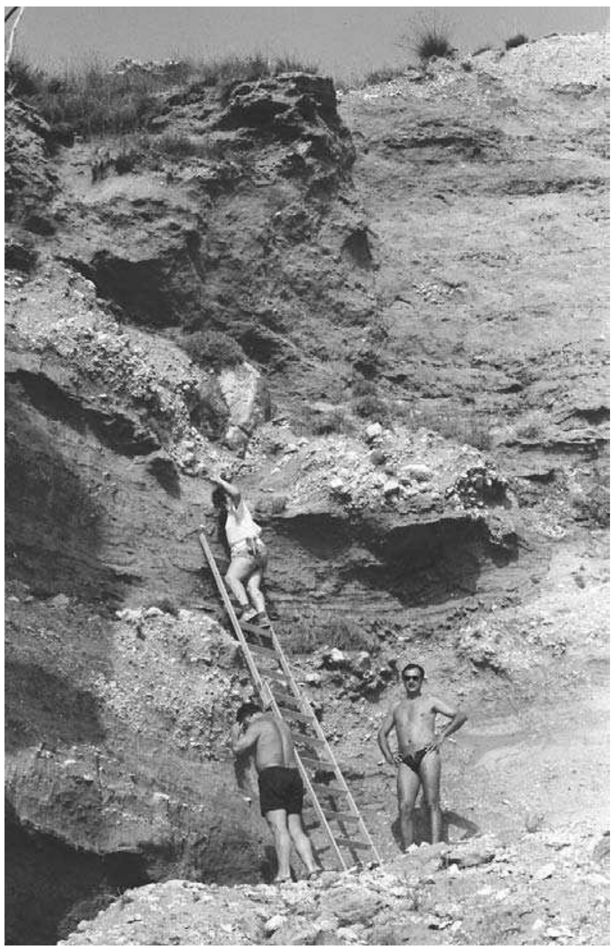


Figure 4.1. Technical approach to vertical outcrops. Logging was limited to about 6 m height. Photo taken in 1990.

Slika 4.1. Tehnički pristup vertikalnim izdancima. Snimanje je bilo ograničeno na visinu od ca 6 m. Snimljeno 1990.

Figure 4.2. Mapping of extensive outcrop using a crocque technique. Finding a suitable position was very tricky procedure at the Baška-Žarok study site on Krk island. Photo taken in 1990.

Slika 4.2. Kartiranje strmog I širokog izdanka korištenjem kroki tehnike. Pronalaženje optimalne pozicije bilo problematično na lokaciji Bška-Žarok na otoku Krku. Snimak iz 1990.

like the cliffs of the study zone Krk-Baška. The crocque technique was very helpful but not always convenient (Fig. 4.2). It was used along with additional scales set on the outcrop to compensate for the paralax. Alternatively, a square metre net was marked over the whole outcrop and then the section was mapped. Drawing an outcrop map on the base of photo-mozaic was additional very helpful technique, and was used for the 3 km long coastal section at the Novigrad Sea.

4.2. LABORATORY METHODS

4.2.1. SEDIMENTARY ANALYSES

Laboratory analyses of collected rock samples and samples of loose sediments were utilized during my affiliation with INA-Projekt (1986-1992). The samples were subjected to a classic grain size analyses by sieving. Samples were dried and sieved using a set of sieves from ø 65μ to 500μ. Then the sediments were classified according to Friedman and Sanders (1978). After sieving, coarse sand and gravel fractions of each sample were subjected to a macroscopic and/or microscopic visual analysis of particle shape, sphaericity, roundness and surface texture, separately for each sieve-fraction of one sample, and then results were combined and statistically processed. Each of these sieved fractions was subjected to a macroscopic and/or a microscopic determination of particle lithology.

Statistical processing of granulometric data was as an additional method for interpretation of a sedimentary environment. It was applied for sediments at the Krk-Baška, Pag-Bošana and Novigrad study locations. Results of the applied statistical method, as described later, confirmed interpretation based on field study of sedimentary structures, lithofacies and their relation.

Determination of sedimentary environment on the basis of granulometric analysis of recent sediments was performed by various authors. Stewart (1958) defined an area of river zone, wave zone and calm water on a diagram of the asimetry coefficient (SK = skewness) and median (phi) ratio, and ratio between phi-deviation (quartile deviation) and median. Buller and McManus (1972) determined areas of all basic sedimentary environments on log-diagramme based on ratio of quartile deviation and median.

The comparison of data obtained in this research with these diagrams confirmed interpretation of sedimentary environments for most of the samples as will be mentioned in following Chapters.

Petrographic composition of sand, gravel and boulder deposits was studied in thin-sections. Selected samples of sand and fine gravel deposits were taken and mixed with epoxy resin, and then cut into thin-sections. Classic thin-sections were produced from rock samples or lithoclasts taken from coarse-grained sediments.

Samples of cemented sediment were cut and standard thin sections were made for microscopic petrographical analysis. Some samples were cut and polished, etched in diluted HCl and stained with alizarine Red-S and KFeCN and an acetate peel was produced for microscopic analysis (Bouma 1969; Marjanac 1984). Purpose of staining was to determine ratio of carbonate and noncarbonate componen, especially in diamictites.

The results obtained by described methods were used as fundamental data for further research continued years later, after 1998.

4.2.2. DATING OF SEDIMENTS

4.2.3.1. Radiocarbon dating

Three dates were obtained based on radiocarbon dating method using carbon isotope ^{14}C (see Chapter 6). Samples of Pleistocene sediments in the study zone Krk-Baška-Žarok, which contained significant amount of organic matter (commonly charcoal particles) (Fig. 4.3.), were taken for radiometric dating. Sample preparation and isotope measurements were undertaken in the Laboratory for Low Radioactivity at the Institute "Ruđer Bošković" in Zagreb, in the period 1989 to 1990, financed by the INA-Naftaplin petroleum industry research project.

Figure 4.3. Sandy to gravelly clay (paleosol) rich in organic matter, which is commonly burned plant debris. Photo taken in 1990. (details in Chapter 6)

Slika 4.3. Pjeskovito-šljunkovita glina bogata organiskom tvari koju uglavnom čine komadići nagorenog bilja. Snimak iz 1990. (detalji u poglavlju 6.)

4.2.3.2. Uranium series dating

Secondary carbonates (calcite) that occur as cement in studied moraines were dated using U-series (Hughes et al., 2010). Samples were collected at 10 locations and by 2010 three dates were obtained (sampling locations shown in Figures 4.4., 4.5. and 4.6.). Partial preparation and extraction of powdered sample was executed in the laboratory at the University of Manchester by Philip Hughes. Chemical preparation and isotope measurements were undertaken at the UK Natural Environment Research Council Uranium Series Facility at the Open University using standard methods following the procedures described in Hughes et al. (2010).

Figure 4.4. Sampling location near Borisov Dom hut in Velika Paklenica in 2006.

Slika 4.4. Mjesto uzorkovanja u blizini Borisovog doma u Velikoj Paklenici 2006. g.

Figure 4.5. Sampling location at study site 200 in Velika Paklenica in 2006.

Slika 4.5. Mjesto uzorkovanja na točki 200 u Velikoj Paklenici 2006. g.

Figure 4.6. Sampling location at the NE end of the Novigrad coastal section in 2006.

Slika 4.6. Mjesto uzorkovanja na SE kraju profila na JZ obali Novigradskog mora, 2006. g.

5. SEDIMENTARY CHARACTERISTICS OF STUDIED PLEISTOCENE DEPOSITS

5.1. INTRODUCTION

The Pleistocene deposits studied in the regions of Kvarner, Southern Velebit Mountain and Northern Dalmatia (Fig. 3.1.) encompass a variety of sediments deposited by different sedimentary processes predominantly in terrestrial paleoenvironments: glacial, lacustrine, fluvial and aeolian. Sediments of marine paleoenvironment are rarely found exposed above the present sea level.

The studied sediments are classified according to their depositional origin and are assorted in three major groups: glacigenic (glacial, glaciofluvial, glaciodeltaic and glaciolacustrine), alluvial and marine. Paleosols, considered as fourth group, were not studied in detail and are only briefly discussed in Chapter 5.5. Glacigenic, alluvial and marine sediments are described in terms of lithofacies, facies associations and location of occurrence in the following chapters (5.2. to 5.4.). The description of lithofacies is given separately for each of the three groups, although a particular lithofacies, such as diamict, can be of different sedimentary origin. It seemed more convenient for understanding of each sedimentary group to associate the lithofacies description in the same chapter.

The studied sediments comprise both unlithified and lithified types including varieties of different consolidation degree. In many cases apparently lithified sediment is just superficially cemented. Thereafter, both the loose-sediments terminology and the hard rock terminology was used for lithofacies description and coding (Table 5.1.).

The primary object of study were glacigenic sediments, namely glacial, glaciofluvial, glaciodeltaic and glaciolacustrine. Their geomorphological significance is discussed in Chapter 6, while their stratigraphy and paleoenvironmental reconstruction is presented and discussed in Chapter 7.

The lithofacies classification and coding system was modified after Ben & Evans (2010) for glacigenic sediments, and after Miall (1996) for glaciofluvial/fluvial sediments. The key to graphics used in sediment logs, including graphic presentation of sedimentary textures and structures and all other characteristics observed in a sediment succession, is given in Tables 5.2.-1., 5.2.-2 and 5.2.-3.

Table 5.1. Coding and lithofacies classification for loose sediments (non-lithified) and lithified sediments (modified after Mial, 1978 and Ben & Evans, 2010).

Tablica 5.1. Oznake i klasifikacija litofacijesa za nevezane (nelitificirane) i litificirane sedimente (prilagođeno prema Mial, 1978 i Ben & Evans, 2010).

CODE	**LITHOFACIES** (LOOSE SEDIMENT)	LITOFACIJES (NEVEZANI SED.)
E	**Erratic / Mega-block**	eratik, mega-blok
D	**Diamict**	diamikt
Dmm	Diamict matrix-supported, massive	diamikt s muljnom potporom, masivan
Dcm	Diamict clast-supported, massive	diamikt sa zrnskom potporom, masivan
MDcm	Mega-Diamict clast-supported, massive	mega-diamikt sa zrnskom potporom, masivan
-s	stratified	slojevit
-g	graded	graduiran
-r	reworked	prerađen
BL	**Boulder**	blokovi
BLm	Boulder, massive	blokovi, masivni
BLs	Boulder, stratified	blokovi, slojeviti
BLg	Boulder, graded	blokovi, graduirani
BLcs	Boulder, clast-supported	blokovi sa zrnskom potporom
Bp	Boulder pavement	blokovi, pločnik
G	**Gravel**	šljunak
Gmm	Gravel matrix-supported, massive	šljunak s muljnom potporom, masivan
Gmg	Gravel matrix-supported, graded	šljunak s muljnom potporom, graduiran
Gcm	Gravel clast-supported, masive	šljunak sa zrnskom potporom, masivan
Ghs	Gravel horizontal stratified	šljunak, horizontalno slojevit
Gcs	Gravel cross stratified	šljunak, koso slojevit
GS	Sandy gravel	pjeskoviti šljunak
S	**Sand**	pijesak
Sm	Sand, massive	pijesak, masivan
Smg	Sand, graded	pijesak, graduiran
Sl	Sand, laminated	pijesak, laminiran
Scl	Sand, cross laminated	pijesak, koso laminiran
Srl	Sand, ripple laminated	pijesak s riplovima
Stcl	Sand, trough-cross laminated	pijesak, koritasto laminiran

GS	Gravelly sand	šljunkoviti pijesak
CyS	Clayey sand	glinoviti pijesak
M, CL	**Mud, Clay**	mulj, glina

CODE	**LITHOFACIES** (LITHIFIED SEDIMENT)	LITOFACIJES (LITIFICIRANI SED.)
B	**Breccia**	breča
Bmm	Breccia matrix-supported, massive	breča s muljnom potporom, masivna
Bmg	Breccia matrix-supported, graded	breča s muljnom potporom, graduirana
Bcm	Breccia clast-supported, massive	breča sa zrnskom potporom, masivna
Bcg	Breccia clast-supported, graded	breča sa zrnskom potporom, graduirana
Bcs	Breccia clast-supported, stratified	breča zrnske potpore, slojevita
C	**Conglomerate**	konglomerat
Cmm	Conglomerate matrix-supported, massive	konglomerat s muljnom potporom, masivan
Cmg	Conglomerate matrix-supported, graded	konglomerat s muljnom potporom, graduiran
Ccm	Conglomerate clast-supported, massive	konglomerat sa zrnskom potporom, masivan
Ccg	Conglomerate clast-supported, graded	konglomerat sa zrnskom potporom, graduiran
Ccs	Conglomerate clast-supported, stratified	konglomerat sa zrnskom potporom, slojevit
CA	**Calcarenite**	kalkarenit
CAm	Calcarenite, massive	kalkarenit, masivan
CAl	Calcarenite, laminated	kalkarenit, laminiran
CAcl	Calcarenite, cross laminated	kalkarenit, koso laminiran
CArl	Calcarenite, ripple laminated	kalkarenit s riplovima
CSm	Calcisiltite, massive	kalcisiltit, masivan
CSl	Calcisiltite, laminated	kalcisiltit, laminiran
M	**Mudstone, marl**	muljac, lapor, glinac

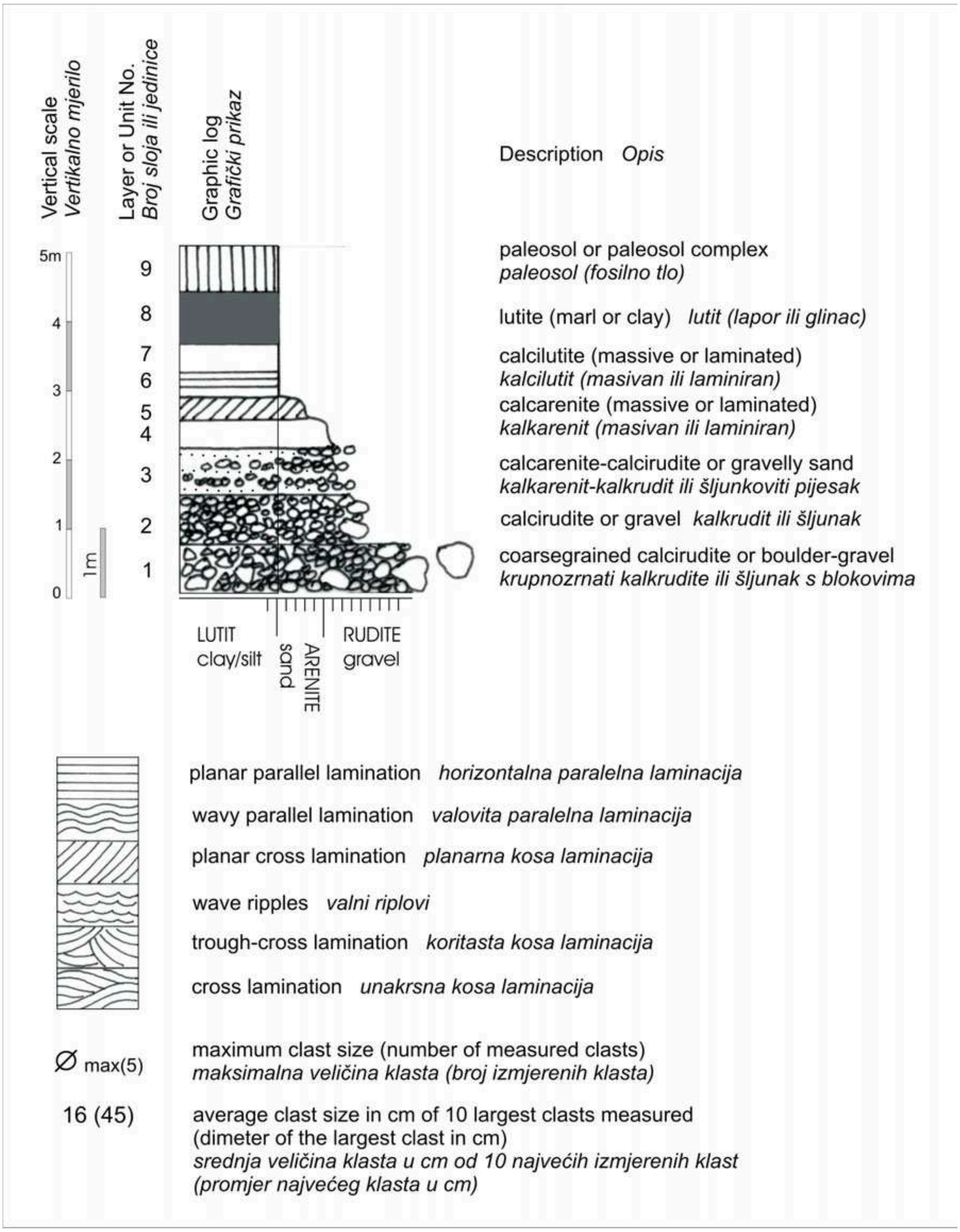


Figure 5.1. Key to graphic presentation of detailed sedimentary logs.

Slika 5.1. Legenda za detaljne sedimentološke stupove.

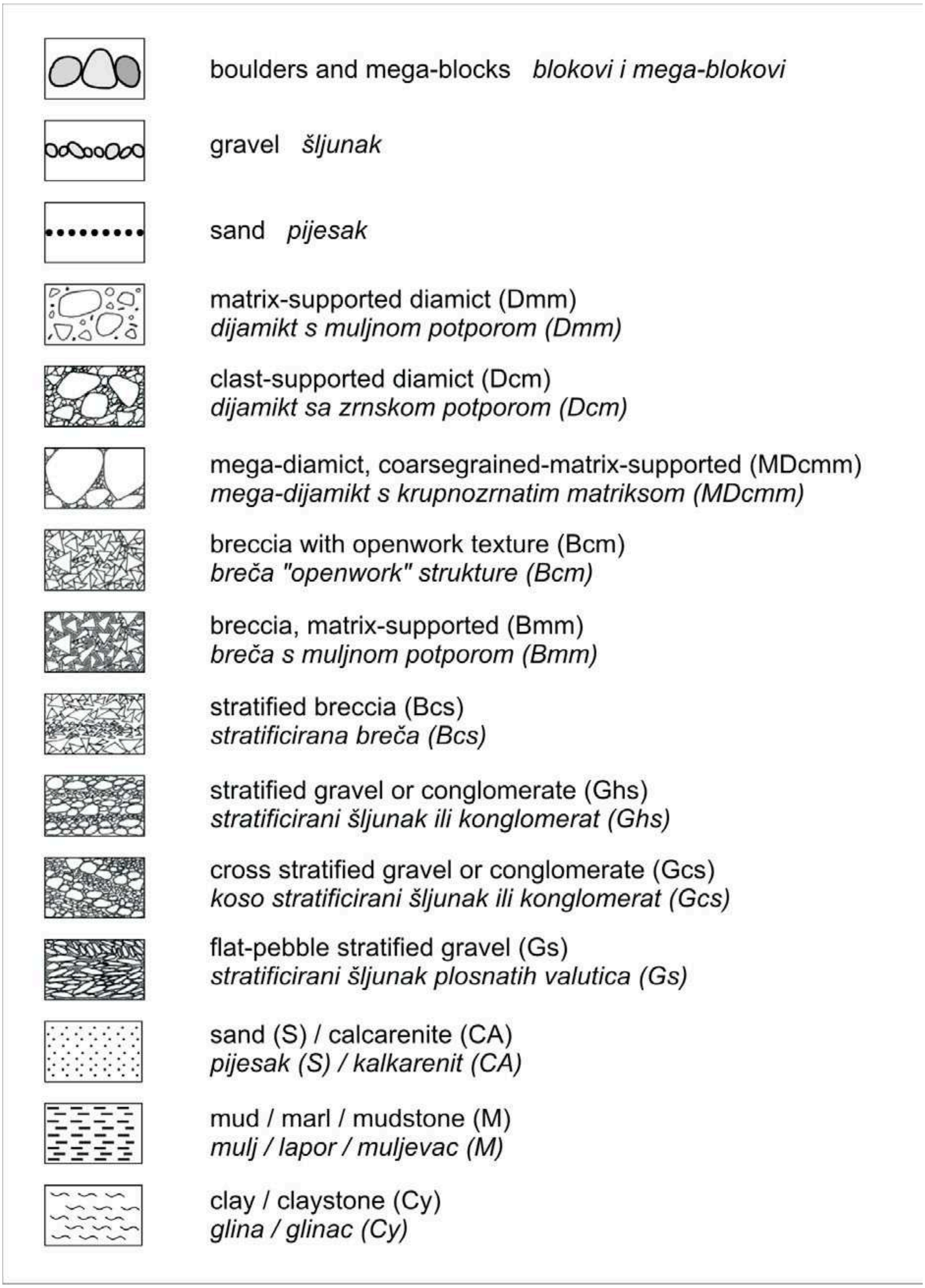


Figure 5.2. Key to lithological symbols.

Slika 5.2. Legenda litoloških simbola.

Figure 5.3. Key to graphic presentation of various sediment characteristics and fossil content, used in sedimentary logs.

Slika 5.3. Legenda grafičkih oznaka za različita obilježja sedimenata i fosilnog sadržaja, korištenih u sedimentološkim stupovima.

5.2. GLACIGENIC SEDIMENTS

Glacigenic deposits encompass all types of sediments deposited in direct contact with ice (glacial) or by ice influence (glacifluvial, glacilacustrine, glacimarine). Glacial deposits are by definition sediments carried by active or stagnant ice and accumulated in ice-contact zones, namely subglacial, inglacial and supraglacial. Brodzikovsky and Van Loon (1991) were the first who described and discussed in detail glacigenic sediments from sedimentological aspect. Their detailed distinction and subdivision of sedimentary environments, facies and facies association was adopted as the framework for the studied Pleistocene glacigenic deposits. This framework was simplified and modified according to specific conditions of studying ancient glacial environments, which predominantly refer to degree of preservation of sedimentary bodies and landforms.

The studied sediments interpreted as glacigenic include sediments of glacial, glacifluvial, glacideltaic and glacilacustrine environments. Glacial deposits described in Chapter 5.2.1. encompass all sediments accumulated in direct contact with ice, namely tills or tillites. Glacifluvial, glacideltaic and glacilacustrine sediments, described in Chapters 5.2.2. through 5.2.4., are of proglacial and periglacial environments, although they can as well originate in ice-contact zones, such as kame-terrace deposits. These are partly described in this Chapter and partly as glacial landform in Chapter 6.

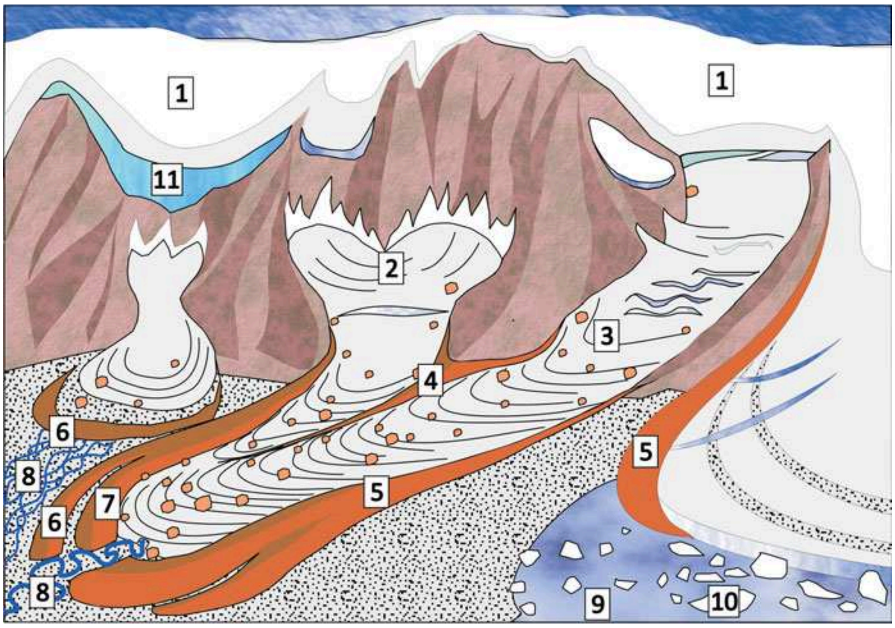


Figure 5.4. Glacial sedimentary environments and glacigenic sediments. 1 - ice cap/plateau; 2 - cirque; 3 - valley glacier; 4 - medial moraines; 5 - latteral moraines and kame-terraces; 6 and 7 - terminal or end moraines; 8 - glaciofluvial outwash plain; 9 - proglacial lake; 10 - ice-blocks; 11 - hanging valley.

Slika 5.4. Glacijalni taložni okoliši i glacigeni sedimenti. 1 - ledena kapa/plato; 2 - cirk; 3 - dolinski ledenjak; 4 - središnja morena; 5 - bočne morene i kame-terase; 6 i 7 - završne morene; 8 - glaciofluvijalna ravnica ispiranja; 9 - proglacijalno jezero; 10 - ledeni blokovi; 11 - viseća dolina.

5.2.1. GLACIAL SEDIMENTS - TILLS AND TILLITES

Ancient glacial environment is traditionally recognized by finding tills or tillites and glacial landforms. Till or tillite (lithified) is a diamict, an unorganized sediment, unsorted, with large variety of clast sizes usually floating in fine-grained matrix (commonly clay or silty/sandy clay), and composing sediment bodies called moraines, which in modern environments are specific geomorphologic forms depending on their position in relation to active or stagnant ice (medial, lateral, basal and terminal).

When studying ancient glacial environments, it is commonly very hard to recognize morainal bodies due to variable degree of preservation. They are usually degraded by erosion or destructed by a younger glacial advance, or even completely destroyed. Therefore, conclusion on the origin is based on detailed study and analyses of sediment remains and their structural and textural characteristics. Recognition of till or tillite can also be a problem if various field criteria are not met, as discussed by Dremains & Schlüchter (1985), which also includes some regional criteria like glacial landforms and erosional features.

The advantage of the presented study area is that each Pleistocene glaciation was weaker than the previous one, so the sediments attributed to the Middle Pleistocene have not been destroyed by the Late Pleistocene glaciation - the Last Glacial Maximum (LGM). Nevertheless, erosional processes active during interstadials and Holocene were significant and most of those sediments were reworked or destroyed, and resedimented in the Adriatic basin. Thus, today we can find only erosional remnants of the Pleistocene sediments in restricted exposures, but fortunately at many locations within the study area.

The study of Pleistocene sediments led to recognition of glacially derived deposits - tills (unconsolidated) and tillites (consolidated). Tills/tillites are considered as primary sediment type of glacigenic origin (Ben & Evans, 2010). They strictly accumulate in direct contact with ice in form of subglacial, inglacial or supraglacial till.

Tills and tillites, represented by diamict lithofacies described bellow, were found throughout the study area (Fig. 3.1.). Since the field exploration is stil ongoing there are new outcrops of tills/tillites, which were not yet studied in detail but are considered in this Thesis as supporting evidence, and are listed in Chapter 3 as locations under preliminary study. The diamict as a non-genetic term is used only for lithofacies description. A common characteristic for all studied diamict types is that they are locally cemented, especially outcrop surfaces. Despite of the variable degree of cementation, these sediments are considered as unlithified in general and are classified as such (see Table 1 in Cpt. 5.1.). The diamict lithofacies are generally described in the following chapter, while tills and tillite and respective diamict types and their facies association is given in Chapters 5.2.1.2. to 5.2.1.9.

Although the term “till” is genetically defined sedimentological term and “moraine” is a geomorphological term describing a glacial landform, preference to use the term “moraine” in combination with geographical position was taken only to group their regional occurences and make general distinction between groups eg. “Krk moraines”, “Rujno moraines”, “Paklenica moraines”, “Obrovac moraine”, “Novigrad moraines”, "Ždrilo moraine" and "Ražanac moraine". The moraines in terms of landforms and stratigraphy are described and discussed in Chapter 6.

5.2.1.1. DIAMICT LITHOFACIES

Diamicts in general are unorganized and unsorted sediments, composed of debris highly variable in size, with matrix or clast support. Their name does not imply depositional origin. Thus, they are herein described in terms of various lithofacies in relation to clast size and shape, matrix- or clast-support characteristics, and debris:matrix ratio.

There are diamicts, which are clast supported, but there are also diamicts of a very noticeable difference between a type of matrix. The matrix can be composed of finegrained sediment (clay or carbonate mud with variable admixture of silt or sand or very fine gravel), and is considered as matrix-support *sensu stricto*. The other type, considered as matrix-supported *sensu lato,* consists of a lot of gravel and small boulders, wich as a gravel-boulder component acts as coarsegrained-matrix support to abundance of extra large boulders and mega-blocks. This type of sediment is named a mega-diamict or mega-breccia/conglomerate.

These three basic types of diamicts (clast-supported, matrix-supported and coarsegrained-matrix-supported; Table 5.1.) are described in further text. Nevertheless, transitional types between each exist and will be described in the context of a particular location of occurrence in chapters 5.2.1.2. to 5.2.1.9. These diamicts are interpreted as of glacial origin based on diagnostic ice-striated clasts (Atkins, 2003) and detail context is given in the cited chapters.There are variations within each type regarding clast:matrix ratio, clast characteristics and clast lithology. Some diamicts show evidence of reworking by water, resedimentation and sorting.

Regarding their lithologic composition, diamicts are up to 90% carbonate rock due to the geological framework of the study area where carbonate rocks predominate. Their clast composition is discussed further on, relative to location of occurrence.

Diamict matrix-supported, massive (Dmm)

Dmm lithofacies is common in the study area and has been found at many localities in all three study regions (see Cpt. 5.2.). Both terms matrix-supported breccia and matrix-supported conglomerate are also used in the text depending on clast morphology and rate of lithification. This lithofacies is herein differentiated and described as breccia and conglomerate in order to instantly indicate clast angularity or roundness, which implies on later interpretation of till/tillite type. There are variations between the two and will be indicated in Chapter 5.2. in relevance to the study site.

Matrix-supported breccia (D/Bmm)

The matrix-supported breccia was found on Krk and Pag Islands and in Paklenica. It consists of 25 to 60% clay-silt matrix and angular to subrounded limestone debris of 5 to 30 cm in longer diameter axis. Boulders up to 1 m in diameter are scarce. Matrix is well cemented carbonate mud and silt with yellow-redish to grey-brown color on fresh surface. The color of weathered surface of matrix varies from greyish-yellow to grey and contrasts with white to yellowish color of limestone debris (Fig. 5.5. and 5.6.). Distribution of clacts within matrix varies from fewer dispersed in more matrix (clasts float in the matrix) to high concentration of clasts (clasts dominate over matrix) (Fig. 5.6.). Zones with higher concentration of debris (Fig. 5.7.) are commonly of open-work texture and porous due to loosely packed unsorted debris. Drusy or fibrous calcite cement is commonly found in voids. Coarse debris (cobbles and boulders) is predominantly angular and sharp edged, elongated to medium sphaerical. The subrounded and medium sphaerical clasts also occur. Clast lithology varies from only limestone debris (monomict breccia) to a mixture of limestone, breccia, sandstone, dolomite and marl

Figure 5.5. Dmm lithofacies. Matrix-supported massive breccia (D/Bmm) with angular limestone debris found in sedimentary sequence of the Pag kame-terrace described in Chapter 6.1. Irregular distribution of debris in the greyish-yellow carbonate matrix is clearly visible. Sediment is lithified. Scale is 20 cm.

Slika 5.5. Dmm litofacijes. Breča s muljnom potporom (D/Bmm), masivna, s uglatim vapnenačkim klastima, koja se nalazi u slijedu sedimenata kame-terase Pag, opisane u Poglavlju 6.1. Jasno je vidljiv neravnomjeran raspored klasta u sivkasto-žutom karbonatnom matriksu. Sediment je litificiran. Mjerilo je 20 cm.

(polymict breccia). Ice-shattered clasts are rare but were found at nearly all study locations. Due to a high percentage of matrix, it is possible that glacial striae were not produced.

Matrix-supported breccias are interpreted as lateral and supraglacial till or tillite, due to their relationship with other lithofacies and geomorphological characteristics described in Chapters 5.2. and 6.

Figure 5.6. Dmm lithofacies. Matrix-supported massive breccia (D/Bmm) showing variable concentration of angular limestone debris in carbonate matrix. Grey color of the matrix surface is due to weathering. Sediment is lithified. Note scale in upper left corner - 20 cm. The study site Krk-Gajevi (see Cpt. 3).

Slika 5.6. Dmm lithofacies. Breča s muljnom potporom masivna (D/Bmm), u kojoj je vidljiva varijabilna koncentracija uglatih vapnenačkih klasta u karbonatnom matriksu. Siva boja površine matriksa je rezultat trošenja. Sediment je litificiran. Vidi mjerilo u gornjem lijevom kutu - 20 cm. Lokacija Krk-Gajevi (P. 3.).

Figure 5.7. Dmm lithofacies. There is a zone of clast concentration and very little matrix visible. Note an ice-shattered clast on the right side. The study site Krk-Gajevi (Cpt. 3)

Slika 5.7. Dmm litofacijes. Vidi se zona visoke koncentracije klasta s vrlo malo matriksa. Na desnoj strani se vidi raspucani klast. Lokacija Krk-Gajevi (P. 3.)

Matrix-supported conglomerate (D/Cmm)

The matrix-supported conglomerate is more commonly found, and is characteristic for the Paklenica study zone. This polymict conglomerate is composed of 10 - 30% clay matrix and 70 - 90% debris of various lithologies (Fig. 5.8.). Usual color of the matrix is pinkish-grey (5YR 8/1-8/4) (Fig. 5.8.), derived from the Permian micritic limestones and Lower Triassic red-colored mudstones and siltstones, and carbonate mud produced from limestones and dolomites. The matrix color is locally darker and more grey depending on prevailig lithology of the source area and the bedrock, such as shown in Figure 5.12..

Degree of consolidation varies from very low (like at Rujanska Kosa and few locations in Velika Paklenica) to a well cemented rock (Velika Paklenica, Bezimenjača), but is more or less supraficial, as earlier mentioned. At some outcrops surficial cementation is less than 0.5 m deep. The majority of clasts range in size from 2 mm to 25 cm (Fig. 5.8.), rarely up to 1 m (Fig. 5.10.). Overall sorting is poor, but if discarding the boulder clasts the sorting is medium. Large clasts are dispersed randomly and are variously oriented within the sediment. The clasts are subangular to medium rounded, and their sphaericity varies from low to medium, and exceptionaly high, all depending on their lithology.

Glacial striae and grooves are common on boulders (Fig. 5.11) and micro-striae on gravel enclosed in clay matrix. These conglomerates are interpreted as subglacial till or tillite.

The matrix-supported diamict (polimict matrix-supported conglomerate) is best exposed at Rujanska Kosa and in the junction zone of Bezimenjača and Velika Paklenica (below Sklopine, Fig. 5.50.), and is defined as the Rujno Member (describe in Chapter 5.2.). It apparently occurs bellow Paklenica Member diamicts as discussed in Chapters 6 and 7.

Diamict clast-supported, massive (Dcm)

The clast-supported diamict consists either of angular debris or rounded debris, namely breccia or conglomerate. The clast-supported diamict commonly has a very low percentage of finegrained matrix. Angular, sharp-edged and predominantly splint-shaped clasts compose a diamict also referred to as "clast-supported breccia" if lithified. Subrounded to well rounded and faceted debris compose a diamict also referred to as "clast-supported conglomerate" if consolidated (Fig. 5.13.). The clast size spans from gravel to boulders, and even extra large boulders 1-2 m in diameter can be found in massive breccias (Fig. 5.14.). Such boulders and blocks are subrounded and faceted (Fig. 5.9.). Megablocks are locally found in breccias. One or more generations of calcite cement is often found in openwork breccia.

Figure 5.8. Dmm lithofacies. Matrix-supported massive conglomerate (D/Cmm), found at several outcrops in the upper section of the Velika Paklenica canyon and Veliko Rujno, is well cemented and contains lithoclasts of Permian, Triassic and Jurassic age.

Slika 5.8. Dmm litofacijes. Polimiktni konglomerat s muljnom osnovom (D/Cmm), koji se nalazi na nekoliko izdanaka u gornjem dijelu kanjona Velike Paklenice i na Velikom Rujnu, dobro je cementiran i sadrži permske, trijaske i jurske litoklaste.

Figure 5.9. A detail of clay matrix that contains abundant medium rounded finegrained gravel. Lithoclasts of this size are mostly dark-grey Jurassic limestones.

Slika 5.9. Detalj muljnog matriksa koji sadrži brojne klaste srednje zaobljenog sitnog šljunka. Litoklasti ove veličine su najčešće tamnosivi jurski vapnenci.

Figure 5.10. Large limestone boulders up to 1 m in diameter are locally found in the conglomerate within Paklenica study zone. The scale is 20 cm.

Slika 5.10. Klasti vapnenca do 1 m promjera penegdje se nađu u konglomeratu u području Velike Paklenice. Mjerilo je 20 cm.

Figure 5.11. One of the many ice-striated and grooved boulders found in the matrix-supported diamict at Veliko Rujno study sites.

Slika 5.11. Jedan od brojnih klasta s glacijalnim strijama i nekoliko brazdi nađen u dijamiktu s muljnom potporom na Velikom Rujnu.

Figure 5.12. Diamict matrix-supported (Dmm) exposed near the Paklenica mountain hut "Borisov dom" along the trail to Bezimenjača. It is primarily composed of dolomie debris.

Slika 5.12. Dijamikt sa sitnozrnatom osnovom otkriven blizu Pakleničkog planinarskog doma uz put prema Bezimenjači. Sastoji se većinom od klasta dolomita.

Figure 5.13. Dcm lithofacies. A clast-supported conglomerate (D/Ccm) studied at Sklopine location in Velika Paklenica (location SV(VP)-11, Fig. 3.58.) consists of well rounded boulders and subordinate fine-grained matrix. A 1 m long walking stick is for scale. Photo taken in 2007.

Slika 5.13. Dcm litofacijes. Dijakmikt je konglomerat sa zrnskom potporom i vrlo malo sitnozrnatog matriksa. Sadrži dobro zaobljene klaste. Nalazi se na lokaciji Sklopine u Velikoj Paklenici (lokacija SV(VP)-11, Sl. 3.58.) . Mjerilo je štap dug 1m. Snimljeno 2007.

Figure 5.14. Dcm lithofacies. A clast-supported diamict of the Pag kame-terrace (location K(P)-24/1, Fig. 3.49.) is commonly an open-work, unsorted breccia (D/Bcm) containing large boulders. A scale placed on a fasetted boulder is 20 cm long. Photo taken in 1989.

Slika 5.14. Dcm litofacijes. Dijamikt sa zrnskom potporom u kame-terasi Pag (lokacija K(P)-24/1, Sl. 3.49.) je pretežno nesortirana breča bez matriksa (open-work) (D/Bcm) s velikim blokovima. Mjerilo postavljeno na fasetirani blok je dugo 20 cm. Snimljeno 1989.

There is usually no sorting, but due to washout process some breccias were reworked and thus became medium sorted, or even well sorted and graded because of re-sedimentation, what is commonly visible in lithofacies association of studied kame-terraces (see Cpt. 6.4.).

Mega-Diamict, coarsegrained-matrix-supported, massive (MDcmm)

A very specific lithofacies is classified as mega-diamict, a mega-brecca or mega-conglomerate because of common occurence of boulders 1 to 5 m in diameter and mega-boulders or mega-blocks, which are 15 to 25 m across. The rest of the sediment that appears as "matrix" to this outsized debris consits of predominating gravel to boulder (less than 1 m in diameter) debris and very litle matrix composed of silt to granule-size sediment, including subordinate percentage of clay component. Beacause of these specific characteristics, the sediment was named "coarsegrained-matrix supported diamict" instead of clast-supported (Figs. 5.15. to 5.19.).

The debris is in general well packed, but there are also empty interspaces, which document removal of fines by washout processes. These interspaces are locally filled with micritic calcite secondary cement or only drusy or fibrous calcite cement, which was at several locations sampled for U-series dating. The clast roundness varies from subangular (Fig. 5.16.) to rounded (Fig. 5.17.). The percentage of particular type of clasts is variable so mega-diamicts include all transitional types from breccia to conglomerate, which is described relative to a particular location of occurrence. Larger boulders are often faceted with rounded keels/edges. Many clasts are fractured or chrushed. Striations and grooves were found on many of them at various locations. Clast sorting and imbrication is locally present. The characteristics like ice-faceted and polished clasts, ice-shattered clasts, ice-striated clasts and sediment texture proves the glacial origin of mega-diamicts. They are interpreted as subglacial, englacial or supraglacial till, which had built morainal bodies, namely lateral or ground moraines, and are discussed in Chapters 5 and 7.

The mega-diamict (mega-breccia) lithofacies was recognized at many locations within the study area (Fig. 5.20.). It is a very distinct and easily recognizeable lithofacies, and was first studied and described in Velika Paklenica at Anića Luka study site (location SV(VP)-22, Fig. 3.59.) (Marjanac & Marjanac, 2004; Marjanac & Marjanac, 2011). This site was chosen for the type-locality and the mega-diamict lithofacies was defined as the Paklenica Member.

The Paklenica Member most probably represents the maximum of Middle Pleistocene ice extent as indicated in Figure 5.20. and discussed in Chapter 7.

Figure 5.15. Megadiamict lithofacies (MDcmm). Anića moraine in Velika Paklenica is the mega-diamict (mega-conglomerate) (location SV(VP)-22, Fig. 3.59.). Boulders are subrounded, polished, faceted and imbricated. The sedimentary texture is masked by supraficial secondary carbonate precipitate. Photo taken in 2009.

Slika 5.15. Mega-dijamikt litofacijes (MDcmm). Anića morena u Velikoj Paklenici je mega-dijamikt (mega-konglomerat) (lokacija SV(VP)-22, Sl. 3.59.). Metarski klasti su slabo zaobljeni, polirani, fasetirani i imbricirani. Struktura sedimenta je maskirana sekundarnim karbonatnim izlučevinama. Snimljeno 2009.

Figure 5.16. Mega-diamict lithofacies (MDcmm) at Kneževići village in Velika Paklenica (location SV(VP)-12, Fig. 3.58.) is a mega-breccia with many boulders larger than 2 m across. Photo taken in 2006.

Slika 5.16. Mega-dijamikt litofacijes (MDcmm) kod sela Kneževići u Velikoj Paklenici (lokacija SV(VP)-12, Sl. 3.58.) je mega-breča s brojnim klastima većim od 2 m u promjeru. Snimljeno 2009.

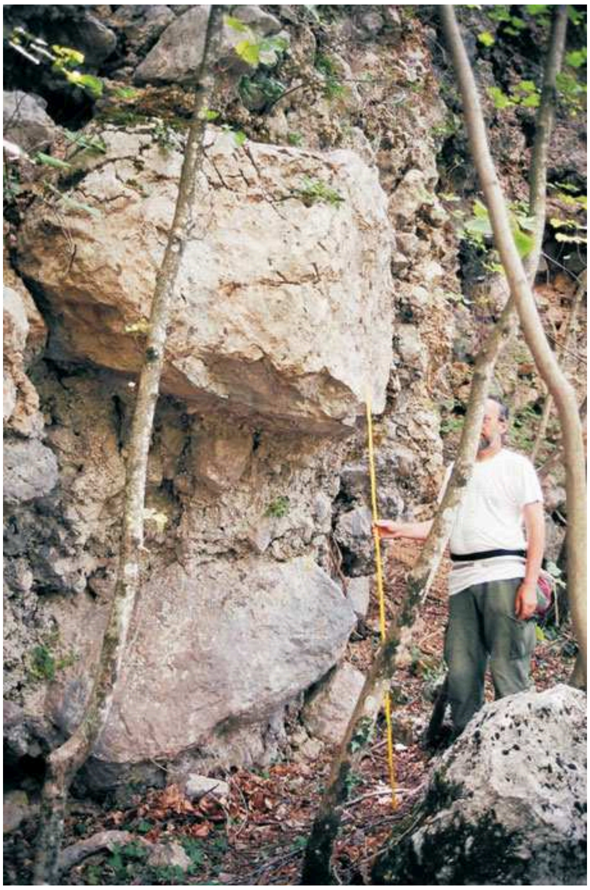


Figure 5.17. Mega-diamict lithofacies at Novigrad section (ND(N)-10, Fig. 3.82.) interpreted as subglacial till (ground moraine). Boulders and megablocks are rounded and faceted, commonly polished. Photo teken in 1989.

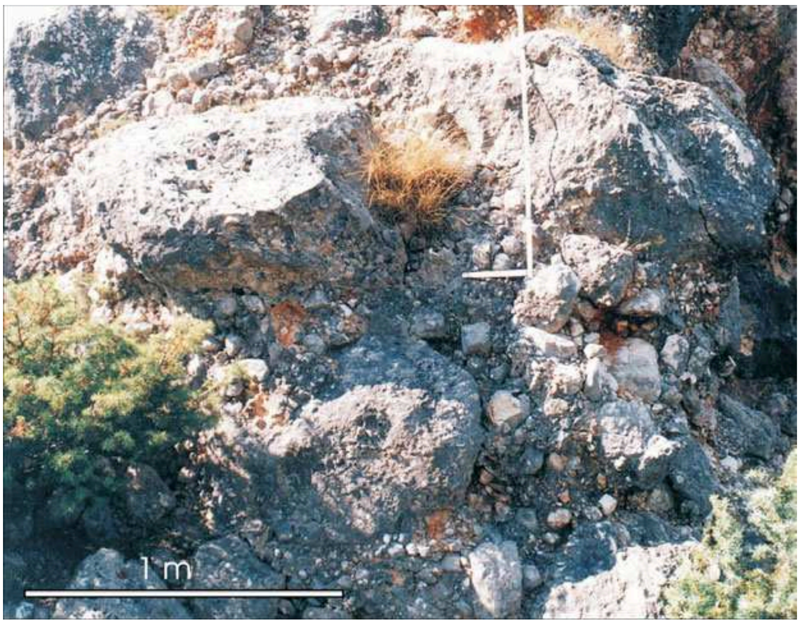
Slika 5.17. Mega-dijamikt litofacijes na profilu Novigrad (ND(N)-10, Sl. 3.82.), interpretiran kao subglacijalni til (podinska morena). Blokovi i mega-blokovi su zaobljeni i fasetirani, često polirani. Snimljeno 1989.

Figure 5.18. Mega-diamict lithofacies at Obrovac study location (location ND(O)-14, Fig. 3.82.). The mega-block is from thick-bedded Promina Conglomerates (Eocene-Oligocene). It has polished and striated bottom surface. Photo taken in 2006.

Slika 5.18. Mega-dijamikt litofacijes kod Obrovca (lokacija ND(O)-14, Sl. 3.82.). Ovaj mega-blok potječe iz debelo uslojenih Promina konglomerata (eocen-oligocen). Donja ploha je polirana i ima strije. Snimljeno 2006.

Figure 5.19. Mega-diamict lithofacies at Baba study location on Krk Island (K(K)-1, Fig. 3.2.) is a mega-breccia with boulders 1-2 m in diameter. Boulders are angular to subrounded, some of them polished. Photo taken in 2004.

Slika 5.19. Mega-dijamikt litofacijes na lokaciji Baba na otoku Krku (K(K)-1, Sl. 3.2.) je mega-breča s klastima promjera 1-2 m. Klasti su uglati do slabo zaobljeni, poneki polirani. Snimljeno 2004.



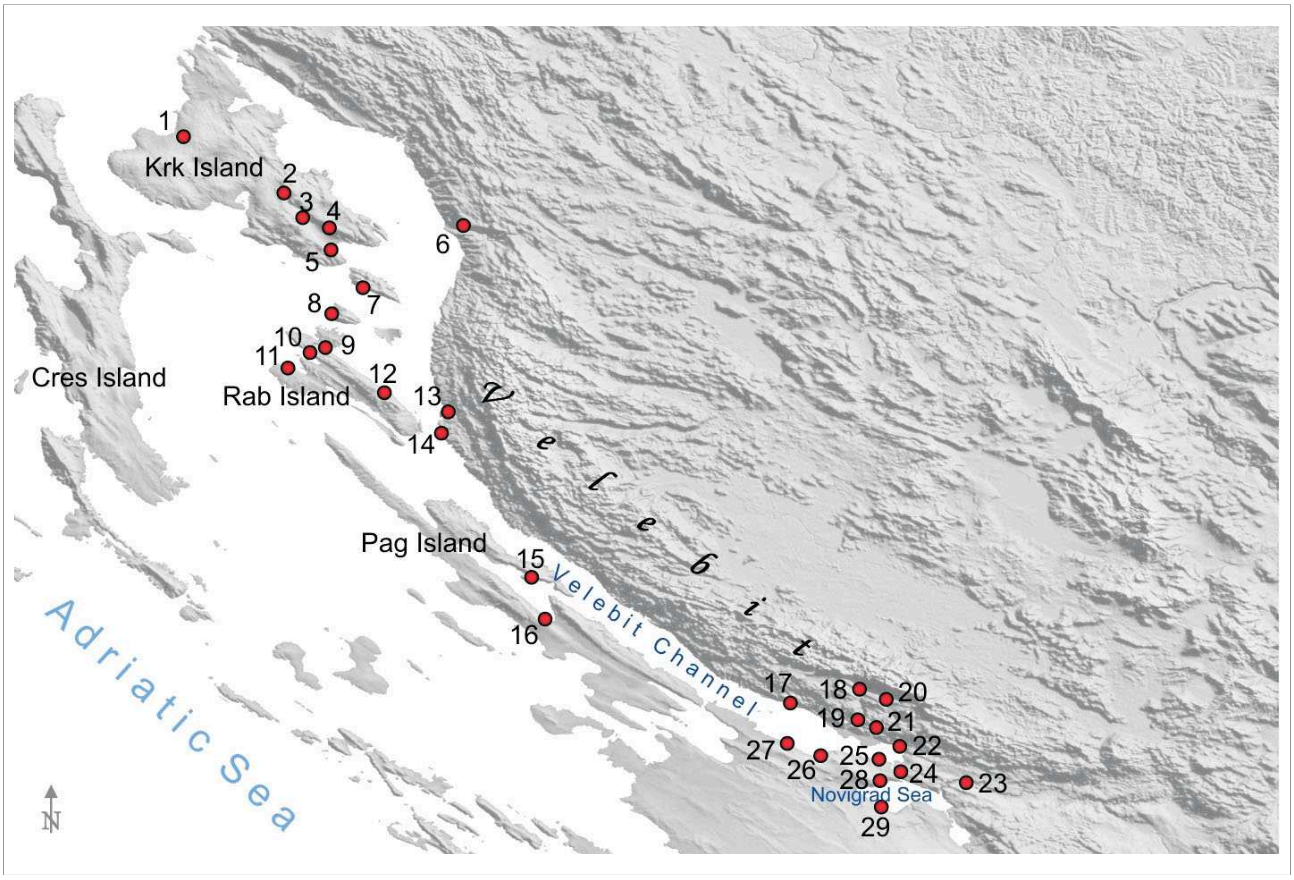


Figure 5.20. The megadiamict lithofacies was recognized at 29 locations within the study area from the Krk Island to Novigrad Sea.

Slika 5.20. Mega-dijamikt litofacijes prepoznat je na 29 lokacija unutar istražnog područja od otoka Krka do Novigradskog mora.

Location list / Popis lokaliteta:

1 - Malinska, 2 - Baba, 3 - Suha Ričina, 4 - Jurandvor, 5 - Baška - Gajevi, 6 - Senjska Draga, 7 - Prvić, 8 - Grgur, 9 - Lopar, 10 - Supetarska Draga, 11 - Kalifront, 12 - Krklant, 13 - Jedrelića Draga, 14 - Jablanac - Stinica, 15 - Metajna, 16 - Pag, 17 - Kusača, 18 - Bezimenjača, 19 - Velika Paklenica Canyon, 20 - Velika Paklenica valley, 21 - Mala Paklenica Canyon, 22 - Provalija - Modrič, 23 - Obrovac, 24 - Maslenica, 25 - Ždrilo, 26 - Ražanac 1, 27 - Ražanac 2, 28 - Posedarje, 29 - Novigrad.

5.2.1.2. KRK MORAINES

The moraines of Krk Island are erosional remnants of morainal bodies associated with kame-terrace deposits recognized in Baščanska Draga valley (Chpt. 6.2.3.). The sediments are interpreted as subglacial till/tillite representing ground moraine and till representing lateral moraine. Within kame-terraces (see Chpt. 6.2.3.) occur tills/tillites that are probably accummulations of englacial and supraglacial debris.

The most common till/tillite is a mega-diamict lithofacies (Mdcmm, Table 5.1.) found at locations along the slopes of Baščanska Draga valley (Baba, Suha Ričina, Batomalj, Jurandvor, Gajevi) and Malinska in the northwest part of the Krk Island (Fig. 5.21.). According to later described characteristics it is interpreted as subglacial till representing a ground moraine and is recognized as the Paklenica Member (see Chpt. 7). At locations Gajevi, Batomalj and Jurandvor it occurs in the base of kame-terrace deposits.

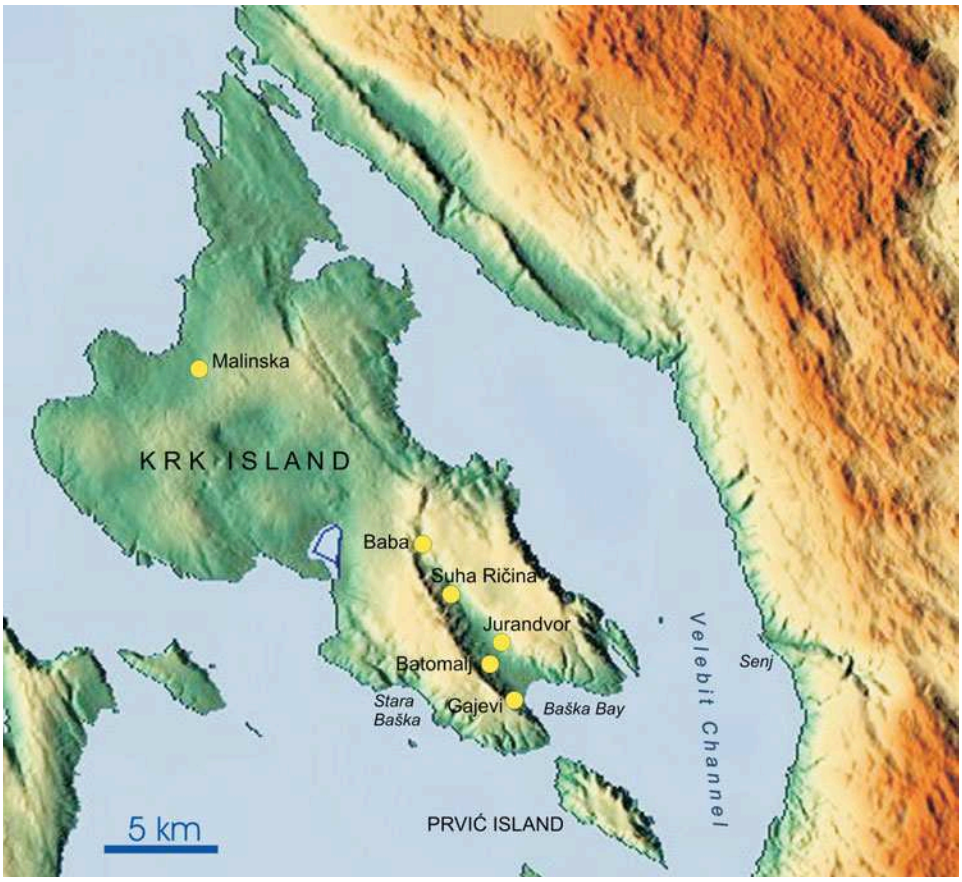


Figure 5.21. Locations of Paklenica Member on Krk Island. Till/tillite classified as mega-diamict lithofacies are best exposed at these six locations and occur in association with kame-terrace deposits at Gajevi, Batomalj and Jurandvor.

Slika 5.21. Lokacije Paklenica člana na otoku Krku. Til/tilit zastupljen mega-dijamikt litofacijesom najbolje je otkriven na šest prikazanih lokacija, a u asocijaciji s naslagama kame-terasa nalazi se na lokacijama Gajevi, Batomalj i Jurandvor.

The second type of till/tillite is a matrix-supported diamict lithofacies (Dmm, Table 5.1.), which is interpreted as lateral moraine at location Gajevi, and is also found in kame-terraces at locations Gajevi, Batomalj and Jurandvor. A clast-supported diamict occurs locally as a laterral or vertical variation of the matrix-supported diamict, visible at location Gajevi (Fig. 5.7.). The clast-supported diamicts are common within deposits of kame-terraces.

Paklenica Member

Tills and tillites recognized as the Paklenica Memeber were studied at locations Baba, Suha Ričina, Batomalj, Gajevi and Jurandvor. At location Malinska only brief observation was made while the petrol station construction excavation was open. The Paklenica Member on Krk Island includes both ground moraine and lateral moraine tillites. The first is a mega-diamict (MDcmm) and the second is a matrix-supported diamict (Dmm lithofacies), both probably originating from the same glacial event.

Baba

An erosional remnant of a massive morainal sedimentary body is a 24 m high rock wall. Its occurrence is restricted to a small area in the valley (location K(K)-1, Fig. 3.2. and Fig. 3.4.). It is a coarsegrained-matrix-supported breccia (mega--diamict lithofacies MDcmm) composed of a densely packed sand- to boulder-size debris with very little clay matrix. Finer debris of granule and pebble size appears like matrix to boulder clasts (Fig. 5.22.). Boulder clasts 1-2 m in diameter are common. Some of them are ice-faseted with rounded keels/edges. Clasts are predominantly subrounded, although debris of pebble size is angular to subangular. Limestone clasts predominate here. Many clasts are fractured or crushed with a clear dislocation along fractures (ice-shattered

Figure 5.22. Till (MDcmm lithofacies) at Baba. Boulder clasts float in coarse-grained matrix. Photo taken in 2005.

Slika 5.22. Baba til s blokovima koji plivaju u krupnozrnatoj osnovi. Snimljeno 2005.

clasts) (Fig. 5.34.). The orientation of some smaller tabular clasts corresponds to orientation of fractures in boulders, and may indicate transport direction (Fig. 5.33.). The sediment is unhomogenous and semi-consolidated. Subrounded boulders are scattered in the area, documenting erosion and degradation of sediment.

The tillite was deposited over Eocene "flysch" clastics. Morphology and position of this erosional remnant possibly indicate that this was a terminal moraine accumulated in the terminoglacial zone where mixing of subglacial, intraglacial and supraglacial debris is possible, as documented by presence of both angular and rounded debris. The transport directions shown in Figure 5.30. express approximate NNE direction of sediment transport.

Suha Ričina

The outcrop at Suha Ričina is barely visible due to dense vegetation. The tillite shows very similar characteristics to the Baba tillite. Characteristic are medium rounded large boulders 0,5 - 1,5 m^3 (Fig. 5.23.), and medium rounded pebble-sized debris. Cobble-size debris predominates, and some boulder clasts are fasetted. Majority of clasts are angular and subangular. Crushed limestone clasts also occur as a result of excessive pressure during subglacial transport. There are many boulder clasts around 1 m in diametre scattered arround, derived by degradation of the outcrop. The Suha Ričina till extends to the other side of the road where maximum clast size is around 18 cm.

Figure 5.23. Meter-sized boulders in Suha Ričina tillite (MDcmm lithofacies). Some are washed out by erosion and lay in the field. Photo taken in 1991.

Slika 5.23. Metarski blokovi u tilitu kod Suhe Ričine (MDcmm litofacijes). Neki veći klasti su isprani erozijom i leže na livadi. Snimljeno 1991.

Gajevi

The outcrop at Gajevi extends from Baščanska Draga vlley bottom uphil to hight of about 200 m above sea level (Fig. 3.11. A). Both matrix-supported diamict (Dmm) and mega-diamict (MDcmm) lithofacies occur in this zone composing a sedimentary sequence comprising basal moraine, kame-terrace and a latteral moraine discussed in Chapter 6.

The mega-diamict is more or less exposed in thickness of nearly 30 m and is the base of the lower Gajevi kame-terrace (Fig. 5.24.). Since it is well cemented it is clasified as polymict breccia. In spite of a massive texture, there is indistinct slopeward bedding (250/30) visible in the tillite sequence indicating slopeward dumping of supraglacial debris. Sorting is extremely poor. Clast size varies from finest gravel to boulder. Excluding the boulders (Fig. 5.26.) and mega-blocks (Fig. 5.27.), medium grain saze is 9-10 cm. Matrix is calcisiltite to calcarenite. Locally openwork texture of the

Figure 5.24. Tillite (MDcmm lithofacies) at Gajevi. About 30 m thik tillite consists of coarse-grained matrix and many meter-sized boulders and larger blocks. The kame-terrace sediments (see Chpt. 6) were deposited above. Photo taken in 2005.

Slika 5.24. Tilit (MDcmm litofacijes) kod Gajeva. Tridesetak metara debeli tilit sastoji se od krupnozrnate osnove i brojnih metarskih klasta pa i većih blokova. Sedimenti kama-terase istaloženi su iznad. Snimljeno 2005.

mega-diamict enabled calcite crystalisation that partially or completely filled voids (Fig. 5.31.) Percentage of matrix increases upwards, and predominates over floating boulders in the upper part of the tillite sequence (see Chapter 6).

The matrix-supported diamict occurs along the southeast valley slope of the Baščanska Draga valley (Fig. 5.32.) in association with the Gajevi kama-terrace. It is a monomict matrix-supported massive breccia (Dms lithofacies). The sediment consists of 25 to 60% clay-silt matrix and angular to subrounded limestone debris of 5 to 30 cm diametre. The matrix is well cemented carbonate clay and silt with yellow-redish to grey-brown color on fresh surface. Weathered surface of matrix is grey in contrast with white to yellowish color of the limestone debris. In zones with more matrix, clasts float in

Figure 5.25. Tillite (MDcmm) with a tabular limestone mega-block (2x6 m), enclosed in coarse-grained matrix. The mega-diamict Gajevi is the lower part of the kame-terrace. Photo taken in 2003.

Slika 5.25. Tilite (MDcmm) s tabularnim vapnenčkim mega- -blokom (2x6 m) u krupnozrnatoj osnovi. Mega-diamikt kod Gajeva je donji dio kame-terase. Snimljeno 2003.

Figure 5.26. Limestone boulder in Gajevi tillite, enclosed in coarse-grained matrix. It is tabular and subrounded. Scale is 1m long. Photo taken in 1989.

Slika 5.26. Vapnenački blok u Gajevi tilitu, uklopljen u krupnozrnatu osnovu. Pločast i slabo zaobljen. Mjerilo je dužine 1 m. Snimljeno 1989.

Figure 5.27. Calcite cement is commonly found in tillite of mega-diamict type. One to several generations of acicular or drusy calcite is present. It partly or fully filled the voids between clasts. A calcium-rich water satureated the openwork sediment due to ice melting.

Slika 5.27. Kalcitni cement čest je u tilitu mega-diamikt tipa. Prisutna je jedna ili više generacija igličastog ili druznog kalcita koji je djelomično ili potpuno ispunio šupljine između klasta. Kalcijem bogata voda ispunjavala je sediment usljed otapanja leda.

matrix and the rock looks homogenous. Zones with higher concentration of debris are porous due to loosly packed unsorted debris. Matrix is there unevenly infiltrated and there also occurs spary calcite A-cement on grain to grain contacts.

The breccia is attached to very steep, nearly vertical, valley slope which locally appears polished (Fig. 5.32.). Steep slope is partly due to very steep bedding dip of tectonized Cretacous limestones. The contact with rock wall is very sharp. Surface of bedrock (Cretaceous limestones) was fractured and fissured during preglacial tectonics (Fig. 5.34.), and therefore it was easily subjected to cryogenic processes.

Figure 5.28. Gajevi tillite-I occur along a locally subvertical slope of Baščanska Draga valley. Contact of the Cretaceous limestone and the Pleistocene matrix-supported breccia (lithofacies Dmm) is clear sharp. Photo taken in 2009.

Slika 5.28. Gajevi tilit-I nalazi se duž mjestimično subvertikalne padine doline Baščanske Drage. Kontakt krednih vapnenaca i pleistocenske breče s matriks-potporom (litofacijes Dmm) je jasan i oštar. Snimljeno 2009.

The limestone debris is of local origin and represents cryoclastic material that has been accumulating between the valley rockwall and the ice. Carbonate fines of cemented matrix were probably brought by glacial melt waters and represents glacial milk.

Figure 5.29. The contact surface of limestone is polished, but affected by weathering. Photo taken in 2009.

Slika 5.29. Kontaktna površina vapnenca je polirana, ali oštećena trošenjem. Snimljeno 2009.

Figure 5.30. Highly fractured Cretaceous limestone in contact with the Pleistocene Gajevi tillite-I. Photo taken in 2009.

Slika 5.30. Izrazito raspucani kredni vapnenac u kontaktu s pleistocenskim Gajevi tilitom-I. Snimljeno 2009.

The tillite is preserved between 160 and 200 m a.s.l. and can be traced with interruptions for about 2 km along the valley slope. The till thickens increases downhill, from 20 cm at the top to a few metres, and 20 m lower it becomes stratified slope-dipping breccia transforming into a higher kama-terrace. Even lower, it alternates with reworked till (meltout till), ablation till and glaciofluvial sediments of the Gajevi lower kame-terrace (Cpt. 6.).

Malinska

Till defined as mega-dijamict near small town of Malinska was exposed by excavations for construction works in 2006. It is partly matrix-supported and partly in clast contact (Fig.5.28.). The matrix is coarse-grained, but locally also represented by clay or clayey marl (Fig. 5.28.). Fracturation is visible on many boulders and smaller debris within matrix. Due to boulldozering piles of large boulders and blocks were left loose, so faceted and polished ones were found. Ice-striated surfaces were found on a mega-boulder (Fig. 5.25.) and on smaller clasts.

Figure 5.31. Till (MDcmm lithofacies) exposed by construction works beside the road to Malinska. Many metre-sized and even larger boulders were left in piles. Some ice-faceted and ice-polished boulders were found. Besides coarse-grained matrix, locally appears clayey matrix of greenish-gray color (see figure bellow). Photo taken in 2003.

Slika 5.31. Til (MDcmm litofacijes) raskopan tijekom građevinskih radova pokraj ceste za Malinsku . Brojni blokovi ostali su nagomilani otkopavanjem, te su nađeni fasetirani i polirani blokovi. Uz krupnozrnatu osnovu pjavljuje se i glinovita osnova zelenkasto-sive boje (vidi sliku dolje). Snimljeno 2003.

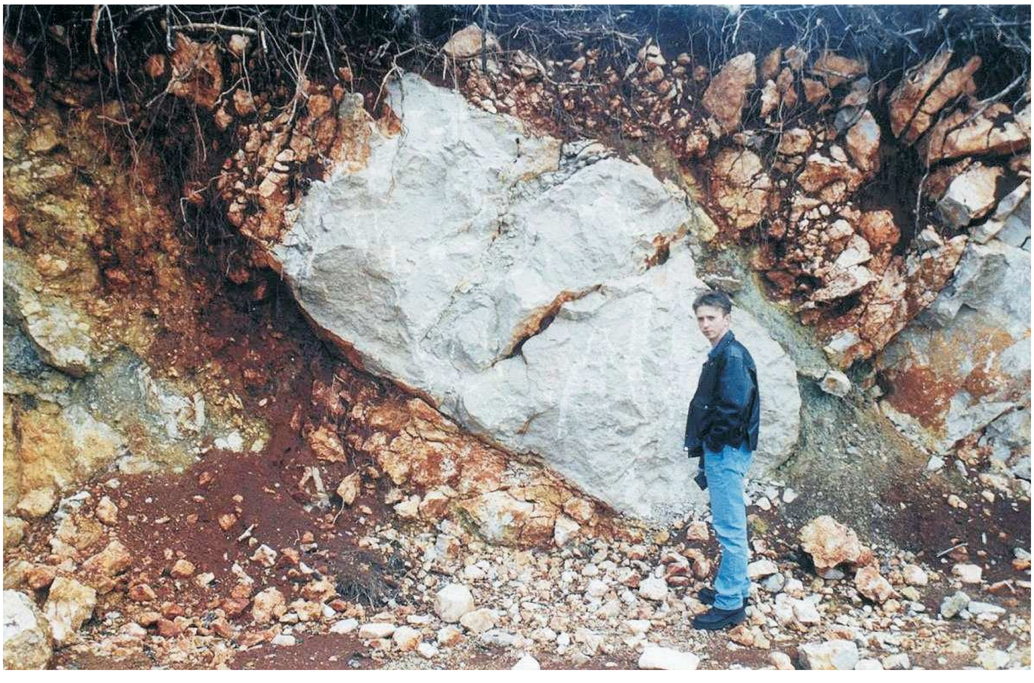


Figure 5.32. Tabular limestone mega-block in till near Malinska. The mega-block is rounded and polished, with glacial striae on its surface. A coarse-grained matrix is visible below the block and clayey matrix on the right side. Photo taken in 2003.

Slika 5.32. Vapnenački mega-blok u tilu kod Malinske. Mega-blok je zaobljen i poliran, a na površini su dobro vidljive glacijalne strije. Krupnozrnata osnova je vidljiva ispod bloka, a glinovita osnova s desne strane bloka.Snimljeno 2003.

Figure 5.33. Baba till. The boulder, 1,5 m across, is floating in coarse-grained matrix. White arrow-pointed lines show imbrication of more/less tabular clasts. Red arrow-pointed lines show fractures, which likely formed during transport. Upper red arrow points at the part of boulder with breaking tendency. All structures indicate left to right transport. Scale in lower left is 1m. Photo taken in 2003.

Slika 5.33. Baba til. Klast 1,5 m promjera u krupnozrnatoj osnovi. Bijele strelice pokazuju imbrikaciju manje-više pločastih klasta, a crvene pukotine vjerojatno nastale tijekom transporta. Gornja crvena strelica pokazuje djelomično odlomljen dio velikog klasta. Spomenute strukture ukazuju na transport s lijeva u desno. Mjerilo dolje lijevo je 1m. Snimljeno 2003.

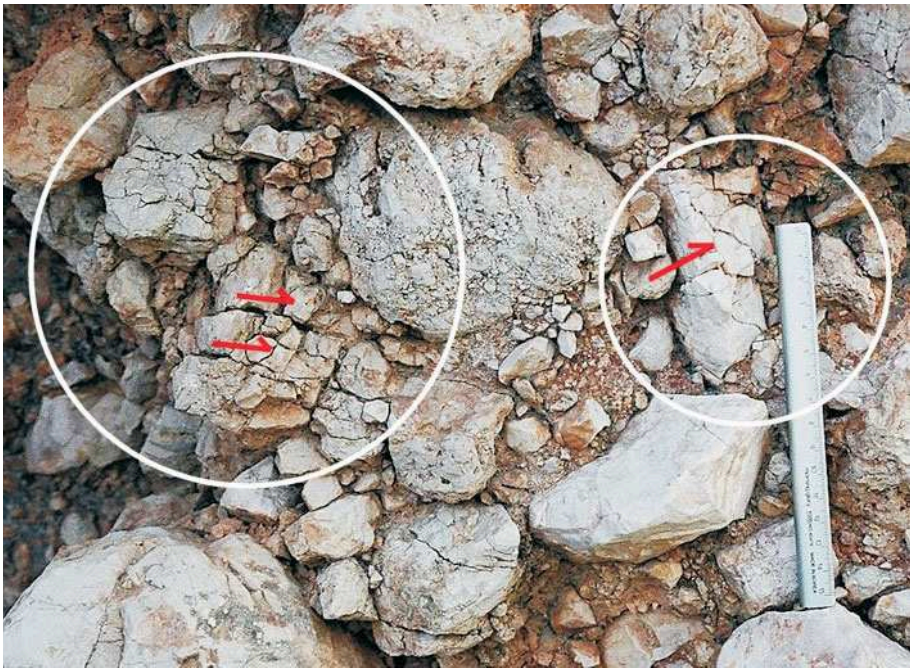


Figure 5.34. The Baba-till is characterized by many ice-shattered clasts. Circles isolate clasts with clear dislocations along fractures that ocurred during subglacial transport. Scale is 20 cm long. Photo taken in 2003.

Slika 5.34. Baba-til se odlikuje brojnim ledom raspucanim klastima. Zaokruženi klasti su raspucani s vidljivim pomacima duž pukotina, što je posljedica drobljenja i smicanja tijekom transporta ledom. Mjerilo je dužine 20 cm. Snimljeno 2003.

5.2.1.3. SENJ MORAINE

The Senj-moraine is ascribed to the Paklenica Member, and its outcrops are localized to the lower section of the Senjska Draga valley, at oposite side of the Velebit Channel looking from the Baška Bay (Fig. 3.21.).

Till is a mega-diamict (MDcmm lithofacies), locally a matrix-supported diamict (lithofacies Dmm) type, deposited in subglacial environment and interpreted as a ground moraine. Tills are exposed along the road at 52 m a.s.l. and are more-or-less unconsolidated. Only matrix-supported type is locally cemented. In the later the amount of matrix varies from 10 to 30 %. Clasts are randomly organized, either clustered with clast-to-clast contact, or float in finegrained matrix composed of redish silty/sandy clay derived from early Triassic red coloured noncarbonate clastics. The debris consists of Jurassic grey limestones, Upper Triassic redish limestone and Triassic darkgreen andesite clasts up to 30 cm in diameter (Fig. 5.40.). The Jurassic limestone clasts are much larger, and reach up

Figure 5.35. A diamict deposited in a terminoglacial zone in the lower section of the Senjska Draga valley. The bedrock are steeply inclined thick-bedded Cretaceous limestones. The circle shows a large block plucked from the bedrock and entrained into subglacial debris, but only to a short transport indicated by no reshaping of the clast. Gaps in eroded bedrock are filled with till (for detail in rectangle see Fig. 5.37.). Photo taken in 2010.

Slika 5.35. Dijamikt istaložen u terminoglacijalnoj zoni u donjem dijelu doline Senjske Drage. Stijensku podlogu čine debelo uslojeni kredni vapnenci vrlo strmog položaja. U krugu je veliki blok otkinut od podloge i uklopljen u subglacijalni detritus. Vrlo kratki transport dokazuje potpuna uglatost klasta. Udubljenja nastala erozijom podine ispunjena su tilom (slika 5.37. prikazuje detalj u okviru). Snimak 2010.

to 2 m (Fig. 5.42.), while Triassic clasts are gravel and small boulder-size debris. The clasts are subrounded to well rounded, commonly faceted and elongated. Rare clasts are frost-fractured (ice-shattered) (Fig. 5.41.). Some limestone boulders show karstification before glacial entrainment (Fig. 5.42.).

The bedrock of the Senj-moraine are well-bedded Jourassic and Cretaceous limstones dipping 35-40° West (Fig. 21.B.), which is not in coordance with the dip of bedded limestones visible at outcrop (Figs. 5.36. and 5.37). It is though clearly visible that ice-plucking occured producing tabular mega-blocks (one is circled in Fig. 5.36.) and the gaps were filled with till (Fig. 5.37.). The plucked blocks are angular suggesting short transport within till which consists of rounded and faceted debris.

Further downstream, the till becomes better sorted and stratified. Sorting and stratification occured during ice melt phases. Stacked mega-blocks were covered with reworked till, predominantly stratified gravel which accumulated in a mega-block shadow as seen at location in Figure 5.39..

Figure 5.36. The detail in rectangle from Fig. 5.36. shows till (Dmm lithofacies) composed of well rounded pebbles and boulders and sandy matrix. It filled gaps that originated by glacial plucking of bedded limestone bedrock. Photo taken in 2010.

Slika 5.36. Detalj uokviren na slici 5.36. prikazuje till (Dmm litofacijes) sastavljen od dobro zaobljenih klasta različite veličine i pjeskovite osnove. Til je ispunio depresije nastale ledenjačkom erozijom uslojenih vapnenačkih naslaga u podini. Snimljeno 2010.

Figure 5.37. The left extent of the outcrop shown in Fig. 5.31. The diamict is partly reworked subglacial till. It is visible ont left side that gravel is better sorted and stratified. The matrix-supported diamict contained both polished and rounded clasts and angular clasts. Photo taken in 2010.

Slika 5.37. Lijevi nastavak izdanka na slici 5.31. Dijamikt je djelomično prerađeni subglacijalni till. Na lijevom kraju se vidi da je sediment bolje sortiran i stratificiran. Dijamikt s muljnom potporom sadrži i zaobljene polirane klaste i uglate klaste. Snimak 2010.

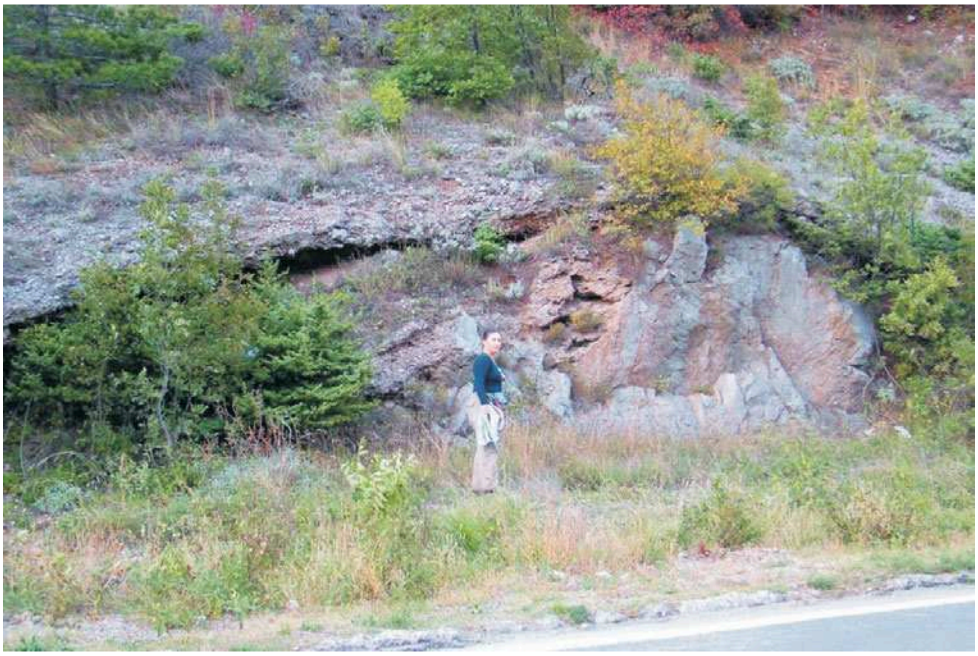


Figure 5.38. Tills of Senjska Draga are partly reworked in downstram direction where they become stratified and better sorted. Figure shows stratification in the shadow of a mega-block. It is not clear if stratification and sorting occured during ice recession or by subglacial strams. Photo taken in 2010.

Slika 5.38. Til u donjem dijelu Senjske Drage je djelomično prerađen i postaje stratificiran i bolje sortiran sediment. Slika prikazuje stratifikaciju nizvodno u sjeni mega-bloka. Nije sasvim jasno da li je stratifikacija i sortiranje posljedica povlačenja leda ili je rezultat subglacijalnih vodotoka. Snimljeno 2010.

Figure 5.39. Faceted and rounded lithoclasts in subglacial till of Senjska Draga. Majority of clasts are limestones (L), but andesite (A) clasts are also common.

Slika 5.39. Fasetirani i zaobljeni litoklasti u subglacijalnom tilu Senjske Drage. Većina klasta su vapnenci (L), ali su i klasti andezita (A) česti.

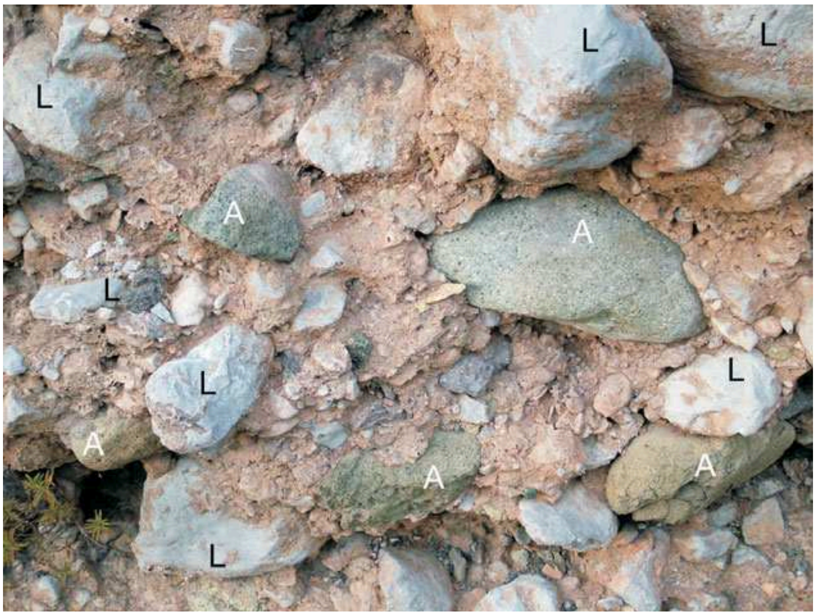


Figure 5.40. The subglacial till in Senjska Draga valley. There is an ice-shattered clast in the middle. Glacial striae were found on some of smaller rounded clasts.

Slika 5.40. Subglacijalni til u Senjskoj Dragi. U sredini je raspucani klast. Glacijalne strije nađene su na manjim zaobljenim klastima.

Figure 5.41. Rounded and polished limestone cobbles and boulders in the subglacial till of Senjska Draga. Earthy matrix is easily washes out.

Slika 5.41. Zaobljeni i polirani klasti u subglacijalnom tilu Senjske Drage. Zemljasti matriks se vrlo lako ispire.

5.2.1.4. JABLANAC MORAINE

The Jablanac moraine, represented by till of mega-diamict lithofacies (MDcmm), have been recently recognized and interpreted in terms of glacial origin, and will be the object of further detail study. The Jablanac till/tillite is exposed in the area of Jablanac and along the coast towards Stinica and in Jadrelića Draga valley northwards of Stinica (Fig. 5.43.). According to its position in the field (at sea level) and sedimentologic characteristics, this till/tillite is ascribed to the Paklenica Member, although its minimum age provided by the U-series dating is only between 61.000 and 65.000 years.

Figure 5.42. Locations of Jablanac moraines in the coastal zone between Jablanac and Jedrelić Draga. For details see also Fig. 3.34..

Slika 5.42. Položaj Jablanac-morena u obalnoj zoni od Jablanca do Jedrelić Drage. Za detalje vidi Sliku 3.34..

The till exposed in Jablanac is in contact with lithologically very similar Jelar-breccia. Distinction between the two is based on striated clasts and boulders and clasts of Jelar-breccia, which are also found in the mega-diamict (Fig. 5.44.) interpreted as till.

The Jablanac till is cemented to a variable degree, tipically unsorted, predominantly clast-supported and massive. The debris consists predominantly of limestone rocks. Sandstone and bauxite clasts found at the Stinica section are sporadic, and are smaller in size (10-15 cm). The limestone clasts vary in size from granule to large boulder or rarely mega-blocks. Many are 2-3 m in diameter (Fig. 5.43. and 5.45.) or even up to 5 m across (Fig. 5.46.). These large lithoclasts are commonly polished, ice-faceted and ice-striated. Such debris is found at all sections: Jablanac, Stinica and Jedrelić Draga (Fig. 5.47.). There are also ice-shattered clasts (Fig. 5.47. D) and fractured clasts (Fig. 5.47. F). Glacial striae were also observed on many fragments of gravel and small cobble size. Angular and subangular debris is predominantly of smaller size (Fig. 5.43.) and is considered as component of a coarsegrained matrix of mega-diamicts, as explained in Chapter 5.2.1.1.. Larger voids between clasts are commonly filled with micritic calcite, which may be of primary or secondary origin. Secondary cementation by drusy calcite is common and visible at all sections. The calcite was sampled for U-series dating at the Jedrelića Draga and Jablanac sections. Locally occurs earthy matrix, which may be a paleosol residuum.

At the Jablanac location the till is overlain by alluvial fan deposits, which consist of stratified angular debris and several paleosol intervals (described in Chapter 6).

Figure 5.43. The mega-diamict lithofacies (MDcmm) exposed at the Jablanac ferry-port. The semiconsolidated sediment contains large boulders which are ice-faceted, polished and ice-striated (Fig. 5.40.). Photo taken in 2009..

Slika 5.43. Mega-dijamikt litofacijes (MDcmm) na profilu uz cestu u Jablanačkoj trajektnoj luci. To je polukonsolidirani sediment s metarskim blokovima koji su fasetirani, polirani i s jasnim glacijalnim strijama (Fig. 5.40.). Snimak 2009.

Figure 5.44. The coastal section of the Jablanac till exposed half way between Stinica and Jablanac. There is a fault zone visible at the left end, documenting postglacial tectonics. The Jablanac till is a mega-diamict lithofacies (MDcmm). Photo taken in 2009.

Slika 5.44. Jablanac til se nalazi na pola puta između Stinice i Jablanca. Na lijevom kraju se vidi rasjedna zona koja ukazuje na postglacijalnu tektoniku. Jablanac til je mega-dijamikt litofacijes (MDcmm). Snimak 2009.

Figure 5.45. The Jablanac till with a large limestone boulder over 2 m in longer axis, found in coastal exposure on the way to Stinica village. Both large and small boulders are subrounded and faceted. The scale is 1 m. Photo taken in 2009.

Slika 5.45. Jablanac til s blokom vapnenca promjera više od 2 m, nađen na obalnom profilu na putu prema Stinici. I veliki blokovi i manji klasti su slabo zaobljeni i facetirani. Mjerilo je 1 m. Snimljeno 2009.

Figure 5.46. A large irregular limestone mega-block over 5 m in longer axis (scale is 2 m) in Jablanac till. There is a clear contrast between the block and coarsegrained matrix of this mega-diamict (mega-breccia). An exposure half way from Jablanac to Stinica. Photo 2009.

Slika 5.46. Veliki nepravilni vapnenački mega-blok preko 5 m po dužoj osi (mjerilo je 2 m) u Jablanac tilu. Jasan je kontrast između bloka i krupnozrnate osnove ovog mega-dijamikta (mega-breče). Izdanak približno na pola puta od Jablanca prema Stinici. Snimak 2009.

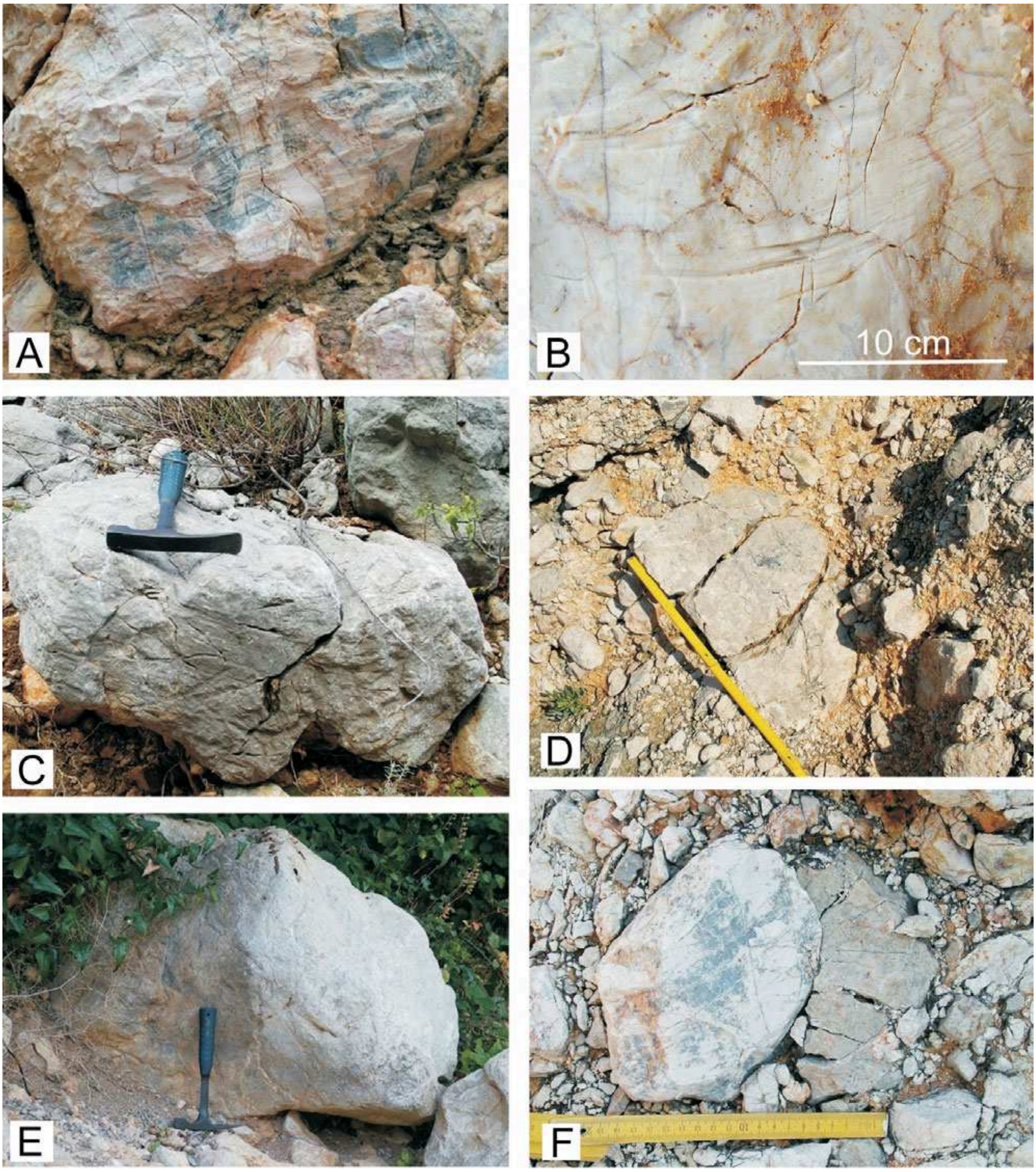


Figure 5.47. Lithoclasts found in Jablanac till/tillite (MDcmm). A - limestone boulder with glacial striae and grooves (Jablanac section); B - glacial striae on a limestone clast (Stinica section); C - ice-fasetted limestone boulder with glacial striae and grooves; D - ice-shattered limestone clast, half rounded with flat bottom (Stinica section); E - ice-fasetted and polished limestone boulder (Jedrelića Draga section); F - medium rounded and fasetted limestone clast (left) in contact with fractured limestone clast due to pressure in transport (right) (Stinica section). Photos taken in 2009.

Slika 5.47. Litoklasti u Jablanac tilu/tilitu (MDcmm). A - vapnenački klast s glacijalnim strijama i brazdama (profil Jablanac); B - glacijalne strije na vapnenačkom klastu (profil Stinica); C - ledom fasetirani vapnenački blok s glacijalnim strijama i brazdama; D - ledom razlomljeni vapnenački klast, poluzaobljen (profil Stinica); E - ledom fasetirani i polirani vapnenački blok (profil Jedrelića Draga); F - poluzaobljeni i fasetirani vapnenački klast (lijevo) u kontaktu s raspucanim vapnenačkim klastom (desno) usljed pritiska prilikom transporta (profil Stinica). Snimljeno 2009.

5.2.1.5. PAKLENICA MORAINES

Paklenica moraines are represented by three typical litofacies, matrix-supported diamict (Dmm), clast-supported diamict (Dcm) and mega-diamict (MDcmm), including transitional types. Based on later discussed characteristics, the diamicts are interpreted as glacial tills or tillites composed of subglacial or supraglacial debris. The Paklenica diamicts occur in Veliko and Malo Rujno valleys, Bezimenjača valley and Velika Paklenica brook valley, both striking NW-SE, in full extent of the

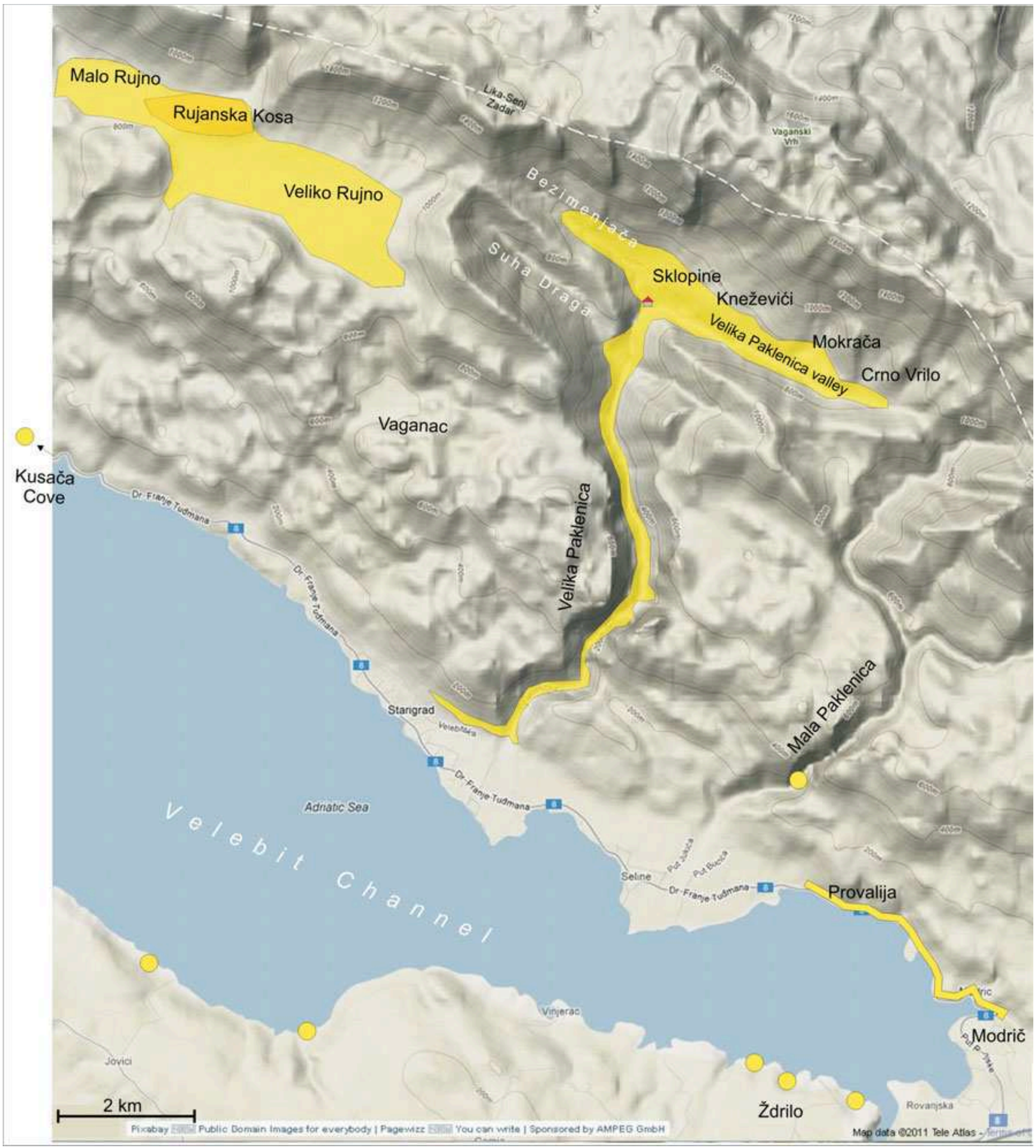


Figure 5.50. Tills/tillites of all lithofacies types are found in the yellow-coloured areas of Veliko and Malo Rujno, Velika and Mala Paklenica, and on many locations along the coast of Velebit Channel. For details see also Figsures 3.59. and 3.82.)

Slika 5.50. Tilovi/tiliti svih litofacijelnih tipova nalaze se unutar područja označenog žutom bojom, te na mnogo mjesta duž obale Velebitskog kanala. (za detalje vidi Slike 3.59. I 3.82.).

Velika Paklenica Canyon striking NE-SW, then in the canyon of Mala Paklenica, and the area of Starigrad-Paklenica (areas marked yellow in Fig. 5.50.). The mega-diamicts also occur at coastal locations (marked yellow in Fig. 5.50.) along the coast of Velebit Channnel and commonly extend bellow the sea level. Their thickness varies from few tens of centimeters in Veliko Rujno to more than 100 m at Rujanska Kosa.

Since Veliko Rujno was populated until the 1960's and people used land and raised cattle, in some areas they cleaned the ground from large boulders, and used then for stone walls to border their property. In the area of Velika Paklenica tills/tillites are also well preserved in thickness up to 50 m (Sklopine, Fig. 5.50.), possibly even more since the bedrock is not exposed.

Veliko Rujno is the type locality for determination and description of the Rujno Member characterized by matrix-supported conglomerate lithofacies, and Velika Paklenica is the type locality for determination and description of the Paklenica Member characterised by predominating and regionaly recognized mega-diamict lithofacies. Both are discussed in Chapters 6. and 7..

Rujno Member

Tills or tillites determined as the Rujno Member occur throughout the Malo and Veliko Rujno valleys, in Bezimenjača valley and in the upper section of the Velika Paklenica Canyon (Fig. 5.50.).

The diamict exposed in a pit located on the south slope of the Rujanska Kosa is a typical till, matrix-supported and massive, composed of about 30 % clay-silt matrix and 70 % poorly sorted debris of pebble to boulder size (Fig. 5.51. and 5.52.). There is at least 30 % boulder clasts out of 70 % debris. Large clasts are dispersed randomly and variously oriented within the sediment. The clasts are angular to medium rounded, and their sphaericity varies from low to medium, only exceptionaly high, all depending on clast lithology. Limestone boulders 60-80 cm in size occur locally (Fig. 5.1.-18). Some boulders are ice-fasetted. Glacial striae are common on boulder clasts (Figure 5.56.). Among predominating Jurassic limestone and dolomite dark-grey clasts, there are also Permian dolomite yellowish-grey clasts and Lower Triassic siltstone, sandstone and oolitic limestone clasts in various shades of red colour (Fig. 5.57. and 5.58.). Matrix is pinkish-grey (5YR 8/1-8/4) clayey silt derived from the Permian micritic carbonates and Lower Triassic finegrained clastics. The matrix is abound with rounded granules and very small pebbles (Fig. 5.9.). The degree of cementation is extremely variable, from none to fully cemented. In the marginal zones of the Rujanska Kosa ridge this till was partly reworked and became better sorted, stratified and lithified - a matrix- to clast-supported conglomerates (see Chpt. 6.). In matrix-free voids there is calcite A-cement at grain to grain contacts Fig. 5.54.).

Figure 5.51. Till of Rujanska Kosa moraine is a semi-consolidated matrix-supported diamict (Dmm), locally well cemented and classified as polymict matrix-supported conglomerate (Cmm). The debris is well rounded and commonly with glacial striae.

Slika 5.51. Til Rujanske Kose je polukonsolidirani sediment, diamikt s muljnom osnovom (Dmm), mjestimice dobro cementiran i klasificiran kao polimiktni konglomerat s muljnom potporom (Cmm). Klasti su dobro zaobljeni i često sa glacijalnim strijama.

Figure 5.52. Detail of the till shown above. Dark-grey pebbles are Jurassic limestones. Yellowish clayey silt matrix is probably derived from Permian finegrained sediments. A pen for scale is 15 cm long. Photo taken in 2011.

Slika 5.52. Detalj tila prikazanog na slici iznad. Tamno sivi klasti su jurski vapnenci. Žućkasti glinovito-siltni matriks je vjrojatno nastao od permskih sitnozrnatih sedimenata. Mjerilo je flomaster dug 15 cm. Snimljeno 2011.

Figure 5.54. Well cemented type of the Rujno diamict (polymict matrix-supported conglomerate) occurs closer to the base of Rujanska Kosa moraine. It is poorly sorted with well rounded debris and redish micritic matrix which probably derived from Permian and Lower Triassic clastics. The debris is composed of Permian, Triassic and Jurassic rocks. Photo taken in 2011.

Slika 5.54. Dobro cementirani Rujanski diamikt (polimiktni konglomerat s muljnom potporom) nalazi se u nižim nivoima bliže bazi Rujanske kose. To je slabo sortirani sediment s dobro zaobljenim klastima i crvenkastom mikriktnom osnovom, koja vjerojatno potiče iz permskih i trijaskih klastita. Klasti su permske, trijaske i jurske stijene. Snimljeno 2011.

Figure 5.55. Litified diamict (polymict matrix-supported conglomerate) is also found in upper section of the Velika Paklenica canyon, in vicinity of the mountain hut "Borisov dom". Poor sorting, random orientation of clasts and large span of clast sizes (Fig. 5.10.) are the main characteristics of the Rujno till (see Chpt. 3.2.1.1.). Photo taken in 2008.

Slika 5.55. Litificirani diamikt (polimiktni konglomerat s muljnom potporom) nalazi se i u gornjem dijelu kanjona Velika Paklenica u blizini Borisovog doma. Slabo sortiranje, raznolika orijentacija klasta i veliki raspon veličine klasta glavne su karakteristike Rujno-tilova (vidi Poglavlje 3.2.1.1.). Snimljeno 2008.

Well cemented diamict (matrix-supported conglomerate/breccia) occurs at southwest slope of the Bezimenjača valley, in the surroundings of the mountain hut “Borisov dom” and in the upper section of the Velika Paklenica Canyon southwards of Suha Draga (Fig. 5.50.). This type of diamict is traceable further seawards in the canyon, but the ammount of easily recognizeable Permian and Lower Triassic lithoclasts decreaces.

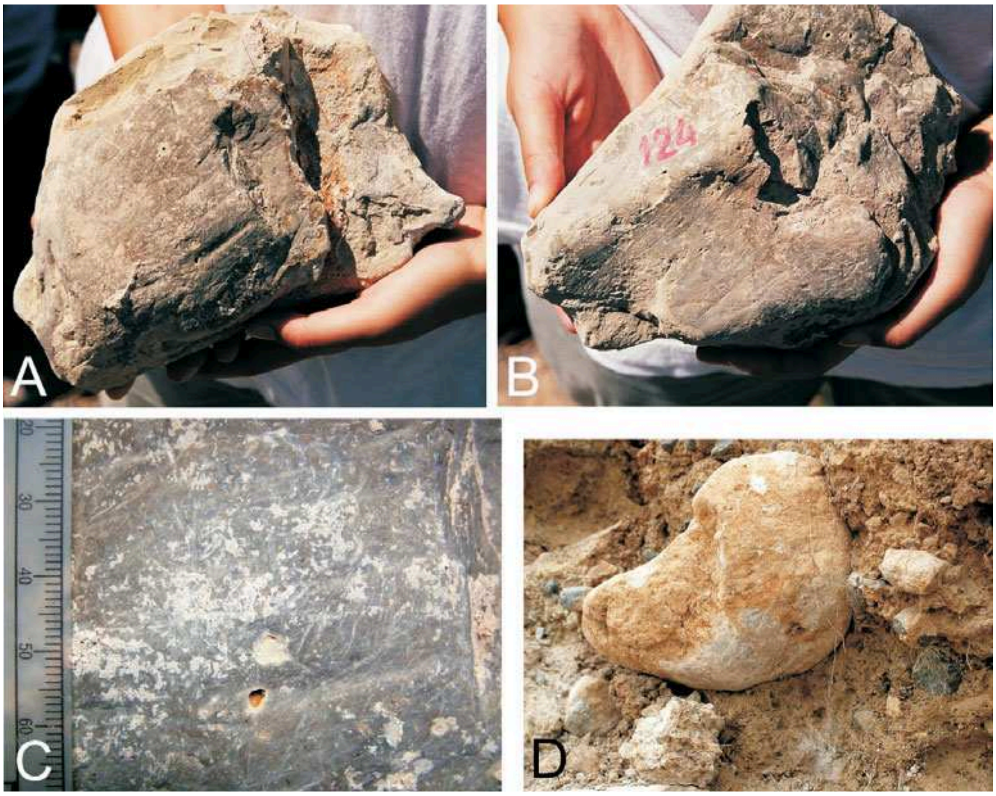


Figure 5.56 Boulders from Rujno till are commonly rounded and striated. The limestone clast (A, B) has several grooves and a lot of centimeter sized multiorinted glacial striae.

Slika 5.56. Klasti iz Rujno tila često imaju strije na površini. Vapnenački klast (A, B) ima nekoliko brazdi i mnogo centimetarskih strija različito orjentiranih.

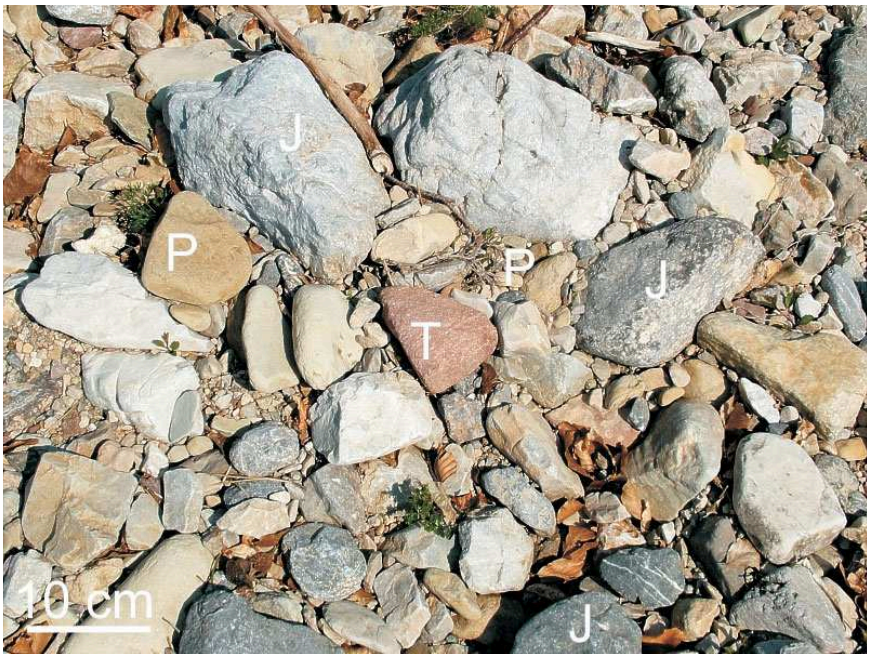


Figure 5.57. Easily distinguished Permian (P), Lower Triassic (T) and Jurassic (J) lithoclast washed out from Rujno till.

Slika 5.57. Lako prepoznat- ljivi permski (P), donjo- trijaski (T) i jurski (J) lito- klasti isprani iz Rujanskog tila.

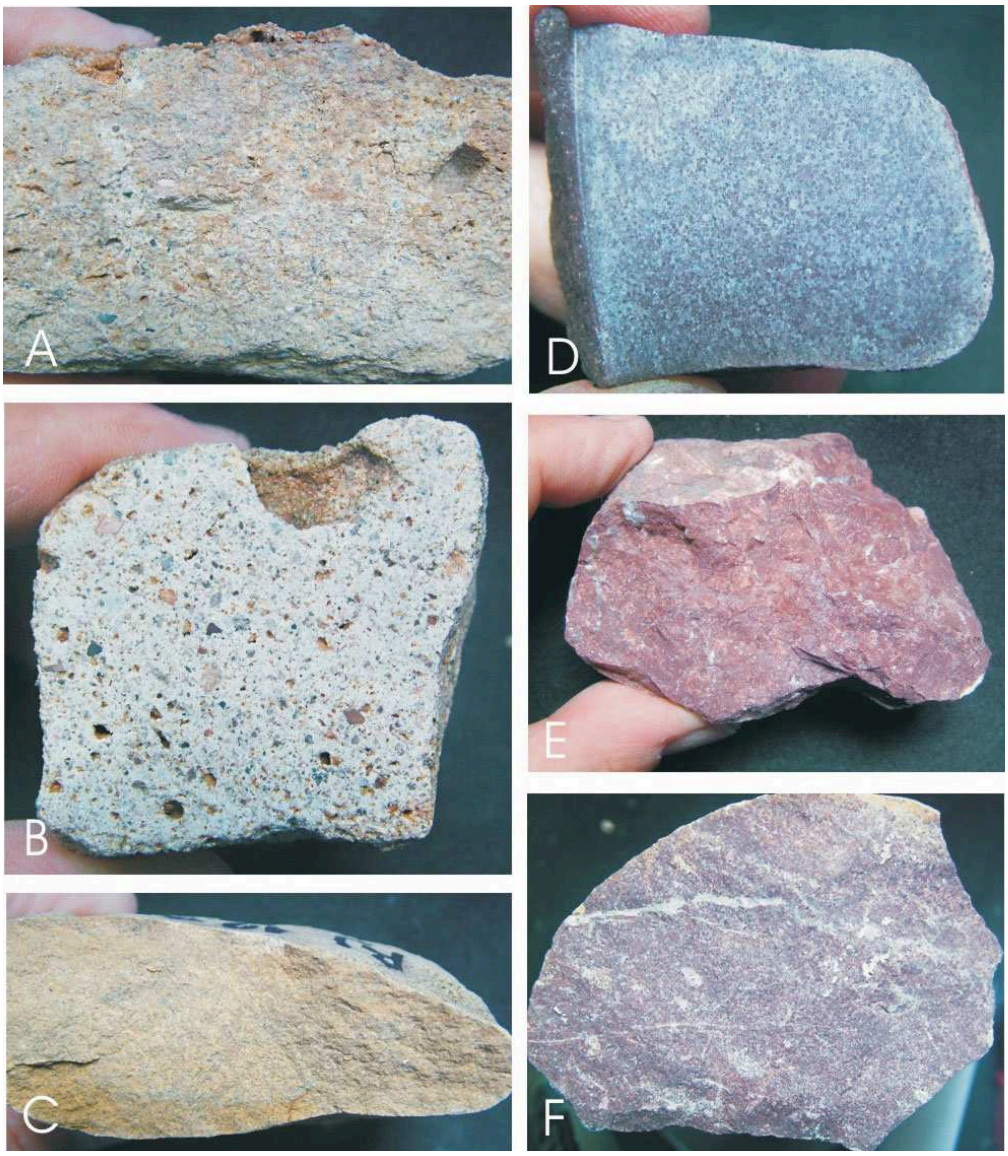


Figure 5.58. In the valley of Veliko Rujno there is a lot of washed out morainal material and various lithoclasts are found on the valley surface. Besides predominating Jurassic limestone clasts, very common are clasts of Permian clastics (A, B) and dolomite (C), and various Lower Triassic oolitic limestones (D, E, F).

Slika 5.58. U dolini Velikog Rujna nalazi se velika količina ispranog morenskog materijala, te se mogu naći različiti litoklasti. Osim dominantno prisutnih klasta jurskih vapnenaca, vrlo su česti klasti permskih klastita (A, B) i dolomita (C), te različitih oolitičnih vapnenaca donjeg trijasa (D, E, F).

Till with slightly different matrix and higher percentage of debris occurs in the area of Crno Vrilo in the most upstream zone of the Velika Paklenica brook (Fig. 5.50.). It is poorly sorted, matrix-supported diamict composed of ca 80 % lithoclasts and ca 20 % matrix. The matrix is brownish-grey clayey sand, and looks very earthy probably because of present pedogenic processes. The limestone debris consists of variety of clasts from granule to boulder size.There is a lot of rounded debris of 1-30 cm diametre. The average size of 10 largest clasts is 148,5 cm. Boulder-sized clasts are subrounded to well rounded, predominantly of low to medium sphaericity, rarely platy. Some are fasetted with sharp to rounded keels. Glacial striae are visible on several clasts. Pebbles broken in halfs are also present. The large clasts are localy ligned in strings, that resamble slope-dip stratification.

Platy clasts are slope-inclined and appear imbricated. Since the sediment is unlithified, many clasts have been whashed out and they are found in piles around the stream, as well as in the area of Rujno.

Figure 5.59. Till of the Rujno Member at Crno Vrilo in the Velika Paklenica valley. There it forms hummocks partly eroded by torrents, which washed away the fines and left piles of subglacial debris. Clasts of cobble to boulder size are commonly ice-fasetted, rounded and glacial striae were found on few clasts. Photo taken in 2005.

Slika 5.59. Til Rujno člana kod Crnog Vrila u dolini potoka Velika Paklenica. Til izgrađuje humke koji su djelomično erodirani bujičnim tokovima, pa je isprana glinovito-siltna osnova, a zaostale su gomile subglacijalnih blokova različite veličine. Klasti su uglavnom obrađeni ledom - fasetirani, zaobljeni, a na ponekima su uočene glacijalne strije. Snimljeno 2005.

Paklenica Member

Rujno

A part of Rujanska the Kosa ridge is covered by loose egg-shaped boulders about 50 to 80 cm long (Fig. 5.60.). Most of them are ice-fasetted, rounded and some are polished. Fewer are found cemented into the substrate which is a matrix-supported breccia-conglomerate composed of nearly 90% cobble and boulder debris, and micritic carbonate cemented matrix. This diamict is interpreted as subglacial tillite, and has similar characteristics to mega-diamict lithofacies and is ascribed to the Paklenica Member. This lithofacies extents to the end of the Malo Rujno valley and further southwestwards to Pričatrnja and Zavrata valleys. In those valleys the till has been partly reworked and became locally better sorted and stratified, but still bares large boulders.

Figure 5.60. The surface of Rujanska Kosa moraine is covered with 0,5-1,0 m size loose boulders, rounded and fasetted, interpreted as sublimation till. Those are predominantly limestone boulders due to prevailing carbonate rocks in the area of the Velebit Mountain. Photo taken in 2004.

Slika 5.60. Na površini morene Rujanske Kose razasuti su zaobljeni i fasetirani klasti veličine 0,5-1,0 m interpretirani kao sublimacijski til. Klasti su uglavnom vapnenački zbog pretežno karbonatnog sastava planine Velebit. Snimljeno 2004.

Velika Paklenica

The Paklenica Member predominantly occurs in Bezimenjača, Velika Paklenica valley and Velika Paklenica canyon. The characteristic mega-diamict lithofacies is best visible at the Kneževići village and in the lower section of Velika Paklenica Canyon bellow Anića Luka (Fig. 5.50.).

The mega-diamict is more-or-less cemented with micritic calcite, rarely drusy calcite. The U-series dating of drusy calcite yielded minimum age of till as >350 ky BP (detailes in Chapter 7). The sediments consists of very large lithoclasts (mega-blocks) enclosed (”floating”) in a coarsegrained matrix which itself is a clast- or matrix-supported diamict (breccia or conglomerate) (Fig. 5.61.; see description in Chapter 5.1.). Predominating limestone and dolomite debris spans in size from cobbles to mega-boulders. The boulders attain 1 to 10 m in diametre (largest measured is 25 m) (Figs. 5.61. to 5.65.). Such mega-blocks are found at many locations as shown in Figures 5.69. and 5.70.. The cobbles and smaller boulders are subrounded to rounded, commonly sphaerical to oval, most of them ice-fasetted and polished (Fig. 5.71.), and some bullet-shaped (Fig. 5.72.). The sediment is extremely unsorted to poorly sorted. Elongated boulders usually lay on their larger surface with longer axis commonly horizontal (Figs. 5.64. and 5.65.). Local imbrication indicates push and transport direction (Figs. 5.73. to 5.75.). Elongated large clasts, two to several meters long, are found even in vertical

Figure 5.61. Mega-diamict of the Paklenica Member is visible along the path through the V. Paklenica gorge towards Anića Luka. Coarse-grained matrix of the mega-diamict is a matrix-supported conglomerate/breccia itself as explained in Chapter 5.2. Meter-sized boulders and larger ones, including mega-blocks, "float" in coarsegrained matrix. Charcteristic megablocks are commonly faseted and rounded, some well polished and with evidence of previous karstification. Photo taken in 2009.

Slika 5.61. Mega-diamikt Paklenica člana vidi se cijelim putem kroz kanjon V. Paklenice prema Anića luci. Krupnozrnata osnova mega-diamikta je sama za sebe breča/konglomerat s muljnom potporom, kako je opisano u Poglavlju 5.2.. Metarski blokovi pa i veći, uključujući mega-blokove, "plivaju" u krupnozrnatoj osnovi. Karakteristični mega-blokovi su uglavnom fasetirani i zaobljeni, neki dobro polirani, a neki s tragovima prethodne karstifikacije. Snimljeno 2009.

position within the coarsegrained matrix (Figs. 5.63. and 5.66.), which was possible only if debris was mixed with ice during accumulation and transport. Glacial striae (Figs. 5.76. to 5.79.) are rarely preserved, or possibly masked by secondary cements, or destroyed by corrosion. Glacially polished surfaces are visible but usually destroyed by corrosion (karstification). Ice-shattered clasts are frequent, best visible in mega-diamict at the Kneževići site. Ice-fracturing commonly broke lithoclast into two or three pieces, and due to pressure and transport motion those fragments were more-or-less disslocated from each other (Fig. 5.80.).

There are also boulders with more-or-less eroded and smoothened karren, which provide evidence of preglacial karstification discussed in Chapter 6 and 7.

The most impressive outcrops of the mega-diamict tillite type exist in the Velika paklenica valley at the Kneževići village and on the oposite side of the valley (Fig. 5.63.), and the forhead of the Anića Luka bellow the wall of Anića Kuk (Fig. 5.50. and 5.64.).

The mega-diamict at the Anića Luka was interpreted as collapse sediment by Perica (1993), and later as terminal moraine of the V. Paklenica by Marjanac & Marjanac (1999). The revised interpretation is discussed in Chapter 6.

Figure 5.62. The Paklenica Member type locality. Moraine remnants below Anića Kuk are preserved in patches on both sides of the Velika Paklenica gorge. The upper photo shows moraine patches across the Anića Kuk pointed by arrows. The lower photo shows the moraine on the oposite side directly beneath the steep wall of Anića Kuk. Tillite on the left formed about 50 m high wall which remained compact due to cementation. The arrow points at sharp contact between the tillite and nearly vertical bedrock wall. Details are shown in Figures 5.55. to 5.57. and 5.59. Photos taken in 2010.

Slika 5.62. Tipski lokalitet za Paklenica član. Ostatci morene ispod Anića kuka sačuvani su u izoliranim pojavama "naljepljenim" na strme zidove kanjona Velike Paklenice. Gornja slika prikazuje morenu nasuprot Anića kuka (pojave označene crvenim strelicama). Donja slika prikazuje morenu neposredno ispod visoke stijene Anića kuka. Tilit na lijevoj strani tvori oko 50 m visoki zid sačuvan zbog cementacije. Žuta strelica označava oštri kontakt tilita i subvertikalne stijenske podloge. Detalji su prikazani na Slikama 5.55. do 5.57. i 5.59. Snimljeno 2010.

Figure 5.63. Tillite of the Paklenica Member is also found aproximately oposite of the Kneževići village in Velika Paklenica valley. This mega-diamict forms an expressed terrace with a vertical wall more than 50 m high. An elongated mega-block, more than 10 m long and in narly vertical position, is visible on the left side. Note a person in circle for scale. Photo taken in 2004.

Slika 5.63. Tilit Paklenica člana također se nalazi u dolini potoka Velika Paklenice približno nasuprot sela Kneževići. Ovaj mega-diamikt čini istaknutu terasu s vetikalnim zidom preko 50 m visine. Izduženi mega-blok, duži od 10 m vidi se na lijevoj strani u subvertikalnom položaju. Za mjerilo vidi čovjeka u kružnici. Snimljeno 2004.

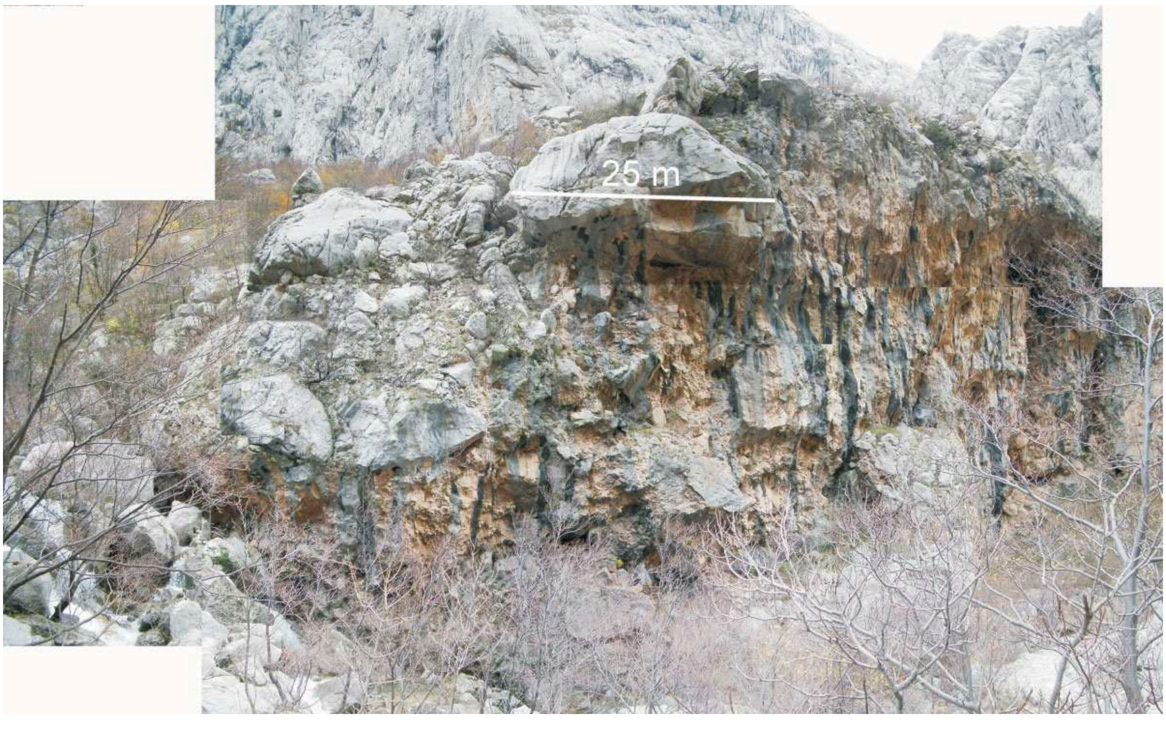


Figure 5.64. Tillite of the Paklenica Member below Anića Kuk is a mega-diamict lithofacies (MDcmm). Characteristic are mega-blocks of 10 m to over 25 m arcross. Blocks are subrounded and commonly have grooved and striated rather flat bottom. Glacial striae and grooves on the largest mega-block are shown in Figure 5.71. Photo taken in 2006.

Slika 5.64. Tilit Paklenica člana ispod Anića kuka je mega-diamikt litofacijes (Mdcmm). Karakteristični su mega-blokovi od 10 m do više od 25 m najveće dužine. Blokovi su slabo zaobljeni i česte su strije i brazde na donjoj plohi. Glacijalne strije I brazde vidljive na najvećem mega-bloku prikazane su na Slici 5.71. Snimljeno 2006.

Figure 5.65. An exposure of mega-diamict located near entrance to Velika Paklenica gorge. The characteristic mega-bloks lay among up to metre-sized cobbles, within the coarsegrained matrix. The mega-block on the left is 6 m across, and the one on the right is 10 m across. Their bottom and side surfaces are polished. The one on the right is also fractured. Most of the cobbles are fasetted and rounded. Photo taken in December of 2011.

Slika 5.65. Izdanak mega-diamikta se nalazi u blizini ulaza u kanjon Velike Paklenice. Sadrži tipične mega-blokove uklopljene među metarske klaste unutar krupnozrnate osnove. Lijevi mega-blok je dug 6 m, a desni 10 m. Odozdola i postrani su dobro polirani. Desni blok je ujedno i raspuknut na više mjesta. Manji klasti su uglavnom fasetirani i zaobljeni. Snimljeno u prosincu 2011.

Figure 5.66. A mega-block cemented in vertical position within coarsegrained matrix, found in tillite of the Velika Paklenica gorge bellow the Anića Kuk. The block was brought and deposited by ice. Photo taken in 2007.

Slika 5.66. Mega-blok cementiran u vertikalnom položaju unutar krupnozrnate osnove, zapažen u tilitu u kanjonu Velike Paklenice podno Anića kuka. Klast je subangularan i razlomljen u gornjem dijelu. Blok je transportiran ledom i istaložen zajedno s ostalim detritusom. Snimljeno 2007.

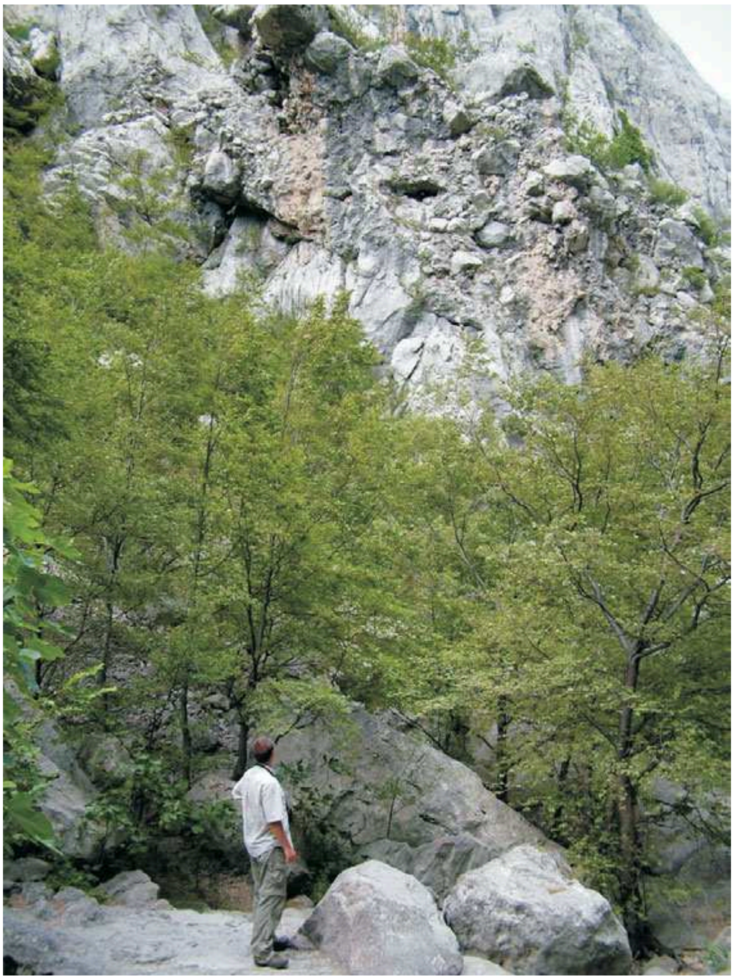
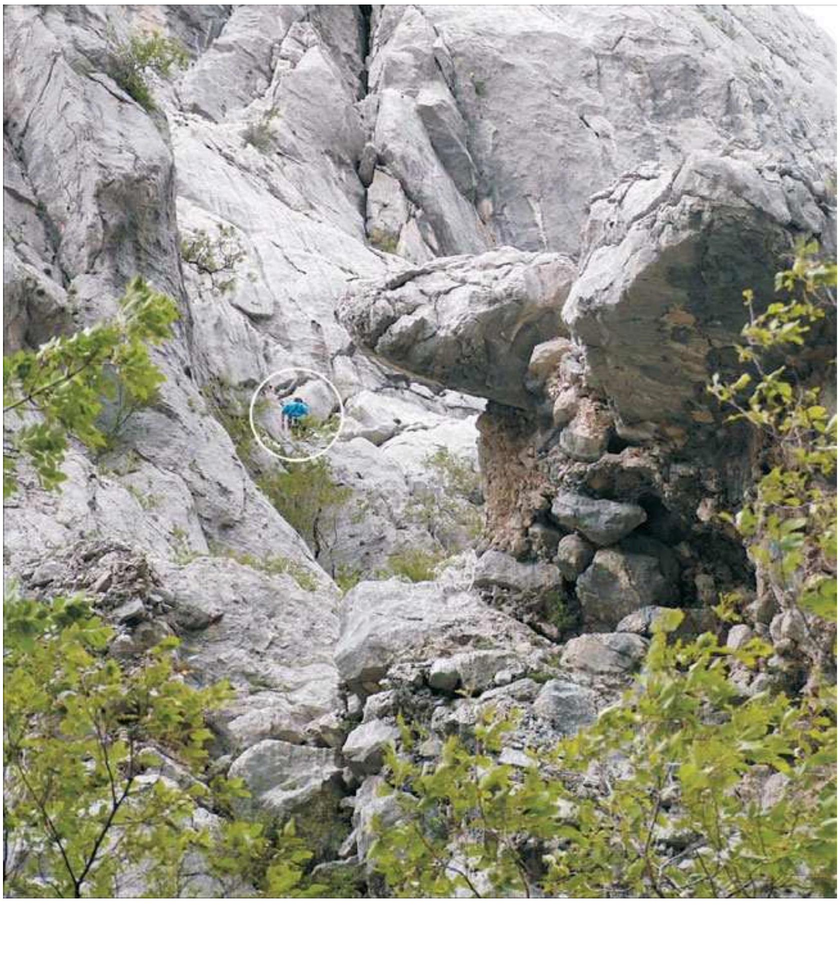


Figure 5.67. A patch of tillite (mega-diamict of Paklenica Member) in sharp contact with bedrock along the slopes of the Velika Paklenica canyon bellow the Anića Kuk. Photo taken in 2006.

Slika 5.67. Tilit (mega-diamikt Paklenica člana) u oštrom kontaktu s pdlogom. To je izolirani erozijski ostatak u kanjonu Velikae Paklenice podno Anića Kuka. Snimljeno 2006.

Figure 5.68. A detail of tillite shown in Figure 5.55. It sits bellow the ice-polished wall of Anića Kuk. Two megablocks stand out from the coarsegrained-matrix. Megablocks are polished, subrounded and ice-faceted, and orinted parallel to extention of the canyon. For scale note a climber in a circle.

Slika 5.68. Detalj tilita prikazanog na Slici 5.55. Leži podno ledom poliranog zida Anića kuka. Dva mega-bloka strše iz krupnozrnatog matriksa. Mega-blokovi su polirani, poluzaobljeni i fasetirani, postavljeni u orjentaciji kanjona. Za veličinu vidi penjača u krugu.



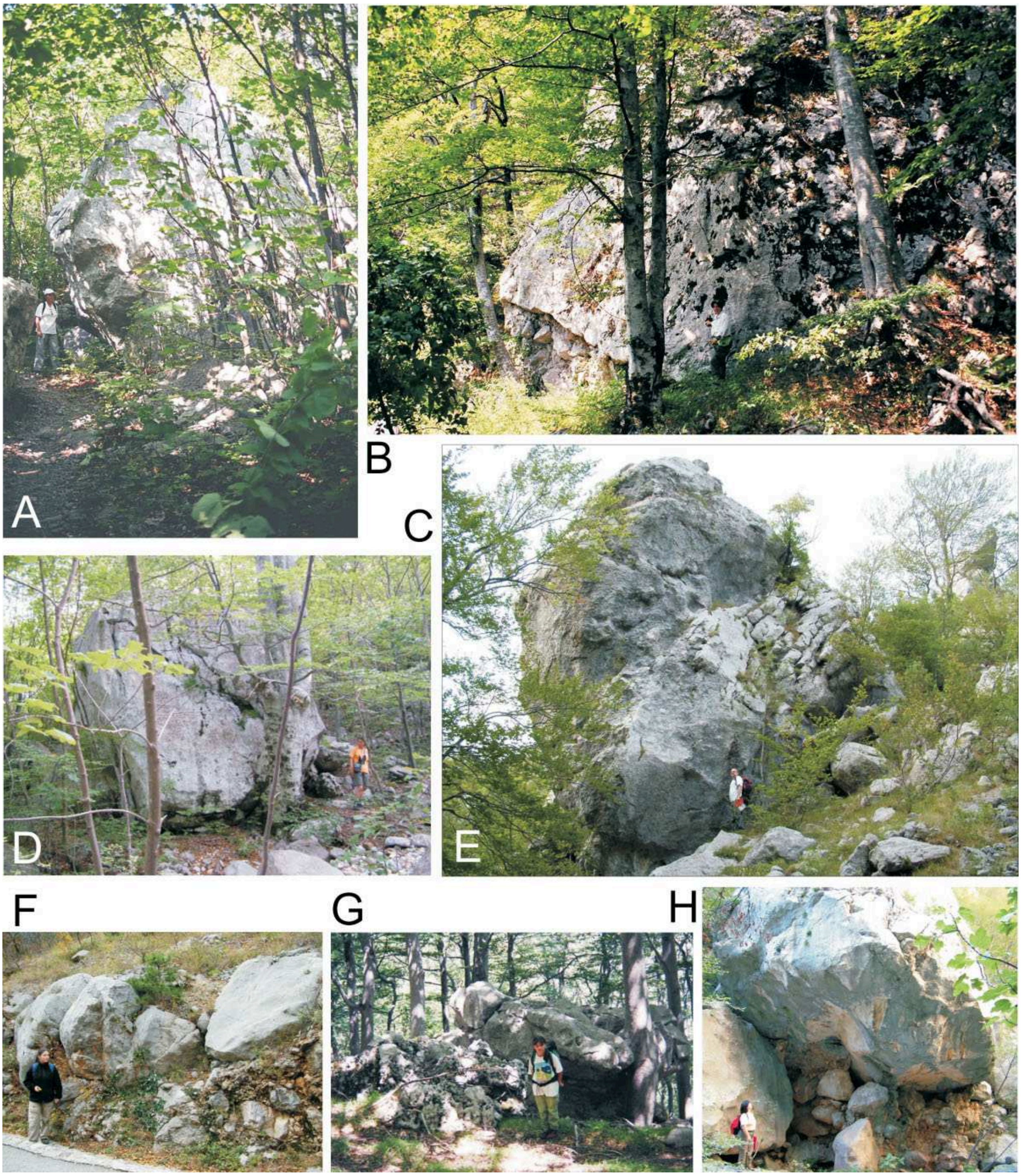


Figure 5.69. Mega-blocks in the Paklenica tillite (MDcmm lithofacies of the Paklenica Member) found at various locations in the upper valley of Velika Paklenica brook (A, B, D), in the Brezimenjača valley (G) and in the Velika Paklenica canyon (F, H). Mega-blocks are within the mega-diamict or they sit on it. Some boulders are rounded (F, G, H) and probably belong to subglacial till while the others (A, B, C, D) may have been transported supraglacially.

Slika 5.69. Megablokovi u Paklenica tilitu (MDcmm litofacijes Paklenica člana) nalaze se na različitim lokacijama u gornjem dijelu doline potoka Velika Paklenica (A, B, D), u dolini Brezimenjači (G) i u kanjonu Velika Paklenica (F, H). Megablokovi su uklopljeni u mega-diamiktu ili sjede na njemu. Neki blokovi su zaobljeni (F, G, H) i vjerojatno pripadaju subglacijalnom tilu, dok su ostali (A, B, C, D) dio supraglacijalnog transporta.

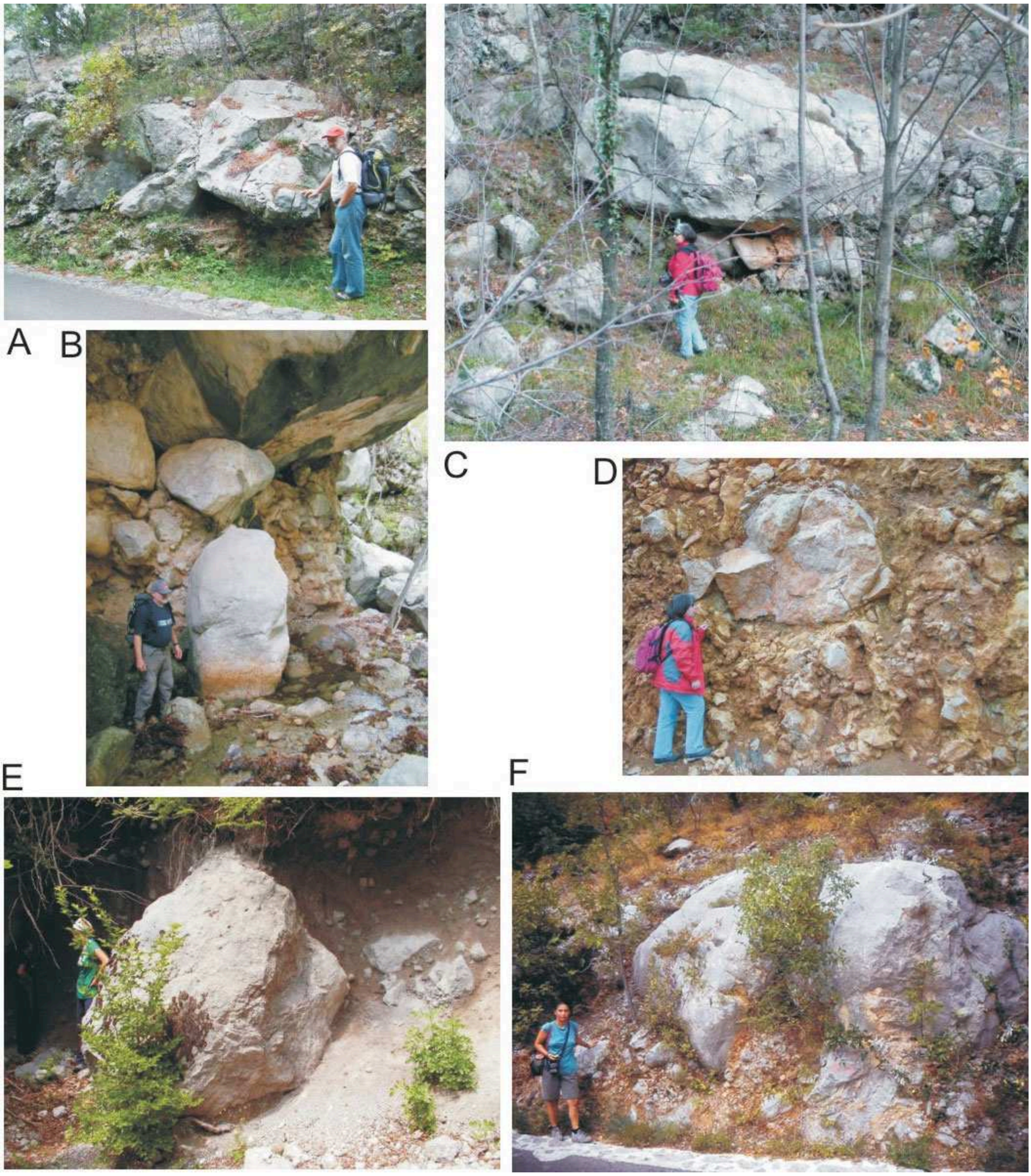


Figure 5.70. Mega-blocks in the Paklenica till (MDcmm lithofacies of Paklenica Member) found at various locations in the Velika Paklenica canyon, between entrance and Sklopine (Fig. 5.50.). The mega-blocks are inclosed in partly cemented coarsegrained matrix of the mega-diamict. These are subrounded to medium rounded, fasetted and some polished (B,F). The sediment is subglacial till.

Slika 5.70. Mega-blokovi u Paklenica tilu (MDcmm litofacijes Paklenica člana) nalaze se na različitim lokacijama u kanjonu Velika Paklenica, od ulaza do Sklopina (Fig. 5.50.). Mega-blokovi su uklopljeni u djelomično cementiranu krupnozrnatu osnovu mega-diamikta. Blokoi su slabo do srednje zaobljeni, fasetirani i neki polirani (B, F). Sediment je subglacijalni til.

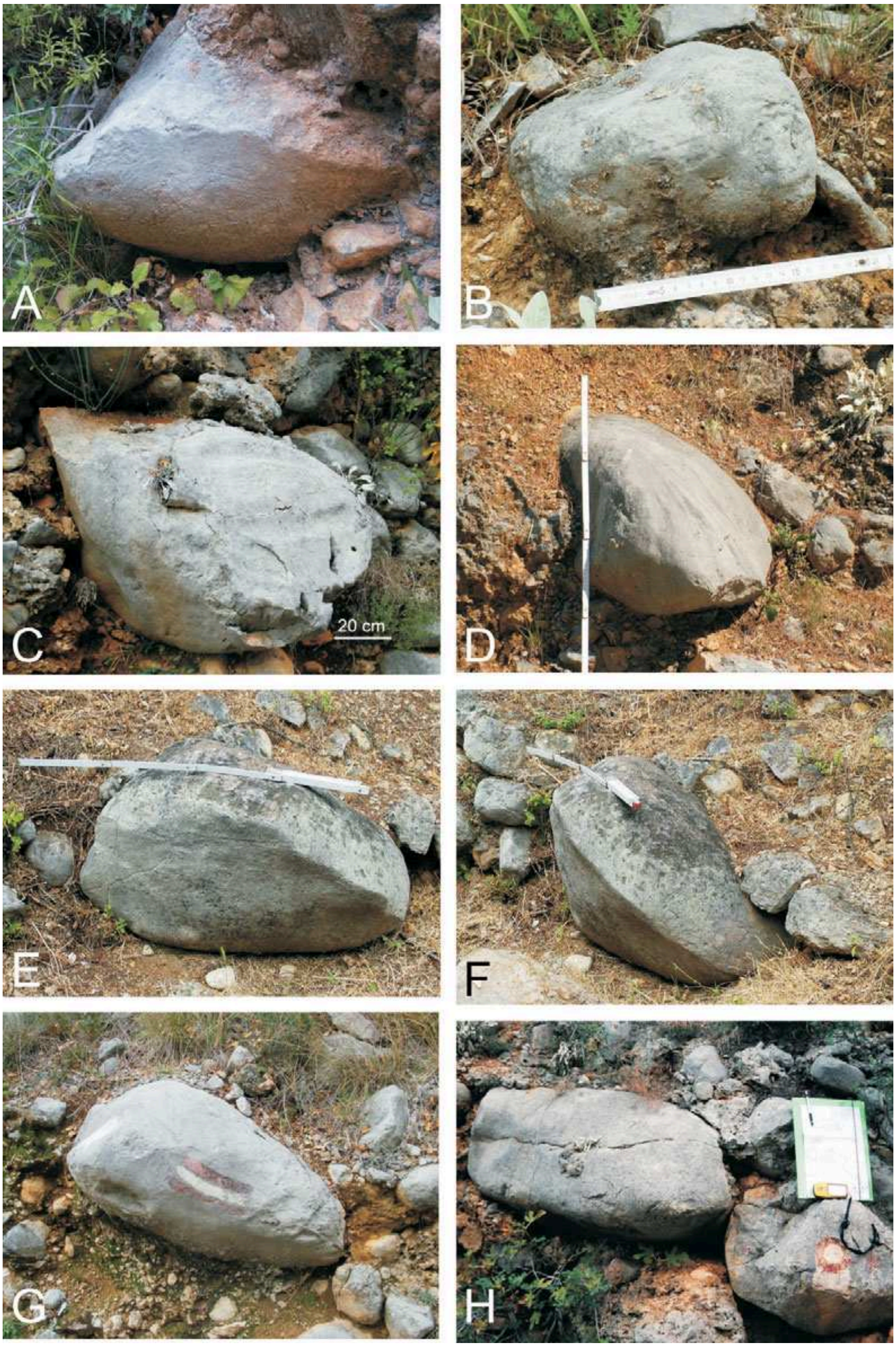


Figure 5.71. Boulders of various shapes found in the Paklenica till (mega-diamict lithofacies) in the lower section of the Velika Paklenica canyon exposed along the road. A - partially ice-fasetted with well rounded and polished bottom surface; B - rounded and striated; C - fasetted, sharp-pointed at one end and rounded and grooved on other side; D - bullet-shaped side of a polished boulder; E - ice-fasetted and polished; F - polished discoidal boulder with sharp keel; G - rounded and polished; H - ice-fasetted and rounded.

Slika 5.71. Blokovi različitog oblika u Paklenica tilu (mega-diamikt litofacijes) u donjem dijelu kanjona Velike Paklenice uočeni na izdancima duž ceste. A - djelom fasetirani klast s dobro zaobljenom i poliranom donjom plohom; B - zaobljeni s glacijalnim strijama; C - fasetirani, ušiljeni s jedne strane i zaobljen s druge gdje se vide i ožiljci (groovs); D - polirani i vrha oblikovanog poput metka; E - fasetirani i polirani; F - polirani diskoidalni blok s oštrim grebenom (keel); G - zaobljeni i polirani; H - fasetirani i zaobljeni.

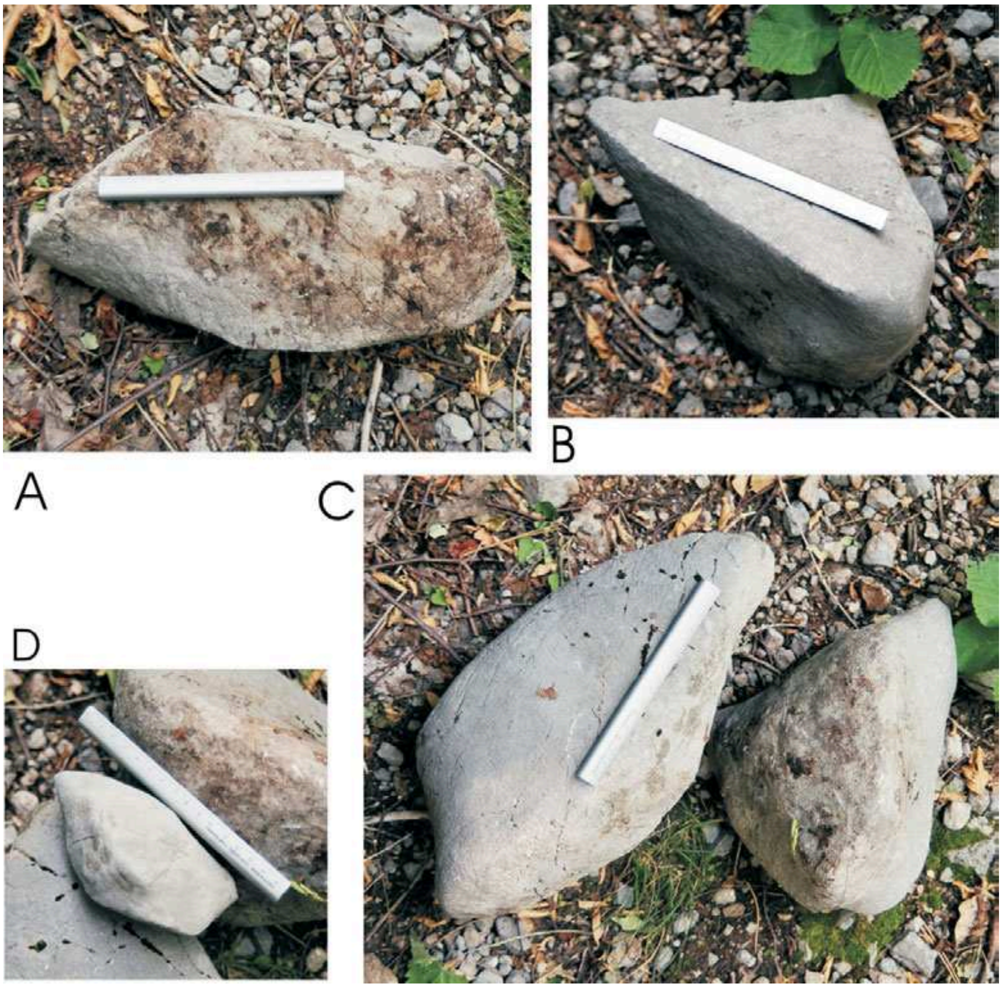


Figure 5.72. Lithoclasts washed out from till (mega-diamict of the Paklenica Member) at the Kneževići village (Fig 5.50.). Clasts show results of typical shaping by subglacial transport - polishing and fasetting, as well as pentagonal and bullet shapes. Scale is 15 cm.

Slika 5.72. Litoklasti isprani iz tila (mega-diamikt Paklenica člana) kod sela Kneževići (Fig. 5.50.). Klasti su oblikovani tipično za subglacijalni transport - polirani i fasetirani, karakterističnog penta- gonalnog presjeka. Mjerilo je 15 cm.

Figure 5.73. Detail of Paklenica Member mega-diamict bellow Anića Kuk. Visible right imbrication of elongated large boulders indicates subglacial stress direction during glacial advance. Photo taken in 2006.

Slika 5.73. Detalj mega-diamikta Paklenica člana ispod Anića kuka. Desna imbrikacija izduženih velikih blokova ukazuju na subglacijalni smjer pritiska u vrijeme napredovanja ledenjaka. Snimljeno 2006.

Figure 5.74. Imbricated rounded discoidal boulders in the subglacial till (mega-diamict lithofacies of Paklenica Member) visible in the lower section of Velika Paklenica canyon. Transport was from right to left. Photo taken in 2006.

Slika 5.74. Imbricirani zaobljeni diskoidalni blokovi blokovi u subglacijalnom tilu (mega-diamikt litofacijes Paklenica člana) u donjem dijelu kanjona Velike Paklenice. Transport je bio s desna u lijevo. Snimljeno 2006.

Figure 5.75. Imbricated discoidal and ice-fasetted boulders in the lower section of the Velika Paklenica canyon. Transport was from right to left. Photo taken in 2006.

Slika 5.75. Imbricirani diskoidalni I ledom fasetirani blokovi u subglacijalnom tilu u donjem dijelu kanjona Velike Paklenice. Transport je bio s desna u lijevo. Snimljeno 2006.

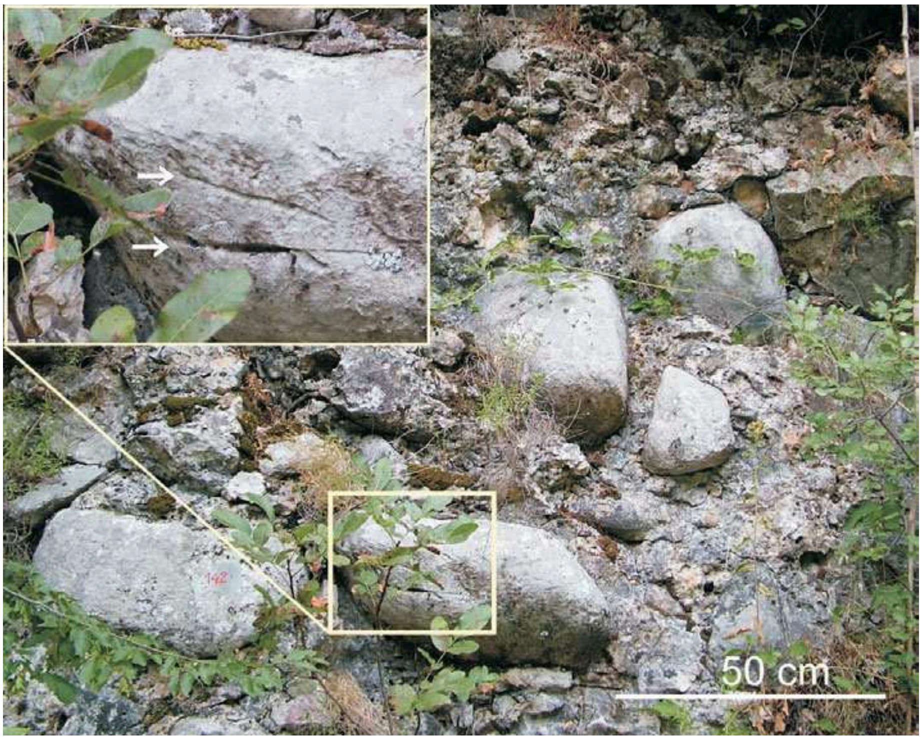


Figure 5.76. Tillite in Anića Luka, middle part of the Velika Paklenica canyon. Some rounded and ice-fasetted boulders are also ice-striated. Striations are usually very fine, but can be more expressed like small grooves as shown in detail. Photo taken in 2008.

Slika 5.76. Tilite u Anića Luci, u srednjem dijelu Velike Paklenice. Neki zaobljeni I fasetirani veliki klasti također imaju strije. Strije su uobičajeno vrlo fine, no mogu biti naglašene poput manjih brazdi kao što se vidi na detalju slike. Snimljeno 2008.

Figure 5.77. A rounded discoidal limestone boulder of 1 m diameter with three systems of glacial striae was found in the mega-diamict (Mdcmm, Paklenica Member) in the valley of the Velika Paklenica brook (location oposite of Kneževići, Fig. 5.50.). Photo taken in 2004.

Slika 5.77. Zaobljeni diskoidalni vapnenački blok promjera 1 m, s tri sistema glacijalnih strija nađen je u mega-diamiktu (Mdcmm, Paklenica član), u dolini potoka Velike Paklenice (lokacija nasuprot Kneževića, Fig. 5.50.). Snimljeno 2004.

Figure 5.78. Detail of the 25 m large mega-block in tillite beneath Anića Kuk (Fig. 5.64.). White lines mark glacial striae, red lines mark distinct grooves, and an arrow points at polished bottom surface. Photo taken in 2010.

Slika 5.78. Detalj 25 m velikog mega-blok u tilitu podno Anića kuka (Sl. 5.64.). Bijele linije ocrtavaju glacijalne strije, crvene linije duboke brazde, a strelica ukazuje na poliranu donju plohu bloka. Snimljeno 2010.

Figure 5.79. One of many boulders with glacial striae, found in til at Starigrad cementary. Matrix is clayey sand but its redish-brown colour and earthy appearence is due to pedogenic processes. Photo taken in 2012.

Slika 5.79. Jedan od mnogih klasta s glacijalnim strijama, nađen u tilu kod Starigradskog groblja. Glinovito-pjeskovita osnova je crveno-smeđe boje i zemljastog izgleda zbog pedogeneze. Snimljeno 2012.

Figure 5.80. The mega-diamict (mega-breccia, MDcmm) above Kneževići and Parići villages. Subangular to subrounded clasts show clear fracturing (Details 1 and 2) and dislocation of clast parts (Detail 1) caused by ice movement. Scale is 1 m. Photo taken in 2007.

Slika 5.80. Mega-dijamikt (mega-breča, MDcmm) iznad sela Kneževići i Parići. Uglati i slabo zaobljeni klasti pokazuju jasne raspukline (Detalj 1 i 2) i smicanje dijelova klasta duž raspuklina (Detalj 1) uzrokovano kretanjem leda. Mjerilo je 1 m. Snimak iz 2007.

Velebit Channel coastal zone (Kusača, Provalija, Modrič, Ždrilo)

The coastal zone of the Velebit Channel, aside and oposite of Velika Paklenica (Fig. 5.50.), has been preliminary studied very recently and only brief information is given about most significant characteristics of recognized mega-diamict lithofacies. The most important atributes are ice-fasetted and polished boulders and mega-blocks, common presence of glacial striae on lithoclasts within large size span, and common ice-shattered clasts. These sedimentary characteristics were found and observed at the road-cut section in the Kusača cove, at road sections between Provalija and Modrič villages, in three coves bellow Ždrilo village and few locations oposite of Starigrad-Paklenica, all marked yellow in Figure 5.50..

The mega-diamict is well exposed in the Kusača cove, above and bellow the road. The characteristics of the Paklenica Member are well expressed. Here the till overlays the glaciolacustrine

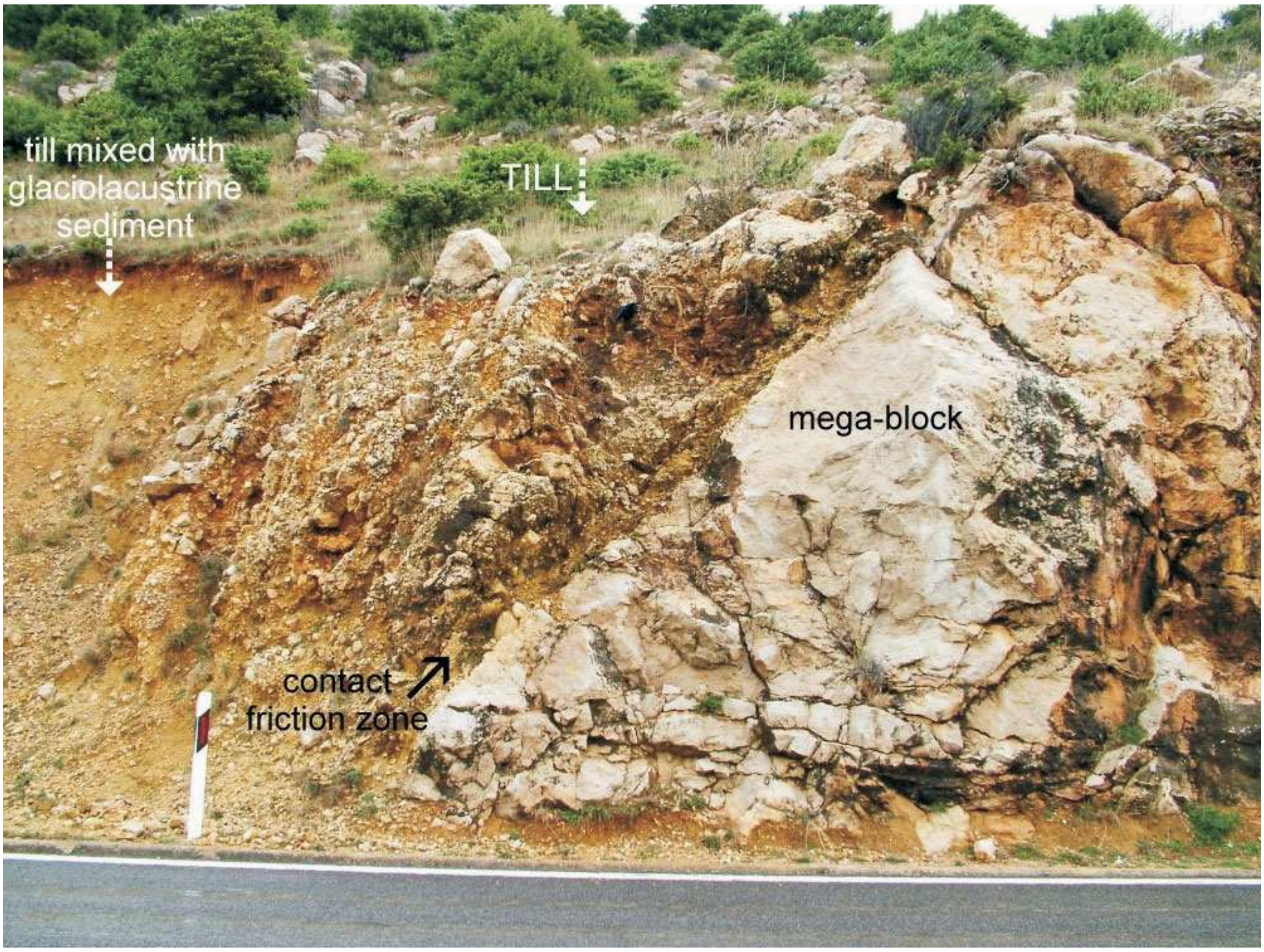


Figure. 5.81. The road section in the Kusača cove. Mega-diamict lithofacies with extraordinary large limestone mega-block. The finergreained component of till contains a lot of striated boulders (figure bellow). Till is partly a mixture of subglacial debris and underlaying glaciolacustrine silty sediment. There is shearing zone visible at till/mega-block contact. Photo taken in 2010.

Slika 5.81. Profil u zasjeku ceste u uvali Kusača. Dobro se ističe mega-diamikt litofacijes s izuzetno velikim vapnenačkim mega-blokom. Sitnijezrnata komponenta tila sadrži brojne veće klaste s glacijalnim strijama (slika ispod). Till je djelomično mješavina subglacijalnog kršja i podinskog glacio-jezerskog siltnog sedimenta. Uočljiva je zona smicanja na kontaktu til/mega-blok. Snimljeno 2010.

Figure 5.82. A detail of till at the Kusača section. One of many fasetted clasts (20-50 cm) with rounded keels and glacial striae found in gravely clayey silt matrix. Photo taken in 2010.

Slika 5.82. Detalj tila na profilu Kusača. Jedan od brojnih većih klasta (20-50 cm) koji su fasetirani, zaobljenih bridova i s izraženim glacijalnim strijama. Klasti su u šljunkovitom glinovito-siltnom matriksu.

laminated silty sediments, and is partly mixed with the lake sediment as noted in Figure 5.81.. The till contains many limestone clasts (pebble to boulder size) with glacial striae (Fig. 5.82.). There is a pyramid-shaped limestone mega-boulder visible at road section (Fig. 5.81.). Compressed lacustrine sediment is visible bellow it. A shear zone with a lot of striated clasts in clayey matrix exists in contact with the mega-block (Fig. 5.81.), which means that the mega-block was stuck in soft lacustrine sediment and subglacial debris mooved along its surface under high pressure.

There are also extensive outcrops of the mega-diamict along the road between Provalija village and Modrič village (Figs. 3.82. A), where many boulders and mega-blocks with glacial striae were found (Figures 5.83. to 5.85.). Near Modrič there is another representative exposure of the mega-diamict type till showing mega-blocks (1 m to 3 m acrosss) in coarsegrained matrix (Fig. 5.87.). The mega-blocks are angular and sharp-edged, but with polished bottom surface. Boulders and cobbles differ in roundness, from angular to well rounded. Polished and striated surface occurs on bouth types (Fig. 5.85.). Matrix is typical coarsegrained as explained in Chapter 5.1., with many ice-shattered clasts.

Ždrilo is onother significant locality for glacial interpretation of mega-diamicts and definition of the Paklenica Member. The exposure shows glacially deformed glaciolacustrine varved sediments (see also Chapter 6) bellow and the mega-diamict with megablocks above (Fig. 5.88.), with very irregular contact. It is actually a mixing zone where mega-blocks occur enclosed in previously deposited glaciolacustrine finegrained sediment and also mega-blocks (ripup clasts) of semi-consolidated lacustrine sediment enclosed in mega-diamict (Fig. 5.89.). This chaotic sediment is subglacial till accumulated during a phase of glacial advance, as discussed in detail in Chapters 6 and 7. Many ice-fasetted, polished, striated and ice-shattered clasts occur in the Ždrilo mega-diamict (Fig. 5.90.) that is rather well cemented with a lot of calcite filled voids. The U-series dating of the calcite yielded minimum age of till at 347 ky BP (detailes in Chapter 7).

Figure 5.83. A mega-block with polished and rounded bottom surface and glacial striae (marked with white line) seen at road section in Zečica cove close to Provalija village (Fig. 5.50.). Photo taken in 2011.

Slika 5.83. Mega-blok zaobljene i polirane donje strane s glacijalnim strijama (oznaka bijelom linijom) snimljen na profilu uz cestu u uvali Zečica blizu Provalije (Fig. 5.50.). Snimljeno 2011.

Figure 5.84. Limestone boulder with glacial striae found in till (mega-diamict of Paklenica Member) near Modrič village (Fig.5.50.). Photo taken in 2011.

Slika 5.84. Vapnenački blok s glacijalnim strijama nađen u tilu (mega-diamikt Paklenica člana) kod sela Modrič (Fig. 5.50.). Snimljeno 2011.

Figure 5.85. Smaller ice-fasetted limestone clast with glacial striae found in till (mega-diamict of Paklenica Member) near the Modrič village (Fig. 5.50.). Photo taken in 2011.

Slika 5.85. Manji vapnenački klast s glacijalnim strijama nađen u tilu (mega-diamikt Paklenica člana) kod sela Modrič (Fig. 5.50.). Snimljeno 2011.

Figure 5.86. Ice-fasetted and rounded limestone clast (Promina conglomerate) with glacial striae found in till (mega-diamict of the Paklenica Member), in a road-cut section by Maslenica bridge. Photo taken in 2011.

Slika 5.86. Fasetirani i zaobljeni vapnenački (Promina konglomerat) klast s glacijalnim strijama nađen u tilu (mega-diamikt Paklenica člana) na profilu u usjeku ceste kod Masleničkog mosta. Snimljeno 2011.

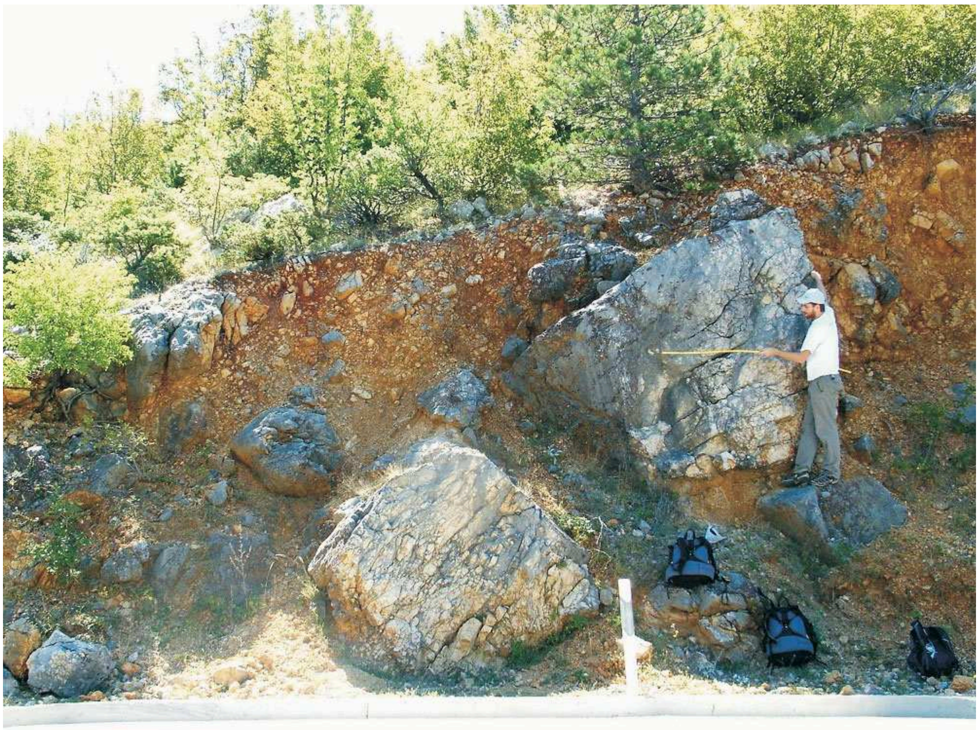


Figure 5.87. The road-cut exposure of mega-diamict lithofacies at Modrič village. Fasetted, subrounded, medium sphaerical boulders, 1-3 m across, “float” in coarsegrained matrix (matrix-supported diamict). Photo taken in 2011.

Slika 5.87. Izdanak mega-diamikt litofacijesa na zasjeku ceste kod sela Modrič. Fasetirani, slabo zaobljeni, srednje sferični blokovi “plivaju” u krupnozrnatoj osnovi (diamict s matriks potporom). Snimljeno 2011.

Figure 5.88. Coastal exposure of the mega-diamict tillite type near Ždrilo village. The arrows point at mega-blocks enclosed in glaciolacustrine finegrained sediment. Tillite containes many ice-shattered clasts and clasts with glacial striae (Fig. 5.90.). Photo taken in 2011.

Slika 5.88. Obalni izdanak mega-diamikta u uvali podno sela Ždrilo. Strelice pokazuju mega-blokove uklopljene u glacio-jezerski sitnozrnati sediment. Tilit sadrži brojne ledom raspucane klaste i klaste s glacijalnim strijama (Fig. 5.90.). Snimljeno 2011.

Figure 5.89. The Ždrilo site. The overriding glacier eroded glaciolacustrine sediments and produced rip-up clasts visible within mega-diamict deposit (tillite). Visible size of the clast is 3x12x5 meters. Photo taken in 2011.

Slika 5.89. Ždrilo lokalitet. Ledenjak je u fazi širenja prešao preko glacio-jezerskih sedimenta, erodirao ih i proizveo blokove (rip-up klaste), koji se vide u mega-diamiktu. Vidljive dimenzije klasta su 3x12x5 metara. Snimljeno 2011.

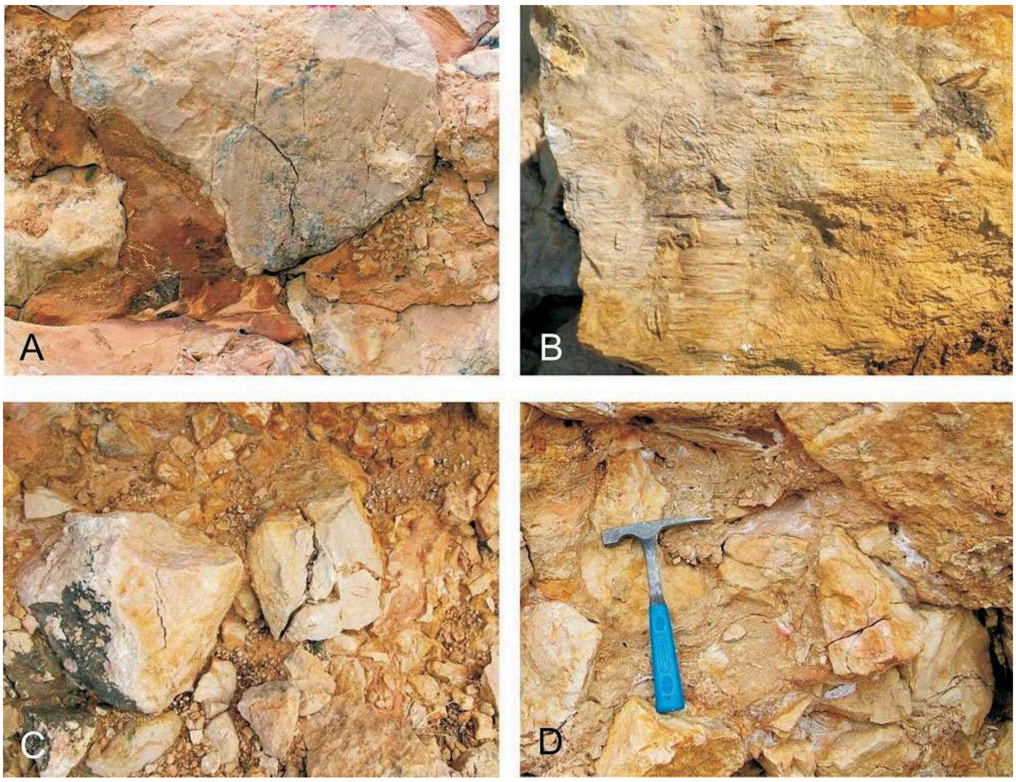


Figure 5.90. Lithoclasts of the Ždrilo mega-diamict are polished (A), striated (B) and ice-shattered (C, D). Photos taken in 2011.

Slika 5.90. Litoklasti u Ždrilo mega-diamiktu su polirani (A), imaju glacijalne strije (B), i često su ledom raspucani (C, D). Snimljeno 2011.

5.2.1.6. NOVIGRAD MORAINES

Novigrad moraines were studied along the southwest coast of the Novigrad Sea (Fig. 3.33.), where they occur in association with different glacial and non-glacial facies. The quality of exposure is very good and different facies could be traced for three kilometers more-or-less continuosly, except for few intervals coastal cliffs. Therefore, the hole section was photographed from the boat and a digital photo-mosaic was produced to study lateral facies transitions (Appendices I-A, I-B, I-C, I-D).

Two distinct diamict lithofacies, interpreted as subglacial tills (ground moraines), were recognized at the Novigrad section:

- an older till which is the mega-diamict lithofacies ascribed to the Paklenica Member (Novigrad M-1) and
- a younger till which is a matrix-supported diamict declared as the Novigrad Member (Novigrad M-2).

Their chronostratigraphical atribution and correlation with other moraine occurences in the study area is discussed in detail in Chapters 6 and 7.

Paklenica Member

The mega-diamict lithofacies at the Novigrad section posesses all charcteristics of the Paklenica Member previously described at its type locality in Paklenica, except its visible thickness is dominantly smaller, up to 5 m above sea level at most. The mega-diamict (allo-unit 1, App. I-A, I-B, I-C and I-D) is discontinuously exposed in length of about 1,5 km, forming a hummocky topography. Otherwise, it extends below the sea level, so its thickness must be greater than exposed. At studied location the Novigrad M-1 till was deposited over the Cretaceous limestone bedrock exposed bellow at sea level and in the hinterland, indicating that inherited relief of deposition was a hilly terrain. Locally, the bedrock limstone appears polished and also karstified (Fig. 5.91.), but probably prior to glaciation.

The Novigrad M-1 till is overlain either by glaciofluvial or glaciolacustrine deposits. It is common to find transitional facies which are gravel deposits interpreted as meltout till or glaciofluvial outwash deposits (Figures 5.96. and 5.98.), which are discussed in Chapter 6.

The clast sizes span from small to very large boulders or mega-blocks (Fig. 5.95.), the largest measured is over 10 m across (Fig. 5.92.). The boulders are rounded and more or less sphaerical, some are elongated or platy, and many are ice-fasseted, polished and rarely have pitted corrosion surface (Fig. 5.93.). Boulders are tipically ice-shattered (Fig. 5.94. A, B, C) or broken under pressure (Fig. 5.94. D). Glacial striae or grooves were found on some boulders, rather poorly preserved. At many places along the coast there are piled loose boulders and mega-blocks washed out from the Novigrad M-1 till (Fig. 5.95.).

The Novigrad mega-diamict is commonly reworked, fines are washed out and boulders resorted. In depressions of the hummocky moraines there occur inversley graded boulder beds (Fig. 5.96., 5.97.), indicating wash-out process and reworking of moraine surface. Those boulders are well packed and form a boulder pavement (Figs. 5.97.).

Large tabular boulders are locally imbricated paralel to bedrock slope, probably a result of push pressure during glacier advance.

Boulder-clast lithologies variate predominantly among carbonate rocks, usually limestones (crystaline, micritic, stromatolitic, rudist-rich, foraminiferal). Amongs finer debris, clasts of Paleogene foraminiferal limestone and hybrid arenites are found.

Figure 5.91. Limestone bedrock of the Novigrad M-1 till (MDcmm) appears polished and karstified. Photo taken in 2003.

Slika 5.91. Vapnenačka podloga Novigrad M-1 tila (MDcmm) izgleda polirano ima tragove karstifikacije. Snimljeno 2003.

Figure 5.92. Older Novigrad moraine (M-1) with a mega-blok. Photo taken in 2003.

Slika 5.92. Starija Novigrad-morena (M-1) s mega-blokom. Snimljeno 2003.

Figure 5.93. Boulders in older till (M1, Paklenica Member): rounded and ice-polished (A), ice-fasetted, well rounded and polished (B), rounded and ice-plished (C), ice-fasetted and polished (D), angular with pitted corrosion surface (E) and fasetted with pitted corrosion surface (F).

Slika 5.93. Klasti u starijem tilu (M1, Paklenica Member): zaobljen i poliran (A), fasetiran, zaobljen i poliran (B), zaobljen i poliran (C), fasetiran i poliran (D), uglat s jamičasto korodiranom površinom (E), i fasetiran s jamičasto korodiranom površinom (F).

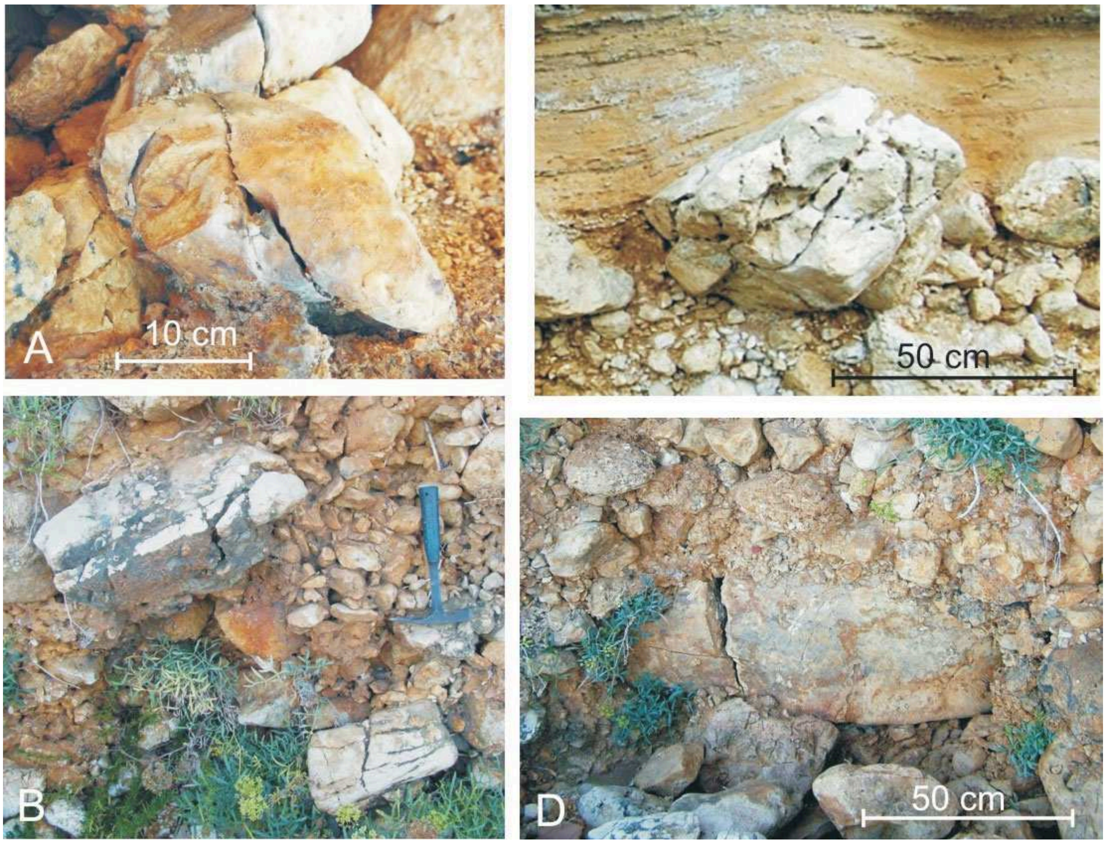


Figure 5.94. Boulders in Novigrad M-1 till are commonly ice-shattered (A, B, C) and some broken in half due to vertical pressure (D).

Slika 5.94. Klasti u Novigrad M-1 tilu su često ledom-raspucani (A, B, C), a neki razlovljeni zbog vertikalnog pritiska (D).

Figure 5.95. Loose boulders and mega-blocks of the Novigrad M-1 till are locally washed out and remained as piles along the coast of Novigrad section. Boulders are commonly ice-fasetted and polished, but due to weathering polished surfaces are corroded. Photo taken in 2008.

Slika 5.95. Mnogi blokovi su isprani iz Novigrad M-1 tila i leže u gomilama na više mjesta uz obalu duž profila Novigrad. Blokovi su uglavnom ledom fasetirani, a polirane plohe pretežno su korodirane zbog izloženosti trošenju. Snimljeno 2008.

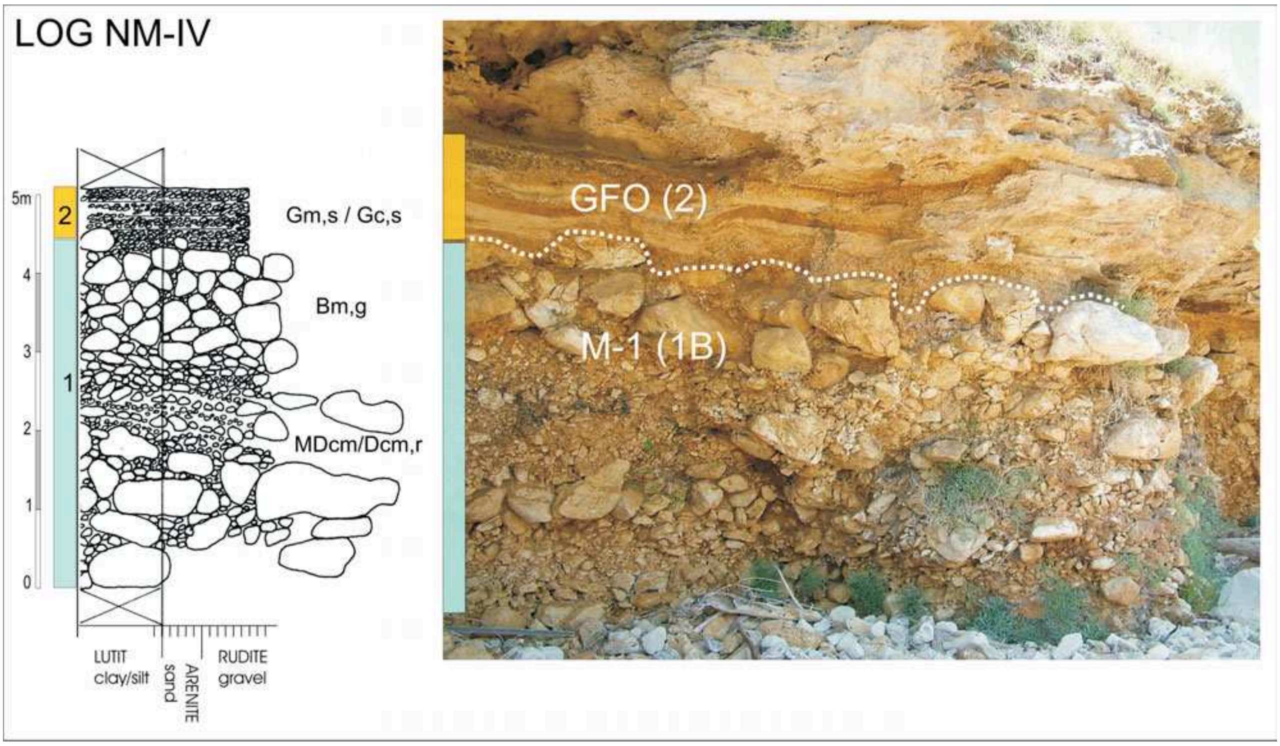


Figure 5.96. The Paklenica Member mega-diamict shown in sediment log (1) is the older moraine (M-1) exposed at the sea-level at Novigrad section. This till is partly washed out and reworked, thus lacks a finegrained component, which produced openwork texture and clast support. Linear segregation of larger boulders occured and produced a boulder layer visible at the top of the till interval (Bm). Inverse grading is locally visible. On the top of the boulder-layer were deposited glaciofluvial outwash gravels (2) that are stratified.

Slika 5.96. Mega-diamikt Paklenica člana prikazan na stupu (1) je starija morena (M-1) koja se vidi na profilu Novigrad na razini mora. Till je djelomično ispran i prerađen, pa uglavnom nedostaje sitnozenata komponenta, te je sediment openwork strukture i zrnske potpore. Došlo je do separacije većih klasta na površini morene (Bm). Mjestimično je vidljivo i inverzno graduiranje. Iznad horizonta s blokovima istaložen je stratificirani šljunak glaciofluvijalnim ispiranjem (2).

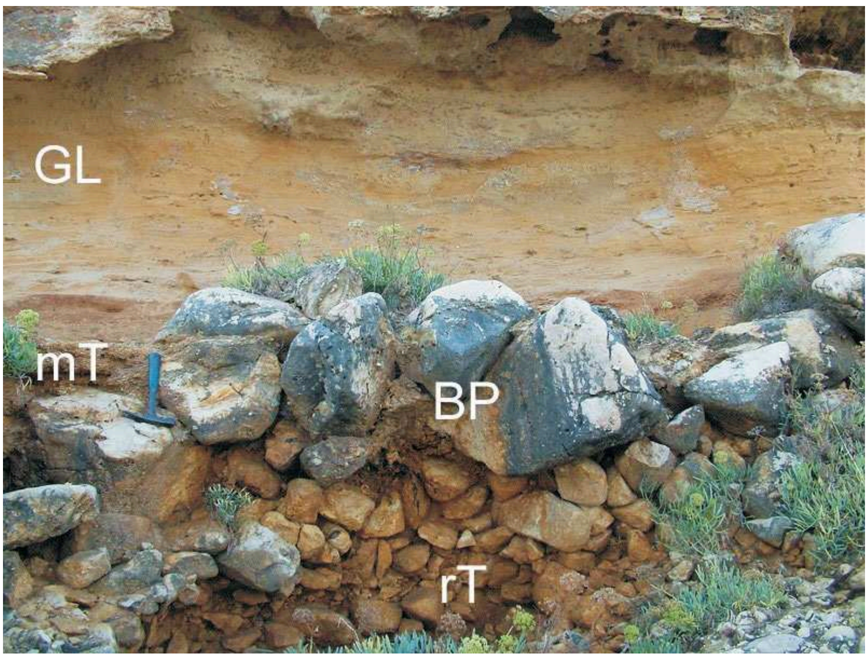


Figure 5.97. Boulder pavement (BP) overlain by glaciolacustrine sediment (GL). Gravel sediment (glacial outwash or meltout till (mT)) is locally found in gaps between boulders above the reworked till (rT). Photo taken in 2008.

Slika 5.97. Blok-horizont (BP) povrh prerađenog tila (rT) prekriven glacio-jezerskim sedimentom (GL). Prostor između blokova mjestimično je zapunjen šljunkom, koji je meltout-til (mT) ili sediment ispiranja. Snimljeno 2008.

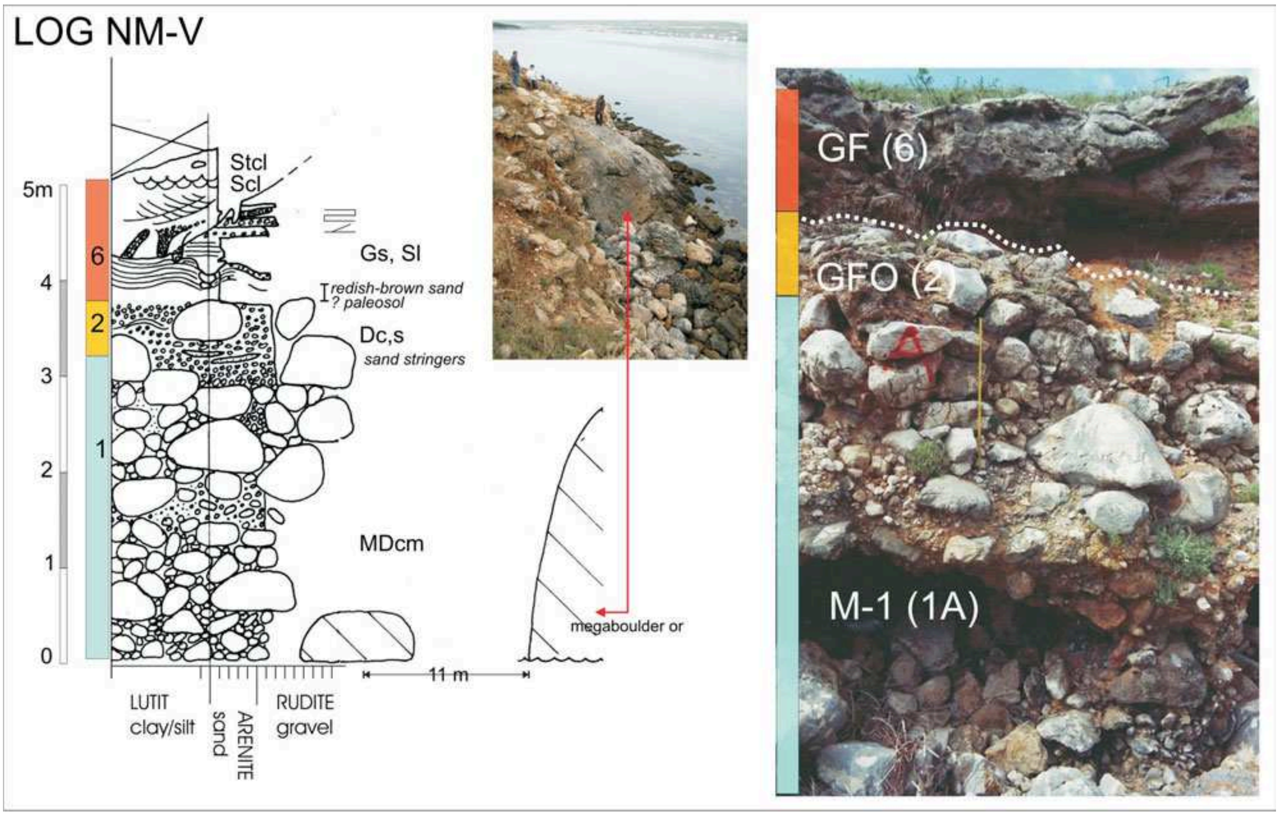


Figure 5.98. A typical cross-section of the Paklenica Member mega-diamict lithofacies (1) exposed at the Novigrad section. There is a mega-block exposed close to location of presented sediment log (figure bellow and App. x-3). The sediment log shows glacial (1), proglacial (2), and glaciofluvial (6) deposits .

Slika 5.98. Interval 1 je tipični mega-diamict litofacijes Paklenica člana koji se vidi na profilu Novigrad. Nedaleko lokacije prikazanog sedimentnog stupa nalazi se mega-blok koji izviruje na razini mora (slika ispod I Prilog x-3). Stup prikazuje glacijalni sediment (1), proglacijalni (2) i glaciofluvijalni (6).

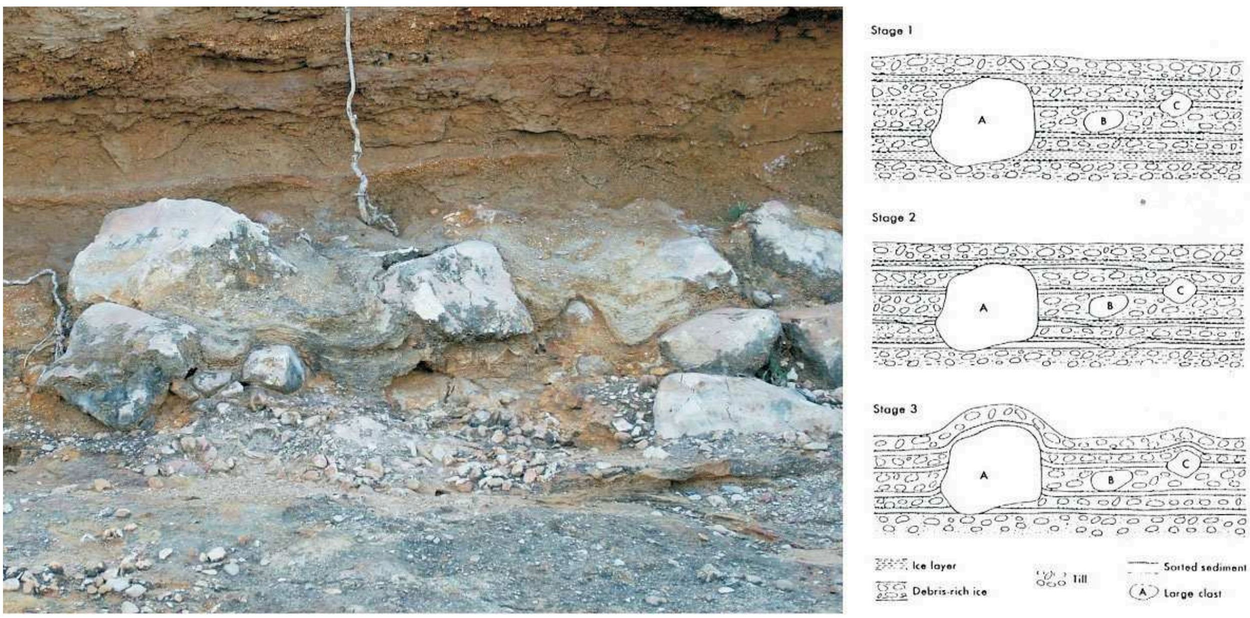


Figure 5.99. The meltout till atop of Novigrad M-1 subglacial till (MDcmm). The third stage of meltout till development, as sketched by Shaw (1977), is clearly recognized. Photo taken in 2009.

Slika 5.99. Meltout til iznad subglacijalnog tila Novigrad M-1 (MDcmm). Treći stadij postanka meltout tila, kako je prikazao Shaw (1977), lako je prepoznatljiv. Snimljeno 2009.

At the Novigrad section, as mentioned before, a typical meltout till was recognized atop of the Novigrad M-1 subglacial till (Fig. 5.99.). The sediment is a clast-supported massive gravel (Gcm) or stratified (Gc,s). It drapes the irregular surface of the subglacial till (MDcmm). As ice melts away, englacial debris setles down, while silt and sand are washed away by meltwaters.

Novigrad Member

The Novigrad section is the type locality for description of the Novigrad Member represented by matrix-supported diamict lithofacies (Dmm) described in Chapter 5.1. This diamict is interpreted as subglacial till named Novigrad M-2 or younger Novigrad moraine. It is preserved and exposed at the NW side of the Novigrad section, a minor occurrence acording to other facies (allounit 5, App. x-4). This younger till overlays the glaciolacustrine sandy deposits at very sharp and irregular contact (Fig. 5.100.). There are no deformations visible in underlying deposit within span of the exposure. Visible depth of erosion is up to 3 m (Fig. 5.101.). There is bauxite sediment in the base of contact

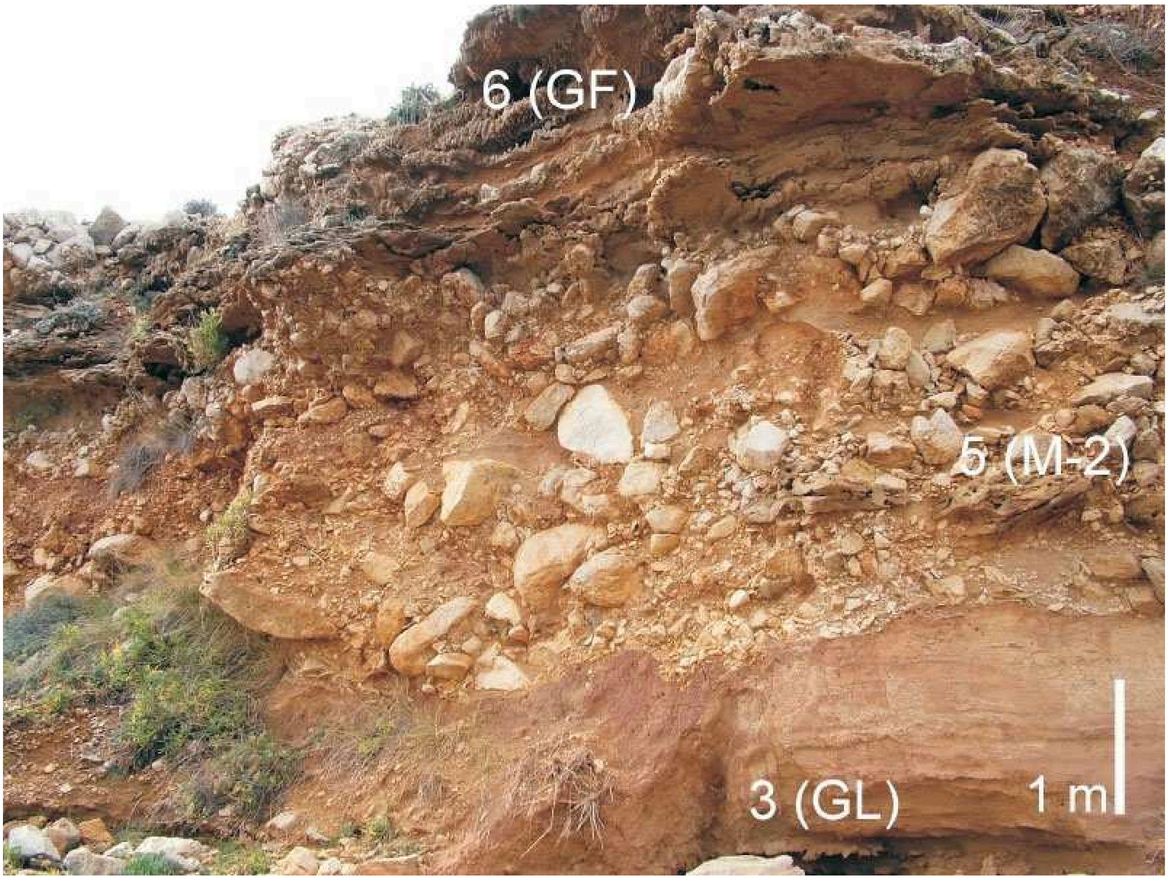


Figure 5.100. The Novigrad M-2 till (younger Novigrad moraine) overlies the glaciolacustrine (GL) sand deposits at sharp, irregular contact. Glaciofluvial (GF) deposits lay atop of till. Photo taken in 2010.

Slika 5.100. Novigrad M-2 til (mlađa Novigrad morena) leži na glacio-jezerskim pjeskovitim sedimentima u oštrom nepravilnom kontaktu. Glaciofluvijalni sediment (GF) leži na tilu. Snimljeno 2010.

Figure 5.102. A detail of the contact zone between glaciolacustrine sediment and the Novigrad M-2 till. There is a meter-sized ice-fasetted lithoclast protruding into the underlaying sediment. Photo taken in 2010.

Slika 5.102. Detalj kontaktne zone između Novigrad M-2 tila i glacio-jezerskog sedimenta u podlozi. Vidi se metarski ledom fasetirani klast utisnut u podinski sediment. Snimljeno 2010.

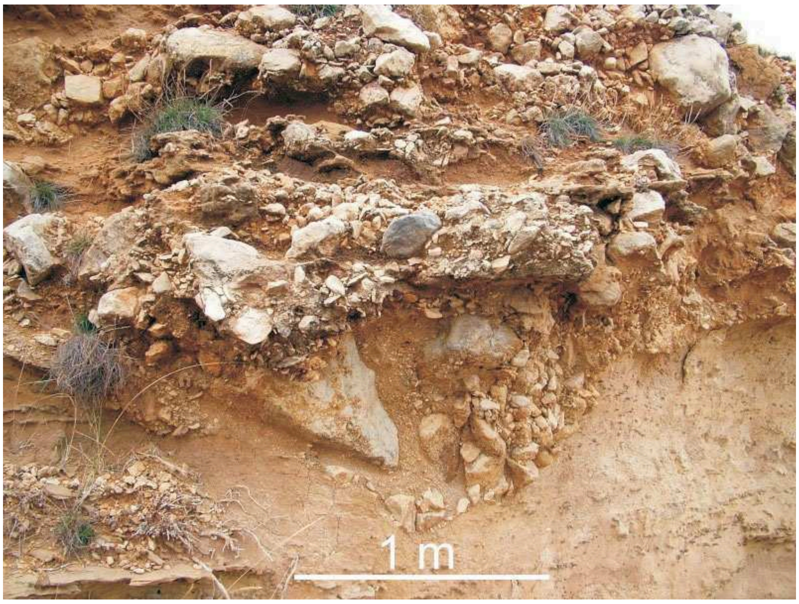
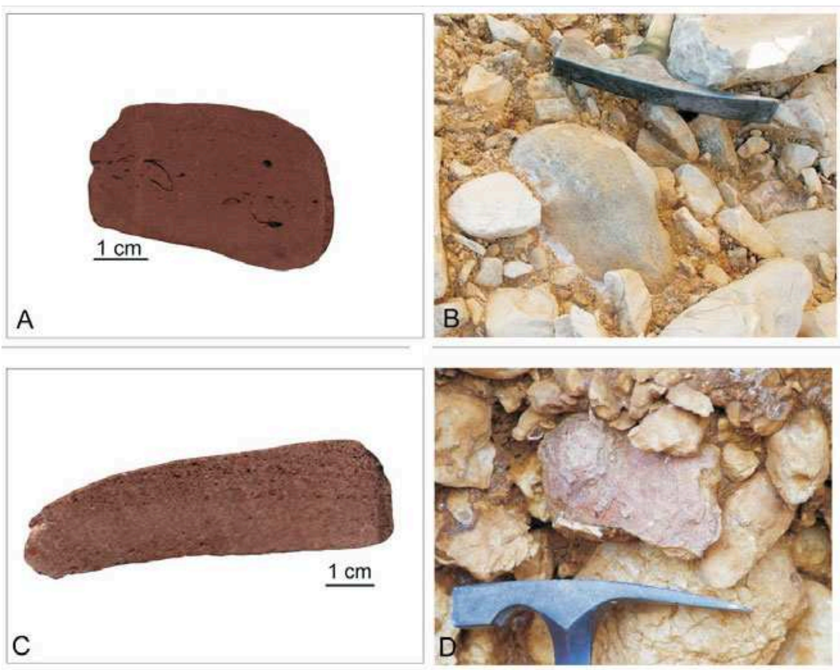


Figure 5.103. In the base of Novigrad M-2 till occurs a bauxite clast nearly 1 m large. A semi-consolidated bauxite sediment was brought by ice; a lot of bauxite deposits exist at K/T boundary in Northern Dalmatia. Photo taken in 2010.

Slika 5.103. U bazi Novigrad M-2 tila nalazi se klast boksita koji je kao polukonsolidirani sediment transportiran ledom; naslage boksita nalaze se uz granicu K/T u sjevernoj Dalmaciji. Snimljeno 2010.

Figure 5.104. Clasts of the Lower Triassic red siltstone with bivalves (A) and calcarenites (C, D), and Eocene sandstone clasts (E) found in the Novigrad M-2 till.

Slika 5.104. U Novigrad M-2 tilu nađeni su klasti donjo-trijaskih crvenih siltita sa školjkašima (A) i laminiranih kalkarenita (C, D), te klasti eocenskih pješčenjak (B).



(Fig. 5.102.) which looks like deformed soft-sediment clast, though it is not clear whether deformation is due to former depositional conditions or is related to Novigrad M-2 till deposition. Otherwise, there are a lot of bauxite deposits at K/T boundary exposed in Northern Dalmatia, which were ripped and transported by glaciars.

The Novigrad M-2 till is 2-4 m thick. It is poorly cemented, and composed of debris from gravel to boulder size and finegrained sandy matrix (Fig. 5.100.). There are also meter-sized clasts but are not so common as in the Novigrad M-1 till. The clasts of 50-100 cm large are predominantly ice-fasetted, medium to well rounded and polished. Many are tabular and elongated, fewer are medium sphaerical. Larger clasts (more than 1 m) are rare but of same characteristics. Clasts smaller than 50 cm in diameter are predominantly subangular to medium rounded, commonly platy or splinter shaped, rarely rounded and subspherical. Such differences indicate mixture of longer transporeted and shaped debris and shorter transported debris may be even of local origin. Some large tabular sandstone clasts present in till indicate local origin, because such lithology is found at Novigrad section within older glaciolacustrine interval, which at the same time documents high rate of erosion. Clast lithology varies within different limestone types, and other lithologies are rarely found, like red siltstone with bivalves, red laminated calcarenite, micaceous red sandstone (all Lower Triassic clastics), and laminated brownish-grey sandstone (Eocene clastics). One clast of Triassic gypsum sediment was also found, and togeather with Triassic clastics indicate a very long trasport from area of Knin (discussion in Chapter 7).

Among the isolated clasts or clustered debris occur lenses of laminated sand and silt sediment, and pockets of masive sand mixed with eroded paleosol which had developed above glaciolacustrine deposits (see Chapter 5.5.). The sediment was deposited as the subaerial hyperconcentrated debris flow (Nemec, 2009), but due to sand parts it could be subaquatic slightly diluted, though not in contradition with glacigenic interpretation.

The Novigrad M-2 till is overlaped with glaciofluvial sediments (allo-unit 6 in App. I-A, I-B, I-C and I-D, see also Chapter 5.3.)

5.2.1.7. OBROVAC MORAINE

The mega-diamict lithofacies (MDcmm) interpretid as till is recognized as the Paklenica Member based on all typical characteristics. The diamict is a semiconsolidated sediment. It is exposed at the roadcut section near the Obrovac town (Fig. 3.82.). It is unsorted to poorly sorted, and consists of large clasts “floating” in poorly cemented coarse-grained (gravel-size) matrix. The clasts are commonly medium- to well-rounded, elongated to subsphaerical, and range in size from gravel of 20 cm to blocks of several meters across, with no particular orientation. Exceptional are mega-blocks measuring 5 m to more than 15 m in longer axis (Figs. 5.105. and 5.106.). Lithologically, the clasts and blocks are derived from Tertiary (Oligocene) carbonate clastics - the Promina-conglomerates. The contact with bed-rock is not visible, and the sediment is additionally tectonized, with several minor subvertical faults visible.

All large clasts and blocks have glacial striae on all their surfaces. The striae are differently oriented, some are long and straight, some are short, curved or straight. They are mm-size shallow grooves, commonly tightly spaced and grouped as sub-parallel striae. Some groups of striae are mutually crossed at sharp angles. The curved striae indicate rotation of the block, whereas the straight

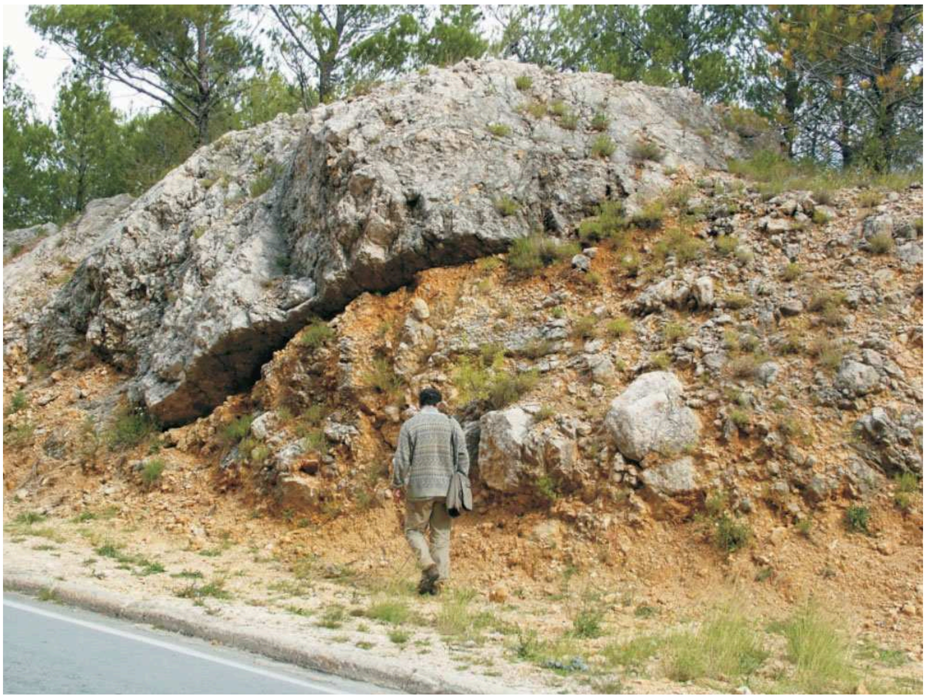


Figure 5.105. The mega-block, at least 10 m across, is derived from thick-bedded Promina-conglomerates which built large part of Norther Dalmatia. The block’s bootom surface is polished and grooved. It lays in coarsegrained matrix abound in rounded and striated boulders. Photo taken in 2008.

Slika 5.105. Mega-blok, dužine preko 10 m, potječe iz debelo uslojenih Promina-konglomerata koji izgrađuju veliki dio Sjeverne Dalmacije. Donja površina bloka je polirana i izbrazdana. Blok je u krupnozrnatoj osnovi s mnogo manjih i zaobljenih blokova s glacijalnim strijama. Snimljeno 2008.

ones indicate block sliding over hard substrate. Ice-shatered clasts also occur (Fig. 5.107.). Fractures and dislocation along shear planes document transport under pressure.

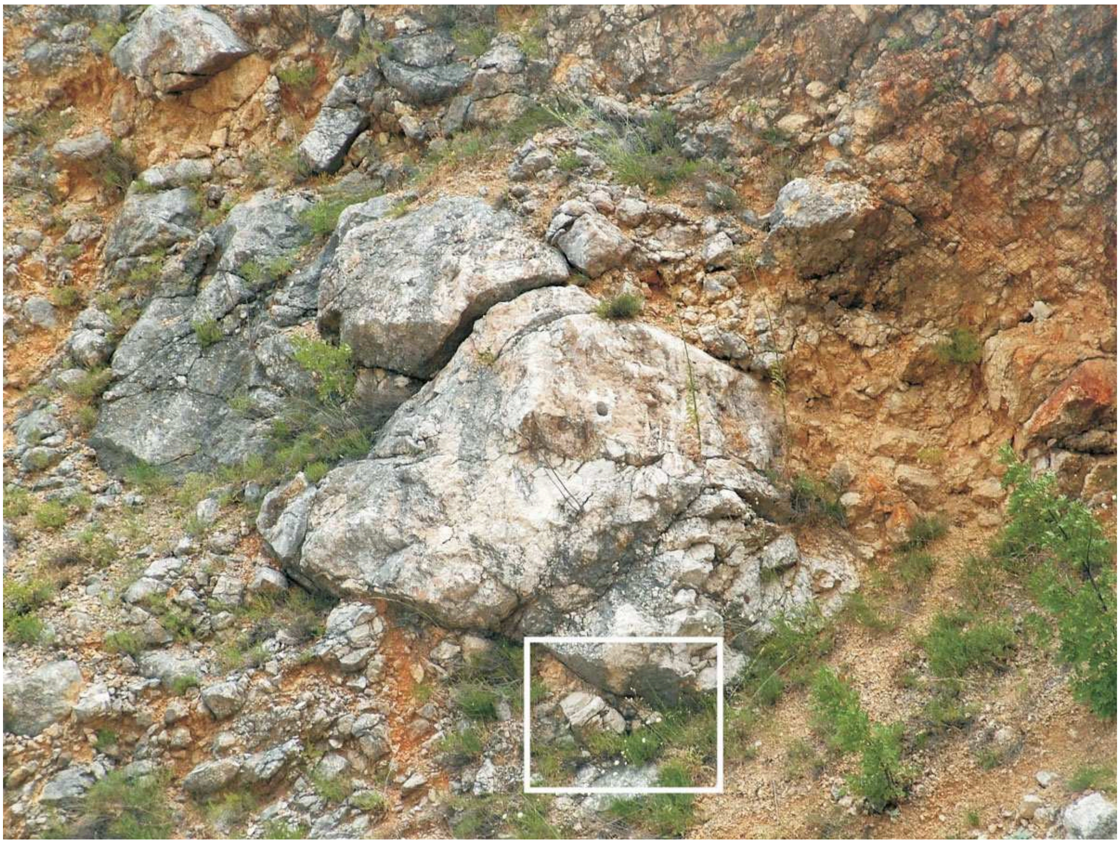


Fig. 5.106. A rounded and fasetted mega-blok (2-3 m x 7 m) with polished bottom surface. It derives from Promina-conglomerates, and its roundness and polished surfaces indicate longer subglacial transport. Diamict arround it appears as coarsgrained matrix. Many boulders are ice-shattered (detail in Fig. 5.107.) and crushed. Photo taken in 2008.

Slika 5.106. Zaobljeni i ledom-fasetirani mega-blok (2-3 m x 7 m) s poliranom donjom površinom. To je klast Promina-konglomerata, i njegova zaobljenost i poliranost ukazuje na duži subglacijalni transport. Ispod njega se vide ledom-raspucani (detail in Fig. 107.) i drobljeni klasti. Snimljeno 2008.

Figure 5.107. Detail framed in Figure 5.106. shows rounded ice-shattered boulder. Coarsegrained matrix inbetween consists of subangular to rounded debris and sandy matrix.

Slika 5.107. Detalj uokviren na Slici 5.106. pokazuje ledom-raspucani zaobljeni klast. Krupnozrnata osnova između sastoji se od poluuglatih do zaobljenih klasta i pjeskovite osnove.

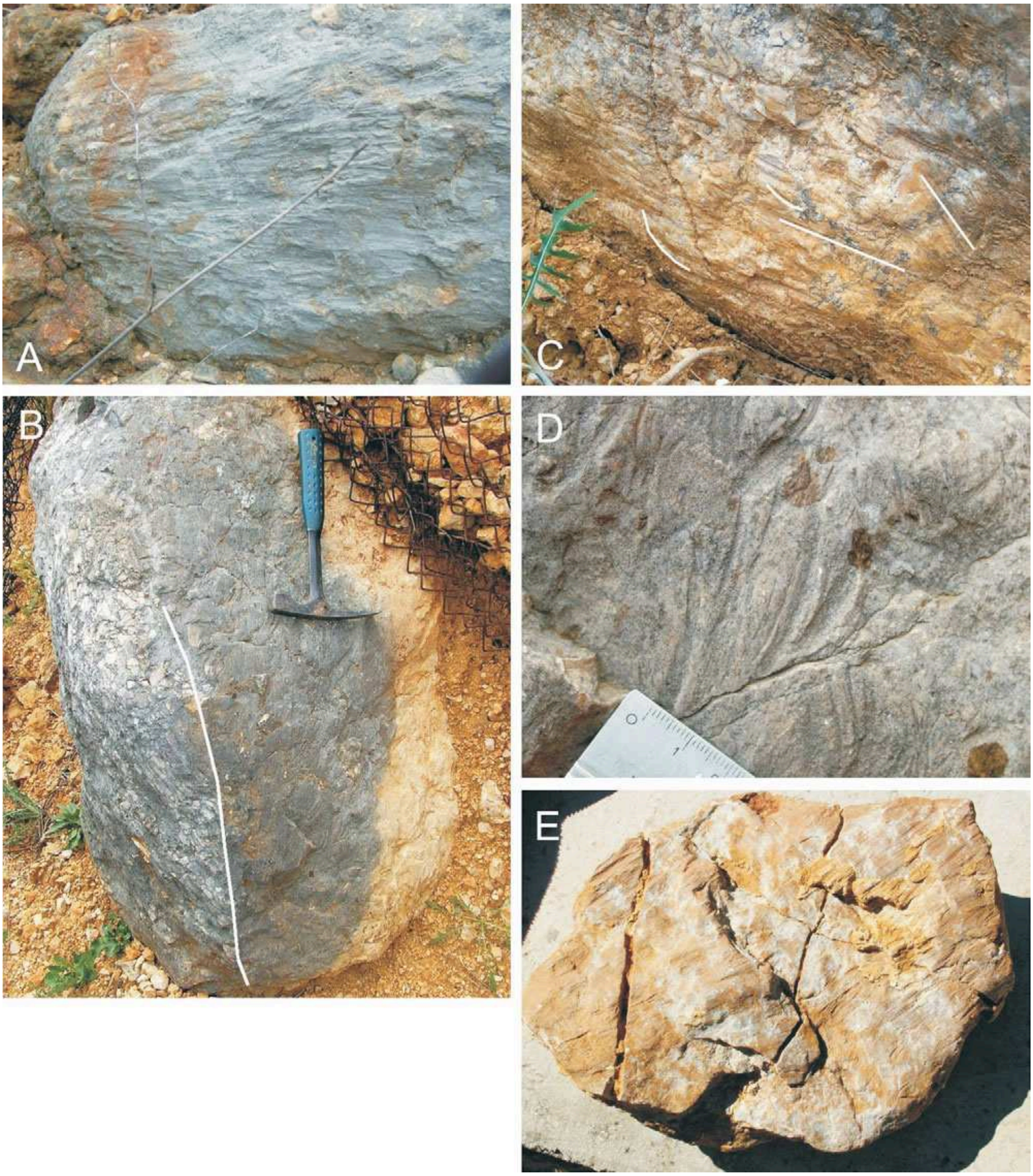


Figure 5.108. Lithoclasts with glacial striae and grooves found in the Obrovac moraine. All boulders are from the Promina-beds (conglomerates are A, B, C, D; micritic limestone E). A - boulder with straight glacial striae focused to left zone indicating transport from right to left; B - ice-fasetted and polished boulder with three systhems of striae on each side of the keel (white line); C - detail of the left side of B boulder with straight striae and grooves in two different orientations, and arched striae; D - detail of the right side of B boulder with predominant arched striae; E - ice-shattered and striated clast. Photos taken in 2006.

Slika 5.108. Litoklasti s glacijalnim strijama nađeni u Obrovac moreni. Svi klasti potječu iz Promina naslaga (A, B, C, D su konglomerati, a E mikritni vapnenac). A - klast s ravnim glacijalnim strijama orjentiranim prema lijevom vrhu, koje ukazuju na transport u lijevo; B - ledom fasetirani i polirani klast s brazdama i tri sistema strija na obje strane od zaobljenog brida (bijela linija); C - detalj lijeve strane klasta B s brazdama i ravnim strijama u različitoj orjentaciji, i lučnim strijama; D - detalj desne strane klasta B s pretežno lučnim strijama i brazdama; E - ledom raspucani klast sa strijama. Snimljeno 2006.

5.2.1.8. KARIN MORAINE

Diamict sediment exposed at the Karin section (Fig. 3.82.) is interpreted as subglacial till and based on its characteristics and location it probably belongs to the Novigrad Member. This till is a semi-consolidated matrix-supported diamict lithofacies (Dmm) (see Chapter 5.1.). It lays over glaciolacustrine laminated sediment very similar to Novigrad glaciolacustrine interval. There is no sharp contact, but a very distinct transitional mixing zone, where subglacial debris was mixed with the underlying soft glaciolacustrine deposit and oriented flame texture or loading is visible (discussed in Chapter 6). Therefore, the percentage of matrix decreases upwards, being dominant in lower part (Fig. 5.109.) of till interval and indistinct in the upper part. Average clast size is 1-30 cm.They are variously shaped, platy, splinter or sphaerical. Bullet shaped (Fig. 5.110.) clasts are rare. The clast orientation is very random, but above the mixing zone appear clusters of imbricated clasts (Fig. 5.111.). Effects of shearing are visible in marl clasts (Fig. 5.112.) due to movement under pressure in subglacial zone. The same is indicated by in one direction oriented flame structure (Fig. 5.111.).

Figure 5.109. The Karin till is a matrix-supported diamict (Dmm) with more matrix in lower part closer to underlaying glaciolacustrine sediments. Sediment is unorganized and clasts are randomly oriented. There is less matrix in upper part. Photo taken in 2006.

Slika 5.109. Karin till je diamikt s muljnom potporom (Dmm), s više matriksa u donjem dijelu bliže podinskim glacio-jezerskim sedimentima. Diamict je nesortiran i klasti su različito orjentirani.Udio matriksa se smanjuje prema gore. Snimljeno 2006.

Figure 5.110. Till loaded into underlaying glaciolacustrine sediment. There is a bullet shaped clast, much larger than other clasts. Photo taken in 2006.

Slika 5.110. Till utisnut u podinski glacio-jezerski sediment. Vidi se klast oblika metka, mnogo veći od ostalih klasta. Snimljeno 2006.

Figure 5.111. Karin till overlays glaciolacustrine laminated sediment (marl). Mixing zone with oriented flame and load texture is visible. In upper section till is better sorted, poorly stratified, and there are clusters of imbricated platy clasts. Transport and push direction from left to right. Photo taken in 2006.

Slika 5.111. Karin til leži na glacio-jezerskom laminiranom sedimentu (lapor). U sredini se vidi zona miješanja s orjentiranom plamenom teksturom i utiskivanjem. U gornjem dijelu je till bolje sortiran i slabo stratificiran, te se vide nakupine imbriciranih klasta. Snimljeno Snimljeno 2006.

Figure 5.112. Glaciolacustrine sediment is at the bottom. Loading and shearing occured in the mixing zone. Sheared clast is on the left. Photo taken in 2006.

Slika 5.112. Glacio-jezerski sediment vidi se pri dnu. Utiskivanje i smicanje vidljivo je u zoni miješanja. Klast s plohama smicanja vidi se na lijevoj strani. Snimljeno 2006.

5.2.2. PROGLACIAL AND PERIGLACIAL SEDIMENTS

A vastness in front of a glacial terminus, considered as periglacial area, differs in terms of a terrestrial terminus or if ice cap or glacier ends in a marine or lake basin. As mentioned by Brodzikowsky & Van Loon (1991), the most generally accepted definition of the term “periglacial” is that the periglacial area covers a continental area with permafrost and cryogenic processes, though the authors use the term as “*...exclusively in the sense of belonging to a permafrosted area in front of an ice cover*” (p. 91), but also discuss a proglacial zone in terms of a periglacial subenvironment. Some authors (Bennett & Glasser, 2009; Benn & Evans, 2010) use only the term “proglacial” referring to depositional environment in front of an ice cap or a glacier, directly influenced by melt-waters and thawing and freezing processes. Brodzikowsky & Van Loon (1991) also considered the periglacial environment without and with the proglacial subenvironment, referring to lack or presence of proglacial lake and buried ice blocks.

Herein, both terms are used in the sense that proglacial (ice-proximal) sediments are those deposited in the ice front area (*sensu* Benn & Evans, 2010; proglacial subenvironment *sensu* Brodzikowsky & Van Loon, 1991) and periglacial (ice-distal) are those deposited away from direct influence of the ice, but still affected by cryogenic processes and waters from distant ice.

Later described proglacial sediments were deposited either in a proglacial lake or on outwash plains. In case of a proglacial lake environment, a direct influence of ice is characterized by production of ice-blocks with ice-rafting debris during glacier recession, subglacial meltwaters rich in subglacial debris which can form turbidity currents and debris flows, and erosion by subglacial melt-waters. If a glacier ends on land, then vast outwash plain forms with glacifluvial sediments. Periglacial cryogenic features (e.g. sediment fill of former ice-wedges and cryoturbation) were found in sediments of the Novigrad section and are presented and discussed in Chapter 6.

The studied proglacial sediments are glacilacustrine sediments at Seline (Fig. 3.59.), Ždrilo, Novigrad and Karin (Fig. 3.82.) sections, glacial outwash sediments at Novigrad section, glacideltaic sediments at Seline section, and glacifluvial sediments at the Novigrad section and Velika Paklenica (Fig. 3.59.). Glacifluvial sediments at Smilčić and Paljuv (Fig. 3.82.) are interpreted as sandars, and are of proglacial to periglacial environment.

Relation of the progalcial and periglacijal deposits with those of glacial environments is discussed in Chapter 7, and their stratigraphy in Chapter 8.

5.2.2.1. LITHOFACIES

The most common lithofacies represented in the interpreted proglacial and periglacial sedimentary sequences are clay, silty clay, and calcisiltite that primarily compose varved sediments, than the most frequent sand and gravel lithofacies (calcarenites and calcirudites) that compose glacilacustrine, glacifluvial and deltaic units. Very coarse gravel to boulder lithofacies occur sporadically in those units.

Clay

Clay sediment occurs within Novigrad sediment succession in the younger glacilacustrine interval composed of cross-laminated and ripple-laminated sands, and it forms massive or faintly laminated layers up to 10 cm thick, or occurs in lenticular bedded sand-silt intervals as shown in the Log N-4b of the Novigrad section (Appendix 5/1). Such redish-brown clay layers, which occur within glacilacustrine sequence of Novigrad section, are commonly eroded by currents produced by subglacial meltwaters flowing into a proglacial lake basin (see Chapter 7). The clay is locally very bioturbated (Fig. 5.113.), and locally contains irregular lenses of clayey calcisiltites with current ripple lamination (Fig. 5.114.).

Figure 5.113. Intensively bioturbated interval. Glacilacustrine sequence of Novigrad section. Photo taken in 2004.

Slika 5.113. Izrazito bioturbirani interval. Glacilakustrinske naslage na profilu Novigrad. Snimljeno 2004.

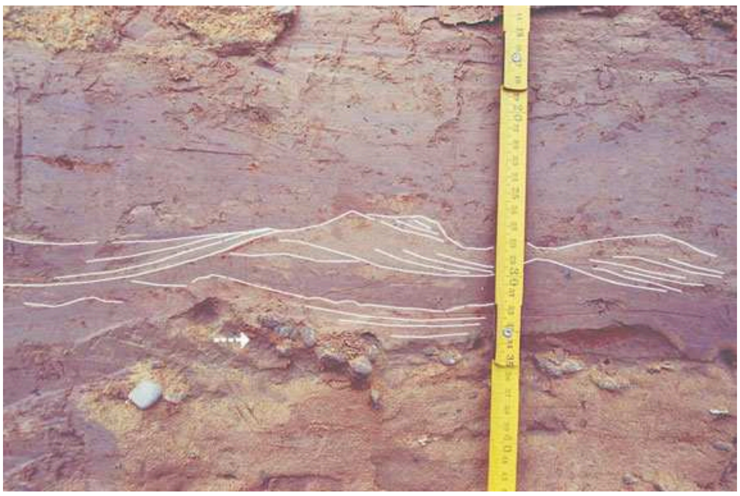


Figure 5.114. Clay sediment of glacilacustrine sequence at Novigrad section, with isolated clayey silt current ripples. There is a dropstone stringer bellow the clay bed deposited by undermelting of rafting ice-blocks. Photo taken in 2004.

Slika 5.114. Sloj gline u glacilakustrinskim naslagama na profilu Novigrad, s izoliranim strujnim ripplovima glinovitog silta. Ispod gline se vidi niz ledenjačkih utrusaka istaloženih otapanjem iz plutajućih blokova leda. Snimljeno 2004.

Massive clay and silty clay deposits in various shades of redish-brown color are also found in the glacifluvial units of Baška on the Krk Island, and form paleosols developed between different allostratigraphic units 5A, 10A, 12A and 14A (Appx. 5/2-A). Those are lenticular beds, because clay has been deposited in erosional depressions, and later overlain by glacifluvial sands and gravels. A nearly one meter thick clay sediment of dark grey color also occurs within glacifluvial sequence of the Pag Island and represents also a paleosol (see Chapter 5.6.).

Figure 5.115. Detail from younger glacilacustrine unit of Novigrad section shows calcarenites with flaser bedding. Laminated clay occurs among ripple laminated sands. Photo taken in 2010.

Slika 5.115. Detalj mlađeg dijela glacilakustrinskih naslaga na profilu Novigrad prikazuje kalkarenite s flaser teksturom. Laminira glina se nalazi između intervala vrlo sitnog pijeska i silta sa strujnim riplovima. Snimljeno 2010.

Varvite

An alternation of clay and silt to very fine-grained sand laminae are defined as varved clay-silt or varvite. Generally, varves are rhythmic alternation of clay and silt to fine sand laminae. The term "varve" resembles layers in periodical repetition and was first used in 1862 by Gerard de Geer (Zolitschka, 2007), who defined varves as annual cycle composed of coarse-grained light colored summer lamina and a fine-grained dark colored winter lamina.

The varved clay-silt sediments, just preliminary investigated, occur at the Ždrilo section in Poljica cove (Figs. 3.82., 3.93.). Varvite (Fig. 5.116.) is semi-consolidated (hard when dry) deposit and consists of light to dark brown and rusty brown silt laminae in alteration with white to light grey clayey laminae. The boundaries between silt and clay laminae are sharp, sometimes with developed small-scale flame structures, sometimes marked by erosional surfaces and sometimes marked by bioturbations. In the section studied by Adžić (2012) the silt laminae vary from 1 mm to 10 cm in thickness. The clay laminae are considerably thinner, 1 to 30 mm. Traces of bioturbation are visible at the contact of silt and clay laminae. Silt and clay laminae are in most cases further differentiated which might imply the variation of sediment inflow during their deposition. At the boundary between dark and light laminae many plant macro fossils are preserved. Adžić (2012) determined more than 70 specimens. In both light grey and brown laminae well preserved ostracods were found and several species determined (see Chapter 7).

Varvite of the Ždrilo section was deposited in a proglacial lake environment as indicated by dropstones found in varved-like siltites at the Seline section (a proximal part of the paleolake) (Fig. 5.130.), and overlaying lodgement till (Figs. 5.88., 5.89.). The light colored laminae represent winter seasons when lake froze and sediment intake was low (only clay), and darker laminae represent summer seasons when sediment (silt and sand) input was much higher due to melt-waters and rain-falls. Thickness variability of both light and darker laminae, and their complexity, may reflect longer or shorter winters, and wetter or dryer summers.

Figure 5.116. Varvite at Ždrilo section in Poljica cove, which is very finely laminated clay-silt sediment. Thicker light laminae at the bottom may represent longer winters with very short summers, and complex darker varves may reflect longer summers with oscillating weather conditions. Photo taken in 2010.

Slika 5.116. Varvit na profilu Ždrilo u uvali Poljica je vrlo fino laminirani sediment gline i silta. Svjetlije deblje lamine u donjem dijelu možda predstavljaju duže zime s kratkim ljetima, a kompleksne tamnije varve moguće dokumentiraju duga ljeta vrlo promjenjivih vremenskih prilika. Snimljeno 2010.

Figure 5.117. Varved-like siltite at Novigrad section represents the lower glacilacustrine unit. Although it appears massive, an alternation of silt and clayey silt laminae produced vague horizontal parallel lamination. Dropstones are common in this unit. Photo taken in 2010.

Slika 5.117. Siltit sličan varvama na profilu Novigrad predstavlja donji dio glacilakustrinskih naslaga. Iako sediment djeluje masivno, izmjena siltnih lamina i lamina glinovitog silta daje slabo vidljivu vodoravnu paralelnu laminaciju. Ledenjački utrusci su česti u ovom intervalu. Snimljeno 2010.

Varved-like calcisiltite

This lithofacies comprises calcisiltites (40 - 80 % carbonate) which are locally several meters thick. Calcisiltites appear massive, but a vague horizontal lamination is visible produced by alternation of silt and clayey silt laminae. Weathered surface of the sediment is masking even this vague lamination. There are several horizons with isolated clasts up to 10 cm in diameter (exceptionally 20 cm), which are faceted or rounded, and interpreted as dropstones (Fig. 5.117.).

Biota in siltites is poorly diversified and represented by two cold-water ostracod species *Candona neglecta* Sars and *Scottia browniana* Kempf, and characean gyrogonites. Rare bioturbation also occurs.

The massive, faintly laminated calcisiltites were deposited from sususpension in a proglacial lacustrine environment. The dropstones found at several levels within siltite unit were brought and discharged by floating and undermelting ice-blocks. Soft sediment deformation under fallen dropstone is visible locally if the sediment at the lake bottom was well laminated.

The varved-like siltites are exposed at the Seline (Figs. 3.59.) and Novigrad (Fig. 3.82.) sections. At Seline they occur in association with proglacial deltaic conglomerates, and at Novigrad in association with older glacial deposits (tills) and younger glacifluvial deposits (Appendix. 5/1).

Sand / Calcarenite / Hybrid arenite

Sediments composed of arenite-size grains, regardless of mineral composition, are herein called “sands” if unconsolidated. Since most of the sand deposits are predominantly composed of carbonate particles, they are called calcarenites. In sediment successions also occur sand deposits with about half carbonate and half non-carbonate debris (quartz sand), thus named hybrid arenites. Sands or arenites are generally loose to poorly cemented. Cementation is commonly selective, so it is usual to find an exposure completely cemented at the surface. Selective cementation of particular layers (especially fine-grained) is also common, probably due to difference in clay content, meaning that less clay content enables faster cementation. However, the fine-grained sands are well cemented at some levels making odd-shaped concretions generally in horizontal position, which is common at all studied locations.

Sand sediment vary from fine-grained to coarse-grained, and gravelly. The fine-grained sands (calcarenites) occur in large part of Novigrad section representing glacilacustrine and glacifluvial deposits, and built major parts of glacifluvial sedimentary units at Baška (Krk Island) and Bošana (Pag Island) localities.

Bedding is very different and includes: cross-bedding (planar or trough-cross), lenticular, wavy and flaser bedding common in fine-grained sands, and horizontal bedding. Sinsedimentary deformations occur locally and are described and discussed in relation to a particular section (Baška, Pag, Novigrad). Common structures of fine-grained sands/calcarenites are normal grading in massive sand-to-silt layers, horizontal or wavy parallel lamination, ripple-lamination (current, climbing, and wave ripples), cross-lamination (planar or trough-cross) and scour-and-fill lamination. These are characteristic for the younger glacilacustrine unit of the Novigrad section (Figs. 5.118., 5.119.).

Very fine-grained lenticular bedded calcarenites are interbedded with marls and clay laminae which may be interpreted as "varve-couplets" of proximal lake environment (Fig. 5.120.).

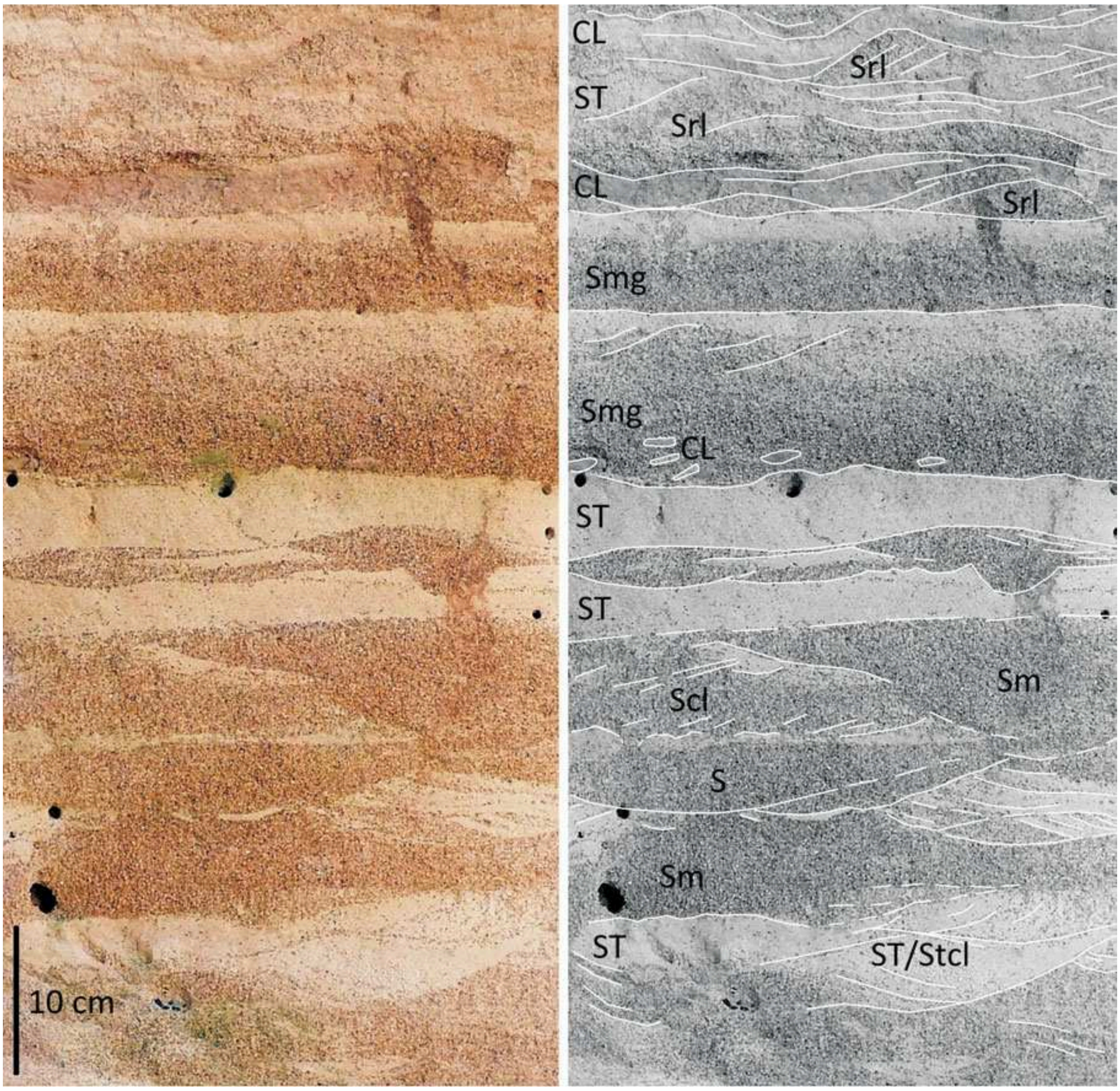


Figure 5.118. Detail of the younger glacilacustrine unit of Novigrad section, showing ripple and cross laminated calcarenites. Some sand layers are normally graded to silt (Smg). Some are faintly graded or ungraded, rippled, and sometimes representing few centimeters high isolated ripples ("starving ripples" in the middle within silt layer (ST)). Contacts are sharp and erosional. Rare clay laminae (CL) occur atop of ripples. Current ripples indicate transport from left to right, as well as imbricated mud chips in the normally graded sand bed (Smg).

Slika 5.118. Detalj mlađeg dijela glacilakustrinskih naslaga na profilu Novigrad prikazuje laminirane kalkarenite. Neki slojevi su normalno graduirani od pijeska do silta (Smg). Neki su slabo graduirani ili negraduirani, s riplovima, i mjestimično prestavljaju izolirane strujne riplove ("nepotpuni riplovi"), vide se u sredini slijeda između slojeva silta (ST)). Kontakti su oštri i erozijski. Rijetke su lamine gline (CL) povrh strujnih riplova. Strujni riplovi pokazuju transport s lijeva u desno, isto kao i imbricirani klasti gline u normalno graduiranom sloju arenita (Smg).

Figure 5.119. Detail of the section above the one shown in Figure 5.118. A - field view; B - interpreted image. Three intervals of laminated calcarenites are recognizable: the lower with “starving ripples” and faint cross lamination, the middle one with massive graded sand and climbing sand ripples above, and the upper interval with scour-and-fill sand-silt sediment.

Slika 5.119. Detalj kalkarenita koji se nalaze iznad kalkarenita prikazanog na slici 5.118. A - terenski snimak, B - interpretirani snimak. Uočljiva su tri intervala: donji s “nepotpunim strujnim riplovima” i nejasnom kosom laminacijom, zatim srednji interval s masivnim graduiranim arenitom i “penjućim strujnim riplovima”, te gornji interval s tragovima erozije-i-ispune.

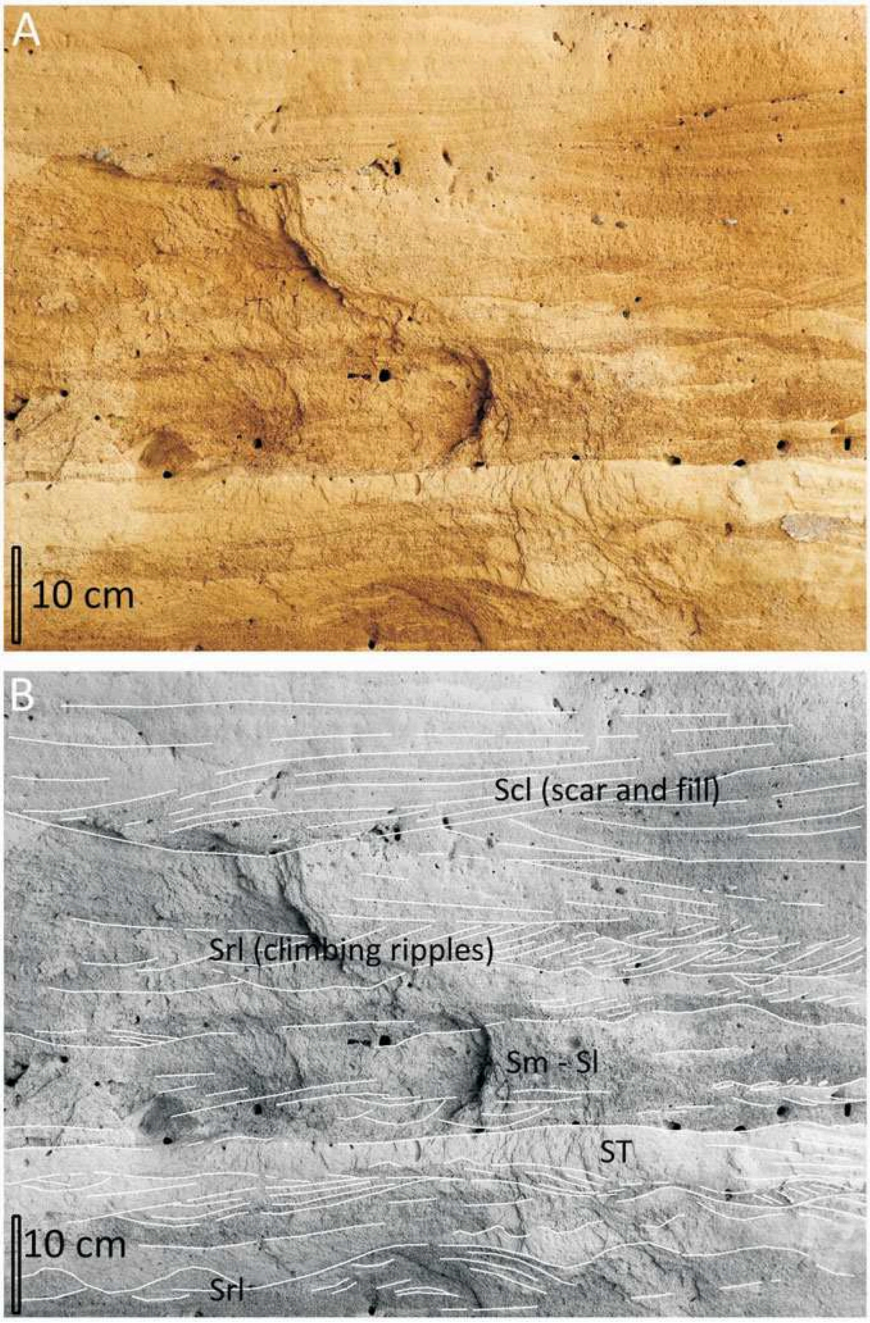


Figure 5.120. Calcarenites of glacilacustrine unit at Novigrad section. Interbedding of irregular lenticular sand layers (”starved current ripples”), faintly laminated clayey silt and wavy clay layers form wavy bedding.

Slika 5.120. Kalkareniti glacilakustrinske jedinice na profilu Novigrad. Izmjena nepravilnih lećastih slojeva pijeska (”nepotpuni strujni riplovi”), slabo laminiranog glinovitog silta i valovitih slojeva gline stvorila je valovitu slojevitost.

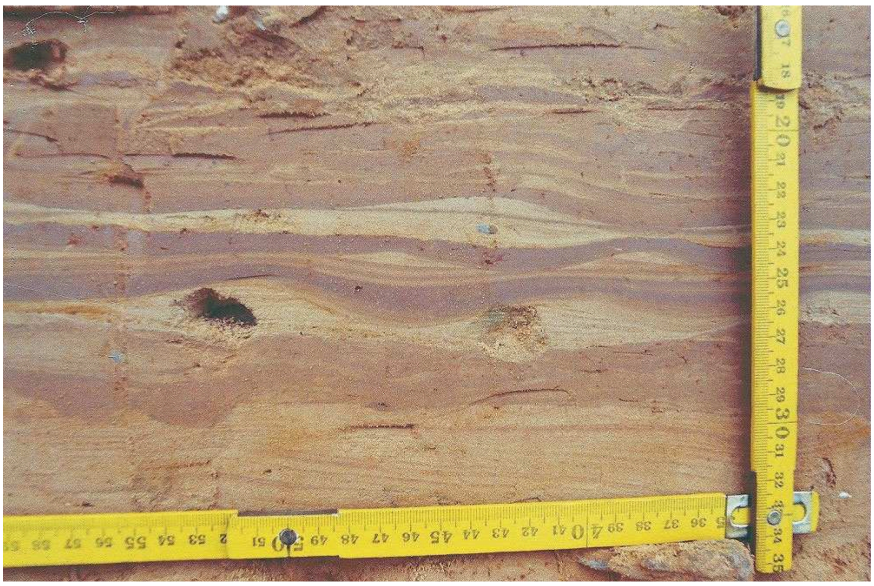


Figure 5.121. Ripple laminated gravelly calcarenites of Seline section. The calcarenites with pebble stringers occur within glacideltaic sequence in alternation with glacilacustrine calcisiltites.

Slika 5.121. Šljunkoviti kalkareniti s riplovima, otkriveni na profilu Seline. Kalkareniti s nizovima valutica dio su glacideltaičnih naslaga u izmjeni s glacilakustrinskim kalcisiltitima.

Gravelly calcarenites or sands (Fig. 5.121.) are more common in glacideltaic sequence at Seline section, and are of characteristic redish color. There they are wave-ripple or current-ripple laminated, which indicated deposition in a proximal zone of a proglacial lake (see Chapter 7).

Gravel / Calcirudite

Gravel deposits occur in various forms within studied sediment succession. They are usually loose sediment or poorly cemented (glacifluvial deposits of Krk, Pag and Novigrad sections). In some sequences they are well cemented breccias or conglomerates (Velika Paklenica and Seline sections).

The bedding type varies from massive, graded bedding, horizontal or wavy parallel bedding, planar-cross or trough-cross bedding, to channel-fill bedding. Thickness of gravel beds spans between few and hundred centimeters, while channel-fill gravels reach several meters in thickness. The particle size varies from granule to pebble, and rarely spans to cobble size. Each type is described and discussed in relation to a particular section of occurrence.

Fine-grained calcirudites

These are gravels predominantly composed of granule-sized carbonate debris, and occur as loose or poorly cemented, medium to well sorted deposits. The roundness varies from low to medium. They are mostly clast-supported and show open-work texture (Fig. 5.122.), although low percentage of earthy matrix is locally present. They can occur in alternation with calcarenite/sand beds, and such intervals are usually planar-cross or trough-cross bedded and represent channel-fill deposits (Figs. 5.123., 5.124.).

Coarse-grained calcirudites

These are pebble-to-cobble size gravel deposits, rarely unconsolidated, and usually medium to well cemented. The loose sediment types are less represented in the studied sediment successions, although they occur at most locations where glacifluvial sediments were studied, especially at the Baška (Appx. 5/2-A and 5/2-B) and Novigrad sections (Figs. 5.131., 5.132.).

Flat-pebble conglomerate

This is an exceptional type of coarse gravel deposit (Fig. 5.126.) occurring only at the Novigrad section (Fig. 5.131.). An interval about 2 m thick consists of layers composed of variously packed flat rounded, mostly discoidal pebbles, as shown in the sediment log N-1b and photos A and B (Fig. 5.131.). There are distinct horizons, several centimeters thick, with steep imbricated or vertically oriented flat pebbles. Otherwise, flat pebbles are imbricated in left or right orientation and well packed, locally containing 1-10 % sandy matrix. The characteristics indicate deposition in a beach zone where wave swash sorts and imbricates pebbles. Considering that this conglomerate occurs in association with glacifluvial and glacilacustrine deposits, it is assumed that vertical orientation of flat pebbles was caused by ice frosting along river banks in periglacial environment.

Horizontally and wavy stratified calcirudites

These are medium to coarse gravel sediments occurring locally between lodgement till (moraine M1 at Novigrad section) and glacilacustrine or glacifluvial channel-fill cross-bedded gravels at the Novigrad section. They are poorly to medium sorted clast-supported calcirudites, locally well cemented with spary calcite "A" cement or by micritic calcite matrix. They were deposited by glacial melt-waters and are interpreted as glacial outwash deposits, described later in Chapter 5.2.2.3.

Matrix- to clast-supported conglomerates

These are lithified coarse gravel deposits occurring at the Seline section (Fig. 5.127.), where they compose major part of glacideltaic sequence (see Chpt. 5.2.2.4.). Conglomerates are polymict, composed of primarily carbonate clasts, that are medium- to well rounded. Many clasts are faceted with glacial striae. The matrix is calcimicrite or calcisiltite. In transitional types (matrix- to clast-supported) intergranular voids are frequent, and are either empty or filled with spary calcite or just drusy calcite "A" cement occurs.

Massive matrix-supported diamicts

These are unsorted calcirudite composed of either angular (breccia) or rounded (conglomerate) debris and sandy or micritic matrix (between 10 and 30 % approximately). Diamicts with angular debris are predominant lithofacies in the allostratigraphic units 3, 6 and 8 of the Baška section (Appendix 5/2-A, 5/2-B). They are interpreted as subaerial mass-transport deposits or subaerial debris flow deposits, typical in proglacial environment (Brodzikowski & Van Loon, 1991). Diamicts, commonly breccias, represent fill of choot channels (Photos b and k in Appendix 5/2-A) indicating high erosional energy.

Figure 5.122. Planar cross bedded calcirudite of glacifluvial sequence at Bošana section on the Pag Island. The finegrained layers are well sorted and contain up to 10 % earthy matrix. The coarsegrained layers are clast-supported medium sorted sediment of open-work texture. Layers are massive ore graded.

Slika 5.122. Planarno koso stratificirani šljunci u glacifluvijalnim naslagama na profilu Bošana na otoku Pagu. Sitnozrnati slojevi su dobro sortirani i sadrže do 10 % zemljaste osnove. Krupnozrnati slojevi su sediment sa zrnskom potporom i "open-work" strukturom. Slojevi su masivni ili graduirani.

Figure 5.123. Fine-grained calcirudite of glacifluvial deposits exposed in a gravel pit on the Pag Island. The section shows about 10 m of cross-bedded point-bar sediments.

Slika 5.123. Sitnozrnati kalciruditi u glacifluvijalnim naslagama otvorenim u šljunkokopu na otoku Pagu. Vidi se oko 10 m sedimenta meandarskog spruda.

Figure 5.124. Planar cross bedded calcirudites representing a part of point-bar deposits of the glacifluvial sequence at the Novigrad section. Hight of the outcrop is ca 5 m.

Slika 5.124. Planarno koso uslojeni kalciruditi predstavljaju dio meandarskog spruda unutar glacifluvijalne jedinice na profilu Novigrad. Visina izdanka je oko 5 m.

Figure 5.125. Coarse gravel stringers interbedded with fine gravel and sandy gravel. The gravel deposits belong to the allostratigraphic unit 8 of Baška section (Appx. 5/2-A).

Slika 5.125. Nizovi krupnog šljunka u izmjeni s finozrnatim calciruditima i pjeskovitim ruditima. Naslage pripadaju alostratigrafskoj jedinici 8 na profilu Baška (Pr. 5/2-A).

Figure 5.126. Flat pebble conglomerate is exceptional gravel deposit and occurs only at Novigrad section. It represents fluvial beach deposit. There is one of few distinct intervals with steep imbrication to vertical orientation of flat pebbles, probably caused by ice frosting.

Slika 5.126. Konglomerat sastavljen od plosnatih valutica je tip kalkrudita koji je nađen samo u slijedu naslaga na profilu Novigrad. To je sediment riječne plaže. Vidi se jedan od nekoliko horizonata gdje su plosnate valutice strmo imbricirane ili vertikalno orjentirane, što je najvjerojatnije posljedica smrzavanja.

Figure 5.127. Cross bedded matrix-supported conglomerate at Seline glacideltaic sequence.

Slika 5.127. Koso uslojen konglomerat s muljnom potporom na profilu Seline pripada glacideltaičnim naslagama.

5.2.2.2. GLACILACUSTRINE SEDIMENTS

The glacilacustrine sediments are best preserved and exposed along the coast of Seline (Figs. 3.59., 3.76.), along the SW coast of the Novigrad Sea (Figs. 3.82., 3.84.), and in Poljica cove near Ždrilo (Figs. 3.82., 3.93.), and are herein for the first time interpreted as sediments of a proglacial paleolake. Minor, but important exposures of glacilacustrine sediments also occur in the Kusača cove (1), near Provalija (3) and at coast of the Karin Sea (6). The locations 7 and 9 mark extensive occurrence studied by previous authors and discussed in Chapters 7 and 8.

The glacilacustrine sediments were studied at the Novigrad and Seline sections, and preliminary at the Ždrilo and Karin sections (Fig. 5.129.). Sediments are presented in this Chapter, while other locations are discussed in Chapter 7 on paleoenvironmental reconstruction. The common characteristics of glacilacustrine successions are varved and varved-like sediments (Fig. 5.129.) and occurrence of dropstones (Fig. 5.130.), as major indicators of glacigenic origin.

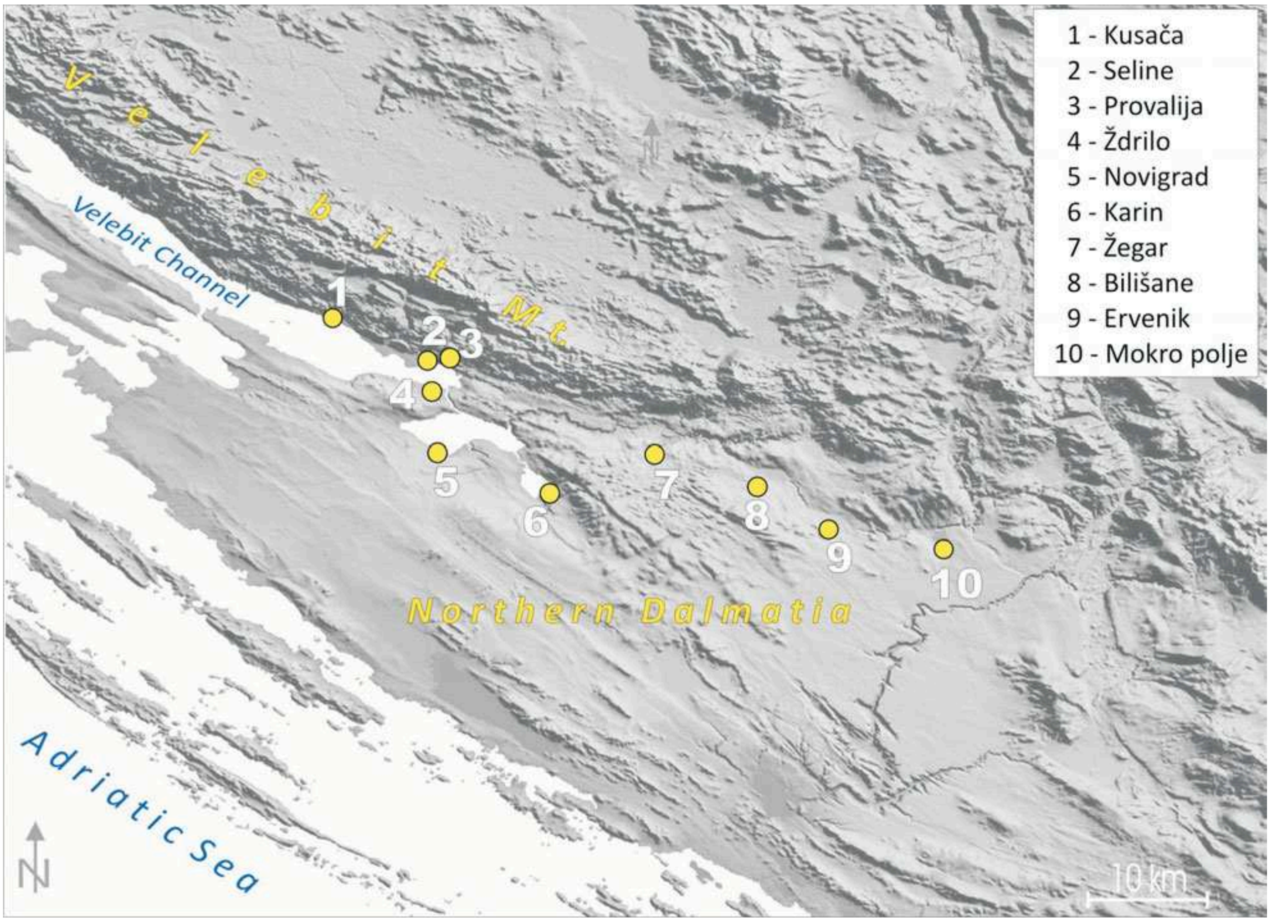


Figure 5.128. Locations of glacilacustrine sediments in the South Velelbit (locations 1, 2, 3) and Northern Dalmatia (locations 4 - 10) study regions.

Slika 5.128. Lokacije glacilakustrinskih naslaga u istražnim područjima južni Velebit (lokacije 1, 2, 3) i sjeverna Dalmacija (lokacije 4 do 10).

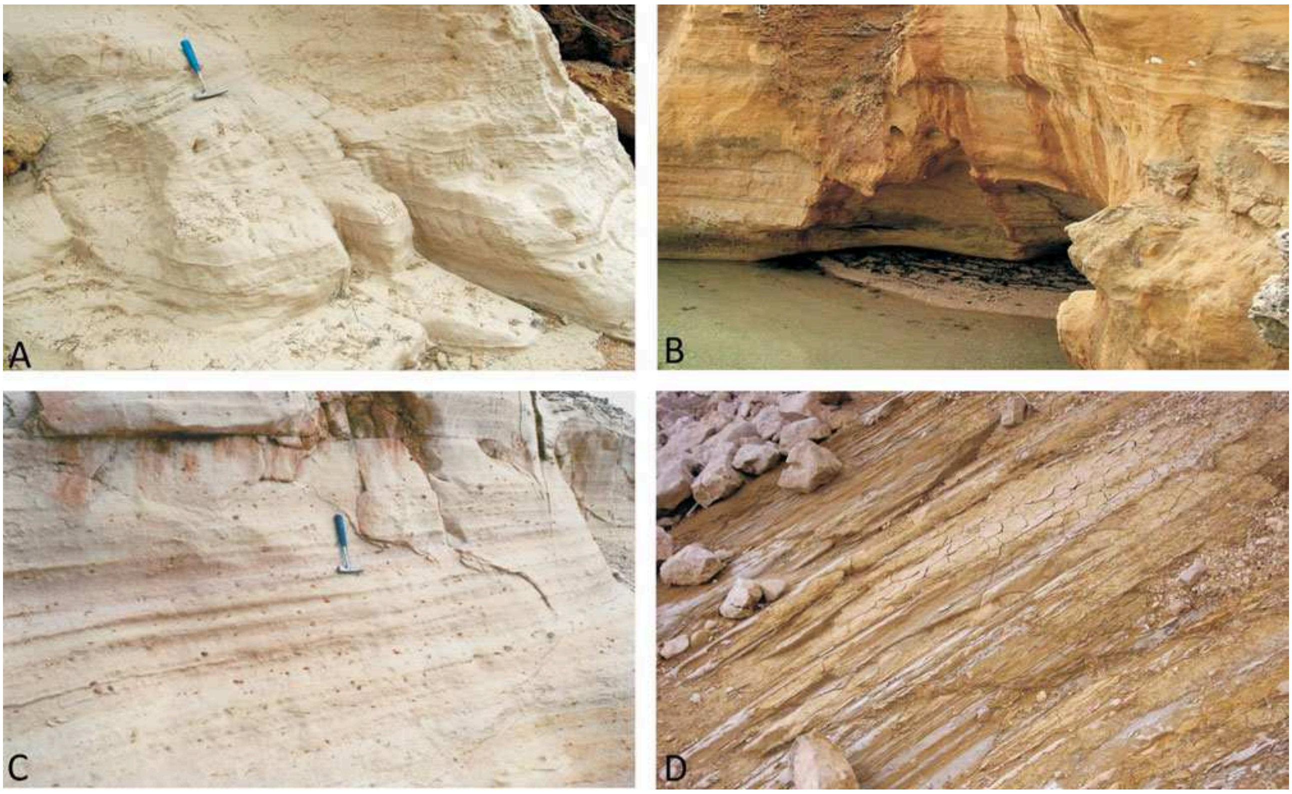


Figure 5.129. Glacilacustrine sediments of Karin (A), Novigrad (B), Seline (C) and Ždrilo (D) sections.

Slika 5.129. Glacilakustrinski sedimenti na profilu Karin (A), Novigrad (B), Seline (C) and Ždrilo (D).

Figure 5.130. Dropstones in glacilacustrine sediments of Novigrad section (A, B, C) and Seline section (D, E, F). Dropstones are ice-fasetted and rounded, except a flat pebble (F).

Slika 5.130. Ledenjački utrusci u glacilakustrinskim sedimentima na profilu Novigrad (A, B, C) i profilu Seline (D, E, F). Utrusci su fasetirani i zaobljeni, osim plosnate valutice (F).

The glacilacustrine deposits of Novigrad section are represented by varved-like calcisiltite (Fig. 5.117.) and lenticular bedded calcarenite lithofacies (Figs. 5.118, 5.119. and 5.120.). Both lithofacies occur throughout the Novigrad section as allostratigraphic unit 3 shown in Figures 5.169. and 5.170..

The varved-like calcisiltites occur in the **lower (older) part** of the glacilacustrine allo-unit and their visible thickness from sea-level up is three meters at most, since their base is not exposed (see log N-1a in Fig. 5.131.). Surface weathering and cementation masks the vague lamination resembling varves (photo E in Fig. 5.131.). There are several horizons with ice-rafted-debris (IRD). These isolated cobble-size limestone clasts are commonly faceted and rounded, and are classified as dropstones. The dropstone structure, as presented by Benn & Evans (2010) is not recognized in the calcisiltites probably because of their massive texture (Fig. 5.130. C).

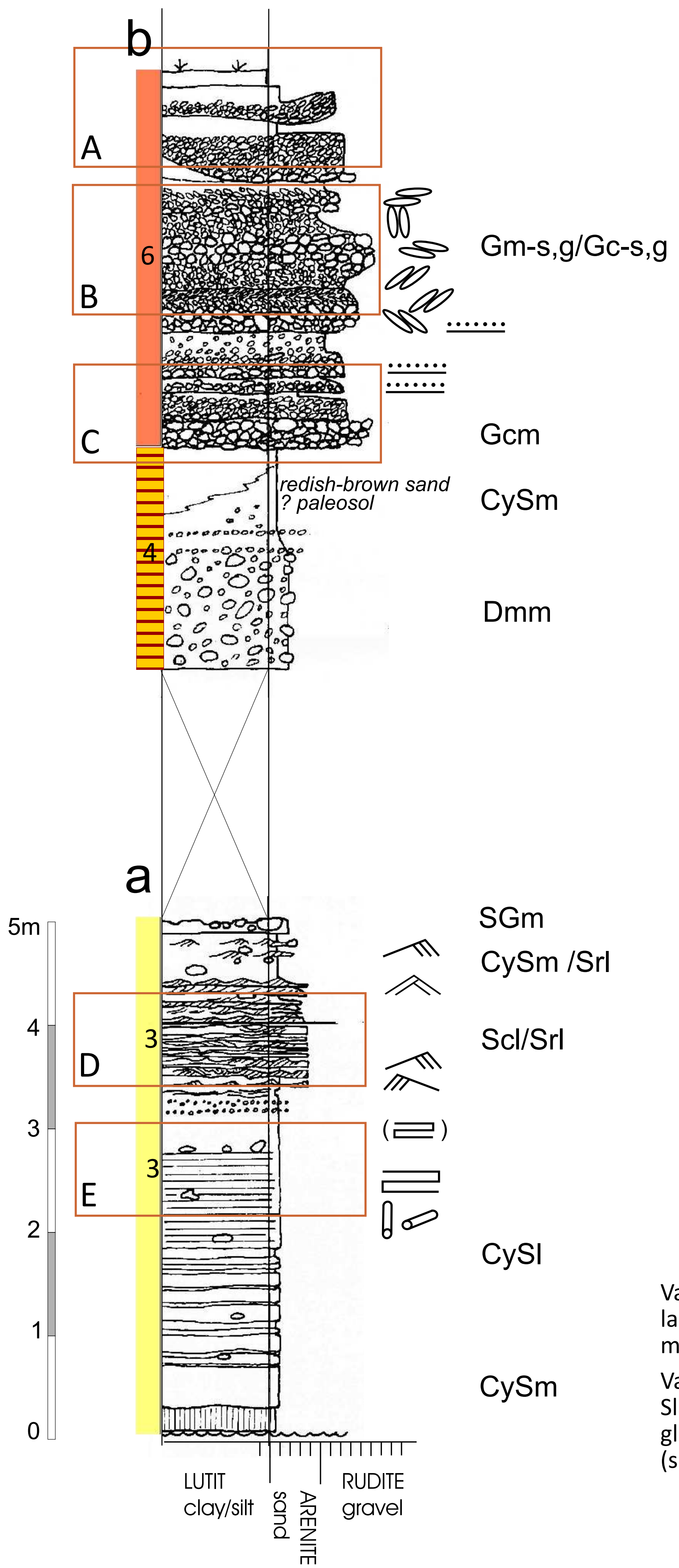
The calcisiltites can be classified as calcareous marls, and were deposited from suspension in a quiet environment. Amount of noncarbonate component spans within 10 to 70 %. The vague horizontal lamination is due to minor variations in clay content, which resembles varves. Alternation of more clayey and less clayey calcisiltites can be interpreted as annual winter-summer cyclicity. Sedimentation occurred in distal proglacial environment, away from dynamic terminoglacial zone. Seasonal summer thawing produced ice blocks with IRD.

The **upper (younger) part** of the glacilacustrine allo-unit is represented with generally rippled calcarenites. Calcarenates vary from those with 90 % carbonate component to hybrid arenites with ca 50 % carbonate. This package consists of lenticular, wavy and flaser-bedded calcarenites presented in sediment logs N-1a (Fig. 5.131.), log N-2 (Fig. 5.132.), and logs N-3 and N-4b (Fig. 5.133.). Calcarenites also occur in the whole length of the Novigrad section, and their thickness is 1 - 5 m, although their real thickness is not known due to erosional contact with the overlying sediments.

The variability in development of lenticular (log N-4b in Fig. 5.133.), wavy and flaser-bedding is partially visible in various segments of the Novigrad section, indicating transitions from subtidal to wave dominated environment of deposition (Reineck & Singh, 1973). The wave-rippled calcarenites (logs N-1a in Fig. 5.131., N-3 and N-4b in Fig. 5.133.) indicate periods of decresed sediment input and shallowing of the lake, while intervals with domination of current-ripples (logs N-1a and N-2, Figs. 5.131. and 5.132.). indicate periods of intensified subglacial melt. Soft sediment deformations occur in lenticular bedded intervals as shown in the log N-4b (Fig. 5.133.), and small-scale ice wedge casts (1-3 cm) were noticed in flaser bedded intervals.

In the upper section of the rippled calcarenites locally occur “linguoid” (Fig. 5.134.) structures, usually associated with “kettle-like forms” and sedimentary wedges (see Chapter 6). They are very similar to accumulation tongues of rill marks (usually better developed in finer sediment),

LOG N-1a, 1b

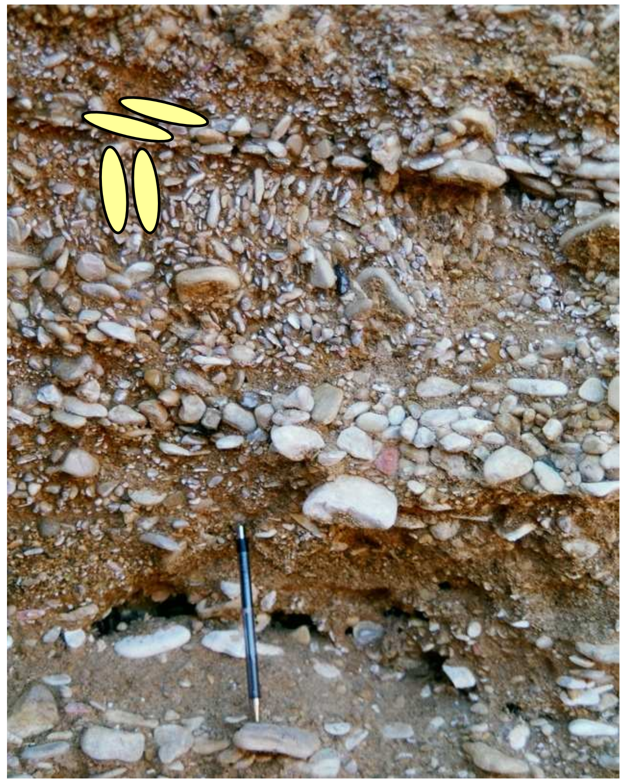


A

Flat-pebble river beach gravel (flat-pebble conglomerate) with sand lenses.

Šljunak riječne obale (conglomerate) s lećama pijeska.

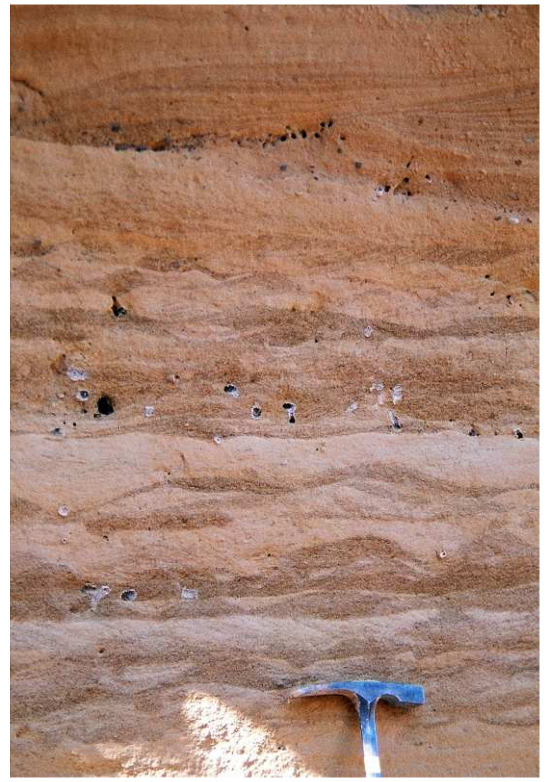
B



Flat-pebble river beach gravel (flat-pebble conglomerate). There is a distinct horizon with sub-vertically stacked flat pebbles, and horrizontally arranged to slightly imbricated flat pebbles are above. Vertical orientation was probably caused by frosting.

Šljunak riječne obale (conglomerate) čine plosnate valutice, koje su različito orjentirane. Ističe se horizont sa subvertikalno orjentiranim valuticama, a iznad njih su vodoravno do blago koso orjentirane valutice. Vertikalni položaj plosnatih valutica je vjerojatno posljedica smrzavanja.

D



Ripple laminated sand unit of glaci-lacustrine sequence. Isolated currant ripples are visible as darker sand sediment, while lighter intervals are of massive clayey sand or silty sand.

Mlađa jedinica glacilakustrinskih naslaga sa strujnim riplovima. Izolirani strujni riplovi prepoznaju se kao sediment tamnije boje dok su svjetliji intervali od masivnog glinovitog ili siltoznog pijeska.

C

Fluvial gravel beds, clast-supported or with sandy matrix. They overlie a paleosol complex.

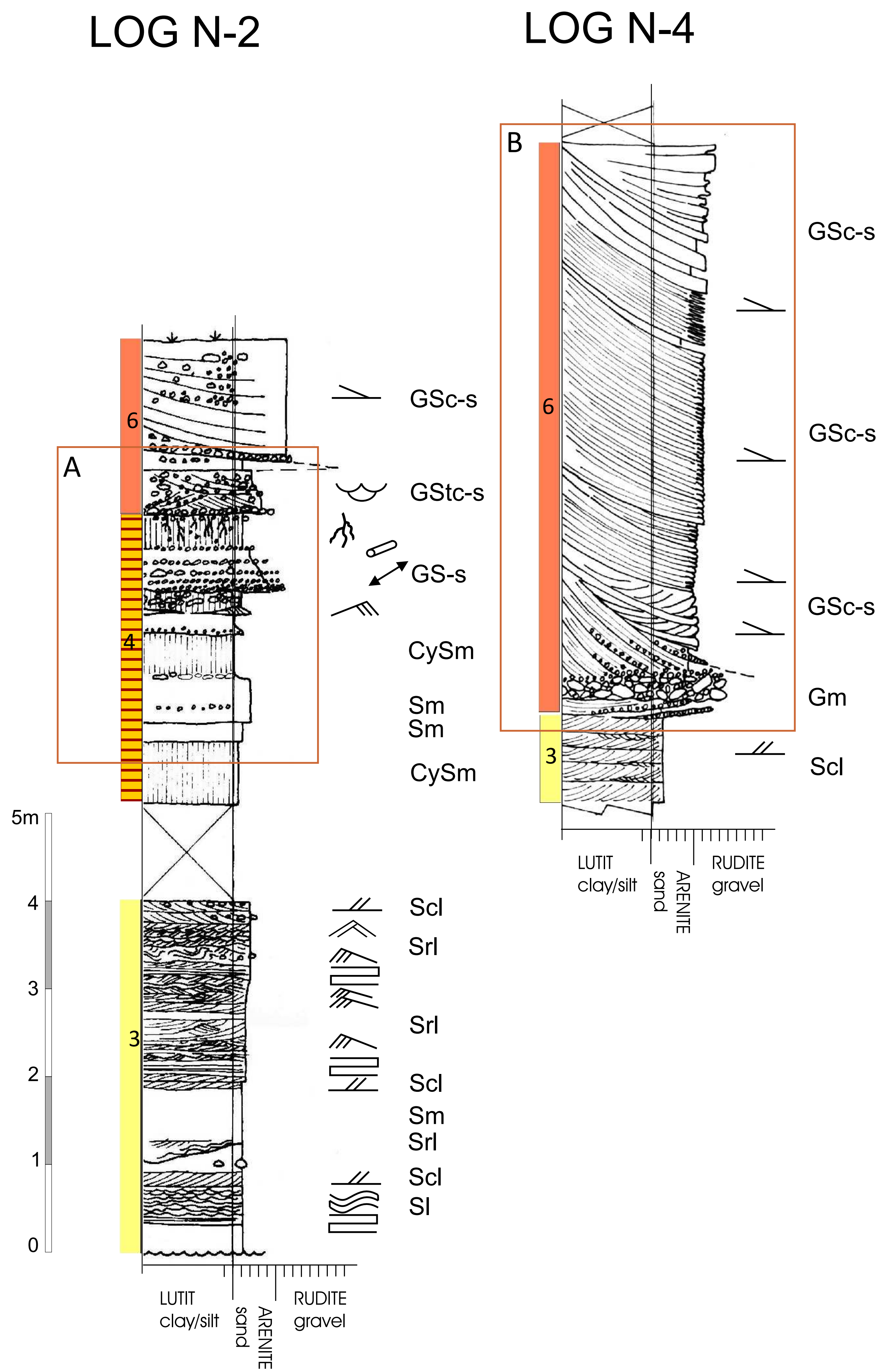
Riječni stratificirani šljunci, sa zrnskom potporom ili pješčanom osnovom, istaloženi na paleo-pedo-kompleksu.

E

Varved-like clayey-silty sand (finegrained calcarenite). Vague horizontal parallel lamination is visible due to alternation of more- and less-clayey layers. There is a massive clayey-sand bed (finegrained calcarenite) with dropstones.

Varvama sličan sediment je glinovito-siltozni pijesak (sitnozrnati kalkarenit). Slabo vidljiva vodoravna paralelna laminacija nastala je izmjenom više ili manje glinovitih slojeva siltoznog pijeska. Uočljiv je masivni sloj glinovitog pijeska (sitnozrnatog kalkarenita) s ledenjačkim utruscima.

Figure 5.131



Glacifluvial unit of Novigrad section. A wide fluvial channel, incised in glacilacustrine sediments is filled with cross stratified gravelly sand. On the channel bed deposited gravel to boulder sized debris forming channel lag deposit.

Glacifluvijalna jedinica na profilu Novigrad. Široki riječni kanal, usječen u glacilakustrinske sedimente, ispunjen je koso uslojenim šljunkovitim pijeskom. Na dnu kanala istaložen je ruditni detritus.

Paleosol complex formed above the glacilacustrine unit. There are two recognizeable paleosol horizons distinguished as redish-brown sediment. Bothe horizons contain black pebbles (pebbles with Fe-Mn coating). Fossil rhizoids are well visible in upper horizon. Ripple laminated sand, selectively cemented, is between the paleosols. Fluvial gravelly sand lies above.

Fosilni pedokompleks nalazi se iznad glacilakustrinske jedinice. Uočljiva su dva horizonta paleotla, prepoznatljivi po crvenkastosmeđoj boji. Oba sadrže "crne" valutice (valutice s Fe-Mn ovojnicom). Fosilni rizoidi su dobro vidljivi u gornjem horizontu. Pijesak s riplovima, djelomično cementiran, nalazi se između paleosola. Iznad leži riječni šljunkoviti pijesak.

Figure 5.132.

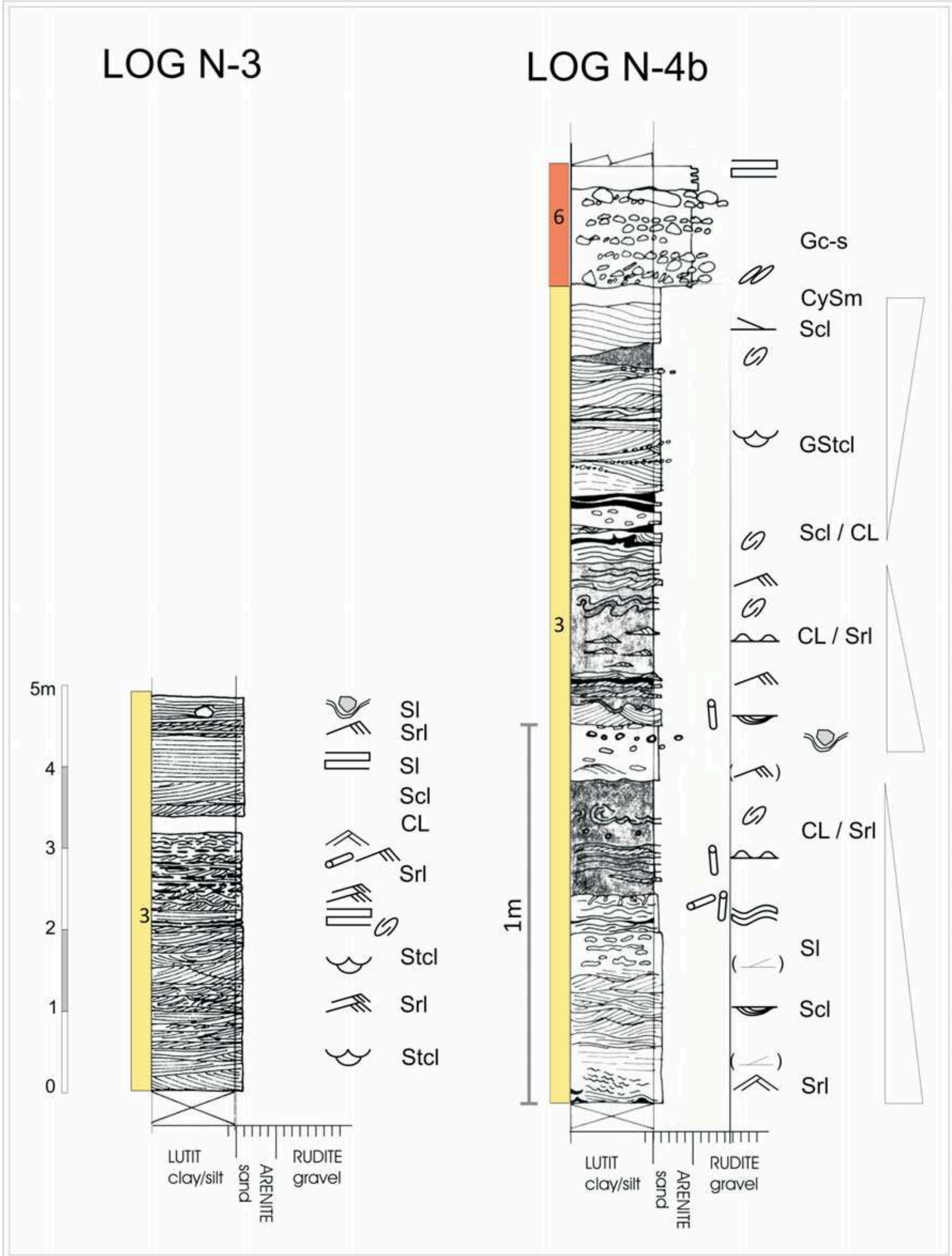


Figure 5.133. The sediment log N-3 and a detailed log N-4b present the younger part of the glacilacustrine allo-unit 3 represented with rippled calcarenites. Correlation of logs is shown in Appendix 5/1. Two fining upward trends, and one coarsening upward trend are visible in the log N.4b. Dropstones occur before the second fining upward sequence, which indicate glacial retreat and thawing phase when IRD are brought into the lake. Thicker cross- and trough-cross laminated calcarenites mark the coarsening-upward sequence, which ends by erosional contact with overlaying glacifluvial deposits.

Slika 5.133. Sedimentološki stup N-3 i detaljni stup N-4b prikazuju mlađi interval glacilakustrinske allo-jedinice 3 zastupljene kalkarenitima s riplovima. Korelacija stupova prikazana je u Prilogu 5/1. Na stupu N-4b prepoznatljiva su dva trenda usitnjavanja, i jedan trend okrupnjavanja koji se očituje u debljim slojevima koso i koritasto-koso laminiranih kalkarenita. Ledenjački utrusci nalaze se na početku drugog trenda usitnjavanja, i ukazuju na fazu povlačenja i taljenja ledenjaka s povećanim donosom detritusa u jezero.

which form in thin water film (2 cm at most) or by sudden expulsion of water from sediment due to compaction, and are considered as a document of intermittent subaerial exposure of the surface (Reineck & Singh, 1973). The water expulsion from the sediment likely to have produced the accumulation tongue forms at the Novigrad section. The water originated from thawing of buried ice (discussed in Chapter 6, "kettle-forms"), and produced very dense and highly-concentrated flows emerging to the surface. Alternatively, pressure caused by glacial push could have caused water expulsion from the lake sediment, and the highly-concentrated flows suddenly froze as they emeerged to the surface and dried. Thus they could have been preserved by early cementation and later burrial with sediment. According to visible unidirectional or centrifugal distribution of these accumulation tongues, it is possible that all described processes took a role.

Figure 5.134. Linguoidal sediment forms occurring within younger glacilacustrine calcarenite unit may be rill mark accumulation tongues. Both photographs show unidirectional tongues, and arrows indicate flow direction. The largest tongues (photo bellow) are about 1 m long and 20-30 cm wide. Photos taken in 2010.

Slika 5.134. Jezičaste sedimentne forme, koje se nalaze unutar mlađeg kalkarenitnog intervala glacilakustrinskih naslaga, mogu biti tragovi otjecanja vode. Obje fotografije prikazuju jednosmjerne jezičaste forme, a strelice pokazuju smjer toka. Najveći nađeni jezici (slika dole) su oko 1 m dugački i 20-30 cm široki. Snimljeno 2010.

Figure 5.135. Larger dropstones occur in rippled calcarenite interval. When settling on the lake bottom dropstones compressed and slightly deformed the bottom soft sediment, producing typical dropstone structure.

Slika 5.135. Veći ledenjački utrusci nalaze se i u kalkarenitnom intervalu. Prilikom pada na jezersko dno proizveli su udubljenja i djelomično deformirali mekani sediment dna, te stvorili tipičnu teksturu ledenjačkog utruska.

In the same zone also occur larger dropstones with typical dropstone structure (Benn & Evans, 2010) (Fig. 5.135.). Some are faceted and rounded, and some are of irregular shape, but all span in diameter between 10 - 30 cm.

Seline Section

Glacilacustrine sediments represent minor part of the Seline profile, and occur at four different stratigraphic horizons in alternation with glacideltaic conglomerates (Fig. 5.168.) described in Chapter 5.3.4. The first two intervals are very thin (less than 1 m), and there occur yellowish-colored massive to cross-laminated siltites to very fine calcarenites, as seen in photo 2 in Figure 5.168. Plant debris, exceptionally fossil leafs, occur in these sediments. In the third interval, about 5 m thick, lacustrine sediments, represented by radish siltites and calcarenites with current and wave ripples in the upper part, occur in alternation with cross-bedded deltaic conglomerates (photo 2, Fig. 5.168.).

The thickest interval (ca 10 m) of lacustrine deposits is the last, the youngest in logged succession. It is represented by varved-like calcisiltite and very fine calcarenite lithofacies, with common dropstones (Fig. 5.129. C). There is one even younger interval (ca 5 m thick), not shown in the log, which is represented by massive calcisiltite. In both intervals, the sediments are light brown, ochre to whitish colored. They contain abundant fossil plant debris, rarely fossil leafs, and molds of fossil gastropods and bivalves (Figs. 3.78., 3.79., 5.136.). Many gastropod molds are deformed and compressed horizontally or vertically (Fig. 5.136. E, F), at least 3 to 4 times their normal dimension. Shells of both gastropods and bivalves were completely dissolved, thus it was not possible to determine species except for the bivalves that belong to the genus *Unio*, a common fresh-water bivalve. The dropstones (Fig. 5.130.) occur throughout the varved-like unit indicating proximity to a glacier.

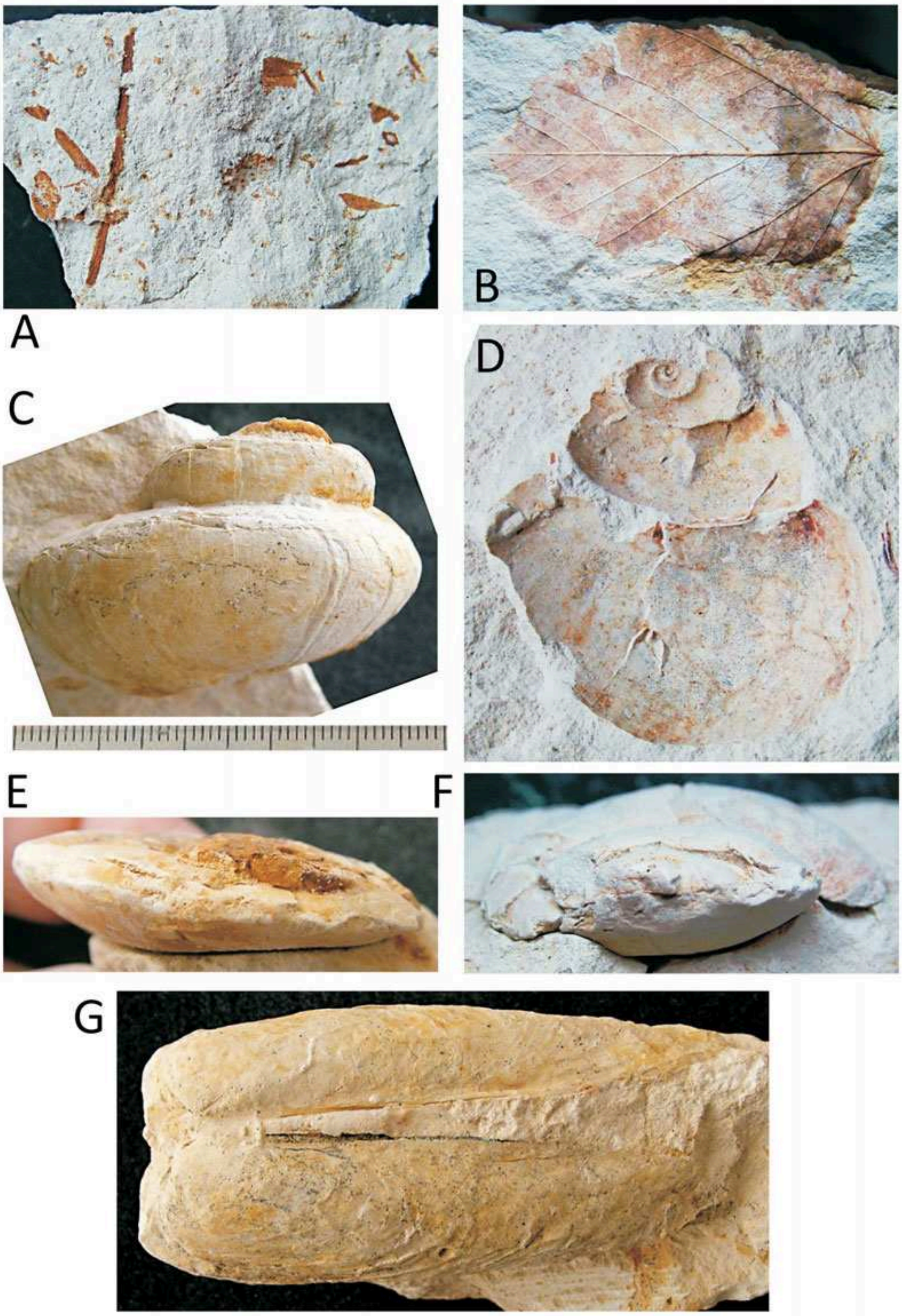


Figure 5.136. Remnants of fossil biota found in glacilacustrine siltites at the Seline section. A - fossil plant debris dispersed in sediment; B - well preserved fossil leaf of a deciduous tree; C - gastropod mold, undeformed, with poorly preserved relief of the missing shell; D - poorly preserved gastropod mold; E - gastropod mold, compressed along vertical axis and deformed; F - gastropod mold, compressed along horizontal axis and partly crushed; G - mold of a bivalve, freshwater genus *Unio*. Scale is 5 cm for all images.

Slika 5.136. Ostaci fossilnih organizama u glacilakustrinskim siltitima na profilu Seline. A - trunje fosilnog bilja raspršeno u sedimentu; B - dobro očuvani fosilni list listopadnog drveta; C - kamena jezgra puževe kućice, nedeformirana, sa slabo sačuvanom teksturom otopljene ljušture; D - slabo očuvana kamena jezgra puževe kućice; E - kamena jezgra puževe kućice, komprimirana po vertikalnoj osi; F - kamena jezgra puževe kućice, komprimirana po horizontalnoj osi, djelomično zdrobljena; G - kamena jezgra slatkovodne školjke roda *Unio*. Mjerilo je 5 cm za sve slike.

Glacilacustrine sediments of the Ždrilo section are typical varved sediments (varvite lithofacies, Fig. 5.116.), composed of alternating clay and silt laminae representing annual winter-summer cyclicity. Estimated thickness of sediments is about 20 m. They are steeply inclined (Fig. 5.138. left) and tectonized due to glacial push, which is also indicated by frequent small scale soft-sediment deformations (Fig. 5.138. right).

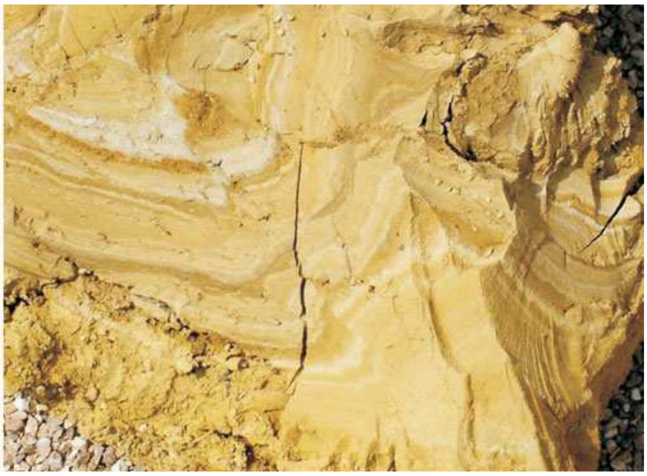


Figure 5.137. Varvites at Ždrilo section are inclined at 30° - 70° and dip southeastwards, as shown on the left. Frequent small-scale deformations like faults and folds are visible in the sediment (right), produced during glacial advance. Photos taken in 2011.

Slika 5.137. Varvit kod Ždrila je ustrmljen, nagnut 30° - 70° prema jugoistoku (slika lijevo). Česte su deformacije malih dimenzija, rasjedi i bore (slika desno) stvorene u vremenu napredovanja leda. Snimljeno 2011.

Varve sedimentology was not studied yet in detail, but numerous plant macro fossils were collected and determined by Adžić (2012a, b), who also studied varves in 1 m thick interval.

Adžić (2012) determined the fossil leaves and found prevailance of *Taxodium* sp. Leafs of *Quercus* sp. and *Zelkova* sp. were also frequent, and those of *Castanea* sp., *Acer* sp., *Fagus* sp., *Liquidambar* cf. *europea*, *Buxus* sp., *Pterocarya* sp., *Tilia* sp., and fruit of *Ulmus* sp. were rare.

Figure 5.137. Fossil leaf of *Taxodium* sp. Scale is 5 cm.

Slika 5.137. Fosilni list *Taxodium* sp. Mjerilo je 5 cm.

Varves, both dark and light-coloured laminae contain well preserved juvenile and mature ostracods. Hajek-Tadesse (personal communication, 2010) determined the following species: *Scottia* *pseudobrowniana* Kempf, *Candona neglecta* Sars, *Eucypris* sp. (juvenile form), *Pseudocandona hartwigi* (G.W. Müuller) and *Mixtacandona*?, *Paralimnocythere* cf. *psammophila* (Flössner).

Although not yet studied in detail, the Ždrilo varvites represent a significant input to paleoenvironmental reconstruction presented and discussed in Chapter 7.

Karin Section

Glacilacustrine sediments exposed near Karin are laminated calcisiltites (marls) to fine-grained calcarenites. Their visible thickness along the coast is only 30 - 60 cm, because the base is not exposed. These marls are light yellowish-grey colored, with fine parallel varved-like lamination , similar to Ždrilo but not so contrasting and distinct (Fig. 5.138.). Ostracods are common in marls. The glacilacustrine sediments were eroded and deformed within a shearing zone formed by an advancing glacier (Fig. 5.138.).

Figure 5.138. Glacilacustrine laminated calcisiltites (marls) exposed at Karin sea beach. The marls are weathered and easily break into platy clasts. There is erosional contact with overlaying till visible in upper left side. Flame structure is visible on the right side, which formed in shear zone produced by advancing glacier overriding the lacustrine sediments. Photo taken in 2008.

Slika 5.138. Glacilakustrinski laminirani kalcisiltiti (lapori) otkriveni uz Karinsku plažu. Lapori su trošni i lako se drobe u pločaste klaste. U gornjem dijelu se vidi erozijski kontakt s tilom. Desno se uočavaju "plamene" teksture u zoni smicanja koja je nastala zbog napredovanja ledenjaka preko jezerskih naslaga. Snimljeno 2008.

Laterally occurs an isolated erosional remnant of lacustrine calcisiltites and calcarenites that consist of several laminated packages shown in Figure 5.139.. These deposits have been postdepositionally eroded and overgrown by tuffa that built a large bioherm, of which only a small potion is preserved (Fig. 5.140.). The age of tuffa is not known, but could originate from the last or one of the previous interglacial periods.

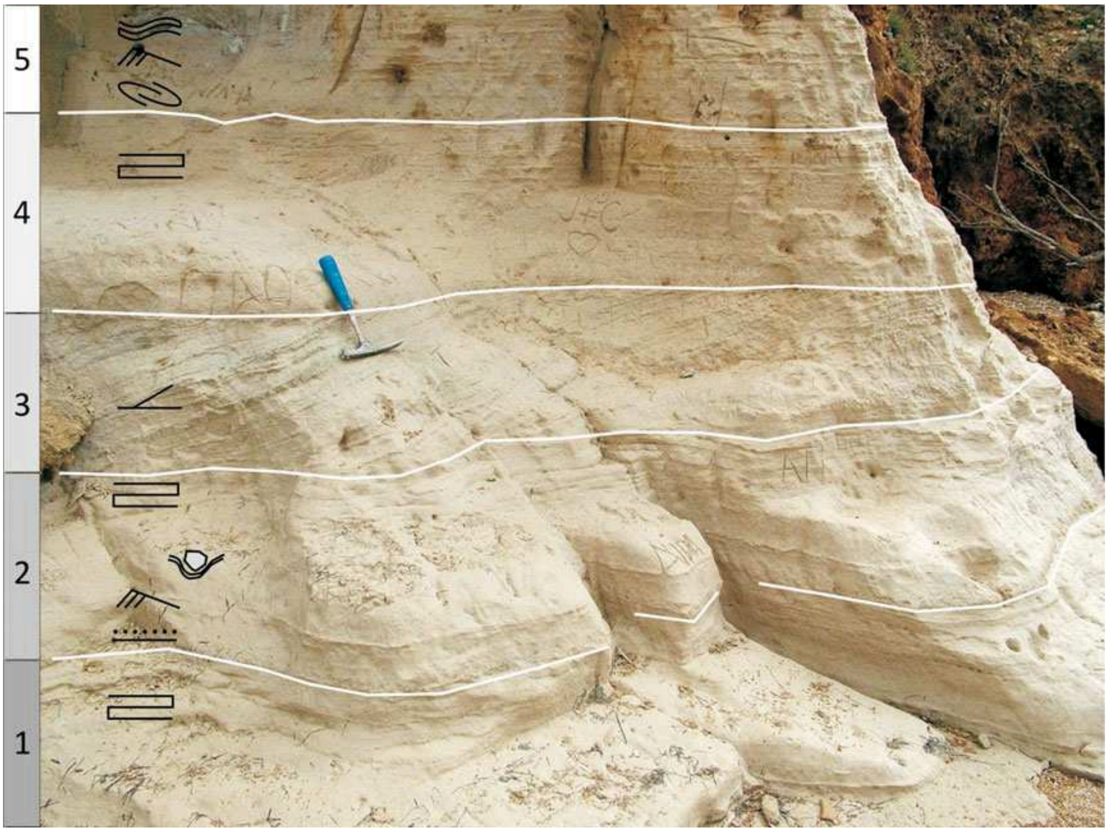


Figure 5.139. Glacilacustrine sediments at Karin Sea coast, which occur laterally to the other outcrop (Fig. 5.138.). This succession consists of five sediment packages separated by clear boundaries: 1 - horizontally bedded (marls) composed of laminated and massive layers; 2 - a package consisting of graded fine-grained gravel bed with ripples, massive marl layer with dropstones, and parallel laminated siltite; 3 - planar-cross bedded package that consists of alternation of calcisiltite and 1 - 3 cm thick calcarenite beds; 4 - vaguely to clearly horizontally laminated calcisiltite and fine-grained calcarenites; 5 - a composite package with synsedimentary soft-sediment deformations and wave and current ripples in the lower part, and parallel horizontal to wavy laminated siltites and fine arenites. The sedimentary characteristics indicate proximal depositional environment of the paleolake. Photo taken in 2008.

Slika 5.139. Glacilakustrinski sedimenti na obali Karinskog mora, nalaze se lateralno od izdanka prikazanog na slici 5.138. Ovaj sedimentni slijed se sastoji od pet paketa osvojenih jasnim granicama: 1 - horizontalno uslojeni lapori sastavljeni od paralelno laminiranih i masivnih slojeva; 2 - paket koji se sastoji od graduiranog kalkarenita sa strujnim riplovima, masivnog calcisiltita s ledenjačkim utruscima, i paralelno laminiranog siltita; 3 - planarno koso uslojeni interval se sastoji od izmjene calcisiltita i 1 - 3 cm debelih slojeva sitnozrnatog kalkarenita; 4 - nejasno do dobro vodoravno laminirani kalcisiltit i sitnozrnati kalkarenit; 5 - kompleksni paket u čijem se donjem dijelu nalazi interval sa sinsedimentacijskim deformacijama mekanog sedimenta, zatim interval sa strujnim riplovima, te vodoravno do valovito laminirani siltit i sitni arenit u gornjem dijelu. Karakteristike sedimenata ukazuju na proksimalni taložni okoliš paleojezera. Snimljeno 2008.

Correlation with previously described lacustrine unit is not clear. There only calcisiltites occur, while at second location there are more calcarenite interbeds, which clearly indicate more proximal depositional zone, indicated also by a planar cross bedded package 5 (Fig. 5.139.) that are small Gilbert-type delta forsets. Proximal deposition is also indicated by graded and current-rippled bed (package 2) deposited from a turbidity current, as well as a massive bed with dropstones within package 2. This unit is more likely equivalent to the upper younger interval of the glacilacustrine sequence at the Novigrad section.

Figure 5.140. Erosional remnant of a large tuffa bioherm/barrier that grew over erosional surface of the glacilacustrine sediments. Photo taken in 2008.

Slika 5.140. Erozijski ostatak velike sedrene barijere koja je rasla na erodiranoj podlozi izgrađenoj od glacilakustrinskih sedimenata. Snimljeno 2008.

5.2.2.3. GLACIFLUVIAL AND DELTAIC SEDIMENTS

Glacifluvial sediments are well represented within the study area, with good quality outcrops. Since they are not basically different from fluvial deposits elaborated by Miall (1984), sediments were studied in such context, but interpreted as glacifluvial on the basis of facies associations. In the study area glacifluvial sediments occur in association with glacilacustrine and glacial deposits. Along the Baška valley on the Krk Island (loc. 1) and Pag channel of the Pag Island (loc. 3, 4, 5), they built extensive kame-terraces (see Chpt. 6.1.2.), while at Novigrad (loc. 11) they are remnants of a large meandering river that existed in a periglacial environment (see Chpt. 7). On the southwest of the Novigrad Sea extensively occur glacifluvial outwash sediments (sandars), which can only be observed in sand and gravel pits (loc. 12). The most representative sections of glacifluvial deposits are located on the Krk Island (1), on the Pag Island (3 and 5) and at the Novigrad Sea coast (11).

Glacifluvial sequences are usually represented with calcarenites and calcirudetes, herein more often called sands and gravels, regarding only the grain size. Composition of sands and gravels is generally carbonate, ca 90 %, and rare noncarbonate particles will be discussed in relation to a particular study site.

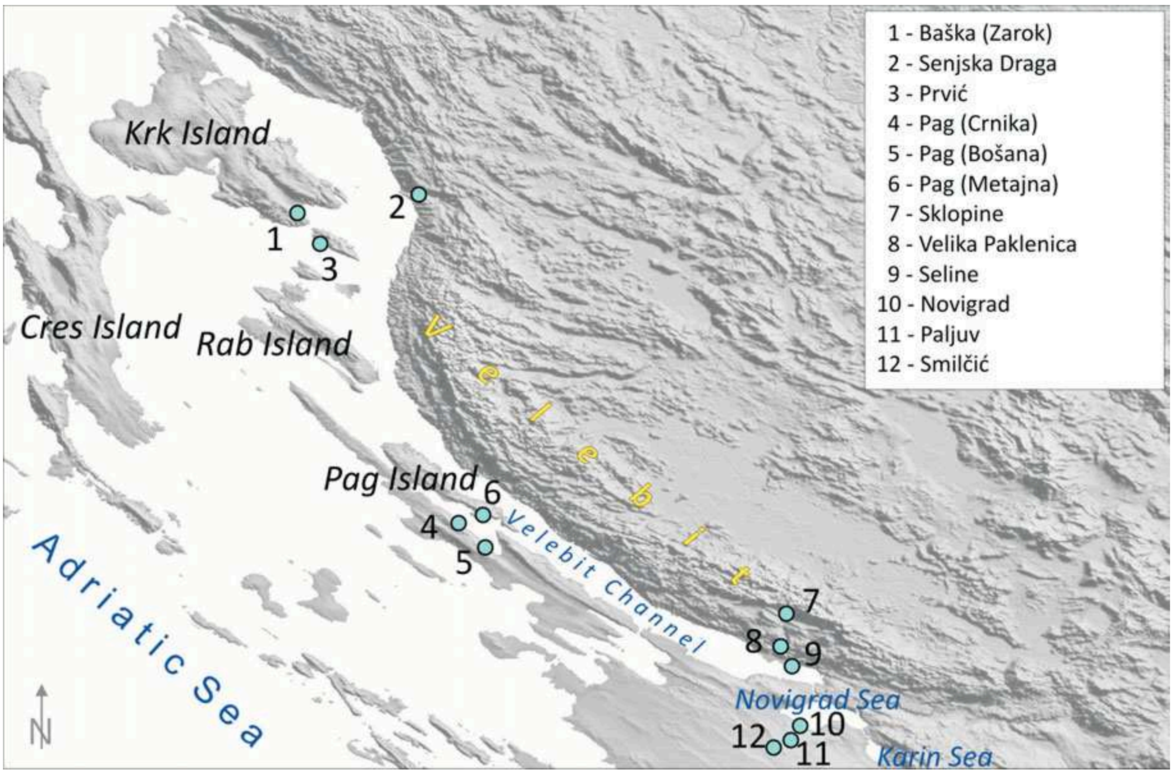


Figure 5.141. Locations with glacifluvial sediments in the study region Kvarner (1 - 6), South Velebit (7 - 9), and Northern Dalmatia (10 - 12). Location 9 marks glacideltaic sediments.

Figure 5.141. Lokacije s glacifluvijalnim sedimentima u istražnoj regiji Kvarner (1 - 6), Južni Velebit (7 - 9), i Sjeverna Dalmacija (10 - 12). Lokacija 9 označava glacideltaične sedimente.

Sediments interpreted as glacideltaic are well exposed along the coast of Seline (Figs. 3.59. and 3.77.), and compose a thick sequence of matrix- to clast-supported conglomerates. The conglomerates contain many clasts with glacial striae, which is the main indication of glacigenic origin.

Glacifluvial sediments of Baška - Zarok Section

The location and context of the Baška - Zarok section is described in Chapter 3.1.1.6.. The sediments were field-analyzed by 9 detailed logs (Fig. 3.15.). Based on the detail outcrop mapping and the log correlation, it was possible to differentiate 14 allostratigraphic units (Appx. 5/2-A and 5/2-B), which are described and discussed as follows, except for the first two allo-units that are marine in origin.

Allostratigraphic units 1 and 2

The unit 1 is a marine transgressive unit that lays at pronounced angular unconformity above the tectonically steepened Eocene clastics (Paleogene ”flysch”). It consist of matrix- to clast-supported conglomerate and breccia, occurring along the transgressive contact (Fig. i in Appendix 5/2-B). This bouldery gravel is stratified with imbricated clasts, and upwards are interbedded with sand and fine gravel.

The unit 2 are shallow marine cross-bedded and rippled calarenites (Fig. j in Appendix 5/2-B) with Pleistocene benthic foraminifers *Astrononion stelligerum, Bulimina fusiformis, Bucella frigida, Elphidium Crispum, and Ammonia beccarii*. These two units compose a transgressive fining-upward sedimentary sequence (logs K-Ba-I, -II and -III in Appendix 5/2-A), ranging from shoreline to shallow shelf deposits.

Allostratigraphic unit 3

Boundary of the unit is distinctly erosional, and the unit is incised into older marine units 1 and 2. The depth of erosion is up to 6 m. Characteristic are narrow asymmetrical channels 1 - 3 m deep and filled with a matrix- to clast-supported diamict (log K-Ba-I in Appx. 5/2-A, photo b in Appendix 5/2-B), which mark the beginning of sedimentation of this unit. This massive diamict is a matrix-supported breccia, in which the matrix is sand size debris and clasts are 14 cm in average, the largest 32 cm. Clasts are subangular to subrounded, variable in shape, and predominantly carbonate in composition. The imbricated clast indicate SE-wards paleotransport. The rest of the unit 3 consists of stratified fine gravel (fine-grained calcirudites) and coarse poorly sorted gravel (coarse-grained calcirudites) in form of shallow channel fill deposits. Average grain size spans between 12 and 18 cm, and size of the largest clasts is 18 - 38 cm. The unit 3 is 10 m thick at most.

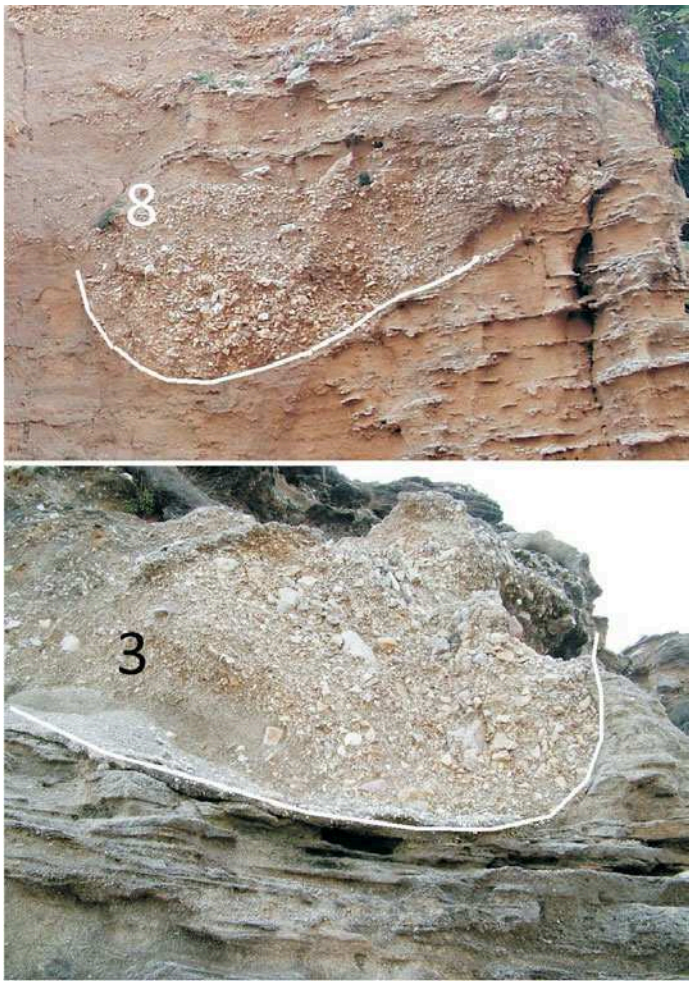


Figure 5.142. Asymmetrical channels in cross-sections perpendicular to paleo-flow direction. The channels of the allo-unit 3 and the allo-unit 8 are deeply incised in deposits of older units. They are filled with matrix- to clast-supported diamict with poorly sorted, angular to subrounded limestone debris. At the axcessible location of unit 3, the clast imbrication was measured yielding SSE-wards paleotransport direction. Photos taken in 2007.

Slika 5.142. Asimetrični kanali u presjeku okomitom na smjer paleotoka. Kanali alo-jedinice 3 i jedinice 8 su duboko usječeni u naslage starije jedinice. Ispunjeni su diamiktom sa muljnom do zrnskom potporom, sa slabo sortiranim uglatim do slabo zaobljenim vapnenačkim detritusom. Na pristupačnoj lokaciji izmjerene su imbrikacije klasta u kanalu jedinice 3, te je dobiven smjer paleotransporta prema JJI. Snimljeno 2007.

Allostratigraphic unit 4

The unit 4 is up to 5 m thick and consists of matrix-supported dimicts, cross stratified gravels, and thin clayey sand interbeds (log K-Ba-I, Appx. 5/2-A). The average clast size spans from 3,5 to 19 cm, and the largest between 7 and 32 cm. The unit is gently incised into the unit 3 along a planar erosional boundary.

Allostratigraphic unit 5

The unit 5 is incised into older units 1 to 4. The erosional boundary is sharp and straight, inclined 15°, and visible depth of erosion is nearly 10 m. The boundary is marked with locally uneroded paleosol (5A; log K-Ba-III in Appendix 5/2-A) that consists of radish-brown silty to sandy clay with limestone concretions, 10 - 20 cm thick (Fig. 5.143.). The silt to very-fine sand fraction contains black glass shards, probably of volcanic origin.

The unit generally consist of cross to planar stratified calcarenites and calcirudites, locally interbedded with coarse-grained calcirudites, which form either poorly sorted lenticular beds or compose planar cross-stratified channel-fill deposits as shown in the right section of the log K-Ba-III (Appx. 5/2-A).

Figure 5.143. Paleosol 5A between allo-units 2 and 5 is a redish-brown silty to sandy clay with granular carbonate concretions ("caliche") and scarce glass shards. Photo taken in 2007.

Slika 5.143. Paleosol (fosilno tlo) 5A između alo-jedinica 2 i 5 je crvenkasto smeđa siltozna do slabo pjeskovita glina sa sitnim karbonatnim konkrecijama (kaliče) i staklene krhotine. Snimljeno 2007.

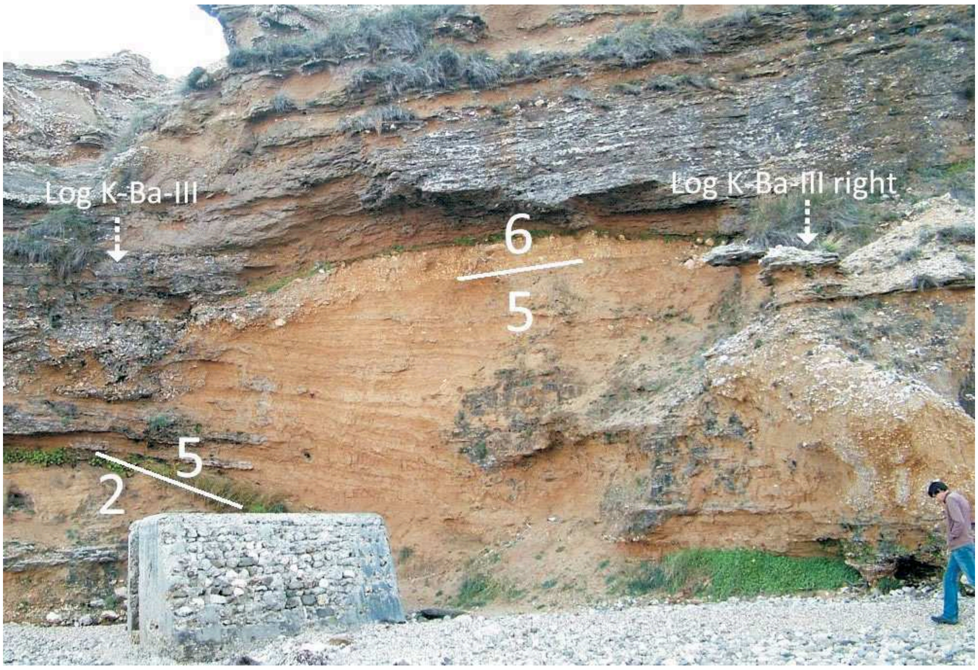


Figure 5.144. Detail of the allo-unit 5 with visible contacts with marine allo-unit 2 and the younger allo-unit 6. Positions of sediment logs in Appendix 5/2-A are marked with arrows. Long cross to planar bedding of arenites and rudites is clear in the middle at fresh outcrop surface. Photo taken in 2007.

Slika 5.144. Detalj allo-jedinice 5 s vidljivim kontaktima s marinskom alo-jedinicom 2 i mlađom alo-jedinicom 6. Označen je pozicija snimljenih sedimentoloških stupova prikazanih u Prilogu 5/2-A. Duga kosa do horizontalna stratifikacija arenita i rudita je dobro vidljiva u središnjem dijelu svježeg izdanka. Snimljeno 2007.

Allostratigraphic unit 6

The unit 6 is characterized with very irregular erosional surface sharacterized by channels deeply cutting into older units 2 and 5. The deposition begun with accumulation of matrix-supported diamicts (matrix-supported coarse-grained calcirudites) that filled channels. These are poorly sorted sediments with angular to subangular limestone debris of 19 cm average size (the largest 28 cm) and sandy matrix. Similar sediment with highly erosional bottom surface exists also in the upper section of the unit (logs K-Ba-IV and -V, Appx. 5/2-A). The clast size in this younger sediment is 23 cm in average, and the largest is 35 cm, but varies laterally. Both are diamicts deposited from subaerial debris flows. The sediment succession between these diamicts consists of planar horizontally- stratified arenites and rudites. The rudites occur as cobble and bolder stringers. Locally occur planar cross-stratified rudites in shallow channels of braided streams.

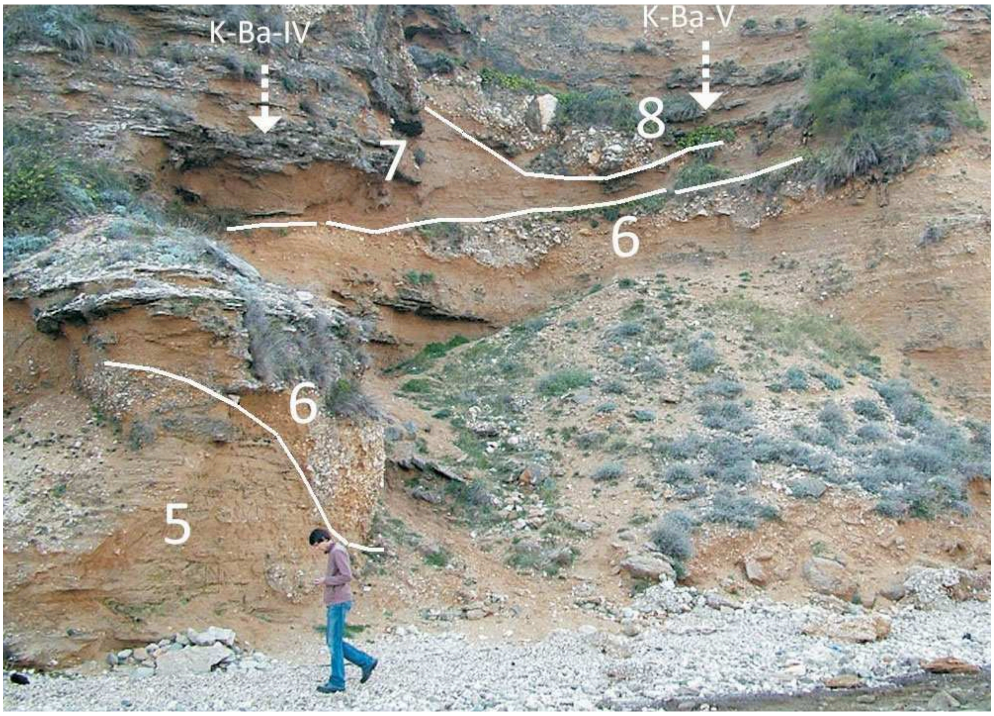


Figure 5.145. Detail view of the allo-unit 6. Deep erosional channel that cut into unit 5 filled with diamict, is visible on the left. The younger diamict with erosional lower surface is visible bellow the boundary with allo-unit 7. Arrows mark locations of detailed logs presented in Appendix 5/2-A. Photo taken in 2007.

Slika 5.145. Detalj alo-jedinice 6. Kanal ispunjen diamiktom i duboko urezan u jedinicu 5 vidi se na lijevoj strani. Mlađi diamikt s erozijskom donjom plohom vidi se ispod granice s alo-jedinicom 7. Označena su mjesta sedimentoloških stupova prikazanih u Prilogu 5/2-A. Snimljeno 2007.

Allostratigraphic unit 7

Unit 7 is an extensive sedimentary body with rather smooth and low inclined erosional boundary (Appendix 5/2-B). The depth of erosion is about 8 m, if looking from the left to right end of exposure. The larger left section of the unit (logs K-Ba-I to K-Ba-VI, Appx. 5/2-A) is represented with fine-grained and coarse-grained calcirudites, calcarenites and diamicts (commonly breccia), while the much smaller right section is predominantly represented with coarse-grained calcarenites and infrequent interbeds of calcirudite.

Part of the unit 7, exposed in the NW gravel pit seen in figure e (Appx. 5/2-B) , represents the youngest part of a fluvial channel fill, composed of coarse-grained calcarenites interbedded with thin layers or stringers of fine-grained calcirudite. The sediments are gently planar cross stratified. The bottom boundary is not exposed in this part. The middle section of the unit 7, as seen in figure d (Appx. 5/2-B), represents flood basin deposits. The sediments are coarse-grained calcarenites interbedded with fine-grained calcirudites and silty clay (figure l, Appendix 5/2-B). These thin bedded, 1 - 10 cm, sediments gently dipp SSE-wards at angle up to 28°. The type of bedding varies from planar parallel to wavy parallel. Layers can be massive and normally or inversely graded, wavy parallel laminated or planar cross laminated. The contacts are commonly erosional and wavy. Small scale sediment deformations, like slide folds and convolutions are frequent.

The left section of the unit 7, as seen in figure c (Appx. 5/2-B) is represented subordinate ly with coarse-grained calcarenites horizontally or cross stratified, and predominantly with coarse-grained calcirudites (bouldery gravel), as visible in logs K-Ba-I and -II (Appendix 5/2-A). The grain size of rudites spans from 6 to 38 cm, and the largest clasts are 9 - 40 cm. In this section unit 7 shows erosive character expressed with channelized diamicts (coarse-grained calcirudites) as shown in logs K-Ba-I and -II.

Figure 5.146. Andezite granule, 8 mm in diameter, frequent in sand and gravel deposits of allo-unit 7.

Slika 5.146. Zrno andezita promjera 8 mm. Vrlo su česta u kalkarenitima i kalciruditima alo-jedinice 7.

Specific of the allo-unit 7 are andezite granules which occur throughout the sediment (Fig. 5.146.) and an erratic boulder found burried in unit 7 (Fig. 5.147.). According to present geological setting, the andezite debris originates from Senjska Draga on the Velebit meeting mainland and thus was brought by glaciers. The erratic boulder (Eocene Foraminiferal Limestone) can originate from the Krk Island, but its size implies transport by ice as the only possible way. It also documents glacigenic origin of sediments.

Figure 5.147. Erratic boulder uncovered in the allo-unit 7. Photo taken in 2007.

Slika 5.147. Eratički blok u allo-jedinici 7, otkiven erozijom. Snimljeno 2007.

Allostratigraphic unit 8

The unit 8 is the smallest in exposed volume and hardly accessible for direct observations. It is represented with matrix-supported diamicts and stratified calcarenites and fine-grained calcirudites (log K-Ba-V, Appx. 5/2-A). Its erosional boundary is irregular, and visible depth of erosion is about 1 m. Large rounded boulders are found in the diamict, one meter-sized (Fig. 5.148.) and one ca 1,5 m diameter (log K-Ba-V). They indicate vicinity of a glacier.

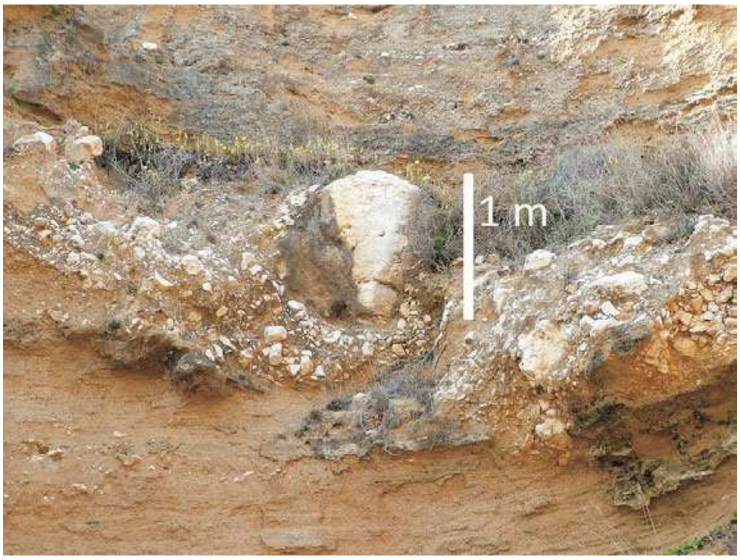


Figure 5.148. Ice-faceted and polished boulder in diamict of the allo-unit 8. Photo taken in 2007.

Slika 5.148. Ledom fasetirani i polirani metarski blok u diamiktu alo-jedinice 8. Snimljeno 2007.

Allostratigraphic unit 9

The unit 9 was reconstructed by outcrop mapping and analysis of photographs, because it was not accessible due to vertical cliffs. It is of similar structure as the allo-unit 7, as seen in photo d in Appendix 5/2-B. It pinches out between allo-units 7, 8 and 13. As visible in Figure 5.149.A, sediments are fine-grained calcirudites to coarse-grained calcarenites, with scattered pebbles and cobbles.

Allostratigraphic unit 10

The unit 10 is exposed in the NW gravel pit (photo d, Appx. 5/2-B), and its small portion is visible on the coastal side (frame d, Appx. 5(2-B). Its erosional boundary is planar and gently inclined on the left side, and flattens rightwards.

There is well visible paleosol 10A between the units 9 and 13 exposed on the left side (Fig. 5.149. A), and between units 7 and 10 exposed in the right pit (Fig. 5.149. B). The paleosol 10A is characterized by burned horizon with abundant charcoal particles and presence of glass shards. The charcoal particles are burned plant debris up to 1 cm size. Locally also occur lime granules and pebbles produced by burning of limestone clasts, which is prisumably a wildfire product. The dating of charcoal particles by 14C in 1990 yielded the age older than 40 ka BP which was the limit of the method.

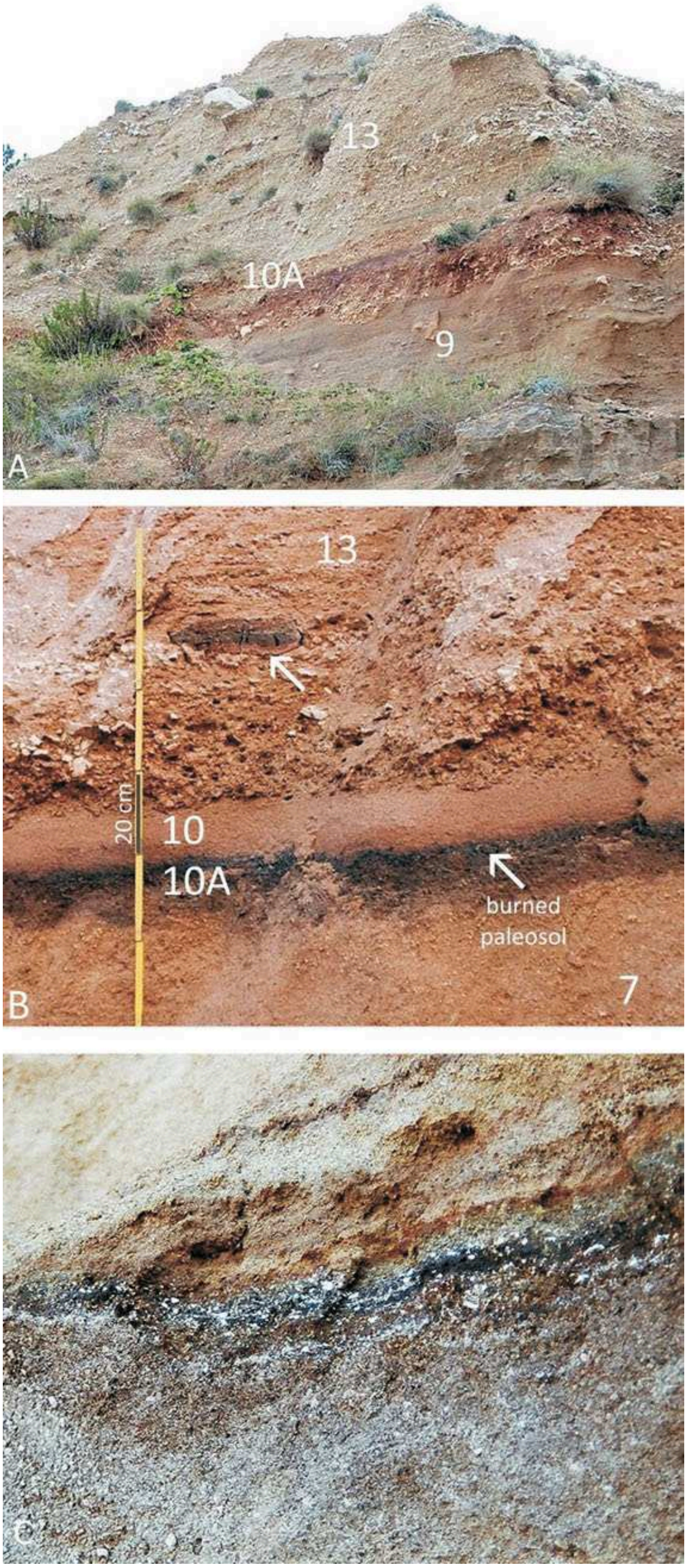


Figure 5.149. Paleosol 10A visible between the allo-units 9 and 13 (A) and between 7 and 10 (B). Figures A and C show coarse-grained substrate of this paleosol, which is a layer of coarse rudite debris mixed with earthy matrix (A) or fine-grained massive calcirudite (C). In figure B the substrate is massive coarse sand to fine gravel. Characteristic black burned horizon is variably pronounced, depending on amount of charcoal. The burned horizon locally contains abundant lime granules seen as white fragments in figure C. The paleosol was being eroded during sedimentation of the allo-unit 13, as indicated by paleosol clasts in the overlaying diamict of unit 13 (pointed by arrow in figure B). Photos taken in 2007.

Slika 5.149. Paleosol 10A vidi se između alo-jedinica 9 i 13 (A) i između alo-jedinica 7 i 10 (B). Na slikama A i C vidi se krupnozrnata podloga paleosola; ruditni detritus u pjeskovito-zemljastoj osnovi (A) i masivni sitnozrnati kalcirudit (C). Na slici B vidi se u podlozi masivni kalkarenit do kalcirudit. Karakteristični crni nagoreni horizont se različito ističe, ovisno o količini ugljenih čestica. Nagoreni horizont mjestimice sadrži brojne klaste vapna koji se vide kao bijeli fragmenti na slici C. Paleosol je djelomično erodiran tijekom taloženja jedinice 13, što se vidi po klastu paleosola u diamiktu jedinice 13 (označen strelicom na slici B). Snimljeno 2007.

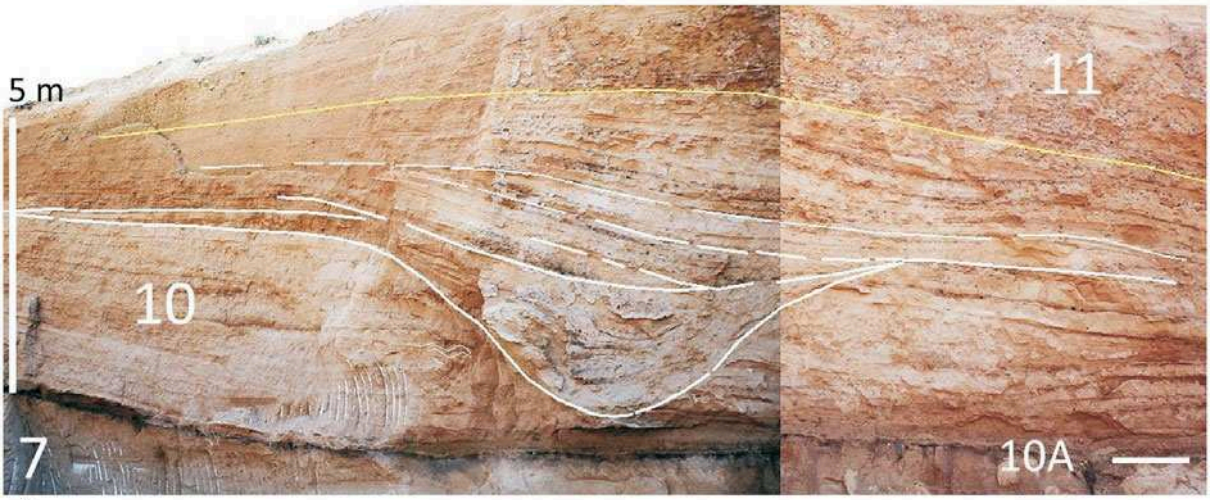
Sediments of the unit 10 are represented by coarsegrained calcarenites interbedded with finegrained calcirudites (logs K-Ba-VII, -VIII and -IX in Appendix 5/2-A), and coarse-grained calcirudites interbedded with fine-grained calcarenites and clayey silts occurring only at the base of the unit (logs K-Ba-VIII, Appendix 5/2-A).

Within the first interval, as described in Figure 5.151., the sediments are gently inclined following the slope of erosional boundary. Sands and gravels (coarse-grained calcarenites and fine-grained calcirudites) are wavy to parallel bedded. There occur isolated intervals of cross-bedded calcarenites which resemble small shallow channels (Fig. 5.151. B). In general, coarser-grained beds are clast-supported and the structure is open-work, while finer-grained beds are commonly normally graded to silt or silty clay. Massive rudite layers have slightly irregular and erosive lower bedding surface with occasional loading structure. Some can be interpreted as a-b-c turbidites (interval 3 in Fig. 5.152.). Synsedimentary soft-sediment deformations are frequent in sediments bellow the channel (Fig. 5.152.) and are variable. There are massive arenite beds with silty clay intraclasts and folds, where intraclasts in some beds are densely stacked and imbricated downslope. There are convoluted or folded silty clay beds, commonly torn apart. There occur deformed packages of calcarenites with silt/clay laminae. Some structures as of interval 4 in Figure 5.152. look very similar to cryoturbation, which would not be unlikely considering the overall periglacial environment.

The second interval are trough bedded sands and gravels (Fig. 5.151.) that represent a fluvial channel fill, which is incised at least 2 m deep.

The overlaying sediments of the third interval are more-or-less planar cross bedded sands and gravels. In the upper part of this interval there are planar parallel bedded or wavy parallel bedded sands and gravels.

The depositional sequence of the unit 10 began with filling up depressions, presumably a flood basin, as indicated by horizontal planar bedding of rudites, arenites and silts (Fig. 151. B). Later predominated deposition on the flood plain slopes, indicated by frequent sinsedimentary soft-sediment deformations (Fig. 152.). The openwork calcirudites were deposited from grain flows, graded beds with occasional ripples and convolutions deposited from small turbidity currents, while clay silt or silty clay laminae and thin beds were deposited from flooding water suspension. Soft-sediment deformations may be interpreted as slope failure occurring by flood events. They could have been generated by traction currents at sudden stronger floods, and even occasional seismic events can be hypothesized. At larger scale, extensive planar graded beds indicate deposition by sheet floods, and cross bedded gravels indicate deposition in braided streams on a flood plain, both common in a periglacial environment as elaborated by Brodzikowsky & van Loon (1991).



A

B

Figure 5.151. Cross section through the allo-unit 10 photographed in 2007 (A) and few years later (B) shows different positions of the channel cross-section of fluvial channel-fill sediments. The unit 10 was deposited over partially eroded paleosol 10A developed above unit 7, and visible as the black horizon. First interval of unit-10 sediments are planar parallel and wavy parallel bedded alternating with coarse-grained calcarenites and fine-grained calcirudites which represent sheet-flood deposits. Channel-fill trough-bedded sediments in the middle display an incised fluvial channel that cut through sediments of the flood plain. The overlaying sands and gravels are low-angle long planar cross-bedded, indicating growth and lateral migration of the channel. The youngest interval are planar parallel bedded sands and gravels. Photo taken in 2005.

Slika 5.151. Detalj alo-jedinice 10 predstavljene sedimentima riječno-kanalske ispune. Jedinica 10 istaložena je preko djelomično erodiranog paleosola 10A razvijenog na jedinici 7, a vidi se kao crni horizont. Prvi interval jedinice 10 čine sedimenti planarno paralelno ili valovito paralelno uslojeni krupnozrnati kalkareniti i sitnozrnati kalciruditi, koji predstavljaju sediment poplavne ravnice. Koritasto uslojen sediment kanalske ispune vidljiv u sredini, predstavlja riječni kanal usječen u poplavne sedimente. Slijed izmjena kalkarenita i kalkrudita s dugom planarnom kosom slojevitošću, koja ukazuje na širenje i lateralno seljenje kanala. Najmlađi interval čine ravno paralelno uslojeni kalkareniti i kalciruditi. Snimljeno 2005.

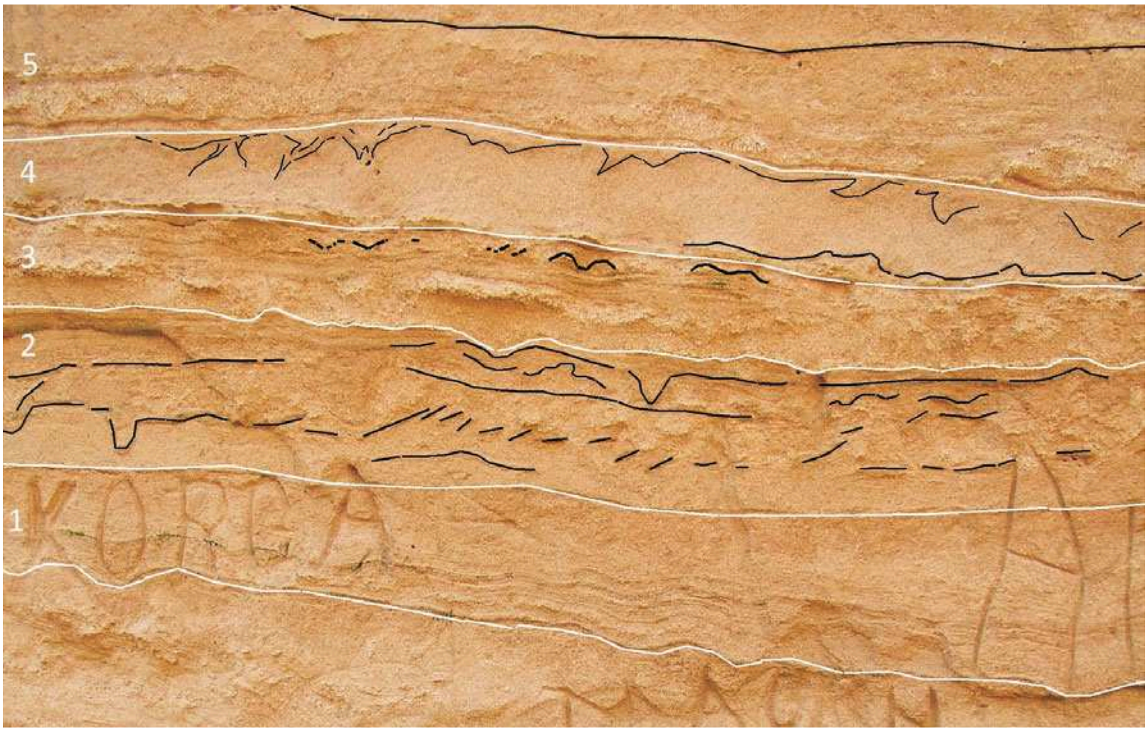


Figure 5.152. Picture shows about 1 m sediments displaying common characteristics of the unit 10, with laminated, massive and deformed calcarenite to fine-grained calcirudite beds. White lines divide undisturbed from disturbed intervals, and black lines follow silty clay laminae or thin beds. Interval 1 is wavy parallel bedded calcarenite/rudite topped with massive arenite bed with poorly visible convolutions. Interval 2 consists of a massive arenite bed bellow and highly disturbed package above with many silty clay intraclast. Interval 3 has characteristics of a Ta-b-c turbidite. Interval 4 is massive calcarenite with cryoturbation-like structures at the top. Interval 5 is coarser-grained and appears massive. Photo taken in 2007.

Slika 5.152. Prikazan je približno 1 m sedimenata, karakterističan za jedinicu 10, s laminiranim, masivnim i deformiranim slojevima kalkarenita do sitnozrnatih kalcirudita. Bijele linije odvajaju neporemećene i poremećene intervale, a crne prate lamine ili tanke slojeve siltozne gline. U intervalu 1 su u donjem dijelu valovito paralelno uslojeni areniti i runditi, a u gornjem je masivni arenitni sloj s nejasnom konvolucijskom teksturom. U intervalu 2 se vidi masivni sloj pri dnu i izrazito poremećeni paket iznad s brojnim intraklastima siltozne gline. Interval 3 ima karakteristike turbiditnog sloja Ta-b-c. Interval 4 je masivni arenit s teksturom poput krioturbacija. Interval 5 je krupnije zrnat, masivnog izgleda. Snimljeno 2007.

Allostratigraphic unit 11

The unit 11 is exposed in the right NW gravel pit as presented in Figure e of Appendix 5/2-B. Its smooth and inclined erosional boundary is visible on the left. The sediments are very similar to those of the allo-unit 10 but display frequent sinsedimentary deformations within the whole succession. Three erosional sessions are recognized within the unit, distincted by erosional surfaces nearly jointing on the left side, which bound three sets of planar cross bedded sediments representing a large point-bar complex of a meandering river, as shown in reconstruction in Appendix 5/2-B. Changes in bedding strike and dip indicate shifting of the river channel. Angular unconformity between the two sets is shown in figure n in the Appendix 5/2-B.

The first set of planar to slightly wavy cross beds is composed of fine-grained calcirudites of granule size. Younger two sets (figure n) are coarse-grained calcarenites with thin interbeds of fine-grained calcirudite. The calcirudite layers are grain-supported with open-work texture, while

Figure 5.153. Detail view of disturbed silty clay thin beds. Photo taken in 2007.

Slika 5.153. Detalj sedimenta s poremećenim tankim slojevima siltozne gline. Snimljeno 2007.

arenites are massive and usually with low percentage of silty clay matrix, inversely graded, or compose parallel laminated intervals with thin clay or silty clay laminae. The third and the thickes set, extends to the right end of the gravel pit (fig. e in Appx. 5/2-B). It is characterized by frequent intervals of deformed beds (log K-Ba-9, Appx. 5/2-A). The deformations are easily noticed by following the silty clay or clay laminae to thin beds (Fig. 5.153.). They can as well be interpreted as seismites, usually characterized by small-scale faulting and folding and are bounded with undisturbed sediments. Though, further detailed investigation of structures is needed.

Allostratigraphic units 12, 13 and 14

The allo-units 12, 13 and 14 were not logged, nor studied in detail, but are reconstructed only by outcrop mapping due to inaccessible cliffs. However, it was possible to reach level of the paleosol 12A (figure H, Appendix 5/2-B).

The unit 12 has rather smooth and undulating erosional boundary. In general, the sediments are calcarenites and calcirudites. Shallow and small channel-fill deposits and cross-bed-sets are visible indicating the deposition in braided streams. The unit 13 partially overlays the units 9, 10, 11 and 13 (Appx. 5/2-B) at gently inclined and planar erosional boundary. As visible in Figure 5.149. A it consists of stratified coarse-grained rudites, predominantly cobble size, with finer-grained interbeds and common occurrence of variously sized boulders. The sediments presumably compose part of an alluvial fan. The unit 14 is poorly preserved and visible at the very end of the gravel pit in thickness of a few meters. Its cross section shows horizontally parallel bedded gravels. Its lower boundary is strait horizontal and marked by the youngest thin paleosol.

The paleosol 12 A has the same characteristics as the paleosol 10A. It is partially preserved and was burnt. The charcoal of burnt plant debris, was dated by 14C in 1990 and yielded age 28 ka BP.

Therefore, it was presumably developed before the LGM. Probably a wildfire burnt vegetated land at the time of LGM. Black glass shards found in this paleosol may indicate on increased volcanic activity that could have been connected with LGM.

Interpretation of the allo-units

Presented allostratigraphic units and there arrangement indicate a complex depositional history, with different intensity of erosional periods or events. Deep erosional incisions into paleorelief, occasionally terraced, developed generally by erosional processes that could have shaped alluvial valleys. The erosional events of lower intensity formed shallow and medium-size channels which laterally migrated and were conduits for subaerial debris flows that filled the channels.

The graphic reconstruction and interpretation is given in Appendix 5/2-B. It is clearly visible that all allostratigraphic units are bounded by more-or-less pronounced erosional surfaces marking either onset of outwash and flooding, fluvial incision and deposition, or non-depositional period and soil formation like 5A, 10A, 12A and 14A. Their tentative chronostratigraphy is given in Figure 5.154. The paleosols represents stratigraphic gaps, and presumably developed in warm periods of MIS-15e, MIS-11 or -9e, and Eemian interglacial MIS-5e. The Paleosol 14A assumably marks Pleistocene-Holocene boundary. The chronostratigraphic attribution of the allo-units should be taken only as approxima until further dating of the sediments becomes available. The attributed sedimentary cycles are interpreted as follows:

The erosional boundary of the allo-unit 3 marks the onset of the first glacifluvial depositional cycle represented by the allo-units 3 and 4. After Early Pleistocene marine transgression (allo-units 1 and 2) of unknown duration, deposited terrestrial clastics of the allo-unit 3. Because of still insufficient data and lacking age of the allo-unit 3, it is just assumed that a stratigraphic gap between the units 2 and 3 represents the Early/Middle Pleistocene boundary. The sediment characteristics of the allo-unit 3 show that there must have existed an exuberant source of debris and high energy subaerial environment for transport and deposition. The paleotransport directions (Fig. 5.155.), channel orientation and low gradient, and deep erosion of the chute channel deposits indicate that the source could not have been in nearby slopes seen today, but only in a proglacial zone of a temperate glacier (see discussion in Chpt. 7). This is also indicated by the characteristics of the following younger allo-unit 4 that consists of braided stream sediments, which are commonly deposited in proglacial outwash plains. The erosional character of this unit is not distinct, meaning that ice was receding slowly and meltwaters had lower energy, thus formed braided water flows and deposited finer debris - sands and fine gravels. Thereafter, it is possible that the units 3 and 4 represent one of the glacial periods within “Cromerian complex” recognized in NW Europe.

The pronounced erosional boundary of the allo-unit 5 is marked by the paleosol 5A, a radish-brown clay probably accumulated in fresh-water ponds formed on paleorelief before deposition of unit 5 characterized by fluvial deposition.

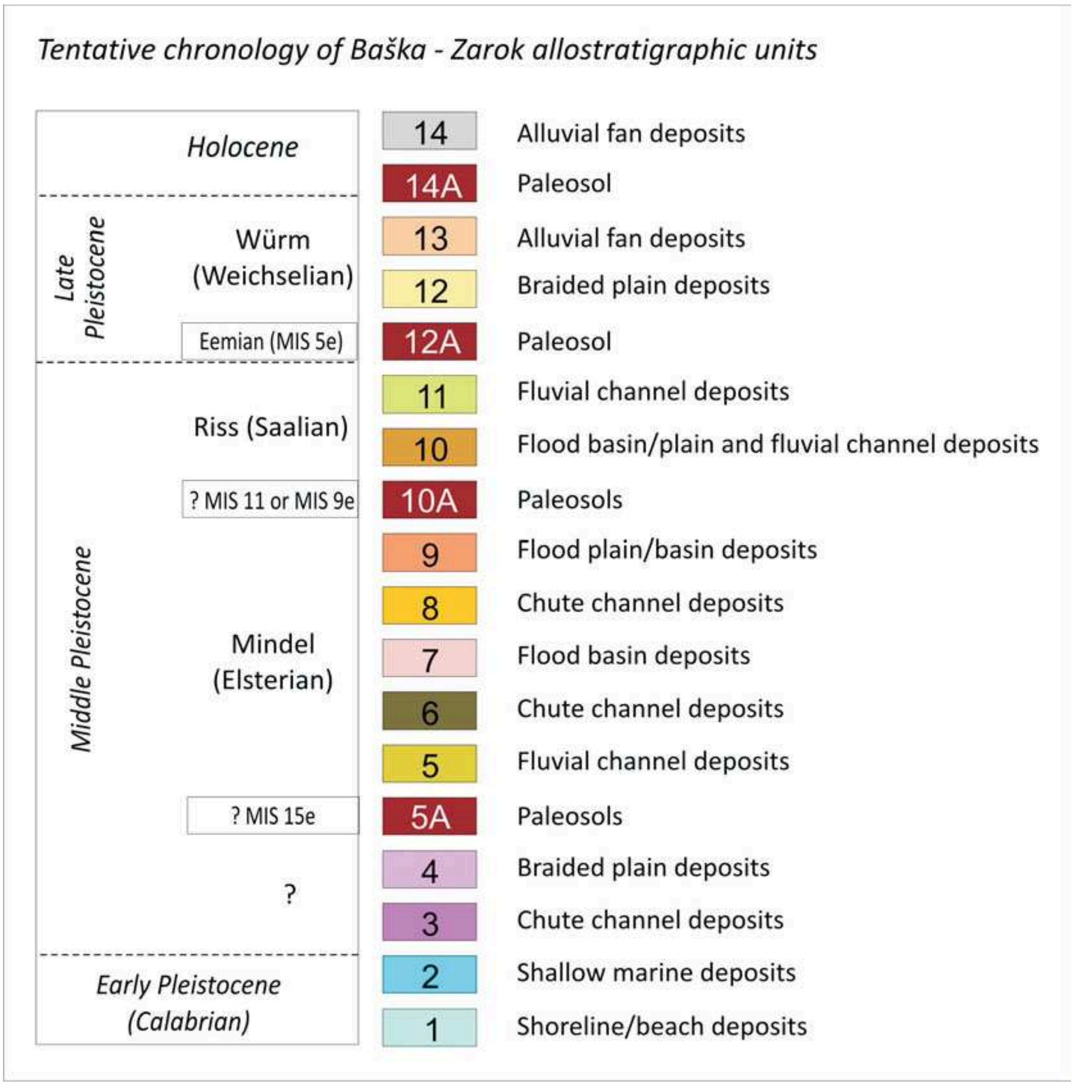


Figure 5.154. Tentative chronostratigraphy of the allostratigraphic units of Baška - Zarok section on Krk Island.
Slika 5.154. Pretpostavljena kronostratigrafija allostratigrafskih jedinica na profilu Baška - Zarok na otoku Krku.

The allo-units 6, 7, 8 and 9 are recognized as two glacial outwash cycles consisting of chute channel phase and flood plane/basin phase. The allo-unit 6 is dominated by chute channel sediments incised in older allo-units 2 and 5, thus characterized by a pronounced erosional boundary. Not so erosive and extensively preserved allo-unit 7, dominated by sheet-flood deposits (alternation of gravel, sand and clay) may indicate seasonal flooding by thawing glacier, which can be compared to varve sedimentation. Its connection with glacial environment is indicated by buried erratic boulder found in this unit (Fig. 5.145.). These sediments also contain frequent granules of andezite, that are considered exotic clasts, because their only source is in upper part of the Senjska Draga on the Velebit Mt. (opposite of Baška, Fig. 3.2.), and far inland near Fužinski Benkovac. This implies that Krk Island must have been part of the mainland during the time of deposition. Another phase of intensive erosion

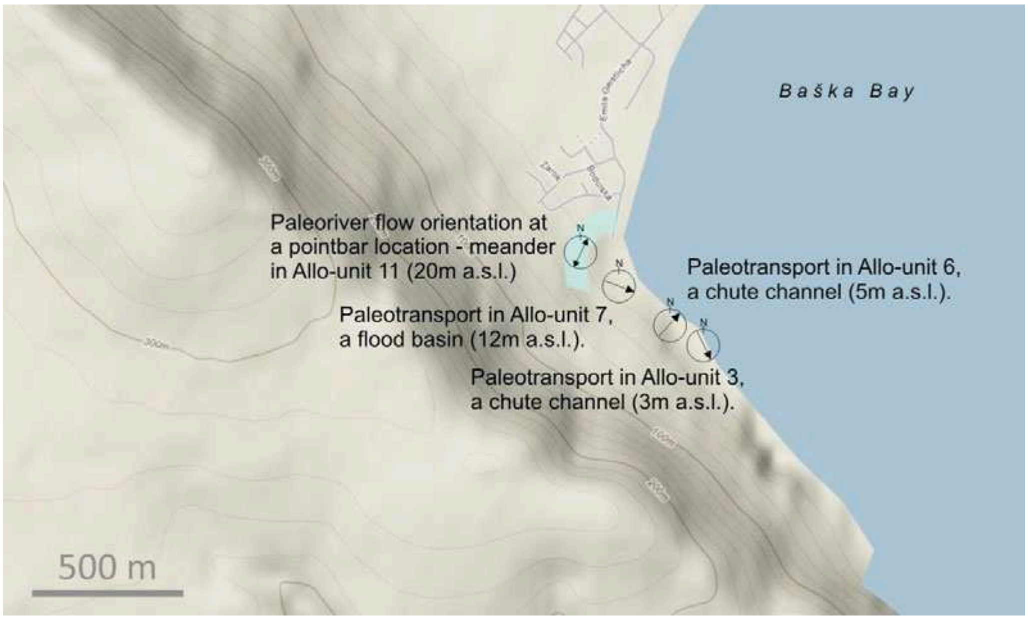


Figure 5.155. Reconstructed paleotransports within particular allostratigraphic units of Baška - Zarok section.
Slika 5.155. Rekonstruirani paleotransporti unutar pojedinih alostratigrafskih jedinica profila Baška - Zarok.

via chute channels is marked by allo-unit 8, which is minor in preserved volume compared to other units. A large faceted and polished boulder found in allo-unit 8 (Fig. 5.148.) indicates proximity of a glacier. The overlaying sediments of allo-unit 9 represent another outwash phase with sheet-flood sediments. The sediment complex is attributed to rather extensive Mindel (Elsterian) glaciation period interpreted on the basis of Ždrilo and Paklenica moraines that were dated to minimal age of 350 ka BP and attributed to the Elsterian glaciation (MIS 12).

The well developed and burnt paleosol 10A is tentatively attributed to the Middle Pleistocene warm period MIS-11 or MIS-9e, but likely represents Riss-Mindel interglacial, the Holsteinian when wildfires could have occurred.

The allo-units 10 and 11 represent a phase of deposition from flood basin to fluvial channel. Thick point-bar and channel fill sediments indicate existence of a large meandering river with wide and deep channel. Paleotransports show nearly N-S orientation of the preserved section of one meander (Fig. 5.155.). This cycle assumably represents a deglaciation phase and the last Middle Pleistocene glacial and postglacial period.

The depositional cycle represented by allo-units 12 and 13 is attributed to the Late Pleistocene documented by 14C age of the paleosol 12A (dated to 28 ka BP) that corresponds to LGM. That means that a wildfire occurred at that time, but the soil developed earlier, presumably during the Eemian interglacial and was eroded by deposition of the unit 12.

The allo-unit 12 represents a periglacial outwash plain and deposition in braided river which restrained with end of the last glacial. The allo-unit 13 documents another phase of erosion and resedimentation of older clastics in an alluvial fan.

The youngest paleosol 14A presumably marks the Pleistocene - Holocene boundary. The last allo-unit 14 is the youngest alluvial fan poorly preserved.

This complex glacifluvial succession is related to glacial deposits of Krk Island described in previous Chapter 5.2. and in later Chapter 6.

Glacifluvial sediments of Pag - Bošana Section

The sediments studied at the Pag - Bošana section (Fig. 3.40.) and interpreted as glacifluvial, compose an erosional remnant of extensive kame-terrace (see also Chapter 6). This terrace extends along the southwest slope and coast of the Pag Channel, and glacifluvial deposits are exposed in several gravel pits along the coastal route. The sediments were logged at two sides of the large gravel pit Bošana, and within this younger succession 7 allostratigraphic units were differentiated (Appendix 5/3). The bedrock is a rather steep slope of the Cretaceous limestone range striking NW-SE with highest peaks about 500 m. The gravel pit is very large and highly exploited, so study of complete succession was imposible.

The allo-units at Bošana are represented by coarse-grained calcarenites and fine-grained calcarenites, commonly granule to pebble-size. Rarely occur cobble layers or isolated boulders, or cobble stringers. Some intervals are more sandy or silty to clayey arenites. Sorting is generally medium to good, and clast roundness varies from angular to medium. The gravel beds are massive, normally or inversely graded. Bedding varies from horizontal parallel, planar cross, trough-cross and wavy parallel, commonly with sharp contacts. Clast composition is predominantly carbonate, spanning from ca 60 - 90 %. The cementation is very poor, usually only superficial. Silty and clayey beds are more compact. Sands and gravels are predominantly grain-supported with open-work structure, massive and inverse- or normal-graded.

An older section was logged on the NW side (right) side of the pit, and is presented by sediment log K(P)-23-L3 (Appendix 5/3). The unit 1 are trough-cross bedded gravels laying directly on the limestone bedrock. The following unit 2 are parallel-stratified sands and gravels of an alluvial origin, which laterally become horizontally and wavy bedded. They were partially deposited over bedrock, so the contact beds are composed of calcirudite with angular cobbles and small boulders sourcing from the bedrock. Above the unit 2 occurs a paleosol horizon as an erosional remnant, and pinches out. It contains lime granules and charcoal that was dated by 14C in 1990, which provided the age older than 40 ka BP. Thus, it is considered contemporaneous to the paleosol 10A at the Baška - Zarok section.

The unit 3 an alluvial sequence consisting of wavy parallel stratified coarse-grained arenite coarsening to a thin gravel layer, and laminated silty clay interval. This silty clay layer extends laterally and borders with a younger unit 4. The unit 4 consists of horizontally stratified coarse-grained calcarenites.

The younger sediments of the allo-units 5, 6 and 7 were logged on SE (left) side of the pit and are presented with sediment logs K(P)-23-L1 and -L2. The unit 5 consists of planar-cross beds of coarse-grained calcarenite and calcirudite of granule size with abundant pebble-size debris, interpreted as a shallow-water Gilbert-type delta (Fig. 5.156.). The unit 6 is represented by ca 5 m thick planar cross-bedded coarse-grained calcarenite interbedded with fine gravel, and fining-upward to predominantly coarse-grained calcarenites. The contact with unit 5 is erosional with irregular gutter casts (Fig. 5.157.). The long planar-cross beds of the unit 6 are exposed in a longitudinal cross-section of a fluvial channel (Appendix 5/3). The unit 7 is 6 - 7 m thick sediment succession consisting of cross and trough-cross bedded fine-grained calcirudites deposited in a braided shallow river, recognized

Figure 5.156. Sediments of the unit 5. Gilbert-type delta forsets with a very poorly preservet top-set. These are planar-cross bedded calcirudites and calcarenites. Bottom-set is not exposed. Photo taken in 2005.

Slika 5.156. Sedimenti jedinice 5. Srednji dio (forseti) delta Gilbertovog tipa, izgrađen of ravno koso uslojenih kalkrudita i kalkarenita. Donji dio delte nije otkriven, dok je gornji (topset) neznatno sačuvan. Snimljeno 2005.

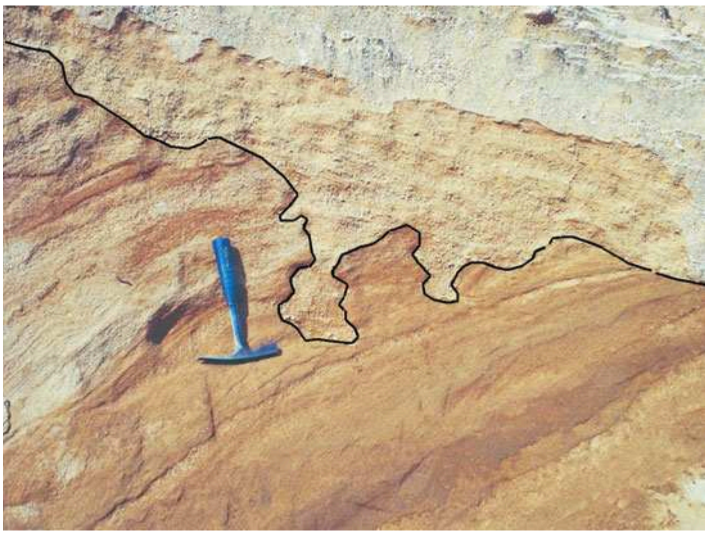


Figure 5.157. Erosional contact between the allo-units 11 and 12 shown in log K(P)-23-L1 (Appx. 5/3). These very irregular gutters must have formed by turbulent water streams during subaerial exposure of unconsolidated cross bedded sediments bellow. They were later filled with sediments deposited from grain flows and debris flows at beginning of deposition of the unit 12.

Slika 5.157. Erozijski kontakt između alo-jedinica 11 i 12 prikazanih na stupu K(P)-23-L1 (Pr. 5/3). Ovi nepravilni erozijski žlijebovi najvjerojatnije su nastali djelovanjem vodenih tokova na površini nevezanog sedimenta. Kasnije su ipunjeni sedimentima zrskih i muljnih tokova na početku taloženja jedinice 12.

from multiple small channel-fill deposits, gravel bars, cross-bedded bars and sheet fine-gravel layers (logs K(P)-23-L1 and -L2, Appendix 5/3).

As previously mentioned, there are several newer gravel pits at Crnika coast between Pag and Novalja. The one was studied in 1990-es (Fig. 5.158.), and others were photo-documented (Fig. 5.159.). The sediments are of same characteristics as in Bošana, but finer-grained, so there predominantly occur horizontally stratified calcarenites. The calcarenite beds are horizontally parallel-laminated or planar cross laminated. The grains in arenite fraction are rounded, while medium angular to subrounded in rare rudite layers. Locally there occur lenticular thin interbeds of sandy/silty clay.

In the newer gravel pit close to the Crnika section, occur equivalent sediments, and two allo-units are recognized (Fig. 5.159.), which possibly correlate with units of Crnika, but the paleosol horizon is not visible. The unit 1 is represented with a package of accretion point-bar deposits, which formed in a large meandering river channel. The structure of the point-bar with multiple channel erosion indicate lateral migration of the channel. As the channel shifted, flood plain sediments deposited above the point-bar, characterized by gently inclined parallel stratification (Figs. 5.158. and 5.159.). The unit 2 is coarse-grained, consisting of stratified calcirudites and calcarenites, probably representing a braided plane deposits as well as the top unit of the Crnika section.

The paleosol horizon occurring between two horizontally stratified units at the Crnika section (Fig. 5.158.) also has burnt surface and contains charcoal and lime granules, the same as the paleosol horizon at the Bošana section. Both are considered time-equivalent to the paleosol 10A of Baška - Zarok section on Krk Island, and accordingly a tentative chronostratigraphy is given in Figure 5.160.

Figure 5.158. Crnika section in a gravel pit studied in 1991. The paleosol equivalent to 10A paleosol at Baška - Zarok section occurs between two sand-gravel units.

Slika 5.158. Profil Crnika u iskopu šljunka istraživan 1991. Između dvije pješčano-šljunčane jedinice nalazi se paleosol istovjetan paleosolu 10A na profilu Baška - Zarok.

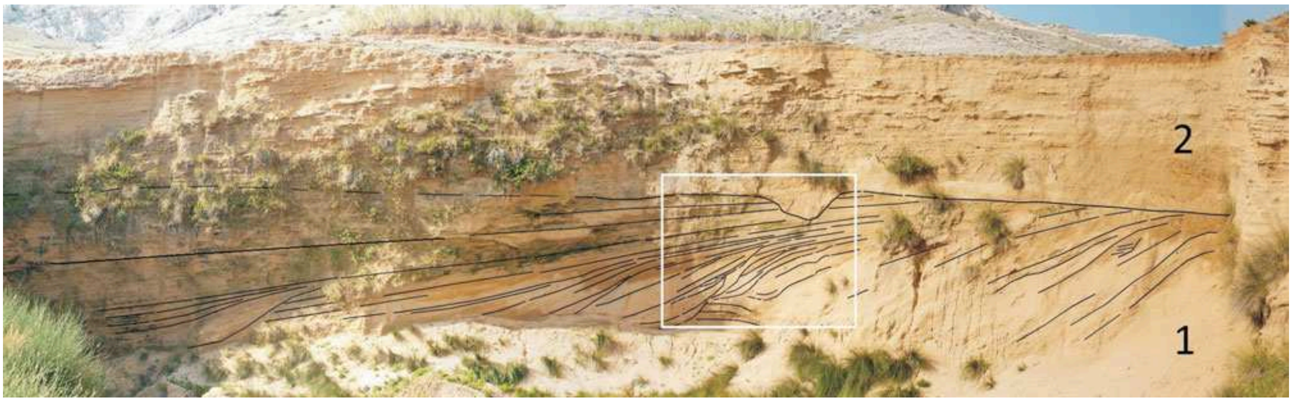


Figure 5.159. Newer gravel pit near Crnika section photodocumented in 2006. Two units are recognizeable: unit 1 is a cross section through a meander point bar deposits and sheet flood deposits, and unit 2 are braided plane sediments. Scene in the box shows erosive contact and a chute channel. 5.160. Photo taken in 2005.

Slika 5.159. Noviji kop u blizini profila Crnika fotodokumentiran 2006. Razaznaju se dvije jedinice: jedinica 1 prikazuje presjek kroz naslage meandarskog spruda i naslage poplavne ravnice, dok jedinica 2 prikazuje presjek kroz naslage prepletene ravnice. Detalj u okviru ukazuje na erozivni kontakt i urezani kanal. Snimljeno 2005.

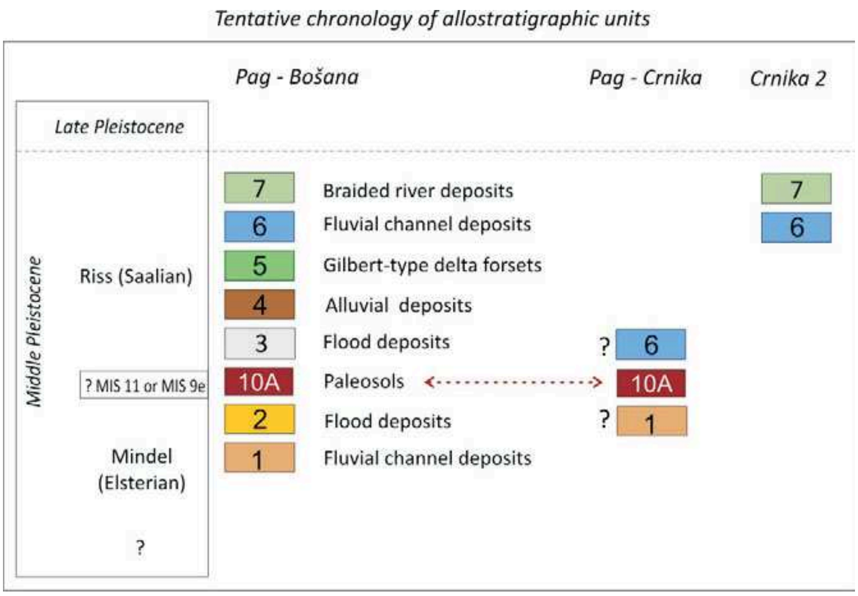


Figure 5.160. Tentative chronostratigraphy and correlation of the allostratigraphic units of Pag and Crnika sections, presuming that the dated paleosol is time equivalent to the paleosol 10A of Baška section.

Slika 5.160. Pretpostavljena kronostratigrafija allo-jedinica profila Pag i Crnika, uz pretpostavku da datirani paleosol vremenski odgovara paleosolu 10A na profilu Baška.

Glacifluvial sediments of Novigrad Section

Glacifluvial sediments studied at the Novigrad section are intensivelly eroded, and isolated sections are preserved along the coastal Novigrad section. Though, fluvial channels and large point-bars are distinctive. The cross-sections through fluvial channels vary from perpendicular to tangential. The widest channel is 22 m across (Fig. 5.163.). The orientation of the point-bar bed-sets indicate on low-sinuosity meandering river, which migrated laterally with flow direction along the present day coastline. They are defined as the allostratigraphic unit 6 shown in Figures 5.169/1 and 5.169/2.

Fluvial incision eroded different previously deposited glacigenic sediments of Novigrad, including a pedogenic complex. Thus fluvial sediments are in contact with glacilacustrine sediments, older subglacial tills or glacial outwash sediments. The visible depth of erosion is up to 3 m.

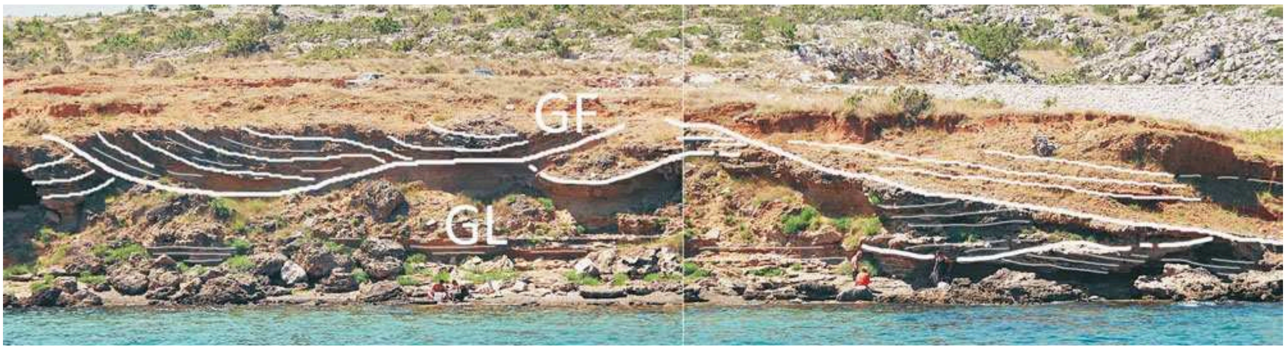


Fig. 5.161. Glacifluvial sequence (GF) of the Novigrad section. Fluvial channel are incised into glacilacustrine unit visible in the middle. The sediments are trough-cross and planar-cross bedded calcarenites and calcirudites. Superimposed channels are result of lateral migration of the channel. See reconstruction in Fig. 5.169/2, Section Novigrad 6-7. Photo taken in 2003.

Slika 5.161. Glacifluvijalne naslage na profilu Novigrad. Riječni kanali su usječeni u glacilakustrinske naslage vidljive u sredini (GL). Sedimenti su koritasto-koso i ravno-koso uslojeni kalkareniti i kalkruditi. Superponirani kanali rezultat su seljenja kanala. Vidi rekonstrukciju na Slici 5.169/2, profil Novigrad 6-7. Snimljeno 2003.

The fluvial sequence of the Novigrad section is represented with planar-cross bedded and trough-cross bedded coarse-grained calcarenites and fine-grained calcirudites; the angle of bedding depends on the orientation of the cross-section in relation to the channel strike. Pebble and cobble size gravel occurs locally composing channel-lag conglomerates (Fig. 5.162.), as shown in Log N-4 (Appendix 5/1). The channel cross-beds, often tangetial and striking parallel to channel flow orintation, are interpreted as point-bars (Fig. 5.162.).

Figure 5.162. Tangential cross-section of fluvial channel deposits. Planar-cross beds of a point-bar seen on the left become horizontal beds on the right indicating strike of the channel. A conglomerate layer at the bottom represents channel-lag sediment. Photo taken in 2006.

Slika 5.162. Tangencijalni presjek kroz naslage riječnog kanala. Ravni kosi slojevi spruda na lijevoj strani postaju horizontalni na desnoj strani zbog dugačijeg presjeka, te ukazuju na orjentaciju kanala. Konglomeratni sloj pri dnu je kanalski *lag*-sediment. Snimljeno 2006.

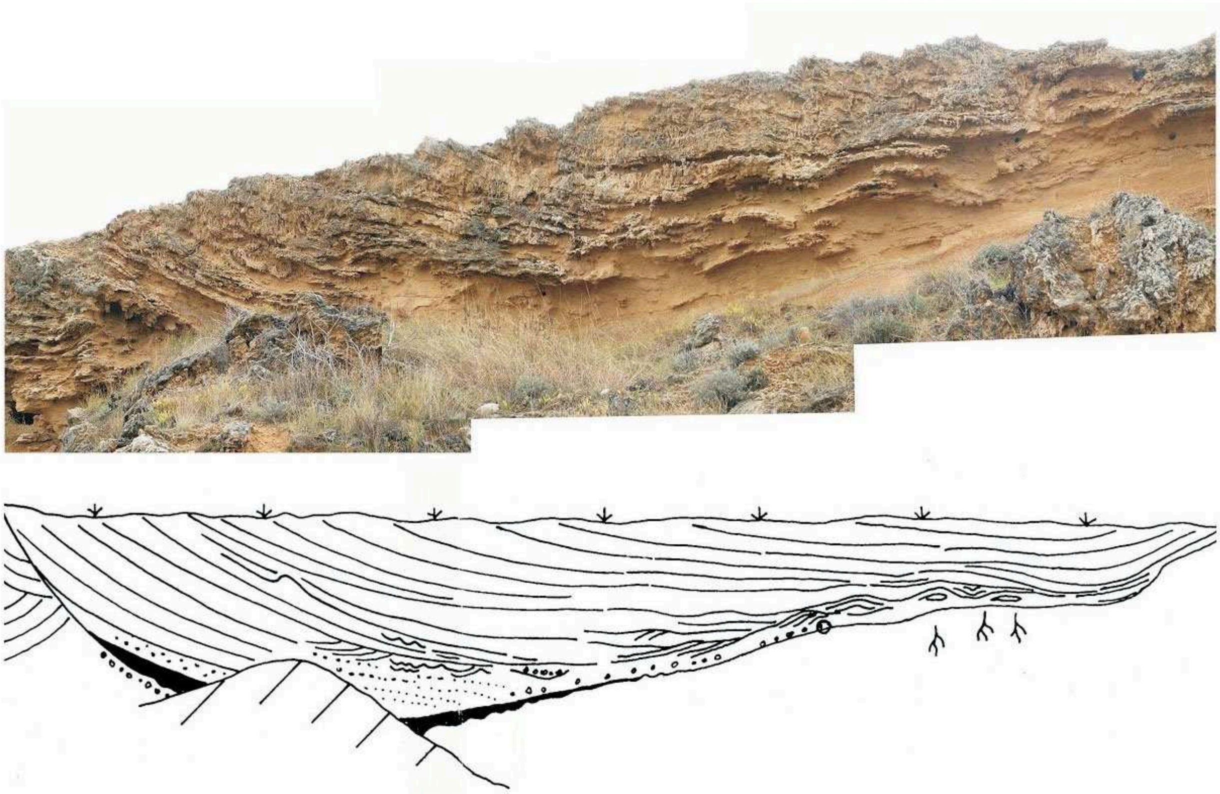


Figure 5.163. Fluvial channel fill deposits in cross-section nearly perpendicular to the channel strike. Accretion of point-bar cross-beds gradually filled the channel. Selective cementation of coarser-grained layers made good distinction of bedding. Vertical rhizoconcretions are common on nearly each horizon. Detail of the cross-section is shown in Figure 5.164. Photo taken in 2006.

Slika 5.163. Sedimentna ispuna riječnog kanala u presjeku približno okomitom na pružanje kanala. Akrecijom kosih slojeva spruda kanal je postupno ispunjen sedimentom. Selektivna cementacija zahvatila je krupnije-zrnate slojeve, te omogućila njihovo jasno raspoznavanje. Vertikalne rizokongrecije vrlo su česte u gotovo svim horizontima. Detalj profila prikazan je na Slici 5.164. Snimljeno 2006.

The channel fill deposits exposed in a profile cross-cutting the channel (Fig. 5.163.) give better insight in sediment structures. This cross-section shows 22 m wide assimetrical channel, which was filled by lateral accretion of the point-bar. The upper portion of the channel sediments is eroded, so initially, the channel was much deeper and wider. At bottom of sigmoidal cross-beds occur small sand dunes perpendicular to their strike as shown in line-art in Figure 5.163.. Abundant rhizoconcretions indicate that point-bar was frequently vegetated. At the channel bottom there is a lenticular bed of massive to lminated gray silty clay up to 10 cm thick. It was deposited from suspension in quiet water ponded at the channel bottom after its incision, before the point-bar growth. Clay sediments overlays a redish paleosol horizon with Fe-Mn nodules 5-10 cm large, which indicate a longer period of stagnant water and low oxigenation, corresponding to sedimentation of grey clay. Rare fossil rhizoids visible in the paleosol indicate paleo-vegetated surface, probably with grass.

At only one location the glacifluvial sediments overlay the younger Novigrad till (Novigrad Member) (see Section Novigrad 4-5, Fig. 5.169/2). There it contains a lot of boulder-size debris, which could be indicative of initially a terminoglacial environment.

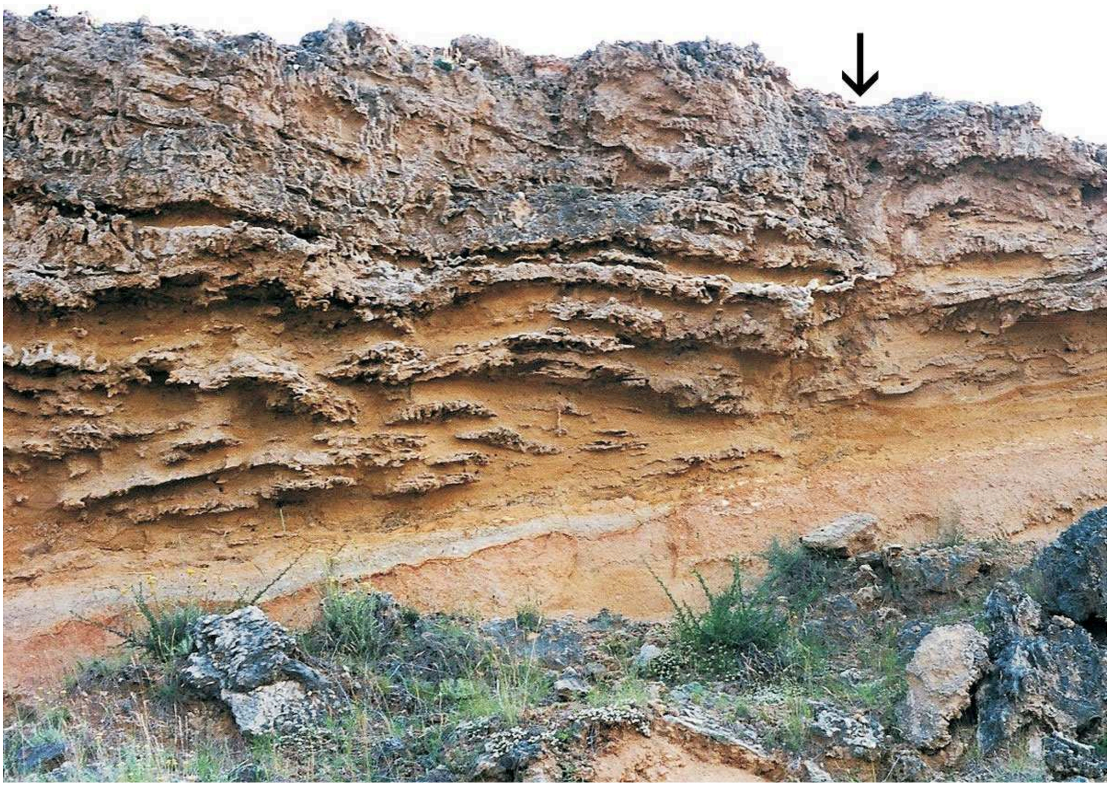


Figure 5.164. Detal of channel fill cross-section. At bottom of sigmoidal cross-beds occur small dunes oriented perpendicular to their strike. Arrow points at a sediment wedge interpreted as an ice-wedge cast. There is a redish paleosol horizon at the bottom, overlain with grey silty clay sediment deposited in stagnant water pond. Photo taken in 2006.

Slika 5.164. Detalj profila kroz sedimente kanalske ispune. Pri dnu sigmoidalnih kosih slojeva nalaze se male dine orjentirane okomito na pružanje slojeva. Strelica pokazuje sedimentni klin interpretiran kao ispuna ledenog klina. Ispod kanalskih naslaga nalazi se crvenkasti paleosol na kojemu je istaložen lećasti sloj sive siltozne gline istaložen u mirnoj ujezerenoj vodi. Snimljeno 2006.

An earlier stage of glacifluvial deposition is represented with planar cross-bedded gravel (calcirudite), low-angle planar cross-bedded sand and gravel (Fig. 5.165.), trough-bedded coarse-grained sands (calcarenites) and trough cross-laminated gravelly calcarenites (Fig. 5.166.). The sediments are well cemented except the trough-bedded calcarenites. The coarser sediments deposited during high yield of debris and high melt-water energy to transport gravel on the outwash plain, forming gravel bars and channel-fills (Fig. 5.165.). Higher discharge and velocity of glacial melt-waters produced planar low-angle gravel flood-sheets topped with thiner sand layers, locally rippled as the flow velocity decreased. Trough-bedded and trough-laminated sands and gravels deposited in shallow channels of braided strams on the outwash plain.

These sediments were deposited above the older Novigrad moraine (Paklenica Member), and as locally visible, underlay glacilacustrine deposits (Fig. 5.165.).

Chronostratigraphy of glacifluvial deposits of the Novigrad section is discussed in Chapter 7.

Figure 5.165. Glacifluvial outwash deposits (GO) overlaying the older Novigrad moraine (M1) and underlaying the glacilacustrine deposits (GL). There is a cross-bedded gravel bar bellow. Above are horizontal to low-angle planar bedded gravels and sands, the sheet-flood deposits. Photo taken in 2010.

Slika 5.165. Glacifluvijalni sedimenti ispiranja /GO) istaloženi na starijoj Novigradskoj moreni (M1), leže ispod glacilakustrinskih sedimenata (GL). U donjem dijelu se vidi sprud izgrađen od ravno-koso slojevitog šljunka, a iznad su vodoravno do blago koso uslojeni šljunci i pijesci.

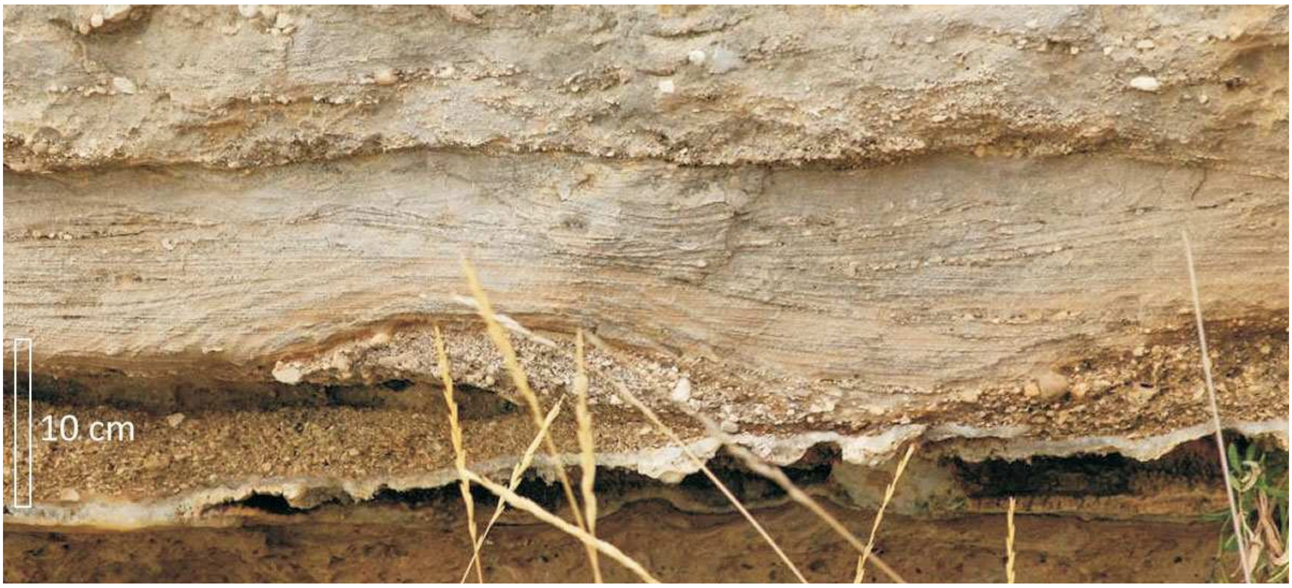


Figure 5.166. Braided stream deposits, fully cemented. Nice hummocky gravel bars are developed bellow trough-cross laminated gravelly coarse sand (pebbly coarse-grained calcarenite). There is a horizontal cavern bellow of lenticular cross-section. Layers of calcite crystals that grew at the cavern bottom were dated by uranium series and yielded ages 121 ky and 110 ky BP (see Chpt. 8). Photo taken in 2010.

Slika 5.166. Sedimenti prepletenih tokova, potpuno cementirani. Razvijeni su humčasti šljunčani (kalkruditni) sprudovi ispod koritasto-koso laminiranih šljunkovitih kalkarenita. Ispod se nalazi kaverna lećastog presjeka u kojoj je razvijeno nekoliko slojeva kristalnog kalcita. Kalciti su datirani metodom uranovog niza i dobivene starosti su 121 i 110 tisuća godina prije sadašnjosti (vidi Pogl. 8). Snimljeno 2010.

Glacideltaic complex of Seline Section

The Seline section is a long coastal exposure uncovering more than 80 m thick sediment succession of alluvial, glacideltaic and glacilacustrine deposits - a glacideltaic complex. Besides the youngest glacilacustrine unit described in the previous Chapter 5.2.2.2., the major part of this succession consists of conglomerates, which first compose alluvial gravel bars and channels (unit A in Fig. 5.168.), and then Gilbert-type deltaic bodies, divided by thin lacustrine sediments and paleosols (unit D in Fig. 5.168.).

Typical lithofacies are well cemented clast-supported and matrix-supported conglomerates, with various transitional types depending on the “matrix : clast” ratio (ca 30 - 60 %). There also occur redish-colored mudstone to siltstone interbeds that are massive, wavy-parallel laminated or current-ripple laminated (Photo 2, Fig. 5.168.), interpeted as lacustrine bottomsets. Very thin interlayers of redish-brown siltstone visible in older interval of the alluvial unit are presumabley paleosols (A, Fig. 5.168.). Yellowish fine-grained calcisiltites to calcarenites, locally rich in fossil plant debris, with parallel or wave-ripple lamination represent up to 0,5 m thick glacilacustrine intervals. They are interpreted as lacustrine marginal sediments, the zone where lake-water was rather shallow and wind-induced waves could form wave-ripples, and plant debris could be accumulated. These intervals, visible in the middle log section, represent periods of aborted debris input, which could have corresponded to another cooling cycle in hinterland.

The alluvial unit is represented by predominantly clast-supported conglomerates, which are composed of poorly to well rounded coarse gravel. Massive poorly sorted beds with average grain size 10 - 11 cm are channel fill deposited by stream grain flows. The layers composed of better sorted conglomerate, with imbricated clasts form channel bars. Cobbles with glacial striae (Fig. 5.167.) were found in massive conglomerates and document glacial origin of the debris and a proglacial outwash environment.

Figure 5.167. Cobble sized clast with glacial striae found in massive conglomerate of alluvial unit. Photo taken in 2011.

Slika 5.167. Valutica s ledenjačkim strijama nađena u masivnom konglomeratu aluvijalne jedinice. Snimljeno 2011.

SEDIMENT LOG OF SELINE SECTION
SV(SS)-37 L1

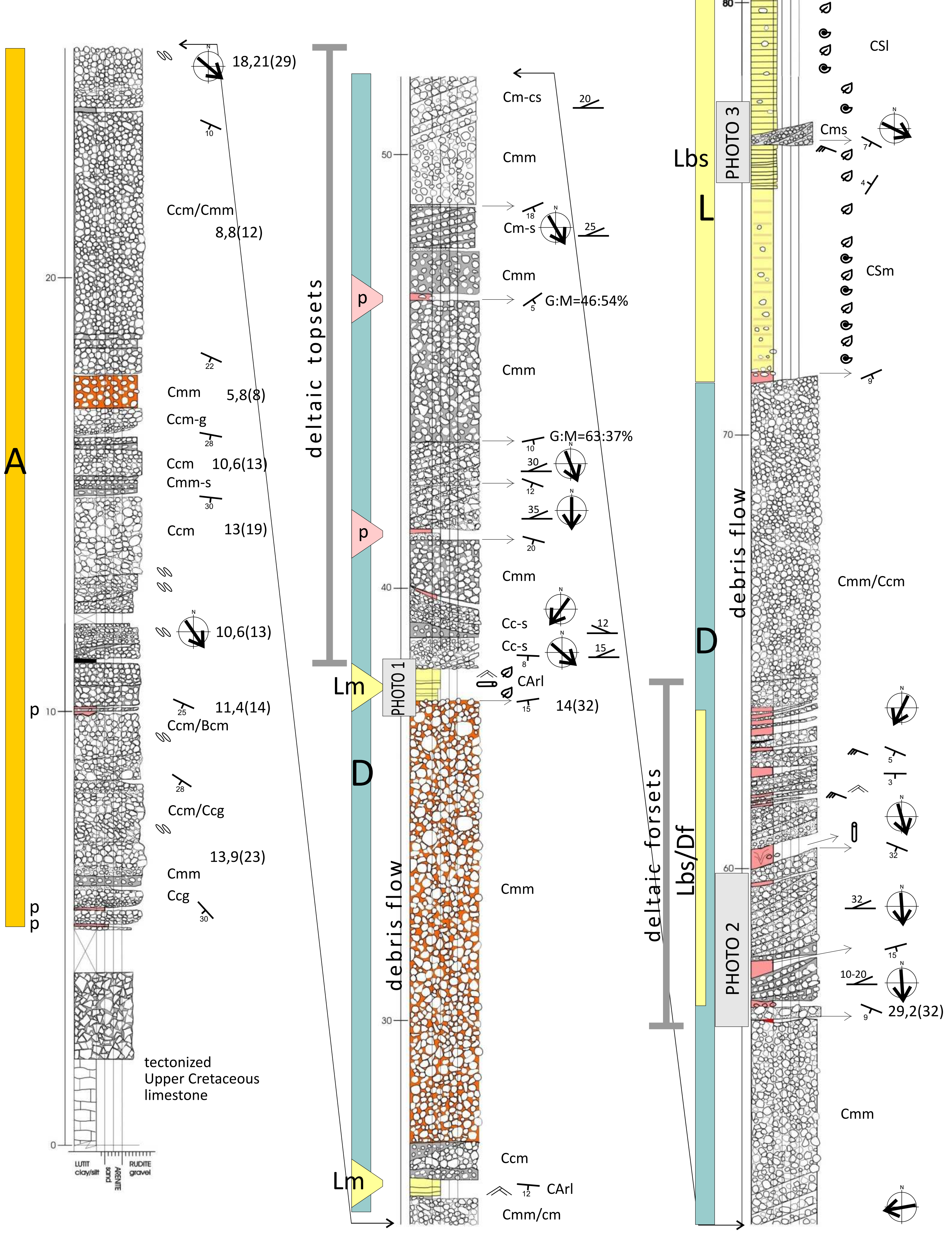


PHOTO 1
Lacustrine rippled bottom sets
and delta forsets.
Jezerski bottom-setovi i deltni forseti.

PHOTO 2
Lacustrine bottom sets, delta forsets and delta topset.
Jezerski bottom-setovi, deltni forseti i deltni topset.

PHOTO 3
Lacustrine rippled bottom sets
with downlaping delta forsets.
Jezerski riplani bottom-setovi i naliježući deltni forseti.

Lbs/Df (lacustrine bottom sets / delta forsets
jezerski bottom-setovi / delta forseti)

Lm (lake-margin deposits / *jezerski rubni sedimenti*)

p (? paleosol / *? fosilno tlo*)

L (lake / *jezero*)

D (delta / *delta*)

A (alluvial environment / *aluvijalni okoliš*)

Figure 5. 168.

The deltaic unit is about 45 m thick sediment succession, dominated by matrix-supported conglomerates.

There are two distinct massive conglomerate beds, each several meters thick, with internal structure changing from matrix- to clast-support. One is located between the two thin lake intervals, and the other occurs bellow the thick lake sequence. Both were deposited by mass transport, debris flow or hyperconcentrated flow carrying abundant washed-out till gravel.

A 16 m thick series of conglomerate beds, consisting of massive channel-fill conglomerates, planar-cross bed-sets (channel bars), and three thin redish-colored siltstone interbeds as possible paleosols, are interpreted as deltaic topsets (Fig. 5.168.), probably of a larger Gilbert-type deltaic body. Above follows a 6 m thick interval of alternatig delta forsets and lacustrine bottomsets (Photo 2, Fig. 5.168.). The internal composition of each delatic body or lobe shows progradation of foresets which were deposited from density flows, and their lower parts are sometimes draped by back-flow ripples. The orientation of delta foresets is not unique, but southwards in general. However, that is a result of shifting of the deltaic bodies due to a restricted accommodation space.

The described deltaic complex corresponds well to a model of glacideltaic and associated deposits, interpreted from exposures in SW Poland by Brodzikowsky & van Loon (1991).

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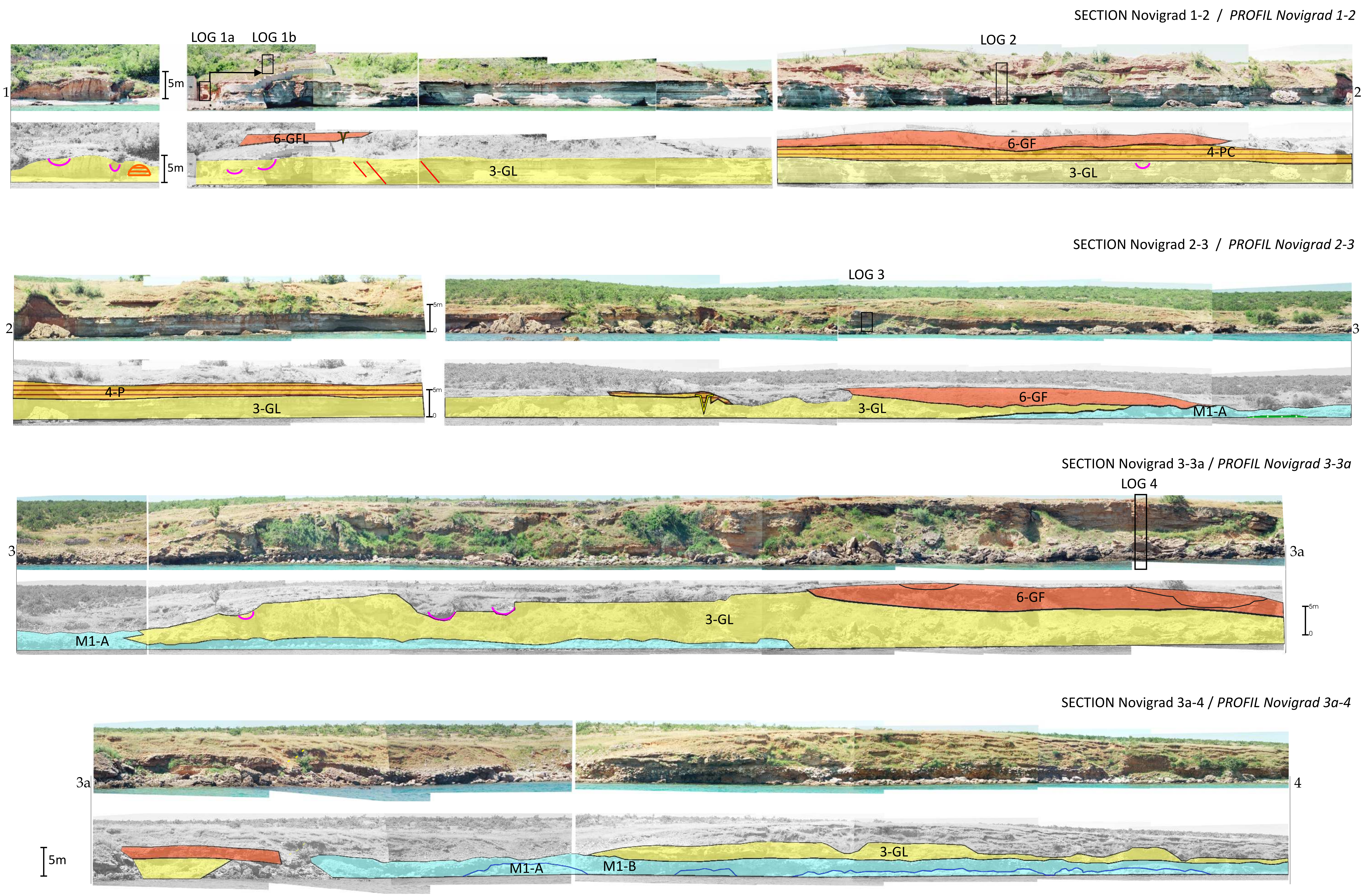


Figure 5.169/1

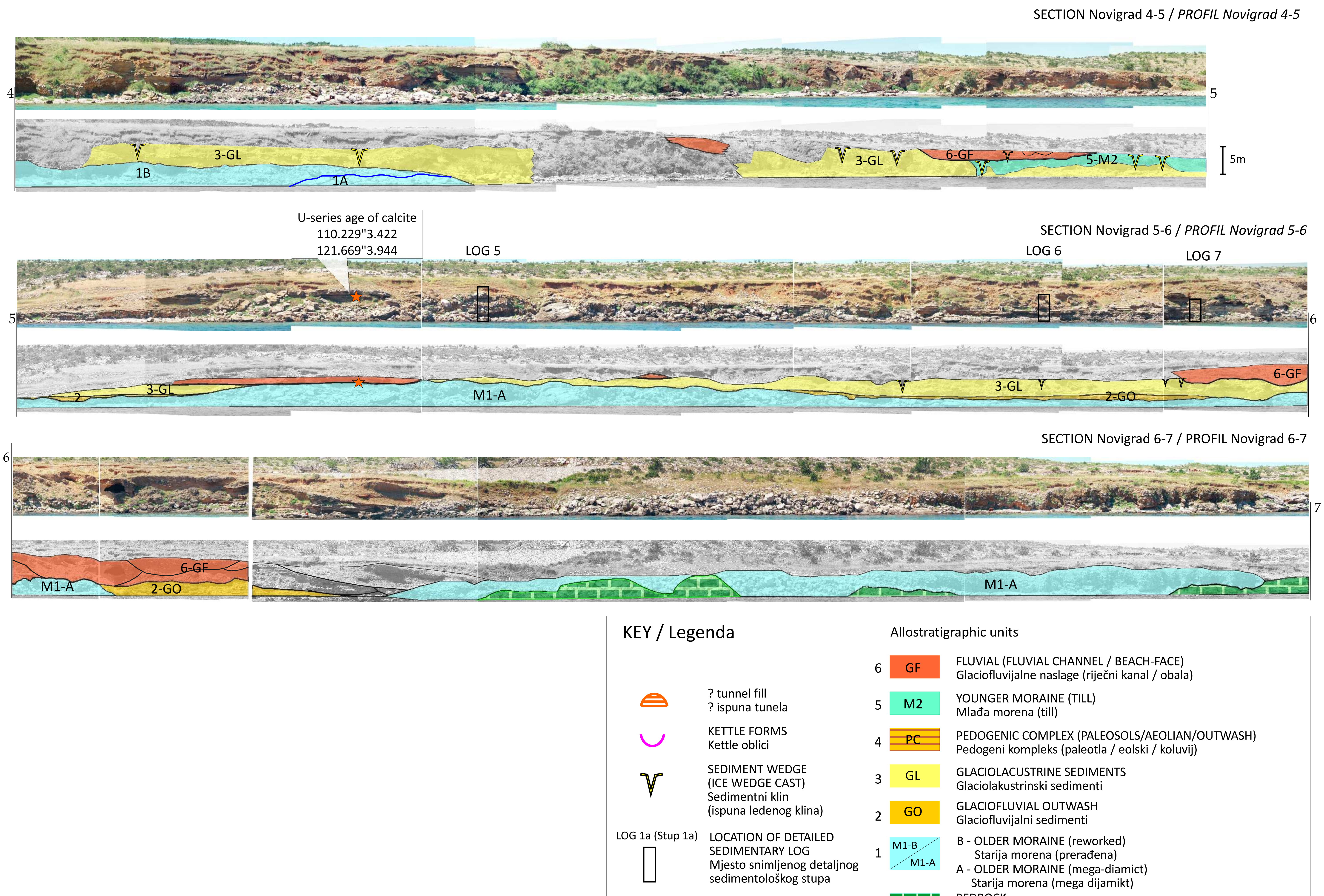


Figure 5.169 /2

6.
GEOMORPHOLOGICAL EVIDENCE

The common geomorphological evidence of glaciation include features of glacial erosion and glacial deposition. Both, depositional and erosional features from small to large scale are documented within the study area from Kvarner to Northern Dalmatia, but most of them are only briefly discussed oppening new questions and further goals of research.

Erratics, which are considered as significant indicators of glaciated relief, are not common but are present. It is expacted that many more exist but are not found yet, usually due to vegetation. Erratics are found in the Velebit area as shown later in this chapter.

Since the primary study object were sediments and sedimentary bodies, therefore the landforms of glacial deposition, including erratics, are presented first in this chapter, and then erosional features.

The most prominent are morainal sedimentary bodies, although generally not preserved with original morphology, and kame terrace sedimentary bodies that are exceptionally well preserved regarding their commonly low preservation potental in ancient glacial environments.

Besides the erosional and depositional landforms of glacial environments, there are features like ice-wedge casts and kettle-like forms presented at the end of this chapter, documenting periglacial environments.

6.1. GLACIAL DEPOSITIONAL LANDFORMS

6.1.1. MORAINES

Tills and tillites described in the Chapter 5.2. represent only erosional remnants of formerly extesive morainal bodies. Due to their generally pachy occurrence, it was not possible to recognize or analyse morphological characteristics of the sedimentary bodies, with exception of the Rujno moraine complex that at the first glance appears least eroded. Therefore, lithological and sedimentological characteristics were basic for the reconstruction of morainal bodies and their interpretation. Their position of occurrence regarding the altitude above the sea-level, was also accounted, although it does not seem crucial. Combinig between litho-, allo- and morfostratigraphy (Hughes, 2005, 2010), three members were defined: Rujno, Paklenica and Novigrad Member, and two tentative members - Sklopine exposed only in Sklopine section of the Velika Paklenica, and Raduč which is exposed in Ličko Polje .

At the present stage of reserch, the Paklenica Member is best defined and the most extensive ground moraine (Fig. 6.1.) attributed to Elsterian (Mindel) glaciation (MIS12) based on U-series age 339 ka BP and an infinite age >350 ka BP (Table 8.1.), may be even older.

The **Paklenica Member** is represented by easily recognizeable mega-diamict lithofaces, which extends from bellow the modern sea level (Ždrilo and Kusača coves) to around 600 m a.s.l. (Velika Paklenica), locally in association with the ovelaying kame terrace deposits (Krk, Pag,

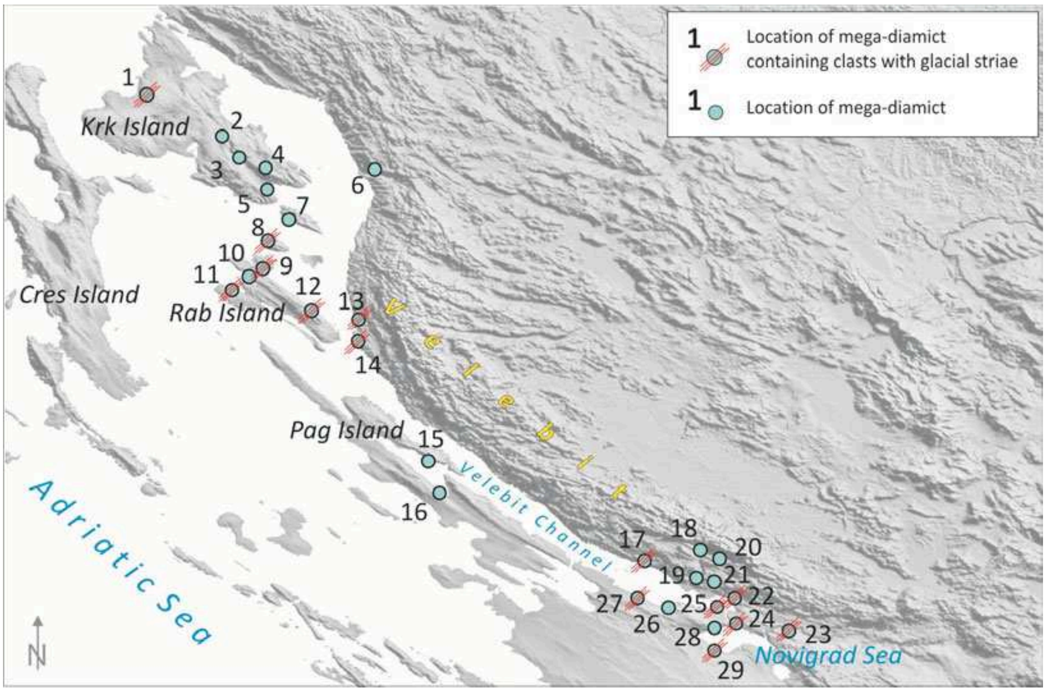


Figure 6.1. Distribution of Paklenica Member mega-diamicts.

Slika 6.1. Distribucija mega-diamikta Paklenica člana.

Figure 6.2. Paklenica Member at the Ždrilo section (loc. 25 in Fig. 6.1.). Left from people are visible glacilacustrine sediments, significantly deformed and mixed with morainal debris.. Photo taken in 2010.

Slika 6.2. Paklenica član na lokaciji Ždrilo (lok. 25 na Sl. 6.1.). Lijevo od ljudi se vide glacilakustrinski sediment, izrazito deformiran i pomiješan s morenskim detritusom. Snimljeno 2010.

Paklenica). The furthest seawards extent is indicated by its remnants on the Krk, Rab and Pag Islands and the SW coasts of the Velebit Channel and Novigrad Sea. The Interpretation as ground moraine is based on many findings of faceted, polished and striated clasts (Figs. 5.47, -71, -72, -76 to -79, -83 to -86, -90, -93 in Chapter 5.2.). Its dominant characteristic are faceted and rounded mega-boulders, ocasionally with polished and striated bottom surface (Figs 5.64 and -78). This moraine documents an extensive ice advance when glaciers have overrided the glacilacustrine deposits of Ždrilo (Figs. 5.88, -89, 6.2.) and Kusača (Fig. 6.3.) localities, though at Novigrad section the Paklenica Member occurs

Figure 6.3. Paklenica Member at the Kusača locality (loc. 17 in Fig. 6.1.). Glacilacustrine sediments are bellow the till. Photo taken in 2010.

Slika 6.3. Paklenica član na lokalitetu Kusača (lok. 17 na Sl. 6.1.). Glacilakustrinski sedimenti su ispod tila. Snimljeno 2010.

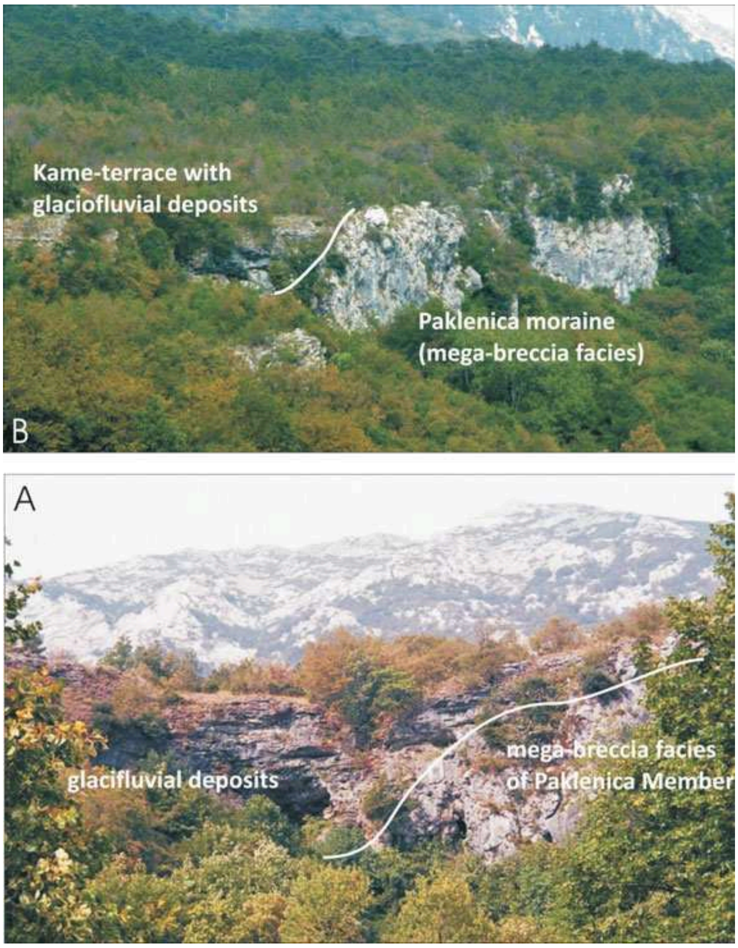


Figure 6.4. Location Kneževići SE of Sklopine (loc. 20 in Fig. 6.1.). Tillite (mega-breccia) of Paklenica Member act as bedrock to glacifluvial deposits of a kame terrace. Photo taken in 2006.

Slika 6.4. Lokalitet Kneževići JI od Sklopina (lok. 20 na Sl. 6.1.). Tilit (mega-breča) čini podinu glacifluvijalnih naslaga kame-terase. Snimljeno 2006.

bellow the glacilacustrine sequence (Figs. 5.169/1, 5.169/2), which indicates different age of glacilacustrine deposits in Velebit Channel and Novigrad Sea. Another specific characteristic are boulders with karren that were partially eroded during glacial transport Fig. 6.5.), which means that already karstified terrain was glaciated.

Figure. 6.5. Rounded boulder in Paklenica tillite with traces of preglacial karstification. Photo taken in 2009.

Slika 6.5. Zaobljeni blok u Paklenica tilitu s tragovima predglacijalne karstifikacije. Snimljeno 2009.

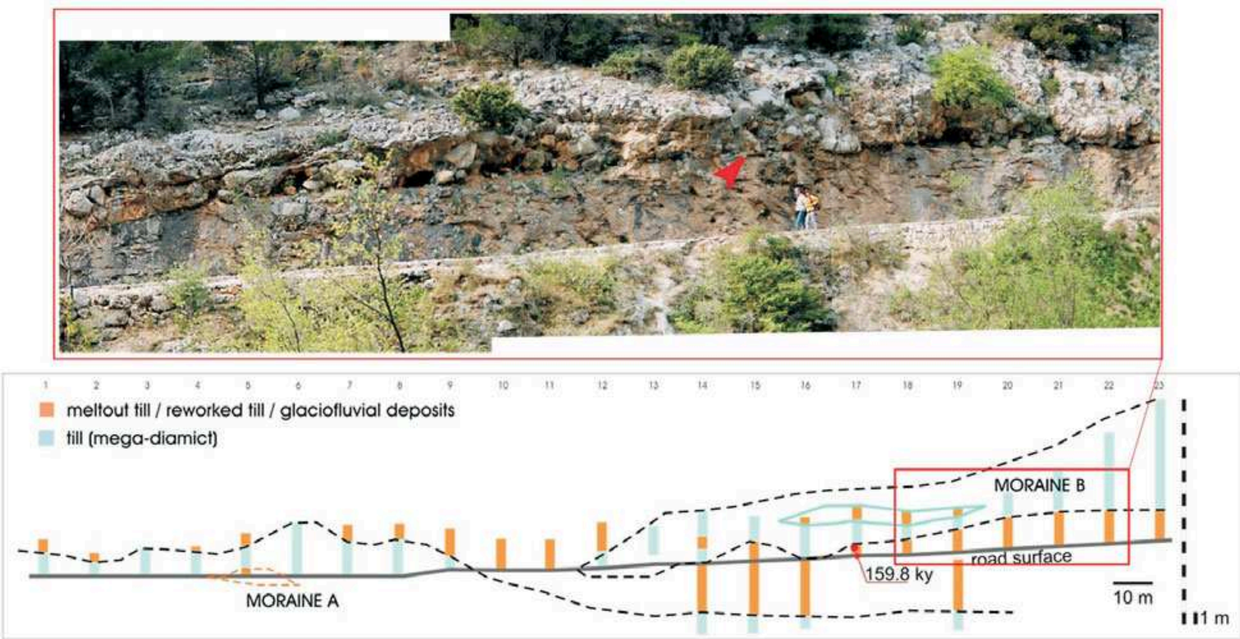


Figure 6.6. The road-cut exposure in Velika Paklenica shows the third cycle of glacier advance during deposition of the Paklenica Member. Mega-diamict (mega-breccia) with large boulders lays at sharp contact above reworked tillite of the previous cycle. Line-art reconstruction shows two morainal bodies and reworked tillite between. Location of dated calcite sample is marked bellow the contact with younger morainal body.

Slika 6.6. Na profilu cestovnog zasjeka u Velikoj Paklenici vidi se treći ciklus napredovanja ledenjaka tijekom taloženja Paklenica člana. Mega-diamikt (mega-breča) s velikim klastima leži u oštrom kontaktu na prerađenom tilitu prethodnog ciklusa. Na grafičkoj rekonstrukciji vide se dva morenska tijela i interval prerađenog tila između. Označena je lokacija datiranog uzorka kalcita neposredno ispod mlađeg morenskog tijela.

In the Velika Paklenica zone, this moraine is well cemented and commonly occurs in form of up to 50 m high wall-faced exposures, seen at Anića Luka (Fig. 5.64.), NW-wards and SE-wards of Sklopine near Kneževići (Figs. 5.63., 6.4.), marginal to glacifluvial deposits of kame terrace. This specific morphology is probably a result of postglacial erosion.

In the lower section of the Velika Paklenica canyon, Paklenica Member is more complex and consists of three cycles, each composed of tillite and reworked tillite, which may be considered as subunits marking ice advance-retreat cycles. This is clearly visible at the road-cut section shown in Figure 6.6.. The moraine overlaying a reworked tillite represents the third visible cycle. The contact between the two intervals is irregular, sharp and erosional. The reworked subglacial till is a matrix- to clast-supported conglomerate. It is locally well sorted into gravel ribbons, locally poorly sorted

Figure 6.7. Reworked tillite bellow the moraine B in Figure 6.5. is matrix- to clast-supported massive conglomerate with subrounded to well rounded clasts of fine to coarse gravel size. Yellow lines mark longer axis orientation, more-or-less random as result of clast rotation in matrix during the subglacial transport. Where clast are concentrated, their orintation is more linear and even imbricated due to traction and shear. Photo taken in 2012.

Slika 6.7. Prerađeni tilit ispod morene B na Slici 6.5. je konglomerat s muljnom do zrnskom potporom, i slabo do dobro zaobljenim klastima veličine sitnog do krupnog šljunka. Žute linije označavaju orjentaciju duže osi klasta, različito orjentiranih zbog rotacije u matriksu tijekom subledenjačkog transporta. Gdje su klasti koncentrirani, orjentacija je više linearna, čak imbricirana, zbog vučenja i smicanja pri kretanju leda. Snimljeno 2012.

Figure 6.8. Glacifluvial stratified calcirudites deposited in depressions between mega-blocks of moraine bellow Anića Kuk. Photo taken in 2007.

Slika 6.8. Glacifluvijalni stratificirani kalkrudit istaložen u depresijama između mega-blokova u moreni ispod Anića Kuka. Snimljeno 2007.

abound in micritic matrix, and locally inversly graded. Sorting and grading occured during higher discharge of subglacial melt-water. The massive parts consist of randomly oriented rounded clasts (Fig. 6.7.) which is characteristic for subglacial transport with lot of matrix. Traction and shearing due to ice advance produced local imbrication of clasts, and shearing plains are locally visible. There are numerous cavities filled with spary calcite, which was sampled at one location and U-series dating yielded age of 159.8 ka BP.

This cyclicity is also noticeable in the middle section of the Velika Paklenica, in Anića Luka. Glacifluvial units are better distinguished there, and also visible at the top of Anića moraine, where they fill depressions between mega-blocks (Fig. 6.8.).

The **Rujno Member**, described in Chapter 5.2. is a matrix-supported diamict with striated clasts, a typical subglacial till, presumably oldest one, although existing even on higher elevations than the Paklenica Member. By its distinct lithofacial characteristics it was found stratigraphically bellow the mega-diamict of Paklenical Member, at locations around Sklopine in the upper section of Velika Paklenica canyon between 400 and 550 m a.s.l. (Fig. 6.9.). This may contradict to its occurrence in Veliko Rujno valley at ca 900 m a.s.l., where it composes a complex of ground and medial moraine.

The morainal bodies of the Rujanska Kosa complex (Figs. 6.10., 6.11.) were identified only by their morphology, while partial internal structure and lithology is known only for the moraine body 2, exposed in a gravel pit. The Rujanska Kosa moraine was first recognized and interpreted as a terminal moraine by Nikler (1975).

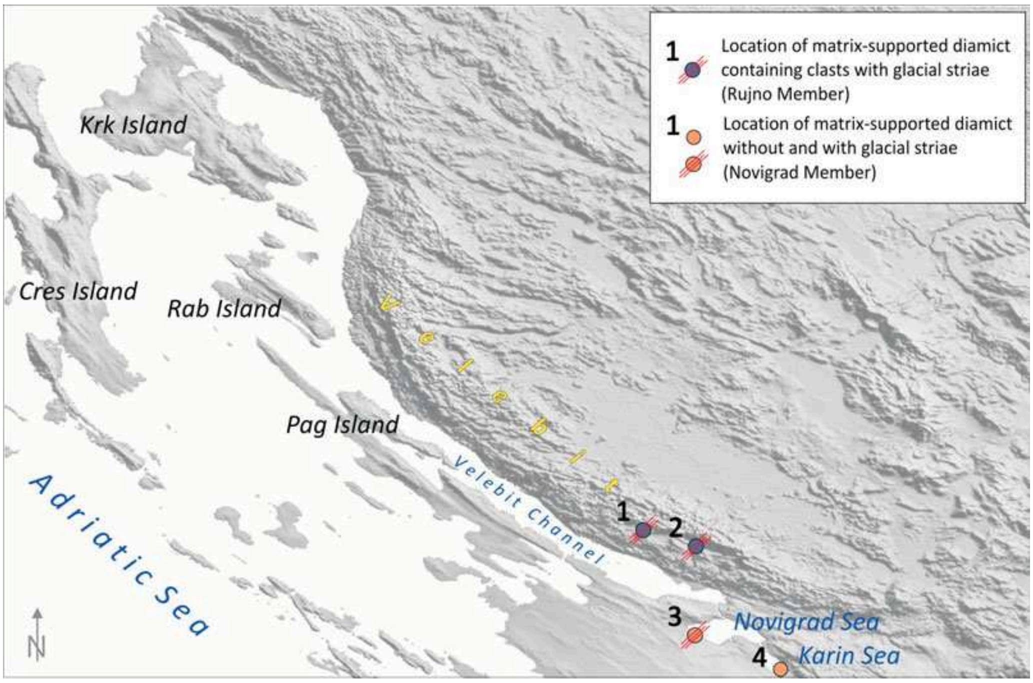


Figure 6.9. Locations of Rujno Member (1, 2) and Novigrad Member (3, 4).

Slika 6.9. Lokacije Rujno člana (1, 2) i Novigrad člana (3, 4).

The moraine-1 has rather sharp ridge morphology and is about 100 m high (Fig. 3.61.). Bouldary till of mega-diamict type is visible on its surface, and many meter-sized rounded clasts are found, some loose and some cemented in gravelly matrix. Rounded boulders are locally abundant as visible in Figure 5.60., and were probably left loose after wash-out by melt-waters and postglacial erosion which carried away the fines. Their considerably larger size than of clasts in the Rujno Member till, may be a good reason to attribute this morainal body to the Paklenica Member. These large loose rounded boulders were sprad all over the Veliko and Malo Rujno valleys, but during historical time were collected by people who built land-bordering stone walls.

Figure 6.10. Rujanska Kosa moraine complex reconstructed upon geomorphological characteristics. Four morainal bodies are distinguished: 1 - medial moraine, 2 and 3 - ground moraines, 4 - possible small terminal moraine. Shaded surfaces of Veliko and Malo Rujno display distribution of variably thick reworked ground moraine. Arrows show local directions of ice movement.

Slika 6.10. Morenski kompleks Rujanska Kosa, rekonstruiran na osnovi geomorfoloških karakteristika. Četri morenska tijela su izdvojena: 1 - središnja morena, 2 i 3 - podinske morene, 4 - moguća mala završna morena. Strelice pokazuju lokalne smjerove kretanja leda.

Figure 6.11. Rujanska Kosa morainal complex. Bodies 1, 2 and 3 distinguish well in size and shape. Body 1 has sharp ridge topography, while the second two are much smaller and with smooth hummocky topography. Photo taken in 2008.

Slika 6.11. Morenski complex Rujanska Kosa. Tijela 1, 2 i 3 dobro se razlikuju po veličini i obliku. Tijelo 1 ima topografiju oštrijeg hrbata, dok su druga dva osjetno manja i glatke humčaste topografije. Snimljeno 2008.

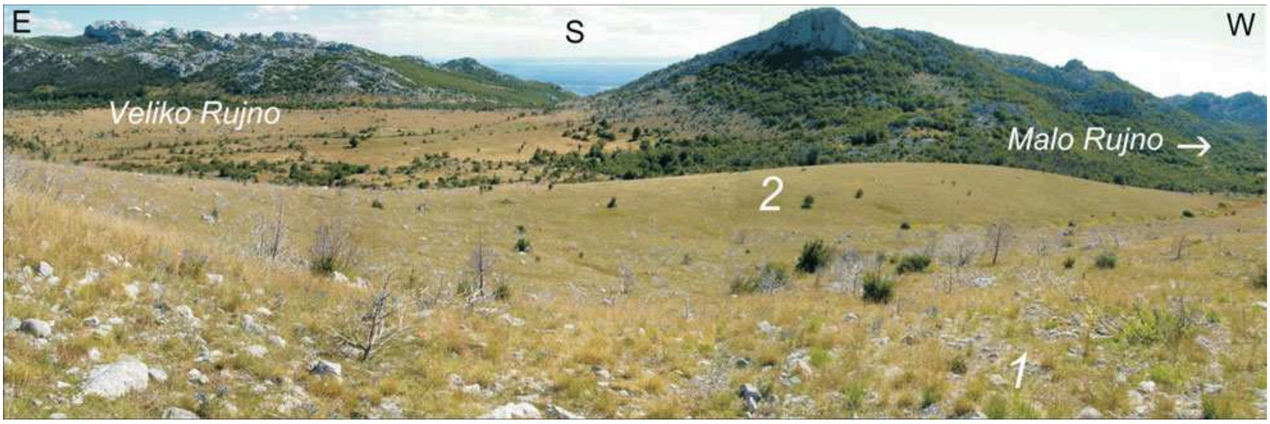


Figure 6.12. Moraine-2 of the Rujanska Kosa complex as seen from the ridge of moraine-1. Photo taken in 2010.

Slika 6.12. Pogled na morenu-2 u kompleksu Rujanska Kosa, snimljen s hrpta morene-1. Snimljeno 2010.

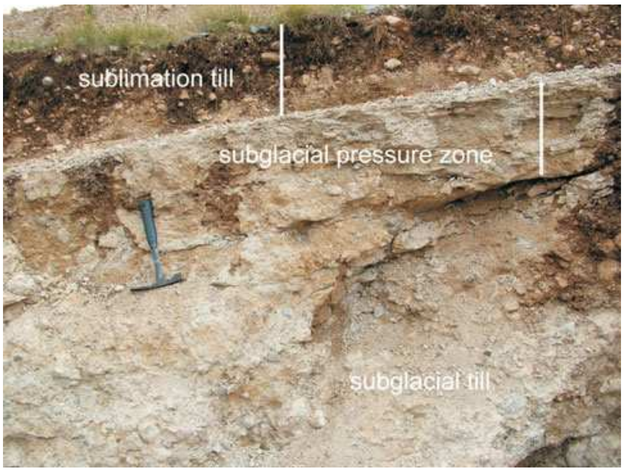


Figure 6.13. Structure of the moraine body 2. Sheared surface of the subglacial till, indicative of subglacial pressure, documents subglacial transport and modeling by ice. Above lays sublimation till deposited by ice recession. Its earthy look is due to pedogenesis. Photo taken in 2011.

Slika 6.13. Struktura morenskog tijela 2. Vidi se površinska zona smicanja, indikativna za sub- glacijalni transport i oblikovanje ledom. Na površini subglacijalnog tila leži sublimacijski til odložen povlačenjem leda. Njegov zemljasti izgled je rezultat pedogenizacije. Snimljeno 2011.

Figure 6.14. Rujanska Kosa morainal complex as photographed by Sokač in 1970 (Sokač, 1973) which was originally interpreted as terminal moraine by Nikler (1973), with added labels. Moraine-4 are two elongated hummocks, which may belog to moraine-1 or can be younger. It appears that moraine-1 is also a composite body.

Slika 6.14. Morenski kompleks Rujanska Kosa kako ju je fotografirao Sokač 1970. g. (Sokač, 1973), a Nikler (1973) ju je interpretirao kao završnu morenu, s pridodanim oznakama. Morenu-4 čine dva humčasta tijela i nije jasno da li pripadaju moreni-1 ili su mlađa tijela. Također se čini da je i morena-1 kompozitno tijelo.

The smaller morainal bodies 2 and 3 have morphology similar to drumlins (Fig. 6.11.) indicating westwards ice movement. The moraine-2 is attached to the medial moraine-1, but appears to be partly under it as seen in Figure 6.12.. It is composed of typical subglacial till, a matrix-supported diamict with striated and faceted clasts (see Chpt. 5.2.) upon which the Rujno Member was defined. Its smooth rounded surface morphology indicates subglacial modeling, as well as the visible shear zone in form of compacted till (Fig. 6.13.). About 30 cm thick layer of sublimation till is preserved at its surface, but it appears earthy because of pedogenesis (Fig. 6.13.). The till is reworked along the southern margin of moraine-2, and there occur stratified rather well cemented matrix- to clast-supported conglomerates of pebble to cobble size debris. Reworked and poorly to well cemented tillites fill the Malo Rujno, Pričatrnja and Zavrata valleys. Washed-out large boulder and erratic blocks are dispersed over this area.

The moraine body 4 consist of two small bodies, today hardly visible due to high vegetation, and inaccessible due to uncleared mine field. The bodies are reconstructed from the photograph taken by B. Sokač in 1970 (Fig. 6.14.). Their attribution is not clear. They can belong to older complex or can as well be remnants of the last glacial (Nikler 1975, Sokač 1973).

The Velika Paklenica Canyon has best preserved profiles of the Rujno and Paklenica Members. Therefore, a topographic profile along the base-line of the Velika Paklenica brook was drawn in order to reconstruct vertical and lateral relationships of the Rujno and Paklenica Members from Sklopine (ca 700 m a.s.l.) down to Starigrad-Paklenica at sea level (Fig. 6.15.). It became clear that there exists another younger moraine above the Sklopine kame terrace, which is tentatively defined as the fourth, **Sklopine Member**, presently of local character (Fig. 6.16.). It is represented by ca. 5 m thick layer of boulder diamict, predominantly clast-supported and with open-work texture.

Figure 6.15. Topographic profile along the Velika Paklenica Canyon and relative vertical and lateral relationships between particular members. A - Longitudinal profile with cross-sections of the Canyon at four different locations, no vertical exaggeration. Note variability in canyon morphology from valley to gorge type, which is deepest in the middle part below Anića Kuk. The origin of gorges is discussed in chapter on erosional features. B - Profile along the SE canyon margin is added to the longitudinal profile. The extent of particular stratigraphic members composing the Velika Paklenica geological structure is labelled above.The Paklenica brook modern base-line shows distinct drop in the section below Anića Kuk at the gorge zone, which suggests change of the erosional base. C - Vertical and lateral relationship between Rujno (RM), Paklenica (PM), and Sklopine (SM) Members, and Seline glacideltaic-glacilacustrine complex. Sklopine area is shown in detail in Fig. 6.16. The Rujno Member occurs mainly in upper section of the Velika Paklenica Canyon, while the Paklenica Member is found throughout the whole area. In the lower section, Paklenica Member is a composite unit built of cyclic alternation of moraine and reworked moraine or glacifluvial deposits. Vertical successions are shematic and do not represent thickness nor correspond to the elevation. The relationship between the Seline complex and Paklenica Member complex is not clear yet.

Slika 6.15. Topografski profil duž kanjona Velike Paklenice po koritu potoka i vertikalni i lateralni odnos pojedinih članova. A - uzdužni profil s poprečnim presjecima kanjona na četiri različite lokacije, bez uvećanja vertikalnog mjerila. Vidi se promjena presjeka kanjona od dolinskog do kanjonskog koji je najdublji ispod Anića Kuka. Postanak kanjona je prikazan u poglavlju o erozijskim oblicima. B - profil duž JI ruba kanjona dodan je radi orijentacije, a stratigrafija stijena koje tvore geološku strukturu Velike Paklenice prikazana je iznad profila. Uzdužni profil pakleničkog potoka pokazuje izrazit pregib ispod Anića Kuka, što ukazuje na promjenu položaja erozijske baze. C - Vertikalni i lateralni odnos Rujno (RM), Paklenica (PM) i Sklopine (SM) članova, i Selinskog glaciodeltaičnog-glaciolakustrinskog kompleksa. Područje Sklopina detaljno je prikazano na Slici 6.16. Član Rujno se nalazi uglavnom u gornjem dijelu kanjona, dok se član Paklenica nalazi po cijelom području. U donjem dijelu profila, član Paklenica je kompozitna jedinica, izgrađena od cikličke izmjene morena i prerađenih morena ili glaciofluvijalnih sedimenata. Vertikalni slijed je prikazan shematski i ne odražava debljine niti visinu članova. Odnos Selinskog kompleksa i kompleksa pakleničkih članova još nije poznat.

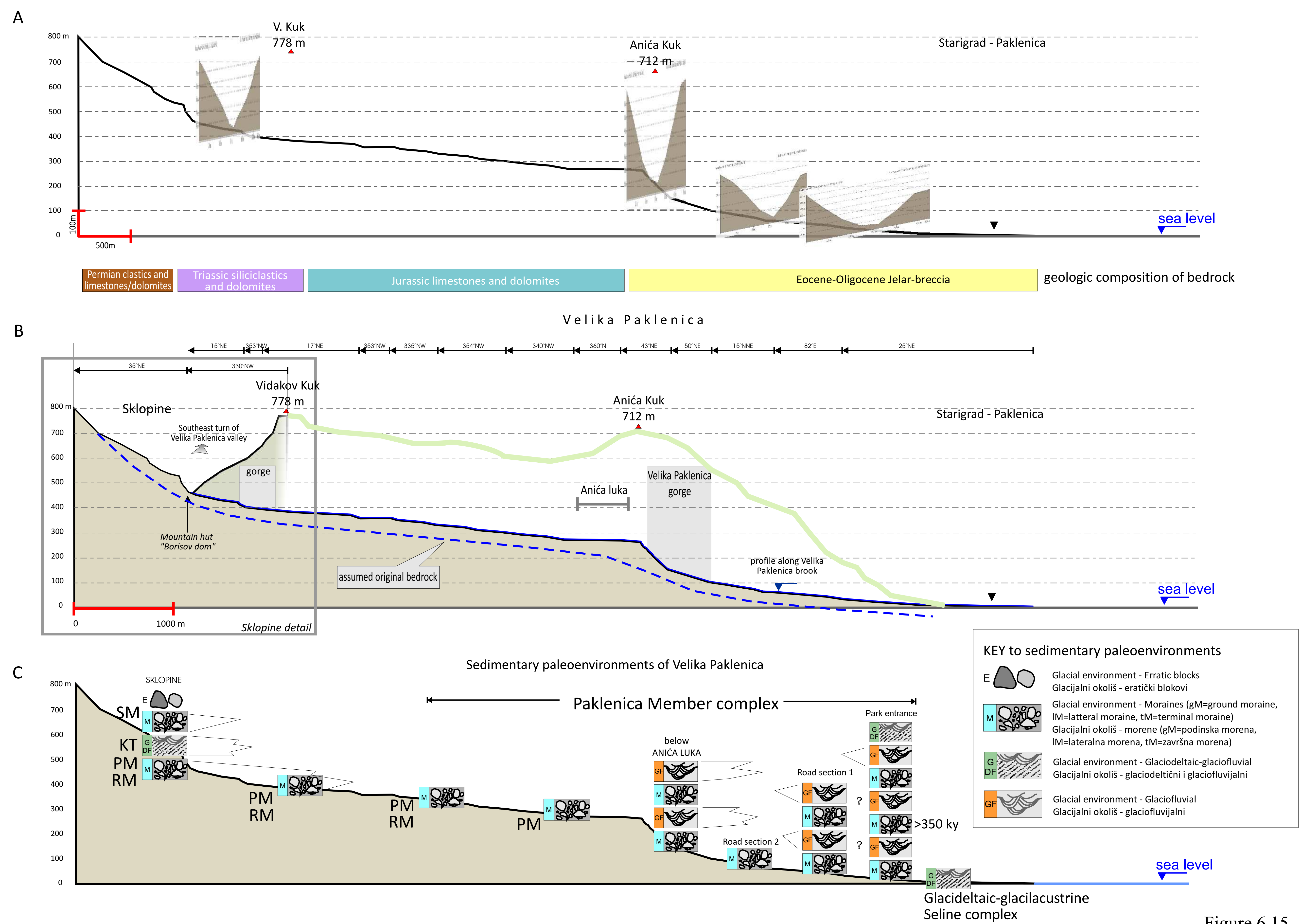

A
V. Kuk
778 m
Anića Kuk
712 m
Starigrad - Paklenica
sea level
100m
500m
Permian clastics and limestones/dolomites
Triassic siliciclastics and dolomites
Jurassic limestones and dolomites
Eocene-Oligocene Jelar-breccia
geologic composition of bedrock
B
Velika Paklenica
Sklopine
Vidakov Kuk
778 m
Southeast turn of Velika Paklenica valley
gorge
Mountain hut "Borisov dom"
assumed original bedrock
Anića Kuk
712 m
Anića luka
Velika Paklenica gorge
profile along Velika Paklenica brook
Starigrad - Paklenica
sea level
1000 m
Sklopine detail
C
Sedimentary paleoenvironments of Velika Paklenica
SKLOPINE
SM
KT
PM
RM
Paklenica Member complex
below ANIĆA LUKA
Road section 1
Road section 2
Park entrance
>350 ky
sea level
Glacideltaic-glacilacustrine Seline complex
KEY to sedimentary paleoenvironments
E Glacial environment - Erratic blocks
Glacijalni okoliš - eratički blokovi
M Glacial environment - Moraines (gM=ground moraine, lM=latteral moraine, tM=terminal moraine)
Glacijalni okoliš - morene (gM=podinska morena, lM=lateralna morena, tM=završna morena)
G DF Glacial environment - Glaciodeltaic-glaciofluvial
Glacijalni okoliš - glaciodeltični i glaciofluvijalni
GF Glacial environment - Glaciofluvial
Glacijalni okoliš - glaciofluvijalni

Figure 6.15.

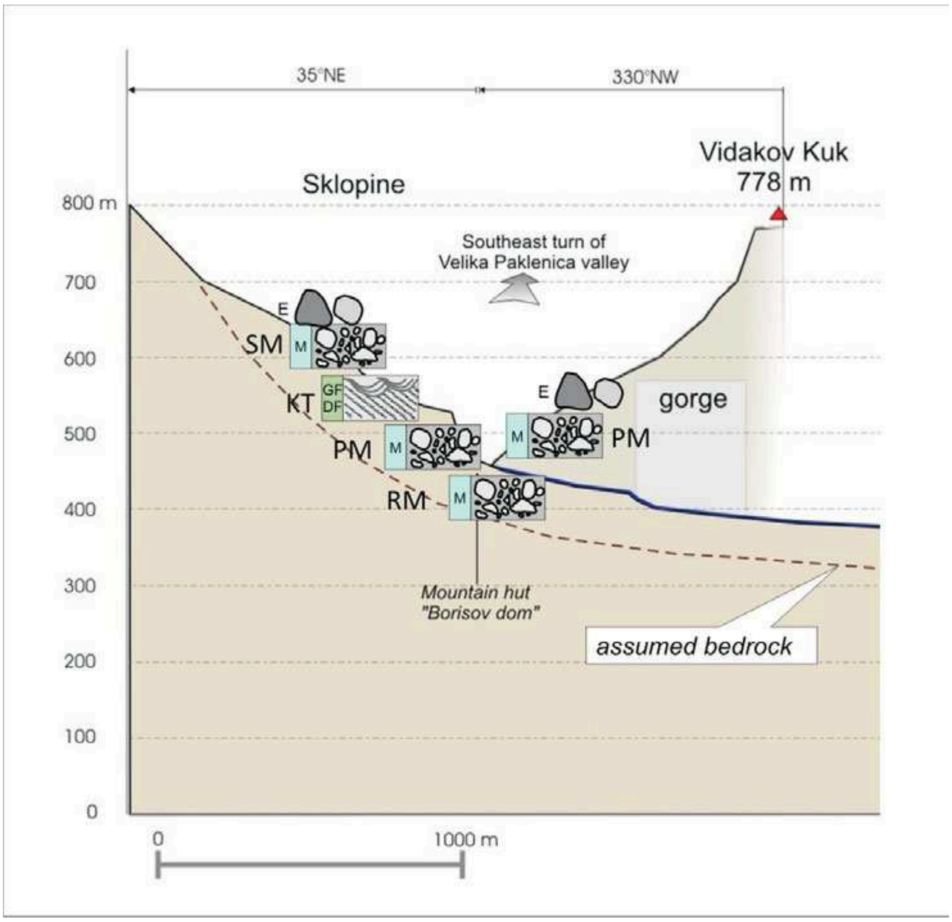


Figure 6.16. Reconstruction of the Sklopine area shows relative position and relationship of particular members. The Rujno Member (RM) is found bellow the Paklenica Member (PM) which supports glacifluvial and alluvial kame terrace deposits (KT). Above lays the Sklopine Member. Mega-blocks are on both sides, some washed out from the moraine and some are erratics.

Slika 6.16. Rekonstrukcija područja Sklopine prikazuje reletivan položaj i međusobni odnos pojedinih članova. Rujno član (RM) se nalazi ispod Paklenica člana (PM) uz koji su istaloženi glacifluvijalni i aluvijalni sedimenti kame terase (KT). Iznad leži član Sklopine. Mega-blokovi se nalaze na obje strane, neki isprani iz morena, a neki su eratici.

The **Novigrad Member** was defined at the Novigrad section (loc. 3 in Fig. 6.9.). It is the younger the Novigrad moraine (M2) described as the allostratigraphic unit 5 of Novigrad section (Fig. 5.169/2), and lays over the Novigrad glacilacustrine sediments, with distinct erosional boundary. It is only comparable to Karin till that also overlays glacilacustrine sediments and possibly belongs to the same glacial event.

Moraines located on the continental side of the Velebit Mt., in Ličko Polje near Raduč (Fig. 3.55.), cannot yet be ascribed to any of defined stratigraphic members. The gravel deposits of Raduč (Fig. 6.17.) are matrix-supported diamicts, composed of silty clay matrix and faceted rounded pebbles with common glacial striae. They are herein for the first time interpreted as subglacial till or ground moraine. Their chronostratigraphic relation to the moraines at the sea-side locations is not yet known, and Raduč moraine is therefore tentatively defined as the **Raduč Member**.

Figure 6.17. A - Raduč ground moraine exposed in a large gravel pit. A glacial valley and peaks of the Velebit Mt. are in the background. B - Raduč till is a massive matrix-supported till. C - Till contains various lithoclasts from the Velebit Mountain proper and foothills. D - polished and striated surface of a clast from Raduč till. Photos taken in 2011.

Slika 6.17. A - Podinska morena kod Raduča otkrivena u velikoj šljunčari. B - Raduč til je masivan diamikt s muljnom osnovom. C - Til sadrži različite litoklaste s područja Velebita i njegovog podnožja. D - Polirana površina klasta s ledenjačkim strijama. Snimljeno 2011.

6.1.2. KAME TERRACES

kame terraces occur in ice-contact zone, and are commonly extensive sedimentary bodies developed by sediment accumulation in zone between a valley glacier ice-margin and a valley slope. They are characterised by glacifluvial deposition during the ice recession. The accummodation space grows as ice melts, and first deposit lateral dump moraines, wich form substrate for glacifluvial accummodation. Rather complex sedimentary bodies can form as reflection of ice-volume fluctuation. It is common that accummulation space of the kame terrace is destabilized by the ice recession, and disintegration of those sediments can occur, which decreses their preservation potential. Thus they are rarely described from ancient glacial environments. Various phases of its degradation and aggradation can be recognized in modern glacial environments, as described by Small (1983) who studied in detail a lateral dump moraine (Fig. 6.18.).

Different processes of accumulation are included in kame terrace formation. Firstly, a glacier must carry abundant supraglacial debris, and even englacial debris in ice-marginal cracks, and a lot of cryoclastic slope material is commonly accounted. When ice tongue melts, supraglacial marginal debris is dumped along valley slopes and stratified away from the ice margin. The slopeward dip of stratified moraine is the main characteristic of these latteral ice-contact sedimentary bodies, which, if preserved, can form expressed terraces in the relief of a glaciated valley. These characteristics were recognized at several locations in the studied area. Supraglacial debris can mix with cryoclastic debris avalanching from valley slopes. The advancing ice melt enlarges the accumulation zone, and more melt-waters enter the area, so glacilacustrine, glacifluvial and alluvial deposition can take place. Sediment accumulation fills up the space between ice and the valley slope forming a kame terrace.

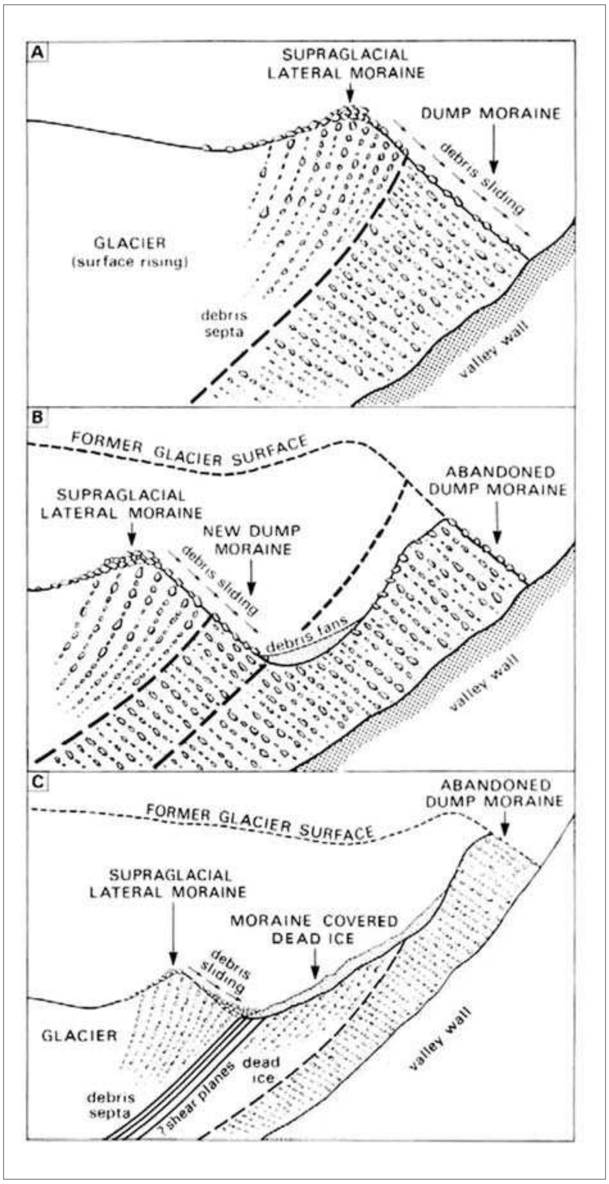


Figure 6.18. Process of lateral dump moraine acummulation as presented by Small (1983).

Slika 6.19. Proces akumulacije bočne “dump” morene kako je prikazao Small (1983).

The kame terraces in the eastern Adriatic Sea realm were recognized on the Krk and Pag Islands (Marjanac & Marjanac, 1994, 1999), and in some other sites, as described below.

In this study all valley-longitudinal sedimentary bodies characterized by slope-dip bedding and terrace morphology are interpreted as kame terraces, in spite Small's (1983) interpretation of lateral dump moraines (Fig. 6.19.). The argument in favour of kame terraces instead of lateral dump moraines is prevailance of stream flow and episodic gravity flow processes in the terrace accummulation, instead of mass emplacement characteristic for the moraines.

The kame terraces are morphologically distinct terraces slightly inclined towards the valley slope. They are recognized at 11 locations (Fig. 6.19.) where they represent erosional remnants of larger sedimentary bodies which extended along both valley slopes. They are partly preserved on the southwest and northeast slopes of the Baška valley (Batomalj, Šupele-Jurandvor, Gajevi) and on the southwest and northeast slopes of the Pag valley (Metajna-1, Metajna-2, Bošane, Gradac, Gorica). The sedimentary body interpreted as a part of kame terrace was also studied on the Prvić island, on the Rab Island's NE steep side, and in the Velika Paklenica valley where they occur only along its northeast slope. The most significant and best studied kame terraces are presented in detail, whereas others are only briefly reviewed.

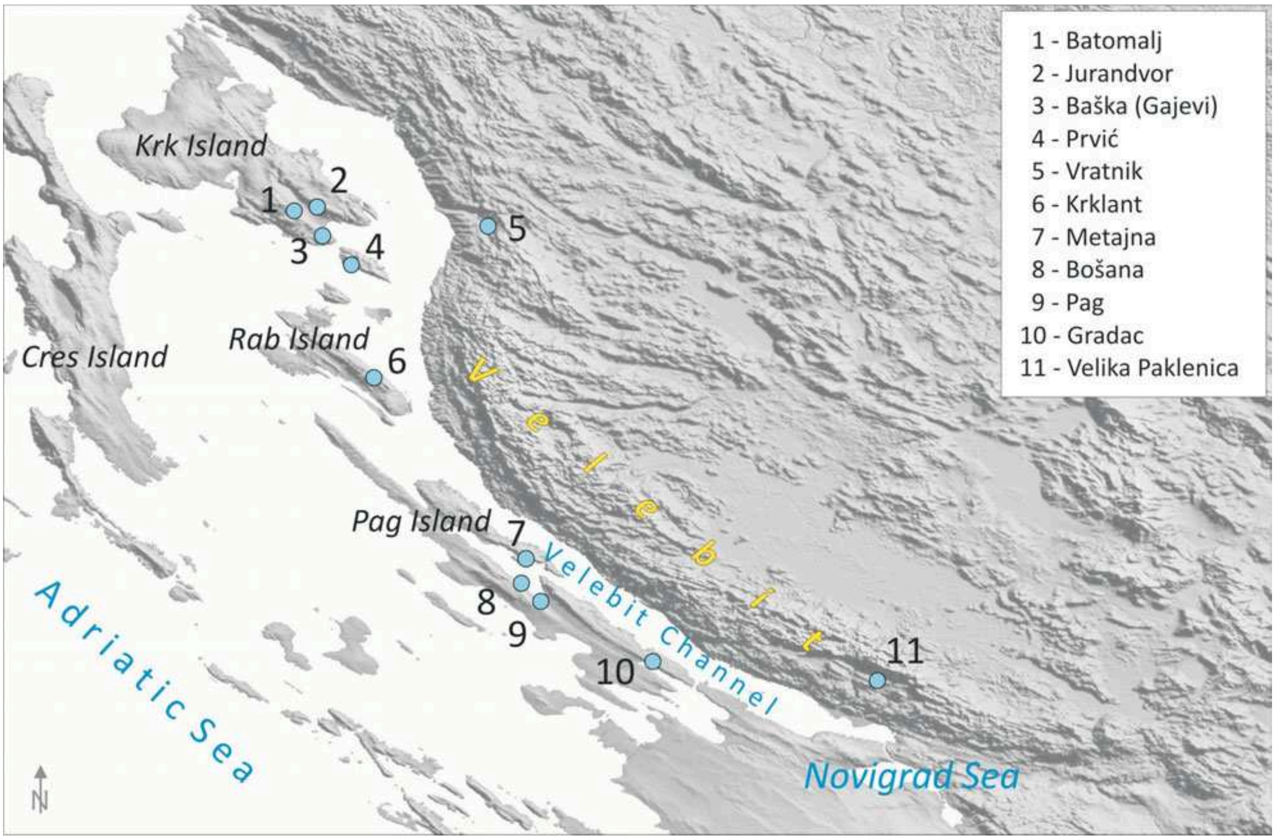


Figure 6.20. Locations of kame terraces in the studied regions.
Slika 6.20. Lokacije *kame*-terasa u istraživanom prostoru.

The studied kame terraces generally occur between the modern sea level and 200 m a.s.l., with exception of Velika Paklenica where the terrace is between 600 and nearly 800 m a.s.l. (Table 6.1.). Their estimated (preserved) hight spans between 5 and ca 200 m, and estimated preserved lateral extent spans from 10 m to more than 1 km.

Table 6.1. Some characteristics of preserved parts of slope-marginal kame terraces.
Tablica 6.1. Osnovne karakteristike sačuvanih dijelova postranih *kame*-terasa.

KAME -TERRACE	ALTITUDE (m) a.s.l.	ESTIMATED HIGHT / EXTENT	VALLEY SLOPE ORIENTATION	TERRACE BEDDING DIP
Krk - Jurandvor	140 - 190	ca. 50 m / ca. 1000 m	230/40	76/20
Krk - Batomalj	80 - 120	40 m / 200-300 m	locally subvertical	200-220/10-20
Krk - Gajevi	50 - 200	150 - 180 m / 500 - 1000 m	40/35 to subvertical	250/30, 200/13
Rab - Krklant	0 - 200	150 - 200 m / ca 400 m	irregular	ca 200-210/15-30
Pag - Metajna-1	50	20 m / 100 m	220/25	30/25
Pag - Metajna-2	20 - 40	5 - 10 m / ca. 100 m	low angle	ca. 360/5-10
Pag - Bošane	10 - 70	80 m / up to 500 m	50/40-80	random
Pag - Crnika	30 - 70	40 m / ca. 1000 m	not exposed	random
Pag - Gradac	30 - 100	60 m / 50 -150 m	30/40	226/36, 302/32
Pag - Gorica	70 - 80	10 m	220/30	30/25
Velika Paklenica	680 - 760	up to 80 m / > 1000 m	not exposed	40/10-15

6.1.2.1. KAME TERRACES OF KRK ISLAND

The kame terrace sediments were studied at three locations in the Baščanska Draga valley (loc. 1, 2, 3 in Fig. 6.20.); Batomalj, Gajevi and Jurandvor. Both Batomalj and Gajevi are remnants of an extensive and complex sedimentary body - a southwest kame terrace of the Baška glacier. The counterpart, northeast kame terrace was a sedimentary body of which we find remnants in surroundings of Jurandvor. The sediments were also traced along the valley slopes from one large outcrop to the other. The kame terraces of the Krk island are built of predominantly thick-bedded coarse-grained carbonate breccia, dipping slopewards at angle of 30-40°, either southwestwards or northeastwards. Exceptionally, bedding is not prominent and coarse-grained sediments appear massive. Glacifluvial unit is unequally preserved.

Figure 6.21. The valley of Baščanska Draga extending NW-SE. kame terraces are preserved of both valley sides.
Slika 6.21. Dolina Baščanske drage, pružanja SZ-JI. Kame-terase su sačuvane uz obje padine doline.

Batomalj kame terrace

This topographic terrace (Fig. 3.10.) is built of slope-dipping thick bedded cemented breccia and trough cross-bedded breccia. It is extensivelly vegetated so the access for observation was restrected. Bedding is irregular and of variable thickness. The breccia is predominantly matrix -supported, although clusters of clasts in contact are present. The matrix is finegrained calcarenite to micritic carbonate, and its amount is variable, ranging from 5 % to ca 25 %. The clasts are angular to subangular, of low sphaericity, and their size spans from 1cm to nearly 50 cm across, although large clasts are rare. Sorting is very poor to locally medium. Massive, clast- to matrix-supported diamict (breccia) occurs bellow the slope-dipping breccia, and above lay shallow trough cross-bedded finer-grained breccias and calcarenites.

Gajevi kame terrace

The Gajevi kame terrace consists of two sections at different elevations between 50 m to about 200 m a.s.l. The coarse-grained clastics can be traced with interruptions from the lower to the upper section, and horizontaly for about 1 km. The lower terrace sediments comprise three allostratigraphic units (Fig. 6.22.) in total thickness of ca 50 m. The allo-unit 1 is the Paklenica Member mega-diamict, rather massive at the base, and uppward it becomes thick bedded (see in Chapter 5.2.1.2.). Associated to the lowest part of this unit occur rare boulders with polished and striated bottom surface.

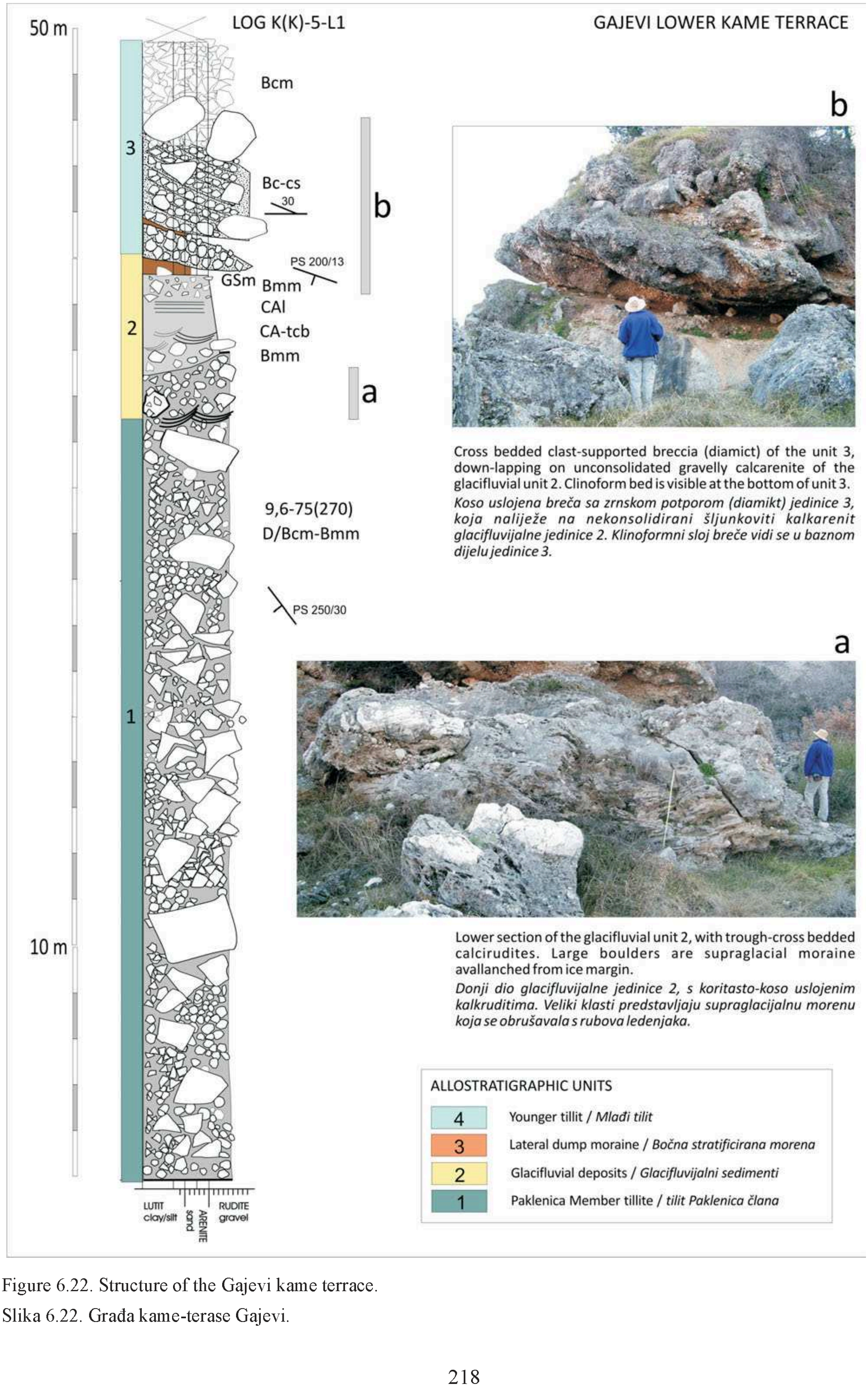


Figure 6.22. Structure of the Gajevi kame terrace.

Slika 6.22. Građa kame-terase Gajevi.

The unit 2 consists of trouhg cross-bedded fine-grained calcirudite with scarce boulders, a thick normally graded coarse-grained calcarenite with turbidite-like structure (Ta-d sequence), and contrasting poorly consolidated calcarenite with dispersed angular pebble-size lithoclasts.

The trough cross-bedded calcirudites were deposited in braided channels, but were influenced by periodical avallanching of supraglacial marginal moraine, as visible by presence of scarce meter-sized and smaller boulders enclosed in this much finer-grained sediments. The thick graded calcarenite bed is probably a turbidite although its cross- and parallel-laminated intervals are hardly rcognizeable. This sediment was likely deposited by high-density turbidity current probably caused by massive thowing of ice margin, while on the kame terrace could have existed a temporary lake or a large fluvial channel. The poorly consolidated calcarenite probably represents this lacustrine or fluvial phase, which is also indicated by glacifluvial complex of Batomalj in the vicinity of Gajevi.

The unit 3 is represented by cross-bedded massive breccias dipping slopewards at around 30°. At the base of unit 3 there are thinner clinoform beds downlaping on the unit 2 clacarenites. The breccias are composed of well packed angular debris, better sorted in thinner layers. Here occur numerous extrasize limestone clasts, and the tabular ones are imbricated down-slope or lay parallel to bedding dip, which indicates ice-marginal source of the debris.

Figure 6.23. Upper, presumably older, Gajevi kame terrase built of slopeward dipping (white lines) stratified diamicts. The NE slope of Baščanska Draga valley and Baška Bay are visible in background. Photo taken in 2006.

Slika 6.23. Gornja, vjerojatno starija, kame-terasa Gajevi izgrađena od stratificiranih diamikta koji su nagnuti prema padini (bijele crte). U pozadini se vidi SI padina Baščanske doline i zaljev Baške. Snimljeno 2006.

The upper Gajevi kame terrace (Fig. 6.23., 6.24.) is morphologically more pronounced terrace located about 100 m higher than the lower terrace. It is built of poorly to well-cemented stratified diamict (clast- to matrix-supported breccia, see Chpt. 5.1.), slopeward dipping at angle 10 - 30°. It is in general poorly sorted. The structure and sediment characteristics are typical of lateral dump moraine presented in Figure 6.18. (Small, 1983).

Figure 6.24. Detail of the upper Gajevi kame terrace. The breccia is slopeward -bedded with the dip angle of ca 30°. Photo taken in 2006.

Slika 6.24. Detalj gornjeg dijela kame-terase Gajevi. Uslojene breče su nagnute prema padini pod kutem od oko 30°. Snimljeno 2006.

Jurandvor kame terrace

Above Jurandvor in the Baščanska Draga valley there is morphologically prominent Jurandvor kame terrace, about 250 m long and about 200 m wide (Fig. 3.8.). It is traceable further along the valley slope (Fig. 6.25.) towards Baška for about 1 km, but with interruptions. It is located at about same altitude as the upper Gajevi kame terrace, and is of similar structure (Fig. 6.26.).

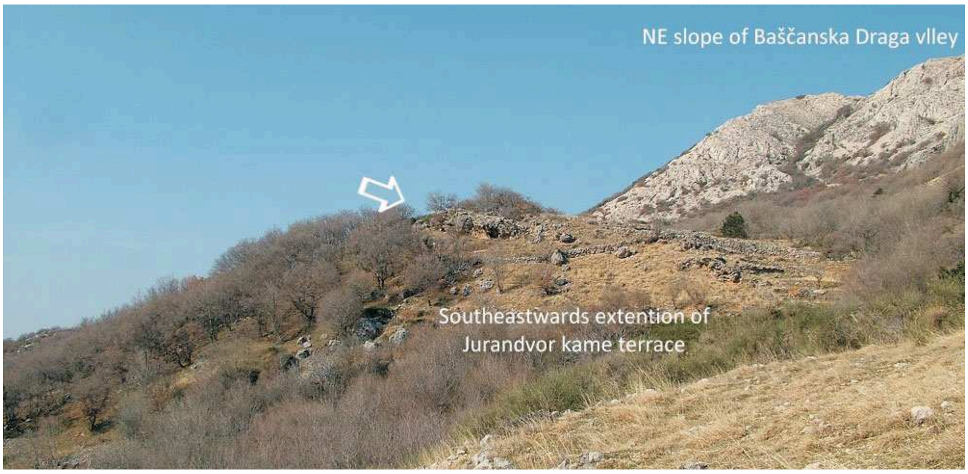


Figure 6.25. Part of preserved Jurandvor kame terrace further south-eastwards (loc. K(K)-3/5, Fig. 3.7.). Photo taken in 2004.

Slika 6.25. Dio očuvane kame-terase Jurandvor jugoistočno prema Baški (lok. K(K)-3/5, Fig. 3.7.). Snimljeno 2004.

The terrace is built of coarse-grained poorly-sorted calcirudites (breccia type diamict lithofacies), locally interbedded with cross-bedded coarse-grained calcarenites. The sediments dip slopeward at an angle of 30-40°, and attain maximal visible thickness of 45 m. There are abundant cobles and metre-sized blocks. The bed thickness seams to decrease upwards. In the top section there is 2 m deep sediment wedge, probably representing an ice-wedge cast. The wedge sediment is gravelly coarse-grained calcarenite with "fluidal" structure. The calcirudites are generally clast-supported, mainly with open-work structure which is locally infiltrated with sand. The ice-shattered clasts are common. In the zone of kame terrace also occur mega-blocks (see Chpt. 6.1.3.).

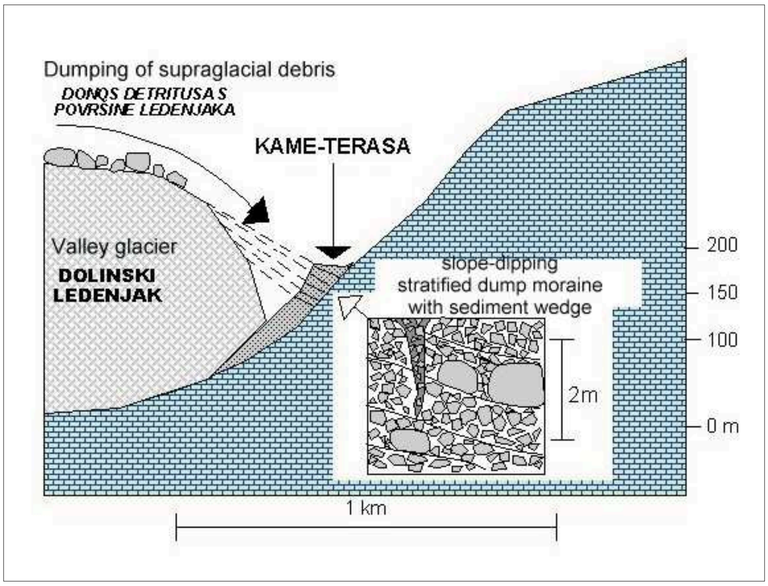


Figure 6.25. Shematic reconstruction of the origin and structure of the Jurandvor kame terrace, from Marjanac & Marjanac (1994).

Slika 6.25. Shematski prikaz nastanka i građe kame-terase Jurandvor, iz Marjanac & Marjanac (1994).

Interpretation

The kame terraces studied in Baščanska Draga valley display common facies association which compose three allostratigraphic units best developed in the Gajevi kame terrace, and partially recognized at Batomalj and Jurandvaor. Commonly recognized is the unit 1 representing a "lateral dump moraine". The second glacifluvial unit is not so well developed but exists at all locations. It is more pronounced in the Gajevi kame terrace (log in Fig. 6.21.), while at Jurandvor and Batomalj kame terraces this unit is apparently represented by braided stream deposits.

This unit represents a period of extensive growth of a typical kame terrace with fluvial, lacustrine or alluvial deposition, occurring by intensified ice melt and increased melt-waters discharge. The unit 3, defined at the lower Gajevi kame terrace, represents another period of lateral dump moraine acummulation, which may indicate previous glacier avance phase and erosion of the kame terrace deposits. This third unit is not recognizeable at Jurandvor or Batomalj, meaning that it did not exist or it was eroded.

According to altitude of each terrace, reconstructed in Figure 6.26., along four topographic cross-sections, the upper Gajevi and Jurandvor terrace are considered time-equivalent, and represent the same phase of glacier stagnation with seasonal melting when "lateral dump moraines" were acummulated.

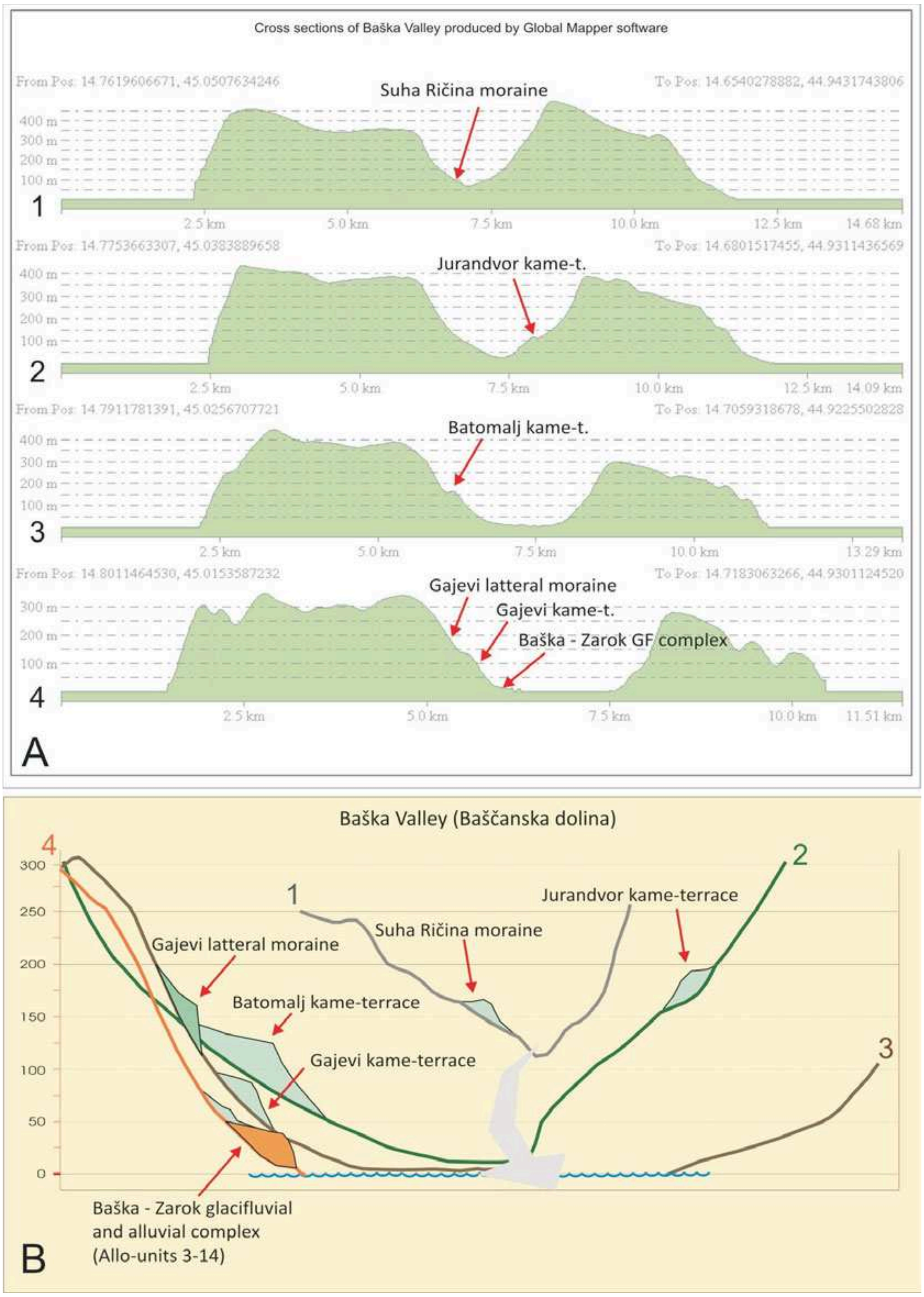
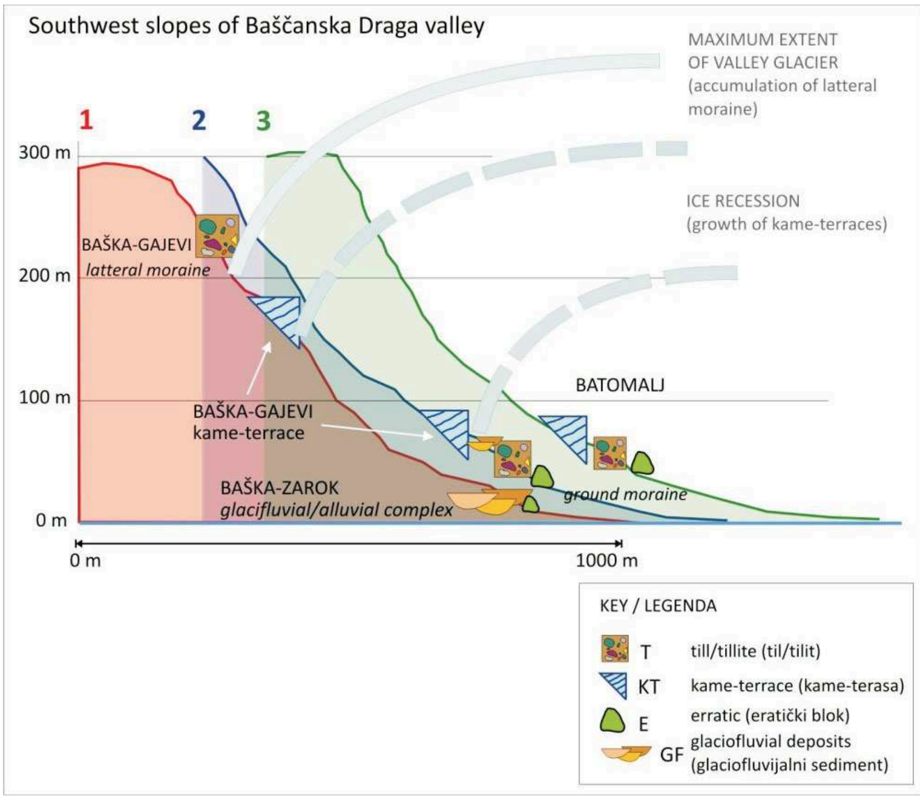


Figure 6.26. Locations and altitude of the kame terraces Jurandvor, Batomalj and Gajevi, and associated moraine of Suha Ričina and glacifluvial-alluvial complex of Baška Zarok. A - Four spaced topographic cross-sections of Baščanska Draga valley display its low U-shape morphology. Vertical exaggeration is 10X. The terraces are well pronounced in cross-profile topography. Red arrows point at locations of particular kame terrace and associated sites. B - Sorted cross-profiles with attached kame terrace sedimentary bodies of estimated size, show their possible correlation across the valley. Grey arrow shows seawards valley gradient.

Slika 6.26. Položaj i nadmorska visina kame-terasa Jurandvor, Batomalj i Gajevi, kao i pridruženih morena Suhe Ričine i glacifluvijalno-aluvijalnog kompleksa Baška - Zarok. A - Četiri topografska profila okomita na pružanje Baščanske doline pokazuju njen blagi U-profil. Vertikalno povećanje je oko 10X. Terase se dobro ističu u topografiji poprečnih profila. Crvene strelice pokazuju položaj pojedinih kame-terasa i pridruženih lokaliteta. B - Poprečni profili prikazani prema nadmorskoj visini, s dodanim sedimentnim tijelima pretpostavljene veličine, ukazuju na njihovu moguću prostornu korelaciju. Siva strelica prikazuje gradijent doline prema moru.

Figure 6.27. Reconstruction of different phases of glacier conditions based on characteristic and distribution of kame terrace sedimentary bodies in Baščanska Draga valley on the Krk Island.

Slika 6.27. Rekonstrukcija pojedinih faza stanja ledenjaka na osnovi karakteristika i distribucije sedimentnih tijela kame-terasa u Baščanskoj dolini na otoku Krku.



The Batomalj kame terrace presumably represents a younger phase, and the lower Gajevi kame terrace represents the youngest phase of glacial recession, and accumulation in lateral to termino-lateral proglacial zone. The lower Gajevi terrace is probably related to glacifluvial complex of Baška - Zarok, described in Chapter 5.2.2., but their relationship will be cleared after further dating of sediments. Nevertheless, at least three phases of glacier conditions can be envisaged, as shown in Figure 6.27.

6.1.2.2. Kame terraces of Pag Island

Kame terraces of the Pag Island occur between 10 and ca 100 m a.s.l., and are best preserved at three locations (7, 8, and 9, Fig.6.20.), but only Bošana and Pag were studied in detail. They differ very much form those on Krk Island, because of much thicker and better preserved glacifluvial units, specially characteristic for Bošana and Crnika that are parts of the same kame terrace. The erosional remnants of the kame terraces at locations Metajna, Gradac, and Gorica are basically similar to Batomalj, Jurandvor and upper Gajevi kame terraces. The kame terraces are located along the slopes of inner Pag Bay (valley) also striking NW-SE as does the Baščanska Draga valley on the Krk island.

The bedrock of kame terraces on the south-west side are Cretaceous limestones which form steep slopes (40-80°), while at Metajna the kame terrace deposits overlay Tertiary “flysh” and limestones. The “flysch” deposits are easily eroded and caused generally high degradation of the kame terrace.

Metajna kame terrace

Only briefly studied Metajna kame terrace is located along a rather steep slope of northeast side of the Pag Bay, between 50 and 100 m a.s.l., and is rather poorly preserved. It is predominantly built of 20 m thick bedded breccia (diamict lithofacies), inclined slopewards at ca 30°. Laterally, at distance of about 500 m, it consist of cross-bedded calcirudites (Fig. 6.28.), up to 10 m thick, with very gentle to more pronounced slopeward dip. The breccias are clast-supported with open-work structure, poorly cemented with common spary calcite cement of “A”-generation.

The interval of bedded breccias (diamicts) is interpreted as the lateral dump moraine, equivalent to the allostratigraphic unit 1 of Gajevi, Jurandvor and Batomalj kame terraces. The cross -bedded breccias are braided stream deposits and represent glacifluvial unit of the kame terrace, equivalent to the allo-unit 2 of the lower Gajevi kame terrace.

Figure 6.28. Metajna kame terrace viewed from the southeast towards Metajna village in the background. Cross-bedded and massive calcirudites (breccias) gently dip slopewards to the right. They overlay the Tertiary “flysch” marls that, due to their low consistancy, cause fast degradation of the better cemented kame terrace deposits. Photo taken in 2008.

Slika 6.28. Metajna kame-terasa gledana s jugoistoka prema Metajni u pozadini. Koso slojeviti i masivni kalkruditi (breče) blago su u desno nagnuti prema padini. Leže na tercijarnim fliškim laporima, koji zbog svoje slabe konzistencije i brže erozije, uzrokuju brzu degradaciju bolje cementiranih naslaga kame terase. Snimljeno 2008.

Bošana - Crnika kame terrace

The Bošana - Crnika kame terrace is well preserved along the SW slope of the Pag Bay NW-wards of the Pag town (Fig. 3.40.). It represents a typical kame terrace by definition, built of thick succession of glacifluvial gravels and sands with valley-longitudinal transport. This glacifluvial complex was studied in detail and is presented in the Chapter 5.2.2.3. on glacifluvial deposits. Such a thick sedimentary sequence must represent a very long period of acummulation, as later indicated by tentative chronostratigraphic correlation with other sites. The sediments deposited while the glacier occupied the Pag valley (Fig. 6.29.), thus it is expected that stagnation phase lasted for a longer time.

Since these deposits are poorly cemented, or uncemented, they were postglacially eroded and a lot of sediment was redeposited in younger alluvial fans that are locally preserved. Further investigation and dating of sediments may give more reliable data for correlation with other kame terraces.

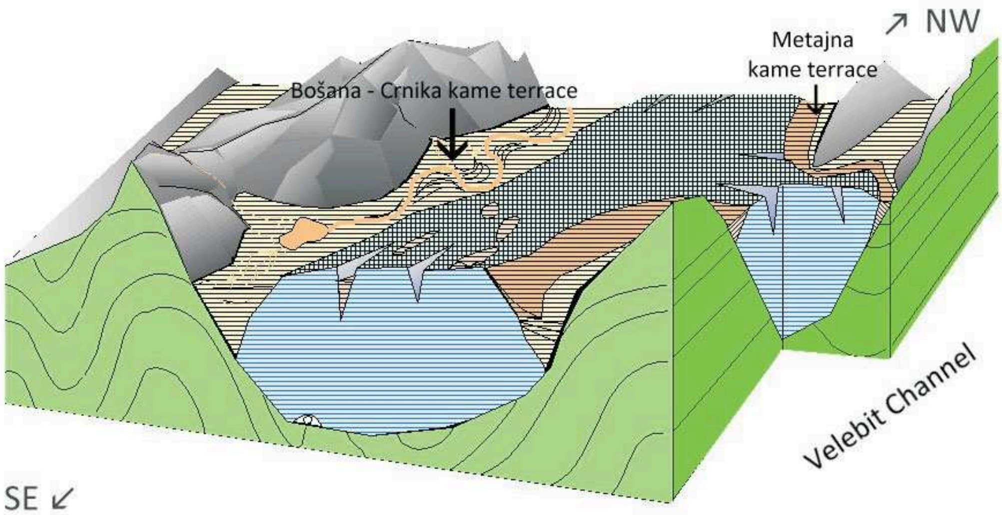


Figure 6.29. Paleoenvironmental and depositional model of the Bošana - Crnika and Metajna kame terraces on the Pag Island. The model covers the area NW of Pag town that is part of Pag Bay, which was a glacial valley.

Slika 6.29. Model peleookoliša i taloženja kame terasa Bošana - Crnika i Metajna na otoku Pagu. Model obuhvaća dio Paškog zaljeva SZ of grada Paga, koji je bio ledenjačka dolina.

Pag - Gradac kame terrace

The Gradac kame terrace is morphologically prominent terrace located on the southwest slope of the Pag Bay in the vicinity of Pag town between 50 and 100 m a.s.l. (Fig. 3.49.). The terrace is about 60 m high, with a flat vegetated top of about 50 m^2. The terrace is built of about 50 m thick succesion of breccias partly shown in sediment log K(P)-24-L1 (Fig. 6.30.), thin to thick bedded (0.5 - 2 m), dipping at 35° (226/36 to 302/32) southwestwards towards the steep valley slope (Fig. 6.31.). Direct contact with locally subvertical slope of the Pag Bay is clearly visible.

The breccias are monomict, predominantly composed of angular to subangular carbonate debris. Large subrounded blocks, 1 to 3 m in diametre are common and enclosed in thicker (over 1 m) breccia beds. In the lower section occur poorly sorted breccias with mega-blocks (Fig. 6.32.).

Two types of breccia occur, clast-supported and matrix-supported. The clast-supported are commonly with open-work framework, varying from fine-grained calcarenite to dominantly

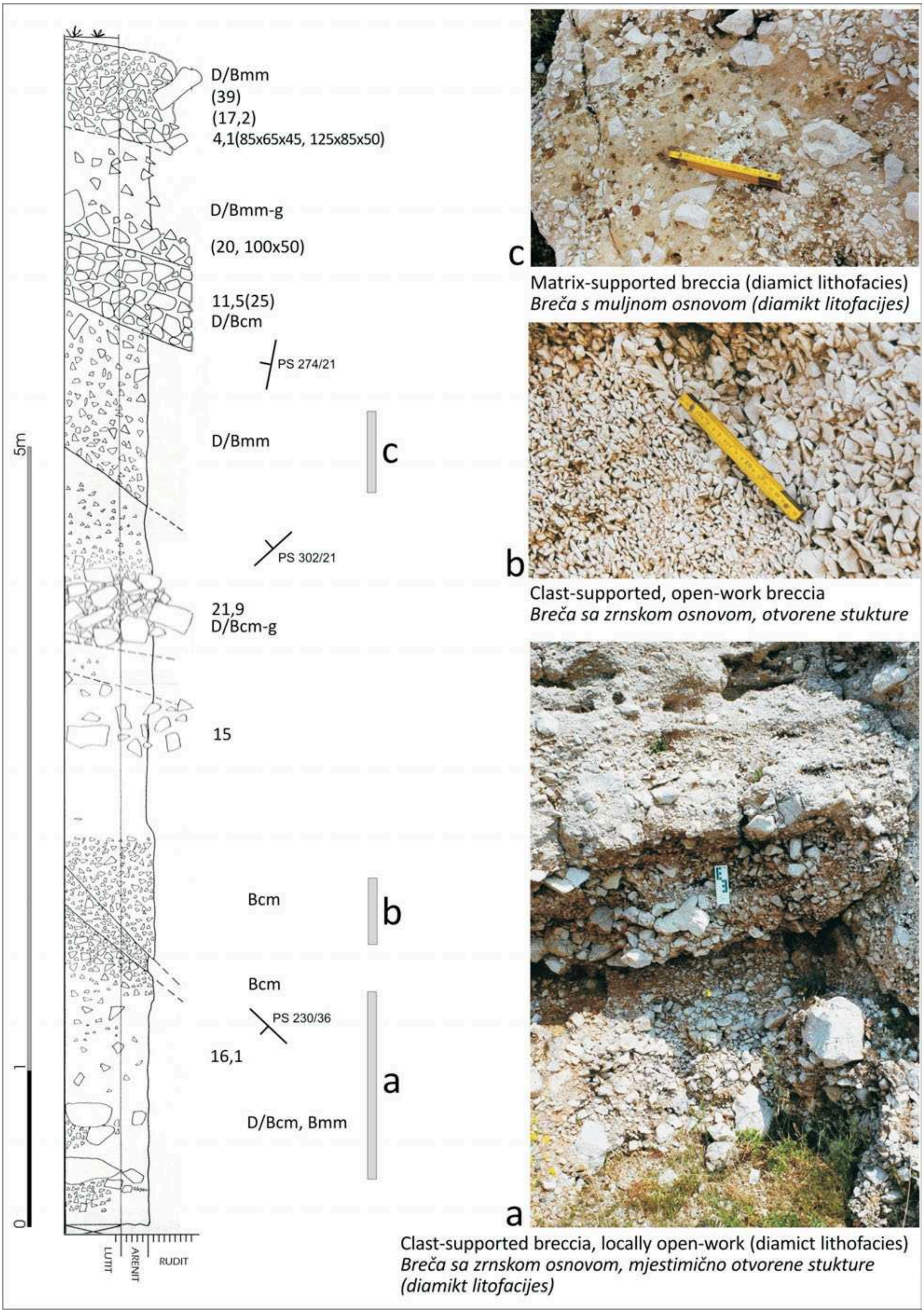


Figure 6.30. Sediment log K(P)-24-L1of Gradac kame terrace. Sediments are poorly to well sorted breccias.

Slika 6.30. Sedimentološki stup K(P)-24-L1 prikazuje građu kame-terase Gradac. Sedimenti su slabo do dobro sortirane breče.

Figure 6.31. Kame terrace Gradac composed of massive bedded breccias. Their slopeward dip constrasts the opposite dip of valley slope. Photo taken in 1989.

Slika 6.31. Kame-terasa Gradac izgrađena je od uslojenih masivnih breča. Njihov nagib je potpuno suprotan of nagiba padine Paške doline. Snimljeno 1989.

coarse-grained calcirudite. Some beds are massive normally to inversly graded and consist of well sorted angular splinter-like debris (Fig. 6.30-b), but in lower section occurs poorly sorted massive breccia (diamict type) with larger subrounded or even faceted boulders (Fig. 6.30-a). The breccias are partly cemented by “A”- generation spary calcite in places of grain-to-grain contact. The matrix-supported breccia is well cemented, with angular to subrounded debris of average clast size 0,5-10 cm. The matrix is carbonate silt or mud that probably represents a secondary infill.

The Gradac kame terrace sediments are interpreted as lateral dump moraine. Its base is poorly exposed and it is possible that the oldest sediments is even marginally subglacial due to scarce faceted and subrounded boulders. The younger beds composed of well sorted debris indicate intensive wash-out by ice-surface melt-waters which could have resorted the fine supraglacial angular debris

Figure 6.32. Northwest side of the Pag - Gradac kame terrace. Bedded breccias dip slopewards to the southwest. In the lower section occur poorly sorted breccas (diamict lithofacies) with common mega-blocks. One framed on the left side is shown in detail photo. Photos taken in 1989 and 2006.

Slika 6.32. Sjeverozapadna strana kame-terase Pag - Gradac. Uslojene breče nagnute su prema padini u smjeru jugozapada. U donjem dijelu nalaze se slabo sortirane breče (diamikt litofacijes) s čestim mega-blokovima. Jedan označen okvirom prikazan je na detaljnoj fotografiji. Snimljeno 1989. i 2006.

deposited as lateral moraine. This dump moraine unit is comapreable with the allo-unit 1 of the Gajevi and Jurandvor kame terraces on the Krk Island.

An extentension of the kame terrace Gradac occurs at Stari Grad further southeastwards. There occur stratified breccias horizontally or cross-bedded, inclined slopewards at 4-10°, exceptionally up to 25°, and the bedrock relief is more smooth with less steep slopes. The breccias are composed of sharp angular detritus with many platy and imbricated clasts with average grain size of 2-5 cm., but larger clasts 10 cm - 1 m in size also locally occur. The breccia is poorly sorted, although finergrained detritus is better sorted. The sediment is locally poorly graded and predominantly of open-work structure, and medium to well cemented. An interval of massive and wavy laminated sands (unconsolidated calcarenites) occurs within breccias. The calcarenite interval consists of a massive gravelly sand layer, massive gravelly silty sand and 50 cm thick laminated sand-silt varve-like package (alternation of yellowish sand and redish clayey sand).

The breccias were deposited in braided streams and in a smaller lake, indicating more typical kame terrace depositional environments, glacifluvial and glacilacustrine.

Still preserved patchy occurrences of kame terrace deposits are also found on the other side of the Pag cannal near Gorica (Figs. 3.53., 3.54., 6.33.), oposite of Gradac and Stari Grad. It is located at the altitude of 70 - 80 m a.s.l.. There occur cross and trough-cross bedded calcarenites and calcirudites (breccias) which were also deposited in braided streams, and represent glacifluvial kame terrace paleoenvironment.

Figure 6.33. Southwestwards view of the Pag Canal photographed from the Gradac terrace. It displays the low U-shape of a glaciated valley. On the left side is Gorica kame terrace and on the right side is margin of Gradac kame terrace. Photo taken in 1989.

Slika 6.33. Pogled na Paški kanal prema jugozapadu, snimljen s terase Gradac. Uočljiv je niski U-profil glacijalne doline. Na lijevoj strani se nalazi kame-terasa Gorica, a desno je rubni dio kame-terase Gradac iznad Paga. Snimljeno 1989.

6.1.3. ERRATICS

Erratics, usually large boulders, are considered as most certain evidence that an area was glaciated. In the studied area they occur on the Krk, Rab and Pag islands and on southern Velebit Mt. (Fig. 6.34.). Erratics are known to be of exotic lithology not matching the lithology of bedrock at place of their occurence, but in the studied area it is often not the case, due to regional geological framework with predominating Mesozoic carbonate rocks and same lithologic member can cover large areas.

The erratics can be extremely large, though they were transported by ice for tens, even hundreds of kilometers. In the area such as coastal Dinarides in Croatia, which are predominantly built of carbonate rocks (Triassic dolomites, Jurassic and Cretaceous limestones) it is very hard to distinguish exotic lithologies. All erratics are limestone boulders, commonly of the same lithology as the bedrock. Therefore, it was important to eliminate all other possible mechanisms of their emplacement before appending this interpretation. The erratics shown in Figures 6.35. and 6.36. are found at places with no background high relief, so processes like rock-fall or avallanching are excluded. Those boulders usually stand on karstified surface or a pile of small boulder debris. Detailed investigation of their source area, which would include lithological and stratigraphical determinations, was not performed for this study, and only macroscopic characteristics were accounted besides position of their occurrence.

The erratics commonly occur in the area of southern Velebit, but have not been recognized as such by previous researchers. These isolated blocks sitting at exotic positions have local name "*čučavac*" (a squating rock), and are assumed to originate by erosion of local rocks, particularly

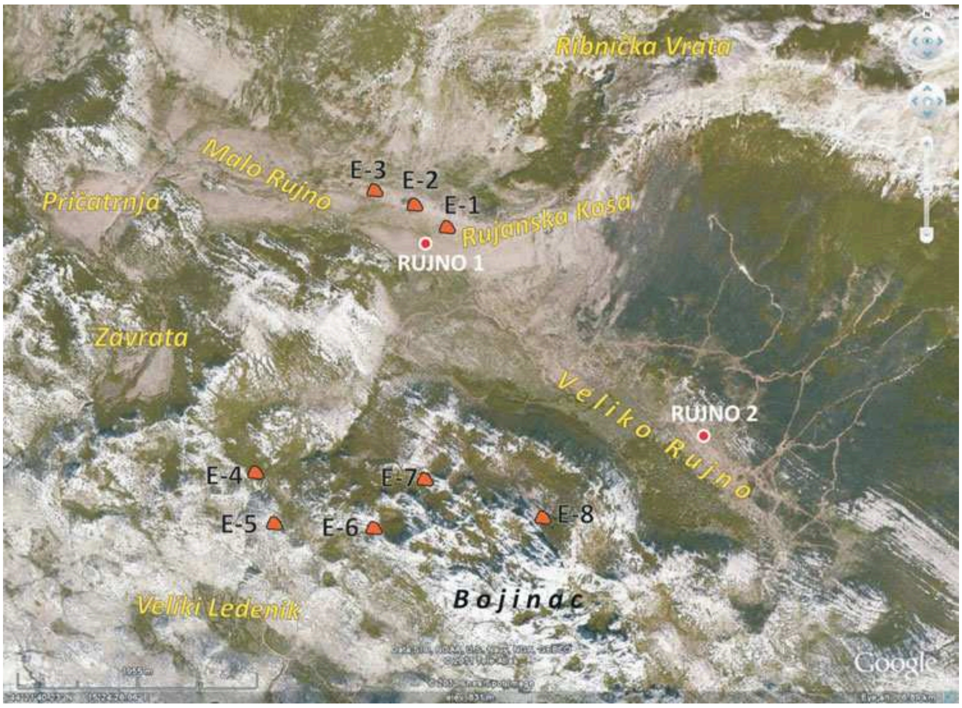


Figure 6.34. Erratics of the Rujno area.

Slika 6.34. Eratici na širem prostoru Rujna.

Jelar-breccia. Such also exist in the study area and can be differentiated from those herein interpreted as erratics.

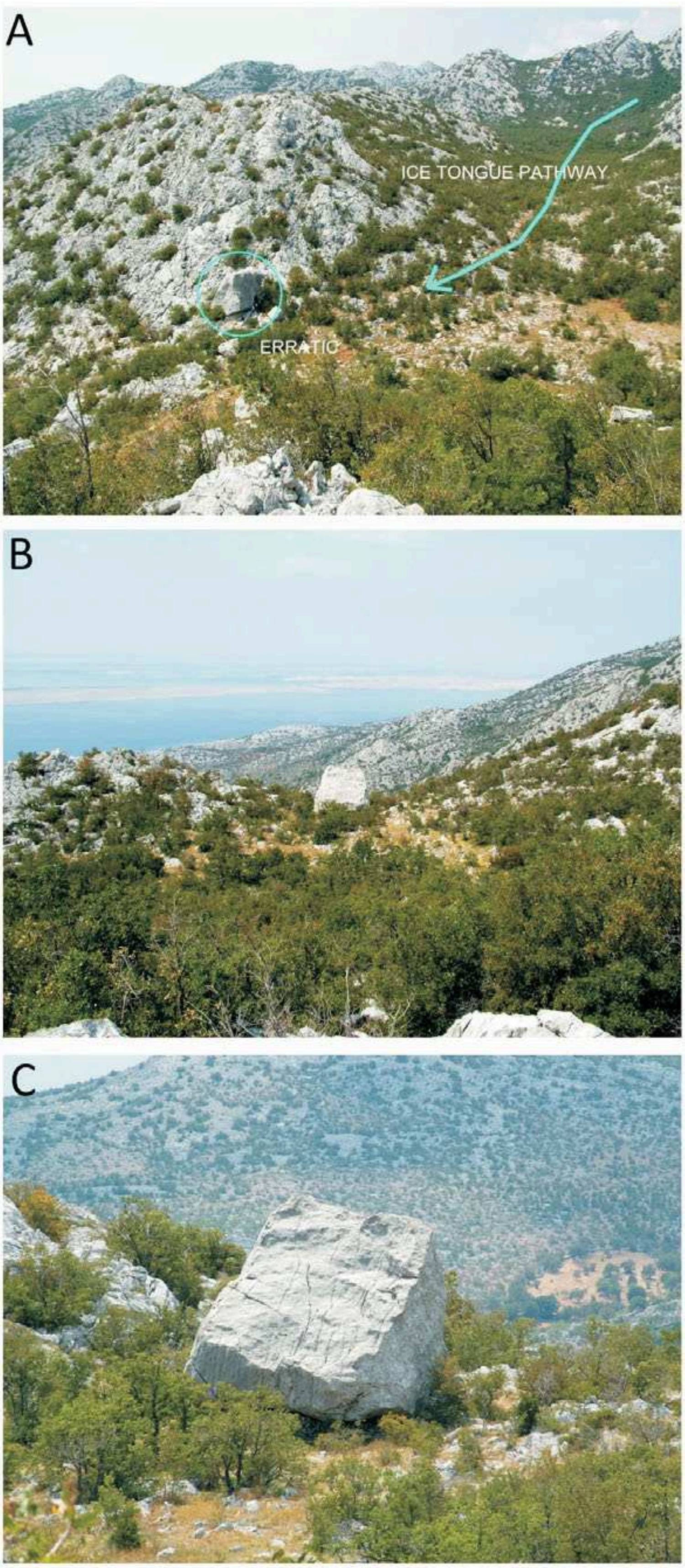


Figure 6.35. One of the very large erratics found in the vicinity of Rujno at location E4 at 581 m a.s.l. (Fig. 6.34.). It sits on smaller boulders, and does not match the local bedrock lithology that are Jelar-breccias. Its province are Jurassic limestones closest in Rujno valley. Figure A shows the path of a glacier from the Rujno area, which brought and left this erratic at the edge of the vlley (B), above a steeper slope. It is 10x14x15 m large. Photo taken in 2004.

Slika 6.35. Jedan od vrlo velikih eratičkih blokova nađen u blizini Rujna na lokaciji E4 na 581 m nadmorske visine (Sl. 6.34.). Sjedi na sitnijim blokovima u čijoj podlozi su Jelar-breče. Eratički blok po litologiji ne odgovara podini, već potječe iz kompleksa jurskih sivih vapnenaca, koji su najbliže na Rujnu. Na slici A je označen put ledenjaka koji je iz pravca Rujna donio i ostavio eratički blok na rubu doline iznad strmije padine (B). Blok je dimenzija 10x14x15 m. Snimljeno 2004.

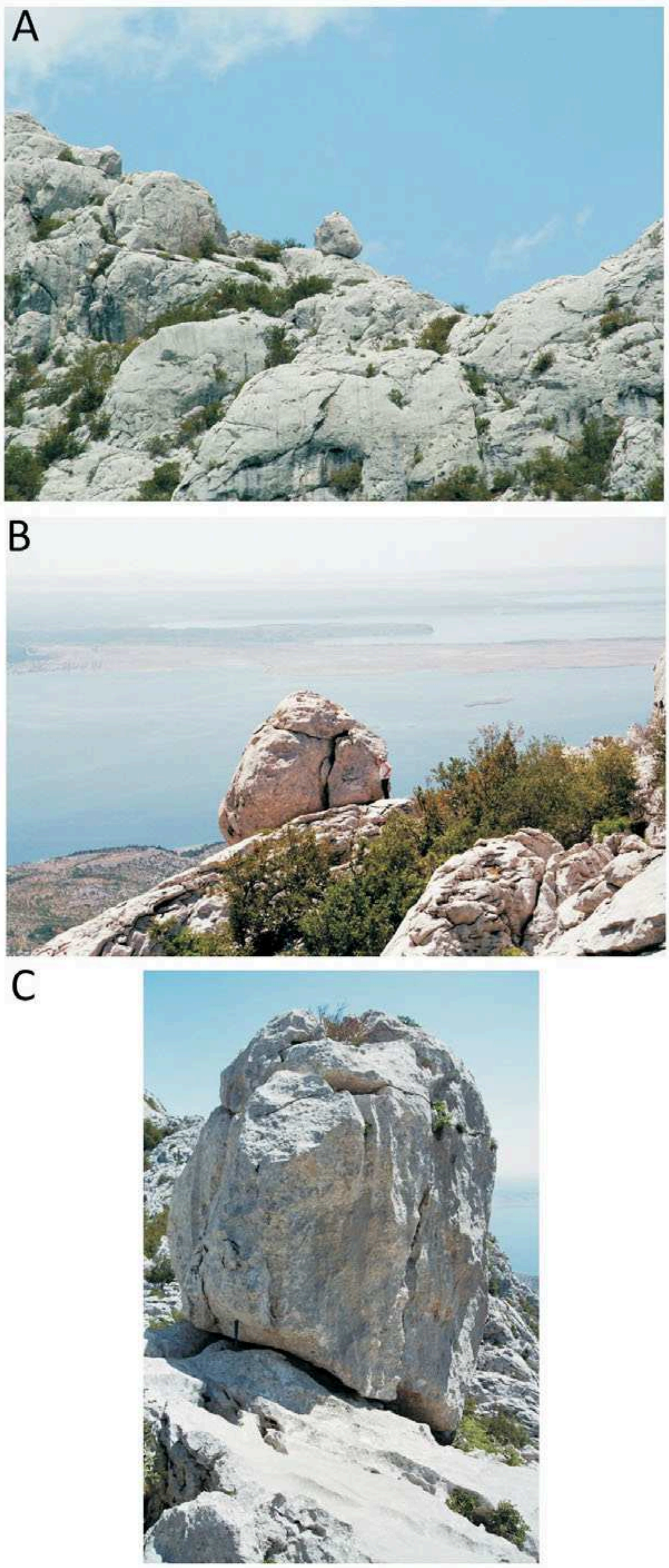


Figure 6.36. Erratic boulder at location E5 (Fig. 6.34.) at 850 m a.s.l., sitting at the edge of a steep slope (A, B) over karstified bedrock made of the Jelar-breccia (C), and was also brought by ice which came from the Rujno area. It's volume is ca 84 m^3. Photo taken in 2004.

Slika 6.36. Eratički blok na lokaciji E5 (Fig. 6.34.), na visini od 850 m. Blok se nalazi na rubu strme padine (A, B), povrh okršene Jelar-breče (C), a donesen je ledom iz smjera Rujna. Volumen mu je oko 84 m^3. Snimljeno 2004.

In the area of Rujno and its surroundings, erratics are found between 500 and 900 m a.s.l., and rest on karstified (fluted) rock surfaces usually on a topographic high (Figs. 6.35. and 6.36.). Many sit on the surface of the Rujanska Kosa moraine ridge (morainal body 1, Fig. 6.11.).

Extra-large mega-blocks, interpreted as erratics, are also located in the zone of the Jurandvor kame terrace in Baščanska Draga valley on the Krk Island, and one is shown in Figure 6.37.. Their size is about 10 m across. The one in figure bellow is Lower Eocene Alveolina Limestone, and was split in two parts probably during the transport. Its bottom surface is polished, striated and grooved, and appears wavy. Valley-longitudinal transport is indicated. The mega-block sits on sheared diamict, which is the matrix-supported breccia-conglomerate, possibly subglacial till.

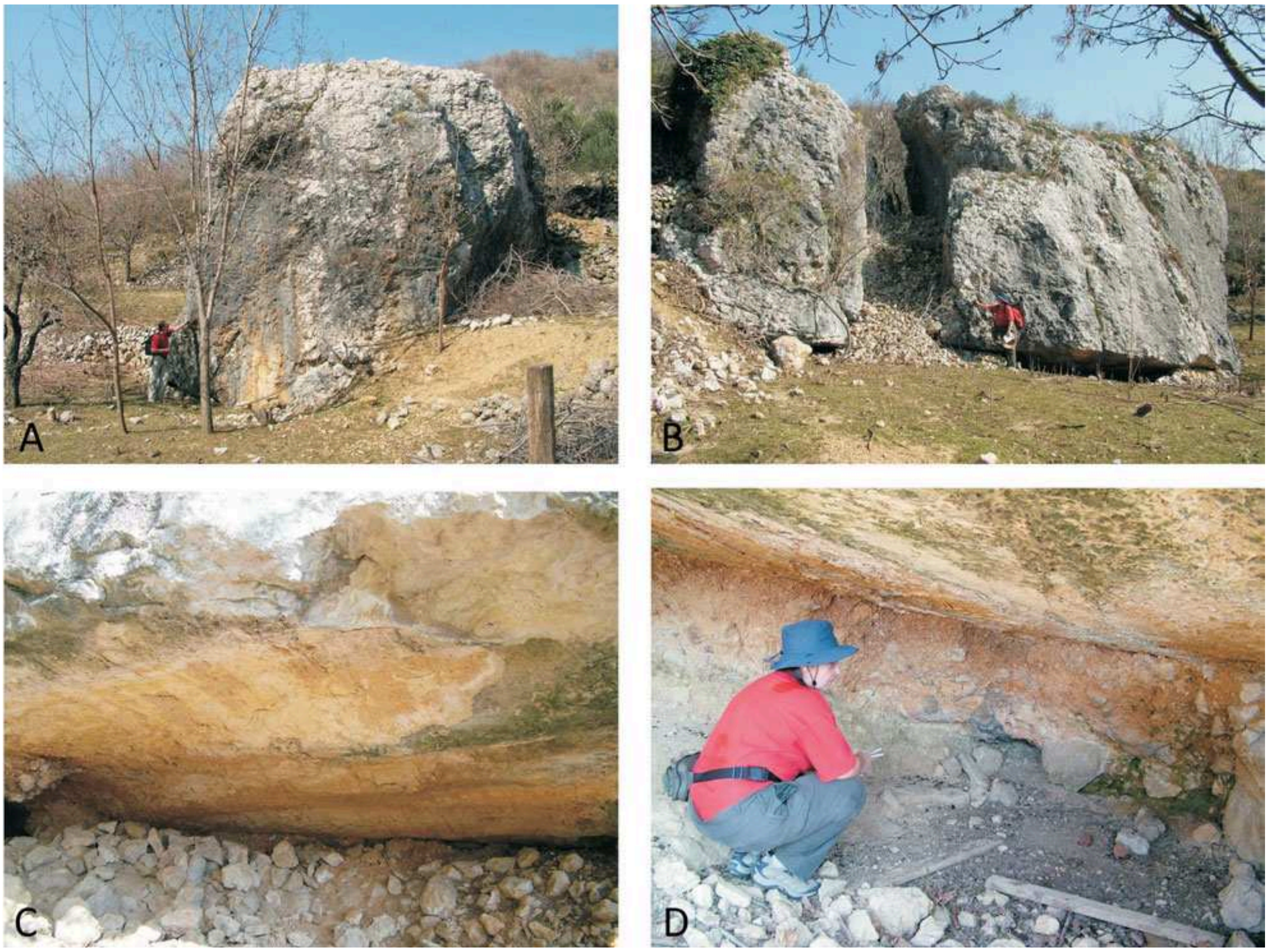


Figure 6.37. The largest erratic block found in the Baščanska Draga valley in the zone of Jurandvor kame terrace. It is 9 m high, 6 m wide (A) and ca 8 m long, but split in two parts (B). Its bottom surface is polished and wavy because it is grooved (C). The block sits on sheared matrix-supported diamict (C). Photo taken in 2007.

Slika 6.37. Najveći eratički blok nađen u Baščanskoj dragi u zoni kame-terase Jurandvor. Visok je 9 m, širok 6 m (A) i 8 m dugačak, ali raspolovljen (B). Donja ploha je polirana, i ima ledenjačke strije i žljebove zbog kojih izgleda valovito (C). Blok sjedi na diamiktu s muljnom potporom (C) s tragovima smicanja zbog pritiska pri transportu. Snimljeno 2007.

6.2. GLACIAL EROSIONAL LANDFORMS

Erosional features have many times been crucial for glacial or non-glacial interpretation of sediments or glaciated or non-glaciated relief, although were not the main object of this study. Therefore, these features are briefly presented because of their importance for the future research.

Ice-striated, -faceted or -polished clasts are small-scale erosional features produced by glacial abrasion that were observed in sediments of ancient glacial depositional environment in the study area. Glacial striae are major diagnostic criterion for glacigenic interpretation of studied diamicts. Ice-striated clast (Figs. 5.56., 5.76 - 79, 5.83., 5.108.) and ice-shattered clasts (Figs. 5.33 - 34, 5.80., 5.94., 5.107.) were found in diamicts at nearly all studied locations, as well as characteristically shaped clasts (Figs. 5.71., 5.72., 5.93.), all described in the Chapter 5. Isolated washed-out striated boulders were ocassionally found scattered in the field (Fig. 6.38.).

Figure 6.38. Boulder with glacial striae found in area of Stap, northwestwards of Rujno. Photo taken in 2008.

Slika 6.38. Blok s glacijalnim strijama nađen na području Stapa, sjeverozapadno od Rujna. Snimljeno 2008.

Among large scale erosional features, there is evidence of subglacial bedrock polishing on the Pag Island, on small island Ravnik in the Velebit Channel (Fig. 3.56.), and in the Veliko Rujno valley (Fig. 6.39.). Those areas are flat polished surfaces, slighly corroded due to wethering. Both on the Pag Island and in Veliko Rujno valley the glacier has sculptured terrain with steep-dipping bedded limestones, and polished it. Patches of those glacial pavements are today uncovered as illustrated in Figure 6.39..

Locally preserved effects of ice-scouring and polishing of valley slopes are visible on the Pag Island at Bošana in the gravel pit (Appx. 5.3.), and several places in Velika Paklenica, where traces of horizontal ice-scouring are preserved on subvertical rock-wall of the Anića Kuk (Fig. 6.40.). Many such surfaces are recognizeable in Velika Paklenica zone, although they are subjected to postglacial weathering processes. Large scale striations are preserved in Libinje (700 - 800 m a.s.l.) eastwards of Velika and Mala Paklenica, where typical ice-shaped relief is visible (Fig. 6.41.).

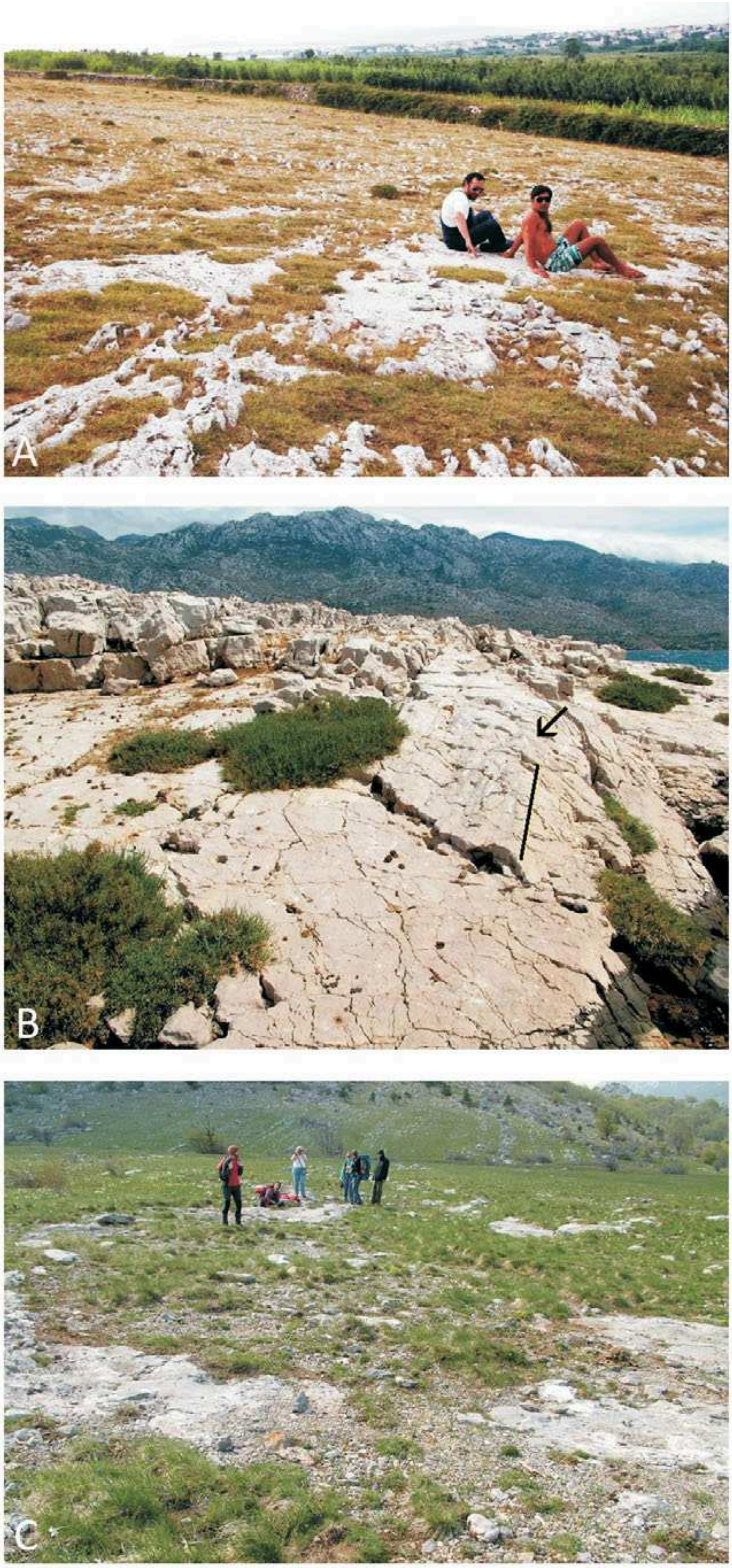


Figure 6.39. Glacially eroded and polished surfaces - glacial pavements.

A - Flat topography between Povljana and Stara Povljana on the Pag Island has been ice-eroded and polished. Bedded limestones of the bedrock dip at angle of 50 - 70°. Photo taken in 1989.

B - A larger polished and faintly striated surface is exposed on the islet Ravnik in the Velebit Channel, which is built of gently dipping to horizontal thick-bedded limestones. Photo taken in 2008.

C - In Veliko Rujno valley there is ice polished horizontal surface of about 100 m^2. Bedded Jurassic limestones that form bedrock of Rujno, have steep dips of 60 to 70°. This surface is mostly covered with thin layer of subglacial till, and uncovered areas are subjected to karstification. Photo taken in 2011.

Slika 6.39. Površine erodirane i polirane ledom - ledenjački pločnici.

A - Ravan reljef između Povljane i Stare Povljane na otoku Pagu nastao je ledenjačkom erpzijom i poliranjem. Uslojeni vapnenci u podlozi nagnuti su pod kutem od 50 - 70°. Snimljeno 1989.

B - Oveća polirana površina sa slabo istaknutim strijama nalazi se na otočiću Ravniku u Velebitskom kanalu, koji je izgrađen od debelo uslojenih vapnenaca, blago nagnutih do horizontalnih. Snimljeno 2008.

C - U dolini Velikog Rujna otkrivena je polirana površina oko 100 m^2. Uslojeni jurski vapnenci u podlozi strmo su nagnuti 60 - 70°. Ova površina je dobrim dijelom pokrivena tankim slojem podinske morene, inače je izložena karstifikaciji. Snimljeno 2011.

Figure 6.40. A remnant of horizontal ice-scouring is visible on the steep rock-wall of Anića Kuk in the Velika Paklenica Canyon. Photo taken in 2011.

Slika 6.40. Trag horizontalne erozije uslijed kretanja leda sačuvan je na litici Anića Kuka u kanjonu Velike Paklenice. Snimljeno 2011.

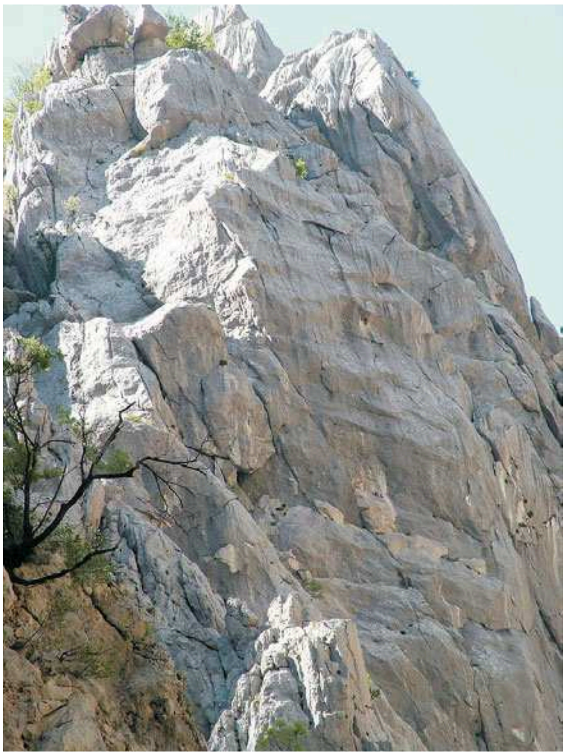
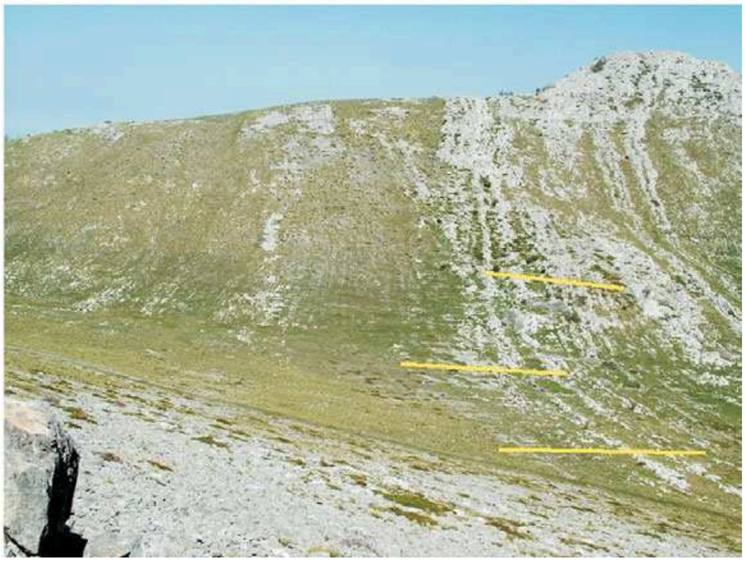


Figure 6.41. Glacially shaped relief of Libinje with wide low U-shape valley. Figure bellow shows the ice-scoured slope of the valley. Yellow lines indicate orientation of large striations and rock streams. Photo taken in 2010.

Slika 6.41. Glacijalni reljef šireg područja Blidinja sa širokom dolinom niskog U-profila. Na donjoj slici vidi se ledom obrađena padina. Žute linije ukazuju na orjentaciju strija i kamenih pruga. Snimljeno 2010.



Even “aerial scouring” (Benn & Eavans, 2010) is speculated upon observation of the Google Earth satelite images. Distinct lineations striking NE-SW are visible on the Google image of Northern Dalmatia (Fig. 6.42.), which do not correspond to any of regional tectonic faults, thus are assumed to be scours produced by the advancing ice (Fig. 6.43.). In the same area exist large surfaces ressembling glacial pavements (Fig. 6.44.). This assumption generally corresponds to the known glacier paths indicated in Figure 6.42..

Figure 6.42. Google Earth satelite image of the Northern Dalmatia. Frame indicates field of observation shown in Figures 6.43. and 6.44. The known paths of glaciers are indicated with arrows.

Slika 6.42. Google Earth satelitski snimak sjeverne Dalmacije. Okvir označava područje opažanja prikazano na slikama 6.43. i 6.44. Strelicama su prikazane poznate trase kretanja ledenjaka.

Figure 6.43. Close-up view of the box area in Figure 6.42. Possible glacial pavements as seen on Google Earth satelite image.

Slika 6.43. Detalj područja u okviru na slici 6.42.. Mogući ledenjački pločnik kako se vidi na Google Earth satelitkom snimku.

Figure 6.44. Close-up view of the box area in Figure 6.42.. Lineations striking NE-SW are assumed to be large scale ice scours formed during glacial advance.

Slika 6.44. Detalj područja u okviru na slici 6.42.. Lineacije pružanja SI-JZ moguće predstavljaju regionalne brazde nastale tijekom napredovanja ledenjaka.

A general remark on erosional features as evididence of Dinaric glaciation is that what is presented just opens a new field of investigation on regional scale and possibility to recognize many large scale features by analyses of satelite images.

6.3. PROGLACIAL AND PERIGLACIAL LANDFORMS

Sedimentological evidence of progalcial and periglacial landforms that existed in the studied area is found in sedimentary succession at Novigrad coastal section. They relate to small and large scale cryogenic processes (ice wedges, cryoturbations) in periglacial environments and features caused by rafting or grounded ice-blocks in a proglacial lake.

6.3.1. SEDIMENT WEDGES

The sediment wedges are common feature at the Novigrad section. In this thesis a general insite on their morphology, structure and sediment fill is given, while future detail research should give more details on their formation and chronology. They are interpreted as ice-wedge casts according to their morphology and structure, and associated facies.

The sediment wedges occur at three different horizons (Figs. 5.169/1, 5.169/2), and are probably of different age too. At the first horizon they are in glacilacustrine sediments, in the second horizon they are related to the younger Novigrad moraine M2, and in the third horizon they occur in glacifluvial sediments. Few wedges penetrated very deep, from paleosol to older Novigrad moraine M1 (Fig. 6.45.).

Their size, shape and sediment fill is greatly variable. The width as well as the depth of sediment wedges spans from a few tens of centimetres to several meters. They are wide or narrow V-shaped in vertical cross-section, and are elongated or irregular, as well as circular in plan view.

Host-sediment to most wedges are laminated calcarenites of either lacustrine or fluvial origin. Bending of laminae or stratification downwards along the wedge margins is commonly visible (Fig. 6.45., 6.46.), but locally they are cut strait by the wedge (Fig. 6.46.). This characteristic is rarely visible in coarse-grained host-sediment as in the case of flat-pebble conglomerate, where flat pebbles are vertically resorted along the wedge walls (Fig. 6.47.). The sediment wedge margins are usually well defined, and the infill is frequently subvertically “striated” (cf. Washburn, 1973, Fig. 3.14.) at least near the margins, and sometimes seem massive.

The sediment fill is different from one to another wedge, varying from fine-grained calcarenite or pebbly calcarenite (Fig. 6.48.) to coarse-grained rudite (pebble- to cobble-size gravel, or bouldery diamict) (Figs. 6.50., 6.51.), thus they can generally be grouped as fine-grained and coarse-grained wedges. The wedge infill depends on type of sediment that was deposeted above ice-wedges before they melted. So, some large wedges have paleosol inside (Fig. 6.45. right). A common characteristics of nearly all fine-grained sediment wedges is that sediment fill is well cemented, or just walls of the wedge are cemented and they are found hollow inside. Few wedges do not have any marginal cemented sediment, but are recognized just as cemented clacarenite dike with "fluidal" surface morphology (Fig. 6.49.). The wedges with coarse sediment infill do not have cemented margins, but they are defined by sharp change in grain size between the host-sediment and infill (Figs. 6.51., 6.52.). The coarsest infill is a clast-supported diamict composed of small boulders up to 20 cm in diameter, and very little sandy matrix (Fig. 6.5.).

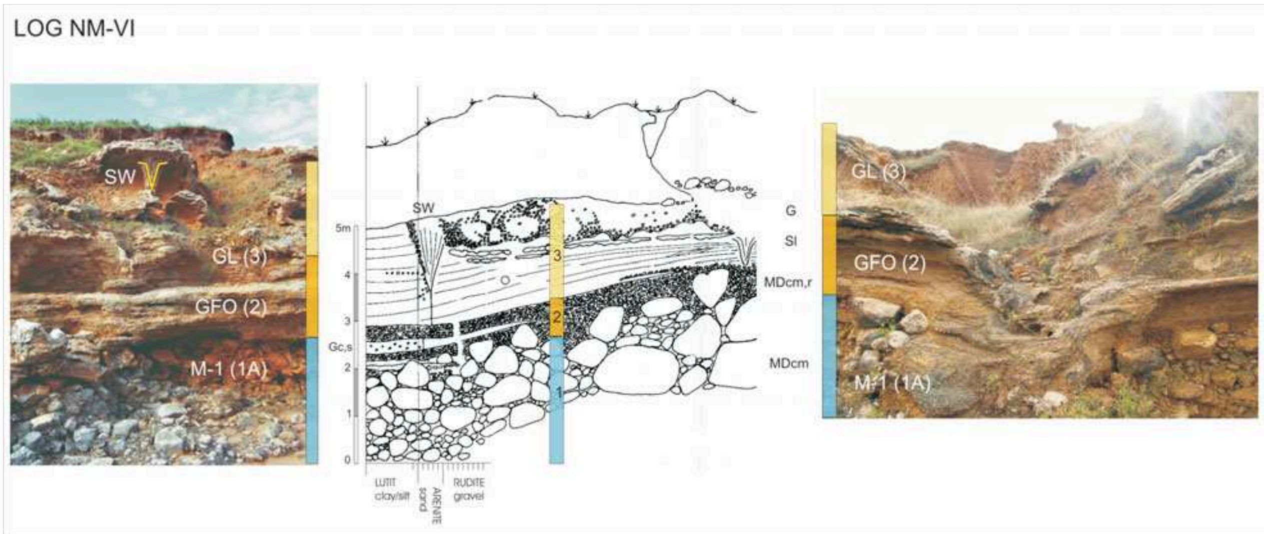


Figure 6.45. Sediment wedges in glacifluvial and glacilacustrine host-sediments. The one on the left is a smaller cemented wedge cast composed of fine-grained diamict. On the right, there is a very large wedge with unconsolidated infill that was more-or-less eroded. This wedge penetrated down to level of moraine-1.

Slika 6.45. Sedimentni klinovi u glacifluvijalnim i glacilakustrinskim sedimentima. Lijevo se vidi manji klin, cementirana sedimentna ispuna od sitnozrnatog diamikta. Desno je vrlo veliki klin s necementiranom ispunom koja je većim dijelom erodirana. Klin je prodro sve do nivoa starije morene-1.

Figure 6.46. Large sediment wedge in glacilacustrine sediments. The wedge fill is unconsolidated finegrained calcisiltite (probably paleosol) containing some dispersed debris. The walls are cemented, steep and irregular, and no downbending of host-sediment is visible. Photo taken in 2008.

Slika 6.46. Veliki sedimentni klin u glacilakustrinskom sedimentu. Klin je ispunjen finozrnatim kalcisiltitom koji sadrži raspršene klaste, a vjerojatno je paleosol. Zidovi su cementirani, strmi i nepravilni. Povijanje slojeva prema dolje nije uočljivo. Snimljeno 2008.

Figure 6.47.Sediment wedge in flat-pebble conglomerates of the glaciofluvial unit. The wedge is filled with finegrained cemented calcarenite with dispersed flat pebbles. The walls are cemented and clearly marked by a zone of subvertically oriented flat pebbles. Photo taken in 2007.

Slika 6.47. Sedimentni klin u konglomeratu s plosnatim klastima (2 - 5 cm) glaciofluvijalne jedinice. Klin je ispunjen sitnoznatim kalkarenitom s raspršenim plosnatim valuticama. Zidovi klina su cementirani, jasno istaknuti zonom subvertikalno orjentiranih plosnatih valutica. Snimljeno 2007.

Figure 6.48. Wedge-cast in glacilacustrine deposits. Sediment fill is cemented calcarenite with dispersed pebbles from overlaying conglomerate. Photo taken in 2007.

Slika 6.48. Sedimentna ispuna klina u glacilakustrinskom sedimentu. Sediment ispune je cementirani kalkarenit s raspršenim valuticama iz krovinskog konglomerata. Snimljeno 2007.

Figure 6.49. Fine-grained sediment wedge in Novigrad moraine-1, composed of calcisiltite and shows “fluidal” structure. The age of associated calcite cement is dated by U-series as of 146 ka BP.

Slika 6.49. Sitnozrnati sedimentni klin u Novigrad moreni-1. Ispuna je kalcisiltit s “fluidalnom” teksturom. Pridruženi calcitni cement izotopski je datiran na146.000 g. starosti.

The sediment wedges are associated with other types of proglacial deformations like various collapse structures that could not be defined due to degraded outcrops. In the upper horizon of the flat-pebble conglomerates, which is also the top level of the sediment wedge, occur sediment deformations, probably caused by gelifluction during presumably fast thawing of ice-wedges under sediment. Above the older Novigrad moraine-1 and close to the base of the large sediment wedge shown in Figure 6.45., occur dish-structures that are interpreted as cryoturbation (Fig. 6.53.). These characteristics clearly indicate an ancient proglacial to periglacial environment. The large wedges and collapse structures, as well as kettle-forms described later, can possibly resemble a period when occured transition from proglacial to periglacial climate, and after a period of ice-wedge thawing. The chornology is not yet clear, although the sediment wedge in Figure 6.49. is older than 146 ka BP as indicated by U-series age of the calcite cements associated with the wege.

Figure 6.50. Sediment wedge, ca 2 m deep, in glacilacustrine sediments bellow the younger Novigrad moraine-2. The wedge is filled with unconsolidated gravelly calcisiltite. The wedge walls are clearly marked with a cemented zone due to easier water percolation along the wedge walls. The overlying moraine eroded lake sediments and part of the wedge. Photo taken in 2006.

Slika 6.50. Sedimentni klin, oko 2 m dubok, nastao u glacilakustrinskim sedimentima ispod mlađe Novigradske morene-1. Klin je ispunjen necementiranim šljunkovitim kalcisiltitom. Zidovi klina su jasno istaknuti cementiranom zonom zbog lakše cirkulacije vode duž zidova klina. Morena-2 erodirala je kako jezerske sedimente tako i dio klina. Snimljeno 2006.

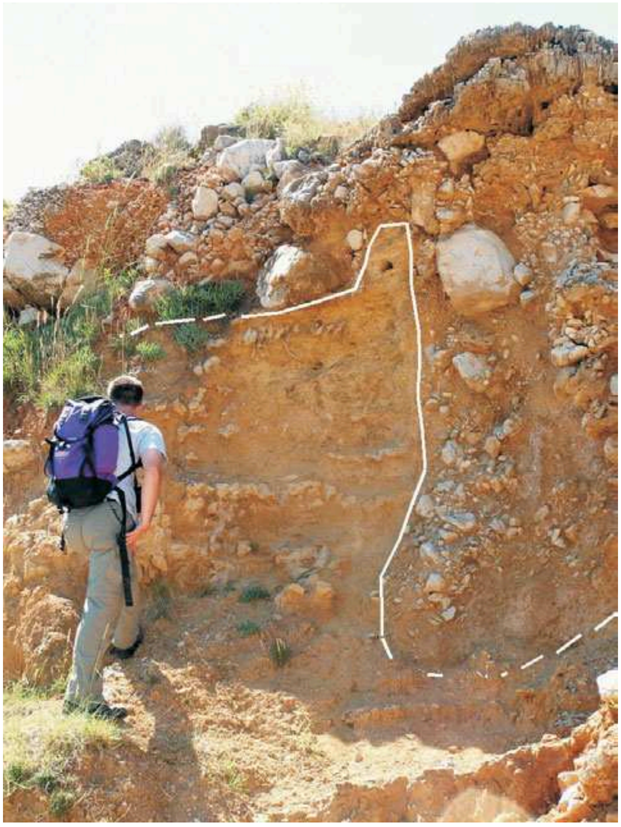


Figure 6.51. Sediment wedge in glacilacustrine sediments bellow younger Novigrad morane-2. The wedge is filled with coarsegrained matrix-supported diamict, possibly moraine material. There is clear margin between laminated lake sediments and the wedge sediment. Photo taken in 2006.

Slika 6.51. Sedimentni klin u glacilakustrinskim sedimentima ispod mlađe Novigradske morene-2. Klin je ispunjen krupnozrnatim diamiktom s muljnom potporom, moguće morenskim materijalom. Jasno se vidi kontakt laminiranog jezerskog sedimenta i diamikta koji čini ispunu klina. Snimljeno 2006.

Figure 6.52. Sediment wedge with irregular vertical walls, formed in glacifluvial to glacilacustrine sediments, photographed from side-view (left) and front-view (right). The wedge is filled with coarsegrained clast-supported diamict. There is clear margin between the stratified host-sediment and the wedge sediment. The scale is 1 m. Photo taken in 1989.

Slika 6.52. Sedimentni klin s nepravilnim vertikalnim zidovima, nastao u glacifluvijalnim i glacilakustrinskim sedimentima, snimljen bočno i sprijeda. Klin je ispunjen krupnozrnatim diamiktom sa zrnskom potporom. Jasno se vidi kontakt horizontalno stratificiranog sedimenta (desno) i diamikta koji čini ispunu klina. Mjerilo na slikama je 1 m. Snimljeno 1989.

Figure 6.53. Dish structures in glacifluvial sand-gravel sediments above the Novigrad moraine-1, found close to the base level of the large sediment wedge shown in Figure 6.45. The structure is interpreted as cryoturbation, which indicates an interruption in sedimentation. Photo taken in 2006.

Slika 6.53. Zdjelasta ("dish") tekstura u glacifluvijalnim pješčeno-šljunčanim sedimentima, u blizini baze velikog sedimentnog klina prikazanog na Slici 6.45. Tekstura je interpretirana kao krioturbacija, što ukazuje na prekid taloženja. Snimljeno 2006.

6.3.2. KETTLE-FORMS

Kettles are by definition rounded collapse structures formed by melting of burried ice blocks, and commonly filled with collapsed sediments. The fossil kettle-forms at the Novigrad section were first described by Marjanac et al. (1993). They are very simillar to modern kattles, but not all their characteristics are preserved, they are herein described as "kettles" *sensu lato*. They can be observed at several location in length of about one kilometer along the Novigrad Sea coast.

Kettles are circular dish-like depressions, one to three metres across and 0,5 - 1 m deep (Fig. 6.54.). They are restricted to the upper interval of the ripple-laminated calcarenites in the glaciolacustrine allo-unit3 of the Novigrad section, which is exposed at the SW part of coast (Fig. 7. /1).

Figure 6.54. Two cross-cutting profiles of a partly preserved kettle-form. Its bowl-shape is clearly expressed by cemented vertical wall and concave bottom. Photo taken in 2008.

Slika 6.54. Poprečni i uzdužni profil kotlića ("kettla"). Cementirani zid i dno ističu njegov zdjelasti oblik. Snimljeno 2008.

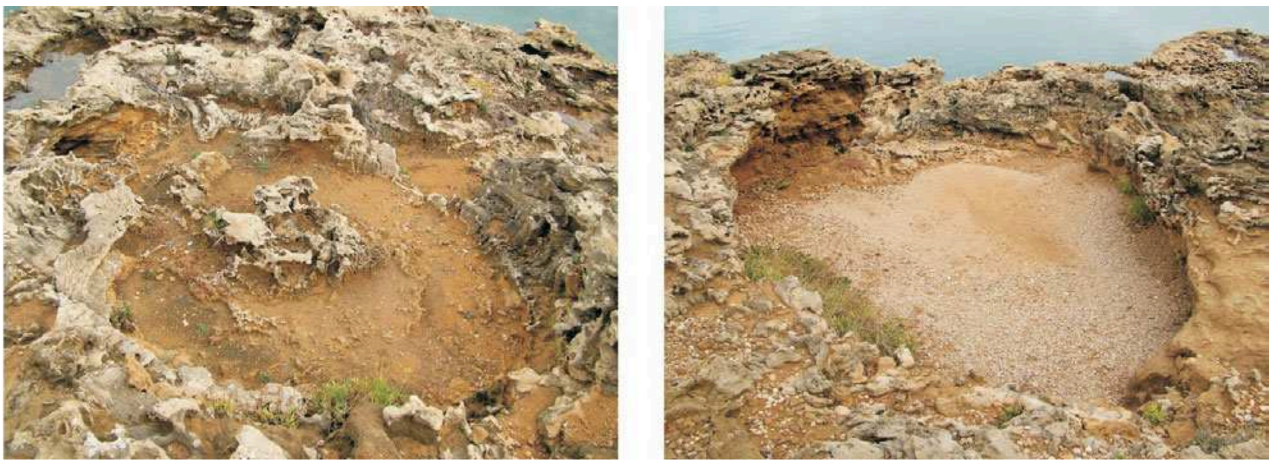


Figure 6.55. Circular kettles. The flat bottoms are cemented finegrained infills.

Slika 6.55. Kotlići ("kettlovi"). Zaravnjeno dno je cementirana sitnozrnata ispuna.

Kettles occur isolated, but also “grouped” and even stepwise connected. Their walls are subvertical or overhanged, while their bottoms are more-or-less or concave, but also flat (Fig. 6.55.). Kettles are commonly found hollow, sediment-empty, probably due to holocene erosional processes (Fig. 6.55.). The walls as well as the bottoms are composed of the well cemented fine-grained calcarenite appearing to be of chaotic massive structure. In the centre of two kettles there is a cemented “heap” of calcarenite (Fig. 6.55.). Only one kettle-form is exposed in vertical cross-section where its concave bowl-shape is clearly visible, and also the cemented chaotic structured clacarenite of the “bowl”.

Noticeable characteristic of the kettles are linguoid structures radially oriented along the kettle rim, commonly showing centrifugal dispersion of sediment. They are about 10 - 30 cm long. Exceptionally large ones (Fig. 6.56.) are found in form of ca 10 m long sheet of deformed sediment at the sea level bellow the sandy lacustrine interval. Such linguoid structures were evidenced by Bishop & Lindqvist (1987) as sand fingers or ephemeral mass-flow features resulting from rapid dewatering of sand-water suspensions by infiltration into porous substrate. This process could have occured by gelyfluction due to sudden ice-block thawing, which was burried in sandy lacustrine sediments.

Figure 6.56. Detail of sheet-like liguoid-structured calcarenites, which occur in the glaciolacustrine allo-unit 3. Photo taken in 2008.

Slika 6.56. Detalj vodoravno položenih jezičastih kalkarenitnih struktura u glacio-lakustrinskoj jednici 3. Snimljeno 2008.

The ripple-laminated interval of the glacilacustrine unit is interpreted as of rather shallow proximal proglacial lake (see Chpt. 5.2.2.), thus many grounded and later buried ice-blocks could have existed in this zone. As the ice receided, lake dried out and a proglacial zone turned into a temporary permafrost area with a lot of buried ice. Such situation corresponds to proglacial subenvironment of continental glaciation as modeled by Brodzikowsky & van Loon (1991) showing a periglacial environment that includes terminoglacial, proglacial and extraglacial subenvironments.

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7.
DISCUSSION

The sedimentological study of the Kvarner, South Velebit and Northern Dalmatia regions carried out for the past twenty years has given completely new insight in the Quaternary, specifically Pleistocene sedimentology in these regions. Long ago hypothesised glaciation of the Dinarides, which was evident from early research results, is documented in this Thesis.

Following all previous researchers who spoke in favour of extensive glaciation of Dinarides and were pioneers in its promotion (Penck, 1900, Hranilović, 1901, Gavazzi, 1903a, b, Schubert, 1909, Milojević, 1922, Bauer, 1934/1935, and Degen, 1936) various sedimentological and geomorphological evidence has been searched for in the study area, and all crucial, always asked for, characteristics have been found at many locations.

Detailed sedimentological study enabled glacigenic interpretation of the studied sediments. Many sites of additional observation and tracing of the lithofacies extent enabled the reconstruction of paleoenvironments. By detailed sedimentological logging and outcrop mapping different lithofacies were identified and interpreted in terms of glacial, glacifluvial, glacilacustrine, and glacideltaic sediments. Marine sediments and paleosols were also evidenced but not studied in detail, thus are not elaborated in this Thesis.

Glacial sediments are represented by diamict lithofacies determined as tills or tillites and interpreted in terms of ground, medial or lateral moraines. The main sediment characteristics for glacial interpretation were clasts with glacial striae, ice-shaped (faceted, bullet-shape and conical) and ice-shattered clasts, and in case of the Paklenica Member the extreme range of clast sizes spanning from fine gravel to mega-blocks. Ground moraines are recognized at many eastern Adriatic localities, eg. on the Krk Island, Rab Island, St. Grgur Island, as well as in Senj, Jablanac, and along the Velebit Mt. coast from Starigrad to Maslenica, on Rujno and in Velika and Mala Paklenica on the southern Velebit Mt., in addition to Ravni Kotari northern coast near Ždrilo, Posedarje, in the Novigrad Sea, near Obrovac and Raduč in Lika (Fig. 6.1.). Medial moraines are recognized only in Veliko Rujno valley on the South Velebit Mt., whereas marginal moraines are recognized in Baška valley on the Krk Island.

Glacifluvial sediments comprise both glacial outwash deposits of braided streams and flood plains, and fluvial deposits of meandering rivers, recognized in the Baška Valley on the Krk Island, Pag Island, and the Novigrad Sea southern coast localities (Fig. 5.141.). The interpretation of these deposits as of glacigenic origin is based on facies association, meaning that they occur with tills or tillites, and contain glacially-derived boulders and blocks, sometimes also lithologically exotic debris such as andesite gravel from the Northern Velebit Mt. (Fig. 7.1.).

Glacilacustrine sediments are represented by siltites and clays, locally classic varves, and varve-like deposits which are recognized at Ždrilo and Seline coastal localities in the South Velebit Channel, in coastal sections of the Novigrad and Karin Sea, as well as in Zrmanja River bank near Žegar, in addition to numerous scattered outcrops all along the study area (Fig.5.128.). The main diagnostic criterion for attribution of lacustrine sediments to a proglacial setting is the presence of drop-stones (Figs. 5.130., 5.131.E). Seasonal freezing of the lake surface and its isolation is documented by typical glacial varves (Fig. 5.116.) as described in the Chapter 5, which commonly occur in association with tills or tillites.

Glacideltaic sediments are represented by conglomerate, calcarenite and calcisiltite lithofacies in alternation. Significant characteristics for glacial attribution are ice-striated clasts which were found in conglomerates, indicating supply of glacially-driven debris which was not transported to the great distance, since the striations are still preserved, as well as lithoclasts that lithologically correspond to the composition of Rujno and Paklenica tills. This exotic debris was derived both from the Velebit Mt. and possibly even from the Lika valley, which could have only been brought by ice. Another argument in favour of glacigenic origin is the association with proglacial lacustrine sediments containing the drop-stones. Glacideltaic sediments were found at the Seline locality, where they build a multi-storey complex body incased in lacustrine fine-grained sediments.

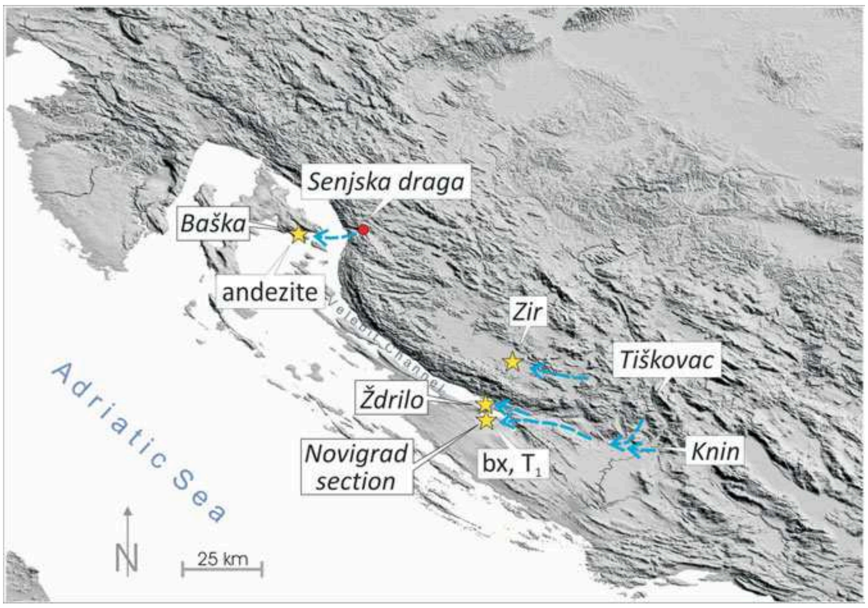


Figure 7.1. Sources of exotic ice-rafted debris like andesite, bauxite, Triassic red sandstone and siltstone that was found in glacigenic sediments at Baška, Ždrilo and Novigrad sections, and on Zir in Lika.

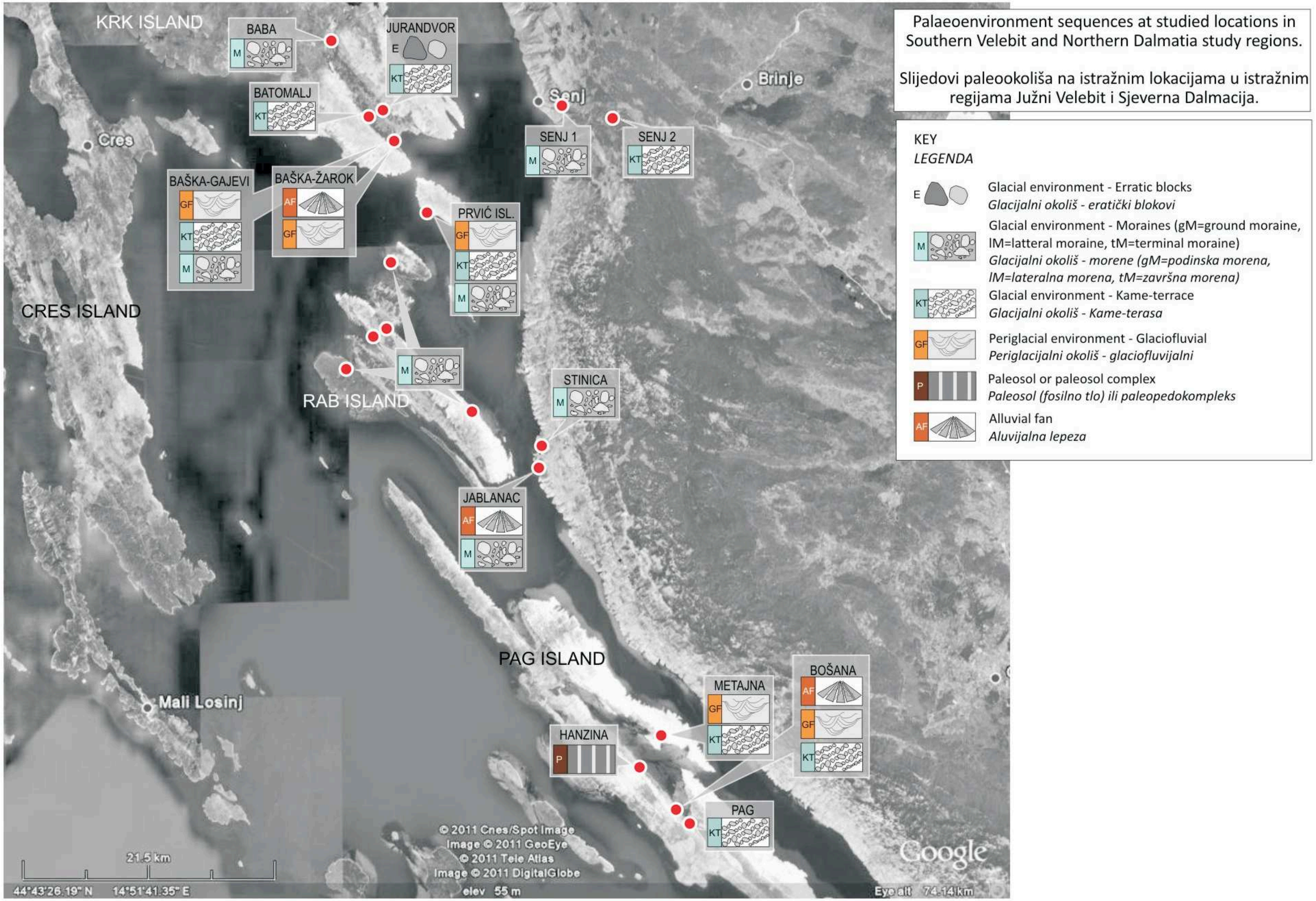
Slika 7.1. Izvorišta ledom transportiranih litoklasta andezita, boksita, donjotrijaskih crvenih klastita koji su nađeni u glacigenim sedimentima kod Baške, Ždrila i Novigrada, te na Ziru u Lici.

The sedimentological data presented in this Thesis provide evidence of extensive glaciations of the Dinarides and the eastern Adriatic Sea coast. The key evidence are: clasts with glacial striae, faceted- and bullet-shaped clasts, ice-shattered clasts, which were found at study sites with diamict lithofacies (Fig. 6.1). The diamict lithofacies described in the Chapter 5.2. are interpreted as of glacial origin and defined as tills or tillites. Their characteristics enabled identification of several members by combining litho-, morpho- and allostratigraphy, as proposed and elaborated by Hughes (2010). The identified members are Paklenica, Rujno and Novigrad Members, in addition to two tentative members of Sklopine and Raduč, which all represent glacial sediments such as subglacial tills or tillites, interpreted as ground- and medial moraines. In this study no evidence was found of terminal moraines, so actual limits of the glacial extent are not identified yet. The Paklenica Member identified at the Novigrad section was previously recognized as a ground moraine by Marjanac et al. (1993), but its extent was not known then. The mega-diamict lithofacies representing the Paklenica Member is most widespread (Fig. 5.20.) and easiest to recognize, and was used as one of two correlation "datums" (Fig. 7.7.). The Novigrad Member is restricted to the Novigrad and Karin Sea area. The tentative Sklopine Member is the youngest moraine, restricted to upper part of the Velika Paklenica around Sklopine. The tentative Raduč Member is newly recognized as till, and presently it can not be attributed any chronostratigraphic position.

The presented sedimentologogical data is summerized as the reconstruction of paleoenvironments and their distribution in the Kvarner, South Velebit and Northern Dalmatia study regions (Figs. 7.2., 7.3.).

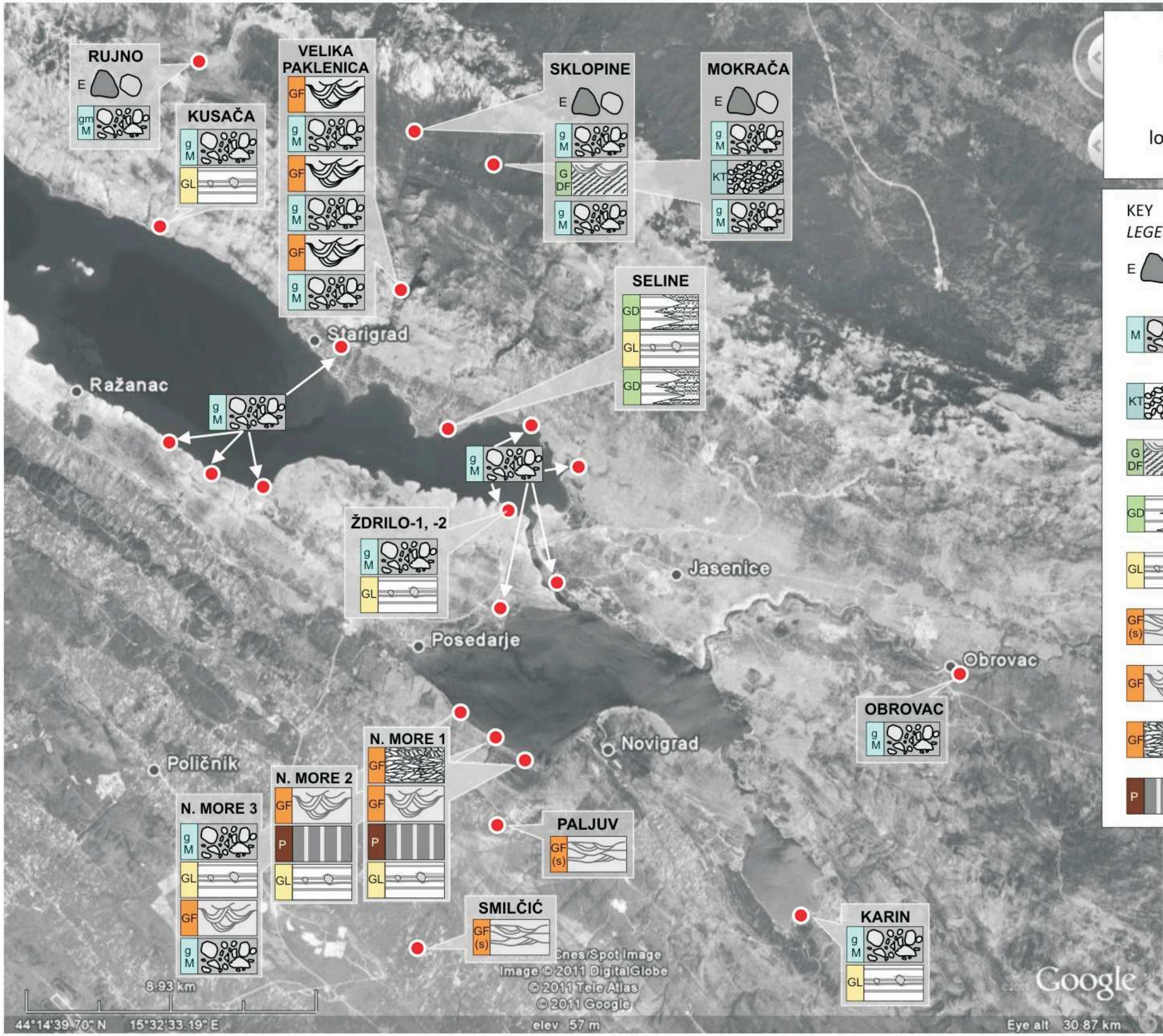
Sedimentological evidence is also based on facies association of characteristic sedimentary bodies which provide geomorphological evidence of the Dinaric glaciation. During the ice retreat, different depositional landforms are produced, eg moraine bodies, kame terraces, kettle mounds, sandar, eskers, drumlins, etc. The preservation potential of landforms such as lateral moraines and kame-terraces is very low, and they are rarely described from ancient glacial environments. They are either destroyed by younger glaciation, or they usually collapse after the ice retreat, and sediments being eroded or redeposited in alluvial fans, commonly defined as paraglacial landforms in glaciated valleys (Ballantyne, 2002).

The depositional landforms interpreted as kame terraces are well preserved in the study area, and were first described by Marjanac & Marjanac (1994, 1999). These kame terraces extend along the valleys of Bašćanska Draga on the Krk Island and the Pag Bay. These are composite ice-contact sedimentary bodies built of glacial and glacifluvial sediments, e.g.. on the Krk and Pag Islands and some are built of slopeward dipping stratified sediments deposited by mass transport of supraglacial debris into the gaps between ice-margin and the valley slope (Fig. 6.25.). The kame-terrace landform



Palaeoenvironment sequences at studied locations in Southern Velebit and Northern Dalmatia study regions.

Slijedovi paleookoliša na istražnim lokacijama u istražnim regijama Južni Velebit i Sjeverna Dalmacija.



Palaeoenvironment sequences at studied locations in Southern Velebit and Northern Dalmatia study regions.

Slijedovi paleookoliša na istražnim lokacijama u istražnim regijama Južni Velebit i Sjeverna Dalmacija.

KEY
LEGENDA

E	Erratic blocks *Eratički blokovi*
M	Moraines (gM=ground moraine, lM=latteral moraine, tM=terminal moraine) *Morene (gM=podinska morena, lM=lateralna morena, tM=završna morena)*
KT	Kame-terrace *Kame-terasa*
G DF	Glaciodeltaic-glaciofluvial *Glaciodeltični i glaciofluvijalni*
GD	Glaciodeltaic and glaciolacustrine *Glaciodeltaični i glaciolakustrinski*
GL	Glacial lake *Ledenjačko jezero*
GF (s)	Outwash plain (Sandur) *Ravnica ispiranja (Sandur)*
GF	Glaciofluvial *Glaciofluvijalni*
GF	Glaciofluvial (river bank gravel) *Glaciofluvijalni (riječni obalni šljunak)*
P	Paleosol or paleosol complex *Paleosol (fosilno tlo) ili paleopedokompleks*

documents a phase of ice-stagnation and extensive ablation which provided a vast amount of melt-water which formed large river systems in this karst area.

Besides inevitable sedimentological evidence presented herein, there is also geomorphological evidence that additionally documents extensive Dinaric glaciation, although geomorphology was not the subject of this Thesis.

It is known that advancing glaciers produce various small- to large scale erosional features and landforms by abrasion and quarrying, like striae, polished surfaces, plastically moulded forms (P-forms), rochés moutonnées, subglacial and ice-marginal channels, cavities, rock basins and overdeepening, troughs and fjords, cirques, and finally landscapes of glacial erosion and 'aerial scouring', etc. (Benn & Evans, 2010).

Regarding the erosional features described in the Chapter 6, it is important to note that all glacigenic deposits lay on carbonate bedrock, namely limestones and dolomites of Mesozoic age, except in the upper part of the Velika Paklenica, from Bezimenjača to Velika Paklenica brook valley where the bedrock are Upper Permian and Lower Triassic carbonates and siliciclastics. The carbonate bedrock was exposed to postglacial erosion and karstification, especially due to vast quantity of melt-water which significantly decreased the preservation potential of glacial erosional features. On the other hand, commonly found glacial striae on limestone clasts in tillites prove differently because these were preserved from chemical weathering by the finegrained matrix.

Clasts with glacial striae were found in all diamicts interpreted as tills or tillites which were consequently classified as ground moraines. The remnants of large-scale glacial striae and P-forms were recognized on the walls of Anića Kuk in the Velika Paklenica gorge, and some other bare-rock surfaces in the range of Paklenica and Rujno. Large striations on the bedrock and stone stripes are visible in Libinje area SE of the Velika Paklenica.

The evidence of glacial polishing of the bedrock was found under glacifluvial sediments at the Bošana locality and near Povljana on the Pag Island, in the Veliko Rujno valley and Libinje on South Velebit Mt..

The most prominent evidence of subglacial erosion are gorges of the Velika and Mala Paklenica which have been compared to the recently uncovered subglacial gorge Les georges de l'Arveyron, when the glacier Mer de Glace retreted (Figs. 7.4., 7.5.). The gorge was eroded and plastically moulded by subglacial melt-waters at the time when the glacier was reaching the lower valley. The analogue situation is assumed for the Paklenica gorges, and many other erosional features on the Velebit Mountain that are described in literature as karst phaenomena. Considering the extent of glaciation and a corresponding thick ice-cap the subglacial moulding of the carbonate bedrock by melt-waters must have been significant.

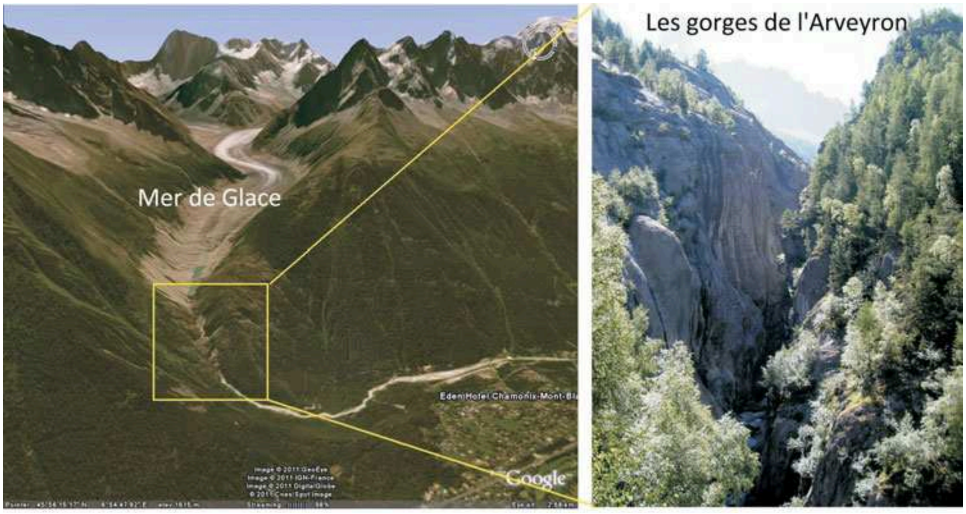


Figure 7.3. Google Earth image of the Mer de Glace glacier (left) and Google photograph of the gorge after recent ice retreat uncovered (right).

Slika 7.3. Google Earth snimak ledenjaka Mer de Glace (lijevo) i Google fotografija kanjona otkrivenog nedavnim povlačenjem leda (desno).

Figure 7.3. Comparison of the gorge Les gorges de l'Arveyron (b) with the gorges of Mala Paklenica (a) and Velika Paklenica (c) shows significant resemblance.

Slika 7.3. Usporedba kanjona Les gorges de l'Arveyron (b) s kanjonima Male Paklenice (a) i Velike Paklenice (c) pokazuje značajnu sličnost.

This research for the first time provided isotope ages for the studied sediments by ^{14}C (in 1990) and U-series (in 2010-2011) dating which are presented in Table 7.1. and the sampling locations in Figure 7.6.. The chronologic data allowed to establish a tentative chronostratigraphy of studied sediments, and attribution to Middle and Late Pleistocene age (Fig. 7.7.).

The glacifluvial complex of Baška - Zarok on the Krk Island contains a paleosol (12A, Appendix 5.1.B) which was dated on 27.800 years BP, which sets it in time of the Weichselian (Würm) glaciation, precisely the LGM. The paleosol at Šilo on the north of the Krk Island with "Striata fauna" characteristic for the Würm interstadial (Marjanac et al., 1992/1993) could be its correlative. The older dated paleosol 10A (Fig. 5.149.) of Baška - Zarok gave ^{14}C age older than 40.000 years BP and they were tentatively attributed to MIS 11 and 9e or MIS 9e and 7e. The paleosol 10A tentatively attributed to MIS 9e (?7e), was further used as a correlation datum because it is also recognized in glacifluvial complex of Bošana on the Pag Island and dated to > 40.000 years BP.

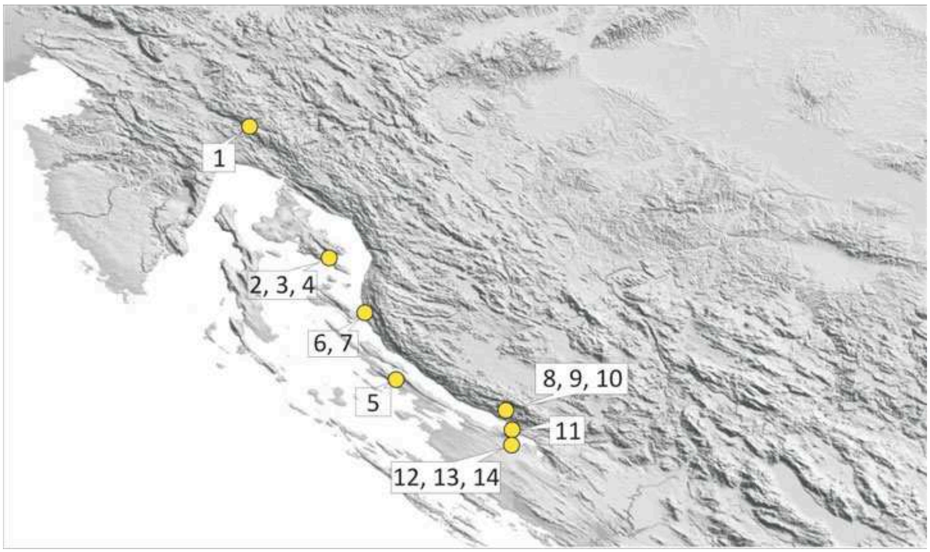


Figure 7.6. Sampling locations for carbon and U-series dating. Location names and results are listed in Table 7.1.
Slika 7.6. Lokacije uzorkovanja za datiranje pomoću ugljikovih i uranovih izotopa. Lokacije i rezultati navedeni su u Tablici 7.1..

LOCATIONS (marked in figure below)	MATERIAL TYPE	RADIOCARBON (14C) AGE	URANIUM SERIES AGE (x 1000 years)	AGE OF DATED MATERIAL	AGE OF SEDIMENT	Reference	INTERPRETATION	
							Alpine Stratigraphy	Pindus Chronostratigraphy (Hughes et al. 2006)
Gomance (1)	bone	17.100 ± 400		MIS 2	MIS 2	Marjanac et al. 2001	Würm Glacial	Tymphiam Stage
Baška - Zarok (2)	charcoal	27.800 ± 1.700		MIS 2/3	MIS 2/3	Z-2153		
Baška - Zarok (3)	charcoal	> 40.000		?	? MIS 6	Z-2150	Riss Glacial	Vlasian Stage
Baška - Zarok (4)	charcoal	> 40.000		?	? MIS 8	Z-2151		
Pag - Bošana (5)	charcoal	> 40.000		?	? MIS 6	Z-2180		
Stinica (6)	secondary calcite (moraine)		61.5 ± 2.5	MIS 5	MIS 6 or older	this study (PH CR 10)		
Jablanac (7)	secondary calcite (moraine)		64.7 ± 1.9	MIS 5	MIS 6 or older	this study (PH CR 6)		
Velika Paklenica 1 (8)	secondary calcite (moraine)		74.7 ± 1.8	MIS 5a	MIS 6 or older	this study (PH CR 2)		
Novigrad 1 (12)	calcite from paleocavern*		110.2 ± 3.4	MIS 5e	MIS 5e	this study (PH CR 7)	Riss/Würm Interglacial	
Novigrad 2 (13)	calcite from paleocavern*		121.6 ± 3.9	MIS 5e		this study (PH CR 8)		
Novigrad 3 (14)	secondary calcite (former ice wedge)		146.4 ± 4.4	MIS 6 ? 7	? MIS 7/8	this study (PH CR 1)	Riss Glacial	Vlasian Stage
Velika Paklenica 2 (9)	secondary calcite (moraine)		159.7 ± 8.2	MIS 6 ? 7	MIS 6 or older	this study (PH CR 3)		
Ždrilo (11)	secondary calcite (moraine)		339.4 ± 61.4	MIS 9	MIS 12 or older	this study (PH CR 4)	Mindel Glacial	Skamnellian Stage
Velika Paklenica 3 (10)	secondary calcite (moraine)		> 350.000	MIS 11	MIS 12 or older	this study (PH CR 9)		

Table 7.1. Results of 14C and U-series dating.
Tablica 7.1. Rezultati datiranja pomoću ugljikovih i uranovih izotopa.

Radiometric dating by U-series provided minimal age of studied sediments, usually much younger than the actual age of their deposition, because the secondary calcite could have bean deposited in the rock interspaces under the vadose condition at any time following the thawing of the ice-matrix in morains and their compaction. The cementation very likely significantly postdated the

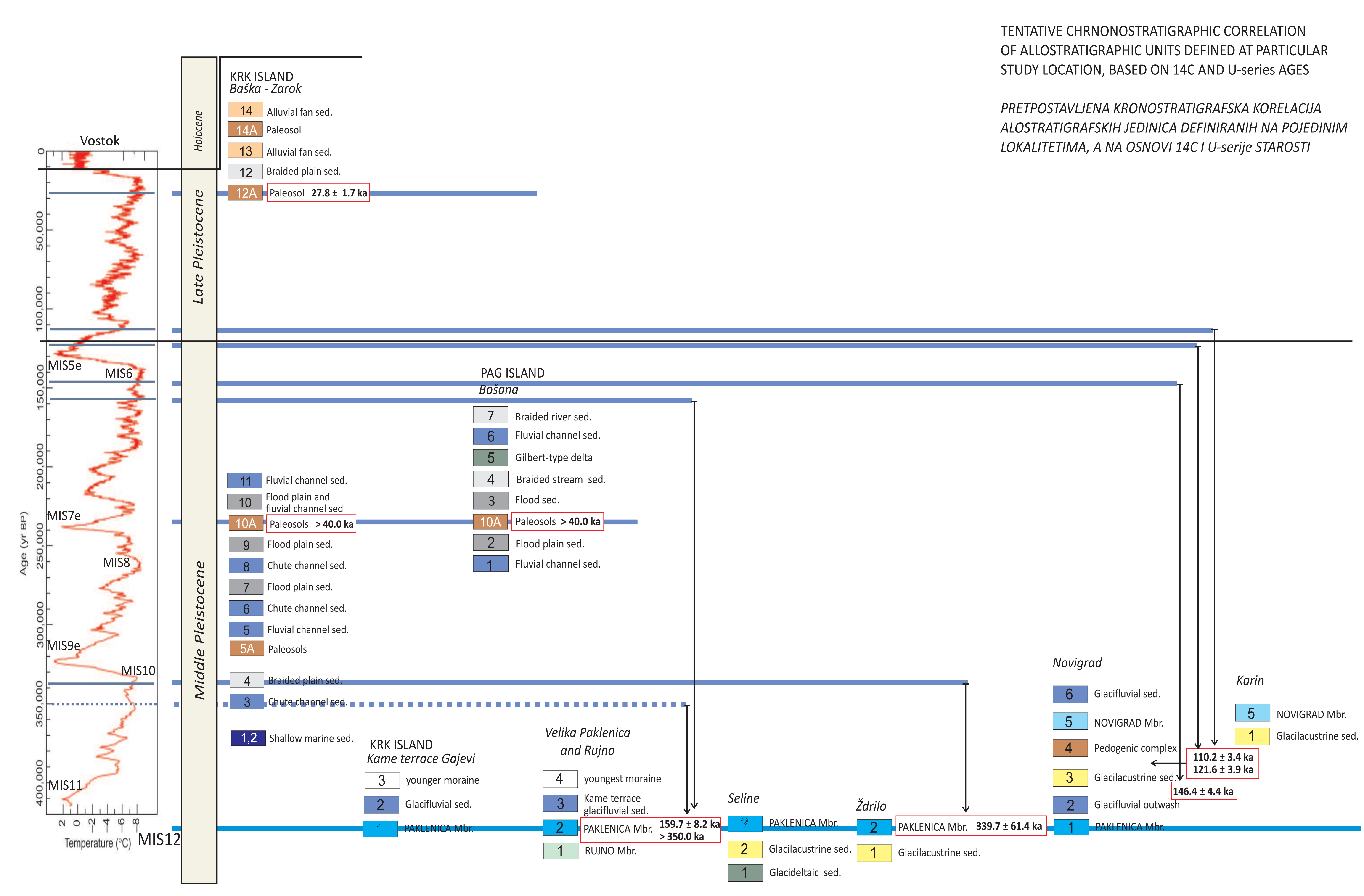

TENTATIVE CHRNONOSTRATIGRAPHIC CORRELATION
OF ALLOSTRATIGRAPHIC UNITS DEFINED AT PARTICULAR
STUDY LOCATION, BASED ON 14C AND U-series AGES
PRETPOSTAVLJENA KRONOSTRATIGRAFSKA KORELACIJA
ALOSTRATIGRAFSKIH JEDINICA DEFINIRANIH NA POJEDINIM
LOKALITETIMA, A NA OSNOVI 14C I U-serije STAROSTI
Vostok
Age (yr BP)
0
50,000
100,000
150,000
200,000
250,000
300,000
350,000
400,000
MIS5e
MIS6
MIS7e
MIS8
MIS9e
MIS10
MIS11
MIS12
Temperature (°C)
Holocene
Late Pleistocene
Middle Pleistocene
KRK ISLAND
Baška - Zarok
14 Alluvial fan sed.
14A Paleosol
13 Alluvial fan sed.
12 Braided plain sed.
12A Paleosol 27.8 ± 1.7 ka
11 Fluvial channel sed.
10 Flood plain and fluvial channel sed
10A Paleosols > 40.0 ka
9 Flood plain sed.
8 Chute channel sed.
7 Flood plain sed.
6 Chute channel sed.
5 Fluvial channel sed.
5A Paleosols
4 Braided plain sed.
3 Chute channel sed.
1,2 Shallow marine sed.
PAG ISLAND
Bošana
7 Braided river sed.
6 Fluvial channel sed.
5 Gilbert-type delta
4 Braided stream sed.
3 Flood sed.
10A Paleosols > 40.0 ka
2 Flood plain sed.
1 Fluvial channel sed.
KRK ISLAND
Kame terrace Gajevi
3 younger moraine
2 Glacifluvial sed.
1 PAKLENICA Mbr.
Velika Paklenica
and Rujno
4 youngest moraine
3 Kame terrace glacifluvial sed.
2 PAKLENICA Mbr. 159.7 ± 8.2 ka > 350.0 ka
1 RUJNO Mbr.
Seline
? PAKLENICA Mbr.
2 Glacilacustrine sed.
1 Glacideltaic sed.
Ždrilo
2 PAKLENICA Mbr. 339.7 ± 61.4 ka
1 Glacilacustrine sed.
Novigrad
6 Glacifluvial sed.
5 NOVIGRAD Mbr.
4 Pedogenic complex
3 Glacilacustrine sed.
2 Glacifluvial outwash
1 PAKLENICA Mbr.
110.2 ± 3.4 ka
121.6 ± 3.9 ka
146.4 ± 4.4 ka
Karin
5 NOVIGRAD Mbr.
1 Glacilacustrine sed.

Figure 7.7.

deposition of moraines and kame terraces, because the samples for dating were collected from voids which were apparently left open after the ice-matrix or fragments were melted. The Ca-saturated waters probably infiltrated the sediment at a later diagenetic stage when aggressive (CO_2-rich) waters dissolved carbonate debris at, or close to the surface, and the sediment temperature was high enough for degassing and calcite precipitation. This explains relativelly young ages of dated calcite cements, and approves putting the actual age of the sediment to a lower stratigraphic level.

The U-series dating of calcite cements in moraines gave minimal ages of Paklenica Member moraines, and its attribution to the Elsterian (Mindel) glaciation of the Middle Pleistocene (Tab. 7.1.). Thus, the Paklenica Member was used as the second correlation datum. It underlays the Gajevi kame-terrace deposits on the Krk Island, and therefore enables the correlation with other localities in the South Velebit Mt. and Northern Dalmatia study regions.

Based also on the U-series ages of calcites, between 146.000 and 110.000 years BP, sampled at the Novigrad section (Fig. 7.6., Tab. 7.1.), it is assumable that sediment wedges (the ice-wedge casts) common in the glacilacustrine unit 3 mark the end of the Elsterian glaciation, and that the Novigrad Member was deposited during the Saalian (Riss) glaciation which is in accordance with Mindel-Riss age of glacilacustrine sediments of Žegar and Ervenik (Malez & Sokač, 1969).

This tentative chronostratigraphic correlation and superposition of the defined allostratigraphic units implies that the Seline glacideltaic complex is the oldest among the studied sediment successions, older than the Rujno and Paklenica Members. The Seline glacideltaic complex indicates the advance of Elsterian glaciation or even an earlier one.

The Paklenica Member regionally correlates with Ninkovići Member in Montenegro found at altitude of 500 and 800 m, which are attributed to Skamnelian stage MIS 12 (Hughes, 2011). Together with evidence of low-altitude moraines in Boka Kotorska (Stepšnik & Žebre, 2010), the Paklenica Member represents the most westwards or north-westwards reaches of the Dinaric ice-cap (Fig. 7.8.).

This chronostratigraphic interpretation of glacigenic sediments, especially those on Veliko and Malo Rujno, contradicts all previous researchers mentioned in previous chapters, who attributed glacigenic sediments and geomorphological features of the Velebit Mountain to Late Pleistocene or LGM. Accordingly, the age of glacigenic sediments in other parts of the NW Dinarides (Risnjak Mt., Northern Velebit Mt., Middle Velebit Mt.) should be revised.

The total extent of the Dinaric ice-cap is at present unknown, and is under current study. Preliminary data indicate far more extensive ice-cap than previously assumed, which extended to inland lowlands and covered all of the Dinaric mountains at the maximum stage of glaciation (Fig. 7.8.). The effects of this widespread ice cover must have been recorded in Dinaric karst systems, as well as in dynamics of the underground water.

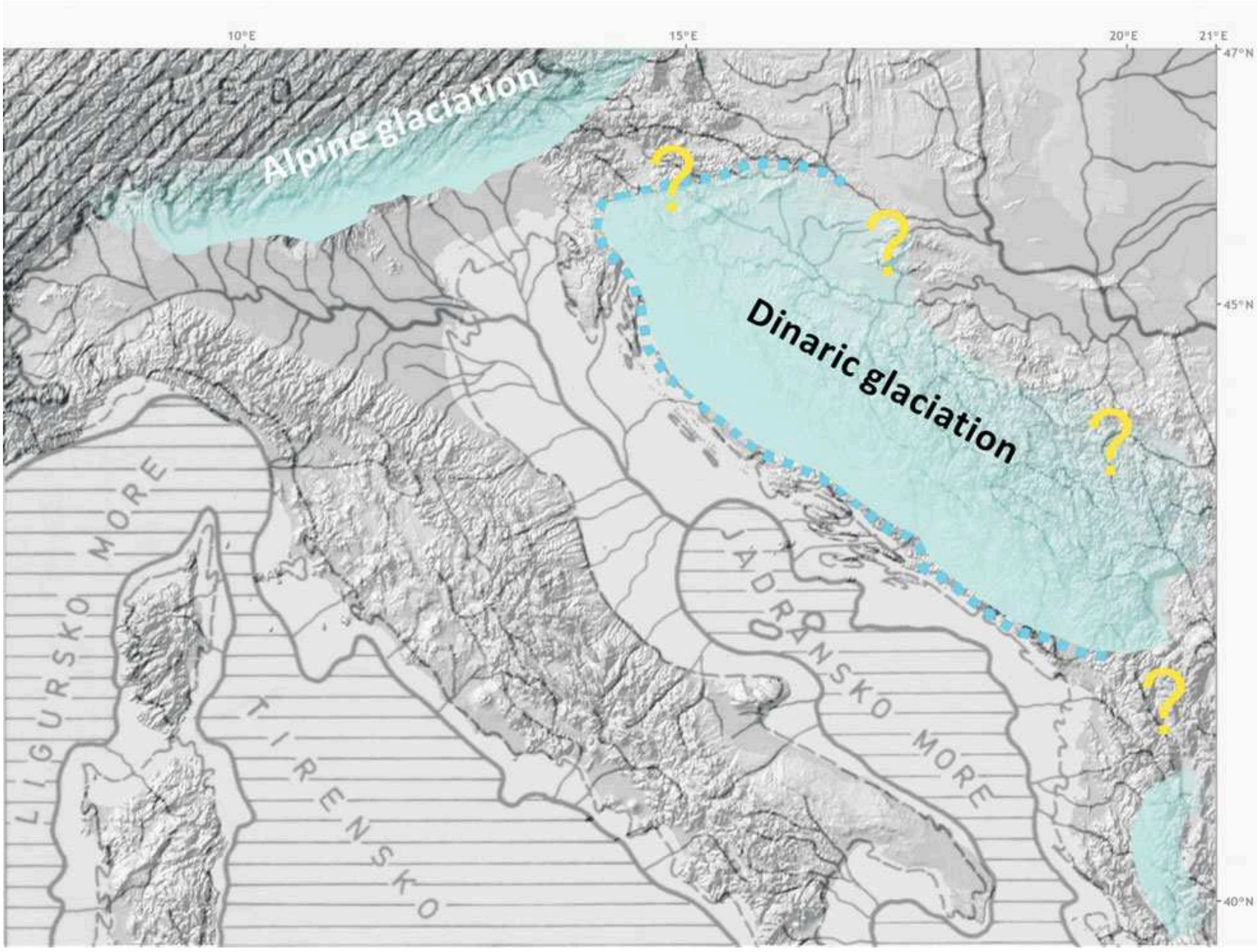


Figure 7.8. The assumed maximal extent of Dinaric glaciation nearly reaches the Alps, and question marks indicate insufficient data for correlation with glaciated Alps on the northwest and Pindus Mountains on the south.

Slika 7.8. Pretpostavljeni doseg Dinaridske glacijacije, no upitnici ukazuju i na nedostatne podatke za korelaciju s oledbom Alpa na sjeverozepadu i Pindus gorja na jugu.

8. CONCLUSION

The main goal of this Thesis titled “PLEISTOCENE GLACIAL AND PERICLACIAL SEDIMENTSOF KVARNER, NORTHERN DALMATIA AND SOUTHERN VELEBIT MT. - EVIDENCE OF DINARIC GLACIATION” was to find evidence of a hypothesized extensive glaciation of the Adriatic and the Dinarides.

The research concentrated on field study of the Quaternary sediments in the regions of Kvarner (the Krk, Rab and Pag Islands, Senjska Draga and Jablanac), South Velebit (Rujno and Velika Paklenica, Kusača, Seline and the coast of Velebit Channel), and in Northern Dalmatia (south coast of the Velebit Channel, Novigrad Sea, Karin Sea, Obrovac, Paljuv and Smilčić), by methods of detailed logging and outcrop mapping.

The sedimentological reasearch provided data for glacigenic interpretation of studied sediments, and the following sediments were determined:

Glacial sediments are diamicts determined as tills or tillites and interpreted in terms of ground, medial or lateral moraines. The main characteristics of glacial origin are clasts with glacial striae, ice-shaped (faceted, bullet-shape and conical) and ice-shattered clasts.

Glacifluvial sediments comprise both glacial outwash deposits of braided streams and flood plains, and fluvial deposits of meandering rivers, represented with sand and gravel deposits. Their glacigenic origin is based on facies association, meaning that they occur with tills or tillites, and contain glacially-derived boulders and blocks, sometimes also lithologically exotic debris.

Glacilacustrine sediments comprise two types, clay-silt sediments with classic varves, and varve-like calcisiltites with drop-stones, which is the main diagnostic criterion for their proglacial character.

Glacideltaic sediments are represented by conglomerate, calcarenite and calcisiltite lithofacies in alternation. Significant characteristics for glacial attribution are ice-striated clasts which were found in conglomerates, and their association with glacilacustrine sediments.

The following depositional paleoenvironments were reconstructed:

The glacial environment where depositon occurs in contact with ice, regarding terminoglacial environment and ice-contact zones between the ice-margin and valley slopes. Glacial paleoenvironment is documented by determined ground and lateral moraines. The ground moraines are indentified as Rujno, Paklenica and Novigrad members in terms of lito-, allo- and morphostratigraphy, and two tentative members Sklopine and Raduč. The Paklenica member, found also on Krk and Rab Islands, documents the furthest extent of glaciation. Another characteristic landform of ice-contact zone are kame terraces well preserved on the Krk and Pag Islands.

The proglacial environment which is influenced by melting ice and glacial outwash processes is evidenced by glacifluvial sediments widespread in Northern Dalmatia, and proglacial lacustrine sediments of Ždrilo, Seline and Novigrad.

The periglacial paleoenvironment, less influenced by ice, but dominantly by permafrost, was recognized in sediments of Novigrad section, were many sediment wedges interpreted as ice-wedge casts and kettle-forms occur, which indicate freezing and thawing effects on sediment due to grounded and burried ice-blocks.

The sedimentological reserch showed that glacigenic sediments are widespread in this north Adriatic region and in Northern Dalmatia, which prooves the far seawards extention of the Dinaric glaciation. At the most advanced phase of glaciation the ice covered islands of Krk, Rab and Pag, a large part of Northern Dalmatia, and the whole Velebit Channel as evidenced by distribution of moraines. When the ice retreted, proglacial lakes were formed as evidenced by glacilacustrine sediments at Ždrilo, Seline and Novigrad. The paleoenvironment sequences also indicate on ice fluctuation and its at least three advances and reatreats.

Tentative chronostratigraphic correlation of sediments was established by combining the litho-, morpho- and allostratigraphy, and the provided ^{14}C and U-series ages of sediments, which allowed attribution of the Middle Pleistocene age to most of the studied sediments.

The hypothesis of extensive Dinaric glaciation is, thus, proven, and new avenues of research are open, regarding its total extent, both inland and seaward, the timing, and associated glaciotectonic deformations.

9 . AKNOWLEDGEMENTS

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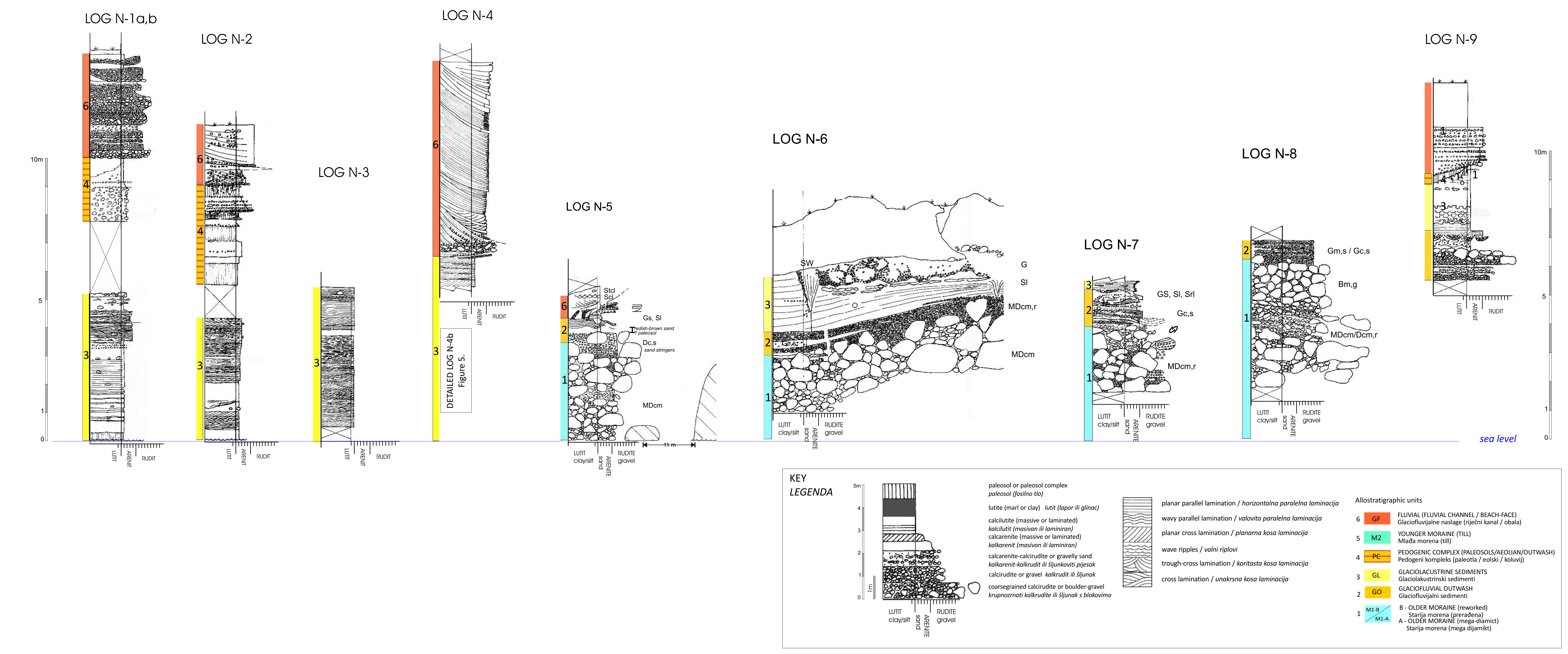
APPENDIX 5/1
PRILOG 5/1

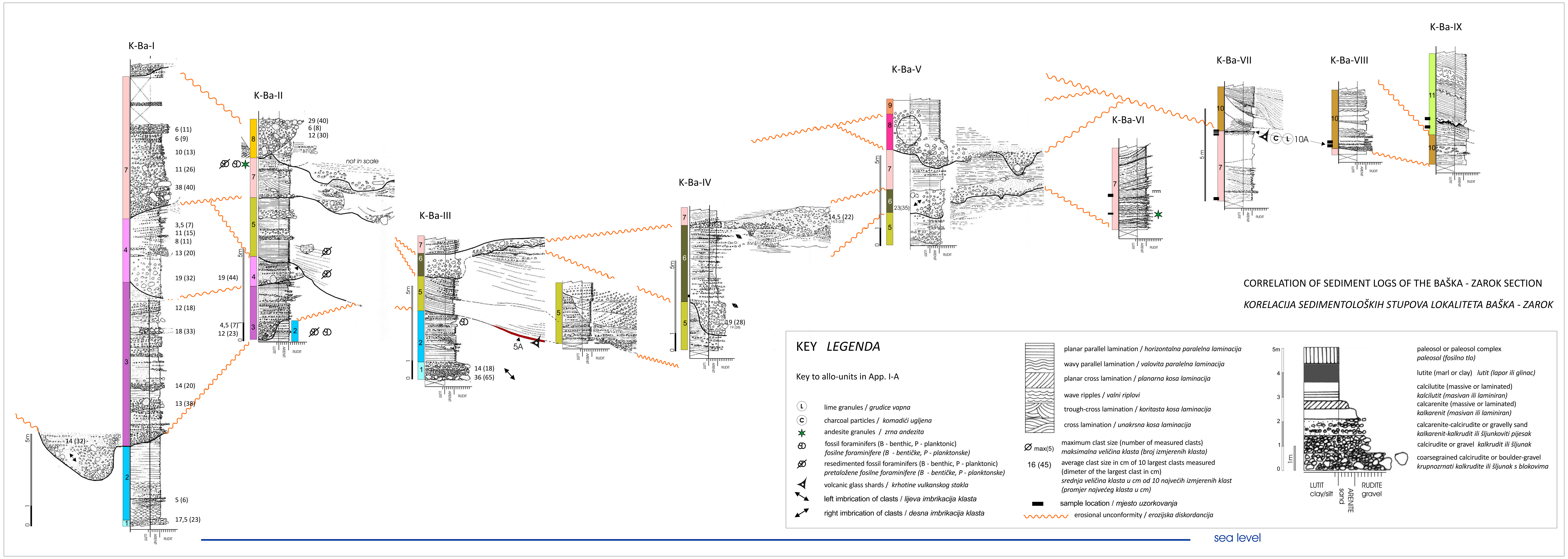
CORRELATION OF SEDIMENT LOGS OF THE NOVIGRAD SECTION
KORELACIJA SEDIMENTOLOŠKIH STUPOVA PROFILA NOVIGRAD



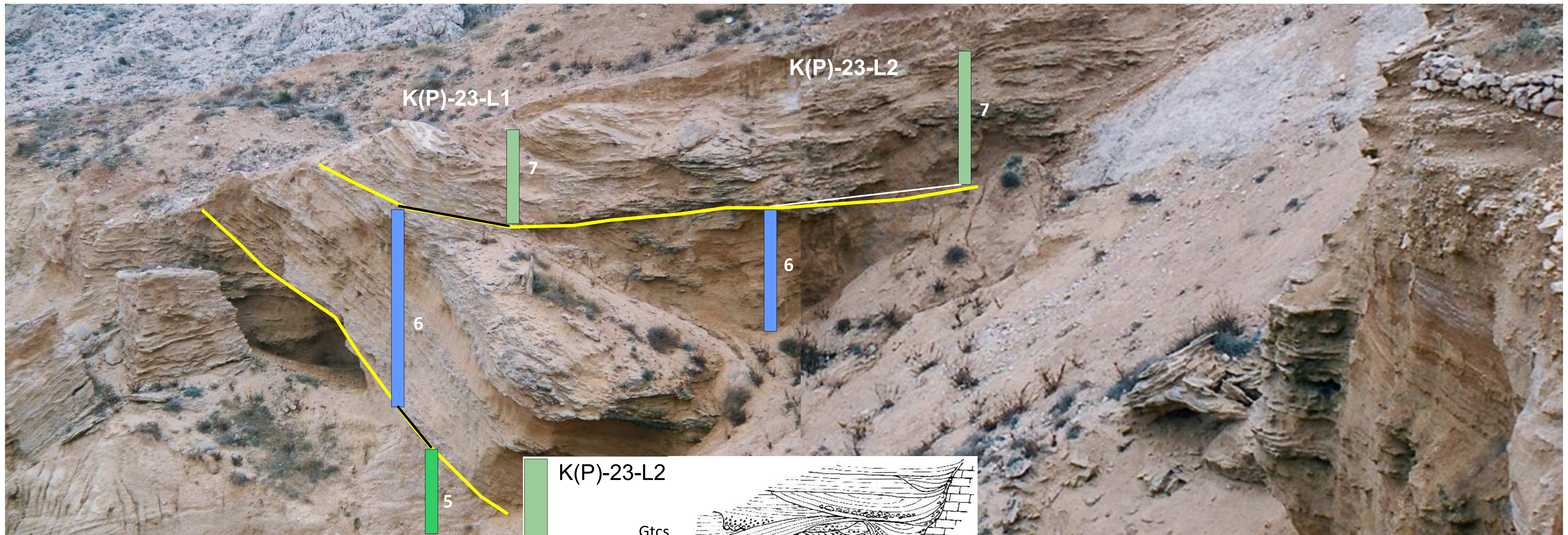

ALLOSTRATIGRAPHY OF THE PLEISTOCENE SEDIMENTS OF THE BAŠKA - ZAROK SECTION
ALOSTRATIGRAFIJA PLEISTOCENSKIH SEDIMENATA LOKALITETU BAŠKA - ZAROK
K-Ba-I
K-Ba-II
K-Ba-III
K-Ba-IV
K-Ba-V
K-Ba-VI
K-Ba-VII
K-Ba-VIII
K-Ba-IX
10m
sea level
Eocene clastics
E / P
?EP/MP
?MP/LP
LGM
5A
10A
12A
14A
>40.000 BP
(14C age)
≈28.000 BP
(14C age)
Erratic boulder
Eratički blok
Andesite grain from unit 7
Zrno andezita u sedimentu jedinice 7
1cm
Fig. b. Debris flow deposit of a choote channel in Allo-unit 3.
Sl. b. Debrit bujičnog kanala u alo-jedinici 3.
1 m
Shallow-marine early Pleistocene deposits
Shoreline deposit (beach)
Eocene marine clastics
Fig. i. Erosional contact between Eocene marine clastic deposits and transgressive Lower Pleistocene shallow marine clastics.
Sl. i. Erozijski kontakt između eocenskih marinskih klastita u podini i transgresivnih donjopleistocenskih plitkovodnih marinskih klastita.
Fig. j. Lower Pleistocene shallow-marine deposits of Allo-unit 2. Those are cross-bedded and ripple-laminated calcarenites with benthic foraminifers.
Sl. j. Donjo pleistocenske plitkovodne marinske naslage alo-jedinice 2. To su koso uslojeni i valno laminirani kalkareniti s bentičkim foraminiferama.
Fig. k. Coarsegrained sediment of Allo-unit 6 is a choote channel fill deposit deeply cut into stratified sand and gravel deposits of All-unit 5.
Sl. k. Krupnozrnati sediment alo-jedinice 6 je ispuna bujičnog kanala, koji se duboko usjekao u stratificirane pijeske i šljunke alo-jedinice 5.
Fig. l. Allo-unit 7. Sand, gravel and clay sediments in wavy stratification, interpreted as flood basin deposits. A lot of andesite grains (f) are found in these sediments.
Sl. l. Valovito stratificirane naslage pijeska, šljunka i gline u alo-jedinici 7, interpretirane kao sediment poplavnog bazena. Brojni fragmenti andezita (f) nađeni su u ovim sedimentima.
2 m
Fig. m. Erosional contact between allo-units 10 and 13. Allo-unit 7 is visible bellow the paleosol 10A. A coarsegrained massive sediment of allo-unit 13 is a channel lag deposit, and stratified sand and gravel of allo-unit 10 are channel fill.
Sl. m. Erozijski kontakt između alo-jedinica 10 i 13. Alo-jedinica 7 vidi se ispod paleosola 10A. Krupnozrnati masivni sediment alo-jedinice 13 je ispuna dna kanala, dok su stratificirani pijesci i šljunci alo-jedinice 10 ispuna velikog riječnog kanala.
Fig. n. Detail of contact between two sets of planar cross beded sands and gravels of allo-unit 11. These are channel point bar deposits with frequent syn-sedimentary deformations.
Sl. n. Detalj kontakta između dva seta paralelno koso uslojenih naslaga pijeska i šljunka u allo-jedinici 11. U sedimentima su česte sin-sedimentacijske deformacije.
Fig. g. Detail of paleosol between allo-units 7 and 10. Found charcoal particles of plant remains were dated by 14C method and yielded age more than 40 ky BP.
Sl. g. Detalj fosilnog tla između alo-jedinica 7 i 10. Nađene čestice ugljena od ostataka bilja datirane su metodom 14C i dobivena je starost veća od 40.000 godinaBP.
Fig. h. Erosional contact between the allo-units 11 and 12 marked with paleosol remnants. Charcol particles of plant remains found in paleosol were dated by 14C method and yielded age is 28 ky BP, which is beginning of the Last glacial maximum (LGM).
Sl. h. Erozijski kontakt između dvije allo-jedinice 11 i 12 s ostacima paleosola. Čestice ugljena od biljnih ostataka datirane su metodom 14C i dobivena starost je 28.000 god BP, što odgovara početku zadnjeg glacijalnog maksimuma (LGM).
KEY / LEGENDA
Major erosion surface (hiatus) *Glavna erozijska granica (hijatus)*
Marine transgression surface *Površina marinske transgresije*
Dip and strike of bedding *Položaj sloja i kut nagiba*
Paleotransport direction based on clast imbrication
Smjer paleotransporta prema imbrikaciji klasta
Name and position of detailed sediment log
Naziv i mjesto detaljnog sedimentološkog stupa
Eocene/Pleistocene boundary (hiatus)
Granica (hijatus) eocen/pleistocen
possible boundary Lower Pleistocene/Middle Pleistocene
Pretpostavljena granica donji/srednji pleistocen
possible boundary Middle Pleistocene/Upper Pleistocene
Pretpostavljena granica srednji/gornji pleistocen
Last Glacial Maximum (Würm)
Maksimum zadnjeg glacijala (Würm)
Allostratigraphic units
xA Paleosols (5A, 10A, 12A, 14A)
14 Alluvial fan deposits
13 Alluvial fan deposits
12 Braided plain deposits
11 Fluvial channel deposits
10 Flood plain and fluvial channel deposits
9 Flood plain deposits
8 Chute channel deposits
7 Flood plain deposits
6 Chute channel deposits
5 Fluvial channel deposits
4 Braided plain deposits
3 Chute channel deposits
2 Shallow marine deposits
1 Shoreline/beach deposits

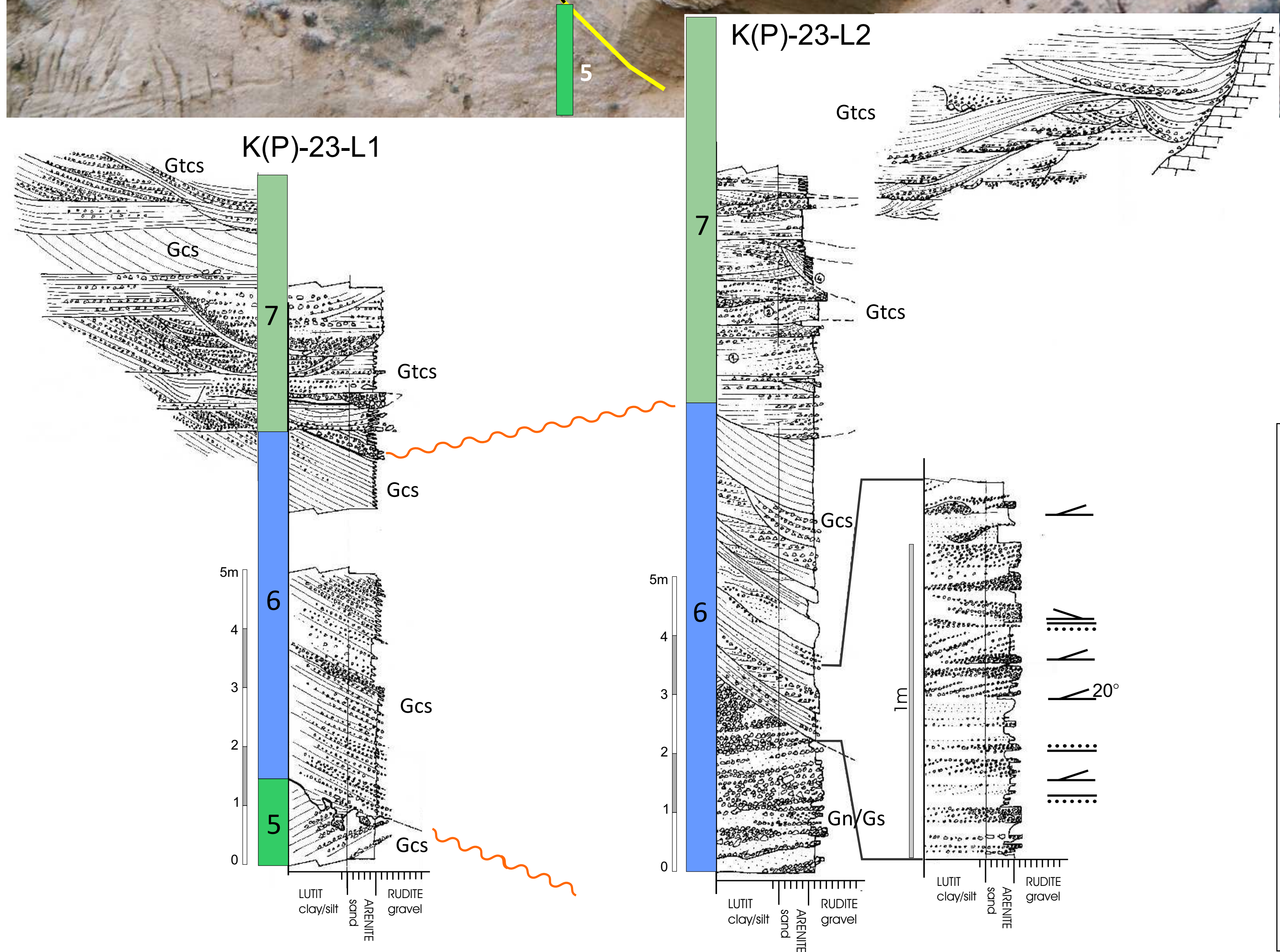
APPENDIX 5/2-A

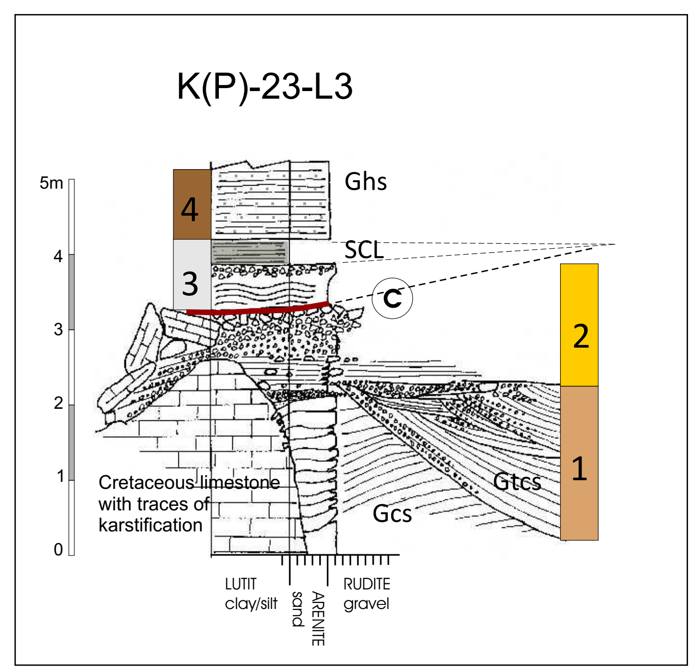
PRILOG 5/2-A



APPENDIX 5/3
PRILOG 5/3







ALLOSTRATIGRAPHY OF THE GLACIFLUVIAL DEPOSITS THE BOŠANA SECTION (PAG ISLAND)
ALOSTRATIGRAFIJA GLACIFLUVIJALNIH NASLAGA LOKALITETA BOŠANA (OTOK PAG)

Glacifluvial deposits of the Bošana kame-terrace on the Island of Pag, exposed in a large sand-pit. A younger sediment succession was logged in the left section and an older succession in the right section of the pit, but their precise correlation is not clear. The logged sediment interval comprises 7 allostratigraphic units, which are presented with detailed sediment logs and marked on the panoramic photo of the Bošana sand-pit (photographs taken in 2004). Steep and polished bedrock exposed by excavations is visible on the right side.

Glacifluvijalne naslage kame-terase Bošana na otoku Pagu otkrivene su u velikom pjeskokopu. Mlađi slijed sedimenata detaljno je snimljen na lijevoj strani, a dio starijeg slijeda na desnoj strani kopa, no njihova korelacija nije precizna. Snimljeni interval obuhvaća 7 alostratigrafskih jedinica, koje su prikazane na detaljnim stupovima i označene na fotografijama (panorama snimljena 2004.). U podlozi izviruje strma i polirana stijenska podloga.

ALLOSTRATIGRAPHIC UNITS

7	Braided river deposits	3	Flood deposits
6	Fluvial channel deposits	10A	Paleosols
5	Gilbert-type delta forsets	2	Flood deposits
4	Alluvial deposits	1	Fluvial channel deposits

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11. GLACIJALNE I PERIGLACIJALNE NASLAGE KVARNERA, SJEVERNE DALMACIJE I JUŽNOG VELEBITA - DOKAZ DINARIDSKE GLACIJACIJE (sažetak na hrvatskom jeziku)

Kvartarni sedimenti, osobito oni Pleistocenske starosti, danas privlače pozornost geologa i drugih znanstvenika jer sadrže informacije o značajnim klimatskim promjenama tijekom posljednjih 2.6 milijuna godina, posebice u odnosu na vrijeme pojave čovjeka. Unatoč ovoj činjenici, kvartaru nije pridodan odgovarajući značaj u vidu opsežnih geoloških istraživanja širom Hrvatske.

S obzirom da su kvartarne naslage u Jadranskom podmorju poznati rezervoari plina, pokazalo se 80-ih godina potrebnim korelirati kvartarne naslage podmorja i kopna, pa su 1988. započela istraživanja kvartarnih naslaga Jadrana, točnije otoka i obalnog prostora. Taj višegodišnji projekt pokrenuo je INA-Naftaplin, a izvođač je bio tadašnji INA-Projekt u Zagrebu.

Tako sam, prvo kao suradnik na projektu te kasnije voditelj, započela istraživanje kvartarnih naslaga 1989. godine, što je s vremenom postalo moj osnovni objekt istraživanja kroz projekt “Sedimentološko i stratigrafsko istraživanje neogena i kvartara vanjskih Dinarida”. Osnovni cilj istraživanja bio je rekognoscirati poznate lokacije i istražiti nove, opisati pleistocenske sedimentne facijese, definirati sedimentacijske procese, rekonstruirati taložne okoliše, te uspostaviti međusobnu korelaciju i kronostratigrafiju. U vrlo kratkom vremenu, rezultati dobiveni preliminarnim istraživanjem, ukazali su na prevladavajuće glacijalne i periglacijalne naslage u prostoru obalnih Dinarida i nekim jadranskim otocima. Rezultati su poduprli radnu hipotezu da je starija pleistocenska oledba imala značajan uticaj na spomenuti prostor, i da su ledenjaci sezali niže od današnje razine mora. To je dalo potpuno novi pogled na paleogeografsku rekonstrukciju obalnih Dinarida i okolnih prostora. Razmišljanja mojeg cjeloživotnog suradnika i životnog suputnika T.Marjanca o zaleđenim jadranskim ravnicama (danas otoci, obala i zaleđe Zadra) i Velebitu, postala su istinom i provocirala živahne diskusije uz 3 km dug profil kvartarnih naslaga uz obalu Novigradsko mora, koje smo tada počeli još intenzivnije istraživati.

Nakon zatvaranja projekta INA-Naftaplina 1991. godine, istraživanje kvartarnih sedimenata u okviru izrade ove Disertacije nastavljeno je kroz znanstveno-istraživačke projekte financirane od strane Ministarstva znanosti, obrazovanja i šprta: "*Evolucija kenozojskih bazena i geneza klastita na području Jadrana*" (119303) voditelja T. Marjanca (Sveučilite u Zagrebu) u razdoblju 1997 - 2000, "*Paleontologija vertebrata i kronostratigrafija kvartara*" voditeljice preminule M. Paunović (Hrvatska akademija znanosti i umjetnosti) u razdoblju 1990 - 1996, "*Geološki učinci pada meteorita" (0119401)* voditelja T. Marjanca u razdoblju 2002 - 2006 i *"Impakti i geološki događaji u evoluciji Dinarida"* (119-000000-1164) također voditelja T. Marjanaca u razdoblju 2007-2011. Rezultati istraživanja tijekom mojega rada u INA-Projektu (1988 - 1992) osnova su ove Disertacije.

Radiokarbonsko datiranje pet uzoraka izvršeno je u laboratoriju Instituta "Ruđer Bošković" u Zagrebu, financijskim sredstvima INA-Projekta. Datiranje pomoću uranove serije izotopa izvršeno je u okviru kolaborativnog projekta "*Timing of extensive ice cap glaciation in the northeast Adriatic mountains, Croatia: implications for moisture supply and cyclogenesis in the Mediterranean basin"* voditelja Ph. Hughes (University of Manchester) financijskom potporom UK Natural Environment Research Council (NERC Grant 2009).

Cilj istraživanja u okviru izrade ove Disertacije bilo je detaljno upoznavanje pleistocenskih sedimenata i svih ključnih obilježja glacijalnih i periglacijalnih taložnih okoliša koji dokazuju Dinaridsku glacijaciju širokih razmjera.

Sedimentološko istraživanje Kvarnera, južnog Velebita i sjeverne Dalmacije, koje se vršilo tijekom prethodnih dvadesetak godina, dalo je potpuno novo viđenje kvartara, osobito pleistocenskih sedimenata ovog prostora. Tako je davno postavljena hipoteza o oledbi Dinarida potvrđena, i rezultati su prikazani u ovoj disertaciji.

Slijedeći sve prethodne istraživače, koji su govorili u prilog prostrane oledbe Dinarida i bili pioniri u njenoj promociji (Penck, 1900, Hranilović, 1901, Gavazzi, 1903a, b, Schubert, 1909, Milojević, 1922, Bauer, 1934/1935, and Degen, 1936), traženi su različiti sedimentološki i geomorfološki dokazi u istražnom prostoru, te su svi ključni, uvijek zahtijevani, dokazi i pronađeni na mnogim lokalitetima.

Temeljem detaljnog sedimentološkog istraživanja sedimenti su interpretirani kao glacigeni. Osim detaljnog snimanja sedimenta i kartiranja velikih izdanaka, izvršena su opažanja i praćenje litofacijesa na brojnim dodatnim točkama, što je omogućilo rekonstrukciju paleookoliša. Identificirani su različiti litofacijesi i interpretirani kao glacijalni, glaciofluvijalni, glaciolakustrinski i glaciodeltaični. Marinski sedimenti i paleotla su samo evidentirani i nisu podrobno razloženi u ovoj disertaciji.

Glacijalni sedimenti su zastupljeni diamiktnim litofacijesima, koji su određeni kao til ili tilit i interpretirani u smislu podinske, središnje ili bočne morene. Osnivna obilježja sedimenata čine klasti s ledenjačkim strijama, fasetirani klasti, klasti ušiljenih vrhova, raspuknuti klasti. Podinske morene su nađene na otocima Krku, Rabu, Pagu i Sv.Grguru, kod Senja, Jablanca, duž obale od Starigrada-Paklenice do Maslenice, na Rujnu, u Velikoj i Maloj Paklenici, kod Obrovca, uz obale Velebitskog kanala, Novigradskog i Karinskog mora, te kod Raduča u Lici (Sl. 6.1.). Središnje morene su samo na Velikom Rujnu, dok su bočne morene nađene u Baščanskoj dolini na otoku Krku. Unitar moena imenovana su tri lito-alo-morfostratigrafska člana Rujno, Paklenica i Novigrad.

Glacifluvijalni sedimenti obuhvaćaju sve one nastale ledenjačkim ispiranjem na prepletenim i poplavnim ravnicama, te riječne sedimente meandrirajućih tokova. Nađeni su u Baščanskoj dolini na otocima Krku, Pagu, te kod Novigradskog mora (Sl. 5.141.). Njigovo glacigeno porijeklo određeno je na temelju pridruženih facijesa, tilova ili tilita, te na osnovi nalaza klasta s ledenjačkim strijama, eratičkih blokova, te ponekad klasta egzotične litologije kao što je andezit, koji je jedino ledom mogao biti donesen iz Senjskog zaleđa na otok Krk. (Sl. 7.1.).

Glacilakustrinski sedimenti su siltiti i gline, lokalno klasične varve, i varvama slični sedimenti, koji su otkriveni u uvali Poljica kod Ždrila, uz obalu kod Selina, duž obale Novigradskog mora i na obali nedaleko Karina (Sl. 5.128.). Osnovni dijagnostički kriterij za proglacijalni karakter jezerskih sedimenata su bili ledenjački utrusci (drop-stones) (Sl. 5.130., 5.131.E), te klasične glacijalne varve (Sl. 5.116.). Ove naslage često se nalaze u asocijaciji s tilovima.

Glacideltaični sedimenti zastupljeni su konglomeratima, kalkarenitima i kalcisiltitma u izmjeni. Nalaz čestih klasta s ledenjačkim strijama unutar konglomerata bio je presudan za glacigenu interpretaciju. Ovi klasti isključivo upućuju na porijeklo iz podinske morene i to iz neposredne blizine, jer inače strije ne bi bile sačuvane. Uz to, litološki sastav konglomerata odgovara sastavu tilova Rujna i Paklenice, koji sadrže litoklaste s područja Velebita a možda i Like. Dodatni argument za proglacijalni okoliš je asocijacija konglomerata s glacilakustrinskim sedimentima. Glacideltaični sedimenti otkriveni su uz obalu Selina i čine 80 m debeo komplex.

Rezultati sedimentoloških istraživanja prikazanih u ovoj Desertaciji pružaju dokaze o prostranoj oledbi Dinarida i istočne jadranske obale. Ključni dokazi su: klasti s ledenjačkim strijama, fasetirani klasti, ušiljeni klasti i polirani, raspucani klasti, koji su nađeni u diamiktnom litofacijesu (Sl. 6.1.). Diamikt-litofacijesi opisani u Poglavlju 5.2. glacijalnog su porijekla i definirani kao tilovi ili tiliti. Njihove karakteristike omogućile su identifikaciju nekoliko članova kombiniranjem lit-, alo- i morfostratigrafije, kao posebnog pristupa ovom tipu naslaga (Hughes, 2005, 2010). Imenovani su Paklenica, Rujno i Novigrad članovi, te dva pretpostavljena Sklopine i Rduč, i svi predstavljaju glacijalne sedimente kao što je subglacijalni til u smislu podinske ili središnje morene. Završne morene nisu pronađene, što znači da krajnji dosezi leda još nisu poznati. Član Paklenica identificiran na Novigradskom profilu već su ranije opisali Marjanac et al. (1993), ali tada njegova raširenost nije bila poznata. Član Paklenica zastupljen je karakterističnim mega-diamikt litofacijesom, koji je ujedno i najrasprostranjeniji na istraživanom području (Sl. 5.20.) i lako prepoznatljiv po brojnim mega-blokovima u krupnozrnatoj osnovi. Zbog toga je korišten kao korelacijski datum (Sl. 7.7.). Član Novigrad je ograničen samo na područje Novigradskog i Karinskog mora. Pretpostavljeni član Sklopine nalazi se samo u gornjem dijelu Velike Paklenice na prostoru Sklopine i okolice. Pretpostavljeni član Raduč je nedavno prepoznat kao til, no za sada mu se ne može utvrditi kronostratigrafska pripadnost niti korelacija s drugim članovima.

Prikazani rezultati rezimirani su u vidu rekonstrukcije taložnih paleookoliša, njihovog rasprostranjenja, vetikalnog slijeda i moguće lateralne korelacije na istraživanom području Kvarnera, južnog Velebita i sjeverne Dalmacije (Sl. 7.2., 7.3.).

Sedimentološki dokazi oledbe također se vide u facijesnim asocijacijama karakterističnih sedimentnih tijela, koja predstavljaju geomorfološke dokaze Dinaridske oledbe. Naime, tijekom povlačenja leda nastaju različiti depozicijski reljefni oblici kao što su morene, *kame* terase, ketlovi, sandar, eskeri, drumlini, itd. Mogućnost očuvanja tijela poput bočne morene i kame terase je vrlo mala, pa su rijetko opisani u nekadašnjim glacijalnim okolišima. Mogli su biti razoreni mlađom glacijacijom, no češće dolazi do kolapsa tog nekonsolidiranog sedimenta nakon povlačenja leda, te se glacijalni materijal pretaloži i preoblikuje u sedimntna tijela poput aluvijalnih lepeza, te se često definira kao paraglacijalni reljefni oblik (Ballantyne, 2002).

Depozicijski reljefni oblici definirani kao kame terase vrlo dobro su sačuvani u Baščanskoj dolini na otoku Krku i uz obale Paškog zaljeva i kanala. Prvi put su ih opisali Marjanac T. & Marjanac Lj. (1994, 1999). Kame terase su složena sedimentna tijela koja nastaju u kontaktu s ledom u bočnoj zoni između leda i padine, a prepoznatljiva su po nagibu slojeva prema padini doline (Figs. 6.25., 6.29.). Kame terase ukazuju na stagnaciju ledenjaka i izrazitu ablaciju kojom nastaju velike količine ledenjačkih voda koje formiraju rijeke ili jezera na kama terasi.

Uz prikazane nepobitne sedimentološke dokaze, postoje i geomorfološki dokazi od kojih su samo neki navedeni, jer geomorfologija nije bila predmet istraživanja u ovoj Disertaciji.

Poznato je da led pri kretanju stvara različite, od malih do velikih dimenzija, erozijske tragove i reljefne oblike procesima abrazije i erozije. To su strije, polirane površine, plastično modelirane stijene (P-oblici), rochés moutonnées, subglacijalni i rubni kanali, šupljine, doline, kanjoni i fjordovi, cirkovi, i na kraju prostrani krajolici s tragovima glacijalne erozije, itd. (Benn & Evans, 2010). Što se tiče erozijskih oblika opisanih u Poglavlju 6, važno je naglasiti da na istraživanom području svi glacigeni sedimenti leže na karbonatnoj stijenskoj podlozi, točnije vapnencima i dolomitima mezozoika, izuzev gornjeg dijela Velike Paklenice, na potezu Bezimenjača - dolina potoka Velika Paklenica, gdje se u podini nalaze gornje-permski i donje-trijaski karbonati i siliciklastiti. Karbonatna podloga bila je izložena postglacijalnoj eroziji i karstifikaciji, osobito zbog velike količine voda nakon otapanja leda, što je umanjilo mogućnost očuvanja erozijskih oblika. S druge strane, brojni vapnenački klasti s ledenjačkim strijama govore suprotno, no njih je od trošenja sačuvao mikritni matriks.

Klasti s ledenjačkim strijama nađeni su u svim diamiktima određenim kao til ili tilit, te su time kalsficirani kao podinske morene. Ostaci ledenjačkog poliranja i erozije (velike strije i P-oblici) vide se na liticama Anića Kuka u Velikoj Paklenici, te nekim drugim mjestima na području Paklenice i Rujna. Velike strije na goloj podini i paralelni nizovi detritusa vide se na Libinju JI od Velike Paklenice.

Dokazi glacijalnog poliranja podine nađeni su u šljunčari Bošana ispod glacifluvijalnih sedimenata, te blizu Povljane na otoku Pagu, zatim u dolini Velikog Rujna i na Libinju na južnom Velebitu. Kanjoni Velike i Male Paklenice najizrazitiji su dokaz subglacijalne erozije, što se dobro vidi u usporedbi s kanjonom Les georges de l’Arveyron ispred ledenjaka Mer de Glace, koji je otkriven povlačenjem ledenjaka u skorije vrijeme (Sl. 7.4., 7.5.). Taj kanjon je erodiran i oblikovan ledenjačkim vodama dok ga je led potpuno prekrivao i silazio mnogo niže u dolinu. Vrlo je vjerojatno da su na isti način nastali duboki uski dijelovi kanjona Velike i Male Paklenice u vrijeme dokazane oledbe, kao i mnogi drugi reljefni oblici na Velebitu koji su u literaturi opisani kao krški fenomeni. Uzmemo li u obzir veličinu ledene kape i odgovarajuću debljinu leda, postaje očitim da je sublacijalno modeliranje reljefa ledenjačkim vodama bilo značajno.

U okviru ovog istraživanja prvi puta su dobiveni podaci o starosti nekih sedimenata pomoću radiometrijskog datiranja uranovim izotopima. Osim prethodno provedenih ^{14}C (1990) analiza, u razdoblju 2010-2011 obavljeno je datiranje 10 uzoraka kalcita iz cementa u morenama na bazu izotopa U-serije (Tablica 7.1), te su prvi put dobivene srednje-pleistocenske starosti sedimenata. Datiranjem kalcita dobivene su minimalne starosti morena, uglavnom puno mlađe od vremena njihovog taloženja i kompakcije. Cementacija se najvjerojatnije odvijala puno kasnije od taloženja morena jer su uzorci uzimani iz cementa u šupljinama, koje su mogle ostati otvorene nakon otapanja ledenog matriksa. Kalcijem zasićene vode vjerojatno su se infiltrirale u sediment u kasnijoj dijagenetskoj fazi kada je agresivna (bogata s CO2) otapala karbonatni detritus pri površini, a temperatura je bila dovoljno visoka za precipitaciju kalcita. To objašnjava relatvno mlade starosti samih kalcita, i dozvoljava atribuciju veće starosti samom sedimentu te stavljanje u niži kronostratigrafski nivo, te je sedimentima pripisana srednje pleistocenska starost. Temeljem dobivenih starosti pretpostavljena je kronostratigrafska korelacija istraživanih naslaga prikazana na Slici 7.7.

Glaciofluvijalni kompleks Baška - Zarok na otoku Krku sadrži paleotlo (12A, Prilog 5.1.B) koje je datirano metodom 14C na 27.800 g BP, što ga stavlja u vrijeme Würmske (Weichselian) oledbe, točnije LGM. Paleotlo kod Šila na Krku sa "Striata faunom", karakteristično za Würmski interstadijal (Marjanac et al., 1992/1993), moglo bi biti istovjetno. Starije datirano paleotlo 10A (Sl. 5.149) u kompleksu Baška - Zarok starije je od 40.000 g BP. Paleotlo 10A moguće predstavlja toplije razdoblje MIS 9e ili 7e. Kao takvo je korišteno kao korelacijski datum, jer je utvrđeno i u kompleksu Bošana na Pagu koje je također starije od 40.000 godina.

Datiranje kalcita iz morena dalo je mnimalnu starost člana Paklenica te je pripisan Mindelskoj oledbi (Elsterian) u srednjem pleistocenu (Tab. 7.1.). Prema tome je član Paklenica korišten kao drugi datum zakorelaciju. Paklenica član nalazi se u podini kame terase Gajevi, i time mogućuje korelaciju tog dijela naslaga s drugim lokalitetima.

Uzimajuću u obzir starosti kalcita, od 146.000 do 110.000 g BP, uzorkovanih na profilu Novigrad (Fig. 7.6., Tab. 7.1.), pretpostavlja se da sedimentni klinovi (ispune ledenih klinova) česti u glacilakustrinskim sedimentima jedinice 3 označavaju kraj Elster glacijacije ondnosno Mindelske, a da se morena Novigradskog člana istaložila u Riškoj oledbi, što odgovara Mindel-Riss tarosti glacilakustrinskih naslaga Žegara i Ervenika (Malez & Sokač, 1969).

Pretpostavljena kronostratigrafska korelacija i superpozicija definiranih alostratigrafskih jedinica ukazuje da su Selinske glacideltaične naslage najstarije među istraživanim naslagama, starije od Rujanskog i Pakleničkog člana. Selinski glaciodeltaični kompleks svakako ukazuje na Mindelsku (Elster) glacijaciju, a možda i stariju.

Član Paklenica je regionalno usporediv s članom Ninkovići u Crnoj Gori (Hughes et al., 2007, 2011) i morenama u Pindus gorju u Grčkoj (Hughes et al., 2006). Ovi nalazi morena zajedno s nalazom morena kod Boke Kotorske (Stepšnik et al., 2010), dokazuju da Paklenički član predstavlja najdalji sjeverozapadni doseg Dinaridske ledene kape (Sl. 7.8) tijekom srednjopleistocenske oledbe (MIS 12).

Kronostratigrafska interpretacija glacigenih sedimenata, pesebno onih na Velikom i Malom Rujnu, protuslovi svim rezultatima već spomenutih prethodnih istraživača, koji su glacigene sedimente i geomorfološke oblike Velebita pripisali isključivo gornjem pleistcenu ili LGMu. Sukladno tome, ptrebno je revidirati starosti glacigenih sedimenata i na drugim područjima SZ Dinarida (Risnjak, sjeverni Velebit, srednji Velebit).

Maksimalno rasprostranjenje Dinaridske ledene kape još nije poznato, i u tijeku je istraživanja. Preliminarni podaci upućuju na mnogo prostraniju ledenu kapu nego ranije pretpostavljeno, koja se širila i prema unutrašnjosti i prekrivala cijele Dinaride u maksimumu glacijala (Sl. 7.8). Efekti ovako rasprostranjenog leda morali su se ogledati u krškom sustavu, kao i u dinamici podzemnih voda.

Zaključak

Osnovni cilj ove Disertacije pod naslovom "Pleistocenski glacijalni i periglacijalni sedimenti Kvarnera, sjeverne Dalmacije i južnog Velebita - dokazi Dinaridske oledbe", bio je dokumentirati pretpostavljenu prostranu oledbu Jadrana i Dinarida.

Istraživanje je usredotočeno na terensko istraživanje kvartarnih sedimenata na području Kvarnera (otoci Krk, Rab, Pag, Senjska draga, Jablanac), južnog Velebita (Rujno i Velika Paklenica, Kusača, Seline i obala Velevitskog kanala), i sjeverne Dalmacije (južna obala Velebitskog kanala, Novigradsko more, Karinsko more, Obrovac, Paljuv and Smilčić), metodama detaljnog snimanja sedimenata i kartiranja izdanaka.

Na temelju sedimentoloških istraživanja utvrđeno je glacigeno porijeklo sedimenata, te su određeni slijedeći sedimenti:

Glacijalni sedimenti su diamikti određeni kao til ili tilit, a interpretirani u smislu podinskih, središnjih ili lateralnih morena. Glavni indikatori glacijalnog porijekla sedimenta su klasti s ledenjačkim strijama, polirani i ušiljeni klasti, raspucani klasti.

Glacifluvijalni sedimenti obuhvaćaju sedimente nastale ledenjačkim ispiranjem na prepletenim ravnicama i poplavnim ravnicama, ili u meandrirajućim rijekama u proglacijalnom i periglacijalnom okolišu. To su naslage pijeska i šljunka u asocijaciji s tilovima, i često sadrže glacijalni detritus i litološki egzotičan detritus.

Glacilakustrinski sedimenti zastupljeni su s dva tipa, glinovito-siltni sediment s klasičnim varvama, i varvama slični kalcisiltiti s ledenjačkim utruscima koji dokumentiraju proglacijalni taložni okoliš.

Glacideltaični sedimenti zastupljeni su konglomeratima, kalkarenitima i kalcisiltitima u izmjeni. Značajna karakteristika glacigenog porijekla su klasti s ledenjačkim strijama koje sadrži konglomerat, te asocijacija s glacilakustrinskim sedimentima.

Rekonstruirani su slijedeći taložni paleookoliši:

Glacijalni taložni okoliš gdje se sedimentacija vrši u kontaktu s ledom na čelu ledenjaka, u bočnoj zoni između rubova leda i dolinske padine, u subglacijalnoj zoni. Ovaj tip okoliša je dokumentiran nalazom podinskih i bočnih morena. Podinske morene su definirane kao Rujno, Paklenica i Novigrad lito-alo-morfostratigrafski članovi. Paklenica član je najrašireniji, od Krka do Novigradskog mora.

Proglacijalni taložni okoliš u kojem dominiraju procesi ispiranja uzrokovani otapanjem leda, evidentiran je glacifluvijalnim sedimentima rasprostranjenim u sjevernoj Dalmaciji, te proglacijalnim jezerskim sedimentima kod Ždrila, Selina i Novigrada.

Periglacijalni okoliš, s oslabljenim utjecajem leda i dominirajućim permafrostom, prepoznat je u sedimentima na profilu Novigrad, gdje su sačuvani sedimentni klinovi interpretirani kao ispune ledenih klinova, ketlovi, i tragovi krioturbacija, koji ukazuju na procese vezane uz smrzavanje i otapanje zaostalih ledenih blokova i zatrpanih u sedimentu.

Sedimentološko istraživanje pokazalo je da su glacigeni sedimenti iznimno rasprostranjeni u području sjevernog Jadrana i sjeverne Dalmacije, što dokazuje doseg Dinaridske oledbe daleko prema moru. U fazi maksimalnog dosega led je prekrivao otoke Krk, Rab i Pag, veliki dio sjeverne Dalmacije, i cijeli Velebitski kanal, što pokazuje distribucija morena. Povlačenjem leda nastala su proglacijalna jezera dokumentirana glacilakustrinskim sedimentima Ždrila, Selina i Novigrada. Slijedovi izmjena taložnih okoliša pokazuju najmanje tri faze širenja i povlačenja leda.

Pretpostavljenja kronostratigrafska korelacija temelji se na definiranim lito-alo-morfostratigrafskim jedinicama, i starosti sedimenta dobivenih radiometrijskim datiranjem pomoću ugljikovih i uranovih izotopa. Prema dobivenim datacijama sedimentima je pripisana srednje pleistocenska starost.

Time je hipoteza o rasprostranjenoj Dinaridskoj oledbi dokazana, što je otvorilo nove smjerove istraživanja s ciljem utvrđivanja stvarnog dosega Dinaridske glacijacije prema moru i prema unutrašnjosti, vremenskog raspona, i glaciotektonskih deformacija.

12. APPENDICES

Appendix 5/1

Correlation of sediment logs of the Novigrad section

Appendix 5/2 A

Correlation of sediment logs of the Baška - Zarok section

Appendix 5/2 B

Allostratigraphy of the Pleistocene sediments of the Baška - Zarok section

Appendix 5/3

Allostratigraphy of the glacifluvial deposits of the Bošana section

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CURRICULUM VITAE

Present position:

Researcher, Institute of Quaternary Paleontology and Geology,
Croatian Academy of Sciences and Arts, 10000 Zagreb, A. Kovačića 5, Croatia

EDUCATION

Primary and secondary education obtained in Zagreb, Croatia. In 1973 was granted the stipend of the American Field Service program. Years of 1973/74 attended the Cubberley Highschool in Palo Alto, California. Graduated with excellent grades from Cubberley Highschool in Palo Alto in June 1974, including the course in physical geology.

Graduate studies in geology (1974 - 1980) finished by obtaining the degree of Graduate Engineer of geology and palaeontology (*Ingeniarius diplomate probatus*) by the Thesis "Geology of Studenec environs, Slovenia", 61 pp. (supervised by Prof. Dr.sc. Ljubomir Babić) in 1980 at the Department of Geology, Faculty of Sciences, University of Zagreb

Postgraduate studies (1980-1982) in Regional Geology at the Department of Geology, Faculty of Sciences, Joint Studies in the Field of Geology at the University of Zagreb. In 1988 obtained the degree of Master of Natural Sciences in the field of Geology (Regional Geology) (*Magistrae scientiarum*) by the Thesis "Sedimentary characteristics and palaeogeographical interpretation of Cretaceous deposits of the Krško hills, Slovenia", 74 pp. (supervised by Prof. Dr.sc. Vladimir Jelaska).

Specialized workshops

2012 PAGES 3rd Varves Working Group Workshop, March 2012, Manderscheid, Germany

2003 Field workshop on loess and paleosoils - Aspach 2003 (Austria), conducted by Birgit Terhorst

2001 Micromorphology workshop: Certificate of attendance at the International workshop on the micromorphology of glaciogenic sediments, Tübingen 2001 (conducted by J. van Meer and B. Terhorst)

APPOINTMENTS

1996 -	Researcher, Institute of Quaternary Palaeontology and Geology, Croatian Academy of Sciences and Arts
1993-1994	Lecturer of clastic sedimentology, Geological institute at the University in Bergen Project assistant of Prof. Ron Steel
1986-1992	Geologist (sedimentologist)(full time), INA-Geological Consulting Zagreb (former INA-Projekt), division of INA Petroleum Industry
1984-1985	Lecturer of physical geology, Chemical and Technology School Centre in Zagreb, Department of Geology

SCIENTIFIC RESEARCH

Since 1986 was in the research team on several projects for petroleum industry (INA-Naftaplin Oil Production Co. and INA-Lendava Oil Production), mainly in sedimentology of source rocks within projects “Exploration of oil and gas in Slovenia”and “Exploration of Paleogene deposits in External Dinarides”.

In 1988 started as researcher in the new project for petroleum industry “Sedimentological and stratigraphical exploration of the Neogene and Quaternary deposits of the External Dinarides”, and became the project leader in 1989.

In the period 1992 - 2005 was researcher/consultant in projects financed by the Croatian Ministry of Sciences (today Ministry of Science, Education and Sport):

- “Palaeontology of vertebrates and chronostratigraphy of Quaternary” (project leader dr. Maja Paunović, Institute of Quaternary Palaeontology and Geology, Croatian Academy of Sciences and Arts)
- “Exploration of Paleogene basins in the Adriatic region” (project leader Dr. Tihomir Marjanac, Department of geology and palaeontology, Faculty of Sciences, University of Zagreb)
- “Evolution of Cenozoic basins and genesis of clastics” in Adriatic region (project leader Dr. Tihomir Marjanac, Department of geology and palaeontology, Faculty of Sciences, University of Zagreb)
- “Cenozoic volcanism of the Adriatic offshore and mainland” sponsored by the Croatian Ministry of Sciences and INA-Naftaplin Oil Production Co. (project leader Dr. Boško Lugović, Faculty of Mining, Geology and Petroleum, University of Zagreb)
- Slovenian-Croatian Project “Exploration of paleoseismicity in the Adriatic, Pannonian Basin and Krško Depression” (project leader Dr. Tihomir Marjanac, Department of geology and palaeontology, Faculty of Sciences, University of Zagreb)
- “Correlation of Palaeolithic and Neolithic in Croatia” (project leader dr. sc. Maja Paunović til 2003, and dr. sc. Vesna Malez later on, Institute of Quaternary Palaeontology and Geology, Croatian Academy of Sciences and Arts)
- “Geological effects of bolide impacts” (project leader Dr. Tihomir Marjanac, Department of geology and palaeontology, Faculty of Sciences)
- 2004 - 2010 I am the co-leader of the project “Geopark Island Rab” financed by the local authorities of Rab.

RESEARCH INTERESTS

Quaternary (Pleistocene) depositional systems and paleoenvironments, glacial geology, depositional events versus climatic changes, catastrophic events and related sediments in geological past, cave deposits, applied geology in geoconservation

PROFESSIONAL MEMBERSHIPS AND FUNCTINS

- INQUA (secretary of the National committee since 1998, and national representative in INQUA)
- ProGEO European Association for Protection of Geological Heritage (member and National representative since 1998)

- Croatian Geological Societ (1978 - 2002)
- Member of the working group for protection of the Dinaric Karst under UNESCO world heritage list (2012)
- Member of the organizing committee of INQUA beannual national meetings

SCIENCE POPULARIZATION ACTIVITIES

Until 2002 was active leader of the Croatian Geological Society's Geoheritage section, and later in 2005 founder and president of the ProGEO-Croatia - Croatian association for the promotion and conservation of geological heritage (president since January 2005).

- Coorganizer of the European Reaserchers Night in Croatia 2010 and 2011 supported by Marrie Currie fund
- participation in the Science Festival since 2006
- coorganizer and coleader of the geological workshops for primary school children

INVITED LECTURES (lecturer)

Marjanac T. & Marjanac Lj. (1987): *Recentna karbonatna platforma u Gabeškom zaLjevu (Tunis).* Hrvatsko geološko društvo

Marjanac T. & Marjanac Lj. (1987): *Kerkenah karbonatna platforma u Tuniškom zaLjevu.* Slovensko geološko društvo

Marjanac T. & Marjanac Lj. (1990): *Novi dokazi za glacijaciju Velebita.* Hrvatsko geološko društvo

Marjanac T. & Marjanac Lj. (1990): *Novi dokazi za glacijaciju vanjskih Dinarida.* INA-Naftaplin

Marjanac Lj. (1992): *Prikaz Međunarodnog skupa sedimentologa IAS u Bergenu*. Hrvatsko geološko društvo

Marjanac Lj. & Marjanac T. (1994): *Middle Pleistocene glaciation in the Adriatic Sea.* Geological institute, University of Bergen

Marjanac Lj. & Marjanac T (1997): *Pleistocenski sedimenti jadranskog priobaLja i otoka.* Slovensko geološko društvo

Marjanac Lj. & Marjanac T. (1998): *Dolina Gomance u doba pleistocena.* Dani Matka Laginje u Klani

Marjanac T. & Marjanac Lj. (1999): *Zaštita geološke baštine, zašto i kako?!* Prirodoslovni muzej Rijeka

Brajković, D., Marjanac, Lj., Mauch Lenardić, J. & Paunović, M. (2001): *Quaternary paleontology: Going to public.* 3rd European Paleontological Association Congress, Leiden

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