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JURASSIC AND CRETACEOUS STRATIGRAPHY AND SEDIMENTARY EVOLUTION OF THE JULIAN ALPS, NW SLOVENIA

ZALOŽBA ZRC

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ANDREJ ŠMUC

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CONTENTS

Abstract

The northwestern part of Slovenia includes the Julian Alps, which structurally belong to the Julian Nappe that forms the eastern continuation of the Southern Alps. What now form the Julian Alps were in the Jurassic part of the southern Tethyan passive continental margin and at that time experienced extensional faulting and differential subsidence related to rifting, whilst during the Cretaceous the area underwent the onset of a compressional regime.

The main purpose of this research is to present a detailed sedimentologic and biostratigraphic study of the Jurassic and Cretaceous successions of the Julian Alps. Fourteen selected sections exposing Lower Jurassic to Upper Cretaceous deposits are presented in detail. The Mt. Mangart area and the Triglav Lakes Valley are of key importance of this research. Other investigated regions include Čisti Vrh, Vas na Skali, Ravni Laz, and Lužnica Lake. Eight lithostratigraphic units were described; four of them were formally described.

Geological maps of the Triglav Lakes Valley and Mt. Mangart areas were made on a scale of 1: 10 000 as well. The Triglav Lakes Valley area is composed of the Krn Nappe, overthrust by the Zlatna Nappe. The area is additionally disrupted by a large strike-slip fault forming a negative flower structure. Mapping the Mt. Mangart area revealed a complex tectonic structure composed of the Mangart structural unit and the Travnik structural unit that are internally thrusted, folded and disrupted by faults. The Mangart structural unit is thus divided into the Mali Vrh, Rdeča Skala, Drn, and Mangart peak subunits.

Three typical successions indicating three different paleogeographic domains are distinguished, and are as follows:

The most complete succession is exposed in the Travnik structural unit. It starts with lower Lower Jurassic platform limestone overlain by Pliensbachian deeper-shelf limestone of the Sedlo Formation, followed by the Toarcian Skrile Formation (black shales with intercalated siliceous limestone). A stratigraphic gap, comprising at least the late Toarcian and Aalenian, separates the Skrile Formation from the overlying lower/middle Bajocian to lower Tithonian Travnik Formation (cherts, siliceous limestone and carbonate gravity-flow deposits). The succession ends with the Biancone-type pelagic limestone of early Cretaceous age. Paleogeographically the basinal Jurassic deposits correspond to the Bovec Trough.

The succession in the Triglav Lakes Valley consists of Pliensbachian platform limestone overlain by the Bajocian to lower Tithonian Prehodavci Formation (condensed limestone of Ammonitico Rosso type). The succession ends with a lower Cretaceous Biancone-type limestone. The Prehodavci Formation was also studied in Ravni Laz, Lužnica Lake, Čisti Vrh, and at Vas na Skali. It is the most common formation of the Julian High.

The most reduced succession is characterized by numerous polyphase Jurassic neptunian dykes cut into the lower Lower Jurassic platform limestone. These deposits are unconformably overlain by the middle Cretaceous Scaglia variegata or Senonian Scaglia rossa formations. The succession is exposed in the Mangart structural unit. Neptunian dykes formed at the margins of the Julian High.

The main sedimentary evolutionary phases during the Jurassic and Cretaceous are: 1) During the early Early Jurassic, the Julian Carbonate Platform was active. 2) Due to extension and accelerated subsidence in the Pliensbachian, the Julian Carbonate Platform was dissected, forming two different paleogeographical domains: a deeper basin named the Bovec Trough and a pelagic plateau named the Julian High. Distal-shelf limestones of the Sedlo Formation were formed in the Bovec Trough, while blocks of the central part of the Julian High were probably emergent. In the marginal parts of the Julian High, neptunian dykes were formed at that time. 3) The latest Pliensbachian lowstand is represented by a Fe-Mn hardground on the top of the Sedlo Formation. 4) Black shales in the lower part of the Skrile Formation in the Bovec Trough were deposited during early Toarcian Oceanic Anoxic Event. The Skrile Formation records a Toarcian transgressive/regressive cycle. 5) A second pulse of accelerated subsidence in the Bajocian caused additional subsidence of the investigated area. The Bovec Trough at that time became part of a deeper basin recording the sedimentation of cherts and siliceous limestones with radiolarians, and started to receive resedimented carbonates from the adjacent Dinaric Carbonate Platform. All the areas corresponding to the Julian High at that time were drowned and were characterized by condensed sedimentation of the Prehodavci Formation. 6) Breccias in the lower part of Member 3 of the Travnik Formation that represent the most proximal facies association of the formation in the basin and a Fe-Mn horizon on the plateau record an upper Bathonian lowstand. 7) A Kimmeridgian tectonic phase is marked by numerous neptunian dykes cut into the Prehodavci Formation and a level of breccias in the basin. 8) At the early/late Tithonian boundary the siliceous pelagic sedimentation and Ammonitico Rosso type sedimentation was replaced by the carbonate background sedimentation of the Biancone limestone. This facies change is regional and synchronous throughout all the western Tethys. At that time Jurassic topography was predominantly flat. 9) A tectonic phase in the Albian caused renewed reorganization of the area and enabled the sedimentation of the Scaglia variegata formation. 10) After a tectonic pulse in the Late Cretaceous the deposition of the Scaglia rossa began.

The succession of the Bovec Trough is correlative with successions of the Tolmin and Belluno basins. The successions are generally similar, however some differences do exist, because the Tolmin and Belluno basins were already deep-water basins during the early part of the Early Jurassic whereas the area of the later Bovec Trough was a carbonate platform (the Julian Carbonate Platform) that was drowned no earlier than the Pliensbachian. Furthermore, in the Middle and Late Jurassic, the Bovec Trough was located closer to the Dinaric Carbonate Platform than the Tolmin and Belluno basins, as evidenced by the relatively late initial subsidence, conspicuous hiatuses and obvious sediment bypass in the Bovec Trough. The condensed successions of the Julian High are correlative with those of the Trento Plateau. They are the most similar to certain parts of the Trento Plateau, where the middle member of the Ammonitico Rosso (RAM) did not develop.

Izvleček

Preiskano območje se nahaja v Julijskih Alpah, ki so del strukturne enote Južnih Alp ali natančneje del Julijskega pokrova. Paleogeografsko je območje Julijskih Alp v juri pripadalo južnemu pasivnemu kontinentalnemu robu Tetide in je bilo zaradi riftinga podvrženo ekstenziji ter razkosano na bloke z različno hitrostjo pogrezanja. V kredi pa je območje v kompresivnem režimu.

Namen tega dela je sedimentološka in biostratigrafska študija jurskih in krednih kamnin v Julijskih Alpah. V ta namen sem na območju Julijskih Alp detajlno preiskal 14 izbranih profilov, v katerih izdanjajo spodnjejurske do zgornjekredne kamnine. Območji Mangartskega sedla in Doline Triglavskih jezer predstavljata ključni območji za razumevanje geološkega razvoja zahodnih Julijskih Alp v juri in kredi. Kot dodatna območja sem proučil tudi jursko-kredne profile v okolici Čistega vrha, Vasi na Skali, ter profila Ravni Laz in Jezero v Lužnici.

Za območji Mangartskega sedla in Doline Triglavskih jezer sem izdelal tudi detajlni geološki karti v merilu 1: 10000. Območje Doline Triglavskih jezer pripada Krnskemu pokrovu, na katerega je narinjen Slatenski pokrov. Te starejše strukture so nato presekane z močnim desnozmičnim prelomom. Območje Mangartskega sedla je strukturno zelo zapleteno zgrajeno. V splošnem ga gradita dve večji enoti: Mangartska in Travniška strukturna enota. Mangartsko strukturno enoto nadalje sestavljajo štiri strukturne podenote: podenota Mali Vrh, Rdeča Skala, Drnska strukturna podenota in podenota Vrh Mangarta.

Na območju Julijskih Alp sem odkril tri tipične razvoje, ki so značilni za tri različne paleogeografske enote.

Najbolj popolno zaporedje izdanja v Travniški strukturni enoti in se začne s plitvovodnimi spodnjeliasnimi apnenci, nad katerimi konkordantno ležijo pliensbachijski apnenci distalnega šelfa Sedlske formacije. Zaporedje se nadaljuje s toarcijskimi črnimi in rjavimi skrilavimi glinavci z vmesnimi plastmi kremenastih apnencev, ki predstavljajo Skrilsko formacijo. Sledijo diskordantno odloženi spodnje/srednje bajocijski do spodnje tithonijski pelagični kremenasti sedimenti z vmesnimi karbonatnimi resedimenti Travniške formacije. Dolga stratigrafska vrzel (zgornji toarcij in aalenij) loči Skrilsko od Travniške formacije. Zaporedje se zaključi s pelagičnimi apnenci tipa biancone zgornjetithonijske in spodnjekredne starosti. Jurske globljevodne kamnine Travniške strukturne enote paleogeografsko pripadajo Bovškemu jarku.

Za zaporedje v Dolini Triglavskih jezer je značilno, da na spodnjejurske plitvovodne apnence diskordantno nalegajo kondenzirani bajocijski do spodnjetithonijski apnenci formacije Prehodavci (apnenci tipa ammonitico rosso). Nad njimi ležijo zgornjetithonijski mikritni apnenci tipa biancone. Apnenci formacije Prehodavci so bili preučeni tudi v Ravnem Lazu, Jezeru v Lužnici, Čistemu Vrhu in pri Vasi na skali. Predstavljajo tipičen razvoj Julijskega praga.

Najbolj kondenzirano sedimentacijo odraža profil v Mangartski strukturni enoti. Tu nad plitvovodnimi zgornjetriasnimi in spodnjeliasnimi plitvovodnimi apnenci z jurskimi neptunskimi dajki neposredno ležijo aptijsko-albijske ali senonske globokovodne kamnine formacije Scaglia variegata in Scaglia rossa. Neptunski dajki so nastajali v robnih delih Julijskega praga.

Sedimentacija na preiskanem ozemlju odraža vpliv ekstenzijske tektonike zaradi riftinga v zahodni Tetidi, evstatičnih nihanj morske gladine in regionalnih paleooceanografskih sprememb. Glavne faze v jurskem do krednem razvoju Julijskega pokrova so naslednje: 1) V spodnji juri je na območju Julijskega pokrova obstajalo plitvovodno območje, imenovano Julijska karbonatna platforma. 2) Faza neenakomernega pogrezanja v pliensbachiju je povzročila razpad Julijske karbonatne platforme na bloke z različno hitrostjo pogrezanja. Nastali sta dve novi paleogeografski enoti: bolj pogreznjeni bloki pripadajo Bovškemu jarku, relativno manj pogreznjena območja predstavljajo Julijski prag. V Bovškem jarku so se v pliensbachiju sedimentirali apnenci distalnega šelfa Skrilske formacije, medtem ko v centralnem delu Julijskega praga ni bilo sedimentacije, ker je bilo območje verjetno dvignjeno na kopno. V robnih

deli hJulijskega praga so v tem času nastajali neptunski dajki. 3) Na meji pliensbachij-toarcij je evstatični padec morske gladine na bolj pogreznjenih blokih povečal intenziteto morskih tokov in s tem ustvaril pogoje za nastanek železovih-manganovih gomoljev, ki so značilni za vrhnji del Sedlske formacije. 4) Spodnjetoarcijski glinavci formacije Skrile predstavljajo značilen sediment globalnega anoksičnega dogodka in transgresije v spodnjem toarciju. 5) Druga faza pospešenega pogrezanja v bajociju je na ozemlju Julijskih Alp povzročila dodatno poglobitev. Območje Bovškega jarka postane del globljevodnega bazena, ki je neposredno povezan z Dinarsko karbonatno platformo, s katere prihaja material za karbonatne turbidite. Območja, ki predstavljajo Julijski prag, se v tem času prav tako potopijo in na njih se začne sedimentacija kondenziranih apnencev formacije Prehodavci (apnenci tipa ammonitico rosso). 6) Zgornjebathonijski padec morske gladine se v bazenu odrazi s horizontom breč, ki predstavljajo najbolj proksimalen turbiditni facies. Na podmorski planoti zaradi močnejših morskih tokov v tem času nastajajo železo-manganovi gomolji. 7) Tektonska faza v kimmeridgiju je povzročila nastanek breč v bazenu, na podmorski planoti pa so nastali neptunski dajki. 8) Na meji spodnji/zgornji tithonij se pelagična kremenasta sedimentacija v bazenih in sedimentacija apnencev tipa ammonitico rosso na podmorskih planotah preneha in začnejo se sedimentirati pelagični apnenci tipa biancone. Ta facialna sprememba je regionalna in istočasna v vseh bazenih v zahodni Tetidi. Globljevodna jurska topografija je tako v spodnji kredi že delno izenačena. 9) Nova tektonska faza v albiju je povzročila ponovno reorganizacijo sedimentacijskega prostora in posledično sedimentacijo formacije Scaglia variegata. 10) Po novi tektonski fazi v zgornji kredi (pred senonom) se je začela sedimentacija formacije Scaglia rossa.

Razvoje Bovškega jarka sem primerjal z razvoji v Tolminskem in Belluno bazenu. Razvoji so si v splošnem podobni, vendar obstajajo pomembne razlike. Območje Bovškega jarka se je potopilo šele v pliensbachiju, medtem ko sta Tolminski in Belluno bazen v tem času že globoka bazena. V srednji in zgornji juri pa je bilo območje Bovškega bazena bliže Dinarski karbonatni platformi kot omenjena bazena. Razvoji Julijskega praga pa so podobni razvojem na Trento platoju. V večini preiskanih profilov Julijskega praga srednji člen formacije Prehodavci ni razvit. Ti profili so podobni profilom v nekaterih delih Trento platoja, kjer srednji kremenasti del formacije Ammonitico Rosso manjka.

1

INTRODUCTION

During the Jurassic the Alpine-Mediterranean region (Southern Alps and Dinarides) belonged to the southern passive continental margin of the Tethys and experienced extension due to rifting. The rifting resulted in a brake up of preexisting carbonate platforms, producing a complex pattern of pelagic basins and escarpment-bounded pelagic platforms, which existed until Late Cretaceous.

The Julian Alps, as the eastern continuation of the Southern Alps, are typical example of a Tethyan rifted margin, characterized by a thick pile of Upper Triassic to lower Jurassic platform limestones overlain by condensed and highly discontinuous Jurassic to Cretaceous deeper-water deposits that show drastic difference in thickness and abrupt lateral facies changes. The study of these deposits and present hiatuses enabled us to elucidate the complex vertical and lateral relationships that characterize the area and thus refine a Jurassic to Cretaceous paleogeography, sedimentary evolution and rifting history of the Southalpine-Dinaric continental margin.

1.1 GEOLOGICAL SETTING

The study area is situated in NW Slovenia in the Julian Alps. The Julian Alps comprise the northwestern part of Slovenia and easternmost part of Italy (Fig. 1.1). They extend from the Soča valley between Tolmin and Kobarid, Mt. Stol ridge between Kobarid and Gemona (Italy) in the south, to the Kanalska dolina (Val Canale, Italy) in the north and the Zgornja Savska dolina (the Upper Sava Valley) in the east.

The Julian Alps are a part of a complex structure of NW Slovenia, formed mostly in the Cretaceous and in the Tertiary during the Alpine orogeny (Doglioni & Bosellini 1987, Poli & Zanferrari 1995, Bresnan et al. 1998, Placer 1999). They structurally

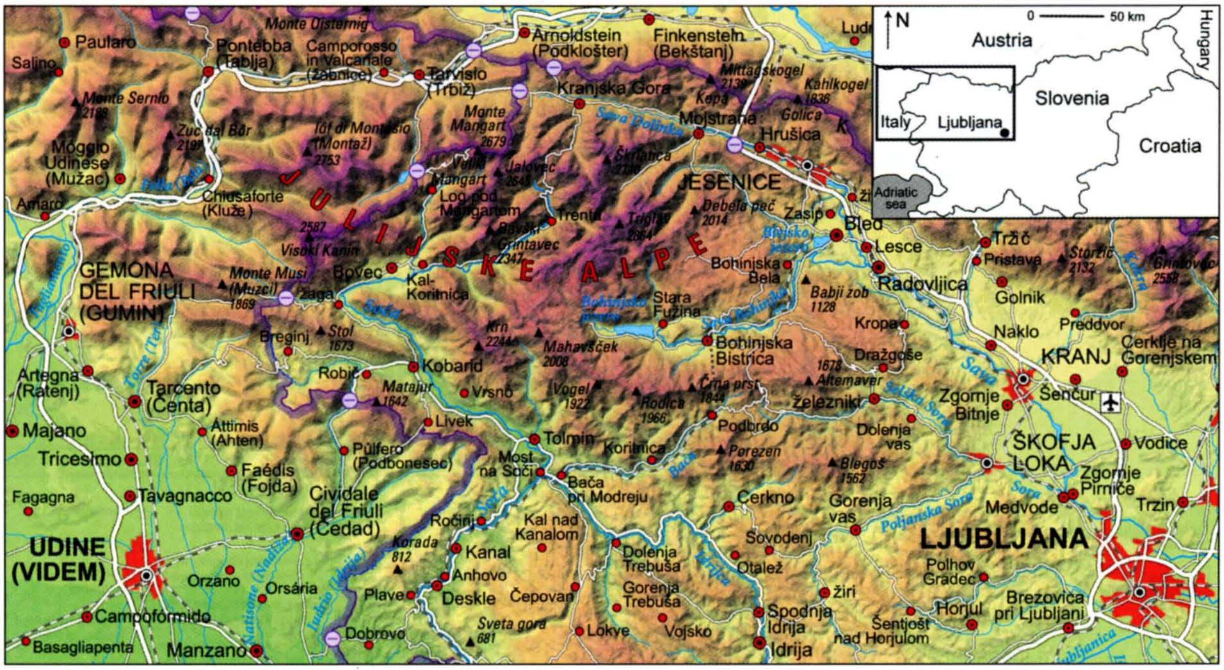


Fig. 1.1 Geographic location of the Julian Alps (enlarged sector of the map of Slovenia 1: 1.000.000, map courtesy of Anton Melik Geographical Institute).

belong to the Julian Nappe, which together with the south-lying, underthrust Tolmin Nappe forms the eastern continuation of the Southern Alps (Placer 1999) (Fig. 1.2). The eastern part of the Southern Alps is marked by a superposition of several Cenozoic tectonic phases: the Mesoalpine (Paleogene) Dinaric SW-directed nappe emplacement is overprinted by Neoalpine (Neogene) south directed Southalpine structures (Doglioni & Bosellini 1987, Doglioni & Siorpaes 1990, Carulli et al. 1990, Bresnan et al. 1998, Placer & Čar 1998, Placer 1999). In western Slovenia the Southalpine front is in direct contact with the External Dinarides and extends in an E-W direction.

In the Jurassic, the Southern Alps and Dinarides belonged to the Adriatic-Apulian microcontinent, bordered to the north and west by the Alpine Tethys and to the east by the Vardar Ocean (Stampfli et al. 2001) (Fig. 1.3) and was a part of the southern Tethyan passive continental margin. In the Mesozoic, the Southalpine-Dinaric continental margin experienced two major phases of extensional tectonics. The first rifting phase, in the Middle Triassic, created numerous relatively shallow basins, most of which were completely filled in by the early Late Triassic (Winterer & Bosellini 1981, Doglioni 1987, Buser 1989, Bertotti et al. 1993, Ogorelec & Rothe 1993). Conversely, the latest Triassic-Early Jurassic rifting dissected the margin into large basins and topographic highs, which were maintained until the Late Cretaceous. These two rifting events do not seem to be directly interrelated (Winterer & Bosellini 1981, Doglioni 1987, Bertotti et al. 1993), however some pre-existing Triassic faults may have later been reactivated.

From the Late Triassic to the earliest Jurassic, W Slovenia belonged to a relatively uniform carbonate platform called the Julian Carbonate Platform (see chapter 1.4.1). During Early Jurassic rifting, the platform was dissected into blocks with different sub-

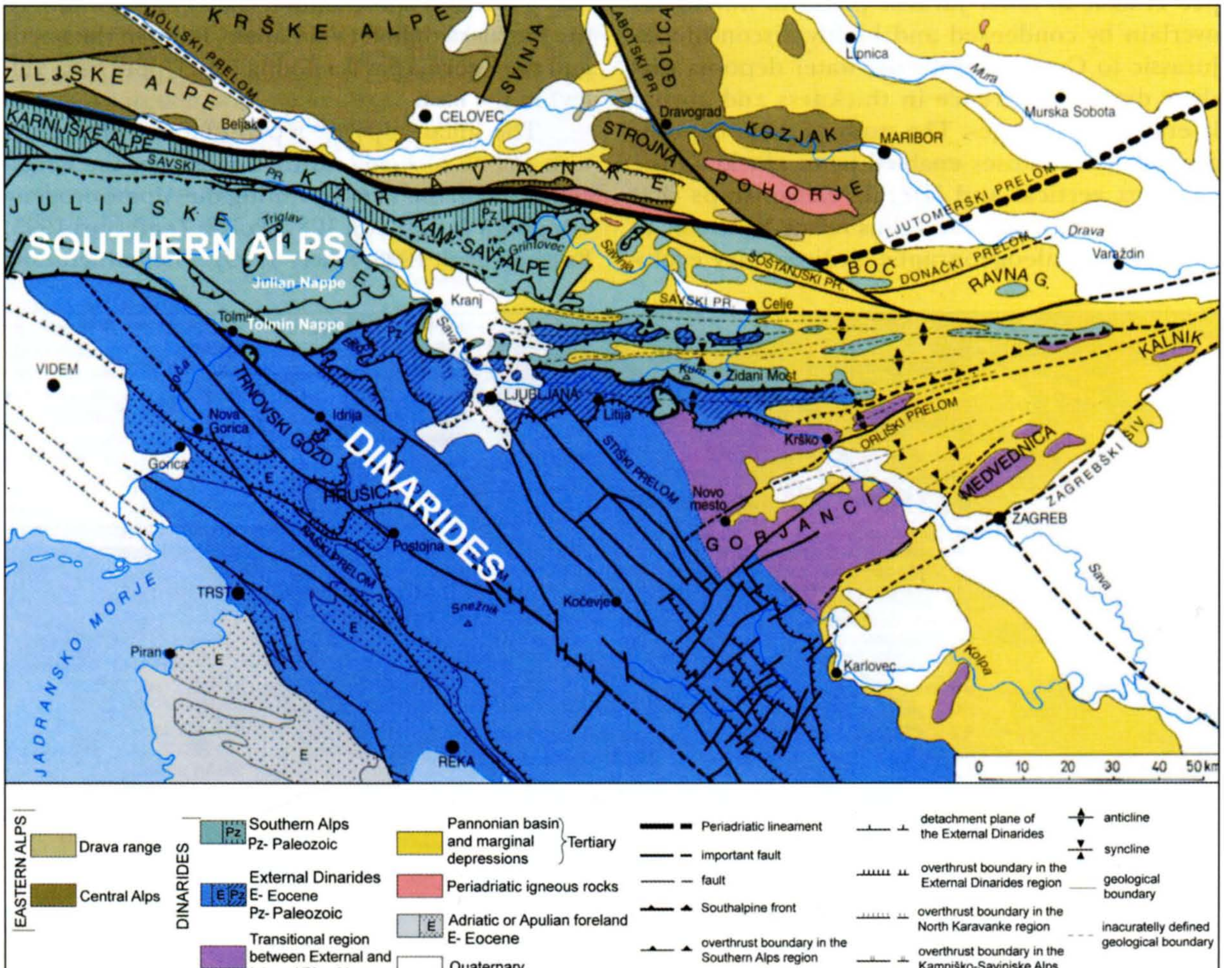


Fig. 1.2 Macrotectonic subdivision of Slovenia (Placer 1999).

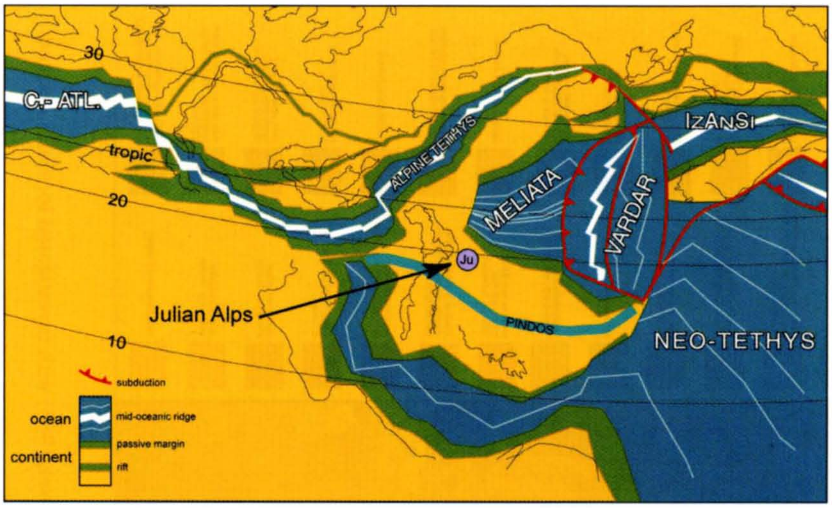


Fig. 1.3 Oxfordian plate reconstruction (simplified after Stampfli et al. 2001).

sidence rates, forming a horst-and-graben structure. The Jurassic sedimentary evolution of the southern Tethyan continental margin is well documented in the Southern Alps of Italy (Bernoulli et al. 1979, 1990, Bosellini et al. 1981, Winterer & Bosellini 1981, Bertotti 1991, Bertotti et al. 1993, Martire 1992, 1996) whereas in Slovenia this information is scarce (Aubouin et al. 1965, Cousin 1970, 1973, 1981, Buser 1989, 1996).

In western Slovenia Jurassic extension led to the formation of three different paleogeographic domains (Buser 1989, 1996, Buser & Debeljak 1996) (Fig. 1.4). The shallow-water Dinaric Carbonate Platform (Friuli Carbonate Platform in the Italian literature) in the south, the pelagic submarine high – Julian High in the north and intermediate deeper-water basin – Slovenian Basin. The pattern of these topographic highs and depressions now dis-

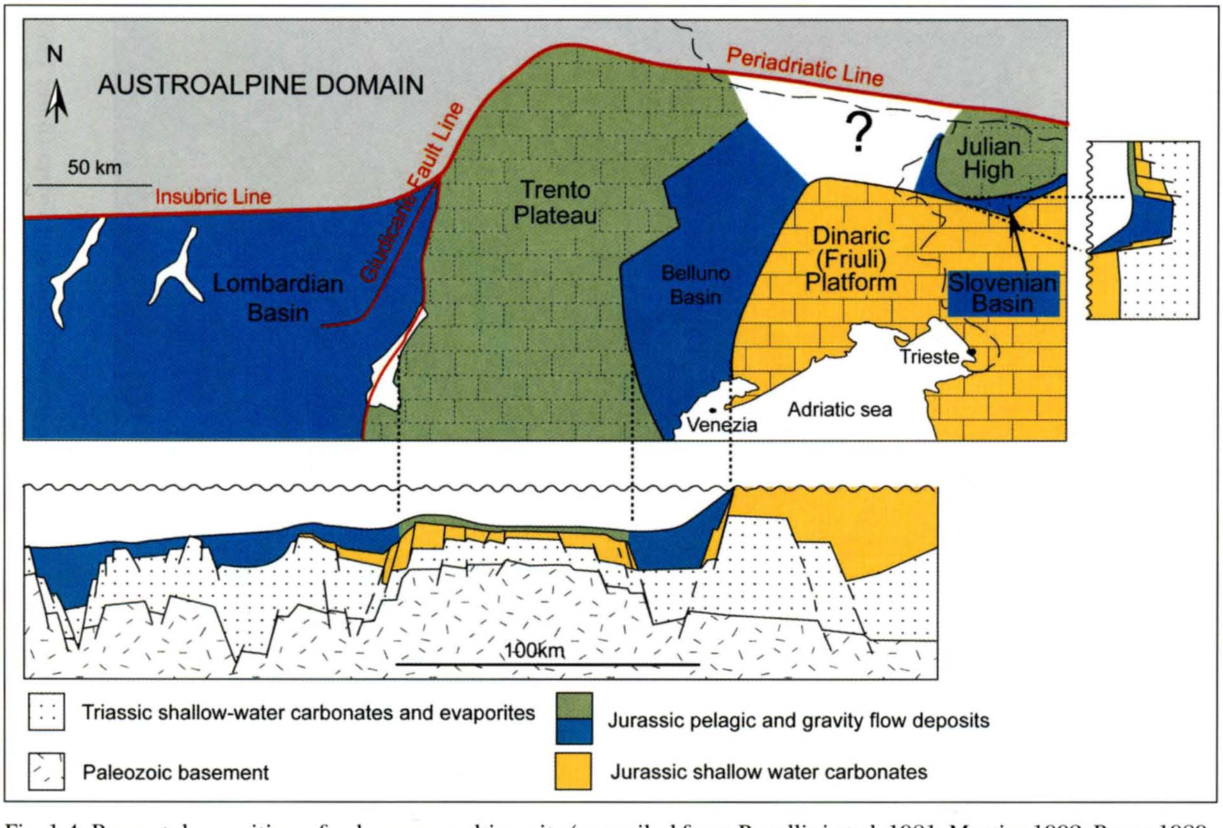


Fig. 1.4 Present-day position of paleogeographic units (compiled from Bosellini et al. 1981, Martire 1992, Buser 1989, and Placer 1999) and schematic palaeogeographic cross-sections at the end of the Jurassic.

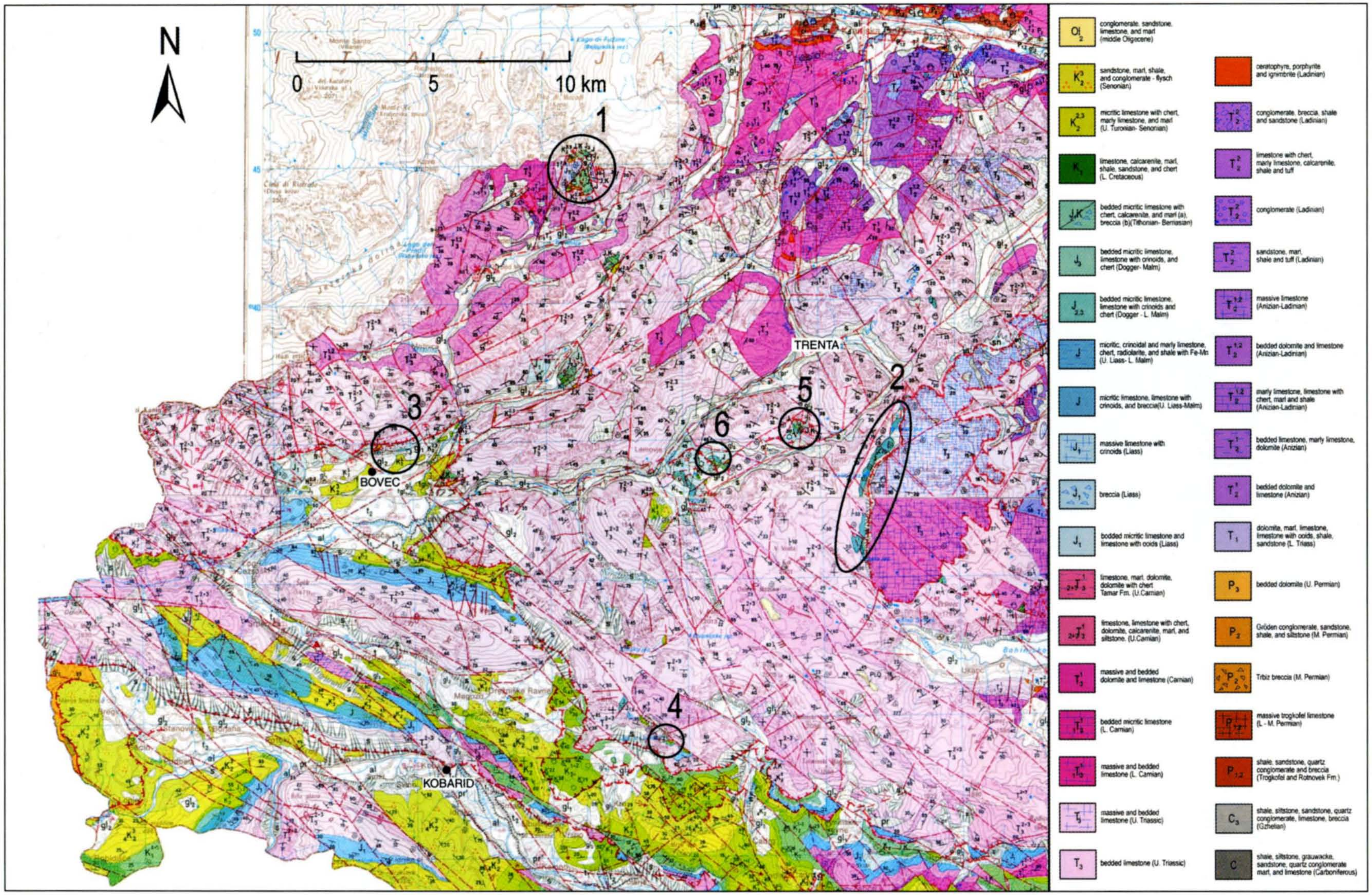


Fig. 1.5 Basic geological map of Yugoslavia, sheets Tolmin and Videm (Buser 1986) and Beljak and Ponteba (Jurkovšek 1986) with investigated localities marked: 1. Mt. Mangart Saddle, 2. Triglav Lakes Valley, 3. Ravni Laz, 4. Lužnica Lake, 5. Čisti Vrh, 6. Vas na Skali.

tributed approximately in N-S direction is similar to the pattern recognized westward, where in the E-W direction we observe the Dinaric (Friuli) Platform, Belluno Basin, and Trento Plateau (Fig. 1.4) (Aubouin et al. 1965, Bosellini et al. 1981, Winterer & Bosellini 1981, Buser 1989, 1996, Buser & Debeljak 1996, Placer 1999).

In northern Italy, the east-west arrangement of the Jurassic paleogeographic units was not significally changed by north-south shortening during the Alpine orogenesis. The units are still arranged in their original order and allow a relatively clear paleogeographic reconstruction. The eastern part of the Southern Alps (northwestern Slovenia) was characterized by NW-SE striking normal faults in the Jurassic. Strong Tertiary polyphase thrusting first in Dinaric (NE-SW) and later in the South Alpine (N-S) directions thus completely obliterated the original Mesozoic paleogeography. Different paleogeographic units are thus only partly preserved and belong to different overlapping thrusts. In northwestern Slovenia facies belts are now primarily E-W oriented but the original geometry of the Mesozoic margin has not yet been reconstructed in detail. The reconstruction of primary Mesozoic spatial relationships is additionally hindered by the fact that in the Julian Nappe, upper Triassic shallow-water strata tend to be preserved while Jurassic and Cretaceous rocks are generally eroded.

The Mesozoic succession in the Julian Nappe is characterized by a thick package of shallow-water Upper Triassic to lower Lower Jurassic limestones overlain by a condensed upper Lower Jurassic to Upper Cretaceous deeper-water deposits. Because of this stratigraphy, the inferred paleotopographic setting of this area (Fig. 1.4) during the late Early to Late Jurassic was thought to be a pelagic submarine high (Julian High in Buser 1996). The Julian High, however, was not a uniform plateau but was dissected into differentially subsided blocks. Some of these blocks became isolated pelagic carbonate platforms (sensu Santantonio 1994), while other blocks formed deeper basins, which received gravity-displaced material from the adjacent shallow-water platforms (Cousin 1981, Šmuc & Goričan 2005).

The similar spatial distribution of topographic highs and depressions in northern Italy and northwestern Slovenia (Fig. 1.4) also raised the question of a possible deeper-water paleogeographic connection between the Belluno and Slovenian basins. Some authors (Aubouin et al. 1965, Cousin 1970, 1981, Buser 1996, Buser & Debeljak 1996) stated that the Belluno and the Slovenian Basin did not form a physiographically uniform basin but were both wedge-shaped and separated by a topographic high, whereas others (Bosellini et al. 1981, Winterer & Bosellini 1981, Bellanca et al. 1999, Clari & Masetti 2002) suggest that they were connected directly. Our recent investigations (Šmuc & Goričan 2005, this study) suggest that at least until the Pliensbachian, the Slovenian and Belluno basins were not continuous but separated by a topographic high, represented by the Travnik structural unit of the Mt. Mangart saddle.

The Julian Alps are composed predominantly of Upper Triassic shallow-water strata (Dachstein Limestone and Main Dolomite) and Jurassic and Cretaceous deposits are relatively rare (Fig. 1.5). They are restricted to relatively small areas and are usually fault-bounded. However, complete successions can be found in a few localities. The key-areas for understanding the Jurassic tectono-sedimentary evolution of the Julian Alps are the Triglav Lakes Valley and Mt. Mangart saddle (localities 1 and 2 in Fig. 1.5). The Jurassic-Cretaceous successions in these areas are relatively well exposed. Additional areas where Jurassic and Cretaceous deposits were investigated are Ravni Laz, Lužnica Lake, Vas na Skali, and Čisti Vrh (localities 3 to 6 in Fig. 1.5). In these localities, the successions are smaller and less well-exposed, so that only one section could be studied from each locality.

1.2 PREVIOUS RESEARCH

Stur (1858, ref. in Diener 1884, p.686) was the first to recognize the Jurassic beds in the Triglav Lakes Valley. The Jurassic age of the beds was later confirmed by Kossmat (1913). Salopek (1933) first described the Jurassic and Cretaceous beds in the Triglav Lakes Valley. Ramovš (1975) dated red nodular limestones of the Triglav Lakes Valley as Oxfordian and Kimmeridgian.

Winkler (1920a, 1920b) and Winkler-Hermaden (1936) investigated the coarse-grained Jurassic Krn breccia at Lužnica Lake and interpreted them as transgressive deposits following the Middle Jurassic orogenic phase. This interpretation was later refuted by Babić (1981) who found out that this "Krn breccia" represents fillings of neptunian dykes provoked by the repeated Jurassic extensional fracturing of a submarine topographic high.

Selli (1963) constructed the first viable geological (1:100 000) and tectonic (1:250 000) map of the Julian Alps.

Cousin (1981) investigated western Slovenia together with northeastern Italy. Within his study he included Jurassic and Cretaceous localities in the Julian Alps: the Mt. Mangart saddle, Bavšica, Bovec, Na Skali, Vrsnik, Triglav Lakes Valley and the Mt. Krn area. Cousin (1981) mapped some of the areas and compiled composite stratigraphic sections of the exposed Jurassic and Cretaceous formations. In the Julian Alps he recognized two parallel N-S oriented basins: "Sillon de Bovec" and "Sillon de Bled", separated by a submarine topographic high (in the Komna area). To the south, these two basins merge with the E-W oriented "Sillon the Tolmin".

The Julian Alps were also mapped for the Basic Geological Map of Yugoslavia, at a scale of 1:100 000 by Buser (1986) (the Tolmin and Videm sheet, 1:100 000) and Jurkovšek (1986) (the Beljak and Ponteba sheet, 1:100 000). Both authors concluded that the Jurassic and Cretaceous strata are restricted to a few square kilometers and that they are predominantly fault- bounded. Furthermore, in the explanatory notes of the maps, the authors described the condensed Jurassic and lower Cretaceous rocks.

Jenkyns (1988) focused on a horizon of organic-rich shales with siliceous-limestone intercalations that occur at the Mt. Mangart saddle, interpreting these deposits as a product of the Toarcian Oceanic Anoxic Event (OAE). Recently, the Toarcian age of these deposits was confirmed using well-preserved and diverse radiolarian faunas (Goričan et al. 2003).

Jurkovšek & Kolar-Jurkovšek (1988) described the crinoids from the Tithonian-Valanginian beds east of Vrsnik. Lower Cretaceous nannoplankton and radiolarians from Vrsnik were described by Pavšič & Goričan (1987).

Buser (1989, 1996) studied the geology and paleogeographic evolution of western Slovenia. He determined that the area of the Julian Alps in Late Triassic and earliest Jurassic belonged to a shallow-water carbonate platform, called the Julian Carbonate Platform. During the early Jurassic, this platform was drowned and became a pelagic submarine high, named the Julian High.

The most extensive research on Jurassic and Cretaceous deeper-water deposits was published by Jurkovšek et al. (1990), focusing on the pelagic beds at Mt. Mangart saddle, Plešivec, Bavšica, Vrsnik, and at Črni Vrh. They mapped and constructed composite stratigraphic sections of the Upper Triassic to Cretaceous formations. Jurkovšek et al. (1990) concluded that until the late Early Jurassic, the sedimentary environment of the rocks forming the Julian Alps was characterized by shallow-water sedimentation on Julian Carbonate Platform that was, in the late Early Jurassic, dissected into differentially subsiding blocks characterized by deeper-water sedimentation.

In the late 1990s we initiated the systematic stratigraphic and sedimentologic research and detailed mapping of the Mt. Mangart saddle and Triglav Lakes Valley. The sedimentary evolution and radiolarian dating of the Travnik section (in this book this section is named MA1) and MA6 section have been published (Goričan et al. 2003, Goričan & Šmuc 2004, Šmuc & Goričan 2005). Herein I describe the lithostratigrapy of these sections and I correlate them with other sections.

1.3 AIMS OF VOLUME

The aims of this volume are to present a detailed sedimentologic and biostratigraphic study of the Jurassic to Cretaceous successions of the Julian Alps, including formal definitions of the lithostratigraphic units, the interpretation of sedimentary environments and discussion of eustatic vs. tectonic factors that controlled the observed depositional pattern. We compare the Jurassic sedimentary evolution of the Julian Alps area to the coeval evolution of the Belluno and Slovenian basins, and Trento Plateau.

1.4 DEFINITION OF THE PALEOGEOGRAPHIC UNITS

The Julian Alps record the rifting and platform drowning and differential subsidence and thus formation of different paleogeographic units in the Jurassic. Because the nomenclature considering these units is not consistently used in the published literature, definitions applied herein are given.

1.4.1 JULIAN CARBONATE PLATFORM

The Julian Carbonate Platform, as defined by Buser (1989), was a Late Triassic to Early Jurassic shallow water platform that was located northward from the Tolmin Trough (see below). The Julian Carbonate Platform deposits are now exposed in the Southern Karavanke Mountains, Julian Alps, and Kamnik-Savinja Alps. According to Buser (1989) the Julian Carbonate Platform formed in the early Carnian (Cordevolian). The platform ceased to exist in the middle to late Early Jurassic when it was dissected into blocks with different subsidence rates (Buser 1989).

1.4.2 JULIAN HIGH

The term Julian High was introduced by Buser (1996) to denote the entire drowned Julian Carbonate Platform that in late Early Jurassic became an isolated submarine high with condensed sedimentation, which lasted until the early Cretaceous. However, in the Middle Jurassic, some drowned blocks of the former Julian Carbonate Platform became deeper basins receiving gravity-displaced material from the adjacent shallow-water platform (e.g. Mt. Mangart, see Cousin 1981, Jurkovšek et al. 1990, Šmuc & Goričan 2005, this volume) and thus not submarine highs. Therefore, in this volume the term Julian High refers only to those subsided blocks, which were in the Middle and Late Jurassic characterized by condensed sedimentation of Ammonitico Rosso-type limestone that is typical of a submarine plateau (e.g., Triglav Lakes Valley). The blocks where the Pliensbachian to Tithonian pelagic deposits are preserved only as neptunian dyke fills also correspond to the Julian High (e.g., the Mangart structural unit). All succes-sions of the Julian High are now exposed on the Julian Nappe.

1.4.3 SLOVENIAN BASIN: TOLMIN TROUGH AND BOVEC TROUGH

The term Slovenian Basin is used in Slovenian geological literature as both a paleogeographic and a structural term. As a paleogeographic unit it was introduced by Cousin (1970) who defined the term "Sillon Slovène" for the area extending from Kobarid to Tolmin and further east, with deeper-water sedimentation essentially from the Late Triassic to Late Cretaceous. Buser (1989, 1996) used the name Slovenian Basin for a wider area. With it, he marked the approximately east-west directed narrow facies belt extending throughout the entirety of Slovenia in which Triassic to Cretaceous deeper-water strata crop out. Recently, Šmuc & Čar (2002) remarked that the term Slovenian Basin is actually used for two temporally different paleogeographic units, because it comprises the Middle Triassic basin and the basin that developed later in the Latest Triassic and Jurassic. Šmuc & Čar (2002) pointed out that Middle Triassic tectonic activity ceased during the Carnian; at that time, carbonate platforms prograded quickly into surrounding basins and filled them almost completely. So by Norian-Rhaetian time, western Slovenia constituted an area with minimal topographic relief (Buser 1989, Ogorelec & Rothe 1993). Larger regional Middle Triassic events do not seem to be directly related to the Late Triassic-early Jurassic rifting events that led to the Jurassic-Early Cretaceous ocean spreading (see Winterer & Bosellini 1981, Doglioni 1987, Bertotti 1993). According to Šmuc & Čar (2002) the Middle Triassic basin and Late Triassic to Jurassic basin share the same name (Slovenian Basin) but belong to two different stages in the paleogeographic evolution of western Slovenia. Herein I propose that the name Slovenian Basin should be limited in time to the Late Triassic and younger basin.

The Tolmin Trough as defined by Cousin (1981) constitutes a part of the Slovenian Basin. It comprises the east-west directed facies belt between Kobarid and Cerkno with deeper-water sedimentation from the Jurassic to latest Cretaceous.

The Bovec Trough was defined by Cousin (1981) to denote the N-S trending small transverse basin with less marked basinal characteristics than the Tolmin Trough. According to Cousin (1981) the Bovec Trough comprises the Mt. Mangart saddle (Travnik hill) and Bavšica area. Herein the subdivision of Cousin (1981) is followed. Structurally, the successions of the Tolmin Trough form the Tolmin Nappe, whereas the successions of the Bovec Trough belong to the Julian Nappe (sensu Placer 1999). Herein the term Bovec Trough is used for the Pliensbachian to lower Cretaceous deeper-water deposits that crop out in the Travnik structural unit.

1.5 METHODS OF INVESTIGATION

Detailed mapping was carried out for the Mt. Mangart saddle and Triglav Lakes Valley areas on a 1: 10 000 scale in order to separate structural units that differ in their stratigraphic evolution.

Sedimentological field observations included the detailed measurement and sampling of 14 sections. The stratigraphic logs were measured in the 1: 100 scale for basinal successions, and in 1: 50 scale for condensed successions. More than 1100 thin sections were prepared for microfacies and biostratigraphic analyses. The successions were dated with foraminifers and calpionellids found in thin sections. Radiolarians were used to date the basinal deposits of Mt. Mangart (Goričan et al. 2003, Goričan & Šmuc 2004, Šmuc & Goričan 2005).

Resedimented limestones of the Travnik Formation were classified according to the classification scheme of turbidite facies of Mutti (1992), which consists of nine main facies types (F1 to F9). For studied sections, local transgressive-regressive cycles were determined and correlated with the Tethyan transgressive-regressive cycles as described in Graciansky et al. (1998), Jacquin & Graciansky (1998), and Jacquin et al. (1998).

Rock samples, thin sections, and radiolarian residues are stored at the Ivan Rakovec Institute of Paleontology, ZRC SAZU, Ljubljana.

2

GEOLOGICAL MAPS OF KEY-AREAS

The Julian Alps are characterized by strong end Cretaceous to Tertiary polyphase thrusting and strike-slip displacement. Thus the different paleogeographic units today belong to different thrust sheets in addition deformed along strike-slip faults. In order to delimit these different structural and therefore different paleogeographic units, the detailed mapping of the key areas Triglav Lakes Valley and Mt. Mangart saddle was necessary.

2.1 GEOLOGICAL MAP OF THE TRIGLAV LAKES VALLEY

Geological map of the Triglav Lakes Valley and main cross-sections are illustrated in Figs. 2.1, and 2.2.

In general the Julian Alps are part of the Julian Nappe, which is internally thrusted and faulted. In the Triglav Lakes Valley area, two of these smaller-scale nappes are present. The Krn Nappe is situated in the central and western part of the valley (see Fig. 2.1) and is composed of bedded Upper Triassic to lowermost Jurassic platform limestones, unconformably overlain by Jurassic and Cretaceous deeper-water deposits (Buser 1986, 1987, this study). The Krn Nappe is overthrust by the Zlatna structural unit that is composed of white, massive Upper Triassic limestones (Buser 1986, 1987). The thrust plane is clearly visible in the northeast-ernmost part of the valley (east of the Prehodavci cottage) and in the southernmost part of the valley (see Fig. 2.1) whereas in the main part of the valley the thrust plane is covered by scree and was located on the basis of different lithology of the overlying nappe.

Both structural units are additionally cut by a large, dextral strike-slip fault in the 20-200^{0} direction. This fault is probably part of a fault called the Vrata fault by Jurkovšek (1986). In the northern (upper) part of the valley, the fault branches, (Figs. 2.1, 2.2, cross section A, B, C) extending southward trough the entire valley. The eastward branch of the Vrata fault is called Špičje fault and the west one is Zelnarice fault. The Triglav Lakes Valley is a topographic depression located between these divergent faults and is characterized by normal faults extending mainly in the NW-SE and SW-NE direction (Fig. 2.1). These normal faults cut the valley into blocks with different subsidence rates and rotations (Figs. 2.1, 2.2 (cross section D), 2.3a,b, 2.4a,b), indicating an extensional regime between the faults. These blocks are recognizable because of the spatial occurrence of the Jurassic Prehodavci Formation (condensed limestones of the Ammonitico Rosso type) (Fig. 2.1). In the northernmost part of the valley, the Prehodavci Formation occurs at the 2050 m of altitude while towards the southern part of the valley, the altitude of the Prehodavci outcrops decreases, so in the southernmost part of the valley the Prehodavci Formation crops out at an altitude of 1650 m (Figs. 2.1, 2.2 (cross section D)). The different rotation of the blocks is clearly evident by the different dips of bedding within each block (Fig. 2.1).

On the basis of these data we concluded that the structure of the Triglav Lakes Valley formed during two different tectonic phases. Overthrusting of the Zlatna Nappe on the Krn Nappe represents the first phase. During the second phase this older structure was cut by the larger dextral strike-slip Vrata fault. In the northern part of the valley the fault parts in branches forming a negative flower structure extending southward trough the valley. The Triglav Lakes Valley thus is an extensional wedge between these branches (Fig. 2.5) as evidenced by different the subsidence and rotation of the blocks in the valley.

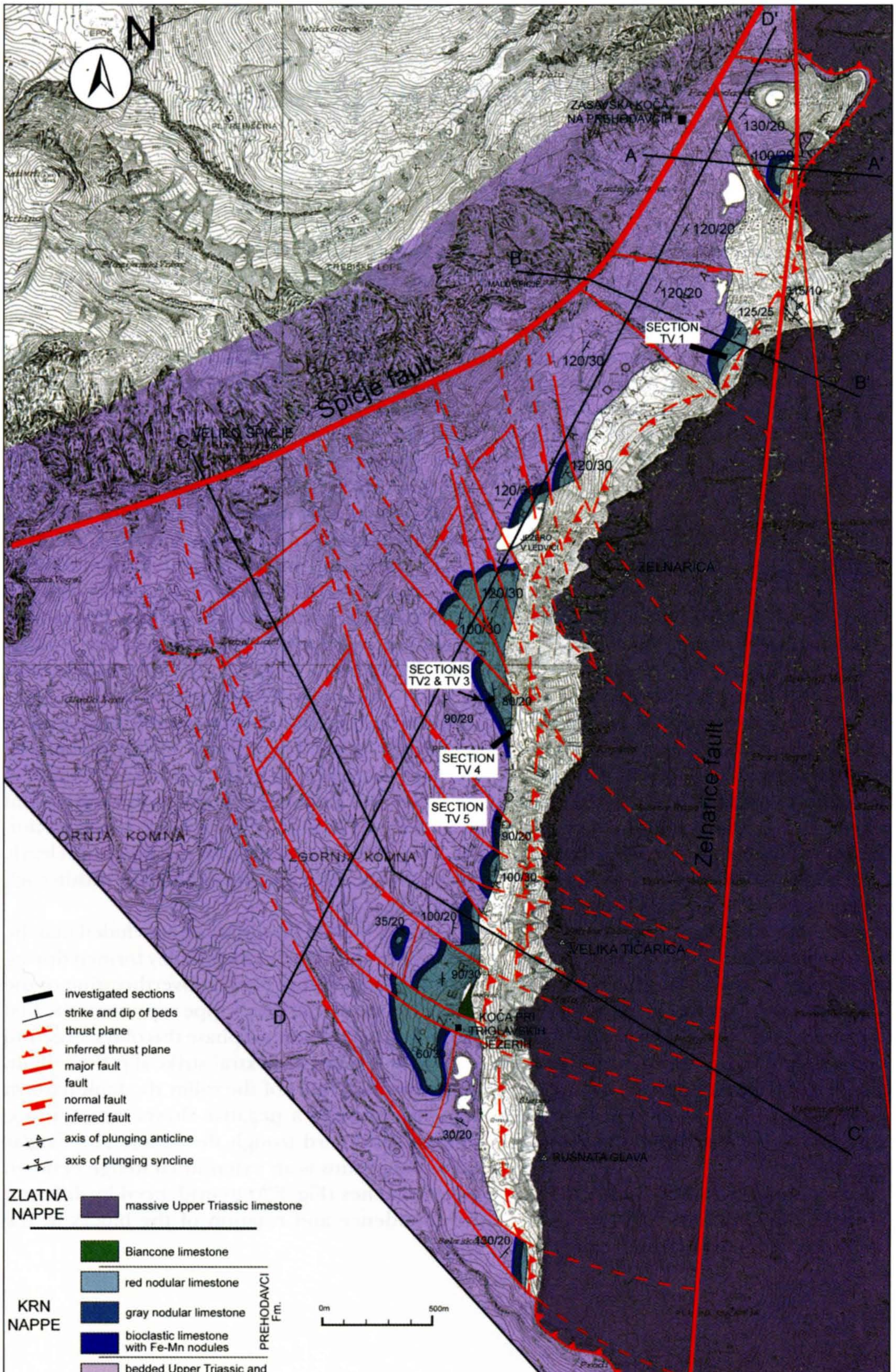


Fig. 2.1 Geological map of the Triglav Lakes Valley and locations of the studied sections.

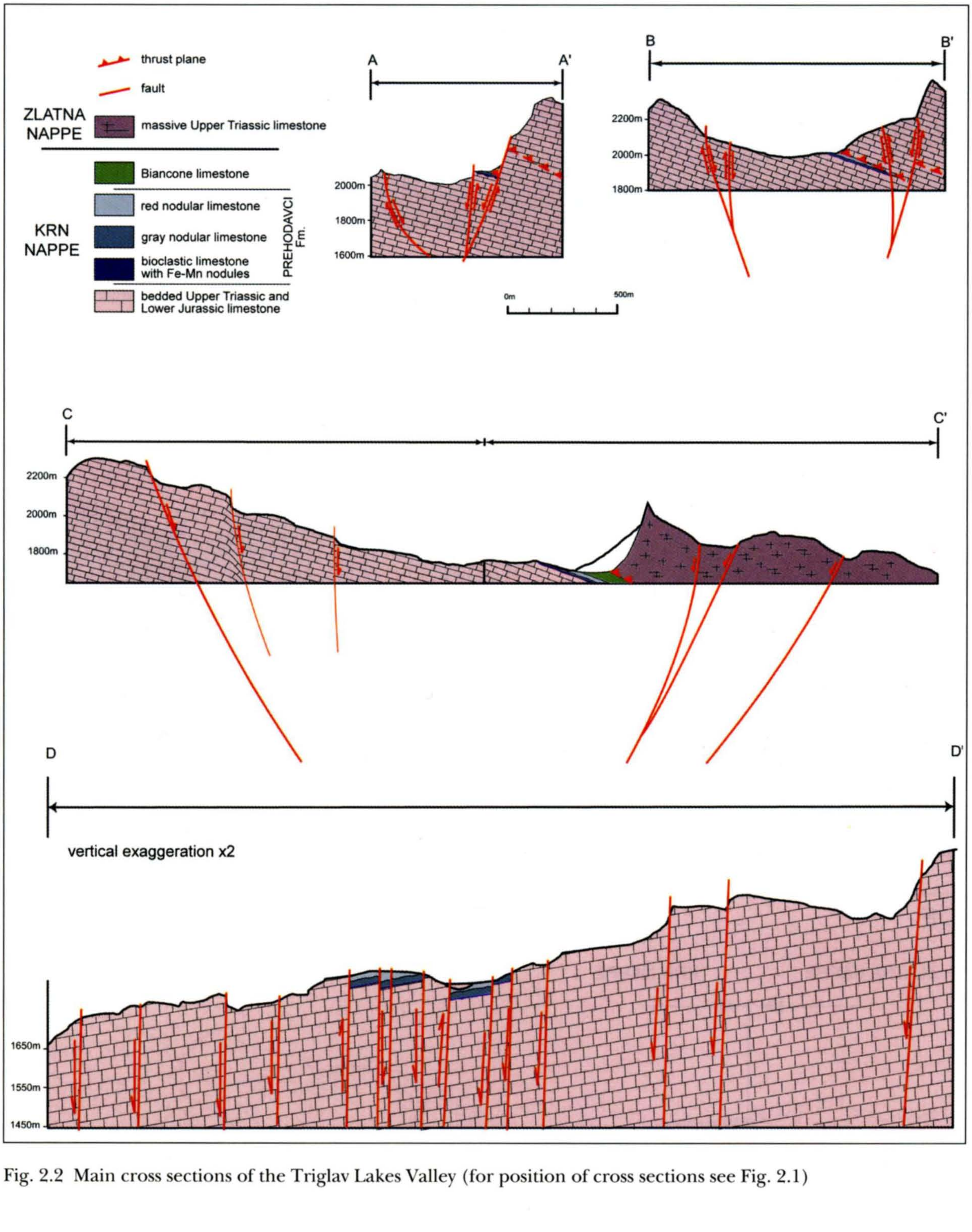


Fig. 2.2 Main cross sections of the Triglav Lakes Valley (for position of cross sections see Fig. 2.1)

Fig. 2.3a Photograph of the northern part of the Triglav Lakes Valley.

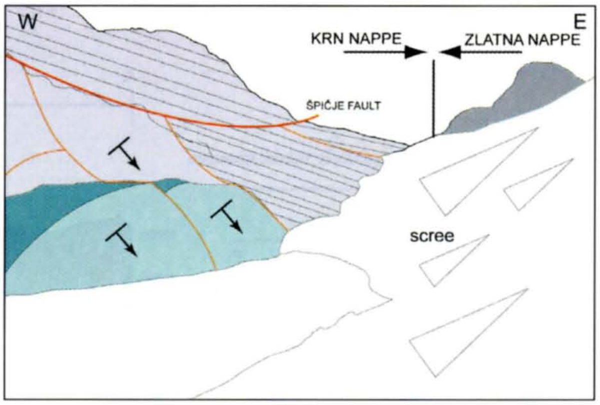


Fig. 2.3b Simplified structural sketch of the photograph in Fig. 3a (for legend see Fig. 2.1).

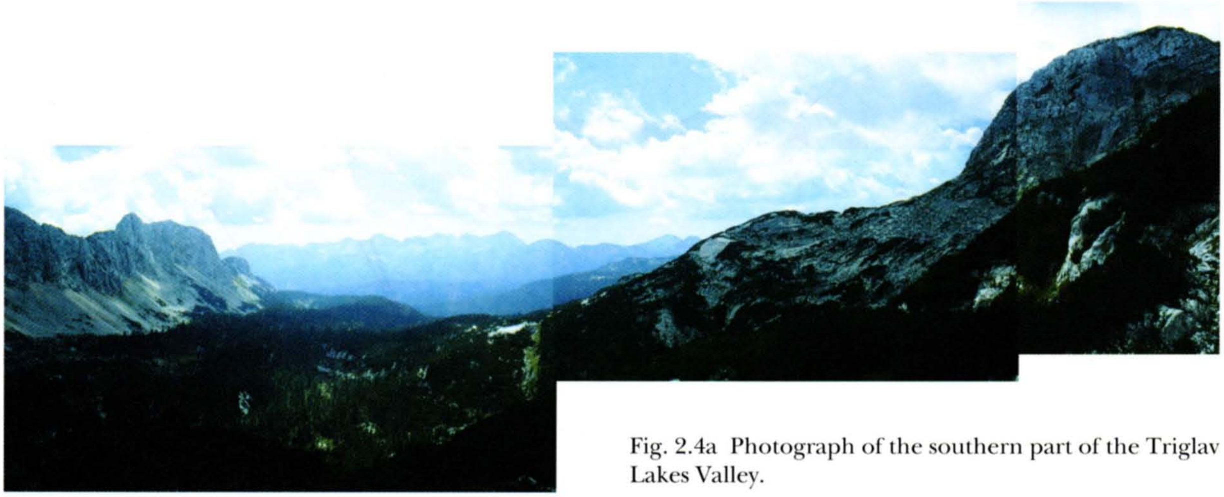


Fig. 2.4a Photograph of the southern part of the Triglav Lakes Valley.

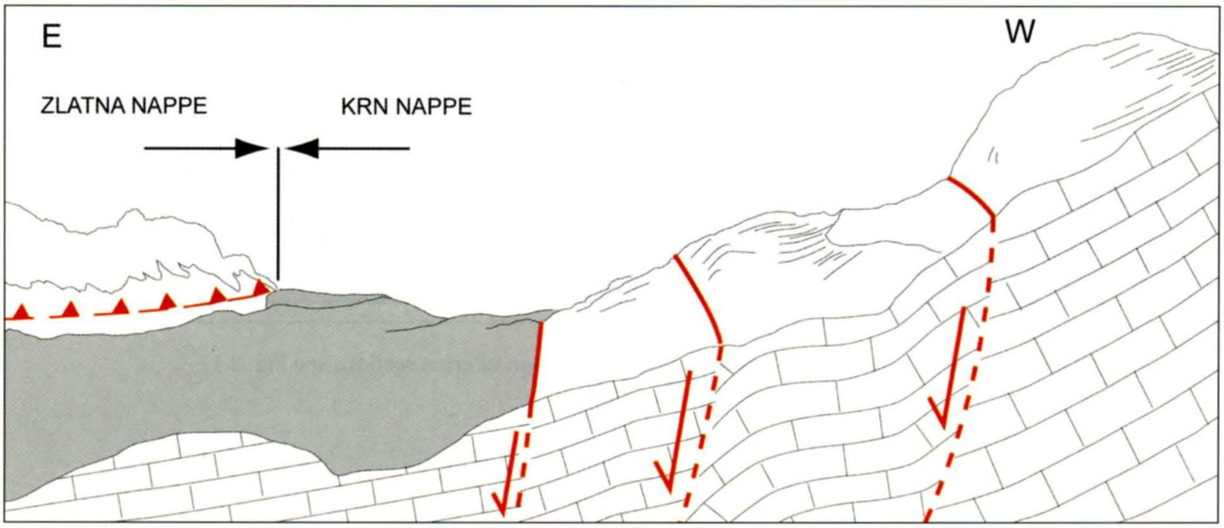


Fig. 2.4b Simplified structural sketch of the photograph in Fig. 2.4a.

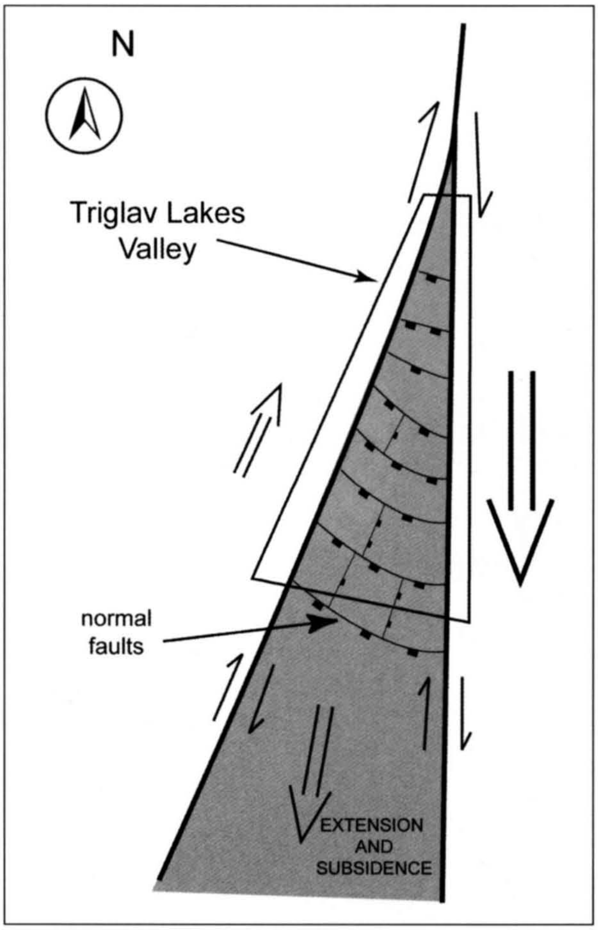


Fig. 2.5 Kinematic reconstruction of the present-day structure of the Triglav Lakes Valley.

2.2 GEOLOGICAL MAP OF THE MT. MANGART SADDLE

Detailed mapping of the Mt. Mangart saddle revealed a complex tectonic structure of the area comprising two larger structural units: the Mangart and Travnik structural units (Figs. 2.6, 2.7, 2.8) that are internally thrusted, folded, and disrupted by faults. The Mangart structural unit is additionally divided into four subunits: Mali Vrh, Rdeča skala, Drn and Mangart peak subunits (Fig. 2.6).

Structurally, the lowermost unit is the Mali Vrh subunit. It is characterized by Upper Triassic to lower Lower Jurassic platform limestones cut by neptunian dykes. These deposits are unconformably overlain by the Senonian Scaglia rossa.

The Travnik structural unit is overthrust on the Mali Vrh subunit. It is characterized by an overturned plunging syncline (Figs. 2.8, 2.9a,b), with developed duplex structures (Figs. 2.10a,b). The Travnik structural unit is composed of Upper Triassic to lower Lower Jurassic shallow water limestones overlain by Pliensbachian to Valanginian/lower Hauterivian deeper-water strata.

The Rdeča skala structural subunit crops out in the thrust zone between the Mali Vrh and Travnik structural units. It is represented by completely tectonized Scaglia rossa.

The Drn and Mangart subunits make up the Mt. Mangart massif. They were uplifted along a large reverse or strike-slip fault over the Travnik structural unit. The Drn structural subunit represents western part of the Mt. Mangart massif and is represented by massive Upper Triassic to early Lower Jurassic platform limestones cut by Upper Jurassic neptunian dykes. These deposits are unconformably overlain by the middle Cretaceous Scaglia variegata. The Mangart peak subunit composes the eastern part of the Mt. Mangart massif and consists of Upper Triassic shallow-water limestone cut by numerous neptunian dykes.

The kinematic interpretation of the present day structure of Mt. Mangart saddle is illustrated and described on Fig. 2.11.

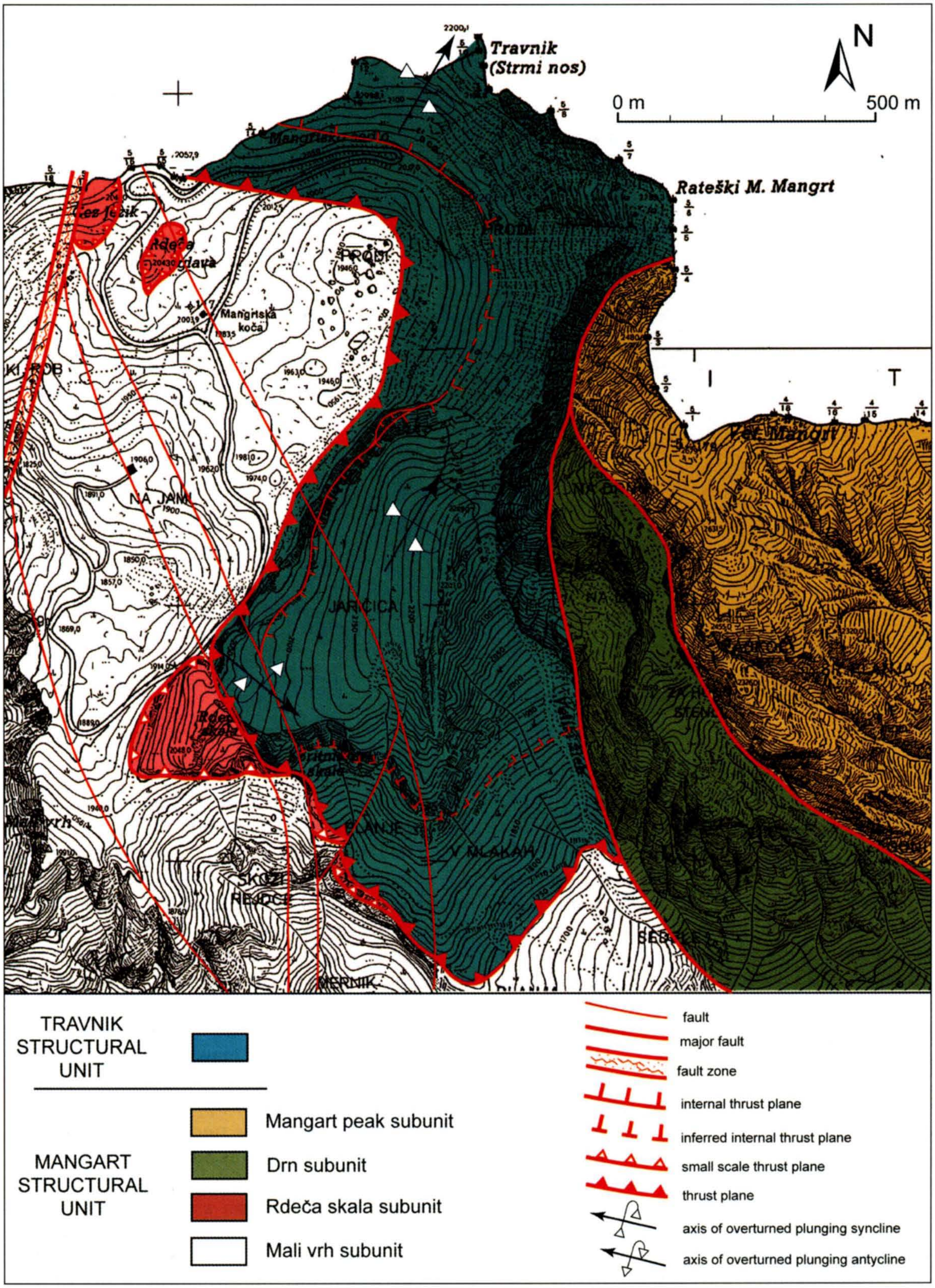


Fig. 2.6 Structural map of the Mt. Mangart saddle.

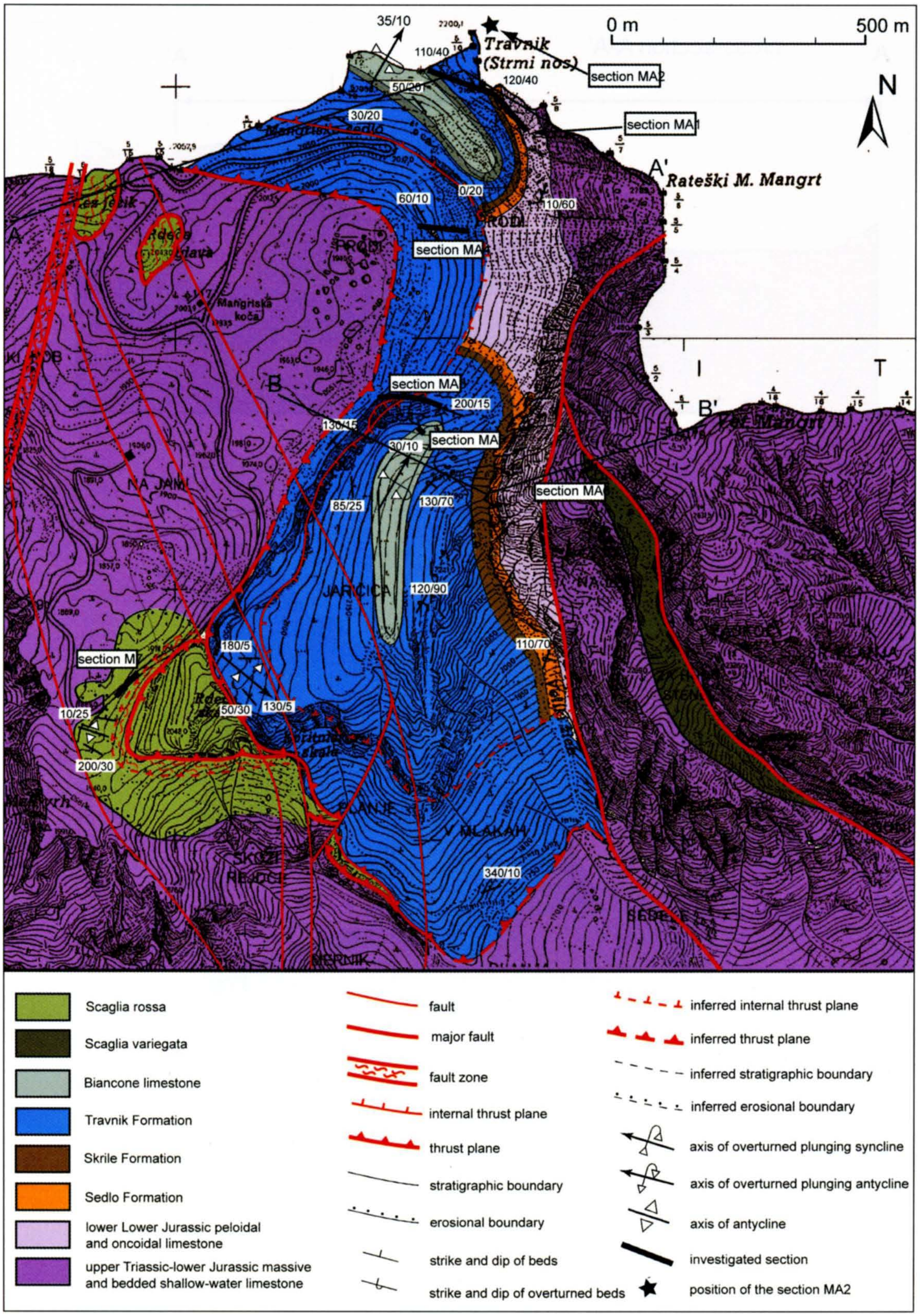


Fig. 2.7 Geological map of the Mt. Mangart saddle with location of the studied sections and cross-sections. The Italian territory was not mapped.

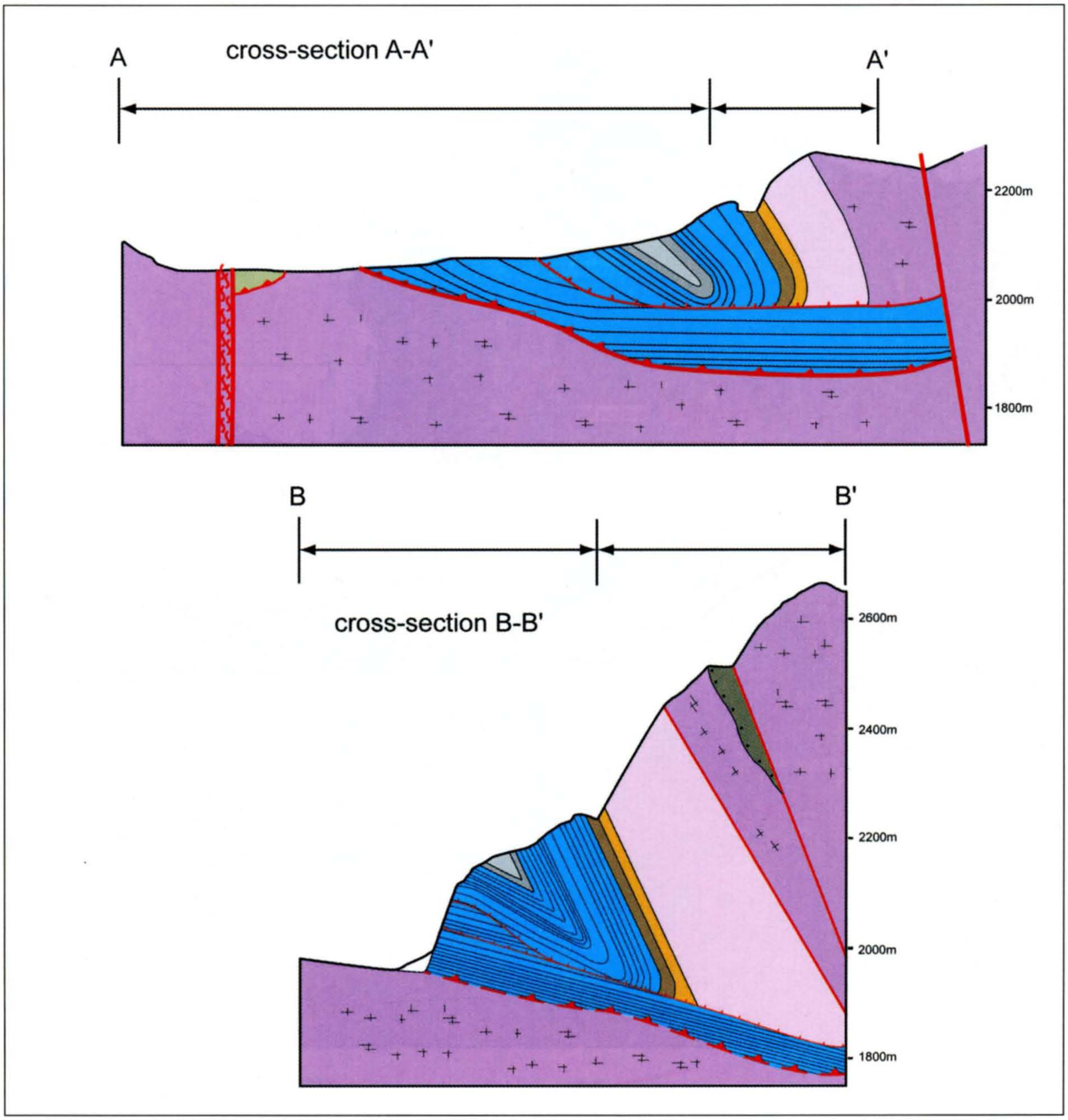


Fig. 2.8 Main cross-sections of the Mt. Mangart saddle.

Fig. 2.9a View of the northern flank of the Mt. Mangart saddle. Photo Franci Cimerman.

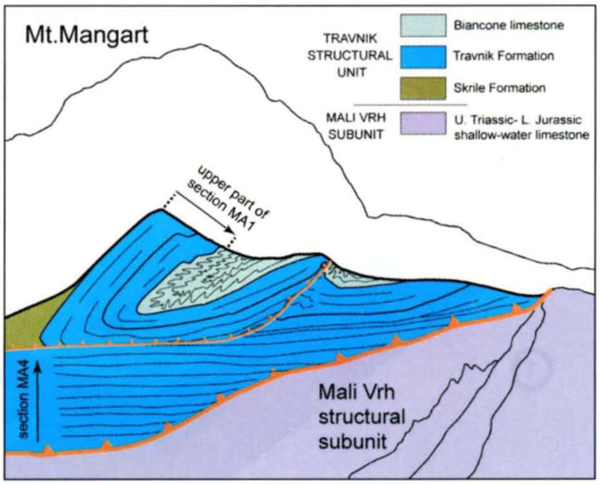


Fig. 2.9b Structural sketch of the photograph in Fig. 2.9a.

Fig. 2.10a View of the western flank of the Jaričica hill (Travnik structural unit), with duplex structures.

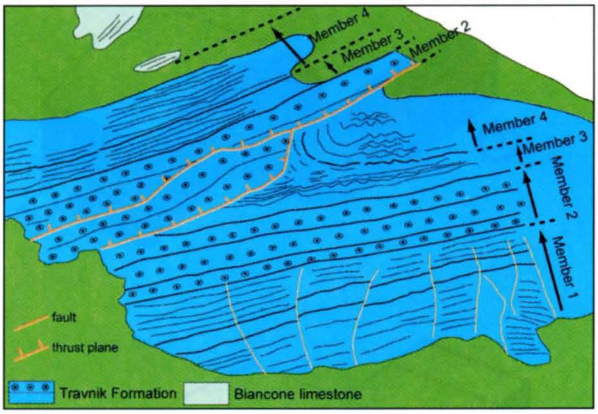


Fig. 2.10b Structural sketch of the photograph in Fig. 2.10a.

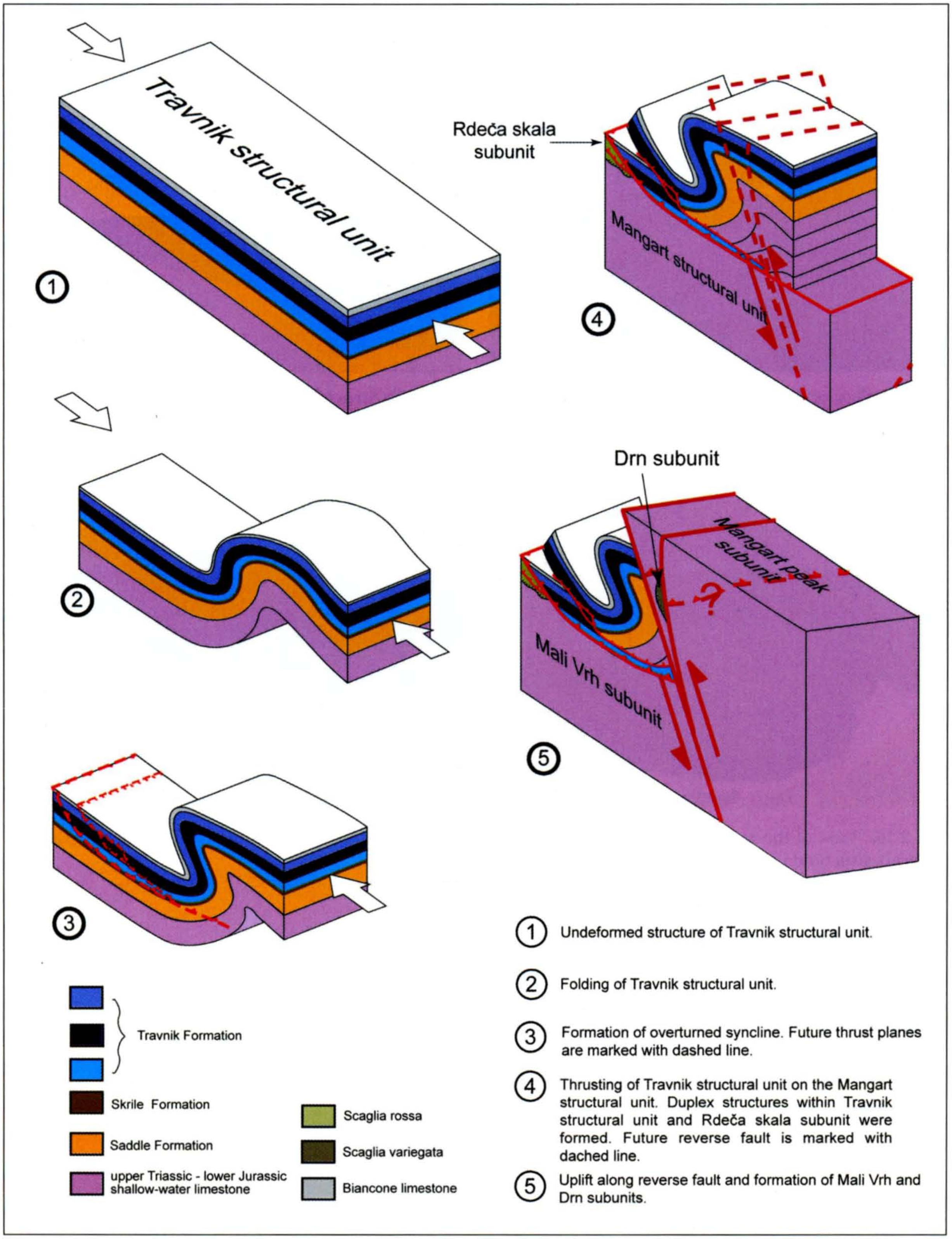


Fig. 2.11 Kinematic interpretation of present-day structure of the Mt. Mangart saddle.

3

STRATIGRAPHY

Definition of the Jurassic and Cretaceous Formations of the Julian Alps are based on the detailed research of 14 selected sections. At Triglav Lakes Valley, 5 sections were measured, they are referred to as TV1-TV5 (Fig. 3.1). Additional sections were measured at Ravni Laz (section R1) (Fig. 3.2), and at Lužnica Lake (section L1) (Fig. 3.2). In the area of Mt. Mangart, 7 sections were logged, and are named MA1-MA7 (Figs. 3.3, 3.4, 3.5a, b, 3.6). Vas na Skali and Čisti Vrh areas did not allow detailed measuring due to poor exposure. In these areas only individual formations were studied in very small outcrops. The geographic positions of the investigated localities are shown in Fig. 1.5, sections TV1-TV5 and MA1–MA7 are, in addition, shown in detailed geological maps (Figs. 2.1 and 2.7).

The locations of the sections are listed in the Table 1.

The formations are described in stratigraphic order. The Jurassic formations (chapter 3.1) are described in accordance with their paleogeographic position. The Cretaceous formations are uniformly developed within the Julian Nappe and are described in the chapter 3.2. Neptunian dykes are described separately in chapter 3.3.

Table 1 The locations of the sections.

Locality 1 (Fig. 1.5) Mt. Mangart saddle			
Section MA1	y = 396612	x = 145500	z = 2165
Section MA2	y = 396638	x = 145747	z = 2140
Section MA3	y = 396308	x = 144821	z = 1990
Section MA4	y = 396403	x = 145250	z = 1950
Section MA5	y = 396423	x = 144711	z = 2162
Section MA6	y = 396817	x = 144768	z = 2518
Section MA7	y = 395943	x = 144341	z = 1913
Locality 2 (Fig. 1.5) Triglav Lakes Valley			
Section TV1	y = 407553	x = 134509	z = 2000
Section TV2, 3	y = 406522	x = 133118	z = 1825
Section TV4	y = 406538	x = 132882	z = 1800
Section TV5	y = 406494	x = 131962	z = 1750
Locality 3 (Fig. 1.5) Ravni Laz			
Section R1	y = 388997	x = 134741	z = 720
Locality 4 (Fig. 1.5) Lužnica Lake			
Section L1	y = 399234	x = 124072	z = 1865
Locality 5 (Fig. 1.5) Čisti Vrh			
Section Čisti vrh	y = 404135	x = 135277	z = 1720
Locality 6 (Fig. 1.5) Vas na Skali			
Section Vas na Skali	y = 401285	x = 134140	z = 1210

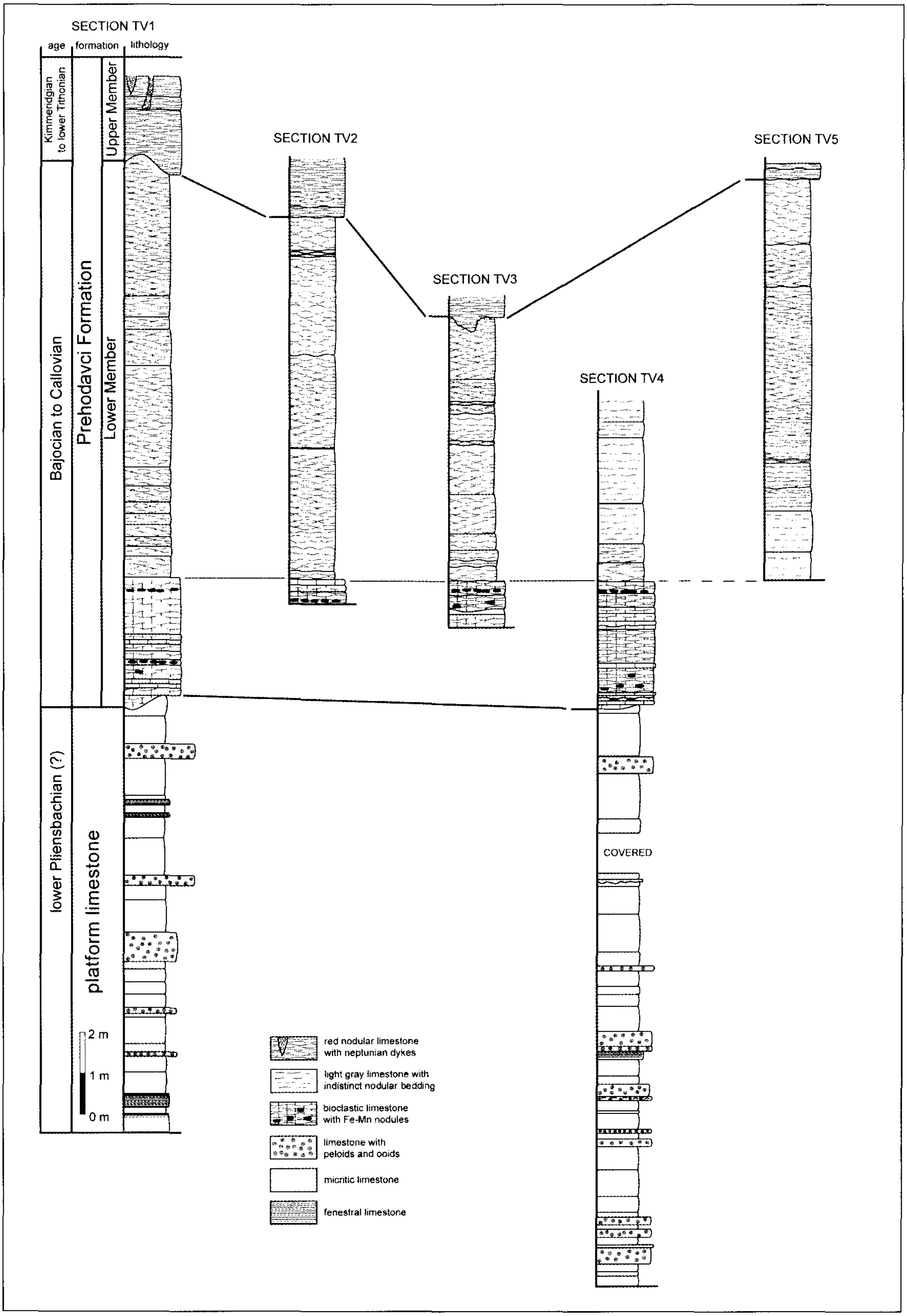


Fig. 3.1 Triglav Lakes Valley sections, for location see Fig. 2.1.

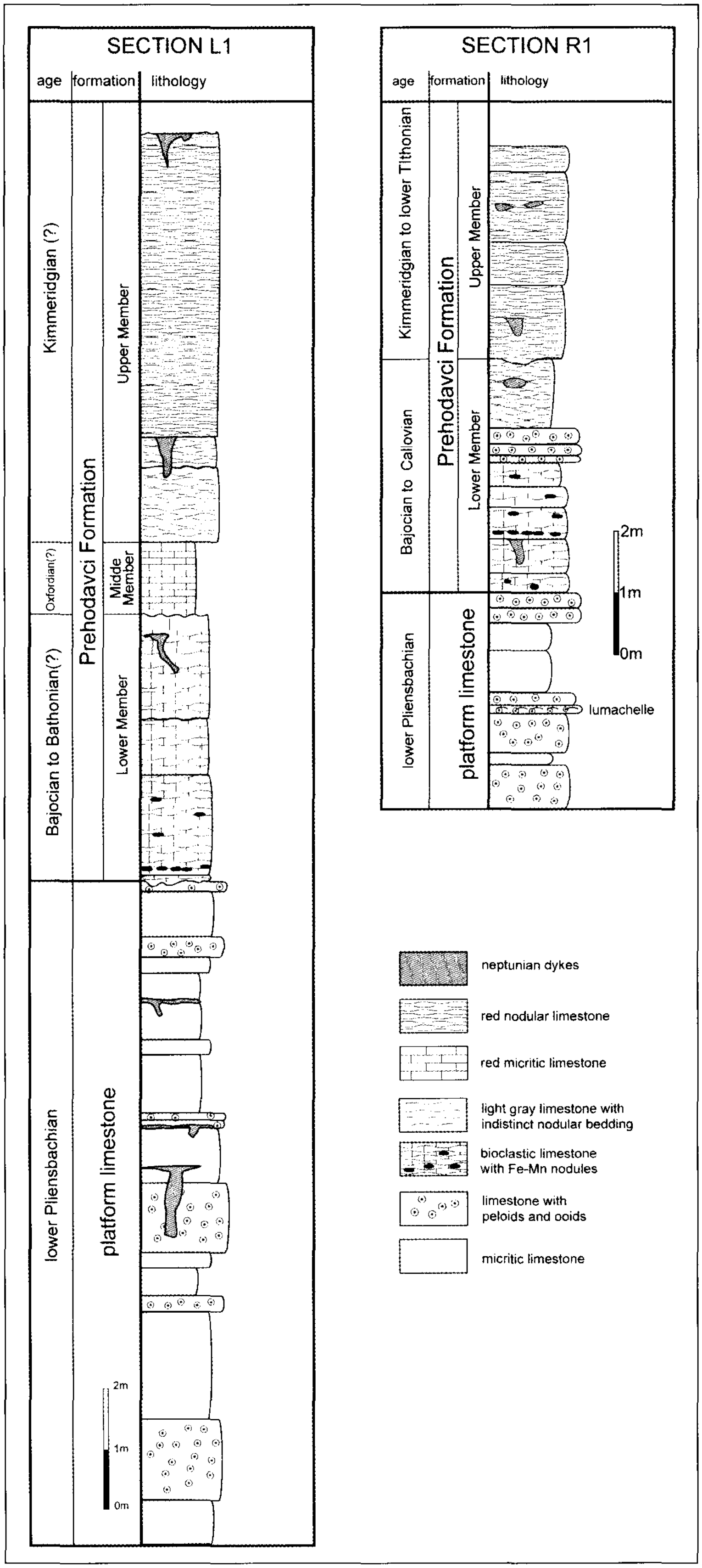


Fig. 3.2 Lužnica Lake (L1) and Ravni Laz (R1) sections, for location see Fig. 1.5.

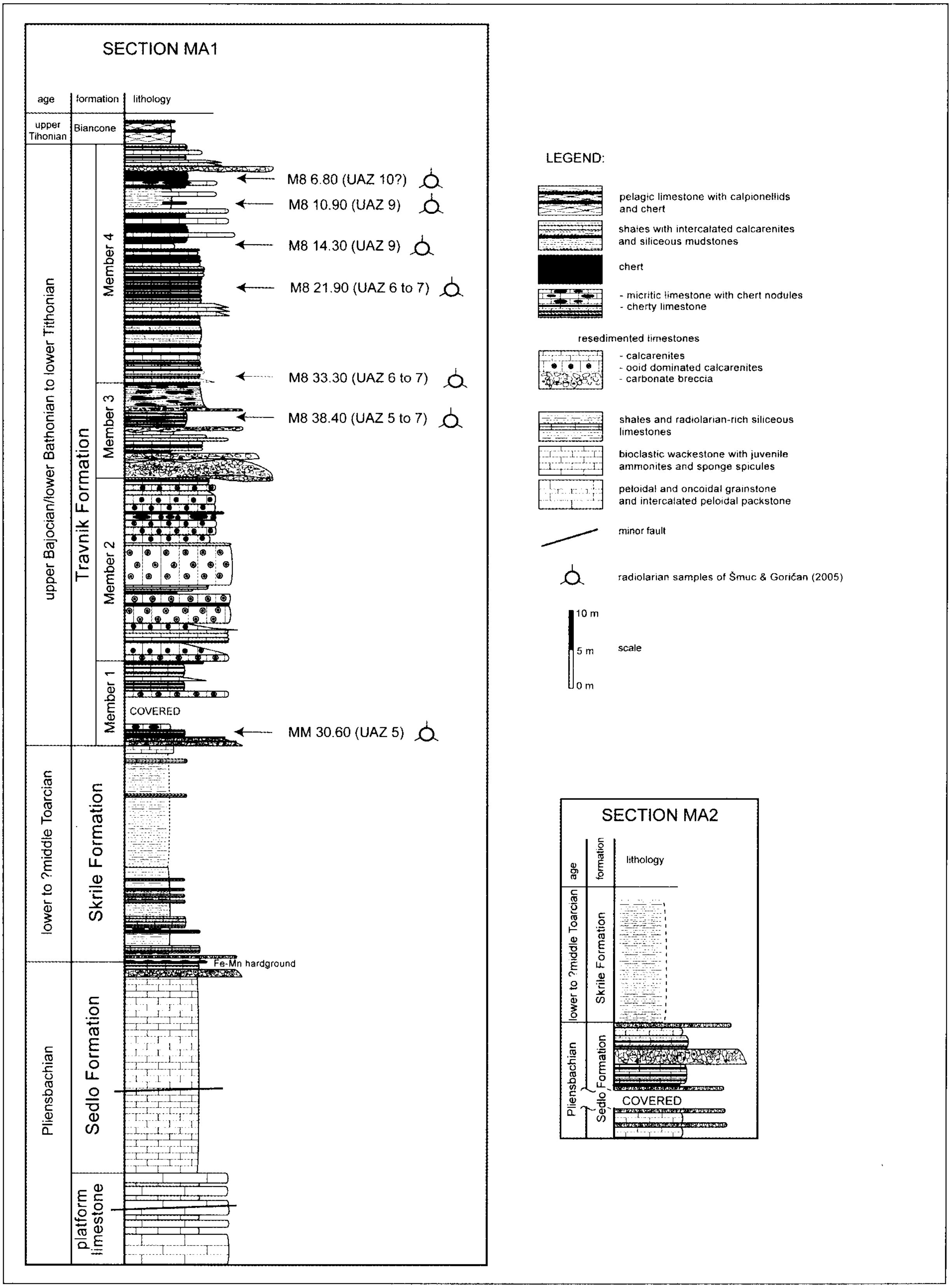


Fig. 3.3 Sections MA1 and MA2 of Mt. Mangart saddle, for location see Fig. 2.7.

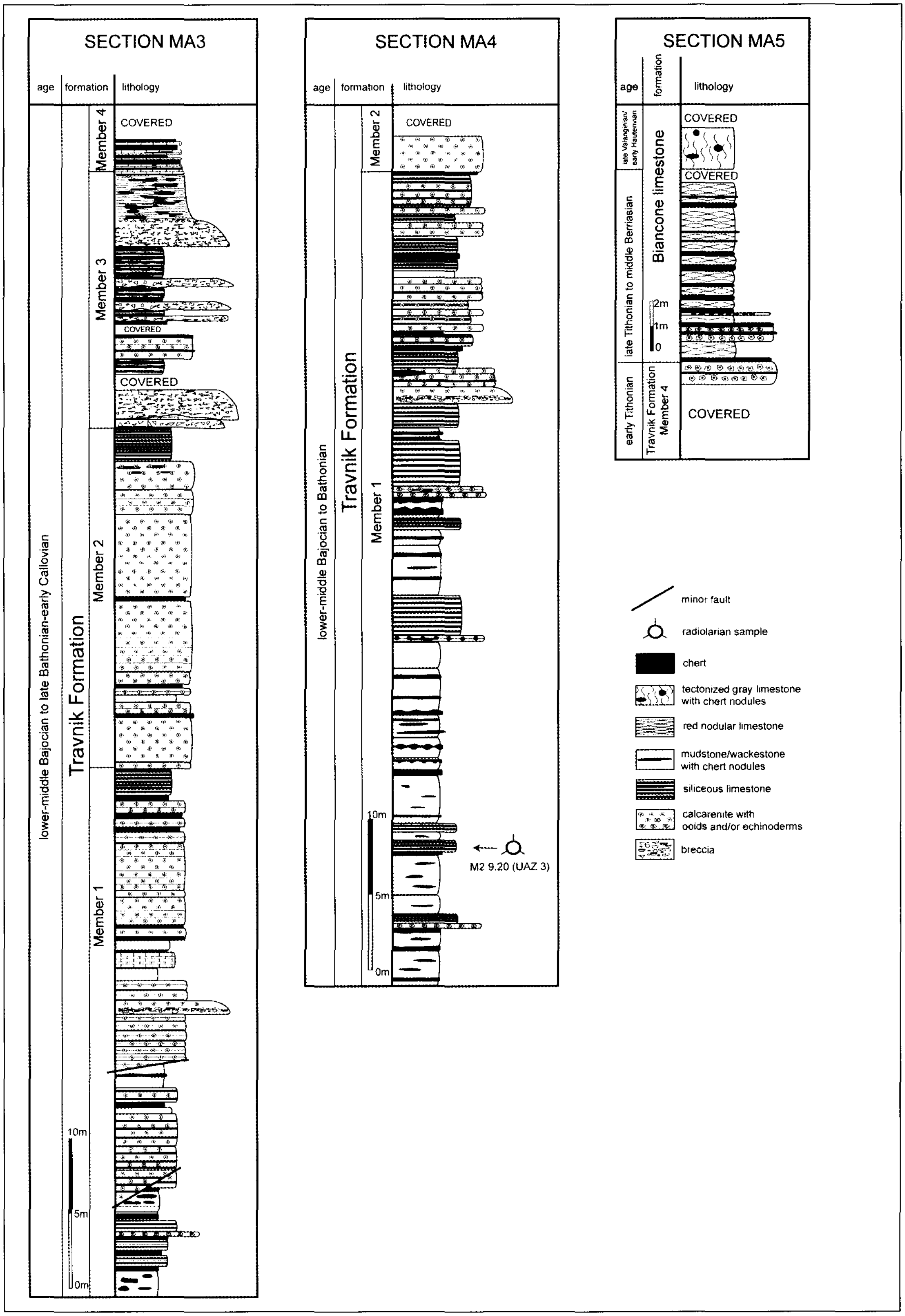


Fig. 3.4 Sections MA3, MA4, and MA5 of Mt. Mangart saddle, for location see Fig. 2.7.

Fig. 3.5a Photograph of the sections MA6, for location see Fig. 2.7.

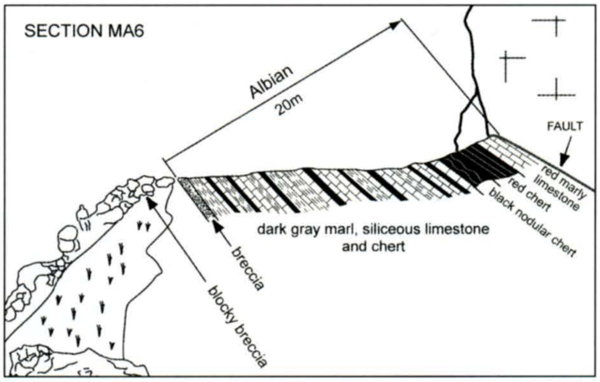


Fig. 3.5b Sketch of the photograph in Fig. 3.4a.

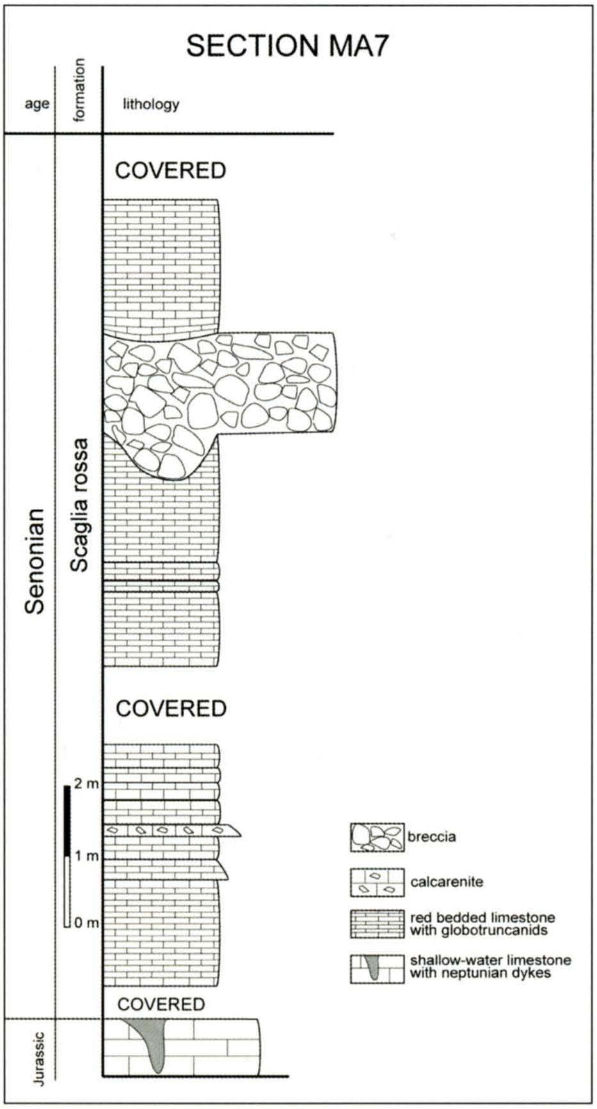


Fig. 3.6 Section MA7 of Mt. Mangart saddle, location Fig. 2.7.

3.1 JURASSIC FORMATIONS

3.1.1 JULIAN CARBONATE PLATFORM

The Lower Jurassic platform limestone conformably overlies the Upper Triassic Dachstein Limestone or a massive limestone containing corals (Turnšek & Ramovš 1987, Turnšek 1997). The Triassic-Jurassic boundary is difficult to define since the transition from the Upper Triassic Dachstein Limestone into Lower Jurassic platform limestone is gradual. Buser (1986) suggested that the first occurrence of oolitic beds and disappearance of limestone with laminoid fenestrae could be used as a good approximation.

Lower Jurassic platform limestones are primarily massive and bedded oolitic limestones that in places alternate with beds of micritic limestone, laminated dolomite, and dolomitic limestone (Cousin 1981, Buser 1986, Jurkovšek 1986, Jurkovšek et al., 1990, Šmuc & Goričan, 2005). At Mt. Mangart saddle, the coral-reef limestones occur in the lowermost Jurassic as well (Jurkovšek et al. 1990, this study). Lower Jurassic platform limestones are commonly rich in algae (*Thaumatoporella parvovesiculifera* (Raineri), *Palaeodasycladus mediterraneus* (Pia), and *Cayeuxia* sp.), and benthic foraminifers (Textulariidae, Valvulinidae, *Lenticulina* sp., and *Agerina martana* (Farinacci)). In the surroundings of Bovec (on the Poljanica hill and at Glijun) the Lower Jurassic (Pliensbachian) beds also contain numerous bivalves (*Lithiotis problematica* (Gümbel)) (Buser 1986, Buser & Debeljak, 1996).

The thickness of the Lower Jurassic platform limestone in the central Julian Alps is assumed to be up to 300 m (Jurkovšek 1986), while for the southern Julian Alps Buser (1986) estimated thickness on the order of 100 m. The age of the platform limestone encompasses the Hettangian to Pliensbachian. This stratigraphic range was determined on the basis of the stratigraphic position and presence of bivalve *Lithiotis problematica* (Gümbel), alga *Palaeodasycladus mediterraneus* (Pia), and foraminifer *Agerina martana* (Farinacci) by (Cousin 1981, Buser 1986, Buser & Debeljak 1996, Jurkovšek 1986, Jurkovšek et al. 1990, Šmuc & Goričan 2005).

A regional discontinuity surface marks the top of the Lower Jurassic platform limestone, which is cut by numerous neptunian dykes and/or overlain by more or less condensed deeper-water strata.

In this study the Lower Jurassic platform limestones were studied in the Triglav Lakes Valley (sections TV1 and TV4, Fig. 3.1), at Ravni Laz (section R1, Fig. 3.2) and Lužnica Lake (section L1, Fig. 3.2), and at Mt. Mangart (section MA1, Fig. 3.3, section MA7, Fig. 3.6). Only the top few meters below the discontinuity surface were investigated in detail.

TRIGLAV LAKES VALLEY, RAVNI LAZ, AND LUŽNICA LAKE: SECTIONS TV1, TV4, R1, L1 (Figs. 3.1, 3.2)

Description of facies.- Lower Jurassic platform limestones conformably overlie Upper Triassic Dachstein Limestone. They consist of up to 1.8 m thick beds of homogenous mudstone to wackestone with pellets that alternate with thinner beds (10–50 cm) of packstone to wackestone with peloids and fenestral limestone.

The homogenous mudstone (Fig. 3.7) to wackestone is light brown. At places it exhibits stromatactis and shelter cavities, birds-eye textures, geopetal infillings and also fenestral porosity. The grains are rare peloids, ostracods, foraminifers (Textulariidae, Valvulinidae), algae, and fragments of bivalves, gastropods and bryozoans. At places pellets are abundant, forming a packstone fabric and represent majority of grains. The limestone is frequently bioturbated.

The interstratified wackestone to packstone, in places a grainstone (Figs. 3.8, 3.9), consists of peloids, ooids, bioclasts and intraclasts of mudstones, fenestral limestones and, grainstones with peloids. Bioclasts are foraminifers (Textulariidae, Valvulinidae), fragments of bivalves, ostracods, brachiopods, gastropods and algae (*Palaeodasycladus* sp.). Fragments of echinoderms are rare. At Ravni Laz these limestones also contains lumachelle with the following bivalves: *Gervilleioperna*? sp., *Mytiloperna*? sp., and *Pseudopachymytilus*? sp. (Fig. 3.10, determined by I. Debeljak).

In the grainstones, grains are cemented first by fine-grained mosaic cement, syntaxial cement and then by coarser sparite and neomorphic micrite.

Fenestral limestones are thin-bedded (in some places bed thickness reaches 30 cm), laminated and exhibit birds-eyes, laminoid fenestrae, shelter cavities, and geopetal infillings (Fig. 3.11). They are characterized by the alternation of up to 0.2 mm thick micritic laminae with up to 0.6 mm thick laminae composed of microsparite (Fig. 3.12). Grains are rare ostracods and pellets.

Age.- The age of this limestone is not well constrained due to the absence of diagnostic fossils. However on the basis of the stratigraphic position, local presence of large bivalves (see above), and correlation with similar beds in the Dinaric Carbonate Platform (Buser & Debeljak 1996), Trento Plateau (Clari & Masetti 2002, and references within) and lower Jurassic shallow-water deposits from Algeria (Elmi et al. 2003) and Morocco (Elmi et al. 1999) an early Pliensbachian age is suggested for these deposits.

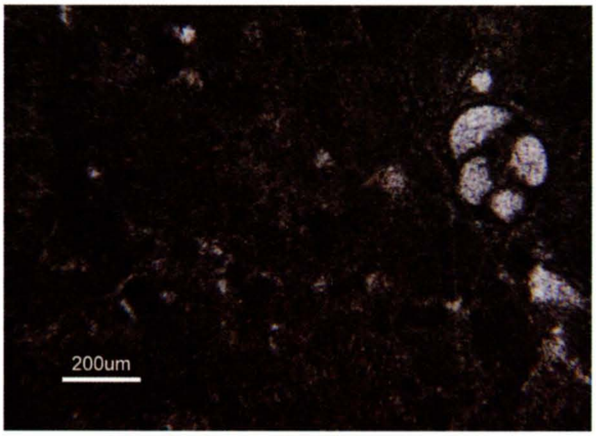


Fig. 3.7 Platform limestones: mudstone with small benthic foraminifers (section TV1).

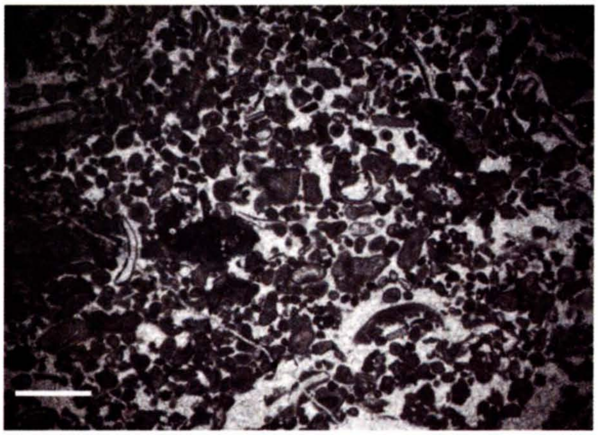


Fig. 3.8 Platform limestones: limestone with peloids, ooids, echinoderm fragments, fragments of bivalves and benthic foraminifers (section TV4). Scale bar is 1 mm long.

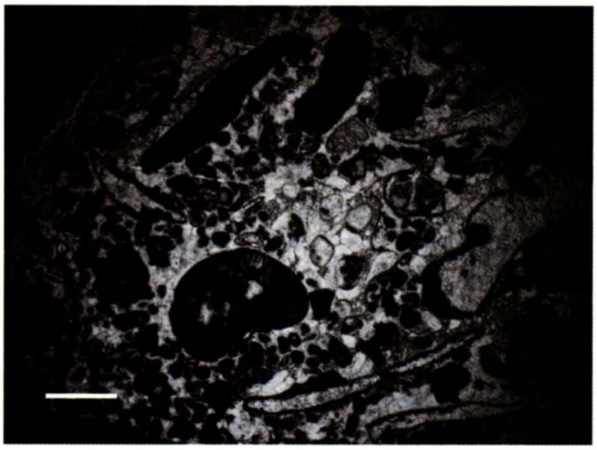


Fig. 3.9 Platform limestones: grainstone with algae, intraclasts, peloids, benthic foraminifers and fragments of bivalves (section R1). Scale bar is 1 mm long.

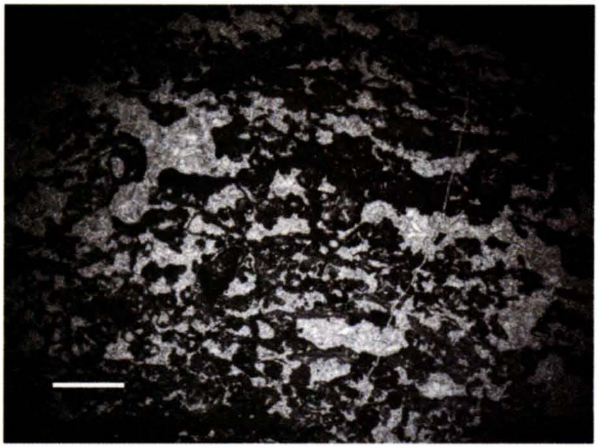


Fig. 3.11 Platform limestones: limestone with fenestral porosity (section TV1). Scale bar is 1 mm long.

Fig. 3.10 Platform limestone: lumachelle of bivalves (section R1, see Fig. 3.2).

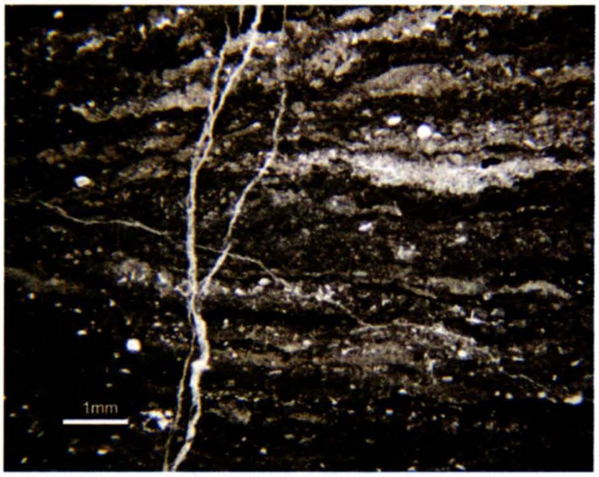


Fig. 3.12 Platform limestones: laminated limestone (section TV1).

Depositional environment.- The micritic limestones were formed in a low-energy subtidal restricted lagoonal environment. Sedimentary characteristics of the interstratified fenestral limestone indicate deposition in subtidal-intertidal environment. Peloidal limestones with various grains were deposited in a high-energy subtidal environment affected by currents. The grains, in particular bivalves were formed on inner parts of the platform and were later transported to the margins. Vertical facies changes observed in all sections reflect changes of the environment, probably due to the high frequency sea-level oscillations (see discussion in chapter 4.1).

MT. MANGART SADDLE – TRAVNIK STRUCTURAL UNIT: SECTION MA1 (Fig. 3.3)

Description.- The dominant lithofacies is a light gray, massive, medium to well-sorted grainstone composed of non-skeletal and skeletal grains (Fig. 3.13). Non-skeletal grains are mainly intraclasts of peloidal wackestone/packstones and mudstones, peloids, micritized ooids and oncoids. The skeletal component consists of echinoderm fragments, gastropods, bivalves, spongiomorphids, fragments of algae and foraminifers. Grains are cemented first by bladed and syntaxial cements and then by coarser sparite.

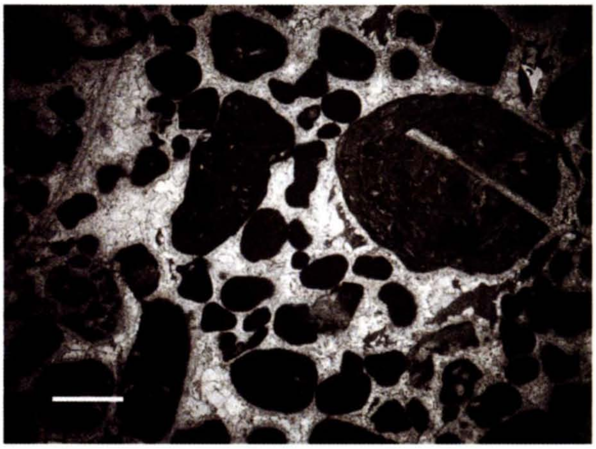


Fig. 3.13 Platform limestones: grainstone with peloids, intraclasts of mudstones, and oncoids (section MA1). Scale bar is 1 mm long.

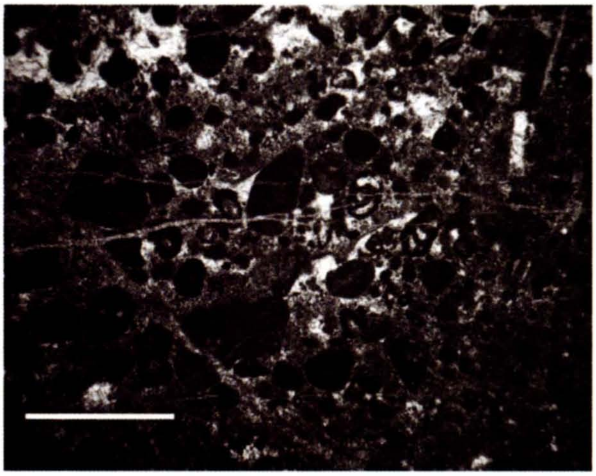


Fig. 3.14 Platform limestones: packstone with peloids, intraclasts of mudstones, benthic foraminifers (section MA1). Scale bar is 1 mm long.

In the uppermost part of shallow water limestones, up to 1 m thick beds of the above described grainstone alternate with up to 30 cm thick beds of a finer-grained wackestone/packstone (Fig. 3.14). Grains are peloids, rare ooids, benthic foraminifers (Textulariidae, Valvulinidae, *Lenticulina* sp., and *Agerina martana* (Farinacci)), rare echinoderms, and bivalves.

Age.- In the upper part of the limestones the presence of *Agerina martana* (Farinacci) (according to the biozonal scheme of Chiocchini et al. (1994) suggests a Pliensbachian age. In the lower part of the section *A. martana* is not present so a Sinemurian age for this lower part is possible, but not confirmed.

Depositional environment.- Grainstones of the lower part were deposited in a high-energy subtidal environment, most probably a sand belt in a marginal part of a shallow-water carbonate platform (cf. Di Stefano et al. 2002). The majority of grains originated from a subtidal lagoonal environment in the platform interior and was later transported to the platform margin. The finer-grained peloidal wackestones/packstones intercalated in the upper part were deposited in hydrodynamically quieter environment located basinward of the marginal sandbelt. The deeper depositional environment is indicated by open marine elements (*Lenticulina* sp.).

MT. MANGART SADDLE: MANGART STRUCTURAL UNIT: SECTION MA7 (Fig. 3.6)

Description.- The uppermost Triassic to Lower Jurassic platform limestone of the Mangart structural unit was studied at section MA7 (Fig. 3.6). It is represented by a light gray massive boundstone. On the hand-specimen and thin section scale it is grainstone with corals, sponges, calcareous algae, and fragments of bivalves, gastropods, brachiopods and echinoderms (Fig. 3.15). Peloids and foraminifers (Involutinidae, Nodosaridae, *Agerina martana* (Farinacci)) are present but not frequent. In places, intraclasts composed of grainstones with ooids are also present. Grains are cemented with sparitic cement.

Age.- In the platform limestone of the Mangart structural unit Jurkovšek et al. (1990) found the following foraminifers: *Galeanella panticae* (Zaninetti & Brönnimann) and *Triasina hantkei* (Majzon), and determined a Rhaetian age for these deposits. However, from the article of Jurkovšek et al. (1990) it is not clear from which part (upper or lower)

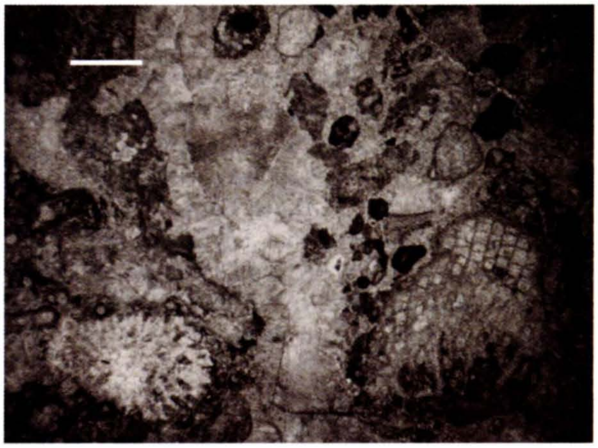


Fig. 3.15 Platform limestones: grainstone with corals and stromatoporoid fragments (Mali Vrh structural subunit, Mangart saddle). Scale bar is 1 mm long

the samples were taken. In our study we found, in the uppermost part of these limestones, *Agerina martana* (Farinacci) suggesting a Pliensbachian age (according to the biozonal scheme of Chiocchini et al. (1994)). On the basis of these data the most probable age range is Rhaetian to Pliensbachian.

Depositional environment.- The Lower Jurassic platform limestone of the Mangart structural unit is a part of a small patch-reef. The presence of intraclasts of grainstones with ooids suggests that the patch reef was located within an oolitic sand belt in the marginal part of the carbonate platform.

3.1.2 JULIAN HIGH

The Julian High represents an isolated pelagic platform (sensu Santantonio 1994) that was formed after the drowning of the Julian Carbonate Platform. The distinctive characteristic of the Julian High is that Pliensbachian platform limestones of the Julian Carbonate Platform are unconformably overlain by Bajocian to lower Tithonian highly condensed limestones of the Prehodavci Formation. In the most condensed sections, the Lower Jurassic platform limestones are penetrated by polyphase Jurassic neptunian dykes and unconformably overlain by middle Cretaceous Scaglia variegata or Senonian Scaglia rossa. The successions of the Julian High are preserved in the Triglav Lakes Valley, at Ravni Laz, Lužnica Lake, and in the Mangart structural unit. At Čisti Vrh and Vas na Skali, only parts of the Prehodavci Formation crop out, and the contact with the underlying platform limestones can not be seen.

PREHODAVCI FORMATION

Type section.- TV1 (Fig. 3.1, for location see Fig. 2.1). The formation is named after Prehodavci saddle in the Triglav Lakes Valley, situated 1.2 km northward of the type section. The Prehodavci Formation was investigated in the Triglav Lakes Valley (sections TV1 to TV5, Fig. 3.1), at Ravni Laz (section R1, Fig. 3.2), near the Lužnica Lake (section L1, Fig. 3.2), at Čisti Vrh, and at Vas na Skali. The best-preserved sections occur in the Triglav Lakes Valley where Jurassic strata crop out all along the valley (see geological map Fig. 2.1).

Short definition.- The Prehodavci Formation is composed of condensed limestones of Ammonitico Rosso type and is subdivided into three members. The Lower Member consists of condensed, red, bedded bioclastic limestones with Fe-Mn nodules that gradually pass into light gray, indistinctly nodular limestones. The Middle Member is composed of thin-bedded micritic limestones. The Upper Member unconformably overlies the Lower or Middle Member. It is represented by red nodular limestone, and by red marly limestones with abundant *Saccocoma* sp.

The Prehodavci Formation unconformably overlies the Upper Triassic to Lower Jurassic platform limestone of the Julian Carbonate Platform. The contact is marked by a highly irregular unconformity surface. This surface is marked with up to 3 m deep and up to 10 m wide oval depressions cut into the Lower Jurassic platform limestones that are filled with limestones of the Prehodavci Formation (Figs. 3.16, 3.17, 3.18).

The Prehodavci Formation is overlain by the upper Tithonian pelagic Biancone limestone. The formation reaches a maximum thickness of about 15 m.

Note.- In the following facies description we are using term "nodules" as defined by Martire (1996): nodules are all the parts of the rock of variable shape (ellipsoidal to very irregular but normally rounded) and size (from few mm to several cm) limited by transitional or sharp boundaries with the surrounding matrix from which they are distinguished by a marked contrast in texture, color, and compactional fabric.

Age.- The Bajocian to early Tithonian age of the formation is determined on the basis of the ammonites found by Ramovš (1975), planktic foraminifers, *Saccocoma* sp., and the stratigraphic correlation with the Rosso Ammonitico Formation. A more precise age assignment is discussed for each member individually, below.

Previous work.- The Jurassic beds were first mentioned by Stur (1858, ref. in Diener 1884, p. 686). He found ammonites in the bedded limestone and assumed that they were Jurassic in age. Later, the Jurassic age of the limestones was confirmed by Kossmat (1913), who found that they overlie the Dachstein Limestone and are overthrust by a massive reef limestone of the Zlatna Nappe. Seidl (1929) first gave a schematic cross-section of Jurassic beds in the Triglav Lakes Valley. Salopek (1933) provided the first general description of Jurassic and lower Cretaceous beds in the Triglav Lakes Valley, finding the following ammonites in the Jurassic beds: *Phylloceras* sp., *Holcophylloceras?* sp., and *Perisphinctes* sp. Ramovš (1975) dated the red nodular limestones in Triglav Lakes Valley as Oxfordian and Kimmeridgian on the basis of the following ammonites: *Enaspidoceras*

Fig. 3.16 Cavities in the Lower Jurassic platform limestone filled with red bioclastic limestone of the Prehodavci Formation. Unconformity surface separating Lower Jurassic shallow-water limestone and the Prehodavci Formation. Triglav Lakes Valley, section TV1.

Fig. 3.17 Photograph of unconformity surface between Lower Jurassic platform limestone and the Prehodavci Formation. Triglav Lakes Valley, section TV1. Photo Rafael Marn.

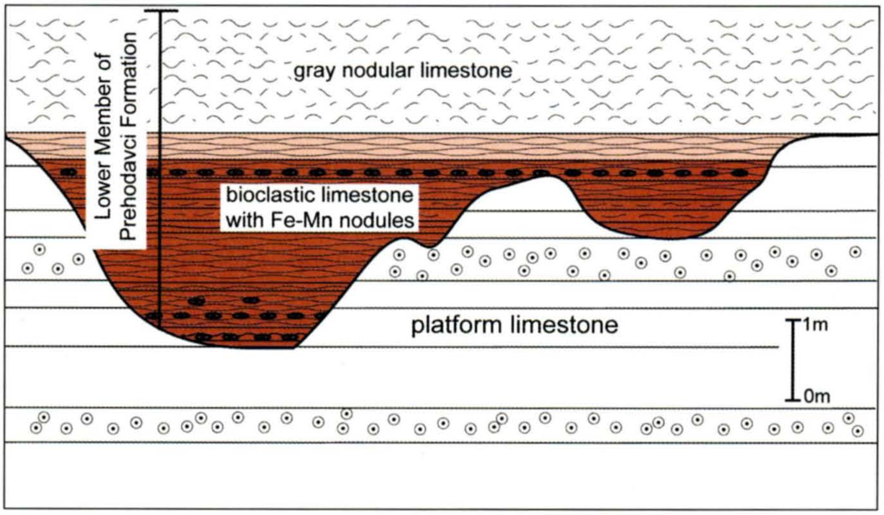


Fig. 3.18 Sketch of unconformity surface between Lower Jurassic platform limestone and the Prehodavci Formation.

sp., *Gregoryceras* sp., *Lytoceras* sp., *Paraspidoceras* sp., and *Sowerbyceras* sp.. The area of the Triglav Lakes Valley was mapped for the Basic Geological Map of Yugoslavia 1: 100 000, by Buser (1986) and Jurkovšek (1986).

LOWER MEMBER OF THE PREHODAVCI FORMATION

The Lower Member of the Prehodavci Formation was investigated at Triglav Lakes Valley (sections TV1-TV5, Fig. 3.1), Ravni Laz (section R1, Fig. 3.2), and Lužnica Lake (section L1, Fig. 3.2) and consists of bioclastic limestone with Fe-Mn nodules, limestone with ooids that occurs only locally, and light gray nodular limestone. The Lower Member is disconformably overlain by either the Middle or Upper Member of the Prehodavci Formation. Both contacts are sharp erosional surfaces. The erosional surface between Lower and Middle Member is straight, while the contact of Lower and Upper Member is irregular and cuts up to 1 m deep into white nodular limestone of the Lower Member.

Age.- The common presence of the planktic foraminifers, protoglobigerinids, in the bioclastic limestone with Fe-Mn nodules suggests a Middle Jurassic age, most probably Bajocian to Bathonian (cf. Caron & Homewood 1983, Tappan & Loeblich 1988, Darling et al. 1997) for the lower part of the Lower Member. The bioclastic limestone is conformably overlain by white nodular limestone, thus according to the stratigraphic position, a Callovian age is assumed for the white nodular limestone. At Ravni Laz (section R1, Fig. 3.2) oolitic limestone is intercalated between bioclastic limestone and white nodular limestone. This facies is most probably latest Bathonian and /or early Callovian.

Bioclastic limestone with Fe-Mn nodules.

The bioclastic limestone with Fe-Mn nodules makes up the lowermost part of the Lower Member and is present in all of the investigated sections, with the exception of section TV5 in Triglav Lakes Valley. Bioclastic limestone unconformably overlies an irregular discontinuity surface developed on top of early Lower Jurassic platform limestone (see Figs. 3.16, 3.17, 3.18) and displays significant thickness variations, from few dm to a maximum of 3 m at places.

Facies description.- The lower part of the member is represented by red, bedded (up to 10 cm), at places nodular wackestone to packstone (rarely grainstone) that exhibits parallel and indistinct cross-lamination (Fig. 3.19).

Fig. 3.19 Lower Member of the Prehodavci Formation: red bioclastic limestone with Fe-Mn nodules. Triglav Lakes Valley, section TV4.

Bedding surfaces are at places marked by Fe-Mn oxides and represent discontinuity surfaces. The limestone is composed of various bioclasts and intraclasts (Fig. 3.20).

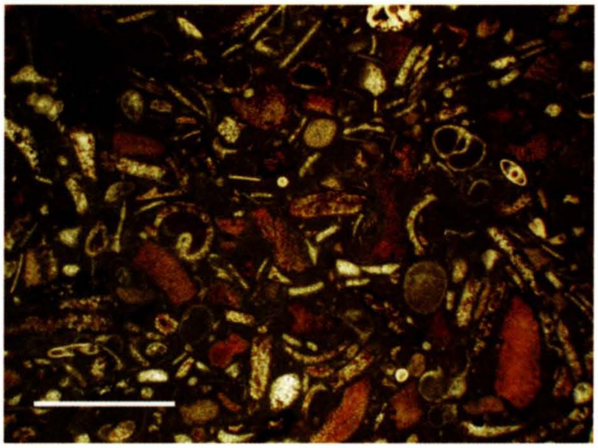


Fig. 3.20 Lower Member of the Prehodavci Formation: bioclastic limestone with echinoderm fragments, gastropods and filaments (section TV4). Scale bar is 1 mm long.

Bioclasts are fragments of echinoderms, benthic foraminifers (*Lenticulina* sp.), gastropod protoconchs, juvenile ammonites, disarticulated valves of thin-shelled bivalves, and algae fragments. Planktic foraminifers (protoglobigerinids) occur in the middle part of the bioclastic facies (Fig. 3.21).

Intraclasts are fragments of limestones composed exclusively of sparite crystals and fragments of bioclastic limestones with the same composition as the host rock. In places, the limestone is com-

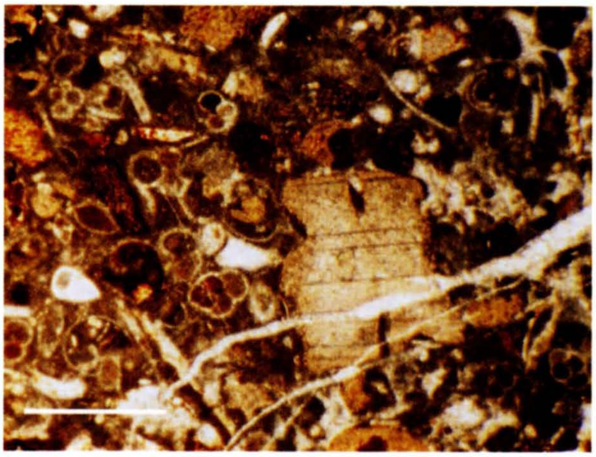


Fig. 3.21 Lower Member of the Prehodavci Formation: bioclastic limestone with echinoderm fragments and planktic foraminifers (section R1). Scale bar is 1 mm long.

posed exclusively of bored echinoderm fragments cemented by syntaxial cement (Fig. 3.22).

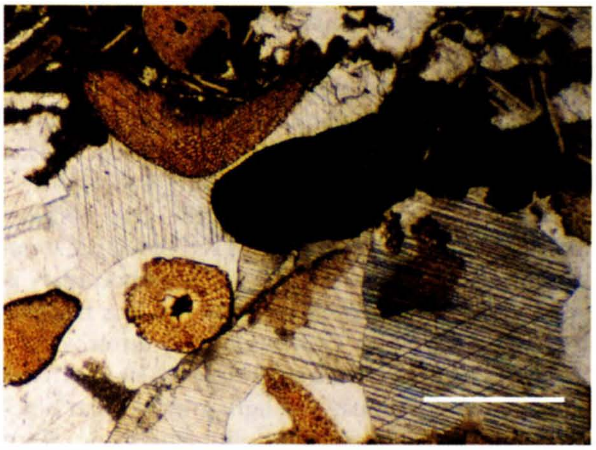


Fig. 3.22 Lower Member of the Prehodavci Formation: grainstone with echinoderm fragments and a completely Fe-Mn incrusted intraclasts (section TV1). Scale bar is 1 mm long.

The distinct feature of the bioclastic limestone is a high abundance of Fe-Mn oxides that occur in different forms:

- as cryptocrystalline aggregates forming irregular patches within the micritic matrix,
- as coatings of bioclasts and fragments of sparitic limestone. Usually Fe-Mn oxides occur on the bored surface of bioclasts and fragments where they represent fillings of very small, straight and branching microborings, usually attributed to the cyanobacteria and fungi (cf. Boggs 1992, Martire 1996). At places also the interior of the bioclasts is thoroughly mineralized (Fig. 3.23).
- as individual Fe-Mn nodules (up to 10 cm in the diameter) (Fig. 3.24)
- individual thin crusts within bioclastic limestones (Fig. 3.25)
- as dissolution residues along stylolites

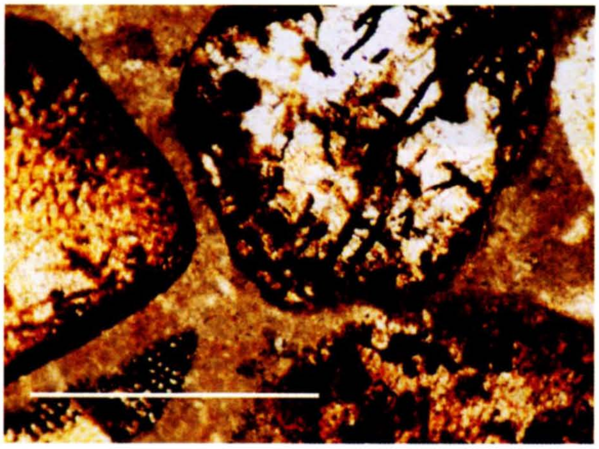


Fig. 3.23 Lower Member of the Prehodavci Formation: Fe-Mn incrusted echinoderm fragments (section TV1). Scale bar is 0,5 mm long.

Fig. 3.24 Fe-Mn nodules in the Lower Member of the Prehodavci Formation, Triglav Lakes Valley. Photo Rafael Marn.

Up-section the wackestone-packstone grades into thick (up to 40 cm) bedded light red wackestone. Generally this limestone is similar in composition to the limestone of the lower part of the Lower Member, but pelagic foraminifers, filaments and calcified radiolarians are more abundant, is devoid of Fe-Mn oxides, and contains pyrite grains as well.

At Ravni Laz (section R1, Fig. 3.2) the lower part of the Lower Member ends with a 40 cm thick

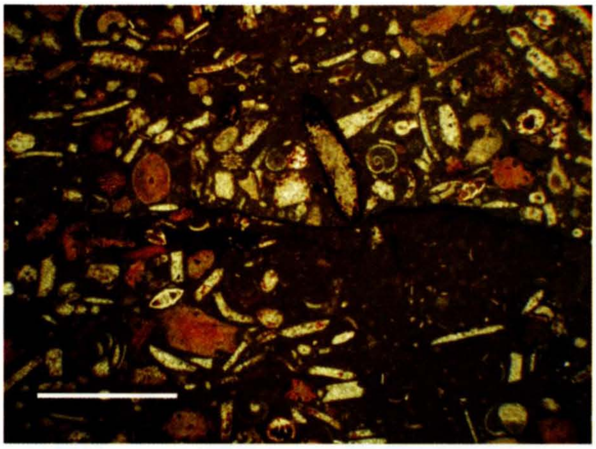


Fig. 3.25 Lower Member of the Prehodavci Formation: Fe-Mn crust within the bioclastic limestone with echinoderm fragments, gastropods and benthic foraminifers (section TV4). Scale bar is 1 mm long.

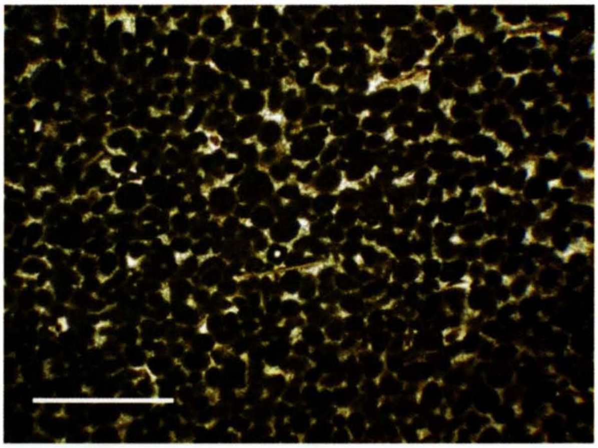


Fig. 3.26 Lower Member of the Prehodavci Formation: packstone with ooids and peloids (section R1). Scale bar is 1 mm long.

package composed of packstone to wackestone with echinoderm fragments, belemnites, and rare planktic foraminifers, calcified radiolarians and filaments.

Depositional environment.- The red nodular bioclastic limestone is a typical deposit of an isolated pelagic plateau (cf. Martire 1992, 1996). Nodular bedding, parallel, indistinct cross-lamination, and composition of the limestone indicate a deposition in a pelagic high-energy environment. Abundant Fe-Mn oxides present in this facies suggest extremely reduced sedimentation rates due to the strong bottom-curents that were sweeping ocean floor and thus prevented high sediment accumulation (Martire 1992, 1996). The sedimentation reached minimum with the formation of the distinct level with concentrated Fe-Mn nodules.

Oolitic limestone

Oolitic limestone is only present at the Ravni Laz (section R1, Fig. 3.2) where it conformably overlies the red bioclastic limestone with Fe-Mn nodules.

Facies description.- This facies consists of three, 10 to 30 cm thick, horizontally laminated beds of grainstone and packstone composed almost exclusively of partly or completely micritized ooids (Fig. 3.26). Other grains are echinoderm fragments, bivalve fragments, and benthic foraminifers. The uppermost bed of the oolitic facies represents transitional facies into overlying light gray white nodular limestone described below. In the upper part of this bed the filaments predominate while ooids become scarce and finally absent.

Depositional environment.- Beds of oolitic limestone occur within a typical condensed pelagic platform facies and are allochthonous gravity displaced deposits (see discussion in chapter 4.4).

Light gray nodular limestone

A light gray nodular limestone is present in the Triglav Lakes Valley (sections TV1-TV5, Fig. 3.1), at Ravni Laz (section R1, Fig. 3.2), and at Čisti Vrh.

In the Triglav Lakes Valley the gray nodular limestone conformably overlies red bioclastic limestones with Fe-Mn nodules. The lower boundary is gradual while the upper boundary of this facies is sharp and irregular and marked by an erosional surface. The thickness of gray limestone varies from 6 to 10 m. At Ravni Laz, the light gray nodular limestone conformably overlies oolitic limestone. Here the nodular limestone is only 1 m thick.

Facies description.- The facies is characterized by a light gray packstone (rarely wackestone) and exhibits indistinct nodular bedding. At places, the nodular bedding is clearly visible (Fig. 3.27).

Bedding surfaces are marked by thin green clay films. Bed thickness is 3 to 5 cm rarely 10 cm. The packstone is composed mainly of disarticulated valves of thin-shelled bivalves (*Bositra* sp.) and calcified radiolarians (Fig. 3.28). Other grains are aptychi, benthic foraminifers, echinoderm fragments, juvenile ammonites, gastropod protoconchs and pellets. In the lower part of the limestone protoglobigerinids are present. At places also ammonite moulds are present, however, they are poorly preserved and do not aid in age determination. Rarely, nodules of wackestone composed exclusively of calci-

Fig. 3.27 Lower Member of the Prehodavci Formation: light gray nodular limestone. Triglav Lakes Valley. Photo Rafael Marn.

fied radiolarians occur. They show ellipsoidal shapes and sharp and at places also transitional boundaries with the matrix. The very distinct features of these facies are up to few cm thick concentrations of pyrite (Fig. 3.29).

Depositional environment.- The nodular gray limestone represents typical deposit of an isolated pelagic plateau as evidenced by presence of mainly pelagic bioclasts (radiolarians, ammonites, filaments and planktic foraminifers) and benthos (foraminifers and echinoderms) while shallow-water elements are completely missing. The indistinct nodular bedding and absence of Fe-Mn oxides suggest lower-energy current regimes compared to the underlying bioclastic limestone with Fe-Mn nodules. The horizons with well-developed nodular bedding suggest that pulsating currents allowed micrite accumulation followed by repeated phases of cementation, bioturbation and current reworking (Martire 1996). The distinct, up to few cm large concentrations of pyrite indicate reducing environment during early diagenesis.

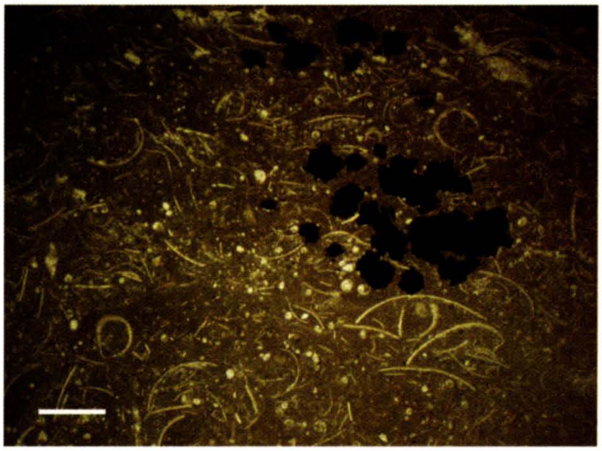


Fig. 3.29 Lower Member of the Prehodavci Formation: pyrite concretions in the light nodular limestone (section TV2). Scale bar is 1 mm long.

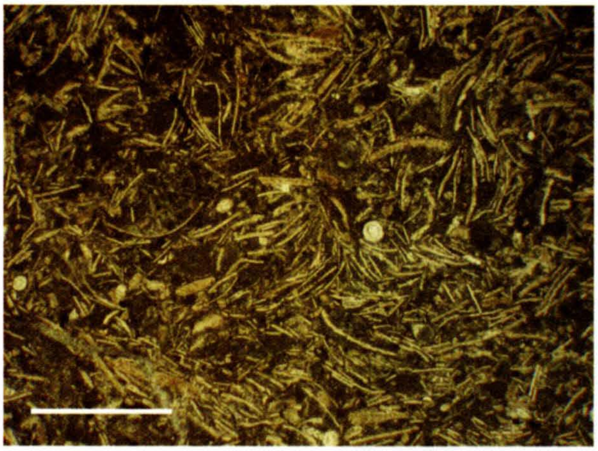


Fig. 3.28 Lower Member of the Prehodavci Formation: light gray nodular limestone with calcified radiolarian moulds and filaments (section TV2). Scale bar is 1 mm long.

MIDDLE MEMBER OF THE PREHODAVCI FORMATION

The Middle Member of the Prehodavci Formation is present only in the Lužnica Lake (section L1, Fig. 3.2). It is a bedded red marly mudstone that disconformably overlies the red bioclastic limestone with Fe-Mn nodules of the Lower Member.

The marly limestone is overlain disconformably by Kimmeridgian red nodular limestone of the Upper Member of the Prehodavci Formation.

Description of facies.- The red marly mudstone (rarely wackestone) is thin, evenly-bedded (bed thickness is up to 7 cm), composed of planktic foraminifers (protoglobigerinids), calcified radiolarians, benthic foraminifers, and echinoderm fragments (Fig. 3.30). The matrix is micrite with a small amount of terrigenous silt-sized micas.

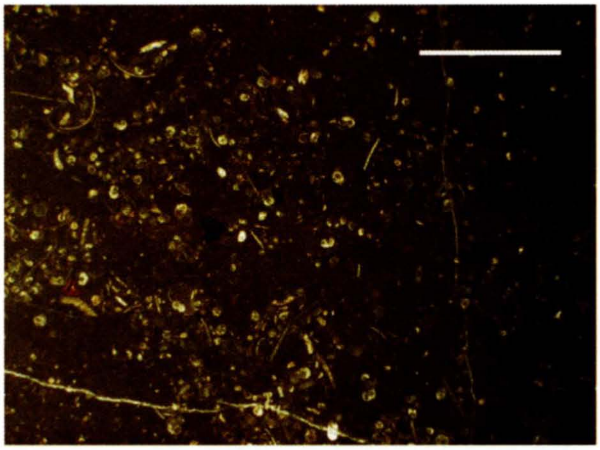


Fig. 3.30 Middle Member of the Prehodavci Formation: mudstone with calcified radiolarian moulds (section L1). Scale bar is 1 mm long.

Age.- On the basis of the stratigraphic position only a general age assignment, between the Callovian to the Kimmeridgian, is possible.

Depositional environment.- The marly mudstone was deposited in a lower hydrodynamic current regime, which permitted deposition of evenly bedded mud-supported sediments. Absence of cementation, and hence of firm ground burrowing, hindered formation of nodular structure (cf. Martire 1996). The presence of the silt-sized micas indicate an increased input of terrigenous material at that time.

UPPER MEMBER OF THE PREHODAVCI FORMATION

The Upper Member of the Prehodavci Formation was investigated in the Triglav Lakes Valley (sections TV1, 2, 3, 5, Fig. 3.1), at Ravni Laz (section R1, Fig. 3.2), Lužnica Lake (section L1, Fig. 3.2) and at Čisti Vrh and Vas na Skali. The Upper Member unconformably overlies the Lower or Middle Member of the Prehodavci Formation (Fig. 3.31). The contact is irregular and cuts up to 1 m deep into the Lower Member.

The Upper Member is a red nodular limestone of Ammonitico Rosso type. The exact thickness of this member could not be determined since the upper boundary is not visible in the outcrops, but can be estimated to at least 2.5 m at Triglav Lakes Valley, 3.5 m at Ravni Laz, and at least 6 m at Lužnica Lake.

Facies description and lateral variations.- This facies is characterized by red color and a marked nodular aspect in outcrop because of the color contrast between the pink nodules and darker matrix (Figs. 3.32, 3.33). Nodules are up to 10 cm large and are mainly intraclasts, ammonite moulds, and early diagenetic nodules.

Fig. 3.31 Irregular contact (arrow) between Lower and Upper Member of the Prehodavci Formation (Triglav Lakes Valley, section TV1). Photo Rafael Marn.

Fig. 3.32 Upper Member of the Prehodavci Formation: red nodular limestone: (Triglav Lakes Valley, section TV1). Photo Rafael Marn.

Fig. 3.33 Upper Member of the Prehodavci Formation: red nodular limestone: (Triglav Lakes Valley section TV1). Photo Rafael Marn.

The intraclasts consist of wackestone to packstone with disarticulated valves of thin-shelled bivalves (*Bositra* sp.), calcified radiolarians, fragments of ammonite shells, echinoderm fragments, juvenile ammonites, gastropod protoconchs, benthic foraminifers (*Lenticulina* sp.), and planktic foraminifers (protoglobigerinids) (Fig. 3.34). The intraclasts show sharp boundaries with the surrounding matrix. In the upper part of the member, they are also bored, borings are coated with the Fe-Mn crusts (Fig. 3.35).

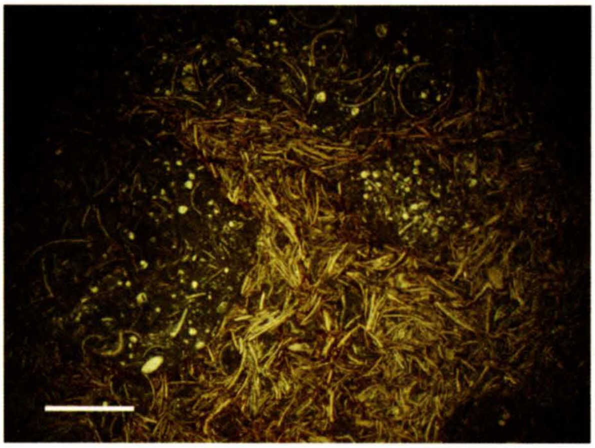


Fig. 3.34 Upper Member of the Prehodavci Formation: nodules of wackestone with filaments and calcified radiolarian moulds embedded in a filament-rich packstone (sectionTV1). Scale bar is 1 mm long.

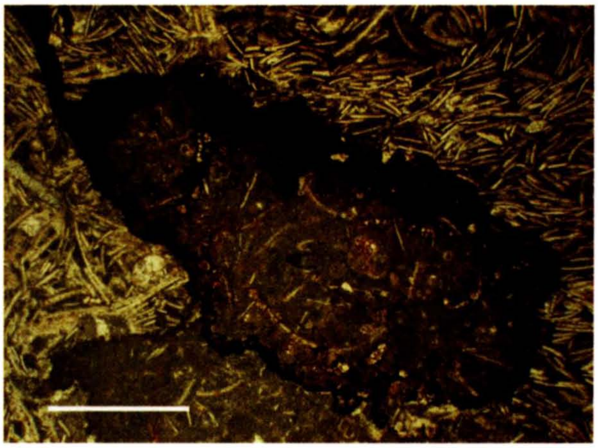


Fig. 3.35 Upper Member of the Prehodavci Formation: Fe-Mn incrusted intraclasts in a filament-rich packstone matrix (section TV1). Scale bar is 1 mm long.

Fig. 3.36 Upper Member of the Prehodavci Formation: ammonite mould in the red nodular limestone: (Triglav Lakes Valley, section TV1). Photo Rafael Marn.

The ammonite moulds are frequent and are generally coated with Fe-Mn oxides. Usually they are broken and abraded, and intact specimens are rare (Fig. 3.36).

The early diagenetic nodules have the same composition as intraclasts but show transitional boundaries with the surrounding matrix.

The described nodules are embedded in a darker, at places, more clay-rich matrix. The matrix consists of packstone with fragments of bivalves (*Bositra* sp.) and rare echinoderm fragments. Bivalve fragments are flat, aligned parallel to the edge of nodules, and form fitted fabric (Fig. 3.37).

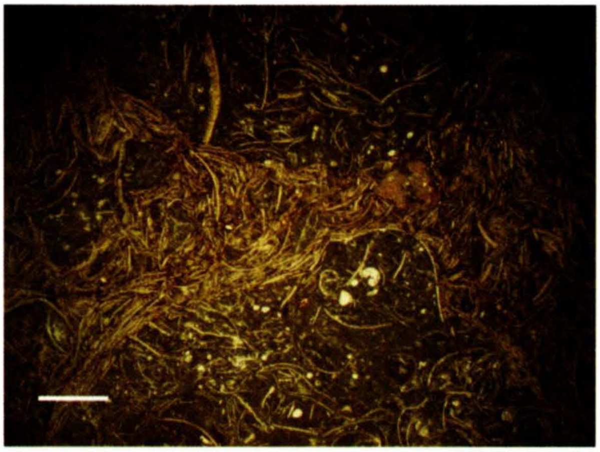


Fig. 3.37 Upper Member of the Prehodavci Formation: nodules of wackestones with filaments and calcified radiolarian moulds embedded in a filament-rich matrix forming fitted fabric (section TV1). Scale bar is 1 mm long.

Stylolites are common. They occur within the matrix and at the boundary between matrix and nodules. In Ravni Laz (sectionR1, Fig. 3.2) a 70 cm thick package of packstone with bioclasts is present in the upper part of the section. Packstone contains abundant *Saccocoma* sp., belemnites, echinoderm fragments, aptychi, calcified radiolarians, and intraclasts (Fig. 3.38).

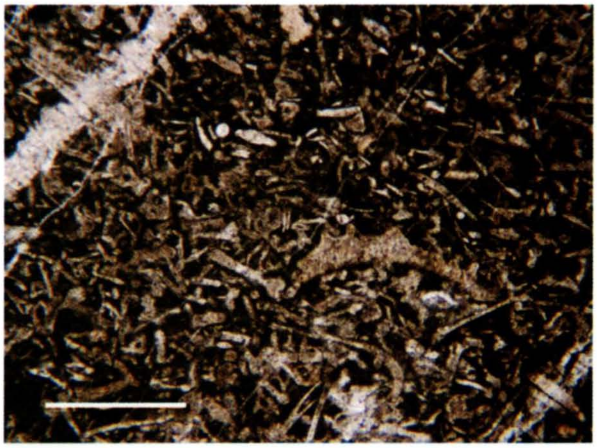


Fig. 3.38 Upper Member of the Prehodavci Formation: packstone with *Saccocoma* fragments and aptychi (Vas na Skali area). Scale bar is 1 mm long.

At Čisti Vrh and Vas na Skali Upper Member of the Prehodavci Formation is composed of nodules that are wackestones with abundant *Saccocoma* sp. fragments, aptychi, and calcified radiolarians.

Rarely, fragments of echinoderms and detritic grains of quartz are present. These nodules are embedded in a clay rich packstone matrix with abundant *Saccoma* sp. (Fig. 3.39), and rare calcified radiolarians and other echinoderm fragments.

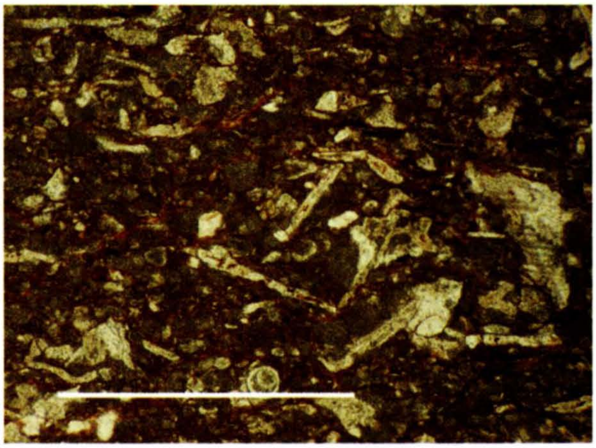


Fig. 3.39 Upper Member of the Prehodavci Formation: clay-rich limestone with *Saccocoma* (Vas na Skali). Scale bar is 1 mm long.

Age.- The ammonite moulds are quite frequent in this facies, however they are usually not well-preserved and very hard to extract from the rock. Salopek (1933) found the following ammonites: *Phylloceras* sp., *Holcophylloceras?* sp., and *Perisphinctes* sp. and determined a Late Jurassic age for the red nodular limestones. This age assignment was later improved by Ramovš (1975) who found the following ammonites: *Enaspidoceras* sp., *Gregoryceras* sp., *Lytoceras* sp., *Paraspidoceras* sp., and *Sowerbyceras* sp., and determined an Oxfordian and Kimmeridgian age. On the basic geological map of Yugoslavia, these red limestones were broadly assigned to the Late Jurassic (Buser 1986). According to the stratigraphic correlation with the Rosso Ammonitico Formation in the Trento Plateau, the Upper Member of the Prehodavci Formation corresponds to the Kimmeridgian to Tithonian Upper Member of the Rosso Ammonitico Formation.

A Late Kimmeridgian to Early Tithonian age for the nodular limestones of the Čisti Vrh and Vas na Skali was assumed on the basis of presence of *Saccocoma* sp. (according to Sartorio & Venturini 1988).

The Kimmeridgian to early Tithonian age of the Upper Member of the Prehodavci Formation is thus most probable.

Depositional environment.- The red nodular limestone of Ammonitico Rosso type represents condensed sedimentation and is typical of sedimentation on isolated pelagic plateaus. Various nodules (intraclasts, early diagenetic nodules and ammonite moulds) indicate the influence of pulsating bottom-currents that allowed micrite accumulation, followed by long and repeated phases of cementation, bioturbation and current reworking (Martire 1996). The higher clay content in the matrix is most probably a secondary enrichment due to the pressure dissolution of micrite (cf. Clari & Martire 1996).

3.1.3 BOVEC TROUGH

The Bovec Trough was a N-S trending small transverse Jurassic basin located in the western part of the Julian Nappe (for definition see chapter 1.4.3). It comprises the area of Mt. Mangart saddle (Travnik structural unit) and Bavšica area (Cousin 1981). The Bovec Trough formed after the disintegration and drowning of the Julian Carbonate Platform. The distinct feature of the Bovec Trough is that sedimentation was basinal from the Middle Jurassic. The Lower Jurassic platform limestones of the Julian Carbonate Platform are overlain by late Pliensbachian distal shelf limestones (Sedlo Formation) followed by the deposition of the black shales (Skrile Formation). The Middle and Upper Jurassic deposits of the Bovec Trough are characterized by pelagic siliceous sedimentation and abundant carbonate gravity-flow deposits (Travnik Formation). The best- exposed sections of the Bovec Trough crop out in the Travnik structural unit on the Mt. Mangart saddle (see Figs. 2.7, 2.8) where 5 sections (MA1 to 5) (Figs. 3.3, 3.4) were investigated. The most complete section is the MA1 section (Fig. 3.3), recording the evolution from the Early Jurassic to the Early Cretaceous. The MA1 section has already been described (Šmuc & Goričan 2005), under the name Mangart section. In this volume the lithostratigraphic units are formally described and detailed facies descriptions are also given.

SEDLO FORMATION

Type section.- MA1 (Fig. 3.3, for location see Fig. 2.7). The Sedlo Formation is named after the Mt. Mangart saddle (sedlo is the Slovenian word for saddle). The Sedlo Formation was investigated in both the MA1 and MA2 sections (Fig. 3.3). In the MA1 section, the Sedlo Formation is completely accessible while in the

MA2 section only the upper part of the formation is visible. The Sedlo Formation corresponds to Unit 2 of Šmuc & Goričan (2005). The development of the Sedlo Formation in the MA2 section is newly explained here.

Short Definition.- The Sedlo Formation lithology ranges from wackestone to packstone rich in echinoderms, juvenile ammonites, sponge spicules and foraminifers. In the upper part of the formation rudstone is intercalated with packstone containing echinoderms. The thickness of the Sedlo Formation at the type locality is 27 m.

The Sedlo Formation conformably overlies the Lower Jurassic platform limestones. The boundary here is sharp and well discernible upon close inspection, because of the facies change, but indistinct in field morphology. However, the limestones of the Sedlo Formation are clearly distinguished from the underlying shallow water grainstones and wackestones (see chapter 3.1.1) due to the marked difference in the texture of limestone (they are much more fine-grained). The Sedlo Formation is unconformably overlain by the lower (to middle?) Toarcian Skrile Formation. This discontinuity surface is marked with a Fe-Mn hardground on the top of the Sedlo Formation. The Pliensbachian age of this formation is constrained by foraminifers, combined with radiolarian dating from overlying strata.

Previous work.- The bioclastic limestone of Mali Mangart was first described by Cousin (1981). He found that the shallow-water lower Lower Jurassic "pseudo-oolitic" limestones are overlain by 20 m of biomicritic limestones with numerous sponge spicules, foraminifers (*Agerina martana* (Farinacci) (by Cousin (1981) determined as *Vidalina martana* (Farinacci)), *Nodosaria* sp.), echinoderm debris, and juvenile ammonites. In the upper part of this succession he found calcareous microbreccias composed of abundant echinoderm fragments and foraminifers (*Agerina martana* (Farinacci), *Involutina liassica* (Jones), *Nodosaria* sp., *Lenticulina* sp.). According to this association he dated this limestones as middle Liassic. Jurkovšek et al. (1990) described the uppermost part of this limestone; they found foraminifers (*Agerina martana* (Farinacci) (by Jurkovšek et al. (1990) determined as *Ophthalmidium leischneri* (Kristian-Tollmann)), radiolarian moulds, sponge spicules, echinoderm fragments and juvenile ammonites. On the basis of the presence of *Agerina martana* (Farinacci) they assigned a Liassic age to this limestone.

Facies description.- The lower part of the formation consists of light brownish-gray, massive to indistinctly bedded (Fig. 3.40), and at places nodular, bioclastic wackestone to packstone. Bed thickness is up to 10 cm.

The limestone is composed of sponge spicules, echinoderm fragments, locally abundant juvenile ammonites, and benthic foraminifers (Textulariidae, *Lenticulina* sp., *Agerina martana* (Farinacci)) (Fig. 3.41). Ostracods and brachiopod shells are rare. Glauconite is present as infilling in chambers of foraminifers or as small individual grains. Pellets are abundant in places.

Fig. 3.40 Sedlo Formation: massive and indistinctly bedded bioclastic limestone (Travnik structural unit of the Mt. Mangart saddle, section MA1). The section is in overturned position. Line in the upper left corner of the photo is 1 m long. Photo Rafael Marn.

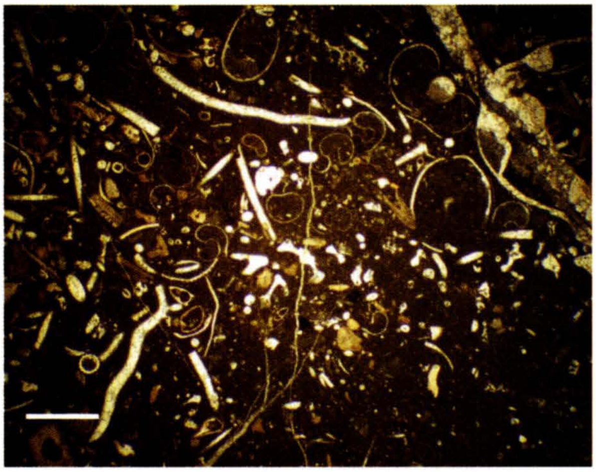


Fig. 3.41 Sedlo Formation: bioclastic limestone with juvenile ammonites, sponge spicules, and echinoderm fragments (section MA1). Scale bar is 1 mm long.

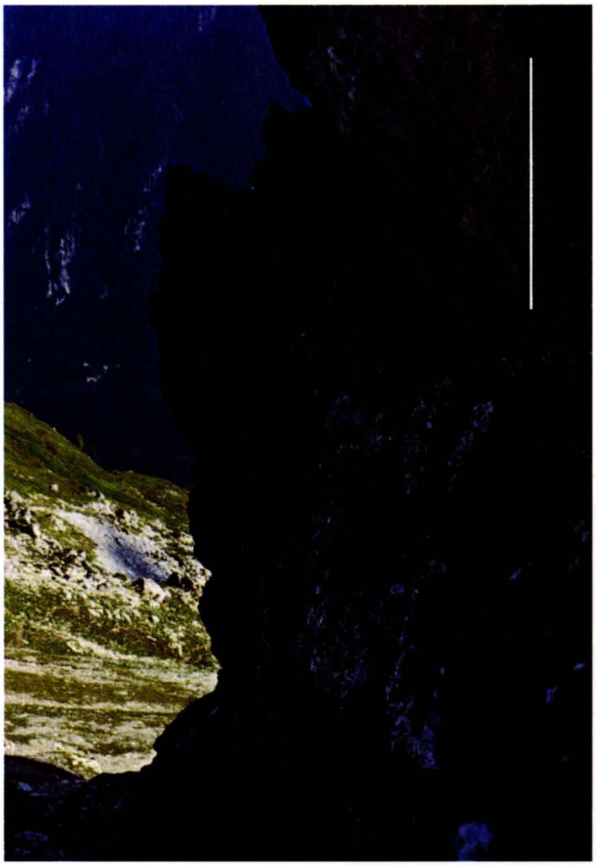


Fig. 3.42 Upper part of the Sedlo Formation: greenish rudstone – packstone and red siliceous limestone (Travnik structural unit of the Mt. Mangart saddle, section MA1). Section is in overturned position. Scale bar is 1 m long. Photo Rafael Marn.

The upper part of the formation is characterized by a distinctive greenish rudstone-packstone and red siliceous limestone (Fig. 3.42).

In the MA1 section (Fig. 3.3) this level is characterized by 1 to 1.8 m thick rudstone-packstone package that is overlain by red siliceous packstone/wackestone, while at the MA2 section (Fig. 3.3), the rudstone package is thicker (up to 10 m) and alternates with red siliceous packstone/wackestone. The upper part of the formation is more argillaceous and darker in color than the lower part, and can therefore be readily distinguished in the field.

The rudstone and packstone are thin-bedded, poorly sorted, moderately to densely packed, and normally graded. Elongate grains are oriented parallel to the bedding. The prevalent grains are fragments of echinoderms and diverse intraclasts. Echinoderm grains show evidence of mechanical breakage and abrasion. Intraclasts are fragments of underlying lithologies represented by clasts of bioclastic wackestones with benthic foraminifers (*Agerina martana*), sponge spicules, juvenile ammonites, and rare echinoderms, clasts of well-sorted grainstones with peloids, micritized ooids, and fragments of bivalves, and also clasts of mudstones, and peloidal mudstones (Fig. 3.43). Other grains include foraminifers (*Lenticulina* sp., *Agerina martana* (Farinacci)), bivalve and brachiopod fragments, and peloids. The matrix is micrite and microsparite. Glauconite, chlorite and pyrite grains also occur within the matrix.

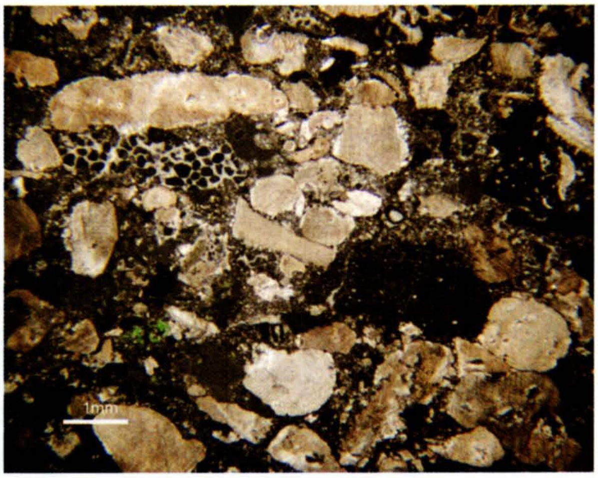


Fig. 3.43 Sedlo Formation: rudstone with echinoderm fragments, and intraclasts of peloidal packstones, and mudstones (section MA1).

The red siliceous packstone/wackestone is bedded, with beds of up to 10 cm thick and slightly nodular. It consists of abundant, partly calcified, sponge spicules and radiolarians (Fig. 3.44).

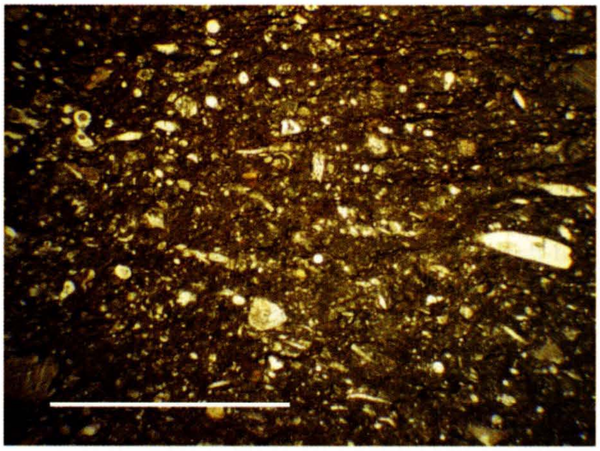


Fig. 3.44 Sedlo Formation: uppermost siliceous limestone with sponge spicules and radiolarian moulds (section MA1). Scale bar is 1 mm long.

Other grains include rare echinoderm fragments that are not present in the topmost beds of the formation. The matrix is partially impregnated by Fe-Mn oxides. The siliceous packstone/wackestone contains Fe-Mn nodules up to 3 cm in size. They occur throughout the uppermost 1.5 m of the formation. At the type section, MA1 (Fig. 3.3) the formation is capped by a 25 cm thick bed composed exclusively of Fe-Mn nodules (Fig. 3.45). The nodules consist mainly of quartz and pyrolusite, with minor amounts of cryptomelane, todorokite and goethite; the MnO content reaches 55 % (Jurkovšek et al. 1990). This bed is not present in the MA2 section.

Age.- The common presence of *Agerina martana* (Farinacci) (according to the biozonal scheme of Chiocchini et al. (1994)) in the lower part of the formation suggests a Pliensbachian age. Because the overlying Skrile Formation is early Toarcian in age (Goričan et al. 2003), the Fe-Mn hardground at the top of the Sedlo Formation approximately corresponds to the Pliensbachian/Toarcian boundary.

Depositional environment.- The lower part of the formation is constructed of bioclastic wackestone and packstones that were deposited in a low energy environment. The presence of open-marine biota (sponge spicules and juvenile ammonites) and the absence of shallow-water elements suggest a deeper depositional environment, most probably that of a distal shelf (cf. Elmi 1990).

Rudstones and packstones in the upper part of the formation exhibit normal grading, relatively dense packing and parallel orientation of the elongate grains and are interpreted as gravity-flow deposits. The presence of completely lithified lithoclasts of older strata indicates exhumation of underlying lithologies by synsedimentary extensional tectonics that produced unstable slopes, uncovered older rocks and enabled erosion. The exhumed rocks were additionally eroded due to mechanical abrasion by the grain-loaded turbulent water (cf. Di Stefano & Mindszenty 2000, Di Stefano et al. 2002).

In the wackestone and packstones with ferromanganese nodules above the resedimented limestones, sponge spicules and radiolarians prevail and benthic calcareous organisms become scarce to absent. Ferro-manganese nodules provide evidence for extremely reduced sedimentation rates

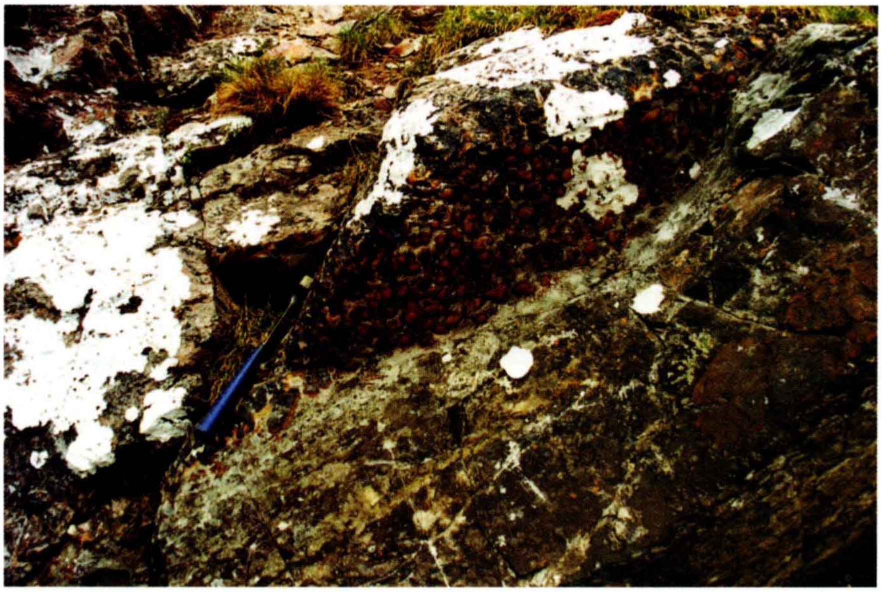


Fig. 3.45 Sedlo Formation: Fe-Mn nodules in the uppermost part of formation. Section is in overturned position (Travnik structural unit of the Mt. Mangart saddle, section MA1).

of this pelagic limestone . The sedimentation rate reached its minimum with the formation of the Fe-Mn hardground.

SKRILE FORMATION

Type section.- MA1 (Fig. 3.3 for location see Fig. 2.7). The Skrile Formation is named after the old name that local people used for the locality of the lower part of the MA 1 section (skrile is the old Slovenian word for shale). An additional section where this formation crops out is the MA2 section (Fig. 3.3). However the outcrop is mostly covered and only the lowermost part of the formation can be studied. The Skrile Formation corresponds to Unit 3 of Šmuc & Goričan (2005).

Short Definition.- The Skrile Formation is a 27.5 m thick succession of organic and manganese-rich calcareous shales with interbedded dark gray siliceous limestone. It unconformably overlies the Sedlo Formation, and is unconformably overlain by the Travnik Formation (Fig. 3.46). The early and possibly middle Toarcian age of this formation was constrained with radiolarians (Goričan et al. 2003).

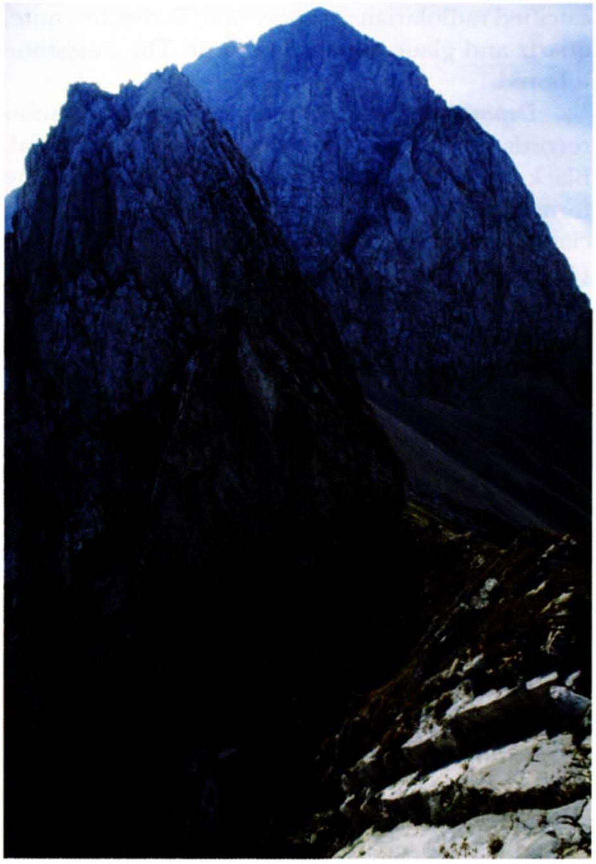


Fig. 3.46 Skrile Formation (arrow) (Travnik structural unit of the Mt. Mangart saddle, section MA1). Section is in overturned position. The visible outcrop of the Skrile Formation is approximately 20 m long. Photo Rafael Marn.

Previous work.- Cousin (1981) first mentioned black calcareous shales and brown marls with rare intercalations of gray limestones with radiolarians at Mt. Mangart saddle. This author estimated 10 m of thickness for these deposits. Jenkyns (1988) provided a more detailed description of black shales. He described 26.5 m of organic-rich black laminated calcareous shales, manganiferrous at the base, and brown marls rich in pollen, that are interbedded with limestone with radiolarians. In shales, Jenkyns (1988) identified quartz, smectite, illite, and determined that organic-carbon values range between 0.48 and 1.7 %. Jenkyns (1988) interpreted these deposits as a product of the Toarcian Oceanic Anoxic Event. Later these deposits were also investigated by Jurkovšek et al. (1990), who identified quartz, calcite, illite and pyrolusite in the manganiferrous shales.

Facies description.- The formation starts with a 40 cm thick bed of dark gray organic-rich, wackestone/packstone with echinoderms, calcified radiolarians, and sponge spicules. The matrix is microsparite.

This wackestone/packstone is overlain by a 10 cm thick bed of very poorly-sorted rudstone. Normal grading is observed within this bed. The rudstone is composed mainly of echinoderm fragments and intraclasts. Intraclasts are mudstone and peloidal packstone. Rare foraminifers, fragments of bivalves and gastropods, glauconite, and phosphate grains are also present. The rudstone is cemented by drusy and syntaxial cement.

Above the rudstone, black laminated calcareous organic-rich shales with interbedded black siliceous limestones are present (Fig. 3.47). In the upper part of the formation, the shales are brown. The shales contain quartz, smectite and illite, and Mn oxides (Jenkyns 1988, Jurkovšek et al. 1990). The TOC values range between 0.48 and 1.7 %, and manganese content is high (up to 9.27 %) in the basal portion and decreases (1.12 % or less) upsection (Jenkyns 1988).

The siliceous limestone intercalated within the shales varies from packstone to mudstone. Bed thickness is up to 15 cm. In the lower part of the formation, beds are abundant and are mainly packstones and wackestones, whilst upward, the beds become rare and are predominantly wackestones to

Fig. 3.47 Skrile Formation: shales with interbedded black siliceous limestones. Section is in overturned position (Travnik structural unit of the Mt. Mangart saddle, section MA1). Photo Rafael Marn.

mudstones. In the lower part of the formation, the siliceous limestone shows both normal and inverse grading, parallel and ripple cross-lamination (Ta-d Bouma sequences), while upsection, only indistinct parallel lamination is present (Td Bouma sequence). The grain-to-matrix ratio and the mean size of radiolarians decrease upward. In the uppermost limestone beds, the grain-to-matrix proportion is again high (packstone/wackestone laminae). The limestone is composed mainly of radiolarians, sponge spicules (only in the lowermost part of the formation), intraclasts of lime mudstone (in the lowermost part of the formation only), and phosphate grains (Fig. 3.48). Authigenic quartz and pyrite occur and are especially abundant in wackestone, while they are less common in the packstone beds. The matrix is micrite with a high organic matter content.

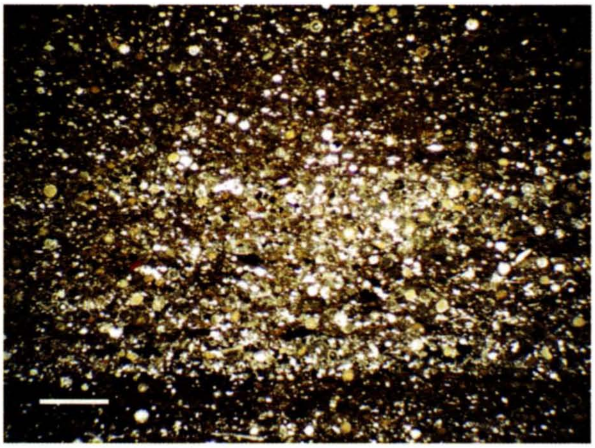


Fig. 3.48 Skrile Formation: normally graded siliceous limestones with radiolarians and mudchips (section MA1). Scale bar is 1 mm long.

The formation ends with 0.90 m of light green, thinly-bedded, laminated, mudstone with Mn dendrites. Echinoderms, ostracods, foraminifers and calcified radiolarians are very rare. Pyrite, limonite, quartz and glauconite are present. The limestone is bored.

Depositional environment.- The Skrile Formation records a high input of terrigenous clayey material. Black organic-rich shales in the lower part of the formation were deposited during the early Toarcian Oceanic Anoxic Event, as suggested by Jenkyns (1988) and confirmed with radiolarian dating (Goričan et al 2003).

The limestone in the lowermost part of the formation is interpreted as hemipelagic limestone and indicates an increase in sedimentation rates following the formation of the Fe-Mn crust. Sedimentary structures and the composition of the rudstone bed are very similar to that in the rudstone beds of the upper part of the Sedlo Formation and suggest a deposition by a high-density gravity-flow.

The sedimentary structures found in the siliceous limestone intercalated within shales are typical of low-density turbidites (e.g. Piper & Stow 1991). The nature of resedimented grains (only pelagic fauna) indicates redeposition of material only within the sedimentary basin.

TRAVNIK FORMATION

Type section.- MA1 (Fig.3.3, for location see Fig. 2.7). The Travnik Formation is named after Travnik hill where the type section is located. Additional sections where this formation was studied are the MA3 and MA4 sections (Figs. 3.4, 3.49). The Travnik For-

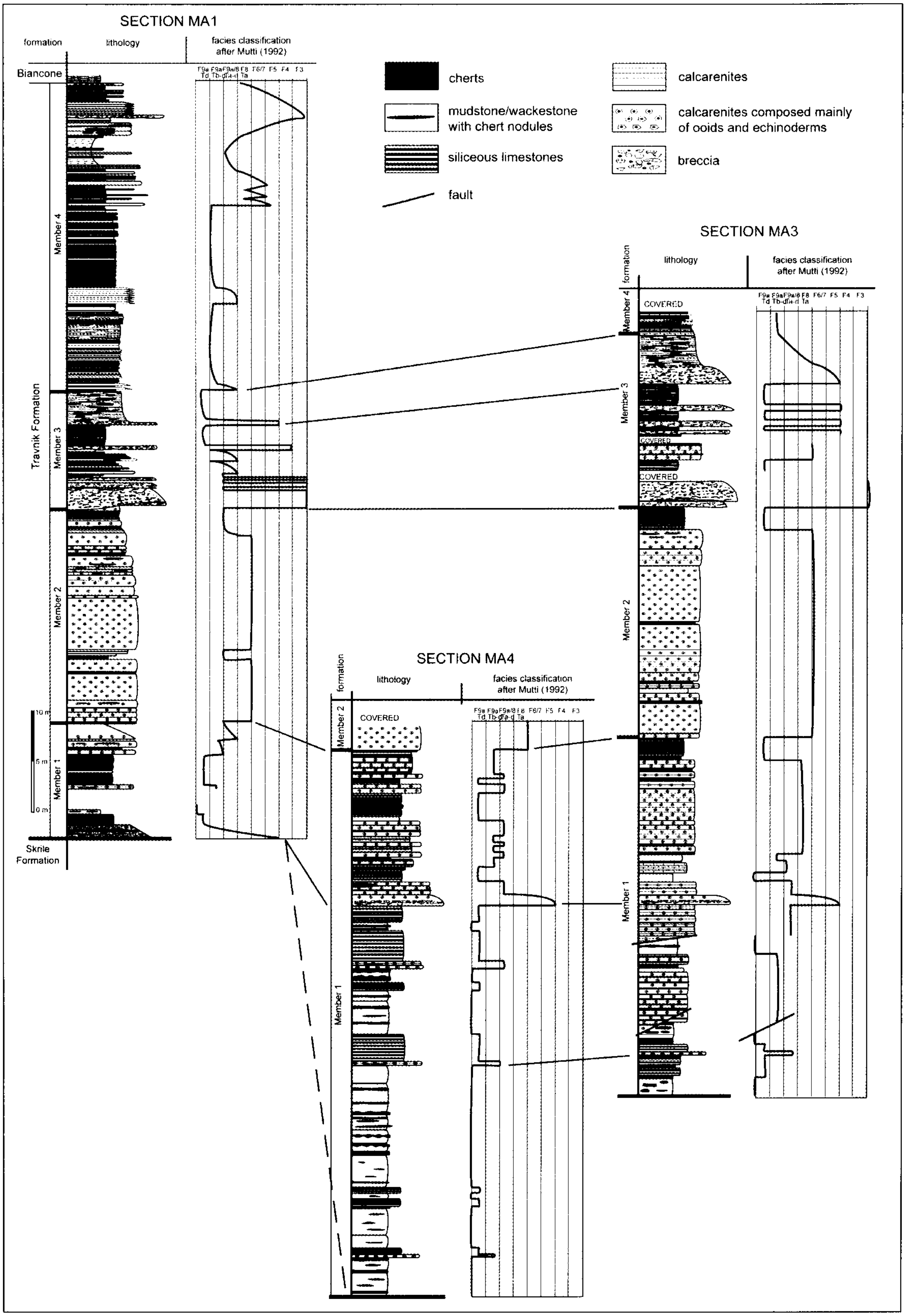


Fig. 3.49 Correlation of the Travnik Formation: MA1, MA3, and MA4 sections.

mation corresponds to Unit 4 of Šmuc & Goričan (2005). The description of the Travnik Formation in the MA3 and MA4 sections is newly presented here.

Definition.- The Travnik Formation is a 77 to 120 m thick succession of cherts, cherty limestones and carbonate gravity-flow deposits. On the basis of different lithology, structure and composition of resedimented carbonates, the Travnik Formation is subdivided into 4 members. The Travnik Formation unconformably overlies the Skrile Formation. The base of the formation is diachronuous. At the MA1section (Fig. 3.3), the base of the formation is late Bajocian or early Bathonian (Šmuc & Goričan 2005), while at the MA3 and MA4 sections (Fig. 3.4), the lower part of the formation is early-middle Bajocian in age. The Travnik Formation is conformably overlain by pelagic, Biancone-type limestone. The maximum range of this formation is thus lower-middle Bajocian to lower Tithonian. The ages of individual members are given below in the description of the members of the Travnik Formation.

Previous research.- Resedimented limestones and siliceous rocks at Mt. Mangart saddle were recognized by Cousin (1981) and Jurkovšek et al. (1990). From the Travnik hill Cousin (1981) described heterogeneous upper Dogger to Malm deposits. According to Cousin (1981), these deposits consist of radiolarian cherts, biomicritic limestones with radiolarians and sponge spicules, calcarenites and carbonate breccias. Calcarenites and breccias contain abundant ooids, intraclasts, echinoderm debris, foraminifers (*Protopeneroplis striata* Weynschenk, *Endothyra* sp., *Nummolocolina* sp., *Trocholina* ? sp., *Meyendorfina* sp.) and filaments. The upper part contains red radiolarian cherts that alternate with red nodular limestones with *Saccocoma*, and white calcareous breccias (Cousin 1981). Jurkovšek and co-authors (1990) described thin-bedded and silicified limestones with ooids and interpreted them as carbonate gravity-flow deposits. Jurkovšek and co-authors (1990) assumed these limestones were Malm in age.

MEMBER 1

The Member 1 of the Travnik Formation represents the base of the formation. The base of Member 1 is laterally diachronuous and variably developed. At the MA1 section (Fig. 3.3, the base of Member 1 is defined by a package of glauconitic breccia overlying the discontinuity surface, while at the MA3 and MA4 sections (Fig. 3.4), the lower part of Member 1 is a homogenous mudstone with cherts, but the contact with the Skrile Formation is not visible. Because of this difference we described separately the deposits of Member 1 for the MA1 section versus the MA3 and MA4 sections.

Member 1 at MA1 section

Facies description.- At the MA1 section (Fig. 3.3), Member 1 begins with a 1.3 m thick package of green, up to 25 cm thick beds of fine-grained, poorly- to medium-sorted clast-supported breccia (Fig. 3.50) that grades into a thin- to medium-bedded, coarse to medium-grained calcarenite.

The breccia consists of filaments, echinoderms, bivalve fragments, foraminifers (Textulariidae, *Lenticulina* sp.), radiolarians, sponge spicules and

Fig. 3.50 Member 1 of the Travnik Formation: basal breccia (Travnik structural unit of the Mt. Mangart saddle, section MA1). Photo Rafael Marn.

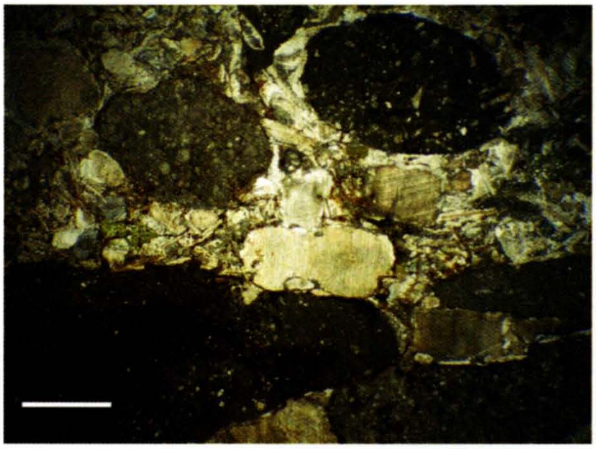


Fig. 3.51 Member 1 of the Travnik Formation: breccia with echinoderm fragments, glauconite and abundant lithoclasts of the bioclastic limestone of the Sedlo Formation, mudstone lithoclasts and lithoclasts of siliceous limestones of the Skrile Formation (section MA1). Scale bar is 1 mm long.

various lithoclasts (Fig. 3.51). The lithoclasts are the bioclastic wackestone/mudstone of the underlying Sedlo Formation, as well as the light gray mudstone and siliceous packstone/wackestone of the Skrile Formation. Glauconite is abundant. The calcarenite exhibits parallel lamination, and elongate grains are aligned parallel to bedding. It has the same bioclasts as breccias, but contains more highly evolved glauconite grains (determined according to classification of Odin & Fullagar 1988) (Fig. 3.52) and it is devoid of lithoclasts. Some of the glauconite grains have a fractured grain surface.

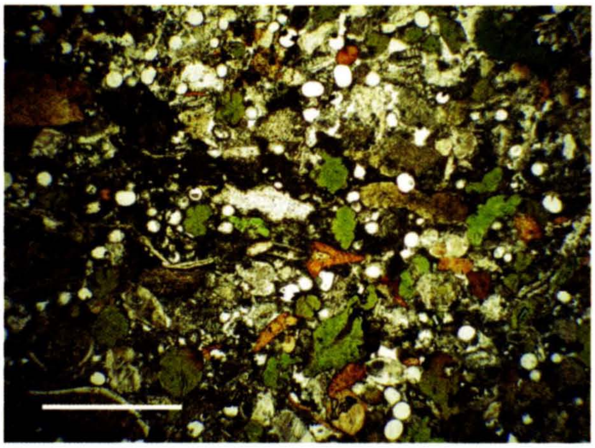


Fig. 3.52 Member 1 of the Travnik Formation: calcarenite with abundant glauconite grains, radiolarians, phosphate grains and filaments (section MA1). Scale bar is 1 mm long.

The breccia and calcarenite are overlain by thin-bedded gray siliceous packstone/wackestone and dark gray laminated cherts that alternate with medium-bedded light gray homogenous wackestones that contain lenses of chert. The siliceous packstone/wackestone shows parallel, low-angle cross lamination and wispy, convoluted lamination (Tb-d Bouma sequences). Grains are partly calcified radiolarians and rare fragments of echinoderms, and phosphate grains. The intercalated wackestone is composed of completely calcified radiolarians and rare filaments. Rare, up to 30 cm thick, ooid bearing, beds are interbedded in the upper part of the member.

Age.- On the basis of radiolarians found in the chert overlying basal glauconitic breccia, Šmuc & Goričan (2005) determined the age to be late Bajocian or early Bathonian.

Depositional environment.- Sedimentary structures of the basal breccias suggest deposition by gravelly high-density turbidity currents. Different lithoclasts of the Sedlo and Skrile Formations indicate exhumation and partial erosion of underlying deposits. The presence of evolved to highly evolved glauconite in the breccia and calcarenite is indicative of long-term sediment starvation in the provenance area (Odin & Fullagar 1988, Amorosi 1995). The breccia corresponds to the F5 facies type. The overlying coarse to medium-grained calcarenites were deposited by sandy high-density turbidity currents and represents the F7 facies type. Siliceous limestones at the top of the unit were deposited by low-density fine-grained turbidity currents and represent Tb-d Bouma divisions of F9a facies type.

Member 1 at MA3 and MA4 sections

Facies description and lateral variation.- Member 1 of the Travnik Formation in the MA3 and MA4 sections (Fig. 3.4) starts with bedded (bed thickness from 5 to 70 cm) homogenous mudstone/wackestone with lenses and beds of black replacement chert (Fig. 3.53).

The limestone is composed of calcified radiolarians, filaments, pyrite, and authigenic quartz (Fig. 3.54). In places the calcified radiolarians predominate.

Beds of medium-grained calcarenite are intercalated. Calcarenites are composed of filaments, echinoderm fragments, intraclasts of mudstone with radiolarian moulds, and glauconite grains. Glauconite occurs as individual grains or impregnates the echinoderm fragments. Phosphate grains, authigenic quartz and benthic foraminifera (*Lenticulina* sp.) are rare.

Fig. 3.53 Member 1 of the Travnik Formation: bedded limestone with chert (Travnik structural unit of the Mt. Mangart saddle, section MA4).

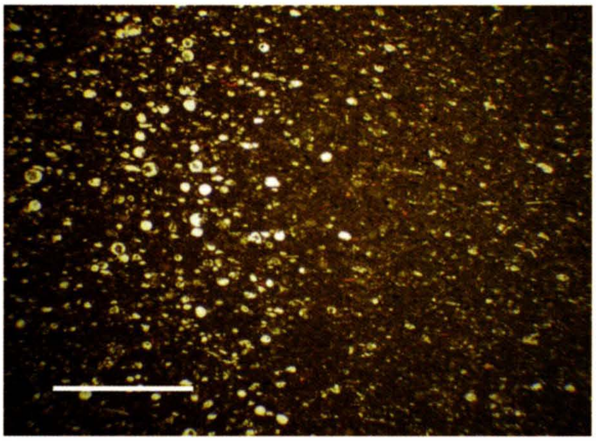


Fig. 3.54 Member 1 of the Travnik Formation: micritic limestone with calcified radiolarian moulds (section MA4). Scale bar is 1 mm long.

In the middle part of the Member 1 at the MA4 section the siliceous packstone/wackestone, ooidal calcarenites, and calcarenites with echinoderm fragments begin to occur.

The siliceous packstone/wackestone exhibits horizontal, ripple-cross lamination, and convolute laminations (Tb-d Bouma sequences), and rarely normal grading (Ta Bouma division). It is composed of partially calcified radiolarians, filaments and rarely sponge spicules, echinoderm fragments and mud-chips. In places phosphate and pyrite grains are also present.

The medium to fine-grained calcarenites are bedded (bed thicknes up to 20 cm) and mainly exhibit horizontal lamination (Tb Bouma division) while normal grading and ripple-cross lamination occurs rarely (Ta-c Bouma sequence). Lamination is defined by alternation of thicker packstone laminae composed mostly of ooids and thinner laminae where filaments predominate. Other grains are peloids, echinoderm fragments, benthic foraminifers (Textularidae, *Lenticulina* sp.), phosphate, and glauconite grains.

The echinoderm calcarenites are bedded (bed thickness up to 10 cm) and consist of grainstones composed predominantly of echinoderm fragments and rare glauconitic and phosphate grains, and mud-chips (Fig. 3.55). In places ooids are also present. Grains are cemented by syntaxial cement.

The upper part of Member 1 is characterized by 1 m thick medium- to fine-grained poorly sorted breccia that grades into a coarse-grained calcarenite. Grains are lithoclasts of wackestone of the Sedlo Formation, siliceous packstone/wackestone of the Skrile Formation, and clasts of mudstone from the lowermost part of the Member 1. Other grains are echinoderm fragments, gastropod and bivalve fragments and small glauconitic grains. The matrix of the breccia is packstone to wackestone with ooids and small echinoderm fragments. In the calcarenites overlying breccias lithoclasts become scarce and ooids start to predominate. Other grains are echinoderm fragments, sponge spicules and benthic foraminifers. This breccia is correlative with the basal breccia and calcarenite at the MA1 section (Fig. 3.49).

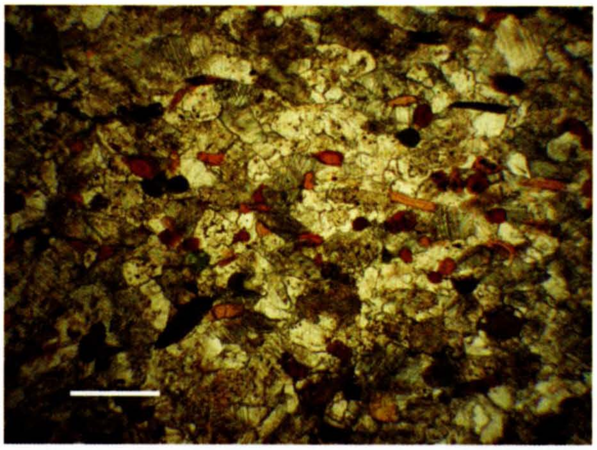


Fig. 3.55 Member 1 of the Travnik Formation: calcarenites with echinoderm fragments, phosphate and glauconite grains cemented by syntaxial cement (section MA4). Scale bar is 1 mm long.

Member 1 of the Travnik Formation ends with alternation of 1 m thick packages of previously described medium-grained calcarenites with ooids and up to 2.5 m thick packages of siliceous limestones with radiolarians.

Age.- The early-middle Bajocian age (UAZ 3 in Baumgartner et al. 1995 a) is constrained by the following radiolarian association (determined by Š. Goričan): *Bernoullius rectispinus* Kito, De Wever, Danelian & Cordey, *Hexasaturnalis suboblongus* (Yao), *Hsuum matsuokai* Isozaki & Matsuda, *Parasaturnalis diplocyclis* (Yao), *Stichomitra* (?) *takanoensis* Aita, and *Striatojaponocapsa plicarum* (Yao). The radiolarian sample was found 9.20 m above the base of the MA4 section (Fig. 3.4).

Depositional environment.- The homogenous limestone with calcified radiolarians is interpreted to be periplatform ooze deposits. Siliceous limestones of the middle part of the member were deposited by low-density turbidity currents and are Ta-d Bouma sequences of F9a facies type. Calcarenites in which ooids and echinoderms predominate were deposited from sandy turbidite currents and represent F8 and F9a facies types. The presence of glauconite grains in calcarenites with echinoderms indicates long-term sediment starvation in the provenance area (Odin & Fullagar 1988, Amorosi 1995).

MEMBER 2

Member 2 is present in all the investigated sections almost without lateral variations in thickness and composition (Fig. 3.3, 3.4, 3.49).

Facies description.- Member 2 is characterized by 0.3–5 m thick beds (Fig. 3.56) of light gray oolitic packstone and grainstone.

Thicker beds are structureless, whereas thinner (less than 0.5 m) beds at places show grading, parallel, and rarely ripple cross lamination (Ta-c Bouma sequences). The limestones are composed primarily of ooids while other grains (echinoderms, peloids, foraminifers (Textulariidae, Involutinidae, Lituolidae), and micritic intraclasts) are rare (Fig. 3.57). Black chert nodules are present in some beds.

Fig. 3.56 Member 2 of the Travnik Formation: limestone megabeds (arrow). The section is in overturned position (Travnik structural unit of the Mt. Mangart saddle, section MA1).

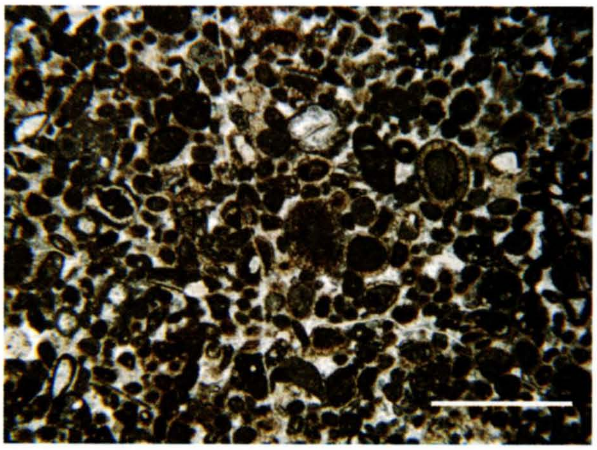


Fig. 3.57 Member 2 of the Travnik Formation: packstone with ooids, peloids, benthic foraminifers (section MA1). Scale bar is 1 mm long.

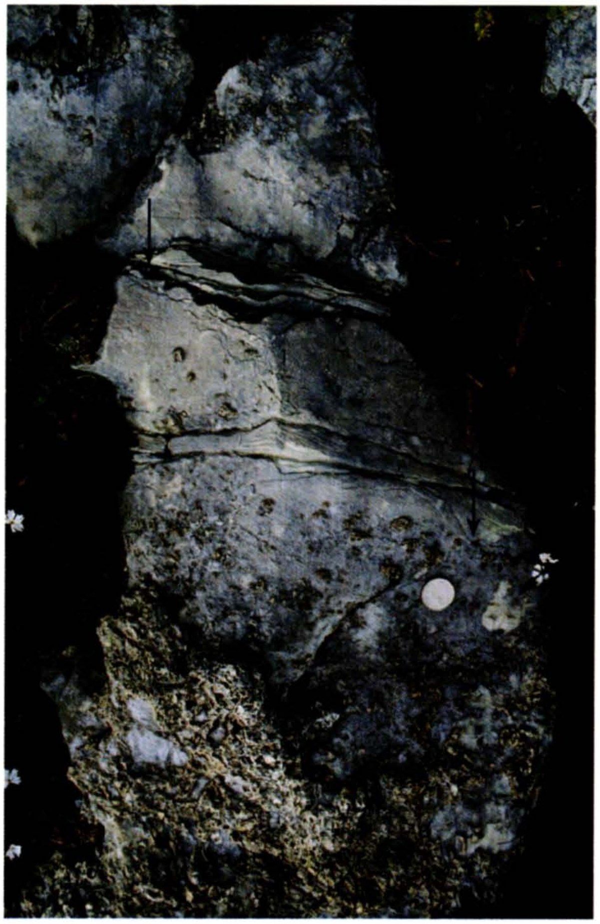


Fig. 3.58 Base of Member 3 of the Travnik Formation: erosional contact between breccias and fine-grained calcarenites (arrow) (Travnik structural unit of the Mt. Mangart saddle, section MA1). Photo Rafael Marn.

Age.- In the MA1 section (Fig. 3.3) the underlying Member 1 is dated as latest Bajocian-early Bathonian (sample MM 30.60 in Šmuc & Goričan 2005, for the position of the sample see Fig. 3.3). Šmuc & Goričan (2005) gave a broad age assignment of latest Bajocian-early Bathonian to late Bathonian-early Callovian for the overlying Member 3 (sample M8 38.40, for the position of the sample see Fig. 3.3). Thus, according to the stratigraphic position of Member 2, a Bathonian age was determined.

Depositional environment.- Thinner beds were deposited from sandy turbidity currents and are F8 and F9a facies types. Thicker, structureless beds most probably were deep-water massive sand bodies (according to Stow & Johansson 2000) and were deposited by highly concentrated sandy turbidity currents. Their thickness is constant in all of the investigated sections thus indicating sedimentation on the basin plain.

MEMBER 3

Deposits of the Member 3 are investigated at the MA1 and MA 3 sections (Figs. 3.3, 3.4, 3.49).

Facies description.- Member 3 starts with several, up to 2.60 m thick, carbonate breccia beds, each of them capped by fine-grained parallelly laminated packstone/wackestone (Fig. 3.58). The lowermost breccia bed is channeled into underlying Member 2. At places only the amalgamated breccia beds are present while fine-grained calcarenites are missing. Breccias are grain-supported, graded and composed of up to 5 cm large lithoclasts of underlying lithologies of Members 1, and 2, and the Sedlo Formation (Fig. 3.59). Other clasts are composed of abundant fragments of echinoderms, fragments of stromatoporoids, corals and foraminifers (Textulariidae, Involutinidae, Lituolidae). Individual breccia beds also occur in the middle part of Member 3. The overlying laminated fine-grained packstone/wackestone is composed of filaments, small echinoderm fragments and micritized ooids (Fig. 3.60).

This package is overlain by thin- to medium-bedded, coarse- to fine-grained limestones showing grading, parallel and wavy lamination (Ta-Tc Bouma divisions). They have a similar composition to limestones of Member 2, but contain fewer ooids.

Thin-bedded, parallelly laminated radiolarian-bearing cherty limestone characterizes the middle part of Member 3.

Member 3 ends with a 3 m thick bed composed of 30 cm thick breccia at the base, which abruptly passes into massive fine-grained indistinctly laminated packstone/wackestone with chert nodules (Fig. 3.61). The breccia has the same composition as the breccias in the lower part of Member 3. The packstone/wackestone with chert nodules is composed of filaments, echinoderm fragments, rare ooids, phosphate grains and pyrite.

Age.- On the basis of the radiolarians in the cherty limestones in the middle part of Member 3 Šmuc & Goričan (2005) (sample M8 38.40, for the position of the sample see Fig. 3.3) determined a broad age assignment of latest Bajocian-early Bathonian to late Bathonian-early Callovian (UAZ 5–7 in Baumgartner et al. 1995a). On the basis of correlation with the Tethyan transgressive/regressive cycles of Jacquin et al. (1998) the breccias of the lowermost part of the Member 3 most probably correspond to the late Bathonian lowstand.

Depositional environment.- The base of Member 3 is characterized by amalgamated breccia beds representing the F3 facies type that were deposited by debris flows. Individual breccia beds are directly overlain by fine-grained calcarenites interpreted to be the dilute "tail" of the same gravity flow that produced each breccia bed, thus indicating substantial sediment by-pass (cf. Mutti 1992). Two breccia beds in the middle part of the member were deposited by gravelly high-density turbidity currents and represents F4/?F5 facies type. Coarse- to fine-grained calcarenites from middle part of M3 member were deposited from a sandy turbidity currents and represent top-cut-off Bouma sequences of F8/9 and F9a facies type. The siliceous limestones were deposited by low-density turbidity currents and represent Tb

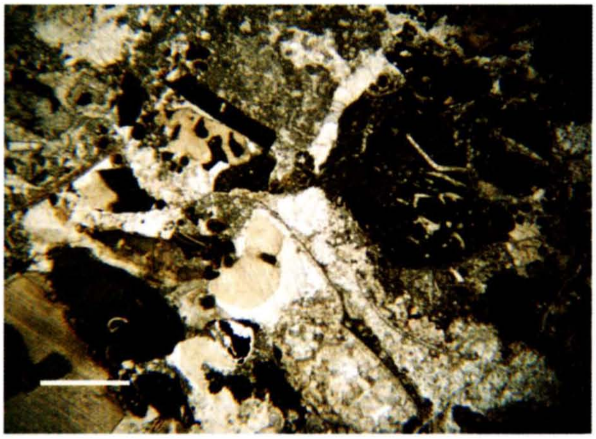


Fig. 3.59 Member 3 of the Travnik Formation: carbonate breccia with lithoclasts of Member 1 and 2 of the Travnik Formation, Sedlo Formation and fragments of stromatoporoids (section MA1). Scale bar is 1 mm long.

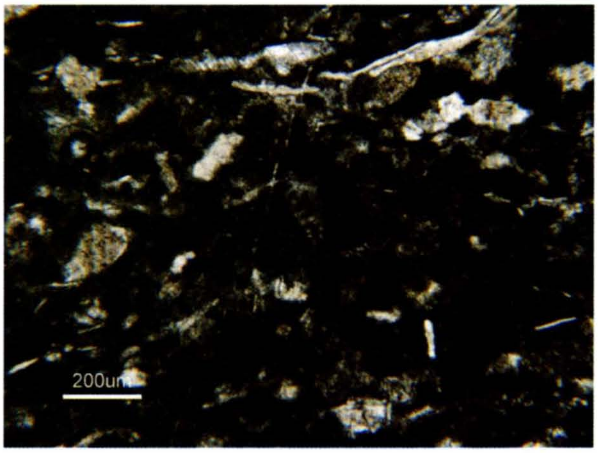


Fig. 3.60 Member 3 of the Travnik Formation: wackestone/packstone with filaments and small echinoderm fragments (section MA1).

Fig. 3.61 Upper part of the Member 3 of the Travnik Formation: massive packstone – wackestone with chert nodules. Section is in overturned position (Travnik structural unit of the Mt. Mangart saddle, section MA1). Photo Rafael Marn.

Bouma sequences of F9a facies type. The massive breccia bed that grades to a fine-grained limestone with chert nodules in the uppermost part of the member was deposited from highly concentrated turbidity current and belongs to a F3/4 facies type.

MEMBER 4

Member 4 was investigated in the MA1 section (Fig. 3.3). Member 4 contains cherty limestones, cherts and siliceous mudstones with intercalations of fine to very coarse- grained calcarenites. Carbonate breccia is present in the uppermost part of the member.

Facies description.- The lower 15 m of Member 4 are characterized by thin-bedded laminated (Td) black cherts and cherty limestones (same composition as cherty limestones of Member 3) with intercalated thin-bedded, fine to coarse-grained calcarenites. Calcarenites show Ta-b and Tb-d Bouma divisions and are packstones composed of filaments, peloids, echinoderm fragments, foraminifers (Textulariidae, Involutinidae, Lituolidae) and phosphate grains. Ooids are rare. In coarse-grained facies, reworked lithoclasts of Member 1, 2, and 3 occur. In the middle part of Member 4, thin beds of orange replacement chert are present.

The upper part of Member 4 starts with red radiolarian cherts with intercalated coarse to very coarse-grained calcarenites (Ta Bouma division) (Fig. 3.62), and continues with a 2.5 m thick, clay-rich package containing intercalations of red calcareous clay-rich chert and coarse-grained calcarenites.

The uppermost part of Member 4 is composed of red laminated and, at places, graded radiolarian-rich marls (Fig. 3.63) with intercalations of a carbonate breccia and coarse-grained calcarenites.

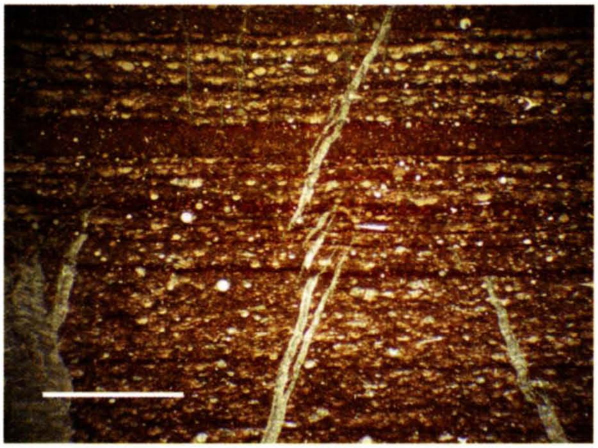


Fig. 3.63 Member 4 of the Travnik Formation: laminated, radiolarian-rich marl (section MA1). Scale bar is 1 mm long.

The intercalated coarse-grained calcarenites are packstones to grainstones composed of peloids, echinoderm grains, foraminifers (Textulariidae, Involutinidae), rare small ooids and mudstone clasts. In the uppermost part of Member 4, the calcarenites are composed exclusively of echinoderm fragments.

The breccia bed (30 cm thick) in the upper part of Member 4 (Fig. 3.64) is coarse-grained (clasts are up to 10 cm), grain-supported and composed mainly of large lithoclasts of underlying lithologies

Fig. 3.62 Member 4 of the Travnik Formation: red radiolarian chert, with intercalated coarse-grained calcarenites. Section is in overturned position (Travnik structural unit of the Mt. Mangart saddle, section MA1). Photo Rafael Marn.

Fig. 3.64 Upper part of the Member 4 of the Travnik Formation: breccia (Travnik structural unit of the Mt. Mangart saddle, section MA1). Photo Rafael Marn.

Fig. 3.65 Member 4 of the Travnik Formation: carbonate breccia with lithoclasts of the Members 1,2,3 of the Travnik Formation, belemnites and peloids (section MA1). Scale bar is 1 mm long.

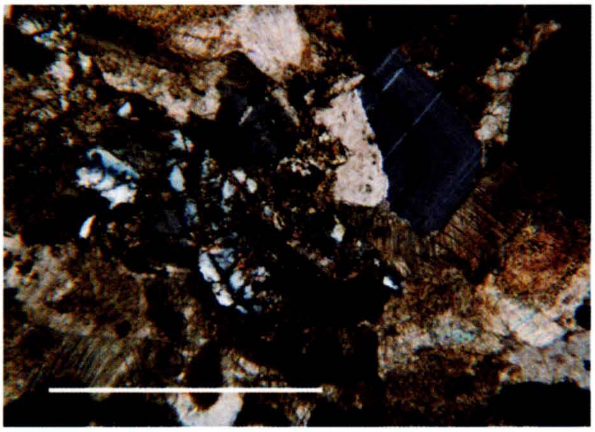


Fig. 3.66 Member 4 of the Travnik Formation: breccia with echinoderms and euhedral detritic grain of bytownite-anorthite feldspar (section MA1). Scale bar is 1 mm long.

of the Travnik Formation (Fig. 3.65). Other grains are echinoderms, belemnites, peloids, foraminifers (Textulariidae, Valvulinidae), fragments of algae and corals. Important constituents are rare but large (up to 2 mm) euhedral detritic grains of bytownite-anorthite feldspars (Fig. 3.66).

Age.- Based on the stratigraphic position and radiolarians found in the siliceous limestones late Bathonian/Callovian to early Tithonian age was determined for these deposits by Šmuc & Goričan (2005). The authors determined the following ages (for the position of the samples see Fig. 3.3): samples M8 33.30, and M8 21.90 corresponds to UAZs 6 to 7 (middle Bathonian to late Bathonian-early Callovian), samples M8 14.30, and M8 10.90 are assignable to the middle-late Oxfordian (UAZ 9), sample M8 6.80 is not younger than late Oxfordian-early Kimmeridgian (UAZ 10?) (for the position of the samples see Fig. 3.3).

Depositional environment.- Cherts, calcareous clayey cherts and marls of Member 4 represent the background pelagic sedimentation. The carbonate admixture in these beds can be either of pelagic or platform origin. Lamination and, at places, grading suggest hydrodynamic sorting. The fine- to medium-grained calcarenites were deposited by low- to medium-density turbidity currents and are base-missing Bouma sequences and correspond to the F9a facies type. Coarse-grained calcarenites belong to the Ta-b Bouma divisions of F8/9a facies and were deposited by sandy, high-density turbidity currents. The breccia bed in the uppermost part of the member is a debris-flow and corresponds to the F3 facies type.

3.2 CRETACEOUS FORMATIONS

The Cretaceous formations are uniformly developed over the entire Julian Nappe. However, the outcrops of the Cretaceous formations are rare in the Julian Nappe and no section with continuous Cretaceous development has been found.

3.2.1 BIANCONE LIMESTONE

The Biancone limestone is a bedded pelagic limestone containing chert. It conformably overlies the Prehodavci Formation and the Travnik Formation. The exact thickness of this unit in the investigated sections is not known since the upper boundary is never exposed, but the thickness can be estimated to be at least 10 m. In the literature the following localities have thus far been reported to have exposures of the pelagic Biancone limestone: Mt. Mangart saddle, Plešivec, Čisti Vrh, Logje in the Bavšica valley, Vas na Skali, Lužnica Lake, and Triglav Lakes Valley (Cousin 1981, Buser 1986, Jurkovšek 1987, Jurkovšek et al. 1990). In this study the Biancone limestone was investigated in the Travnik structural unit of Mt. Mangart saddle (sections MA1, and MA5, Figs. 3.3, 3.4), Triglav Lakes Valley, Čisti Vrh, and at Vas na Skali.

Facies description and lateral variations.- In the Triglav Lakes Valley and at Čisti Vrh the direct contact of the Biancone limestone and the underlying Prehodavci Formation is covered. The Biancone limestone is represented by up to 10 cm thick beds of mudstone to wackestone with up to few cm-thick chert beds and nodules. It is composed of calcified radiolarians, aptychi and calpionellids (*Calpionella alpina* (Lorenz), *Remaniella catalanoi*? (Pop)). Extremely rare echinoderm fragments are also present. In the upper part of this unit *Calpionella elliptica* (Cadisch) is present as well.

At Vas na Skali, the previously described Biancone limestone passes upward into a matrix supported, medium-grained chaotic conglomerate. Clasts are composed exclusively of Biancone limestone (Fig. 3.67) that at places show plastic deformation.

The matrix of the conglomerate is wackestone composed mainly of radiolarian moulds and rare *Calpionella elliptica* (Cadisch). At places the matrix is completely silicified.

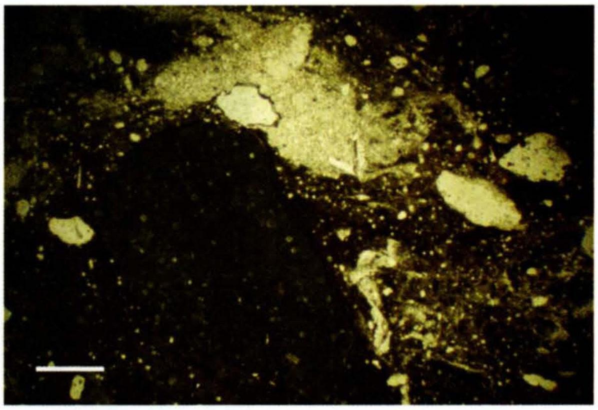


Fig. 3.67 Biancone limestone: conglomerate with clasts of Biancone limestone embedded in a radiolarian-rich matrix. (Vas na Skali). Scale bar is 1 mm long.

The pelagic limestone at Mt. Mangart saddle was investigated in the Travnik structural unit (sections MA1 and MA5, Figs. 3.3, 3.4). The lower part consists of red nodular (bed thickness is up to 5 cm) (Fig. 3.68) mudstone to wackestone composed mainly of calpionellids, aptychi, and calcified radiolarians.

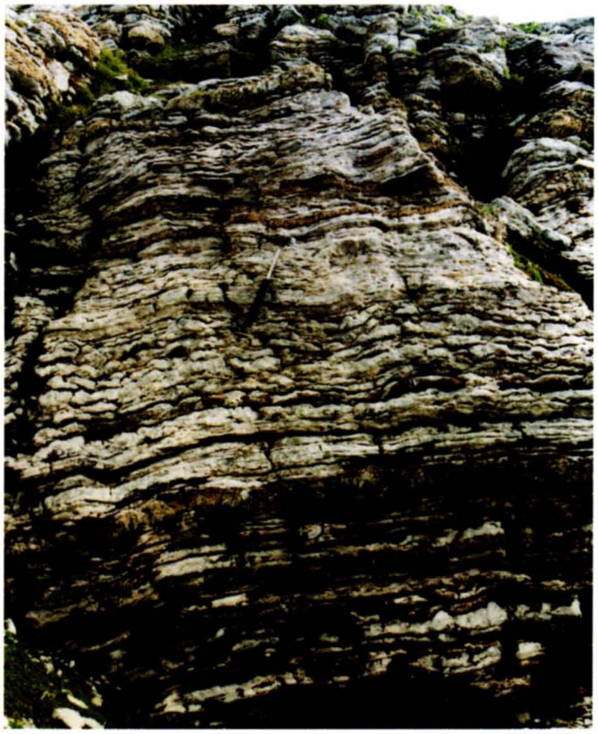


Fig. 3.68 Biancone limestone: nodular limestone with chert beds (Travnik structural unit of the Mt. Mangart saddle, section MA5).

Fig. 3.69 Biancone limestone: tectonized light gray limestone with chert nodules (Travnik structural unit of the Mt. Mangart saddle, section MA5).

Echinoderm fragments and benthic foraminifers are extremely rare. Up to few centimeters-thick beds of red replacement chert occur within nodular limestones. In the MA5 section, a few beds of calcarenite composed exclusively of echinoderm fragments are intercalated in the lowermost part. In the lowermost part *Crassicollaria* sp. and *Calpionella alpina* (Lorenz) are present, while in the middle part *Calpionella elliptica* (Cadisch) occurs. The upper part (exposed only at section MA5) is a strongly tectonized light gray wackestone/mudstone with chert nodules (Fig. 3.69) composed exclusively of calcified radiolarian moulds.

Age.- In the Triglav Lakes Valley, Čisti Vrh and Vas na Skali areas the Late Tithonian to middle Berriasian age of the exposed Biancone limestone was determined on the basis of the *Calpionella alpina* (Lorenz), *Remaniella catalanoi*? (Pop) and *Calpionella elliptica* (Cadisch) (according to Remane 1985 and Grün & Blau 1997). The same age was determined for the red nodular limestones in the lower part of the MA1 and MA5 sections at the Mt. Mangart saddle. The light gray limestones with chert nodules in the upper part of the MA5 section in the Mt. Mangart saddle are dated with radiolarians. A late Valanginian-early Hauterivian age (UAZ 17–18 of Baumgartner et al. 1995a) was determined on the basis of the radiolarians (Goričan & Šmuc 2004, p. 35).

Depositional environment.- The Biancone limestone was deposited by normal pelagic sedimentation in a deeper-water environment. At places nodular bedding suggests the influence of sea-bottom currents that caused slower sedimentation rates and early selective cementation. At Vas na Skali, the Biancone limestone passes upward into chaotic conglomerate. These deposits are interpreted as debris flow deposits that formed due to the local loss of shear strength of the partly consolidated material in a slope environment.

3.2.2 SCAGLIA VARIEGATA

In the Julian Alps, exposures of the Scaglia variegata are very rare. Only five localities have thus far been reported in the literature. These are: Logje in the Bavšica valley, Vas na Skali, Slatenek creek, Lužnica Lake, and Mt. Mangart (Cousin 1981, Buser 1986, Jurkovšek 1987, Jurkovšek et al. 1990, Pavšič 1994, Goričan & Šmuc 2005). In these areas green and gray marls, shales, calcarenites, and cherts, make up the Scaglia variegata deposits. At Mt. Mangart, the Scaglia variegata crops out in the Drn structural subunit. This outcrop was dated by Goričan & Šmuc (2004), and is described below.

Description.- The succession at section MA6 (Fig. 3.5a, b) starts with lower Lower Jurassic platform limestones cut by Jurassic neptunian dykes (see chapter 3.3.1) that are unconformably overlain by 20 m of middle Cretaceous Scaglia variegata. The Scaglia variegata starts with 0.5 m of bedded (bed thickness up to 20 cm) medium-grained breccia that grades into medium-grained calcarenite. The largest clasts in breccia are 3 cm, are densely packed, and elongated clasts are aligned parallel to the bedding. Clasts are composed of echinoderm fragments, lithoclasts of gray, black and orange cherts, and lithoclasts of radiolarian-bearing wackestone to packstone (Fig. 3.70). Glauconite and chlorite are also present. Grains are cemented by blocky sparite that is, in places, completely silicified.

Fig. 3.70 Scaglia variegata: basal breccias with lithoclasts of cherts, and siliceous limestones with radiolarians (section MA6). Scale bar is 1 mm long.

The breccia and calcarenite are followed by 16 m of gray, thin-bedded siliceous limestone that alternates with gray to green marl and chert. Marls are common in the lower part while upwards limestones and cherts predominate.

The uppermost five meters of the succession are composed of 0.5 m of nodularly-bedded black cherts with manganese, 2 m of red bedded chert, and a 2 m of red thin-bedded marly packstone composed almost exclusively of planktic foraminifers (Fig. 3.71). The matrix of limestone is microsparite, at places

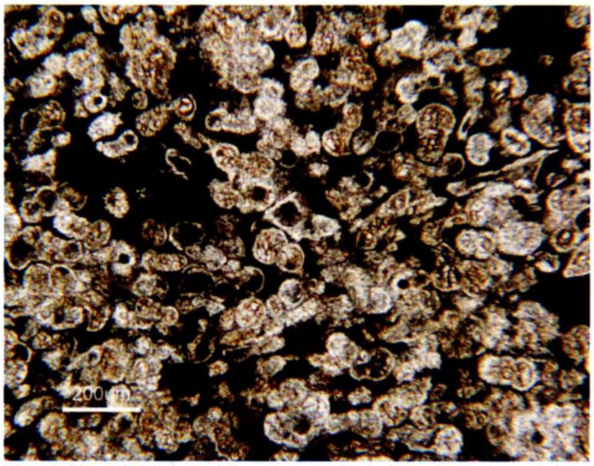


Fig. 3.71 Scaglia variegata: limestone with small keel-less globular foraminifers (section MA6).

completely replaced with Fe-Mn oxides. The most abundant foraminifers are small keel-less globular foraminifers. However, in the uppermost part of the section very rare globotruncanids with developed single keel also occur.

Age.- Based on the radiolarians from the siliceous limestones 4 m above the base of the succession, an early or early middle Albian age was determined (Goričan & Šmuc 2004). In the uppermost part of the succession, globotruncanids with a developed single keel occur. These can be used as a biostratigraphic marker, as the first occurrence of keels in globotruncanids is in the *Rotalipora subticinensis* Zone, i.e. in the late middle Albian (Caron 1985).

Depositional environment.- The basal medium-grained breccia and coarse-grained calcarenite were deposited by a high-density turbidity current. The completely lithified clasts of cherts indicate the erosion of older strata. Glauconite grains indicate sediment starvation in the provenance area (Odin & Fullagar 1988, Amorosi 1995). The marls in the lower part indicate higher input of clay in into basin. Siliceous limestones, cherts and limestones with pelagic foraminifers represent deeper-water pelagic sedimentation.

3.2.3 SCAGLIA ROSSA

In the Julian Alps, the exposures of the Scaglia rossa are more common than those of the Scaglia variegata. The Scaglia rossa deposits occur as smaller erosional remnants on an older (uppermost Triassic to lower Jurassic) platform and deeper-water deposits. Usually the contact of the Scaglia rossa with older strata represents a discontinuity surface, rarely the Scaglia rossa is in fault contact with surrounding rocks (Cousin 1981, Buser 1986, Jurkovšek 1987, Radoičić & Buser 2004). The Scaglia rossa in the Julian Alps was described by Cousin (1981), Buser (1986), Jurkovšek (1987), Jurkovšek et al. (1990) and Radoičić & Buser (2004). Scaglia rossa is characterized by red, rarely gray, thin-bedded limestone and marly limestone with abundant globotruncanids. On the basis of the globotruncanids the Scaglia rossa ranges from the upper Turonian to the lower Maastrichtian (Cousin 1981), however in the Bovec area the Scaglia Rossa is conformably overlain by Campanian flysch deposits (Buser 1987, Jurkovšek 1987, Radoičić & Buser 2004). The thickness of the Scaglia rossa in the Julian Alps ranges from few meters to approximately 100 m.

Fig. 3.72 Scaglia rossa: thin bedded limestone, overlain by coarse-grained breccia (Mali Vrh structural subunit of the Mt. Mangart saddle, section MA7). Photo Rafael Marn.

In this study the Scaglia rossa was studied at Mt. Mangart saddle, section MA 7 (Fig. 3.5). The Scaglia rossa of the Mt. Mangart saddle was previously investigated by Cousin (1981) and Jurkovšek et al. (1990) and assigned to the Turonian and Senonian on the basis of the globotruncanids. My study revealed that at Mt Mangart saddle Scaglia rossa crops out only in Mali Vrh and Rdeča skala subunits of the Mangart structural unit (see Figs. 2.6, 2.7). In the Mali Vrh subunit, the Scaglia rossa unconformably overlies Upper Triassic to lower Lower Jurassic platform limestone cut by large neptunian dykes, while the structural subunit Rdeča skala consists only of completely tectonized Scaglia rossa. The investigated section MA 7 (Fig. 3.6) is a part of the Mali Vrh subunit, however due to the poor exposure, its direct contact with the underlying upper Triassic-lower Lower Jurassic platform limestone is not recorded.

Facies description.- The succession is composed of thin-bedded (bed thickness is 2–5 cm) red and subordinately gray wackestone (rarely packstone and mudstone) (Fig. 3.72) that exhibits horizontal lamination and, at places, normal and inverse grading and ripple cross-lamination (Ta, Ta-c Bouma divisions).

The limestone is composed mainly of small keelless globular foraminifers and globotruncanids with a developed single keel (Fig. 3.73). Sponge spicules, calcified radiolarians, echinoderm fragments, small sparitic grains, phosphate, glauconite and quartz grains are rare. Within these limestones, medium-grained calcarenite and coarse-grained breccia occur. The calcarenitey bed is 10 cm thick and normally graded, and the base is erosional. The calcarenite consists of lithoclasts and bioclasts. Lithoclasts include previously described limestones with planktic foraminifers and mudstones, laminated and graded siliceous limestones with radiolarians, shallow water peloidal grainstones, and cherts. Bioclasts are fragments of *Inoceramus* sp., fragments of echinoderms, and benthic foraminifers (*Lenticulina* sp. and Textularidae) (Fig. 3.74). Other grains are glauconite, phosphate and quartz grains. Grains are cemented by granular sparitic cement and syntaxial cement around echinoderm grains.

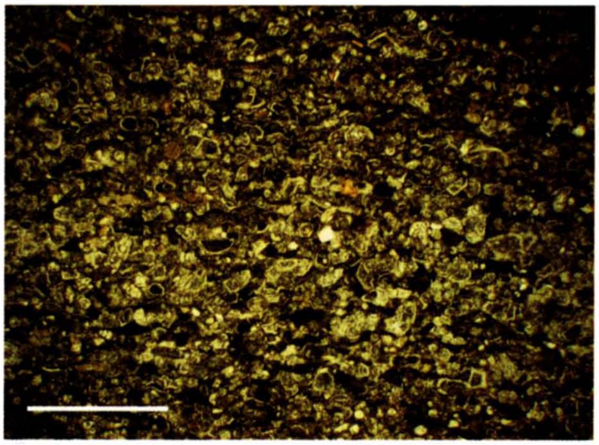


Fig. 3.73 Scaglia rossa: packstone with abundant globotruncanids (section MA7). Scale bar is 1 mm long.

A breccia bed is present in the upper part of the investigated section (Fig. 3.72). It is poorly-sorted, normally graded and clast supported. Clasts are up to 1 m and include:

- limestones with globotruncanids,
- wackestone to mudstone with calcified sponge spicules,
- normally graded and horizontally laminated red siliceous limestones with radiolarians,
- red cherts,
- red laminated marly wackestones to packstones with abundant *Saccocoma*, fragments of echinoderms, aptychi and benthic foraminifers,
- pelletoidal limestones,
- light gray packstone to grainstone composed of peloids, fragments of limestone with fenestral porosity, algae fragments, benthic foraminifers, and echinoderm fragments,
- laminated and normally graded wackestone with pellets and foraminifers,
- light gray shallow water limestones with neptunian dykes.

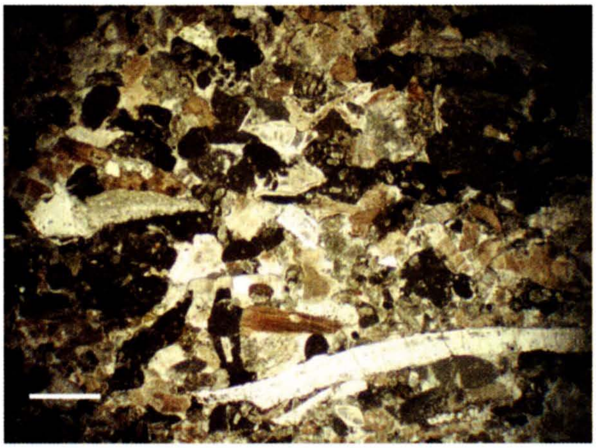


Fig. 3.74 Scaglia rossa: calcarenite with mudstone lithoclasts, *Inoceramus* sp., and fragments of echinoderms (section MA7). Scale bar is 1 mm long.

The matrix of the breccia is a wackestone with planktic foraminifers, described in the lower part of the succession.

Age.- The investigated section MA7 corresponds to the Unit 2 of the Rdeča skala of Cousin (1981, see p. 440, and 441) . Cousin (1981) dated this unit on the basis of the globotruncanids as upper Senonian.

Depositional environment.- The Scaglia rossa represent typical deeper-water sediments in the Upper Cretaceous. The thin-bedded wackestone with normal and inverse grading, horizontal and ripple-cross lamination were deposited by low-density turbidity currents (cf. Piper & Stow 1991, Shanmugam 2000). The normally graded calcarenite bed represents top-cut-off Bouma sequence (Ta) and was deposited by medium-grained turbidity currents. The coarse-grained breccia is here considered to be the product of a hyperconcentrated gravity flow (cf. Mutti 1992). The presence of various clasts of older strata in the calcarenite and breccia indicates exhumation of underlying lithologies by synsedimentary extensional tectonics and erosion at least down to Upper Jurassic deposits (clasts of red marly wackestones with abundant *Saccocoma*). Presence of *Inoceramus* sp., fragments of echinoderms, and benthic foraminifers indicates input from shallow-water areas.

3.3 NEPTUNIAN DYKES

Neptunian dykes are present only in the drowning successions of the Julian High, and they are completely absent in the investigated Bovec Trough sections.

3.3.1 NEPTUNIAN DYKES OF THE MANGART STRUCTURAL UNIT

Neptunian dykes are present in the Mali Vrh, Mangart Peak, and Drn subunits, where they penetrate uppermost Triassic and Lower Jurassic platform limestones.

The structural subunit Mali Vrh is marked by numerous neptunian dykes. They were studied in the MA7 section (Fig. 3.6) and also at roadside outcrops on the road to Mt. Mangart saddle (for location see Fig. 2.7). Two distinct generations of neptunian dykes were differentiated on the base of their geometry and sediment infilling.

The first generation is represented by two major types of neptunian dyke: dykes with irregular-undulate and concave walls and dykes with straight walls exhibiting a jigsaw structure. The former are characterized by up to 20 cm thick oval cavities with smooth and undulate surfaces (Fig. 3.75). Cavity walls are rimed by fibrous cement (Fig. 3.76). The remaining space was filled with red mudstone with fragments of ostracods, echinoderms, ammonites, sponge spicules and benthic foraminifers including *Agerina martana* (Farinacci) (Fig. 3.77). Thin Fe-Mn crusts are present within the mudstone (Fig. 3.78). Rarely the remaining space is filled with wackestone with echinoderm fragments, benthic foraminifers and mudstone lithoclasts. The second type is characterized by straight walls exhibiting jigsaw structure. These fissures are filled by the previously mentioned red mudstone with *Agerina martana* (Farinacci). On

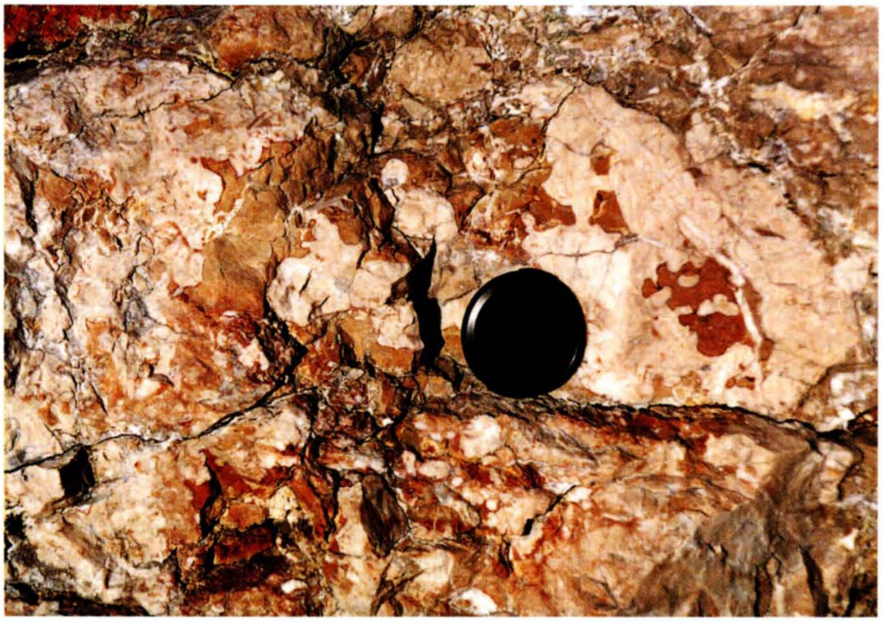


Fig. 3.75 Neptunian dykes with irregular-undulate walls (Mali Vrh structural subunit of the Mt. Mangart saddle). Photo Alenka Eva Črne.

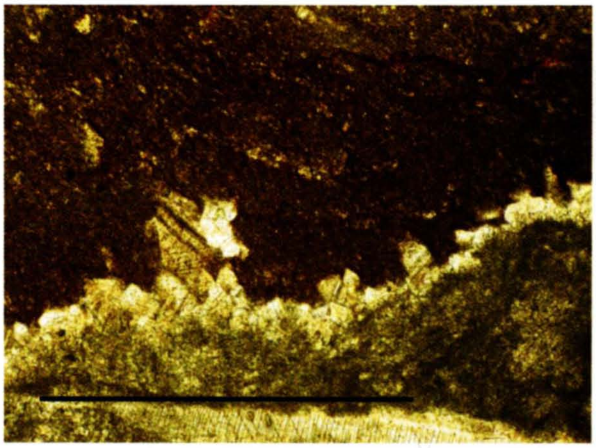


Fig. 3.76 Neptunian dykes: fibrous cement rim around cavity walls. Upper part of the photograph is mudstone (1. generation of neptunian dyke infill of Mali Vrh structural subunit). Scale bar is 1 mm long.

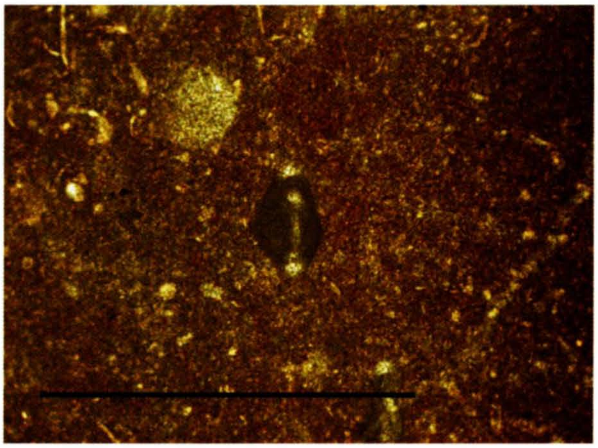


Fig. 3.77 Neptunian dykes: mudstone with *Agerina martana* (Farinacci) (1. generation of the neptunian dyke infill of Mali Vrh structural subunit). Scale bar is 1 mm long.

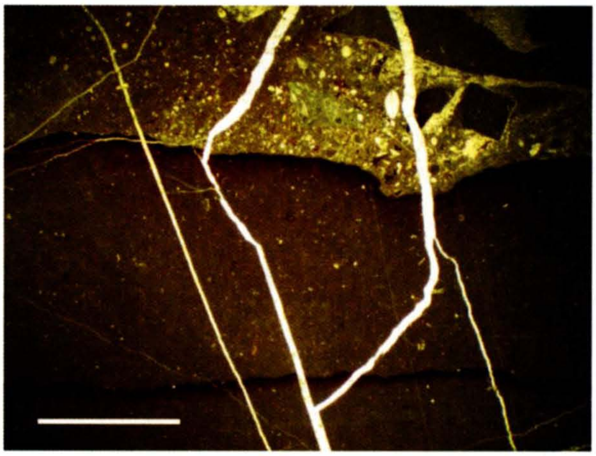


Fig. 3.78 Neptunian dykes: lower part of the photograph is mudstones with Fe-Mn crusts. In the upper part of the photograph wackestone with echinoderm fragments and mudstone intraclasts are present. (1. generation of the neptunian dyke infill of Mali Vrh structural subunit). Scale bar is 1 mm long.

the basis of the presence of *A. martana* the age of the formation of the oldest infilling of neptunian dykes is Pliensbachian (this infilling is coeval with the Sedlo Formation of Bovec Trough, see chapter 3.1.3). The cavities with irregular undulate walls were formed by dissolution, however at places it is clearly visible that dissolution reshaped fractures with straight walls (Črne 2004). Dykes with straight walls were formed by mechanical deformation of the host rock due to the extensional tectonic movements in the Pliensbachian. The jigsaw structure was formed due to the seismic shocks and injection of unlithified plastic sediment. Alternation of cements, sediments, and crusts is indicative of breaks during sediment infiltration.

The second generation of neptunian dykes is the most prominent generation of fractures. It occurs in Mali Vrh and Mangart peak subunits and is marked by two different types: larger chaotic breccia bodies and smaller fractures with smooth and straight walls. Chaotic breccias (Fig. 3.79) are up to few tens of meters large, laterally confined breccia bodies with mostly uneven walls. Only in places is sharp contact with the host rock observed. Jigsaw structure in the breccia is also present (Fig. 3.80a,b). Clasts of breccia are angular and usually not oriented. Clasts can be up to 1 m in size and are composed of massive limestone with corals and smaller fragments of shallow-water grainstones (Fig. 3.81). Some clasts of host rock include evidence of the first generation of neptunian dykes. The first generation of filling is also present as clasts. The matrix is red and gray microsparite with fragments of sponge and echinoderms, and glauconite grains. In the uppermost part, the breccia body clasts are smaller and the matrix is at places laminated. The

Fig. 3.79 Larger chaotic breccia – neptunian dyke filling (Mali Vrh structural subunit of the Mt. Mangart saddle).

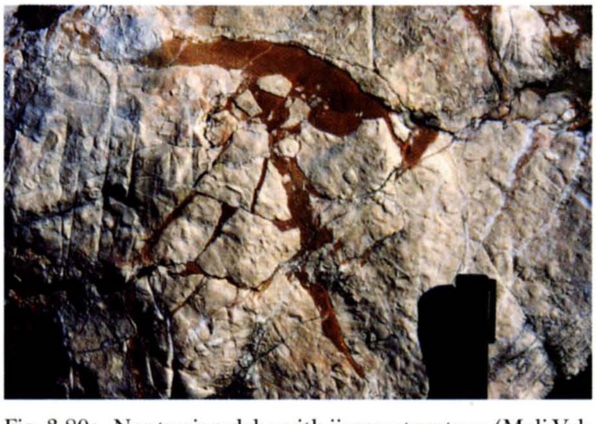


Fig. 3.80a Neptunian dyke with jigsaw structure (Mali Vrh structural subunit of the Mt. Mangart saddle).

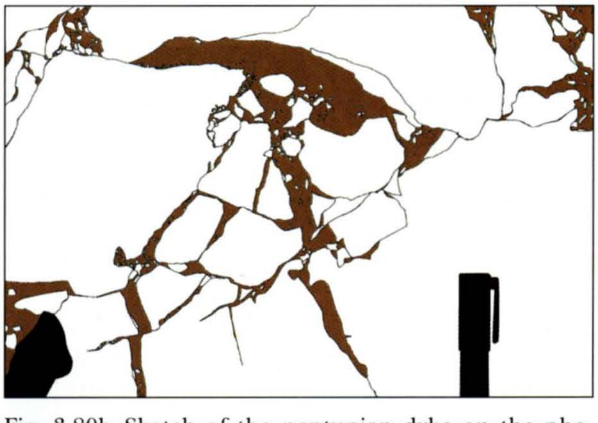


Fig. 3.80b Sketch of the neptunian dyke on the photograph 3.80a White color represents Lower Jurassic platform limestone.

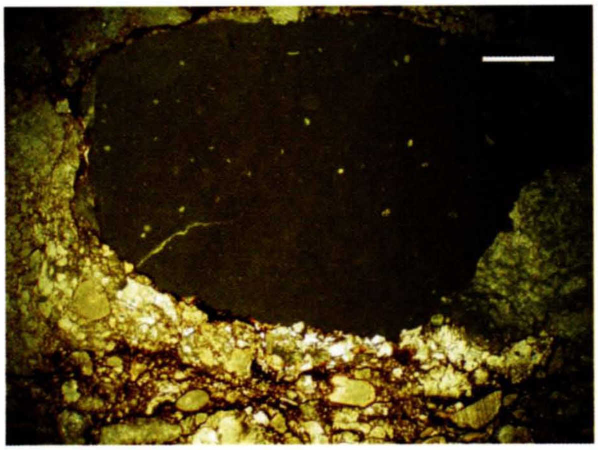


Fig. 3.81 Neptunian dykes: clast of mudstone embedded in matrix with sparite grains and echinoderm fragments. (2. generation of the neptunian dyke infill of Mali Vrh structural subunit). Scale bar is 1 mm long.

second type of neptunian dyke is characterized by subvertical and bedding-parallel fractures with smooth and straight walls. The fractures are up to 40 cm wide, with a penetration depth of a few meters. These fractures are filled by the previously mentioned breccia, and differ only in having a smaller grain size. The age of the second generation of neptunian dykes is poorly constrained due to lack of age-diagnostic fossils. On the basis of the cross-cutting relationship with the first generation of neptunian dykes, the second generation postdates the Pliensbachian. The formation of chaotic breccia bodies and fractures with straight walls is ascribed to the extensional tectonic pulse that caused brittle deformation of host rock, producing wide cracks that were quickly filled as evidenced by the lack of cement on the walls (Črne 2004).

The neptunian dykes of the Drn structural subunit (location Fig. 2.7, stratigraphic position Fig. 3.5a,b) are larger blocky breccia bodies within the lower Lower Jurassic platform limestones. The breccia bodies are laterally confined to a few tens of meters, showing sharp contact with the host rock. The breccia is clasts-supported and consists of cobbles and, more commonly, up to meter-sized boulders of host rock embedded in a red matrix. Boulders of the lower Lower Jurassic limestones also contain older generations of the neptunian dykes, described above. The matrix is red microsparitic limestone with aptychi, fragments of echinoderms and fragments of pelagic crinoid *Saccocoma* sp. Based on *Saccocoma* sp. the most probable age of the matrix is late Kimmeridgian to early Tithonian (e.g. Sartorio & Venturini 1988).

3.3.2 NEPTUNIAN DYKES AT RAVNI LAZ SECTION

At Ravni Laz (section R1, Fig. 3.2), neptunian dykes occur throughout the Prehodavci Formation, but were not recorded in the Lower Jurassic platform limestones. Here, neptunian dykes are subparallel to the bedding and are up to 10 cm thick oval cavities filled with younger sediments. In the lower part of the Lower Member of the Prehodavci Formation, the neptunian dykes are filled with Kimmeridgian to lower Berriasian limestones. The base of neptunian dykes is characterized by laminated and graded packstone to mudstone. Fragments of *Saccocoma* are by far the prevailing grains. The upper part of the dykes is filled with the microsparitic-graded limestones composed of echinoderm fragments, calpionellids (*Calpionella alpina* (Lorenz)), and intraclasts of packstones with *Saccocoma*.

The following neptunian dyke fill consists of lower Berriasian fine-grained breccias. This breccia fills cavities of up to a few tens of centimeters . The breccia is clast supported and composed of lithoclasts of wackestones to mudstones with echinoderm fragments, benthic foraminifers (*Lenticulina* sp., Textularidae) and *Calpionella elliptica* (Cadisch) (Fig. 3.82). Other grains are individual echinoderm fragments and Fe-Mn encrusted bioclasts.

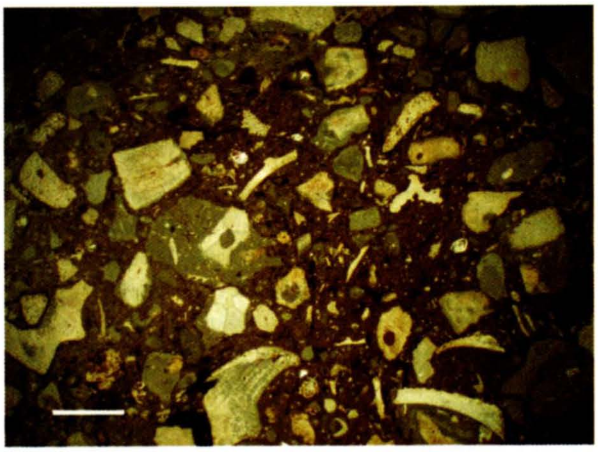


Fig. 3.82 Neptunian dykes: breccia with echinoderm fragments and lithoclasts of wackestone with echinoderm fragments (neptunian dyke infill at Ravni Laz, section R1). Scale bar is 1 mm long.

The youngest neptunian dyke infillings are late Cretaceous in age and occur in the Prehodavci Formation. The neptunian dykes are up to 10 cm wide bed- parallel cavities. In the lower part of the dyke, the fill is wackestones with planktic globular

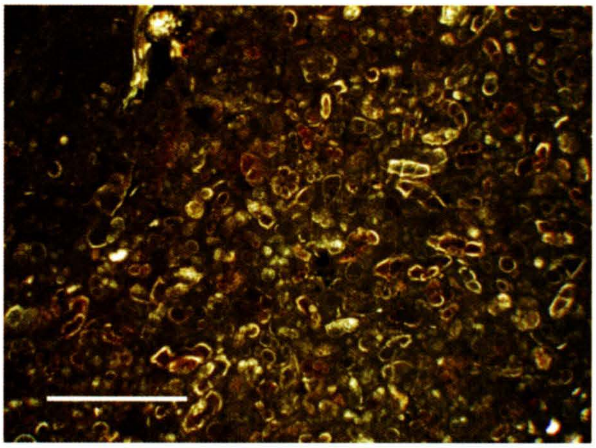


Fig. 3.83 Neptunian dykes: packstone with globotruncanids and rare echinoderm fragments (uppermost neptunian dyke infill at Ravni Laz, section R1). Scale bar is 1 mm long.

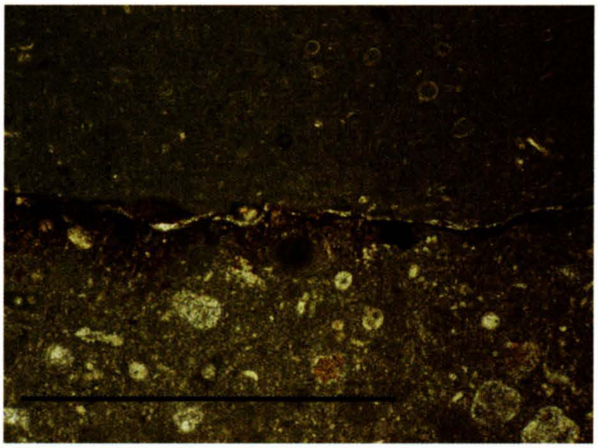


Fig. 3.84 Neptunian dyke: in the lower part of the photo wackestone with echinoderm fragments and protoglobigerinids. Upper part of the photograph is younger mudstone with *Calpionella alpina* (neptunian dyke infill at Lužnica Lake, section L1). Scale bar is 1 mm long.

foraminifers, globotruncanids and rare echinoderm fragments (Fig. 3.83). In the upper part of the fills, the limestones become laminated. The laminations are an alternation of up to 5 mm thick packstone laminae and thinner mudstone. Packstones are composed exclusively of fragments of globotruncanids.

3.3.3 NEPTUNIAN DYKES AT LUŽNICA LAKE SECTION

At Lužnica Lake (section L1, Fig. 3.2) the neptunian dykes occur in Lower Jurassic platform limestones and in the Prehodavci Formation.

In the Lower Jurassic platform limestone, the neptunian dykes are elongated, subvertical or bed-parallel cavities filled with younger limestone. The fill is generally wackestone with small sparite grains overlain by wackestone with planktic foraminifers (protoglobigerinids), belemnites, echinoderm fragments, filaments, and rarely benthic foraminifers (Fig. 3.84). The matrix is micrite to microsparite. On the basis of the presence of planktic foraminifers (protoglobigerinids) this neptunian dyke fill is Bajocian or younger. In places, the remaining pore space is filled by upper Tithonian mudstones with *Calpionella alpina* (Lorenz).

The neptunian dykes in the Prehodavci Formation occur in the bioclastic facies of both the Lower Member and in the Upper Member. In both cases the neptunian dykes are represented by subvertical and bed-parallel cavities up to few dm in diameter. In the bioclastic facies, the neptunian dykes are filled with packstone composed mainly of filaments and encrusted intraclasts of bioclastic limestone. Other grains include echinoderm fragments and gastropod protoconchs. In the Upper Member of the Prehodavci Formation the fill is characterized by an upper Kimmeridgian to lower Tithonian packstone composed of *Saccocoma* sp. fragments and intraclasts of host rock. In the uppermost part of the Upper member the subvertical neptunian dykes are filled with mudstone with calpionellids (*Calpionella alpina* (Lorenz)).

3.3.4 NEPTUNIAN DYKES IN TRIGLAV LAKES VALLEY

Neptunian dykes in the Triglav Lakes Valley are developed only in the uppermost part of the Prehodavci Formation (section TV1, Fig. 3.1) as bed-crossing, up to 50 cm deep and 10 cm wide fractures with a preferential SE-NW orientation (Fig. 3.85) that are filled with two different generations of breccia. At places neptunian dykes exhibit jigsaw structure. The walls of the fractures are usually encrusted with Fe-Mn oxides. The first generation of breccia consists of fragments of ammonite moulds and cm-sized lithoclasts of red wackestones to packstones with disarticulated valves of thin-shelled bivalves, calcified radiolarians of the red nodular facies. The matrix of breccia is packstone with filaments, rare echinoderm fragments, belemnites and foraminifers (*Lenticulina* sp.) (Fig. 3.86). The second generation of breccia

Fig. 3.85 Neptunian dyke with jigsaw structure (Triglav Lakes Valley, section TV1). Host rock is limestone of the Prehodavci Formation. Photo Rafael Marn.

is composed of euhedral grains of detritic quartz, lithoclasts of red nodular limestone, packstone with calcified radiolarian moulds, and wackestones with aptychi. The matrix of the breccia is wackestone with echinoderm fragments, opaque minerals and Fe-Mn incrusted bioclasts.

The straight and smooth walls of the neptunian dykes suggest brittle fracturing of a well-lithified host rock. The opening of these fractures was due to the extensional tectonic movements, after the deposition of Kimmeridgian Upper Member of the Prehodavci Formation.

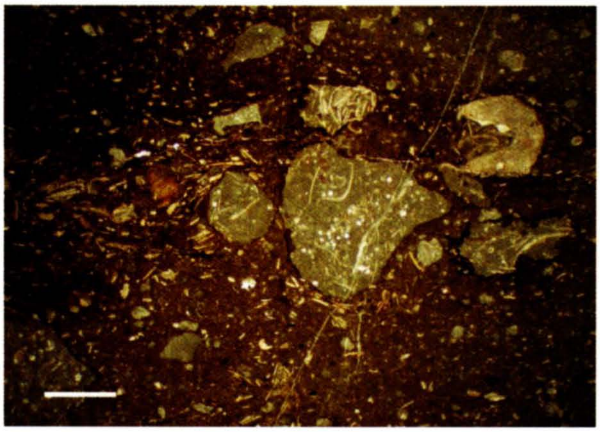


Fig. 3.86 Neptunian dyke: breccia with lithoclasts of wackestone with filaments embedded in a wackestone/packstone with filaments, and rare echinoderm fragments (neptunian dyke infill at Triglav Lake Valley, section TV1). Scale bar is 1 mm long.

Summary.- Neptunian dykes in the investigated area are interpreted to be the product of tectonic extension that produced open cracks that were later filled with younger sediment. According to the age of the host rock and neptunian dyke infillings, four main phases of neptunian dyke formation in the area of the Julian Nappe are recognized:

1) Pliensbachian tectonic phase:

Neptunian dykes in the Pliensbachian platform limestones of the Mangart structural unit. These neptunian dyke infillings range from the Pliensbachian to the Kimmeridgian-early Tithonian.

2) Bajocian tectonic phase:

Neptunian dykes in the Pliensbachian platform limestones with Bajocian tö late Tithonian infillings.

3) Kimmeridgian tectonic phase

Neptunian dykes in the Prehodavci Formation that are filled with the upper Kimmeridgian to Berriasian deposits

4) Late Cretaceous tectonic phase (pre-Senonian):

Neptunian dykes in the Prehodavci Formation that are filled with Upper Cretaceous limestones with globotruncanids.

4

JURASSIC AND CRETACEOUS SEDIMENTARY AND PALEOGEOGRAPHIC EVOLUTION OF THE JULIAN ALPS

The Julian Alps experienced an extension related to the formation of the south Tethyan continental margin that started in the latest Triassic and continued into the Jurassic (see Bertotti et al. 1993). The Jurassic successions in the Julian Alps allow us to decipher the disintegration of the Julian Carbonate Platform, formation of the deeper Bovec Trough and Julian High, to reconstruct the depositional history of the trough and the plateau, and to discuss the main mechanisms controlling the sedimentation on the Jurassic south Tethyan margin.

Correlation of the two most representative sections of the Bovec Trough (MA1) and Julian High (TV1) with Tethyan transgressive/regressive cycles is presented in Fig. 4.1. Correlation among all investigated sections is shown in Fig. 4.2. The time span of formations and stratigraphic gaps is graphically presented in Fig. 4.3.

4.1 HETTANGIAN TO EARLY PLIENSBACHIAN: SHALLOW-WATER SEDIMENTATION ON THE JULIAN CARBONATE PLATFORM

Lower Jurassic platform limestones of the Julian Carbonate Platform represent a continuation of shallow-water sedimentation from the Late Triassic. Facies associations of the investigated Lower Jurassic sections is representative of a shallow carbonate platform with a variety of hydrodynamic conditions. The peloidal, ooidal grainstones to packstones of the Travnik structural unit (section MA1, see Fig. 3.3) represent the high-energy subtidal sand belt environment in a marginal sector of the carbonate platform. The majority of grains originated from a subtidal lagoonal environment in the internal part of the platform and was later transported to the platform margin. The Triglav Lakes Valley (sections TV1, TV4, Fig. 3.1), Ravni Laz (section R1, Fig. 3.2), and Lužnica Lake (section L1, Fig. 3.2) sections represent more protected inner-platform areas. In these sections, tidal flat deposits are represented by laminated limestone exhibiting birds-eyes, laminoid fenestrae, shelter cavities, and geopetal infillings. They are present only in the lower part of the sections. Upwards, the sections consist of alternating lagoonal micritic limestones and higher-energy peloidal limestones with a variety of grains. In the Ravni Laz section (R1, Fig. 3.2) lumachelle of bivalves is present. This facies association most probably represents an inner-outer platform transitional zone (cf. Rey 1997, Ruiz-Ortiz et al. 2004). The vertical alternation of the quiet-water lagoonal limestones and high-energy peloidal limestones, thus suggest changes from an inner to outer platform environment. This alternation was most probably caused by high frequency sea-level oscillations. An additional hypothesis is that the juxtaposition of the higher and lower-energy facies may have been trough tidal channels (cf. Ruiz-Ortiz et al. 2004).

In the marginal parts of the platform (Mangart structural unit of the Mangart saddle) small patch reefs thrived as well.

4.2 PLIENSBACHIAN: DEMISE OF THE JULIAN CARBONATE PLATFORM AND FORMATION OF THE BOVEC TROUGH AND THE JULIAN HIGH

Shallow-water sedimentation of the Julian Carbonate Platform halted in the Pliensbachian. In all investigated sections the platform limestones of the Julian Carbonate Platform are conformably or unconformably overlain by deeper-water deposits, thus marking platform drowning (Figs. 4.1, 4.2, 4.3).

In the Travnik structural unit (section MA1) the drowning succession is gradual and the transitional facies is present below the drowning unconformity. The transitional succession consists of shallow-water grainstones with intercalations of finer-grained peloidal wackestones/packstones. These finer-grained limestones formed in a hydrodynamically quieter environment and contain open marine elements (*Lenticulina*) thus indicating a deepening of

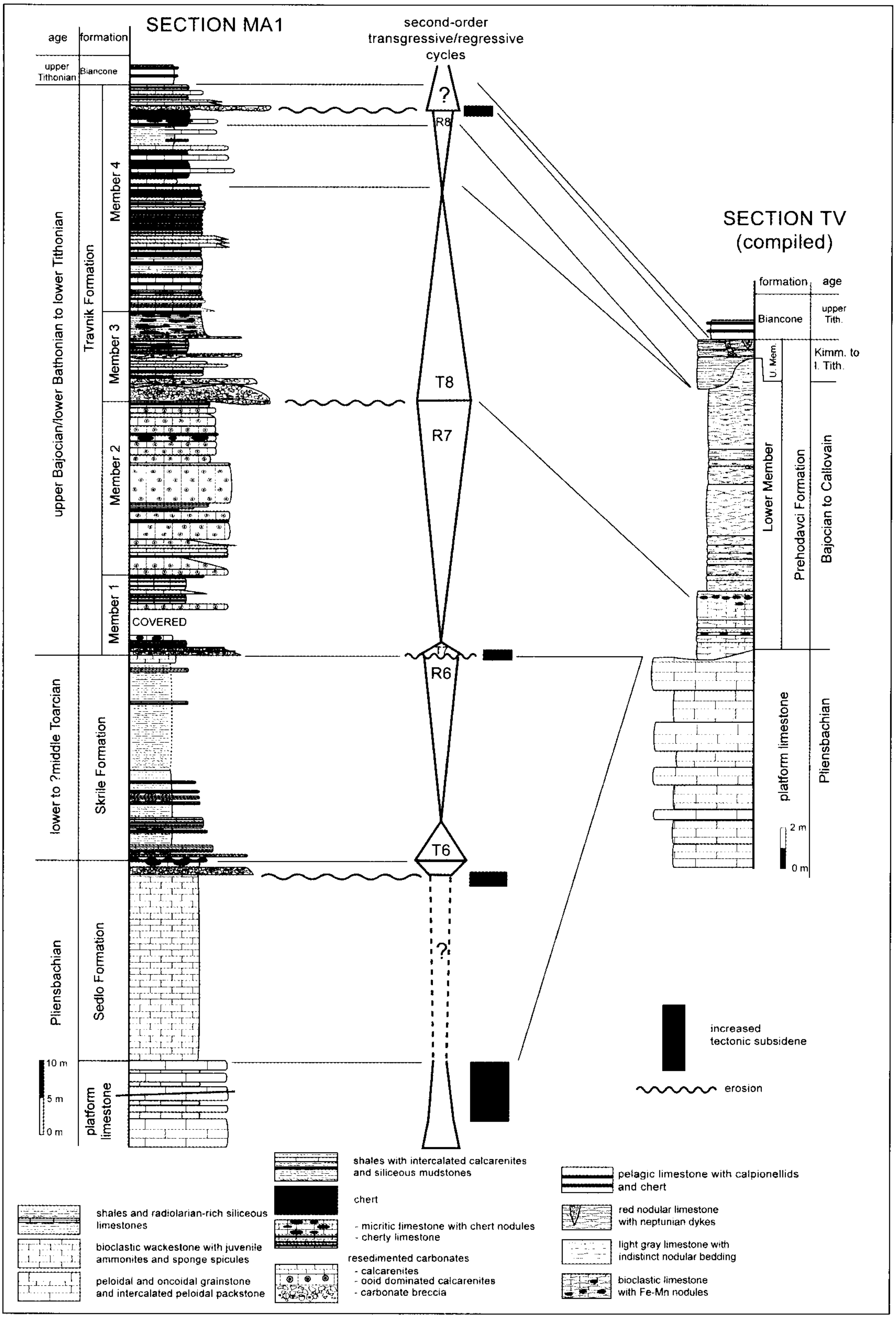


Fig. 4.1 Correlation of the most representative sections of the Bovec Trough (MA1 section) and the Julian High (TV1 to TV5 sections compiled) with second-order transgressive/regressive cycles of Graciansky et al (1998) and Jacquin et al. (1998). Note that the sections have different scales.

the environment. However, at this stage carbonate production on the platform still managed to keep pace with increased subsidence. The intercalated peloidal wackestone/packstones are thus interpreted as markers of incipient drowning. Continuously increasing subsidence rates probably coupled with carbonate productivity decrease due to eutrophication (cf. Dromart et al. 1996, Mallarino et al. 2002) in the Pliensbachian caused the complete drowning of the platform, allowing distal shelf limestones with sponge spicules and juvenile ammonites of the Sedlo Formation to accumulate.

In the Mangart structural unit (MA6, MA7 sections, Figs. 3.5a,b, 3.6), numerous neptunian dykes with the oldest infilling dated as Pliensbachian penetrate the Lower Jurassic platform limestones. Facies of the Pliensbachian infillings are equivalent to that of the Sedlo Formation.

In the Triglav Lakes Valley (TV1, 4), Ravni Laz (R1), Lužnica Lake (L1) sections (Figs. 3.1, 3.2) the Lower Jurassic platform limestones are unconformably overlain by the Bajocian to lower Tithonian condensed limestones of the Prehodavci Formation, demonstrating a stratigraphic gap comprising at least the Toarcian and Aalenian. The drowning unconformity is expressed by up to 3 m deep and 10 m wide oval cavities cut into the lower Jurassic platform limestones that are filled with limestones of the Prehodavci Formation. The morphology of this surface suggests formation mainly by chemical erosion most probably due to a subaerial exposure.

The causes for platform drowning may include rapid sea-level rise from tectonic or glacio-eustacy, and environmental changes that reduced benthic carbonate production (Schlager 1981,1989, 1992, Dromart et al. 1996, Ruiz-Ortiz & Castro 1998, Mallarino et al. 2002, Morettini et al. 2002). In the Julian Alps, however, the tectonically induced subsidence as a main factor controlling the platform drowning is directly evidenced by the presence of Pliensbachian neptunian dykes in the uppermost part of the Lower Jurassic shallow water limestones. Additionally, the differential tectonic movement of isolated blocks is clearly recorded by different manifestations of the drowning unconformity over very short distances: a probable uplift into subaerial environment (Triglav Lakes Valley, Ravni Laz, Lužnica Lake areas), formation of neptunian dykes (Mangart structural unit), and synchronous deepening-upward facies trend in the drowning succession of the Travnik structural unit.

Our data thus indicate that shallow-water sedimentation on the Julian Carbonate Platform ended in the Pliensbachian due to an extensional tectonic phase. At that time the platform was dissected by north-south and east-west trending faults (Buser 1986, 1996) into blocks with different subsidence rates. Two different paleogeographical domains were formed: a deeper-water Bovec Trough (Travnik structural unit) with sedimentation of distal shelf limestones of the Sedlo Formation, and a pelagic platform (sensu Santantonio 1994) named the Julian High. The Mangart structural unit represents the tectonically most active margin of the Julian High. From the Pliensbachian, this area was subjected to repeated tectonic fracturing, deposition and erosion, so that sediments are preserved only within numerous polyphase neptunian dykes. The Triglav Lakes Valley, Ravni Laz, and Lužnica Lake sections represent the interior portions of the Julian High that at that time may have emerged, enabling the formation of a karstic discontinuity surface. An alternative hypothesis is that the inner areas of the Julian High were also drowned, and the discontinuity surface formed by sea-floor dissolution (cf. Di Stefano & Mindszenty 2000). The timing of the formation of this discontinuity surface is difficult to determine because the overlying pelagic sediments are as young as Bajocian.

The Early Jurassic extensional tectonic phase that lasted from the middle Hettangian to the late Pliensbachian is recognized across entire passive south Tethyan continental margin (Winterer & Bosellini 1981, Bertotti et al. 1993, Sarti et al. 1992, Di Stefano & Mindszenty 2000, Di Stefano et al. 2002, Baumgartner et al. 2001, Clari & Masetti 2002).

4.3 LATE PLIENSBACHIAN TO TOARCIAN: SEDIMENTATION IN THE BOVEC TROUGH

In the Pliensbachian, the Bovec Trough is marked by sedimentation of deeper-water distal shelf limestones of the Sedlo Formation (MA1 section, Fig. 3.3). In the upper part of the Sedlo Formation, rudstone – packstone is present. It contain previously cemented echinoderm fragments and clasts of underlying lithologies. Its formation is related to another synsedimentary extensional pulse in the Pliensbachian that produced an unstable slope, uncovered older rocks and enabled erosion. This facies change from distal shelf limestones to echinoderm rudstone – packstone is similar to the change observed in the transition from the Inici M3 Member to

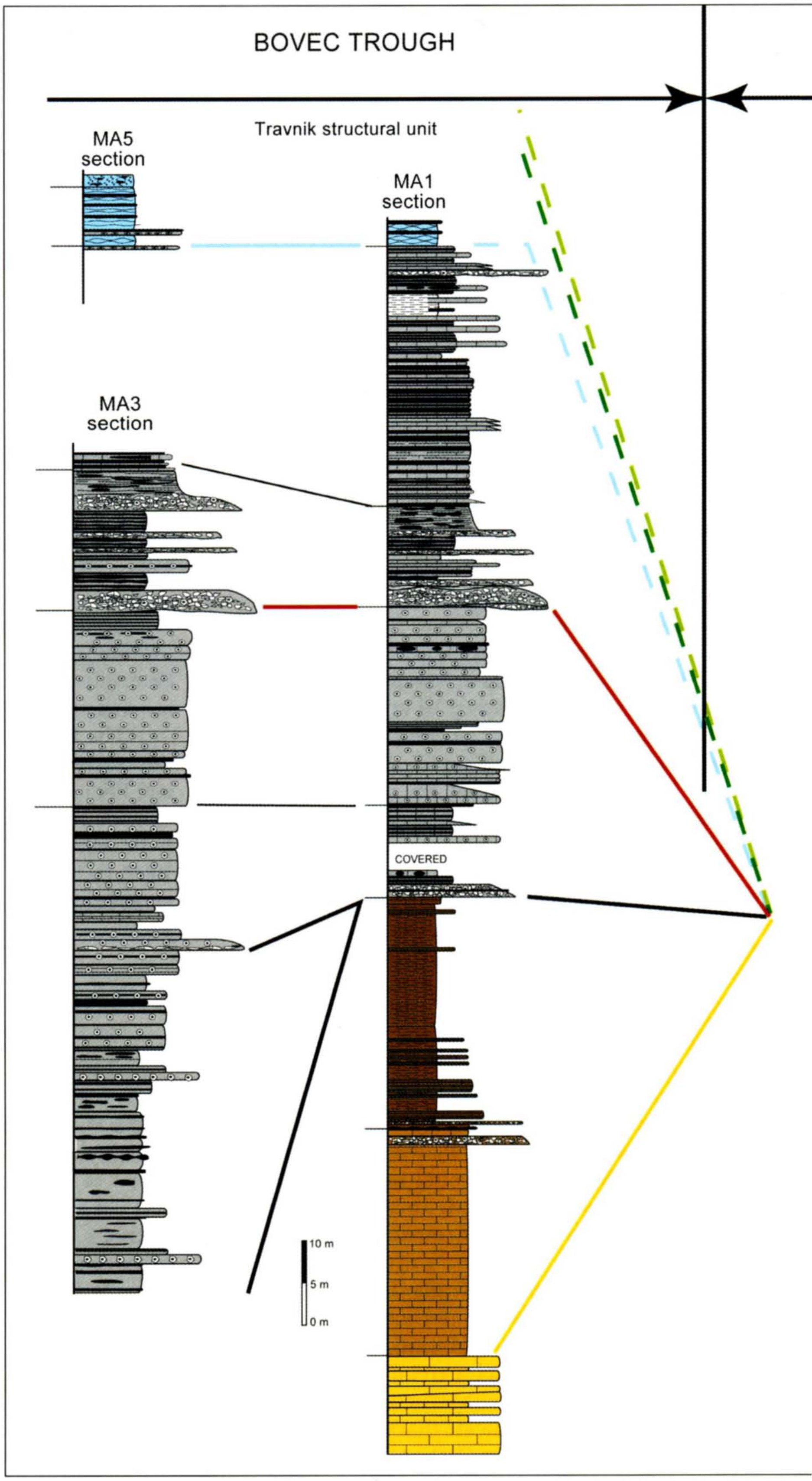
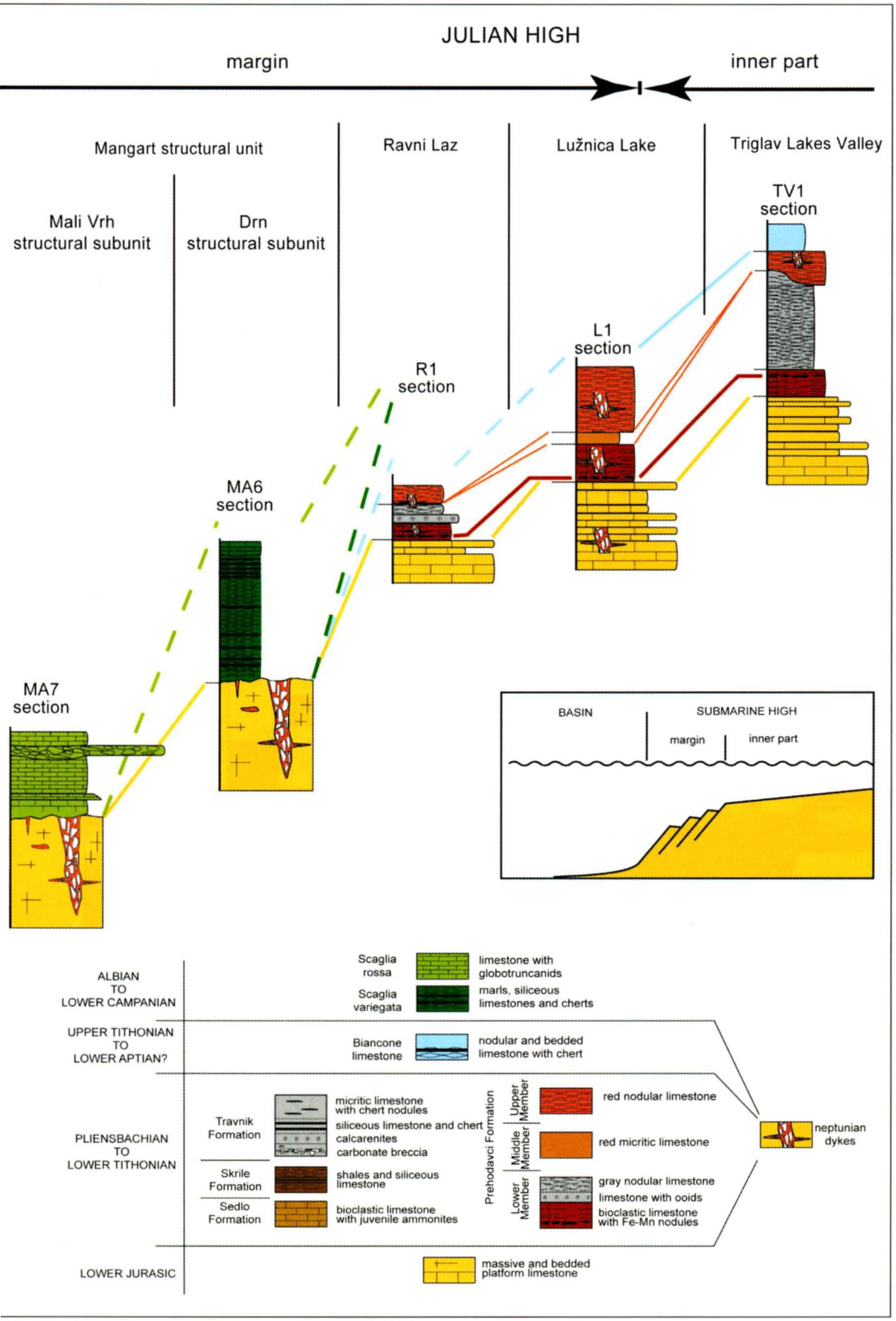


Fig. 4.2 Correlation of the investigated sections in a simplified linear distribution from deeper-basin to inner part of the submarine plateau (for geographic position of the investigated localities see Fig. 1–05).


JULIAN HIGH
margin
inner part
Mangart structural unit
Ravni Laz
Lužnica Lake
Triglav Lakes Valley
Mali Vrh structural subunit
Drn structural subunit
TV1 section
L1 section
R1 section
MA6 section
MA7 section
BASIN
SUBMARINE HIGH
margin
inner part
ALBIAN TO LOWER CAMPANIAN
Scaglia rossa
limestone with globotruncanids
Scaglia variegata
marls, siliceous limestones and cherts
UPPER TITHONIAN TO LOWER APTIAN?
Biancone limestone
nodular and bedded limestone with chert
PLIENSBACHIAN TO LOWER TITHONIAN
Travnik Formation
micritic limestone with chert nodules
siliceous limestone and chert
calcarenites
carbonate breccia
Skrile Formation
shales and siliceous limestone
Sedlo Formation
bioclastic limestone with juvenile ammonites
Prehodavci Formation
Upper Member
red nodular limestone
Middle Member
red micritic limestone
Lower Member
gray nodular limestone
limestone with ooids
bioclastic limestone with Fe-Mn nodules
neptunian dykes
LOWER JURASIC
massive and bedded platform limestone

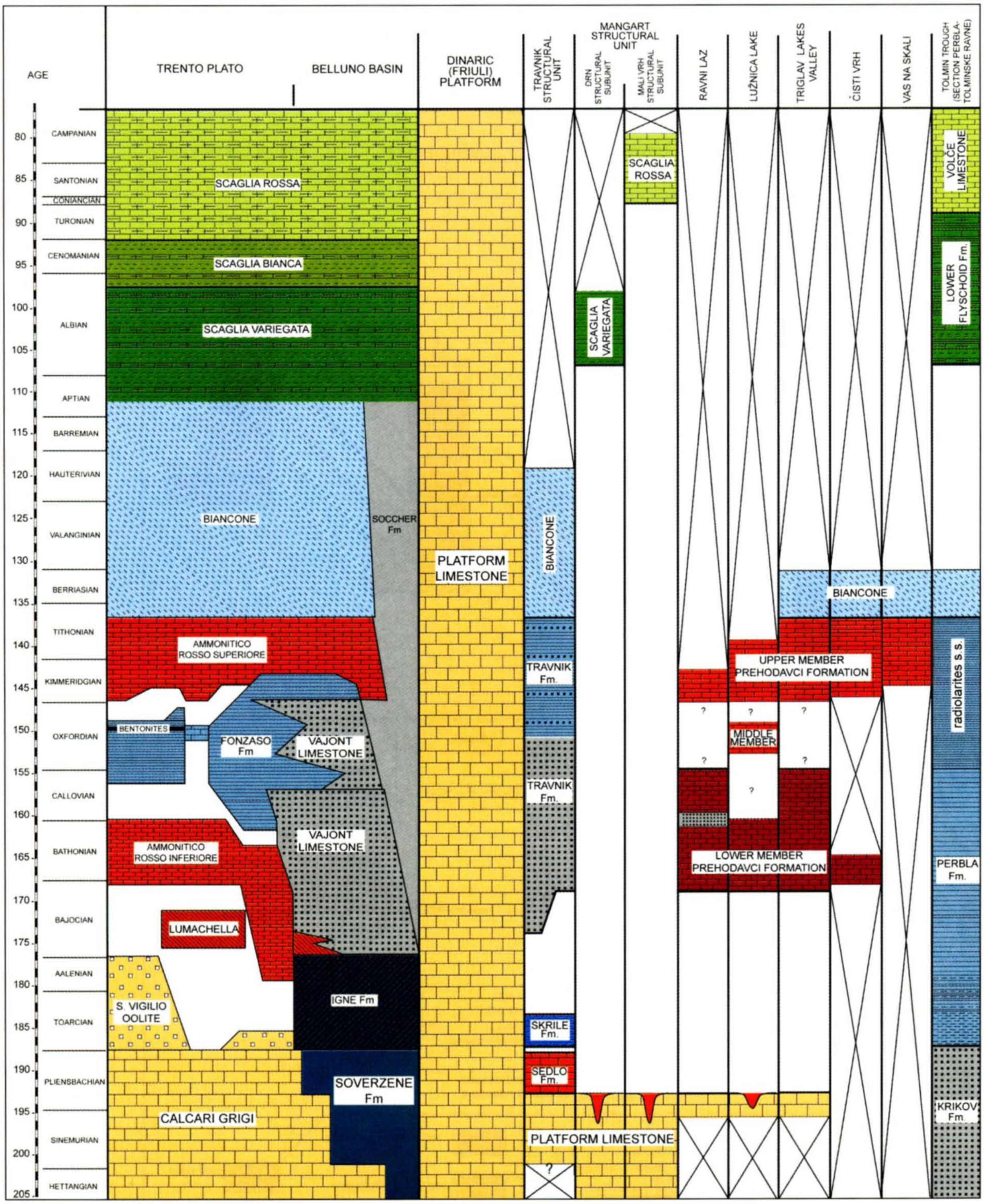


Fig. 4.3 Ages of the Jurassic and Cretaceous formations and correlation of the investigated sections in the Julian Alps with the Trento Plateau and Belluno Basin (Jurassic formations after Baumgartner et al. 1995a, Cretaceous formation after Lehner 1992), and with the Tolmin Trough (section Perbla-Tolminske Ravne) (after Caron & Cousin 1972, Cousin 1973, 1981). Time scale after Odin (1994).

the Calcari a Crinoidi Formation at Monte Kumeta in western Sicily and is similarly interpreted to be a consequence of further down-faulting and relative sea-level rise (see Di Stefano et al. 2002).

The pelagic wackestone/packstone with radiolarians, sponge spicules and Fe-Mn nodules overlying rudstone – packstone indicate extremely reduced sedimentation rates that reached a minimum with the formation of a 25 cm thick Fe-Mn hardground. Slowing of the sedimentation rates and formation of Fe-Mn nodules and crusts in the Bovec Trough is a result of the late Pliensbachian widespread Tethyan regression (R5 in Graciansky et al. 1998) that induced strong bottom currents that swept the sea floor and thus prevented high sediment accumulation (cf. Schlager 1981, Martire 1992, 1996, Tucker 2001).

Sedimentation was restored in the Toarcian when limestones and shales of the Skrile Formation began to accumulate. Sedimentation rates increased most likely because of the weakening of bottom currents due to the early Toarcian transgression (T6 in Graciansky et al. 1998) (Fig. 4.1) and an important increased input of terrigenous clastics. The early Toarcian shales and intercalated radiolarian-bearing limestones are organic-rich sediments deposited during the early Toarcian Oceanic Anoxic Event, also recorded in other parts of the Mediterranean including the Southern Alps (Jenkyns 1985, 1988, Jenkyns & Clayton 1986, Jenkyns et al. 1985, Baudin et al. 1990). The Bovec Trough at that time acted as an anoxic basin, trapping the fine-grained sediments located within the oxygen minimum zone (cf. Jenkyns et al. 1991). Beds of siliceous limestone intercalated within shales, were deposited by fine-grained turbidites. The Skrile Formation records an early to middle Toarcian transgressive-regressive cycle (T6/R6 in Graciansky et al. 1998) (Fig. 4.1). The maximum transgression is represented by the most abundant intercalations of siliceous limestones in the lower part of the formation. At the same level, a peak in abundance of the radiolarian family Pantanelliidae was recorded, which may indicate the maximum development of eutrophic conditions (Goričan et al. 2003).

4.4 BAJOCIAN TO EARLY TITHONIAN: RAPID BAJOCIAN SUBSIDENCE AND SEDIMENTATION IN THE BOVEC TROUGH AND ON THE JULIAN HIGH

In the Bajocian the sedimentation style of the study area was significantly reorganized. The Bovec Trough at this time deepened, and started to receive resedimented carbonates from the adjacent Dinaric (Friuli) Carbonate Platform. Additionally, the inner parts of the Julian High deepened as well, and the sedimentation of the condensed Prehodavci Formation began in the Bajocian. We interpret this reorganization as a consequence of increased subsidence that occurred prior to the middle Bajocian. The accelerated subsidence pulse in the Bajocian is also documented westward in the Belluno Basin and on the Trento Plateau (Winterer & Bosellini 1981, Martire 1992, 1996, Winterer 1998).

In the Bovec Trough, a stratigraphic gap comprising at least the late Toarcian and Aalenian separates the Skrile Formation from the overlying Travnik Formation. Borings in the uppermost limestone beds of the Skrile Formation (section MA1, Fig. 3.3) indicate sediment starvation. Moreover, a subsequent submarine erosion is evidenced by the reworked clasts of the older formation in the basal part of the Travnik Formation. This discontinuity surface is correlative with the Mid-Cimmerian unconformity recorded in most of the European basin margins and structural intrabasinal highs (Jacquin & Graciansky 1998, Jacquin et al., 1998). The diachronuous age of the base and different thicknesses of Member 1 of the Travnik Formation over very short distance indicates the existence of a complex sea-bottom morphology in the Bajocian. Sediment bypassed more elevated areas (MA1 section Fig. 3.3) and was trapped in lower, i.e. quieter areas (sections MA3 and MA4, Fig. 3.4). This sea-bottom morphology in the Bovec Trough was leveled by the Bathonian as evidenced by uniform thickness of Member 2 of the Travnik Formation.

On the Julian High, the condensed limestone (Prehodavci Formation) directly overlies Lower Jurassic platform limestone. These sediments started to accumulate in the Bajocian after a long period of nondeposition. Similar stratigraphic gaps with a maximum range from the Pliensbachian to lower Bathonian are common on submarine highs in the Mediterranean Tethys. They were documented on the Trento Plateau in the Dolomites (Winterer &

Bosellini 1981, Martire 1992, 1996, Baumgartner et al. 1995b, Clari et al. 1995, Clari & Masetti 2002), on the Sabina Plateau in the Apennines (Santantonio 1993, 1994, Santantonio et al. 1996, Santantonio & Muraro 2002), and on the submarine highs in Sicily (Di Stefano & Mindszenty 2000, Di Stefano et al. 2002, Baldanza et al. 2002, Martire & Pavia 2004). These stratigraphic gaps are usually considered to have formed on more elevated areas of structural highs where current activity was strong enough to erode previously deposited sediments or totally hinder sedimentation for a longer time span (e.g. Clari et al. 1995).

The Middle and Upper Jurassic deposits of the Bovec Trough are dominated by siliceous and carbonate background sediments (cherty limestones, cherts and siliceous limestones) and abundant platform derived carbonates that occur as coarse-grained debris-flow deposits, coarse to fine-grained turbidites, and oolitic megabeds.

In the Bajocian the Bovec Trough was characterized by the deposition of periplatform ooze and only a minor amount of fine-grained turbidites (Member 1 of the Travnik Formation). These deposits may correspond to a flooding of the adjacent carbonate platform due to the Bajocian transgression (T7 in Jacquin et al. 1998) and thus elevated off-shore transport of lagoonal mud (cf. Schlager et al. 1994). In the upper part of Member 1 in the MA3 and MA4 sections (Fig. 3.4), a breccia occurs and is correlative with the basal breccias of Member 1 of the Travnik Formation in the MA1 section (Fig. 3.3). The breccias contain many highly evolved glauconitic grains and reworked older lithoclasts. Some glauconitic grains still have preserved fractures on grain surfaces, indicating that they are probably autochthonous and that they developed after the deposition of the breccia. Another possibility is that the grains were formed before the deposition of the breccia and were later transported over relatively short distances (Odin & Fullagar 1988, Amorosi 1995, 1997). The reworked lithoclasts in the breccia document an important submarine erosion event cutting into the substratum down to the Sedlo Formation, which was probably exposed due to normal faulting. At the MA1 section (Fig. 3.3) this breccia level represents the basal part of Member 1, whereas at MA3 and MA4 sections (Fig. 3.4) the breccia is intercalated within periplatform-ooze deposits. The formation of breccias thus cannot be simply a response to a major subsidence pulse in the Bajocian. The breccia could be related to the oversteepening and back-stepping of the basin margin as a consequence of transgression (cf. Emery & Myers 1996) or could mark another extensional tectonic pulse creating slope instability due to normal faulting.

In the Bathonian the thick oolitic beds of Member 2 of the Travnik Formation were deposited. They correspond to maximum ooid production on the adjacent platform. At that time the bioclastic limestone of the Lower Member of the Prehodavci Formation was deposited on the Julian High.

The upper Bathonian deposits of the Bovec Trough are marked by amalgamated successions of resedimented carbonates in the basal part of Member 3 of the Travnik Formation, mostly composed of coarse-grained breccias. Breccias contain lithoclasts of underlying deposits (the Sedlo Formation, and Members 1 and 2 of the Travnik Formation) that indicate exhumation of older strata. On the other hand, the basal breccias of Member 3 represent the most proximal facies association of the Travnik Formation and are correlative with the late Bathonian lowstand (R7/T8 in Jacquin et al. 1998). The breccias thus probably correspond to the late Bathonian lowstand. The late Bathonian lowstand is also recorded in the successions of the Julian High, where in the bioclastic limestones of the Lower Member of the Prehodavci Formation form a distinct horizon with up to 10 cm large Fe-Mn nodules.

At the Ravni Laz section (R1, Fig. 3.2) of the Julian High the beds of oolitic limestone conformably overlie the bioclastic limestone with Fe-Mn nodules. The oolitic limestone occurs within a typical condensed pelagic facies (Prehodavci Formation) and represents allochthonous gravity displaced deposits. A similar situation was reported from the Sabina Plateau in the Apennines where Santantonio and Muraro (2002) described up to 30 cm thick lenses of posidoniid/oolite sediment on the top of the upper Bajocian Bugarone inferiore Formation. The occurrence of ooids on a prominent morpho-structural high is interpreted as a result of overbanking of a turbidity flow that traveled across the adjacent Sabina Basin and impacted a huge obstacle represented by the marginal paleoescarpment of the plateau (Galluzzo & Santantonio 2002, Santantonio & Muraro 2002). We also believe that the occurrence of ooids within typical condensed limestones of the isolated Julian High can be explained in the same way. At the end of the Bathonian the eastern part of the Trento Plateau also started to receive ooids, however this case is different. Namely, by the end of the Bathonian, the Belluno Basin that separated the Trento Plateau from the Dinaric (Friuli) Platform was filled up to be level with the eastern margin of the Trento Plateau (Bosellini et al. 1981, Winterer & Bosellini 1981, Clari & Masseti 2002). Consequently, the Belluno Basin turned into a gentle slope connecting the Friuli Platform to the deeper Trento Plateau (Bosellini et al. 1981).

In the Bovec Trough the general thinning and fining upward trend from the upper Bathonian (Member 3) to Callovian-lower Oxfordian (lower and middle part of Member 4 of the Travnik Formation) corresponds to the second-order transgression T8 of Jacquin et al. (1998) (Fig. 4.1). From the Bathonian upward the resedimented carbonates of the Bovec Trough also show a prominent increase in skeletal and concomitant decrease in ooidal content, finally resulting in beds composed exclusively of echinoderm fragments in the uppermost part of the Travnik Formation, as also observed in the coeval succession of the Belluno Basin (Bosellini et al. 1981).

On the Julian High, above the Fe-Mn nodules we observe a gradual change from high-energy bioclastic facies into the lower-energy light gray nodular limestone of the Lower Member of the Prehodavci Formation. This facies change reflects a weakening of bottom currents during the aforementioned transgression (T8).

In the middle-late Oxfordian, the background sedimentation in the Bovec Trough shows a prominent increase in clay admixture, resulting in the 2.5 m thick clay-rich package in the upper part of the Travnik Formation. We interpret this increased clay content as a consequence of a warm and humid climate in the Late Jurassic that enhanced weathering and therefore increased clay input to the basins (Weissert & Mohr 1996, Thiry 2000, Picard et al. 2002).

In the successions of the Julian High, this level generally corresponds to a stratigraphic gap between the Lower and Upper Member of the Prehodavci Formation (Triglav Lakes Valley sections TV 1,2,3,5 and Ravni Laz: section R1). At Lužnica Lake section (L1) the red micritic marly limestone of the Middle Member of the Prehodavci Formation exists. A similar situation is present in an E-W oriented central belt of the Trento Plateau, where the middle Member of the Rosso Ammonitico Formation (RAM) is completely missing, while moving to the south, the RAM reappears (Martire 1996). On the basis of the geometry of RAM and numerous dykes, slides and seismites concentrated along the top of the Lower Member of the Rosso Ammonitico Formation (RAI) Martire (1996) concluded that after the uniform deposition of RAI the region was affected by an extensional tectonic phase, which generated a typical half graben structure. During the early Callovian to late Oxfordian the elevated areas were bypassed, and sediments were transported into lows and the deeper parts of slopes. It is also likely that the observed irregular sea-bottom topography of the Julian High controlled sedimentation. The Triglav Lakes Valley and Ravni Laz sections represented more elevated areas that were bypassed, while the Lužnica Lake area was a low quiet area where sediment could be deposited. In the Oxfordian this effect may have been enhanced due to the higher input of clay, which prevented early cementation and enabled the winnowing and bypass of sediment in more elevated areas. However, apart from the irregular sea-bottom topography, there is no other evidence (dykes, seismites or slides) for the Callovian extensional tectonic event in the Julian High. So it is possible that this irregular sea-bottom topography was inherited and formed earlier, e.g. during Bajocian subsidence. This assumption is additionally supported by the different thicknesses of the Lower Member of the Prehodavci Formation.

In the Kimmeridgian and early Tithonian, the red nodular limestones of the Upper Member of the Prehodavci Formation were deposited on the Julian High, while at that time the Bovec Trough is marked by sedimentation of cherty limestones, cherts and siliceous mudstones with intercalations of fine to very coarse-grained calcarenites of Member 4 of the Travnik Formation. Of special interest are breccia bed and coarse-grained calcarenites in the uppermost part of the Travnik Formation. They contain large eroded clasts of underlying lithologies and also detritic grains of bytownite-anorthite feldspars and represent the most proximal facies of Member 4 of the Travnik Formation. At this time the Julian High is marked by the development of neptunian dykes that cut the Upper Member of the Prehodavci Formation. At the Drn structural subunit at Mt. Mangart saddle (MA6), Ravni Laz (R1) and Lužnica Lake (L1) sections, the dykes are filled with Kimmeridgian to lower Berriasian limestones, while at Triglav Lakes Valley (TV1) sections the correlative neptunian dykes also contain euhedral grains of detritic quartz. The occurrence of breccia in the Bovec Trough and neptunian dykes on the Julian High coincides approximately with the onset of a compressive regime in the internal domains of the Dinarides (Chanell et al. 1979, Dimitrijevič 1982, Pamić 1982, Karamata 1988, Goričan 1994) and Hellenides (Baumgartner 1985) and with onset of the late Jurassic thrusting in the Northern Calcareous Alps (e.g. Gawlick et al. 1999). In the most external domains of the Dinarides this event resulted in major uplift and emersion of the Dinaric (Friuli) Platform as evidenced by widespread bauxites overlain by Tithonian limestones with *Clypeina jurassica* (Favre) (Dozet 1994, Dozet et al. 1996, Vlahović et al. 2005). Vlahović et al. (2005) interpreted this facies variability of the Dinaric (Adriatic) Carbonate Platform as a consequence of a new tectonic regime, characterized by inverse tectonics, since existing lineaments began to reactivate in order to adjust to compression/transpression. Similarly, we infer that the breccia and calcarenite in the upper part of the Travnik Formation and neptunian dykes in the Upper Member of the Prehodavci Formation are related to the onset of convergent plate movements in the Dinaric Tethys, that caused normal faulting and differential subsidence in pre-existing basins and swells in the external domains.

4.5 LATE TITHONIAN TO EARLY APTIAN: PELAGIC SEDIMENTATION OF THE BIANCONE LIMESTONE

At the early/late Tithonian boundary, the siliceous background sedimentation (cherts and cherty limestones of the Travnik Formation) in the Bovec Trough was replaced by carbonate background sedimentation (Biancone limestone). A corresponding change is observed on the Julian High where the sedimentation of condensed limestones of the Prehodavci Formation is replaced by sedimentation of the pelagic Biancone limestone. The Biancone limestone resulted from normal pelagic sedimentation in a deeper-water environment. The nodular bedding present at places suggests the influence of sea-bottom currents that facilitated early selective cementation. Rare echinoderm grains indicate some limited input from shallower water areas. The Jurassic sea-bottom topography had become predominantly level by the end of the Jurassic as evidenced by the monotonous sedimentation of the Biancone limestone in the Julian High, Bovec Trough and Tolmin Basin (Buser 1986). However, the development of debris flows within the Biancone limestone at Vas na Skali indicate that some minor sea-floor topography still existed.

The facies change from siliceous to calcareous background sedimentation is also observed in the Tolmin Trough (Cousin 1981, Buser 1986, 1987), further south in the Dinarides (e.g. Goričan 1994), and in the Southern Alps (Weissert 1979, Winterer & Bosellini 1981, Baumgartner 1987, Baumgartner et al. 1995b, Bartolini et al. 1999). The only difference is that in the Dinarides this change is abrupt, while in the Southern Alps the change is gradual from the Oxfordian into the Lower Cretaceous.

In the Julian Alps the jungest recorded age in the Biancone limestone is late Valanginian – early Hauterivian (MA5 section, Fig. 3.4) whereas in the Southern Alps (Trento Plateau, Belluno Basin) the deposition of the Biancone limestone may have persisted into the early Aptian (see Fig. 4.3, and chapter 5). In the studied sections, however, the transition to the overlying Scaglia variegata formation is never observed. In the Travnik structural unit, Triglav Lakes Valley, and Vas na Skali area the outcrop conditions do not allow observation of this transition. In the Mangart structural unit the situation is different (MA6, and MA7 sections), here the Biancone limestone is missing and Scaglia variegata or Scaglia rossa unconformably rest directly on the Lower Jurassic platform limestones cut by Jurassic neptunian dykes.

4.6 ALBIAN TO EARLY CAMPANIAN: DEEPER-WATER SEDIMENTATION OF SCAGLIA VARIEGATA AND SCAGLIA ROSSA

The onset of sedimentation of the Albian Scaglia variegata postdates a tectonic phase in the early Cretaceous (Buser 1989, 1996, Jurkovšek 1996) that caused a new tectonic reorganization of the investigated area, as evidenced by basal breccias and discontinuous contact with the underlying deposits. The area of the Julian Alps at that time deepened and became a part of a deeper-water basin with the sedimentation of marls, cherts, siliceous limestones, and limestones with pelagic foraminifers. The Scaglia variegata crops out only at section MA6 (Fig. 3.5a,b) in the Drn structural subunit of the Mt. Mangart saddle. Here the Scaglia variegata unconformably overlies the Lower Jurassic platform limestones penetrated by Kimmeridgian to lower Tithonian neptunian dykes. The contact is marked by basal breccias that contain chert clasts, which indicates erosion of the substratum. The observed stratigraphical relationship is similar to that near Lužnica Lake (Mt. Maselnik in Cousin 1981, Vol. 2, p. 496–497), where Albian variegated marls overlie coarse-grained breccias composed of platform-limestone blocks embedded in a Kimmeridgian-lower Tithonian pelagic matrix, that most probably represent neptunian dyke infill. The deposition of the Biancone limestone was probably regionally uniform (see above), which implies that the Biancone limestone in the Drn structural subunit must have been completely removed by subsequent erosion. Another possibility for explaining the ''anomalous'' stratigraphy of the Drn structural subunit is that the pelagic Cretaceous deposits are draping and escarpment incised in the Lower Jurassic shallow water limestone penetrated by Jurassic neptunian dykes. These discontinuous pelagic sediments thus seal a normal fault of pre-Scaglia age (cf. Martire & Montagnino 2002).

As previously mentioned, exposures of the Scaglia rossa are more common than those of the Scaglia variegata in the Julian Alps. The Scaglia rossa is characterized by deeper-water basinal sedimentation of pelagic limestones with abundant globotruncanids, calcareous turbidites and breccias that contain older deep-water deposits and also shallow-water elements transported from the adjacent Dinaric Carbonate Platform. According to Buser (1987), and Radoičić & Buser (2004) the maximum range of the Scaglia rossa is Cenomanian to Campanian (Buser 1987). Scaglia Rossa usually unconformably overlies older strata. It rests either on the Triassic to Lower Jurassic platform limestones or on Jurassic to early Cretaceous deeper water strata (Cousin 1981, Buser 1986, 1987, 1989, 1996, Jurkovšek 1987). In the study area (section MA7) the Scaglia rossa unconformably overlies Lower Jurassic platform limestones cut by Jurassic neptunian dykes. The contact is erosional. We interpret that the onset of the deposition of Scaglia rossa followed a tectonic pulse in the Late Cretaceous, more precisely before the Senonian. Additional evidence of tectonic activity in the Late Cretaceous lies in the formation of the Upper Cretaceous neptunian dykes at the Ravni Laz section. Due to this tectonic reorganization, the Scaglia variegata, Biancone limestone and condensed Jurassic deposits of the Julian High were locally eroded.

Since the Campanian or the Maastrichtian (Buser 1986, 1996, Jurkovšek 1986), flysch deposits started to fill the existing basin in the Julian Alps area, thus marking onset of a compressional tectonic regime in this part of the Dinarides.

5

CORRELATION WITH NEIGHBORING AREAS

Correlation of the areas is graphically shown in Fig. 4.3, for position of the paleogeographic units see Fig. 1.4 (the Slovenian Basin, of Fig. 1.4 is subdivided into a western (Bovec Trough) and a southern (Tolmin Trough) branch).

5.1 CORRELATION OF THE BOVEC TROUGH WITH THE TOLMIN AND BELLUNO BASINS IN THE JURASSIC

The succession of the Bovec Trough exposed in the Travnik structural unit at Mt. Mangart area is located in the region where the Southern Alps overlap with the Dinarides. The studied succession lies between the Tolmin Trough and the Belluno Basin and represents a possible paleogeographic connection between them. The distinct feature of all three previously mentioned basins are resedimented limestones of Middle and Late Jurassic age that were transported from the Dinaric Carbonate Platform (Friuli Carbonate Platform). We therefore correlate the succession of the Bovec Trough with the successions of the Tolmin and Belluno basins.

5.1.1 CORRELATION WITH THE TOLMIN TROUGH

The lower Jurassic platform limestone and the Pliensbachian Sedlo Formation of the Bovec Trough are time equivalents of the lower and middle Lower Jurassic Krikov Formation (Cousin 1970, 1981, Buser 1986, 1987), which contains deeper-water resedimented limestones with cherts.

The Skrile Formation is correlative with the lower part of the Perbla Formation (Cousin 1973, 1981, Buser 1986, 1987) that consists mostly of shales.

The Travnik Formation corresponds to a middle and upper part of the Perbla Formation (calcareous shales and siliceous limestones) and with radiolarites (black, green and red cherts) (Cousin 1973). Resedimented limestones are locally intercalated in the Perbla Formation and in the radiolarites but are much thinner than those of the Bovec Trough. Coarse to medium-grained resedimented limestones only occur in the most proximal settings of the Tolmin Trough (Rožič 2003a, b) whereas distal parts are characterized only by fine-grained calcareous turbidites.

The upper part of the Bovec Trough succession is marked by the Biancone limestone that is also present in the Tolmin Trough, thus indicating regionally uniform pelagic sedimentation. The thickness of the Biancone limestone in the Tolmin Trough ranges from a few to 30 m (Buser 1986), however the sections are never complete, due to subsequent erosion.

In the Bovec Trough the middle and upper Cretaceous deposits are not preserved, but we suppose that they were similarly developed to those on the Julian High. Correlation of these deposits is discussed in chapter 5.3 below.

The Bovec Trough and the preserved successions of the Tolmin Trough are generally similar, however there are important differences:

- The Tolmin Trough was a deeper basin at the beginning of the Jurassic while the Bovec Trough was still a shallow water carbonate platform.
- The transition from the Krikov Formation to the Perbla Formation in the Tolmin Trough is continuous, while at the Bovec Trough the correlative boundary between the Sedlo and Skrile Formations is discontinuous and marked by a Fe-Mn hardground.
- An important stratigraphic gap is recorded between the Skrile and the Travnik formations in the Bovec Trough, whereas the Tolmin Trough was characterized by continuous sedimentation at that time.
- The preserved successions of the Tolmin Trough contain less oolitic resediments (up to 25 m only) (Cousin 1981, Rožič 2003a, b) that were transported from the Dinaric Carbonate Platform.

These differences suggest that the preserved Jurassic successions of the Tolmin Trough were more isolated from the Dinaric Carbonate Platform, and were formed in a deeper sedimentary environment, compared to the succession of the Bovec Trough.

5.1.2 CORRELATION WITH THE BELLUNO BASIN

In the Bovec Trough the lower Jurassic platform deposits are overlain by Pliensbachian deeper-water limestones of the Sedlo Formation. This mirrors the western part of the Belluno Basin where lower Lower Jurassic Calcari Grigi are overlain by a cherty limestone of the Soverzene Formation (Masetti & Bianchin 1987) but differs from the central part of the Belluno Basin where the Soverzene Formation ranges down to the Hettangian.

The Skrile Formation is correlative to the Toarcian black shales, a member of the Igne Formation of the Belluno Basin (Masetti & Bianchin 1987). The early Toarcian Oceanic Anoxic Event was recorded in both areas. The Igne Formation is, however, much thicker, in general more calcareous, and also contains middle Toarcian and lower-?upper Bajocian deposits: limestones and dolomitic limestones with interbeds of marls and dolostones with chert layers and nodules (Bellanca et al. 1999, Clari & Masetti 2002), while these deposits are completely missing in the Bovec Trough.

Resedimented limestones of Members 1, 2, and 3 of the Travnik Formation are time and facies equivalents of the Vajont Limestone (Bosellini et al. 1981). The age of the Vajont Limestone has been a matter of debate. On the basis of calcareous nannoplankton, Zempolich and Erba (1999) proposed an Aalenian to late Bajocian age, but Clari and Masetti (2002) assigned the Vajont Limestone to the late Bajocian to Bathonian. Our radiolarian data (Šmuc & Goričan 2005) are consistent with the dates of Clari and Masetti (2002).

Member 4 of the Travnik Formation is correlative to the Callovian to lower Kimmeridgian Fonzaso Formation and overlying Ammonitico Rosso Superiore.

The Biancone limestone is present in both the Bovec Trough and the Belluno Basin (e.g. Baumgartner et al. 1995b, Clari & Masetti 2002).

The Bovec Trough succession correlates well with the successions of the Belluno Basin. However, the resedimented limestones of the Vajont Formation are much thicker in the Belluno Basin (800 to 1000 m in most proximal sectors) than coeval Members 1–3 of the Travnik Formation of Mt. Mangart (42 m). This can be explained by paleobathymetry. The Mangart subsided block was located closer to the Dinaric Carbonate Platform and was topographically higher, which is also suggested by its relatively late initial subsidence, conspicuous hiatuses and obvious sediment bypass within the Travnik Formation. On the other hand, in the Tolmin Trough the resedimented limestones with ooids are also very thin (25 m in most proximal areas). Oolite deposition on the platform was strongly controlled by surface currents (Bosellini et al. 1981). A windward position of north-eastern margin of the Dinaric Carbonate Platform facing the Tolmin Trough is thus probable, so that most of the ooids were transported in south-western direction towards the Belluno Basin (Wright & Burchette 1996, p. 368).

Another important observation is that at the succession of the Bovec Trough, a thin layer of coarse-grained breccia composed of reworked basinal rocks and feldspars was found at the top of the Travnik Formation. This layer roughly correlates with the Fonzaso Formation/Ammonitico Rosso boundary. A similar breccia is not known in the Belluno Basin.

5.2 CORRELATION OF THE JULIAN HIGH WITH THE TRENTO PLATEAU IN THE JURASSIC

The successions of the Julian High are typical of the sedimentation on submarine structural highs and are similar to the succession of the westward tilted Trento Plateau in the Southern Alps that belonged to the same passive continental margin (Bosellini et al. 1981, Winterer & Bosellini 1981, Martire 1989, 1992, 1996, Baumgartner et al. 1995b, 2001, Clari & Masetti 2002). The succession of the Julian High is correlative with the succession of the central part of the Trento Plateau.

The lower Jurassic platform limestones of the Julian Carbonate Platform are time and facies equivalents of the lower and middle members of the Calcari Grigi Formation (Clari & Masetti 2002).

On the Julian High the lower Jurassic platform limestones are overlain by Bajocian Prehodavci Formation, marking a long stratigraphic gap. A correlative stratigraphic gap is present also on the Trento Plateau where it occurs between the Calcari Grigi Formation and the Lower Member of the

Rosso Ammonitico Formation (Winterer & Bosellini 1981, Martire 1992, 1996, Baumgartner et al. 1995b, Clari Masetti 2002). In the middle part of the Trento Plateau, the stratigraphic gap comprises the Toarcian to Bajocian, whereas in the other parts of the plateau the gap is shorter. In the western part of the plateau it comprises Bajocian, while at the eastern part the plateau time span of gap is middle Toarcian to Aalenian.

The Lower Member of the Prehodavci Formation is partly time equivalent to the Lower Member of the Ammonitico Rosso Formation (RAI), which consists of pseudonodular, mineralized and bioclastic limestones (cf. Martire 1992, 1996). The bioclastic limestone in the lower part of the Lower Member of the Prehodavci Formation contains abundant Fe-Mn nodules and encrustations and is therefore similar to the mineralized facies of the RAI dated as Middle-Upper Bathonian (Martire 1992). The light gray nodular limestone in the upper part of the Lower Member of the Prehodavci Formation is devoid of the Fe-Mn mineralization and is marked by the dominance of bioclasts. It is the facies equivalent to the bioclastic facies present in the upper part of the RAI. The light gray nodular limestone of the Prehodavci Formation is, however, younger (Callovian) compared to the bioclastic facies of the RAI dated as lowermost Callovian (Martire 1992, 1996).

At the Ravni Laz section the three beds of resedimented oolitic limestones are intercalated between the bioclastic limestone and light gray nodular limestone of the Lower Member of the Prehodavci Formation. Similar beds have not been found on the Trento Plateau.

The red micritic, evenly bedded limestone of the Middle Member of the Prehodavci Formation is present only in one section (Lužnica Lake section L1) where it disconformably overlies a bioclastic limestone with Fe-Mn nodules. Due to the lack of diagnostic fossils, only a broad age assignment between the Callovian to the Kimmeridgian is possible. The red micritic limestone of the Middle Member of the Prehodavci Formation is a facies equivalent to the white to pink mudstones with radiolarian moulds found in the thin-bedded limestone facies of the Middle Member of the Rosso Ammonitico Formation (RAM). RAM was dated as Lower Callovian to Middle-Upper Kimmeridgian (Martire 1992, 1996, Beccaro 2004). The Middle Member of the Prehodavci Formation is represented only by the red micritic limestone, while RAM consists of thin-bedded limestone and abundant chert and cherty limestone (Martire 1992, 1996,). No corresponding cherts and cherty limestones were found in the preserved sections of the Julian High.

The upper Member of the Prehodavci Formation correlates with the Kimmeridgian to Tithonian Upper Member of the Rosso Ammonitico Formation (Martire 1992, 1996, Baumgartner et al. 1995b).

The Biancone Limestone is present in the Julian High and the Trento Plateau.

The successions of the Julian High are in general similar with the successions of the Trento Plateau. The successions of the Triglav Lakes Valley and Ravni Laz are similar to those successions in the middle part of the Trento Plateau, where the Middle Member of the Rosso Ammonitico Formation is missing. On the other hand the Lužnica Lake section represents an anomalous section with its peculiar development of the Middle Member of the Prehodavci Formation that partly corresponds to the sections of the Trento Plateau where the Middle Member of the Rosso Ammonitico Formation is also present. The most important difference between the Julian High and the Trento Plateau is that in the successions of the Triglav Lakes Valley, the neptunian dykes with detritic quartz grains are present in the Kimmeridgian nodular limestones of the Upper Member of Prehodavci Formation. Similar dykes are not known on the Trento Plateau.

5.3 CORRELATION OF CRETACEOUS DEEPER-WATER DEPOSITS WITH THE TOLMIN AND BELLUNO BASINS, AND THE TRENTO PLATEAU

The Albian to upper Cretaceous deeper-water deposits only crop out at the Mangart structural unit (Drn and Mali Vrh structural subunits) of the Mangart saddle. These sediments are correlative with the deeper-water deposits described from the Tolmin and Belluno basins, and the Trento Plateau.

The Scaglia variegata deposits of the Drn structural subunit (MA6 section) are facies and time equivalent of the middle Cretaceous Lower flyschoid formation (Caron & Cousin 1972) of the Tolmin Trough, and to the Scaglia Variegata Formation in the Belluno Basin and Trento Plateau (e.g. Lehner 1992, Luciani & Cobianchi 1999) (Fig. 4.3). In all of these areas a high input of clastics into basins is observed. In the Belluno Basin and in the eastern part of the Trento Plateau, the Scaglia Variegata Formation conformably overlies the underlying

Biancone limestone, while in the western sector of the Trento Plateau a sharp discontinuity surface marked by facies change, hardground and glaucony mineralization occurs between the Biancone limestone and the Scaglia Variegata (Lozar 1995). At the Drn structural subunit and in the Tolmin Trough the contact between the Biancone limestone and Scaglia variegata is also erosional. Thus the Biancone limestone in the mentioned areas is only partly preserved or, in places, is entirely missing (Caron& Cousin 1972, Buser 1986). The Lower fyschoid formation of the Tolmin Trough begins with calcareous breccias overlain by shales and marls with intercalated turbidites. The base of the formation is dated as Albian (or Aptian ?) and is therefore correlative with the basal breccia and calcarenite at the Drn structural subunit at Mt. Mangart. This implies that the early Cretaceous tectonic event that enabled the sedimentation of Albian deposits is regionally traceable within the Julian Alps, and probably occurred within or just prior to the Albian (Goričan & Šmuc 2004). The discontinuity surface between the Biancone limestone and the Scaglia Variegata in the western sector of the Trento Plateau is similarly interpreted as a consequence of an Aptian-Albian tectonic event (Lozar 1995).

The Scaglia rossa deposits of the Mali Vrh subunit (MA7 section) are time equivalent of the red marls and pelagic limestones of the Scaglia Rossa Formation in the Belluno Basin and Trento Plateau (cf. Lehner, 1992, Luciani & Cobianchi 1999), and deeper-water calciturbidites of the Volče limestone of the Tolmin Trough (Buser 1986, 1987, 1989, 1996).

The Volče limestone, however, contains significally more shallow-water grains (Ogorelec et al. 1976). These shallow-water grains originated from the south lying Dinaric Carbonate Platform (Ogorelec et al. 1976, Buser 1996), thus indicating a more proximal position of the Tolmin Trough sections compared to the successions of the Bovec Trough.

The deposition of the Scaglia rossa in the Julian Alps followed a tectonic pulse in the Late Cretaceous. The Late Cretaceous tectonic event is also recorded on the margins of the Dinaric (Friuli) Platform. In the Coniacian-Campanian, the intense destruction of the northern margin of the Dinaric (Friuli) Platform started and the Tolmin Trough began to advance on the former platform (Buser 1989, 1996). Thus the Volče Limestone in places directly overlies shallow-water Upper Triassic and Jurassic limestones (Buser 1986, 1987, 1989, 1996).

6

CONCLUSIONS

In the Jurassic, the Julian Alps belonged to the passive south Tethyan continental margin and contain record of rifting history, platform drowning and subsequent deeper-water deposition. The Jurassic and Cretaceous successions of the Julian Alps correlate with regional tectonics, eustatic sea-level changes and major paleogeographic changes as follows:

1. Lower Jurassic platform deposits of the Julian Alps were deposited on the Julian Carbonate Platform and represent a continuation of shallow-water sedimentation from the Late Triassic. Facies associations of shallow-water deposits are representative of a carbonate platform with diverse hydrodynamic conditions. In the inner parts of the platform, tidal flat and lagoonal limestones were deposited, whereas the margins are marked with a high-energy sandbelt. In marginal parts small patch reefs thrived as well.

2. In the Pliensbachian, shallow-water sedimentation on the Julian Carbonate Platform ended due to an extensional tectonic phase. At that time the platform was dissected into blocks with different subsidence rates and two different paleogeographical domains formed: a deeper-water Bovec Trough (Travnik structural unit of Mt. Mangart saddle) and a pelagic plateau named the Julian High (Mangart structural unit of Mt. Mangart saddle, Triglav Lakes Valley, Ravni Laz, Lužnica Lake, Čisti Vrh, and Vas na Skali). In the Bovec Trough distal shelf deposits of the Sedlo Formation started to accumulate, while the Julian High may have been emergent at that time.

3. The Fe-Mn hardground separating the Sedlo and Skrile formations in the Bovec Trough is interpreted to be the local record of the Pliensbachian/Toarcian lowstand.

4. The black and brown shales, capped by the intensively bored limestones of the Skrile Formation record Toarcian transgressive/regressive cycle.

5. The accelerated subsidence in the Bajocian caused further deepening of the investigated area. The Bovec Trough at that time became a part of a deeper basin with sedimentation of the Travnik Formation which contains siliceous background deposits and resedimented carbonates from the adjacent Dinaric (Friuli) Carbonate Platform (Travnik Formation). Additionally, the Julian High deepened and the sedimentation of the condensed Prehodavci Formation began in the Bathonian.

6. Coarse-grained breccias capped by fine-grained calcarenites at the base of Member 3 of the Travnik Formation represent the most proximal facies association of the Travnik Formation and reflect the late Bathonian lowstand. On the Julian High, the mentioned lowstand is recorded in the Lower Member of the Prehodavci Formation as a distinct horizon with up to 10 cm large Fe-Mn nodules.

7. A middle-late Oxfordian increase in clay admixture in the Bovec Trough is a consequence of a warm and humid climate in the Late Jurassic that enhanced weathering, thus increasing clay input to the basins. This level corresponds to the stratigraphic gap between the Lower and Upper Member of the Prehodavci Formation on the Julian High.

8. The occurrence of Kimmeridgian/? lower Tithonian breccias in the Bovec Trough and coeval neptunian dykes on the Julian High could be related to extensional tectonic movements during the initial stages of compression in more internal Dinaric domains.

9. In the late Tithonian, the Jurassic sea-level morphology had become predominantly leveled as evidenced by monotonous sedimentation of the Biancone limestone in the Bovec Trough, Julian High, in the Tolmin and Belluno basins, and on the Trento Plateau.

10. A tectonic phase in the Albian caused a new tectonic reorganization of the investigated area. The area of the Julian Alps at that time deepened

and became a part of a deeper-water basin with sedimentation of Scaglia variegata.

11. After a tectonic pulse in the Late Cretaceous, the deposition of the Scaglia rossa began.

Comparison with the Tolmin Trough and the Belluno Basin shows that the exposed sections of the Bovec Trough are similar to those in the marginal, western part of the Belluno Basin. In the early Jurassic, the Tolmin Trough and most of the Belluno Basin were already deep-water basins while the Bovec Trough formed after drowning of the Julian Carbonate Platform no earlier than in the early Pliensbachian. The preserved Middle to Upper Jurassic successions of the Belluno and Tolmin basins were deposited in deeper basinal settings located more distally from the Dinaric (Friuli) Platform than the preserved successions of the Bovec Trough. Considering the present day facies distribution (Fig. 1.4), these facts indicate that the Belluno Basin and the Tolmin Trough were not continuous but were wedge-shaped and, at least until the early Early Jurassic, disconnected by a topographic high represented by the area of the future Bovec Basin. The condensed successions of the Julian High show good correlation with the successions of the Trento Plateau. They are found to be most similar to the those parts of the Trento Plateau where the middle member of the Ammonitico Rosso (RAM) did not develop. The successions with development of the equivalent of the RAM are rare in the Julian Alps.

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