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GRAVITY-FLOW DEPOSITS IN THE TOARCIAN PERBLA FORMATION (SLOVENIAN BASIN, NW SLOVENIA)

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Abstract. The Perbla Formation represents typical Toarcian clay-rich pelagic sediments of the southern Tethyan passive continental margin. It was deposited in the Slovenian Basin, located in present-day western Slovenia. During the Early Jurassic the basin was surrounded by the Dinaric (Friuli) Carbonate Platform to the south and by the Julian Carbonate Platform to the north. Today, the transitional areas between the platforms and basin are not preserved due to intense Cainozoic thrusting and erosion, with the only record of the evolution of these areas stored in gravity-flow deposits of the Perbla Formation. Coarser turbidites were deposited on the margins of the basin, with other types of gravity-flow deposits, observed mainly in the central part of the basin. These intercalations reflect regionally recognized events that characterized the sedimentary evolution of western Slovenia at the end of the Early Jurassic. Slumps that occasionally developed into debris-flows reflect uneven sea-bottom palaeotopography that originated during a pre- to early-Toarcian phase of accelerated subsidence. The early Toarcian transgression caused drowning of the adjacent carbonate platforms, an event reflected in the composition of coarser turbidites which consist almost exclusively of echinoderm fragments and thin-shelled bivalves. These turbidites originated from drowned platform margins and/or slopes and were subsequently redeposited in proximal parts of the basin.

Riassunto. La Formazione di Perbla rappresenta una tipica successione di sedimenti pelagici ricchi di argilla, deposta durante il Toarciano sul margine continentale passivo della Tetide. Viene deposta nel Bacino Sloveno, in Slovenia occidentale. Durante il Giurassico inferiore, il bacino era contornato a Sud dalla Piattaforma Carbonatico Dinarico-Friulana, mentre a nord era orlato dalla Piattaforma Carbonatica Giuliana. Le aree transizionali tra piattaforma e bacino non sono oggi conservate a causa dell'intenso raccorciamento avvenuto durante il Cenozoico. La sola documentazione dell'evoluzione di queste aree marginali è conservata dei depositi gravitativi della Formazione di Perbla. Torbiditi più grossolane vennero deposte sui margini del bacino, mentre altri tipi di depositi per flusso gravitativo si osservano soprattutto nella parte centrale del bacino. Queste intercalazioni riflettono eventi regionali che caratterizzano l'evoluzione della Slovena occidentale alla fine del Giurassico Inferiore. I scivolamenti gravitativi che occasionalmente si svilupparono, riflettono la paleo-topografia formatasi prima della base del Toarciano, con subsidenza accelerata. La trasgressione del Toarciano basale causò l'annegamento delle piattaforme carbonatiche adiacenti, evento che si riflette nella composizione delle torbiditi più grossolane, che consistono quasi esclusivamente in frammenti di echinodermi e di bivalvi a guscio sottile e che provengono dai margini delle piattaforme annegate.

Introduction

The successions of the Slovenian Basin are located in the foothills of the Julian Alps (NW Slovenia). During the Jurassic the area was part of the Adriatic - Apulian microplate (Fig. 1) and was largely influenced by the opening of the Piedmont - Ligurian Ocean (Alpine Tethys). The rifted Adriatic – Apulian continental margin consisted of productive carbonate platforms separated by a deeper basins (Winterer & Bosellini 1981; Bertotti et al. 1993; Bernoulli & Jenkyns 2009; Martire 1992, 1996; Sarti et al. 1992; Buser 1996; Winterer 1998). The Slovenian Basin was an approximately W-E oriented, deep-water palaeogeographic domain situated between the Dinaric (Friuli) Carbonate Platform to the south and the Julian Carbonate Platform to the north. During the Early or Middle Jurassic, the Julian Carbonate Platform drowned and became the Julian High pelagic plateau (Buser 1989, 1996; Jurkovšek et al. 1990; Šmuc 2005; Šmuc & Rožič 2010), similar to the Trento Plateau (cf. Bosellini et al. 1981; Winterer & Bosellini 1981; Baumgartner et al. 1995; Martire 1992, 1996; Clari & Masetti 2002; Martire et al. 2006) located to the west in the Southern Alps.

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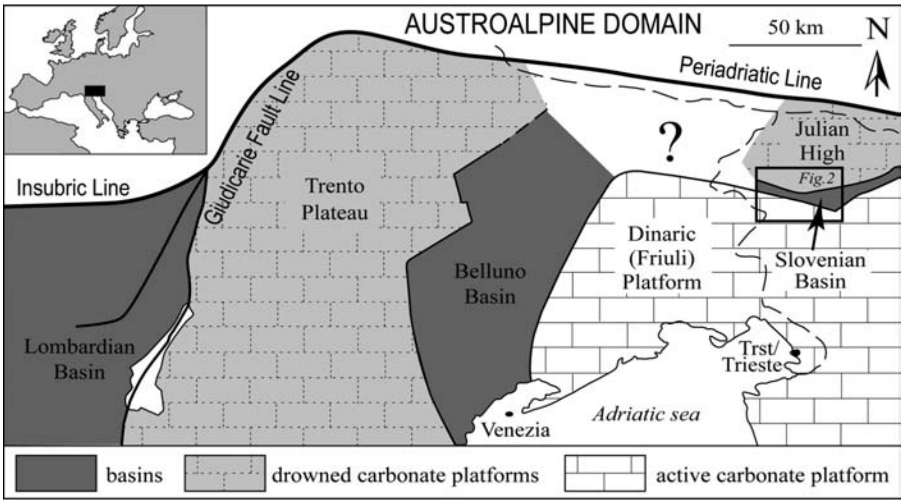


Fig. 1 - Present-day location of Jurassic palaeogeographic units (compiled from Bosellini et al. 1981; Buser 1989; Placer 1999); the facies-belt of the Slovenian Basin is significantly narrowed due to Tertiary thrusting.

In the Toarcian, the entire continental margin was affected by a prominent sea-level rise (Graciansky et al. 1998) which led to the deepening of sedimentary environments on the platforms. Simultaneously, basins were characterized by clay-rich sedimentation documenting the oceanic anoxic event (Jenkyns 1988; Jenkyns et al. 2002). In the Slovenian Basin this transgression is manifested within a Perbla Formation composed mainly of laminated marls and calcareous shales (Cousin 1970, 1981; Rožič 2009). The base of the formation was deposited during the Toarcian Oceanic Anoxic Event (Oven et al. 2007). The Perbla Formation is dominated by pelagic marls, with minor intercalation of carbonate turbidites, debrites and slumps. Although volumetrically of minor importance, these carbonate-gravity deposits provide the only record of sedimentary events in their source areas, i.e. platform margins and/or slopes, since no sedimentary record from these areas remains due to intense Cainozoic thrusting and erosion. In the present paper the occurrence, composition and origin of gravity-flow deposits are described and discussed within the framework of the general sedimentary evolution of the region.

Geological Setting

Structurally, western Slovenia consists of the External Dinarides and Southern Alps, the two being divided by the Southalpine Thrust Front. The External Dinarides in the south are comprised of several nappes with successions of the Dinaric Carbonate Platform, and are characterized by older NE to SW thrusting that ended during the Early Miocene. Typified by younger, i.e. Late Miocene, N to S thrusting, the Southern Alps consist of the Tolmin Nappe, with successions of the Slovenian Basin and the overthrusted Julian Nappe, with successions of the Julian Carbonate Platform and Julian High (Fig. 2). The area investigated in this study

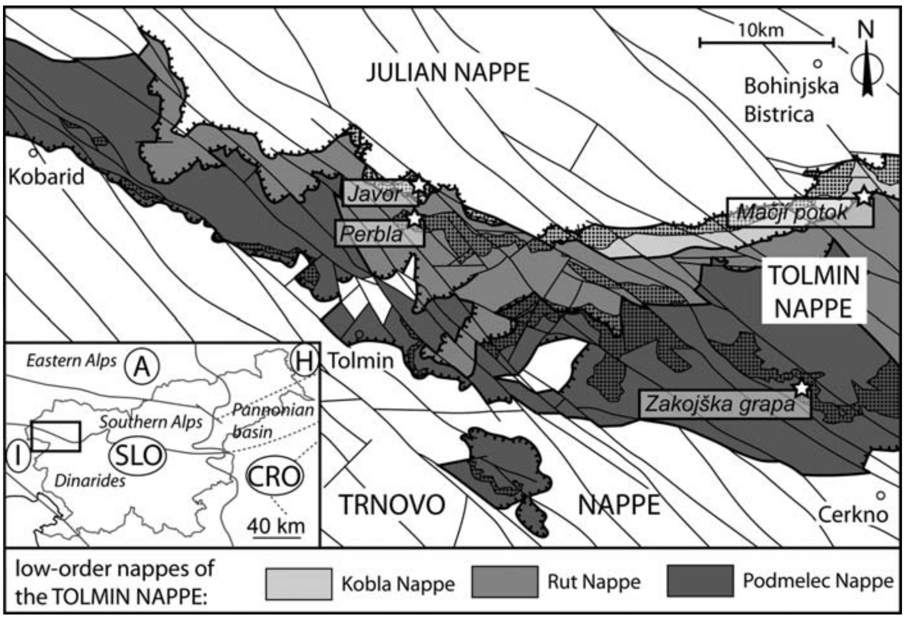


Fig. 2 - Structural division of NW Slovenia (boxed area in Figure 1 and lower left corner) showing locations of studied sections: Shades of grey represent the Tolmin Nappe with successions of the Slovenian Basin (dotted areas are Jurassic outcrops), while in white are the Julian and Trnovo nappes with successions of surrounding carbonate platforms.

is where the External Dinarides and the Southern Alps interfere. The NE to SW thrusting of the Dinaric phase was later overprinted by the N to S-directed Southalpine phase (Placer & Čar 1998; Placer 1999; Vrabec & Fodor 2006). During the Miocene-Pliocene transition major strike-slip deformation initiated, with NW-SE trending dextral faults displacing older fold and thrust structures (Vrabec & Fodor 2006; Kastelic et al. 2008).

The studied sections of the Slovenian Basin are situated within the Tolmin Nappe (Fig. 2), which is further subdivided into three low-order nappes (Buser 1986, 1987). The Zakojška grapa section (46°10'01" N, 13°57'00" E) is located in the lowermost Podmelec Nappe and represents the most proximal section with respect to the Dinaric Carbonate Platform. The Perbla section (46°13'24" N, 13°45'31" E) is associated with the overlying Rut Nappe and palaeogeographically corresponds to the central part of the basin, while the Javor section (46°14'11" N, 13°45'44" E) is located in the uppermost Kobla Nappe and represents the northern part of the Slovenian Basin, i.e., the most proximal to the Julian Carbonate Platform (Julian High). Belonging to a newly discovered small thrust-sheet intercalated between the Kobla and Podmelec Nappes, the Mačji

Fig. 3 - Studied sections of the Toarcian Perbla Formation; for the Zakojška grapa section only the first 25 m of a total 120 m of the formation are shown.

potok section (46°13'36" N, 13°57'34" E) is composed exclusively of the Jurassic succession and is generally similar to the Perbla section.

General Characteristics of the Perbla Formation

The under-lying Hettangian to Pliensbachian Krikov Formation is represented by coarser resediments in the northern part of the basin, but towards the south these deposits are gradually replaced by distal, i.e. fine-grained, carbonate turbidites and hemipelagic limestones. Such facies distribution indicates the Julian Carbonate Platform to the north to be the main source area for the resedimented platform material. In the lower part of the formation, the coarser turbidites are composed mainly of ooids and peloids, whereas upwards echinoderm fragments and mud-chips prevail. Bioclasts are mainly echinoderm fragments, with lesser amount of foraminifers, bivalves, brachiopods, gastropods, sponges, ostracods and bryozoans. Turbidites in the upper part of the formation additionally contain eroded slope intraclasts (bioclastic wackestone) and platform lithoclasts.

The Krikov Formation is overlain with a sharp boundary by the Perbla Formation originally defined by Cousin (1973), and recently revised (Rožič 2009). The Perbla Formation is monotonous throughout the basin, consisting of dark grey, parallel to wavy laminated marls and subordinate calcareous shales (Fig. 3). Thin-bedded or lenticular micritic limestones are intercalated in the lower and upper parts of the formation. The lower part of the formation was deposited during the Toarcian Oceanic Anoxic Event (Oven et al. 2007) and is locally intensively impregnated with manganese (Drovenik et al. 1980; Buser 1986; Rožič 2009). The thickness of the formation varies from 0.6 to more than 100 m (Rožič 2009). Apart from pelagic sediments, gravity-flow deposits occur sporadically in several sections and are described in detail in the following chapter.

The upper boundary of the Perbla Formation, with the Aalenian to lower Tithonian Tolmin Formation, is transitional over a short distance, and is placed below the first occurrence of abundant beds of siliceous limestone or chert that compose the overlying formation.

Numerous samples of the Perbla Formation were analysed by various techniques for nannoplankton and radiolaria, but were all barren. The Toarcian age of the formation has consequently been established on the basis of rare foraminifera, lithostratigraphic correlation and chemostratigraphic data (Oven et al. 2007; Rožič 2009).

Gravity-Flow Deposits

Gravity-flow deposits of the Perbla Formation are mainly represented by carbonate turbidites that occur in all investigated sections (Fig. 3). Coarse-grained turbidites appear at the basin margins, with finer material distributed further to the centre of the basin. Debrites are rare and were observed only in the central part of the basin. Other types of gravity-flow deposit were not recognized within the studied sections, although slumps were observed in the lower part of the formation during geological mapping of adjacent areas in close proximity to the sites.

Turbidites

The Perbla Formation is at its thickest in the south of the basin, reaching 120 m in the Zakojška grapa section (Fig. 3). Coarse-grained turbidites appear only in the lower part of the formation, whereas the uppermost part of the unit is characterized solely by intercalated fine-grained turbidites.

PLATE 1

Fig. 1 - Limestone conglomerate with basinal intraclasts and grainstone matrix composed mainly of smaller intraclasts and echinoderms (lowermost turbiditic bed in the Zakojška grapa section).

Fig. 2 - Coarse-grained grainstone with basinal intraclasts, echinoderms and peloidal grainstone clasts in the centre of photo (lowermost turbiditic bed in the Zakojška grapa section).

Fig. 3 - Coarse-grained grainstone composed of echinoderms that grades into a finer and even-laminated packstone composed of echinoderms and sponge spicules. The matrix in some laminas is recrystallized and dissolution seams are common (lowermost turbiditic bed in the Zakojška grapa section).

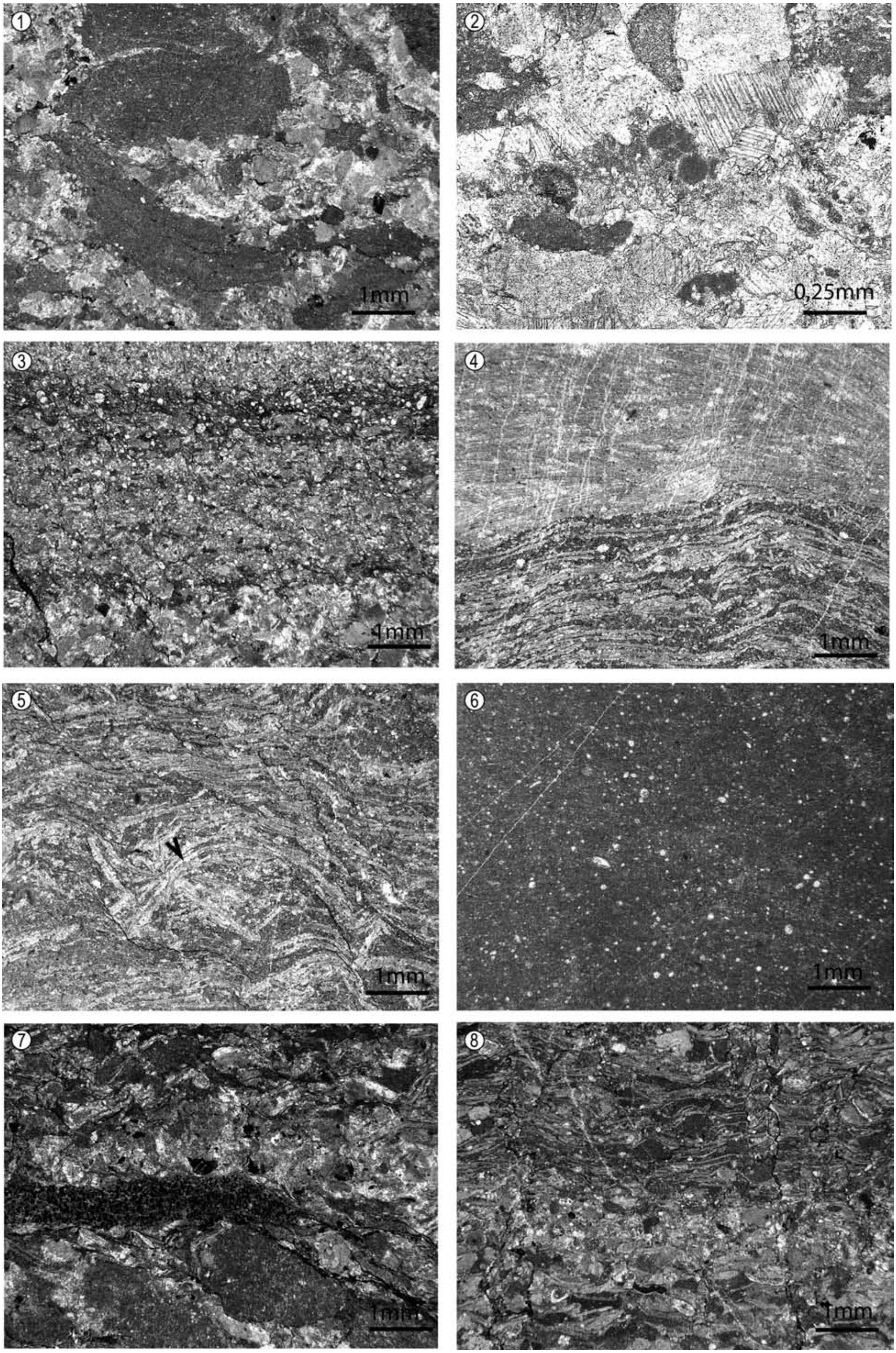
Fig. 4 - Alternating packstone/wackestone laminas composed predominantly of thin-shelled bivalves (lowermost turbiditic bed in the Zakojška grapa section).

Fig. 5 - Wavy-laminated packestone with variable orientation of thin-shelled bivalves. Dissolution seams and silification (arrow) are present (lowermost turbiditic bed in the Zakojška grapa section).

Fig. 6 - Fine-grained wackestone composed of calcified radiolarians and ostracods (lowermost turbiditic bed in the Zakojška grapa section).

Fig. 7 - Limestone conglomerate that grades into grainstone with echinoderms and smaller intraclasts. Intense replacement of basinal intraclasts with framboidal pyrite is observable in the centre of photo (Zakojška grapa section).

Fig. 8 - Alternating laminas of echinoderm-rich packestone and thin-shelled bivalve-dominated packestone/wackestone. Other grains are basinal intraclasts and calcified sponge spicules and /or radiolarians (Zakojška grapa section).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The first bed exhibits an almost complete Bouma sequence and is described in greater detail as a turbiditic bed typical of the formation. It is channelized into substrate and is composed of a conglomerate that grades upwards into coarse-grained grainstone, medium-grained packestone to fine-grained wackestone/packstone. The conglomerate is composed of large basinal intraclasts (mud chips) of up to 3 cm, which are mostly wackestone with calcified radiolarians, sponge spicules and thin-shelled bivalves (Pl. 1, fig. 1). Small clasts of peloidal grainstone are extremely rare (Pl. 1, fig. 2). The grainstone, which also forms the matrix of the conglomerate, is composed of small basinal intraclasts (up to 30% of all grains) and echinoderm debris (Pl. 1, figs. 1-3). More rare bioclasts include lagenid foraminifera, sponge spicules and fragments of brachiopods and bivalves. Two types of bivalve occur: thick-shelled exhibiting a prismatic structure, and thin-shelled. Sporadic phosphate grains are also present. In the packstone, echinoderms become rarer, but thin-shelled bivalves, sponge spicules and calcified radiolarians are more abundant (Pl. 1, fig. 3). The medium-grained packstone to wackestone part of the bed shows even and wavy laminations, and is composed almost exclusively of thin-shelled bivalves (Pl. 1, fig. 4). Occasionally, shells are fragmented and oriented at different angles to the main lamination (Pl. 1, fig. 5). The upper part of the bed consists of wavy and parallel-laminated wackestone or, rarely, packstone (in some laminas), with pellets, calcified radiolarians and rare sponge spicules, lagenid foraminifers, ostracods, thin-shelled bivalves and phosphate grains (Pl. 1, fig. 6). Another coarse-grained bed occurs high in the section, which exhibits a similar composition with intraclasts being more abundant (Pl. 1, figs. 7-8).

In the lower part of the formation a number of other, medium-grained packstone beds are present, occasionally containing a slightly higher abundance of echinoderms and sponge spicules. These beds exhibit base-cut Bouma sequences and were deposited by low-density turbidity flows.

In the lower and upper parts of the formation, dominant clay-rich pelagic sediment is interbedded with thin-bedded or lenticular fine-grained wackestone to packstone, whose composition corresponds to the uppermost, i.e. fine-grained, part of the firstly described bed.

In the northern part of the basin (Javor section) the Perbla Formation is 18 m thick. Here the lower part of the formation is composed of red marls, whereas the upper part is represented by dark green and grey marls and calcareous shales. Carbonate turbidites occur throughout the formation. Coarser beds are present in the lower and middle part of the formation where top-cut Bouma sequences prevail. As with the southern part of the basin (Zakojška grapa section), coarse-grained echinoderm-rich grainstone at the base of the bed grades to a medium-grained packstone in the upper part of the bed, that is composed exclusively of thin-shelled bivalves (Pl. 2, figs. 1-3). These bivalves are generally oriented parallel to the bedding plane and form flat or wavy laminations, but in some laminas they exhibit a fitted fabric around echinoderm grains (Pl. 2, fig. 3). Other grains include rare peloids, lagenid foraminifers, ostracods, as well as intraclasts of basinal mudstones, phosphate and glauconite grains. In the middle part of the formation glauconite and peloids (small basinal intraclasts?) are more abundant (Pl. 2, fig. 4).

In the upper part of the formation, marls alternate with fine-grained laminated wackestones with calcified radiolarians, sponge spicules and thin-shelled bivalves.

The sedimentary structures of the coarse-grained carbonate beds clearly point to sedimentation by turbidite-flow. The composition of these beds documents a resedimentation of the material from platform margin and slopes and erosion of substratum. The composition of fine-grained carbonate beds suggests a hemipelagic origin, although laminations within some of these beds, especially even-bedded and continuous, also hint at a low-density turbidity-flow origin.

Turbiditic beds show several characteristic diagenetic features. Silification is especially intense in the Javor section where the bases of some beds have been completely replaced by nodular chert. In less silicified limestone, partial replacement of individual grains (peloids, thin-shelled bivalves, other fossils) by microcrys-

PLATE 2

Fig. 1 - Grainstone composed almost exclusively of echinoderm fragments (lower part of the Javor section).

Fig 2 - Packestone with echinoderms, small basinal intraclasts and thin-shelled bivalves. Dissolution seams are sub-perpendicular to bedding planes (lower part of the Javor section).

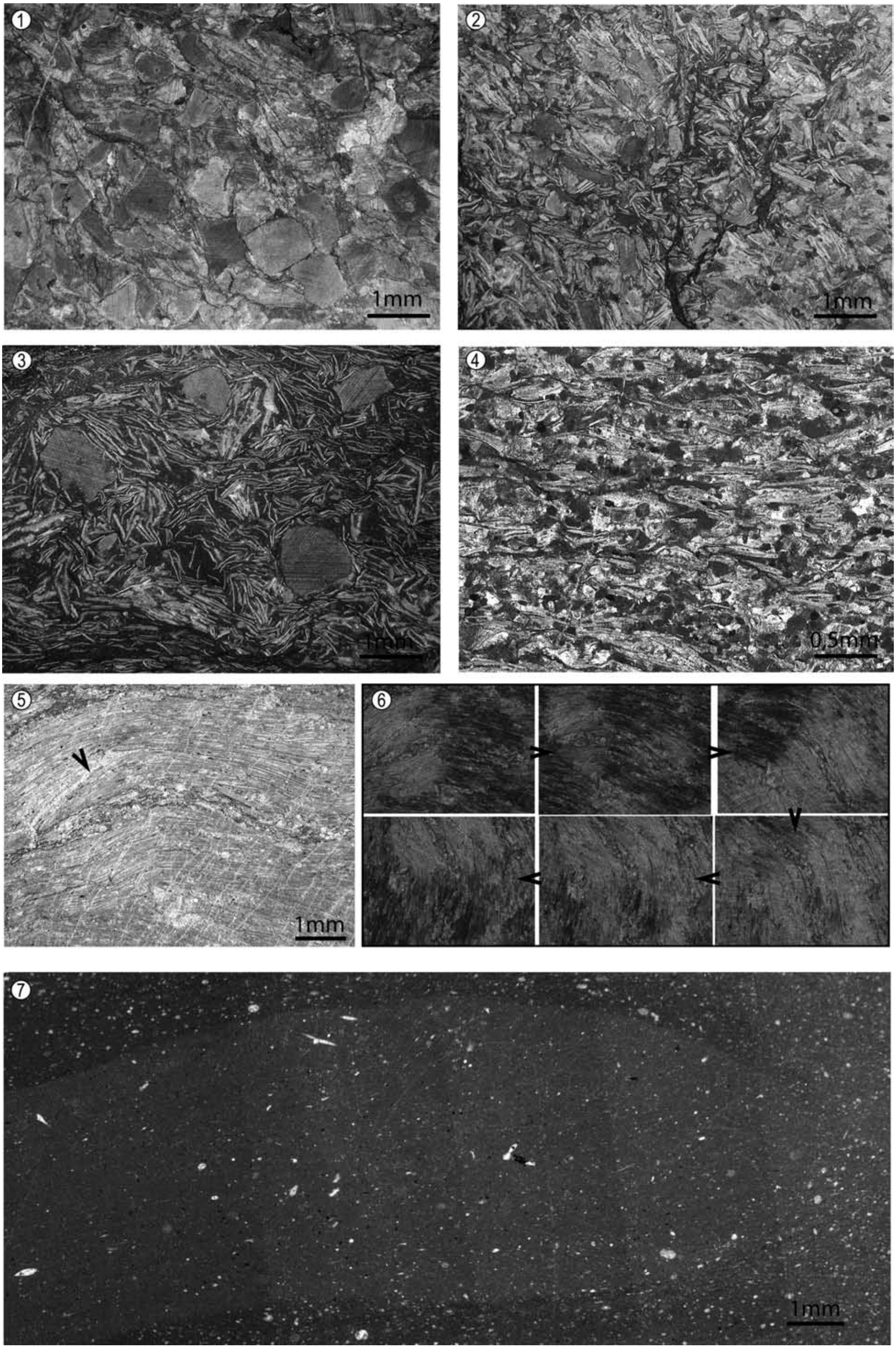
Fig. 3 - Packstone with thin-shelled bivalves showing various orientations; note fitted fabrics around the echinoderms (lower part of the Javor section).

Fig. 4 - Laminated packestone with thin-shelled bivalves, echinoderms and high content of small basinal intraclasts and/or peloids (middle part of the Javor section).

Fig. 5 - Densely packed wavy-laminated packstone composed almost exclusively of thin-shelled bivalves. Strong recrystallization and silification (arrow) is present.

Fig. 6 - Same field as in figure 5 under crossed polars and rotated step-wise in the clockwise direction by a total of 90 degrees (follow arrows).

Fig. 7 - Wackestone clast with calcified sponge spicules and radiolarians in pebbly marl. Grains in marly matrix are similar but more abundant (Perbla section).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talline quartz or chalcedony occurs. Pyrite forms larger subhedral crystals within a micritic matrix and intergranular pores. Framboidal pyrite fills completely or geopetally the foraminiferal moulds. It replaces partly micritic grains (peloids, intraclasts) or completely the radiolarian moulds. Pressure dissolution is strong in some beds and is manifested as dissolution seams that are oriented either sub-parallel or at various angles to the bedding planes. An interesting diagenetic feature is the recrystallization of thin-shelled bivalves that is particularly extensive in the Zakojška grapa section. Where shells are loosely packed, subhedral calcite crystals protrude from shells in the surrounding matrix (Pl. 1, fig. 4-5). In densely packed laminas entire areas several mm in size are recrystallized in single calcite crystals, with an only partly visible primary texture (Pl. 2, fig. 5). This feature is a consequence of two factors: a) the high diagenetic potential of bivalves, b) these beds are isolated by less permeable marls and the migration of diagenetic fluids is limited to the individual beds. Matrix recrystallization to microsparite in the packstone or wackestone parts of beds is also common throughout the formation.

Debrites

Observed in the central part of the basin (Perbla section) where the formation is 24 m thick, debris-flow deposits occur in the lower part of the formation as two beds of pebbly marl of up to 40 cm in thickness. Clasts (up to 10 cm), which are rounded and form approximately 10 % of these beds, are wackestone with calcified radiolarians and/or sponge spicules, ostracods and thin-shelled bivalves (Pl. 2, fig. 7). The matrix corresponds to the surrounding marl.

Debris-flow was also detected in the Mačji potok section, where the Perbla Formation is only 0.6 m thick. At the formation edges it is composed of even-laminated marls, whereas the central part of this thin interval exhibits a massive texture with large (up to 20 cm) limestone clasts. These clasts correspond to those described above, although wackestone clasts with larger (up to 2 mm) and more abundant bioclasts were also detected. In these clasts additional echinoderm fragments occur, as well as the foraminifer *Agerina martana* Farinacci.

Slumps

Slumps were observed in areas adjacent to the Perbla and Zakojška grapa sections. They occur in the lower part of the Perbla Formation as horizons (up to 2 m) of disturbed, folded and partly dismembered marls and fine-grained limestone.

Discussion

The gravity-flow deposits of the Perbla Formation contribute significantly to our understanding of the Toarcian sedimentary evolution of the eastern Southern Alps in two ways:

A) Analysis of debrites and synsedimentary slumps provides evidence of the palaeotopography of the Slovenian Basin.

B) Since they occur at the basin edges and originated from adjacent slopes or platforms margins, carbonate turbidites provide information regarding the environmental changes that have affected the surrounding platforms. The evidence recorded in these turbidites is particularly important, because during intense Tertiary thrusting, primary palaeogeography was completely obliterated and no marginal regions between the basin and the surrounding platforms are preserved today.

A) The intrabasinal source of clasts and matrix in the debrites from the central part of the basin, as well as the occurrence of slumps local to debris flow deposits both document the existence of slopes on the Early Toarcian sea floor. An uneven sea-bottom palaeotopography is additionally evident from the considerable thickness variation of the Perbla Formation, from 0.6 to 120 m (a maximum thickness of 135 m was observed a few kilometres from the Zakojška grapa section). It is therefore inferred here that the Slovenian Basin was composed of several tectonic blocks that experienced differential subsidence and tilting. Such conditions reflect the extensional tectonic phase that is regionally well-documented and reached an acme during the Pliensbachian. Due to the highly variable thickness of the Perbla Formation, we believe it extended at least into the early Toarcian. Regionally, this phase lead to disintegration and accelerated subsidence of palaeogeographic domains (Sarti et al. 1992; Bertotti et al. 1993; Clari & Masetti 2002; Šmuc 2005; Šmuc & Goričan 2005) and formation of extensive neptunian dikes (Babić 1981; Winterer et al. 1991; Buser 1996; Črne et al. 2007; Šmuc 2010). A pre-Toarcian (Pliensbachian) tectonic phase is also well-manifested in the composition of the calciturbidites in the underlying Krikov Formation, where, besides basinal and slope intraclasts (mud chips), disintegrated platform lithoclasts are also present. Most characteristic are grainstones with ooids, peloids, rarer intraclasts and bioclasts cemented by rim and mosaic cements (Rožič 2006, 2009).

B) The distinct change in the composition of calciturbidites from the Krikov and Perbla formations records a major environmental overturn. The fossil assemblage within the calciturbidites of the underlying Krikov Formation is diverse, pointing to an oligotrophic environment in the source area. Conversely, calciturbidites in the Perbla Formation are composed almost exclusively of echinoderms and thin-shelled bivalves. This, together with the appearance of glauconite and phosphate grains, indicates a rapid shift towards deeper-water sedimentary environments in the source areas

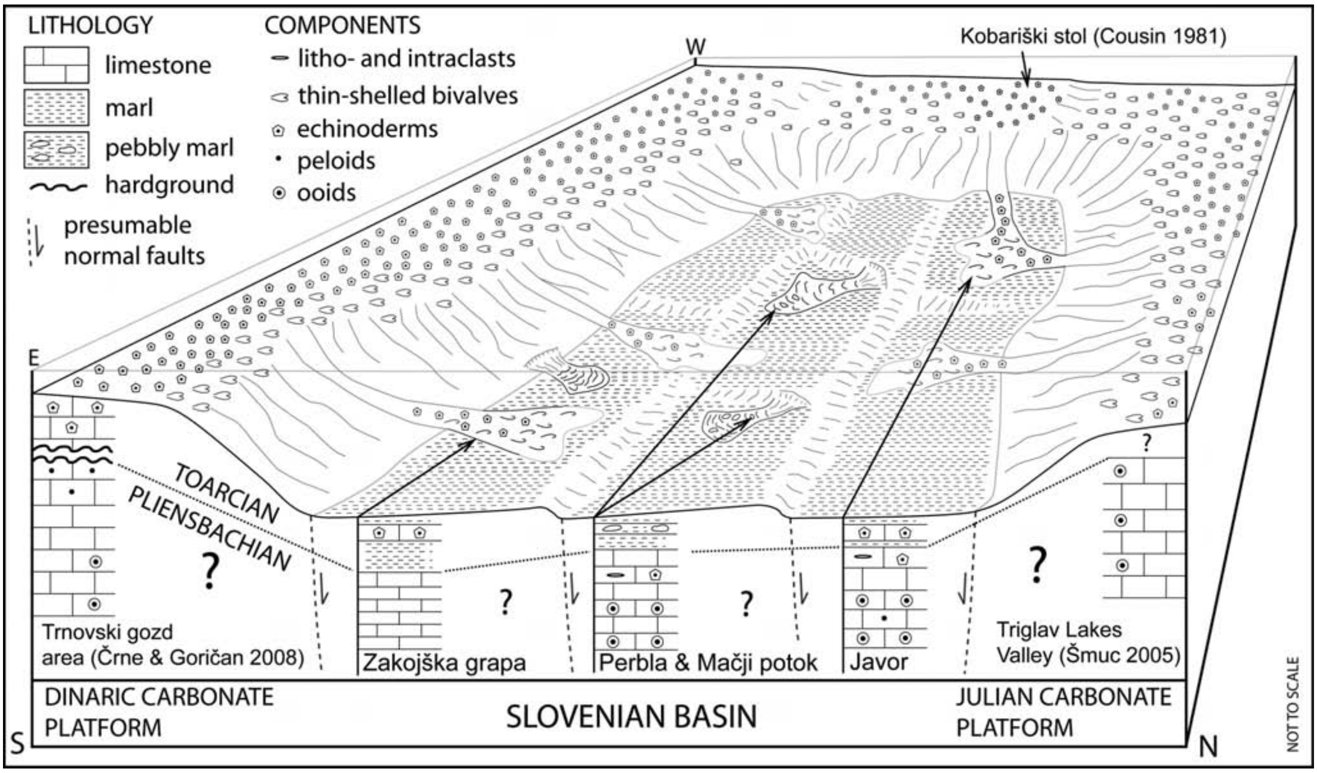

Fig. 4 - Toarcian sedimentary model of the Slovenian Basin and adjacent areas: the uneven sea-bottom palaeotopography caused pelagic sediment redeposition via slumping and debris-flows. In marginal parts of the basin, coarse-grained turbidites were deposited, which originated from adjacent carbonate platforms and slopes. These source areas were dominated by echinoderms and thin-shelled bivalves. Studied successions are drawn in black, with inferences made shown in grey (for details see text). The arrows indicate the proposed palaeogeographic locations of studied sections.

of these calciturbidites; i.e. in the surrounding platforms and slopes. This overturn was a consequence of the prominent early Toarcian transgression (Graciansky et al. 1998), a well known event affecting the entire southern Tethyan continental margin that resulted in the flooding of carbonate platforms and sedimentation of clay-rich sediments in basins (Goričan 1994; Santantonio & Muraro 2002; Clari & Masetti 2002; Goričan et al. 2003; Črne & Goričan 2008; Sabatino et al. 2009).

Calciturbidites in the southern part of the basin (Zakojška grapa section) originated from the adjacent Dinaric Carbonate Platform to the south, which at that time represented the only shallow-water sedimentary environment in the entire region. In the Trnovski gozd area, where the most external platform succession is preserved today, crinoidal limestone dominates late Lower Jurassic succession (Buser 1973, 1978). In this area, the Kovk section was recently studied in detail, with several hardground horizons, intercalations of marly limestone and abundant glauconite documented at the base of the crinoidal limestones. This distinct horizon records the maximum of the Toarcian transgression (Črne & Goričan 2008).

The origin of the coarse turbiditic material in the northern part of the basin (Javor section) is rather enigmatic, since Toarcian sediments are not preserved on the Julian Carbonate Platform to the north. By this time, the platform had most probably emerged before being later drowned, thus resulting in the pelagic plateau (Buser 1996; Šmuc 2005; Šmuc & Rožič 2010). However, on the Trento Plateau from the Italian Southern Alps, very distinct upper Aalenian-Bajocian deposits composed almost exclusively of thin-shelled bivalves (*Posidonia* beds) are present (Sturani 1971; Martire et al. 2006). Although these beds are younger, their presence characterizes Jurassic drowned platforms as thriving pelagic bivalve habitats. Together with echinoderms they represent one of the most important components in the condensed limestones of the Bajocian to lower Tithonian Prehodavci Formation of the Julian High (Šmuc 2005; Šmuc & Rožič 2010). Alternatively, the material in these turbidites could have been supplied from the western flanks of the basin. According to Buser (1996), during the early Early Jurassic the Dinaric and Julian Carbonate Platforms were connected in the area NW of Kobarid (see Fig. 2 for location) where crinoidal limestones overlie the Upper Triassic Dachstein Limestone and are dated broadly to the Early Jurassic (Cousin 1981; Buser 1986). Therefore it can be inferred that this potential 'bridge' probably still existed during the Toarcian and acted as a source of bioclastic sediments for the western part of the Slovenian Basin.

On this basis, a sedimentary model for the Slovenian Basin and adjacent regions during the Toarcian may be constructed (Fig. 4). The basin-floor palaeotopography was uneven due to pre- and early-Toarcian differential subsidence of individual tectonic blocks, which then caused the slumping and redeposition of pelagic clay-rich sediment via debris-flows. Simultaneously, surrounding platforms drowned due to prominent transgression. On the platforms' outer margins and upper slopes, deeper-water environments established, resulting in a decrease in biodiversity. Under such conditions, environmental specialists thrived and the excess material was resedimented by turbidity currents to proximal parts of the adjacent basin.

Conclusions

The Toarcian Perbla Formation of the Slovenian Basin is characterized by clay-rich pelagic sediments, with sporadic gravity-flow deposits in its lower parts. Coarse carbonate turbidites predominate in marginal areas of the basin, while debrites and slumps also appear. Although volumetrically of lesser importance, these deposits document the impact of prominent, regionally recognized geodynamic and environmental changes in the late Early Jurassic.

Slumps and debrites at the base of the formation formed during the rifting event that reached an acme during the Pliensbachian and continued until the early Toarcian. Gravity-forced mass displacement originated due to the presence of an uneven palaeotopography created by differential subsidence of individual blocks within the basin. Additional evidence for the Pliensbachian-Toarcian tectonics are platform lithoclasts present in the underlying Krikov Formation turbidites.

The Toarcian transgression is recorded by the poor variety of grains found in coarser turbidites. These beds are usually composed of crinoidal grainstone grading into packstone composed almost exclusively of thin-shelled bivalves. Other grains include basinal intraclasts (mud-chips) and occasionally abundant glauconite and phosphate. Such compositional monotony reflects the drowning of surrounding platform margins that were source areas for the coarse material found in the turbidites.

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