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SEDIMENTARY SETTING OF ADRIATIC FLYSCH FORMATION (MIDDLE EOCENE-MIDDLE MIOCENE), SOUTHEASTERN MONTENEGRO AS REVEALED BY TURBIDITE SEQUENCES

Kilibarda, Z.[1], Čadjenović, D.[2], Milutin, J. [2], and Radulović, N.[2]

[1] *Indiana University Northwest, Gary, IN 46408, United States, zkilibar@iun.edu*
[2] *The Geological Survey of Montenegro, 81000 Podgorica, Montenegro, geozavod@cg.yu*

Abstract: A 750 m long outcrop of Middle Eocene-Miocene flysch is exposed in an asymmetrical syncline in Crnjak Cove, south of Bar, Montenegro. Texture, physical sedimentary structures, petrography, and trace fossil studied in these sediments allowed the recognition of turbidite facies that display various members of the Bouma sequence (Ta,b,c,d,e). These are interpreted in order to reconstruct the depositional setting of these gravitational deposits. Predominantly clastic lihologies in this 300 m thick sequence are arranged in seven distinct turbidite facies, which represent three superimposed submarine fans. The oldest fan consists of: 1) basal marl (T_1: 0-30 m), which indicate basin to marginal-fan deposits; 2) thin to medium bedded graywackes intercalated with thin mudstones (T_2: 30-140 m), which represent mid fan; and 3) thinly bedded graywackes intercalated with mudstones (T_3: 140-160 m), which indicate outer fan deposits. The second fan is comprised of: 1) thin to medium bedded, coarsening upward graywackes (T_4: 160-190 m) that represent mid fan environment; 2) conglomerates (T_5; 190-200 m) which, in addition to carbonate clasts, also contain large rip-up clasts of siltstones, indicating locally derived channel deposits; and 3) thinly bedded graywackes intercalated with mudstones (T_6; 200-230 m), which represent outer fan deposits. The youngest submarine fan is made of thin bedded graywackes intercalated with mudstones (T_7: 230-300 m) that represent mid fan environment. The graywackes from mid fan facies consist of Bouma's Tb,c,d sets, and at their bases contain flute casts, prod casts, and scour marks. Thin greywackes from outer fan facies contain abundant and diverse *Nereites* ichnofacies.

Keywords: Montenegro, flysch, turbidite, Eocene, trace fossils

1. Introduction

The study area is in southeastern Montenegro, which belongs to the south Adriatic zone (Dimitrijević, 1995). The WNW-ESE trending flysch belt begins about 10 km south of Bar (Fig. 1) and continues toward east-southeast for about 45 km, where it gets submerged by the sea near the coastal town of Shengjin in Albania. Toward WNW the narrow flysch belt is mostly under the Adriatic Sea, but it is exposed in short segments at Luštica in central coastal Montenegro, in Croatia along Dalmatian coast (Marjanac, 1996; Babić and Župančić, 1998), and central Istria (Ćosović et al., 1994; Ćosović et al., 2004). Lush vegetation and colluvium cover flysch and limit its exposures except in several small gullies. However, a 750 m long outcrop of low cliffs in Crnjak Cove south of Bar reveals a complete flysch section. The measured section is between 42°1’10” and 42°1’36” North Latitude and 19°8’46” East Longitude (Fig. 1). The outcrop is an asymmetrically inclined syncline (290° axis trend) that contains several secondary folds. The inclined beds dip toward northeast (10° azimuth), with steeper northern (65-80°) than southern (35-55°) syncline limb. Field work was done in 2007/09 as a part of geological mapping at 1:25,000 scale for sheets Bar and Stari Bar. The outcrop described in this paper has been assigned a type section of Adriatic Flysch Formation. The 60 thin sections were studied to classify, determine composition and fossil content of these rocks.

2. Stratigraphy

Upper Cretaceous limestones in southeastern Montenegro are capped by discontinuous thin bauxite deposits and erosional surfaces that contain ab-

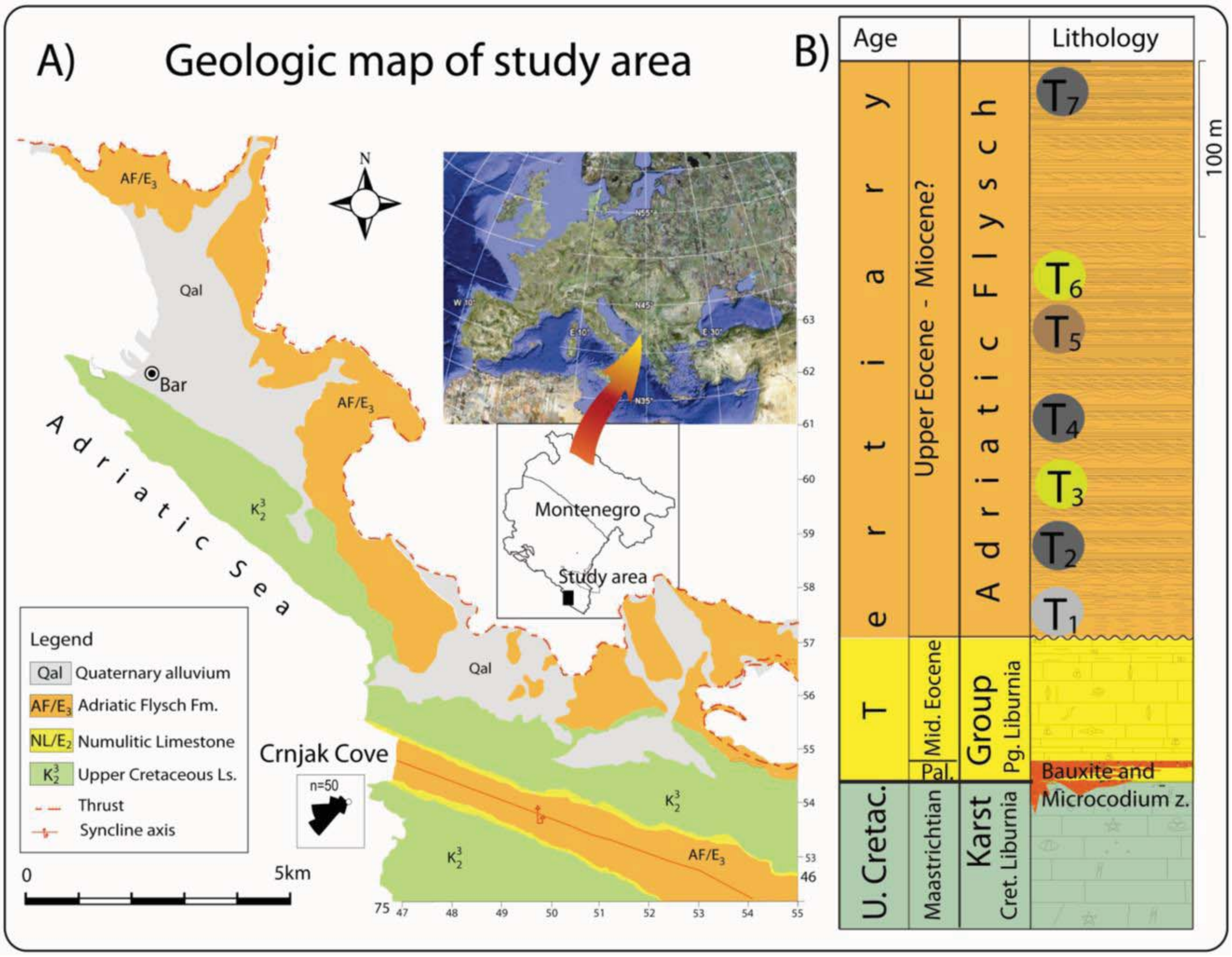

Fig. 1. A) Geologic map of study area with location of Crnjak Cove and type section of the Adriatic Flysch. Rose diagram of paleocurent directions determined from sole marks. B) Stratigraphic column of studied rocks.

undant *microcodium*. This regional unconformity is also present in the northern part of the Adriatic Carbonate Platform (AdCP). Vlahović et al. (2005) consider this unconformity as the termination of the AdCP. However, shallow platform sedimentation in Montenegro and Herzegovina (Radoičić, 1989) and in Istria (Ćosović et al., 2004) resumed by the end of Paleocene, and the AdCP lasted until the middle Eocene, when thrusting caused its disintegration and formation of narrow foreland basins. The Adriatic Flysch Formation disconformably overlies thin (1- 2 m) wackestone that caps about 75 m thick foraminifer (*Nummulites, Discocyclina, Assilina*) rich packstones, grainstones, and rudstones. These rocks represent the youngest units of the AdCP (Fig. 1). Presence of cyanobacterial tubes *Decastronema barattoloi* (de Castro) in the lower part of this formation indicates its Palaeocene age (Ćosović et al., 2008; Zamagni et al., 2008). Mottled and bioturbated wackestone at the top of the formation contains blebs of dark green, reduced zones separated by narrow brownish, oxidized zones. The dark green areas contain small planktonic forams, calcareous nannoplankton, and rare radiolarians, which float in carbonate mud that has specks of pyrite. Oxidized zones contain similar microfossils but also rare bryozoans and larger foraminifers, some of which are partially replaced by glauconite. We interpret the nodular wackestone as hardground surface that developed during rapid sea transgression of early basin, when sedimentation rates were low and some interaction between unconsolidated sediment and oxygenated bottom water took place.

3. Results and Discussion

The turbidite series consists of seven facies (T_1 through T_7), which reflect various segments of three superimposed submarine fans. The lowermost T_1 unit (0-30 m) is made of massive and occasionally poorly laminated bluish green marl, which at several intervals contains thin (10-30 cm) more resistant siltstones and/or very fine sandstones. The marl weathers easily and is poorly exposed because of colluvium and vegetation cover. The marl is the Te member of Bouma Sequence (Bouma, 1962), which contains pelagic fossils of small planktonic foraminifers and calcareous nannoplankton. This unit is equivalent to 'Globigerina marl" (Ćosović et al., 2004) from the northern AdCP, that is also recognized in neighboring areas of southern AdCP, and assigned Middle Eocene age (Mikes et al., 2008). Thin intercalations of siltstone and/or very fine sandstone in the T_1 unit are made predominantly of angular to subangular quartz grains, some feldspars, chert, and mica flakes held by a carbonate matrix that contains a few pelagic microfossils. These rocks have well-developed thin planar lamination and represent the Td member of a Bouma Sequence. In older references (Mirković et al., 1978) this facies was described as a pre-flysch, but we interpret it as a basin-marginal fan deposit, where the tails of turbidite currents occasionally interrupted slow pelagic sedimentation.

The T_2 (30-140 m), T_4 (160-190 m), and T_7 (230-300 m) units contain sandstone layers (10-50 cm) intercalated with thin siltstones (~10 cm) and mudstones (< 5 cm). In these three units the sandstone to mudstone volumetric ratio is about 80:20. The yellowish tan sandstones are predominantly made of medium to fine sand, with intervals of very fine sand and coarse sand. Angular to subangular quartz (70-75 %), feldspars (5-15 %), carbonates (3-10 %), volcanic fragments (2-5%), and micas (1-2 %) are the primary constituents in the sandstones. Feldspars are more common than carbonates in the lowermost T_2 unit, while carbonates are more common than feldspars in the T_4 and T_7 units. Accessory minerals (usually < 2%) in sandstones are zircon, tourmaline, garnet, and pyrite. These texturally immature and poorly sorted sandstones are greywackes (quartz-, feldspar-, and lithic-wackes), which contain carbonate mud that binds the particles. Cross laminations, reflecting migrating and climbing ripples (Tc member), are present in almost all the sandstone beds. Also common is planar lamination in the coarser sandstones (Tb member), and thinner planar lamination in very fine sandstones/siltstones (Td member). Convolute lamination (Tc member) is more common than thin (< 10 cm) massive or graded coarse-grained sandstones (Ta member). Thin, dark green, platy to massive mudstones (Te members) separate sandstone layers. The most common association of sedimentary structures in sandstones is amalgamation and stacking of Tbc members. Truncation of cross-laminated Tc members by plane-laminated Tb or massive Ta members is common (Fig. 2). The sandstone bases contain load casts, flute casts (Fig. 3), groove casts, prod, chevron, and brush marks that indicate WSW to SW paleocurrent directions. The best examples of these structures are found in the syncline's northern limb, in the T_7 unit. The arrangement and stacking pattern of Bouma Sequence members in sandstones of T_2, T_4 and T_7 units, and a narrow range of paleocurrent directions in these facies indicate sand rich mid-fan areas of three superimposed submarine fan systems.

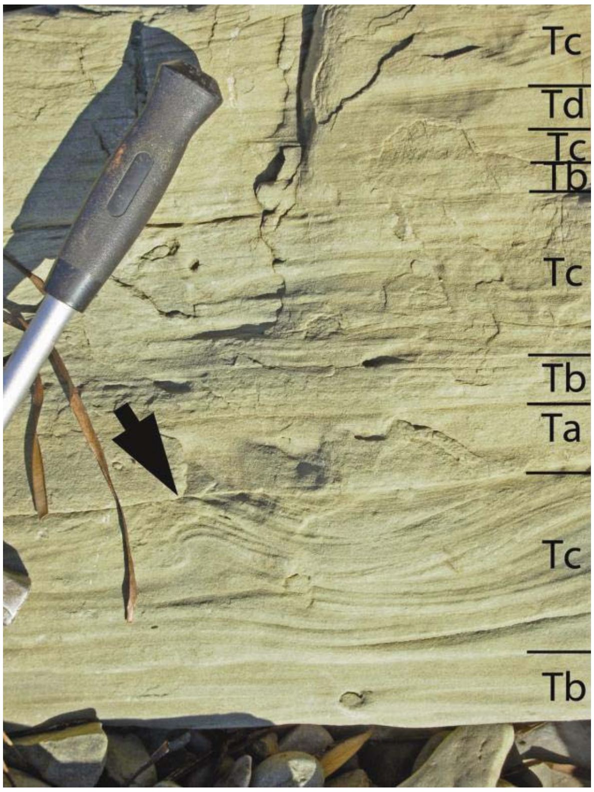

Fig. 2. Stacking pattern of Bouma Sequence members within sandstone from mid-fan (T_2 unit) deposits. Note convolute lamina and truncation (arrow) of cross-laminated Tc member by a massive Ta member. Current flow was from right to left. Hammer is 25 cm long.

The T_3 (140-160 m) and T_6 (200-230 m) units are made of thin (5-10 cm) fine-grained grey sandstones, bluish green siltstones, and olive green platy mudstones, stacked in a Tcde patterns. The sandstone to mudstone volumetric ratio in these facies is about 50:50. The texture and composition of grains in these sandstones is similar to previously described units, with exception of volcanic fragments, which are more abundant (5-10%) than carbonates (0-2%). The coarser sandstones of the Ta member are totally absent in these units, and few poorly defined Tb members are found. Carbonate mud matrix generally exceeds 15% of sandstones making them densely bound greywackes. Well developed cross-lamination (Kilibarda et al., 2009) and planar lamination in these rocks suggest waning stages of turbidity currents transport. The nannofossils identified in the neighboring flysch facies (Radoičić et al.,1991; de Capoa and Radoičić, 1994a; 1994b; Mikes et al., 2008) include *Helicosphaera ampliaperta* (NN2-4), *Calcidiscus leptoporus* and *C. premacintyrei* (NN4), which suggest that Adriatic Flysch sedimentation lasted much longer (Middle-Late Miocene) than previously (Late Eocene) thought (Mirković et al., 1978).

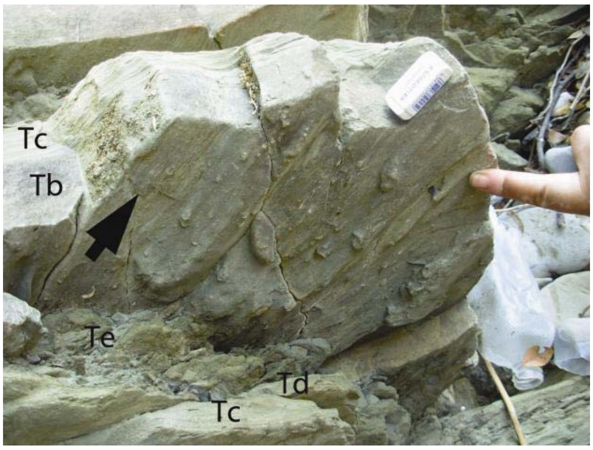

Fig. 3. Flute casts, groove and prod marks on the sole of thin Tb member, which is capped by Tc member. Arrow points to current direction. Eraser is 5 cm long.

The bases of greywackes in the T_3 and T_6 units display a variety of grapholyptid trace fossils that constitute Nereites ichnofacies. Pre turbidite (Seilacher, 2007) association of trace fossils includes *Paleodictyon italicum* Uchman (Fig. 4), *Paleodictyon majus* Meneghini, *Protopaleodictyon incompositum* Vyalov & Golev, and *Scolicia ichnosp.* Post turbidite (Seilacher, 2007) association includes *Helminthoida labyrintica* Heer, *Ophiomorpha rudis* Ksiazkiewicz (Fig. 5), *Scolicia plana* Ksiazkiewicz, and *Taphrhelminthopsis plana* Ksiazkiewicz. Sedimentary structures indicative of lower current energy as well as Nereites ichnofacies with *Ophiomorpha* ichnosubfacies (Uchman, 2009) suggest that the T_3 and T_6 units represent mud rich outer fan environments of two superimposed submarine fans.

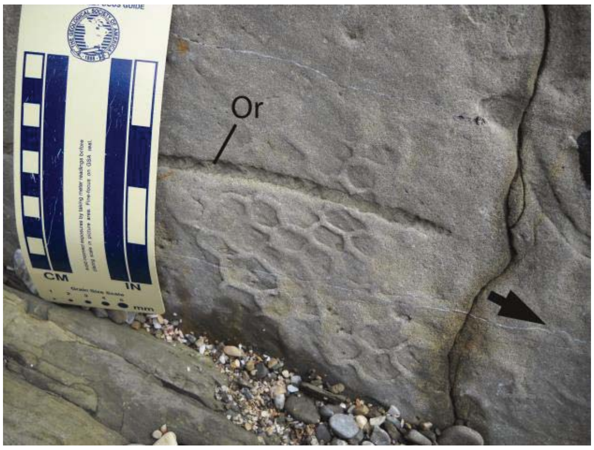

Fig. 4. Pre-turbidite *Paleodictyon italicum,* Uchman, truncated by post-turbidite *Ophiomorpha rudis*, Ksiazkiewicz (Or). Elongation of *Paleodictyon* polygons indicates paleocurrent direction (arrow).


Fig. 5. Ripple casts at the base of thin sandstone with full relief and casts of several large *Ophiomorpha rudis*, Ksiazkiewicz burrows. Hammer is 35 cm long.

The T_5 unit (190-200 m) is made of three stacks (1-2m thick) of conglomerates, gravely sandstones, and lithic arenites, which are separated by thin mudstones. The soles of the conglomerate beds are irregular and in one exposure reveal a 0.5 m deep and 2 m wide scour into underlying mudstones (Fig. 6). The conglomerates are dark gray on the weathered surface and bluish white on the fresh

Fig. 6. Scour at the base of conglomerate bed (T_5 unit) into underlying siltstone/mudstone of T_4 unit. Hammer is 35 cm long.

Fig. 7. Large rip-up clasts (arrows) of laminated siltstones/very-fine sandstones near the base of conglomerate bed (T_5 unit).

surface. They are made of angular to subangular cobble to pebble size carbonate lithoclasts that contain large benthic foraminifers and few, but well preserved bivalves (Kilibarda et al., 2009). In their lower parts the conglomerates contain large rip-up clasts (Fig. 7), which exhibit well-developed cross- and planar lamination. The conglomerates are graded and the thickest single layer is 1.2 m thick. When not truncated by younger conglomerate, the conglomerates transition into tan gravely sandstones and then in coarse to medium grained sandstones. Sandstones contain angular carbonate particles with small siliciclastic component and negligible mud matrix. They are classified as calc arenites. In lower parts of sandstone beds Ta-Ta stacking is more common than Ta-Tab pattern. In some exposures sandstone beds contain complete Tabcd Bouma Sequence. Similar thick conglomeratic units in central Dalmatia (Croatia) were interpreted (Marjanac 1996; Babić and Župančić, 1998) as shallow water, delta deposits on top of the turbidite. However, at approximately the same stratigraphic interval thick conglomerates in Pyrenean turbidite were interpreted as megaturbidites (Seguret et al., 1984) caused by earthquakes. Based on its discordant stratigraphic position and clast composition, which is radically different from underlying and overlying facies, we interpret the T_5 unit as an earthquake triggered channel facies of submarine fan, whose sediments were derived from the lithified costal carbonates and shallow water carbonates of the basin rim.

4. Conclusions

Our sedimentation model (Fig. 8) indicates that three superimposed submarine fans are revealed in

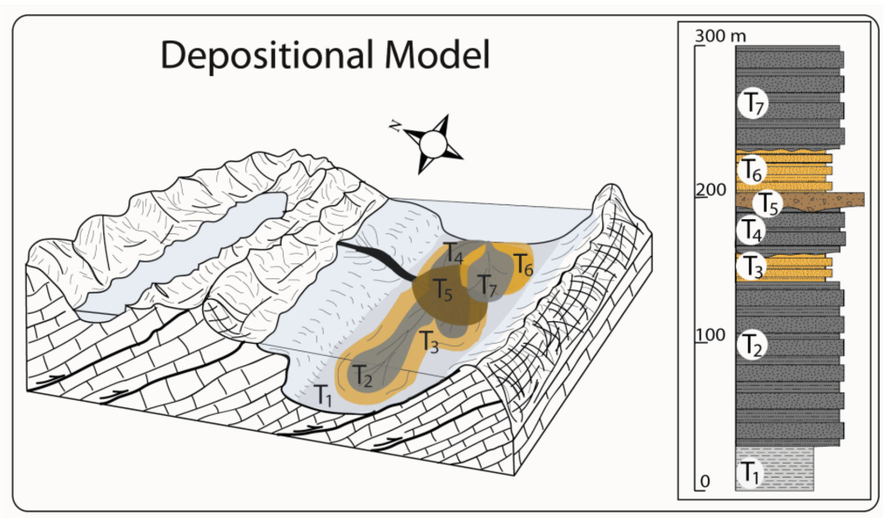

Fig. 8. Depositional model for the Adriatic Flysch Formation (Middle Eocene-Middle Miocene) in Crnjak Cove turbidite.

Crnjak Cove turbidite. The elements of the oldest fan include basin and fan periphery deposits (T_1 unit), mid-fan deposits (T_2 unit) and outer fan deposits (T_3 unit). The sedimentary structures within turbidites suggest that the source of sediment was the ophiolite zone in central Albania. The second fan elements include mid-fan deposits (T_4 unit) and outer fan deposits (T_6 unit), interrupted by locally derived channel deposits (T_5 unit), likely generated by tectonic activity at the end of Oligocene. The youngest fan (T_7 unit) deposition lasted until the Middle Miocene, much longer than previously thought.

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