

The position and age of flysch deposits in the Crimea Mountains (Southern Ukraine)

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The Crimean Mountains (CM) are regarded as part of the Alpine-Himalaya orogenic belt related to the collision of the Eurasian and African plates. Our research in the CM has allowed confirming the existence of at least two flysch formations of different ages: the Taurida Flysch Formation (Upper Triassic/Lower–? Middle Jurassic) and the Sudak Formation (uppermost Jurassic/Lower Cretaceous) in the western and eastern sectors of the CM, respectively. After the Middle Jurassic volcanism, the freshwater claystones with coal-bearing intercalations, as well as local alluvial fan conglomerates were deposited. Then, following the Oxfordian/Kimmeridgian marine transgression, three separated Tithonian/Berriasian carbonate platforms developed: Baydarska, Chatyr-Dag and Demerji/Karabi. At the turn of the Late Jurassic, the deep-water Sudak Basin (eastern sector of the CM) began to develop in the eastern periphery of the Demerji/Karabi carbonate platform. This basin, dominated by turbiditic deposition, was probably connected with the Great Caucasus sedimentary system. Finally, distal flysch sedimentation in the Sudak Basin was followed by debris-flow deposits, with huge blocks of Upper Jurassic limestones. These blocks were derived from destruction of the Karabi carbonate platform. During the Berriasian/Valanginian, the eastern sector of the CM began to subside. As a result, both carbonate platforms (western CM) and the debris flow fans of the Sudak Basin (eastern CM) were overlain by marly shales and/or distal turbidites. This type of deposition lasted until the Aptian/Albian. In the post-Albian period, the Alushta-Salgir tectonic zone was transformed into a SE-dipping thrust fault with at least 10 km amplitude of overthrusting.

Key words: Ukraine, Crimean Mts., stratigraphy, micropalaeontology, flysch.

INTRODUCTION

Flysch sediments, known already for more than 150 years (from [Dubois de Montpereaux, 1837](#)), play an important role in the geological structure of the Crimean Mts. These deposits were traditionally regarded as the Tauric Flysch of Late Triassic/Early Jurassic age ([Muratov et al., 1969](#); [Muratov, 1972](#)). This age has been challenged by [Popadyuk and Smirnov \(1991\)](#), who concluded Early Cretaceous age. This sparked a lively discussion (e.g., [Popadyuk et al., 2010, 2013a, b, 2014](#); [Oszczypko et al., 2012b, c](#)) until [Sheremet et al. \(2014, 2016a\)](#), on the basis of calcareous nannoplanton analyses of flysch-like deposits in the eastern sector of the CM, included both the Tauric Formation and the Lower Cretaceous flysch deposits of the eastern sector of the Crimea into the Tauric Group.

Taking into account our experience in studying the Outer Carpathians flysch, we became interested in the explanation of the controversy related to the Tauric Flysch. With this in mind, we have conducted our studies in the years 2010–2013, during the three short, but intense field work campaigns. Our interest has been focused on the following main questions:

- litho- and biostratigraphic studies of the Tauric Flysch;
- its relationships to overlying lithostratigraphic units;
- lateral and longitudinal spatial variability of the Tauric Flysch, especially along the west-east direction.

We started from the locus typicus of the Tauric Flysch: the Alma and Bodrak valleys and along the Black Sea coast, between the Cape of Sarych in the west and the village of Rybache in the east ([Oszczypko et al., 2012b, c](#)). Then, we tried to recognize the relationship between the Tauric Flysch and the Jurassic?/Early Cretaceous flysch of the eastern sector of the CM ([Oszczypko et al., 2012c](#)).

In Russian publications, the Mesozoic flysch is known as the Tavricheskaya svita, series, group or simply Taurica. We suggest introducing a new term – the Taurida Flysch Formation (TFF), which is more consistent with the formal lithostratigraphic standards, recommending a geographical noun. In this case it will be the Taurida – an ancient Greek name of the Crimean Peninsula.

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GEOLOGICAL SETTING

The Crimean Mts. are part of the southern, deformed boundary of the East European Platform, located between the Scythian Plate (which belongs to the Eurasian continent) and the Black Sea (Figs. 1 and 2). This mountain chain is ~50 km wide and ~150 km long (Figs. 3 and 4; cf. Appendix 1*). It is arch-shaped, with E–W structural trends in the west, and NE–SW in the east. Traditionally, the CM are regarded as the Cimmerian/Alpine orogen (Muratov, 1960, 1969; Koronovsky and Mileev, 1974; Byzova, 1980; Kruglov and Tsytko, 1988; Mileev et al., 1997, 2006, 2009; Nikishin et al., 2015a, c).

First detailed information on tectonic deformations of the Tauric and Eski-Orda series, in the Bodrak Valley, was given by Koronovsky and Mileev (1974). These authors described in places the highly deformed complex, with south-vergent folding and thrusting, related to the Early Cimmerian phase. An interesting view on the structural evolution of the Crimean orogen was presented by Kruglov and Tsytko (1988), who highlighted two Cimmerian orogenic phases: the older (Liasic/Bathonian) one in the NW sector of the CM, and the younger (Valanginian/Hauterivian) one in the SE sector of the CM. The early orogenic phase took place in the outer (external) part of the basin, where the folding of TFF was preceded by pre-folding volcanism. This is well-documented (Kruglov

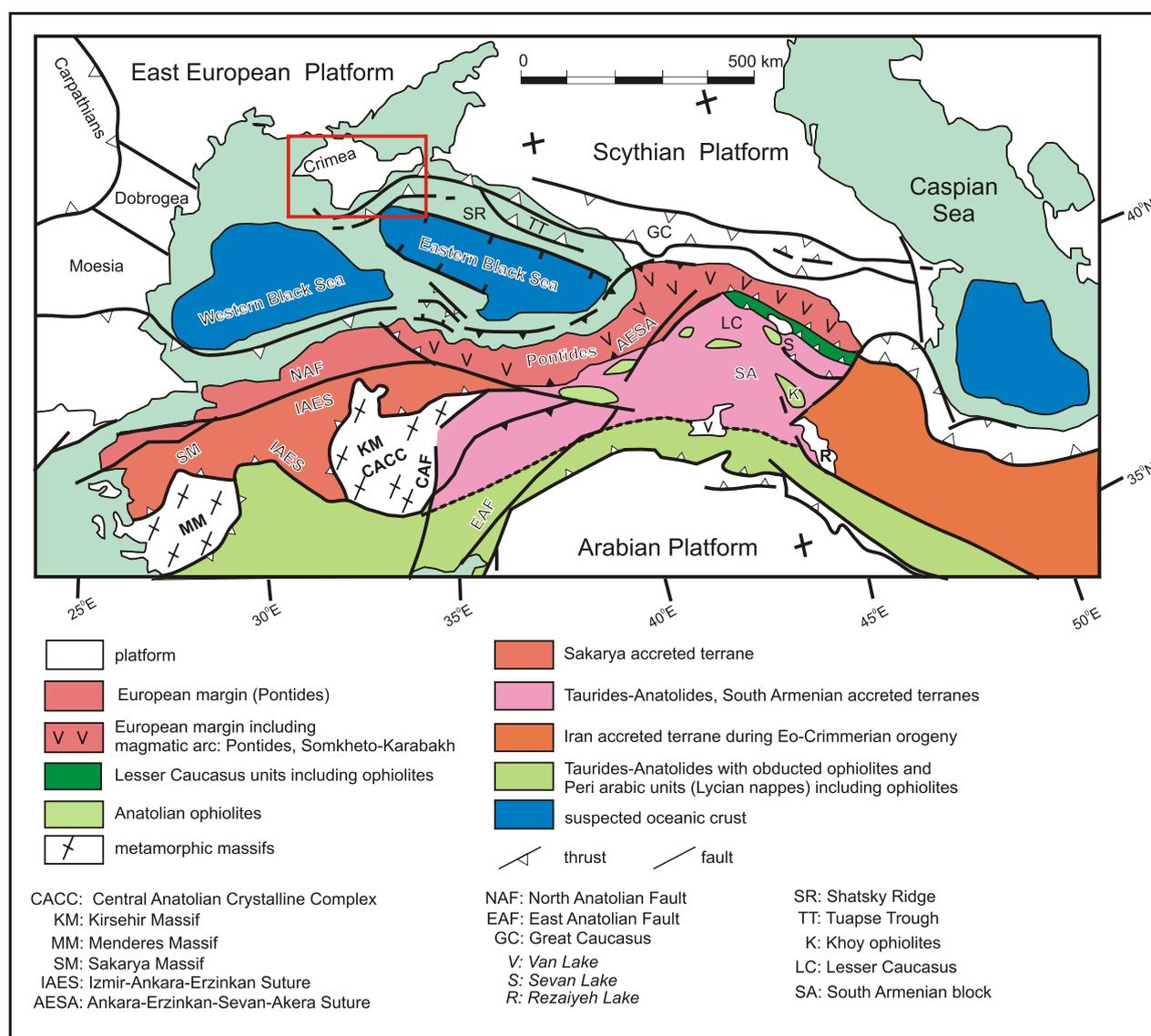


Fig. 1. Structural sketch-map of the Alpine Orogen System of SE Europe and Middle East *sensu lato* after Sosson et al. (2010), simplified

Position of the Crimea Mts. is shown as a red rectangle

* Supplementary data associated with this article can be found, in the online version, at doi: 10.7306/gq.1359

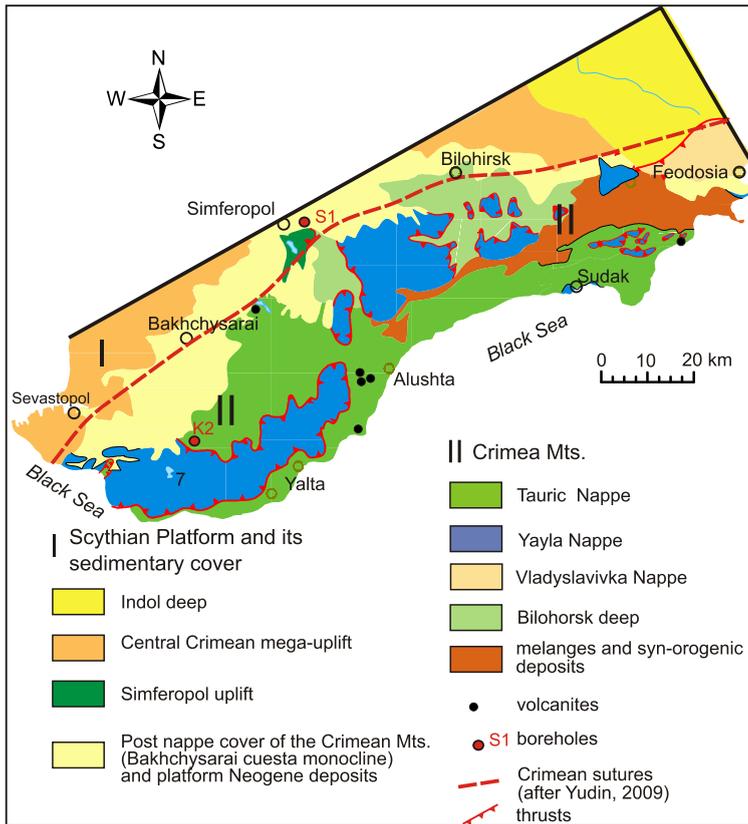


Fig. 2. Tectonic map of the Crimea Mountains (Hurskiy and Kruglov, 2006)

and Tsytko, 1988) by results of the Kacha 2 bore-hole (40 km SW of Simferopol). This borehole drilled to the final depth of 4032 m revealed intensely folded sediments TFF (T₃-J₁) with numerous intrusions (dykes, sills and pillow lavas of diabases, picritic diabases, andesites and basalt-andesites) in the 2270–3930 m depth interval.

Hurskiy and Kruglov (2007) distinguished the following structural complexes:

- autochthonous (Aptian/Albian), fragmentarily preserved in the Salgir and Tonas valleys;
- allochthonous complex with two nappes: lower – the Tauric Nappe, and upper – the Yayla Nappe (carbonate platforms);
- Cenomanian/Eocene post-nappe complex (Fig. 2).

In the Simferopol 1 borehole, beneath the Tauric Nappe, Lower Cretaceous deposits were pierced at a depth of ~4 km (Yudin, 2005, 2013).

The interpretation of Kruglov and Tsytko (1988) clearly shows that sedimentation of the TFF in the external (NW) part of the basin ended up in the Middle Jurassic, and continued through the Valanginian/Hauterivian in the inner (SE) basin. In the Crimea Basin, this deformation took place in close relation with the beginning of the closure of the Neo-Tethys Ocean (Kazmin et al., 2000; Golonka, 2004). However, there was also consequent Alpine deformation (during the Paleogene), related to the Arabia-Eurasia convergence and to the evo-

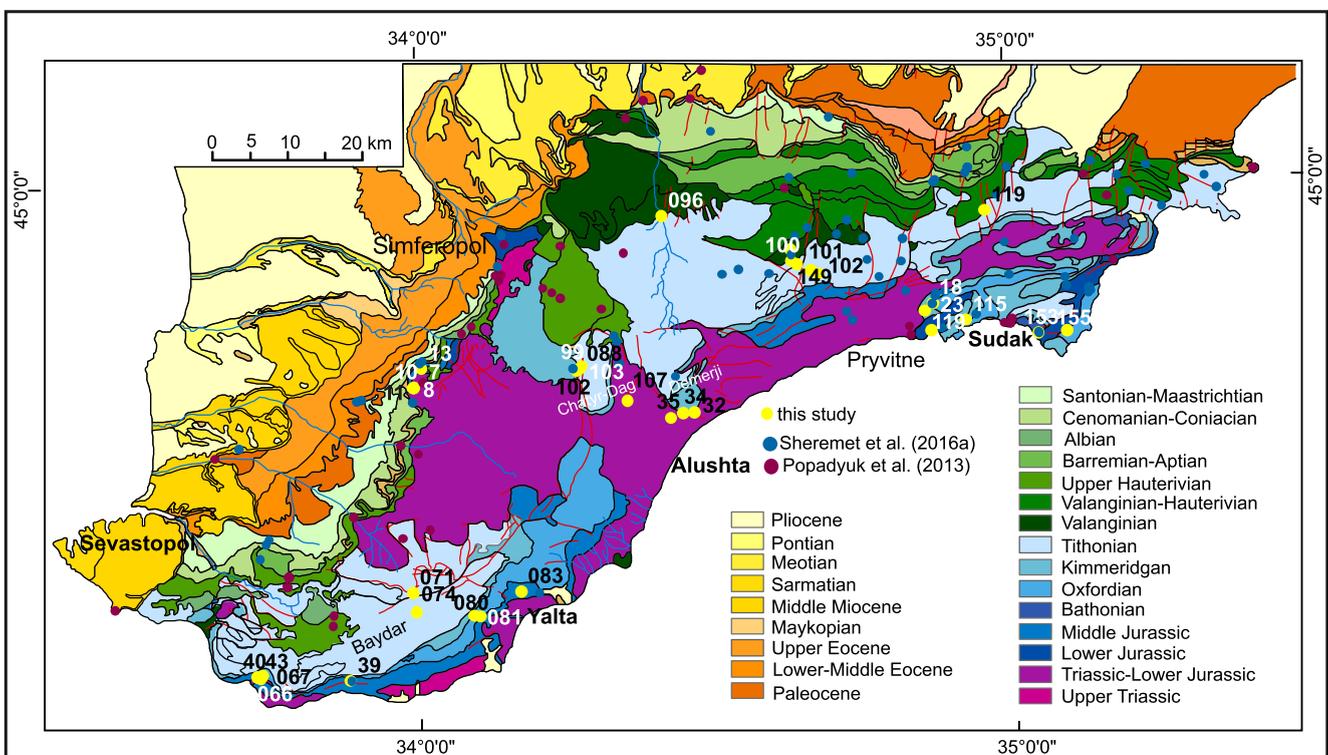


Fig. 3. Simplified geological map of the Crimea Mountains based on Muratov (1960), Pivovarov and Derenyuk (1984) and Popadyuk et al. (2013a), with location of the most recent micropalaeontological data presented by Popadyuk et al. (2013a) and Sheremet et al. (2014, 2016a), and of our study sections (WP) in 2011–2013

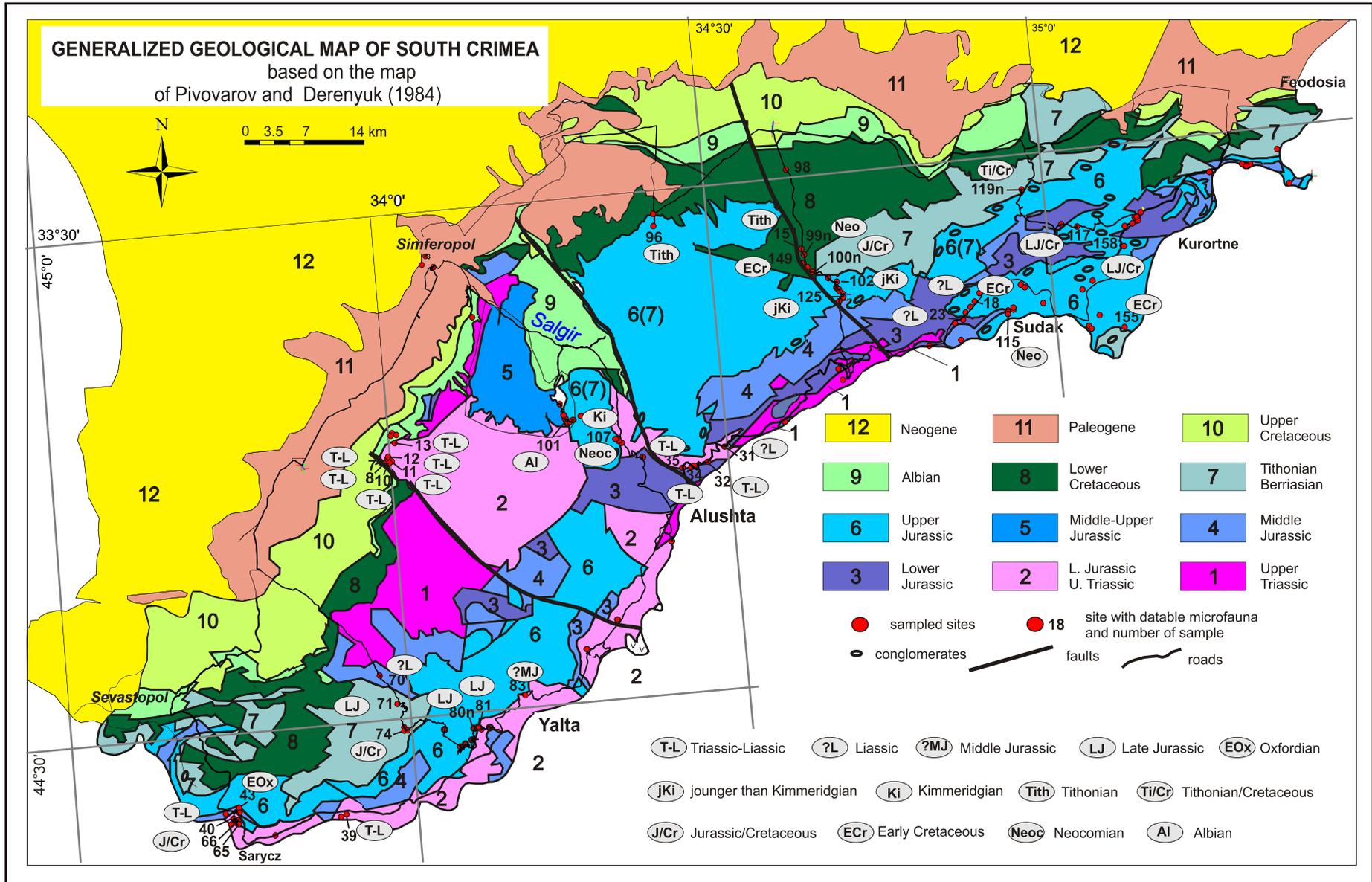


Fig. 4. Simplified geological map of the Crimea Mts. based on Pivovarov and Derenyuk (1984) and Popadyuk et al. (2013a) with location of new dating presented in this paper (see also Appendix 1)

lution of the Neo-Tethys (Bocaletti et al., 1974; Letouzey et al., 1977; Adamia et al., 1981; Zonenshain and Le Pichon, 1986).

As far as the polyphase structural evolution of the Crimea is concerned, there is some controversy about the major structures, especially related to the vergence of thrust sheets and the ages of their development. Mileev et al. (1997) considered the thrust sheet development as Berriasian in age with a south and south-east vergence (N160–N120° in azimuth). Popadyuk and Smirnov (1991) assumed that the thrusting in Crimea was generally north-vergent and had occurred during the Austrian phase (Middle Cretaceous). Galkin et al. (1994) concluded that the allochthonous Upper Jurassic rocks of the Chatyr Dag Massif thrust to the west over the Albian deposits. According to Shcherba (1978), the allochthonous complex (Late Jurassic terranes) was displaced to the south in Late Cretaceous–Early Paleogene times, and the detachment surface was reactivated during the Plio-Quaternary. Kazantsev (1982) and Kazantsev et al. (1989) reported that the structural complexes are involved in north-vergent thrust sheets including rocks aged from the Paleozoic to Sarmatian.

Panek et al. (2009) applied an apatite fission-track thermochronology (AFT) to investigate the low-temperature thermal evolution of the CM. The vast majority of the samples taken from Jurassic sedimentary and magmatic rocks revealed AFT ages in the range of 51–32 Ma (Eocene). These studies showed that the mountain range experienced a thermal overprint after the Late Cimmerian orogeny: at least 4 km of burial by the Early Cretaceous/Late Eocene platform was followed by Middle Pliocene uplift, fluvial erosion and large-scale landslides.

Sheremet et al. (2014, 2016a), based on new micropalaeontological data, proposed Upper Triassic to Middle Jurassic and Lower Early Cretaceous ages of the Tauric Group in the eastern CM, associated with magmatic activity. In this area, they also suggested the Early Cretaceous phase of extension and shortening periods during the Paleocene–Early Eocene, before the main Middle Eocene unconformity. Sheremet et al. (2016b), on the basis of two integrated transects from the eastern CM to the Sorokin Trough (north of the eastern BS; Fig. 2), documented the Early Paleocene to Pliocene shortening phases linked with the Neo-Tethys closure and uplift of the Great Caucasus. This scenario has been supported by Sosson et al. (2016) who reconstructed the palaeogeographic position of the Black Sea Caucasus area from the Tithonian to Early Paleocene.

CURRENT VIEWS ON THE AGE OF THE TAURIDA FLYSCH FORMATION

Distribution of the TFF in the CM is well-illustrated on several general geological maps 1:200,000 (Muratov, 1969; Pivovarov and Derenyuk, 1984; Yudin, 2009), and on serial geological maps 1:200,000: Eupatoria-Sevastopol and Simferopol-Yalta sheets (Bilecki, 2006a, b).

The TFF is traditionally regarded as the oldest sedimentary formation of the CM, exposed in two separate, northern and southern folded belts (Figs. 3 and 4). The northern one, known as the Kacha Uplifted Zone (Kruglov and Tsytko, 1988), is up to 50 km long and up to 25 km wide. In this region, the tectonically multiplied thickness of the TFF reaches a few kilometres (e.g., at least 2299 m in the Kacha 2 borehole, and 4032 m in the Kacha 4 borehole – see Bilecki, 2006a). In the east, this region adjoins the Late Jurassic carbonate platform of the Dolhorukovska Yayla along the Alushta/Salgir transversal fault (Kruglov and Tsytko, 1988; Fig. 4). Towards the SW, the outcrops of the TFF narrow and disappear under the Lower Creta-

ceous transgressive formations in the NW, and under the Middle/Upper Jurassic deposits in the SW and SE (Fig. 4). The southern region of the TFF, which is up to 100 km long and only a few kilometres wide, is situated along the Black Sea coastal zone, between the Sarych Cape in the west and the Sudak area in the east (Figs. 3 and 4). In the north, the TFF adjoins the Main Ridge of the CM along the vertical walls of the Late Jurassic carbonate platform. The nature of this contact is not clear.

The TFF is divided by Pivovarov and Derenyuk (1984) into the Upper Triassic and Upper Triassic/Lower Jurassic members. In the Lozove and Bodrak areas, these members are separated by thick-bedded quartzitic sandstones with imprints of Sinemurian ammonites and blocks of Paleozoic and Mesozoic limestones (e.g., the Eksi-Orda Fm.; Panov et al., 2001). In the coastal zone between Hurzuf and Alushta, the TFF is intruded by Middle Jurassic volcanic bodies: gabbro-diabases, andesites, basalts, diorites and plagiogranites (Pivovarov and Derenyuk, 1984; Kruglov and Tsytko, 1988; Bilecki, 2006b; Yudin, 2009; Solov'ev and Rogov, 2010; Meijers et al., 2010). In the NW sector of the CM, the TFF is transgressively overlain by Lower Cretaceous, mainly Hauterivian deposits (Figs. 3 and 4). Unclear situation is near the town of Dobre (south of Simferopol), where the TFF is covered by red continental conglomerates regarded by Pivovarov and Derenyuk (1984) as Callovian/Oxfordian, and by Popadyuk et al. (2013) as Neogene? Along the Black Sea coast, between the Cap of Sarych and Pryvitne, a prominent position is occupied by the Tithonian/Berriasian carbonate platform (Fig. 4), up to 2000 m thick (Krajewski and Olszewska, 2007; Dorotyak, 2008; Krajewski, 2010). This platform is underlain by the Oxfordian and Kimmeridgian conglomerates, sandstones and limestones (Pivovarov and Derenyuk, 1984), and it lies below the Triassic/Jurassic flysch deposits. This sequence is well exposed beneath the Baydar Yalta-Chatyr-Dag and Demerji yaylas (Figs. 3 and 4). A similar relationship between the TFF and the Upper Jurassic/Berriasian limestone sequences continues eastward (Karabi Yayla) as far as the Arpat Creek in Pryvitne. According to Lalomov (2007), the Upper Jurassic Conglomerate Formation (UJCF) unconformably overlies the TFF in this area, and creates a kind of “lenses” at the base of the Upper Jurassic limestones. In this interpretation, the UJCF is tripartite and reaches 750 m in thickness (e.g., Demerji area). The lower member of this formation (up to 300 m thick) is composed of boulder/pebble conglomerates with sandy clayey matrix. The middle member, up to 250 m thick, is represented by medium- to well-rounded boulder/pebble conglomerates with medium-sorted matrix. The upper member of the UJCF, up to 200 m thick, is dominated by medium/fine-grained sandstones with gravel and small pebbles. In this interpretation, the debris-flow deposits of the UJCF were transported to the basin from the NW. This is confirmed by the granite boulders derived from the Ukrainian Shield (see Lalomov, 2007).

In the Sevastopol area, the uppermost part of the UJCF could be partly correlated with the Hurzuf Formation (~50 m thick), composed of algal limestones, sands and conglomerates (Bilecki et al., 2006a). Probably, a similar position is occupied by the Sukhoriche Formation (Oxfordian/Kimmeridgian), composed of conglomerates, sandstones and biohermal limestones, up to 500 m thick (Bilecki, 2006a).

Along the shoreline, east of the mouth of the Salgir River up to Morskoe village the TFF occurs in a narrow zone tapering toward the E. In this area, the TFF is locally overlain by patches of the Aalenian/Bajocian gravelites with coal intercalations (Pivovarov and Derenyuk, 1984). In the Morskoe village the TFF disappears under a cover of Bathonian/Callovian silty-sandy sediments (Pivovarov and Derenyuk, 1984).

According to Yudin (2009) the contacts of the TFF with older and younger formations are mainly tectonic and accompanied by wide zones of tectonic mélanges. The TFF is transgressively overlain by Lower Cretaceous deposits only between the Salgir and Bodrak rivers. In the rest of the CM, the contacts of the TFF with both the younger and older formations are tectonic.

Until recently, the Late Triassic/Early Jurassic age of the TFF was relatively poorly documented by biostratigraphic, lithostratigraphic and sedimentological studies. The stratigraphic position of the TFF is based on few findings of ammonites (Astakhova, 1968a, b, 1971, 1972, 1976), crinoids, the Upper Triassic bivalve *Monotis salinata* (Klikushyn, 1988; Okay et al., 2015), and palynological data (Bolotov et al., 2004 and references therein). However, when we critically analyse these dates, we should take into account the fact that turbidite sediments contain usually reworked fossils and palynological material (e.g., Oszczypko et al., 2004, 2012a). Reworking processes during the deposition of the TFF are confirmed by the presence of numerous blocks of both sedimentary rocks with fossils, and plutonic and volcanic rocks (Muratov, 1960; Albov, 1964; Ippolitov et al., 2008; Yudin, 2009). Popadyuk (2011) referred to a forgotten publication of Dekhtyareva et al. (1978) where, in addition to the Carboniferous, Permian, Triassic to Middle Jurassic, and Upper Triassic to Lower Jurassic fossils in the exotic blocks of the Eksi-Orda Formation near Simferopol, also the Barremian-Aptian ammonites have been found. Taking into account these data, Popadyuk (2011) questioned the Aptian-Albian age of the TFF, while the age of the post-tectonic sedimentary cover of the CM should be not older than Cenomanian.

Taking into account the interdependence of volcanism and sedimentation of the TFF (see Kruglov and Tsytko, 1988), the studies of detrital zircons from outcrops located near Simferopol and along the Black Sea coast between Yalta and Alushta as well as from the Kastel Massif (west of Alushta) supplied important information (Solov'ev and Rogov, 2010). They provide the following dates (in Ma): 220.1 ± 12 and 169.9 ± 8.6 in the north, 193.6 ± 13.1 , 167.1 ± 12.1 and 154.0 ± 10.2 on the sea-shore, and 149.0 ± 10.9 in the Kastel Massif, thus showing that the age of detrital zircon corresponding to the interval between the Late Triassic to Middle Jurassic and the Oxfordian/Kimmeridgian (Late Jurassic) is similar to the usually accepted age of the TFF, and suggests synchrony of volcanism (Late Triassic–Middle/Late Jurassic) and flysch sedimentation.

Meijers et al. (2010) documented the presence of two groups of volcanic rocks in the Crimea Mts.: older – Aalenian to Oxfordian (~172–158 Ma in the area of the Bodrak Valley and near Simferopol) and younger – Tithonian–Berriasian (~151–142 Ma in Karadag).

The preliminary results of our geological and micropalaeontological studies (Oszczypko et al., 2012b, c) on the TFF in the Bodrak area and along the Black Sea coast confirmed its Upper Triassic–Middle Jurassic age in these localities. They also documented that the Middle/Upper Jurassic Flysch is transgressively overlain by the Upper Oxfordian/Kimmeridgian marine deposits near Laspi. Popadyuk et al. (2013) published a new geological map of the CM (1:200,000) based on determination of 51 foraminifer species and revision of 163 sections (Fig. 3), and pointed out the Aptian/Albian age in the western part of the CM.

The other area of occurrence of the Aptian/Albian deposits is in the eastern part of the CM between Sudak and Feodosia. Unfortunately, in places of typical occurrence of the TFF, samples were barren.

Recently, Sheremet et al. (2014) published important papers concerning large-scale studies of calcareous nanno-

plankton. In course of their project, they collected 224 samples, of which only 52 allowed concluding about their age. These positive samples have been picked up from marly shales, limestones, flysch and flysch-like deposits of the eastern sector of the CM, between Simferopol in the west and Feodosia in the east. The ages of these deposits are not younger than Valanginian in the east and Aptian/Albian in the west. In turn, in the western sector of the CM (W of the Salgir Valley), and along the coastal area between Alushta and Morske, where the TFF is dominant, all samples were empty. However, these results have not been correlated with any lithostratigraphic units shown in geological maps (Pivovarov and Derenyuk, 1984; Bilecki, 2006a, b; Yudin, 2009) and, moreover, samples collected from the unquestionable TFF deposits have been usually barren. In another publication, Sheremet et al. (2016a) give additional micropalaeontological data (e.g., from Berehove and Yalta) and provide a new interpretation of the structural evolution of the CM (Fig. 3).

METHODS

For our studies, we used the geological map 1:200,000 (Pivovarov and Derenyuk, 1984), edited by the Ukrainian Geological Survey. This map well-illustrates the main lithostratigraphic units of the CM (Fig. 4) and shows that the Upper Triassic–Lower Jurassic flysch deposits of the TFF are distributed in two areas: west of the Salgir River (Kacha Uplift) and along the sea shore, between the Sarych Cape in the west and the village of Morske in the east (Figs. 3 and 4).

Initially (2011–2012), our interest was focused on lithostratigraphical studies and sampling of the TFF in its locus typicus area, located west of the Salgir River (Fig. 4) and along the Black Sea coast, between the Sarych Cape in the west and the village of Pryvitne in the east (Oszczypko et al., 2012b, c). Later (2013), these studies were extended on the Jurassic/Lower Cretaceous flysch of the eastern sector of the CM. Our research was carried out along the main road and six selected localities. The studied and sampled sections were documented by GPS way-points (WP) and photographs. During fieldwork, we collected 98 samples for biostratigraphic study, of which 48 samples appeared barren. In the remaining sections (50 samples collected from 37 sites; Figs. 3 and 4) the age determination was based on microfossils (foraminifera and calcareous nannoplankton). Microfacies types have also been determined. In the laboratory, standard processing methods were applied to isolate the foraminifera and dinocysts from shales and mudstones. In general, the samples from shales and mudstones of the TFF contained scarce foraminifera and dinocysts. Additionally, both microfacies and calcareous nannoplankton were analysed in thin-sections from several limestone samples.

STUDIED SECTIONS

WESTERN SECTOR OF THE CM

Our research focused on stratotype areas of the TFF near Prokhladne, south of Simferopol, and along the coast from Rybache in the east to the Sarych Cape in the west (Figs. 3 and 4).

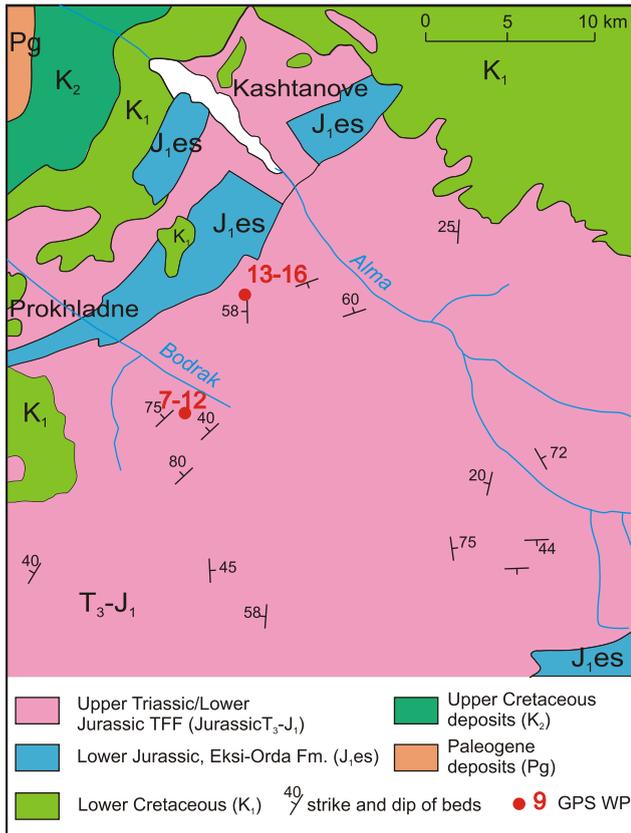


Fig. 5. Geological sketch-map of the Prokhladne area, based on Bilecki (2006b)

Prokhladne area. This area of good outcrops, located on hills between the rivers of Bodrak and Alma (Figs. 5 and 6A–E), is regarded as locus typicus of the Taurida Flysch Formation of Upper Triassic–Lower Jurassic age (e.g., Muratov, 1960; Levitskiy, 1974; Marciniowski and Najdin, 1976; Muratov et al., 1984; Baraboshkin, 1997). In Prokhladne, remains of ammonites (*Dactyloceras* sp.) and belemnites (*Mesoteuthis quenstedtii*) were found at the top of the TFF, which point to the Toarcian/Aalenian age of this formation (Levitskiy, 1974). In the same position, directly below Hauterivian transgressive deposits, Levitskiy (1974) documented the presence of *Palaeopolycheles crymensis*. Modern representatives of this family belong to the marine benthos, occurring at depths of up to 2000 m.

Cartographic position of the TFF in this area is presented on geological maps of Pivovarov and Derenyuk (1984), Bilecki (2006a, b) and Yudin (2009). The first group of exposures (WP 7–12) displays dark grey non-calcareous, fine to very fine, thin- to medium-bedded turbiditic sandstones with shaly and mudstone intercalations, sideritic concretions and rare thick sandstone beds (Fig. 6A–D). Few flute casts of medium-bedded turbiditic sandstone indicate palaeotransport from NW to SE (300°). Greenish-brown shales are covered with reddish/black patina of Fe/Mn minerals (Fig. 6C, E). Subvertically dipping beds are folded and many of them are overturned. Some packages of strongly tectonized beds can be regarded as a kind of “broken formation” (Fig. 6F). About 1.8 km to the north (WP 14, 15; Fig. 5) we found steeply NW-dipping (340/60) thin-bedded turbidites with two diabase sills (0.5 and 4 m thick, see Meijers et al., 2010) showing thermal contacts (Fig. 6D). There is a narrow, up to 1 km wide, NE–SW-oriented syncline of the Eksi-Orda Beds (Lower Jurassic) between the Alma and

Bodrak valleys. Both the TFF and Eksi-Orda Beds are locally transgressively overlain by lobes of Lower Cretaceous deposits, mainly of Albian age (Marciniowski and Najdin, 1976). Bolotov et al. (2004), based on palynofossils and the Norian bivalve *Monotis* sp., documented the Toarcian–Aalenian age of the TFF in the Bodrak River sections. Thin-bedded flysch, similar to that described above, we have observed and sampled also in several exposures along the Black Sea coast, between Rybache in the east and Alushta and the Laspi Bay in the west.

In the poor foraminifera assemblage identified in WP 7, 8, 10–13 (Fig. 5), one species, *Thuramminoides metensis* (Terquem) (Fig. 7), is characteristic for the Middle Triassic, and another one, *Thalmannammina canningensis* Tappan, is also reported from the Triassic–Lower Jurassic. Preliminary studies of organic dinocysts from the Bodrak section (WP 7–17) indicated poorly preserved Lower Jurassic dinocysts: *Phallogocysta* sp., *Walloodinium* and *Nannoceratopsis* sp. *Nannoceratopsis senex* and *N. gracilis* have been occasionally observed, indicating a Late Pliensbachian–Early Bajocian age (Oszczypko et al., 2012c).

Laspi area (Figs. 8, 9 and 10). To the west of Yalta (Figs. 3 and 4), along the coastline, and near Laspi we observed well-exposed flysch. On the geological map of Bilecki (2006a; Fig. 8) these flysch deposits have been included into the upper part the Taurida Formation (T_3-J_1) and the Aalenian/Bajocian flysch (J_2^{ml}) with tuffite intercalations and small subvolcanic diabase veins of Middle Jurassic age. In comparison with the flysch of the Prokhladne sections, turbidites of this area differ in colour and show less intense tectonisation of beds. West of Yalta, in Berehove along the Black Sea coast, we found well-exposed flysch deposits (WP 39; Fig. 8). Previously, these deposits were regarded by Pivovarov and Derenyuk (1984) and Yudin (2009) as the TFF (T_3-J_1). These outcrops display N-dipping (360/35) dark grey thin- to medium-bedded turbidites with thickening- and coarsening-upward sequences (Fig. 9A–C). In general, the flysch deposits from Berehove are significantly different from that of the Bodrak Valley and coastal zones east of Alushta, in both the colour and degree of tectonic deformation of beds.

In the Berehove section (WP 39), a relatively rich Early Jurassic foraminiferal assemblage has been identified in grey siltstones (Figs. 8 and 9A–C, 10; Appendix 1). A thin-section of the same sample also reveals the presence of Upper Jurassic foraminifera. Additionally, from the same locality (Berehove/Kastropol, sample 40 located at 225 m, azimuth 75 from WP 39), Sheremet et al. (2016a) reported the presence of Hauterivian–Early Barremian calcareous nannoplankton. Early Cretaceous (Upper Valanginian–Lower Barremian) calcareous nannoplankton has also been documented in a sample from Yalta (Sheremet et al., 2016a; sample 42).

Going to the west along the road H-19 to the locality of Laspi, we observed and sampled the shaly facies probably belonging to the upper part of the TFF (WP 40; Appendix 1). In the dark beige mudstones, a relatively rich Upper Triassic–Lower/Middle Jurassic foraminiferal assemblage has been documented.

To the NW of the Sarych Cape, above the road H-19, the upper shaly facies of the TFF (WP 40) are transgressively overlain by poorly cemented fine gravel, 10–15 m thick, with claystone (WP 42, 43; Fig. 8). These Upper Jurassic clayey-sandy deposits, with clasts of rhodoid limestones, up to 5 cm across, contain (WP 43) a relatively rich foraminiferal assemblage (Appendix 1) accompanied by ostracods, echinoids, spikes and calcified radiolarians. Its likely age is Early/Middle Oxfordian. A thin-section (WP 43, thin-section 1) revealed the presence of microbial bindstone containing few foraminifera: *Textularia* sp., *Bullopora* sp., *Nubeculariidae*, accompanied by Polychaeta –



Fig. 6. Taurida Flysch Formation of the Bodrak Valley

A – thin-bedded turbidites dominated by dark grey non-calcareous shales and mudstones with rare intercalations of thin-bedded sandstones, with rust-coloured weathering crust (sample WP 7); **B** – sill of Middle Jurassic volcanites; **C** – shaly lithofacies of TFF with few centimetres thick intercalations of very fine sandstones (WP 8); **D** – strongly tectonized shaly lithofacies of TFF (WP 9); **E** – coarsening- and thickening-upward sequence, upper part of TFF; **F** – details of above photographed sequence

Terebella lapilloides Munster, and local accumulations of sponge spicules. This assemblage points to Late Jurassic age. Similarly, a thin-section (WP 43, thin-section 2) from micritic limestone contained poor, but stratigraphically important microfossils (Appendix 1). The age corresponds to late Early–Middle Oxfordian.

In 2012, along the road to Laspi, above samples WP 42–43, samples from the Late Jurassic carbonate platform of the Baydarska (e.g., WP 65; Appendix 1) were collected. These sample contains abundant microfossils indicating Late Jurassic to Early Cretaceous age. The limestones exposed along the road from Laspi to Sokolyne (sample WP 71) contain calcare-

ous nannoplankton (*Nannoconus steinmannii*) indicating Late Jurassic–Early Cretaceous age. Sample WP 74 has also yielded a calcareous nannoplankton assemblage with *Cyclagelosphaera argoensis* and *C. margerelli* Noel, which indicates Late Jurassic to Early Cretaceous age (Appendix 1).

Chatyr-Dag Yayla (Figs. 11 and 12). In the Salgir River Valley, near Dobre (a few kilometres south of Simferopol), we turned off the main road and continued moving up the local road towards the Chatyr-Dag Massif (1527 m a.s.l.). In the roadside exposures, red thick-bedded conglomerates with the red sandy-clayey matrix occur. These NW-dipping continental deposits stretch along the road for a few hundred metres (Fig.

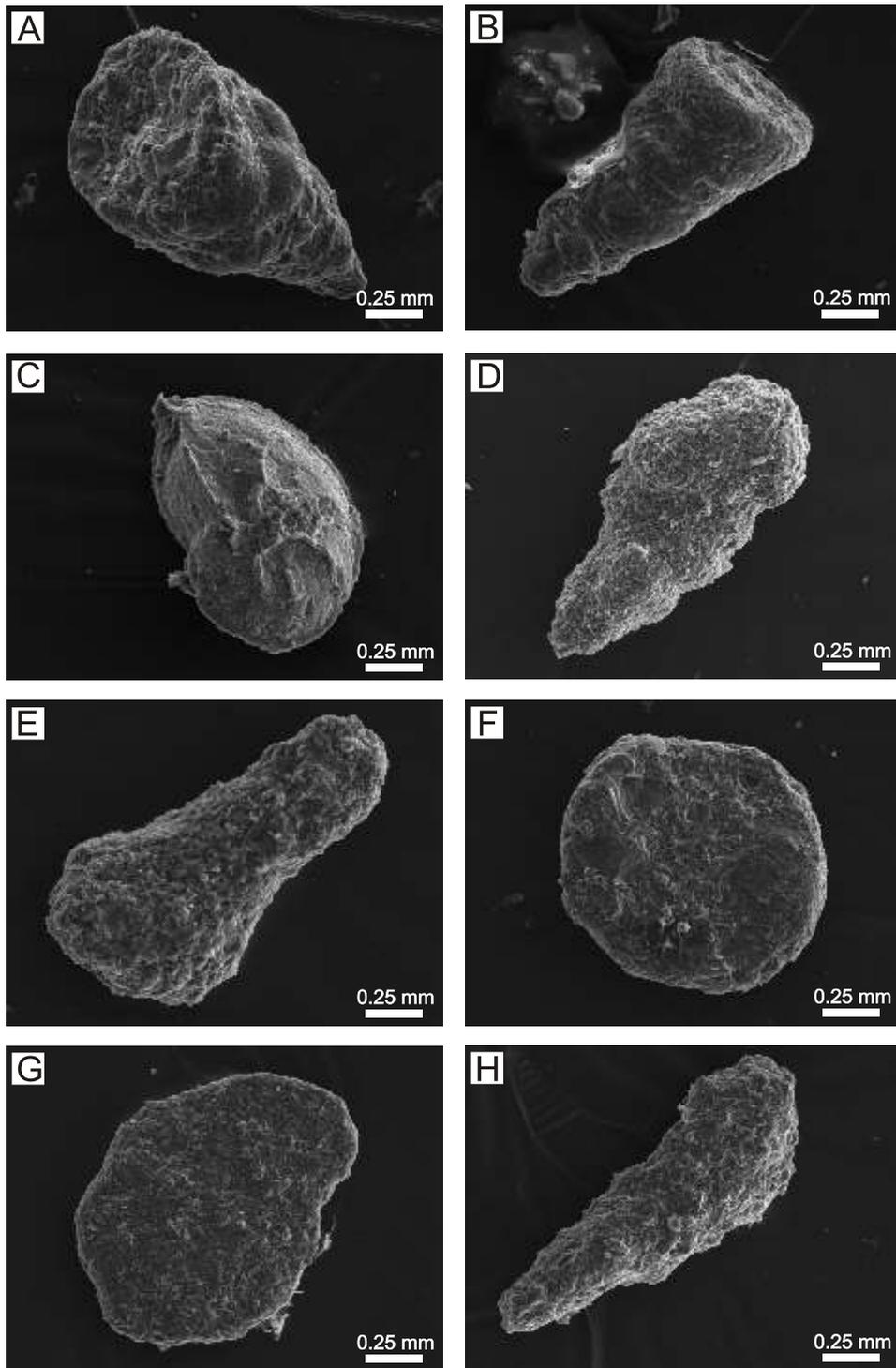


Fig. 7. Microphotographs of foraminifera from TFF (Late Triassic–Early Jurassic), obtained by water maceration

A – *Kechenotiske* cf. *maurikensis* Haig and Mc Cartain, WP 39, side view; **B** – *Palustrella exigua* (Schwager), WP 18, side view; **C** – *Astacolus* cf. *varians* (Bornemann), WP 40, side view; **D** – *Textularia* aff. *haeusleri* Kaptarenko Chernousova WP 18"2011", side view; **E** – *Ammobaculites* cf. *rhaeticus* Kristan-Tollmann, WP 23, side view; **F** – *Thuramminoides metensis* (Terquem), WP 8, side view; **G** – *Trochammina* sp., WP 39, apertural view; **H** – *Vermeulinoides* cf. *liasina* (Terquem and Berthelin), WP 39, side view

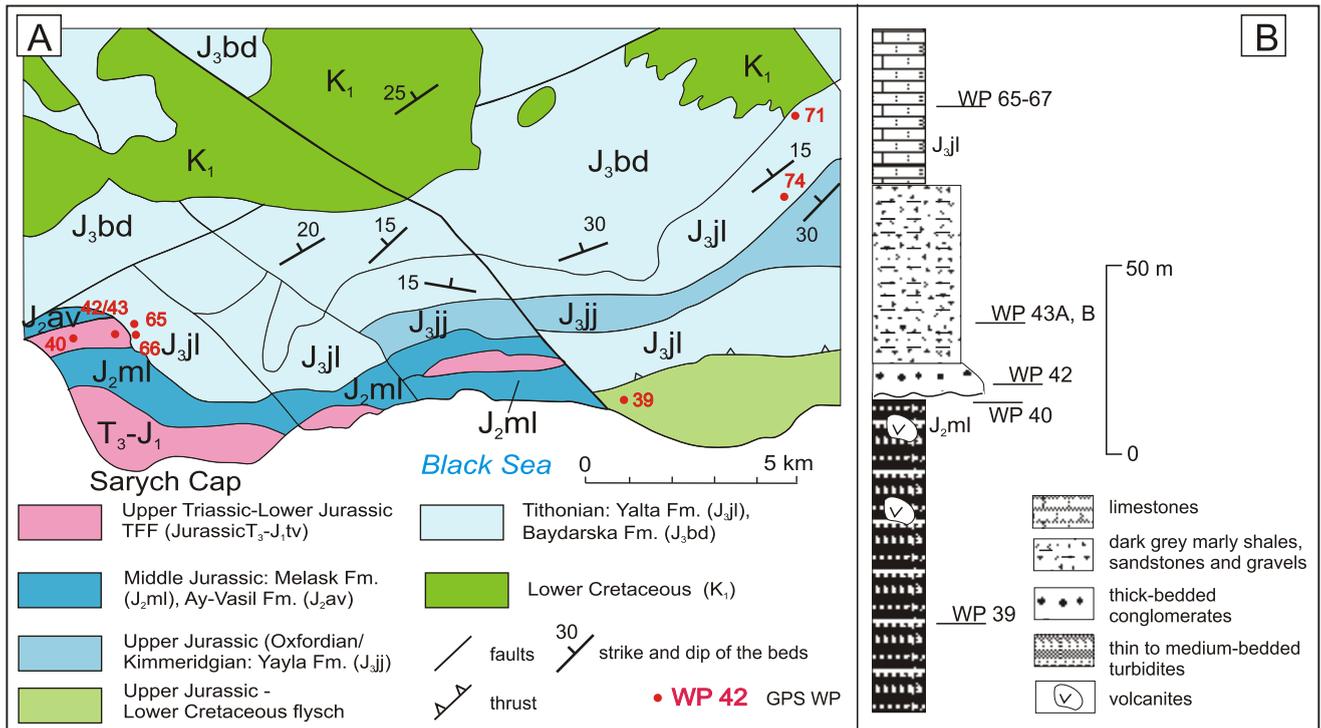


Fig. 8A – geological sketch-map of the Laspi area, based on [Bilecki \(2006a\)](#), with location of sampled sections; **B** – simplified lithostratigraphic profile with location of sampled sites



Fig. 9. Relationship of TFF to the Late Jurassic carbonate platform of Baydarska Yayla near Laspi

A – locations of samples WP 38/39; **B** – WP 42/43, poorly cemented, coarse-grained sandstones, conglomerates and limestone concretions in sandy matrix of the Upper Oxfordian/Kimmeridgian, at the base of hard limestones (Tithonian/Berriassian, see [Oszczypko et al., 2012b, c](#)); **C** – fine gravels and sands (sample WP 42); **D** – Tithonian/Berriassian limestone

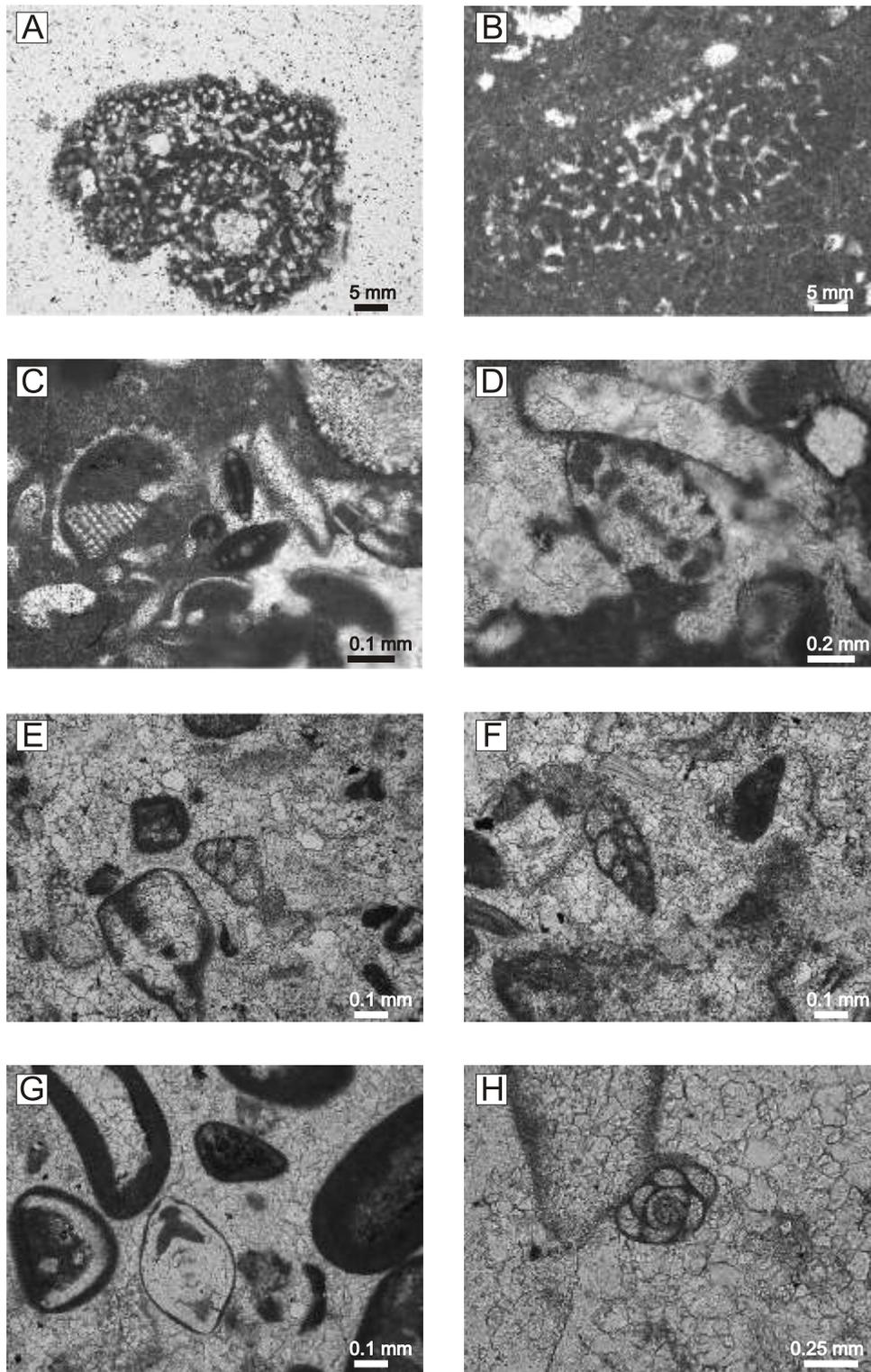


Fig. 10. Foraminifers of the Crimea Mts. found in thin-sections

A – *Anchispirocyclus lusitanica* (Egger), S.6/WP 71, equatorial cross-section, Late Jurassic (Tithonian); **B** – *Anchispirocyclus lusitanica* (Egger), S.6/WP 71, oblique cross-section, Late Jurassic (Tithonian); **C** – “*Vidalina*” *martana* Farinacci, WP 70a, equatorial and oblique cross-section, Lias; **D** – *Involutina* cf. *liasica* (Jones), WP 70a, axial cross-section, Early Jurassic; **E** – *Pseudomarssonella osoviensis* (Bielecka and Styk), WP 70a, axial cross-section, Middle Jurassic; **F** – *Siphovalvulina variabilis* Septfontaine, WP 70a, axial cross-section cutting, Middle Jurassic; **G** – *Protopenneroplis striata* Weynschek WP 70a, cut crosswise, axial cross-section, Middle Jurassic; Sudak-Feodosia transect; **H** – *Quinqueloculina* cf. *occulta* Antonova, WP 70a, cut crosswise, axial cross-section, Middle Jurassic; Sudak-Feodosia transect

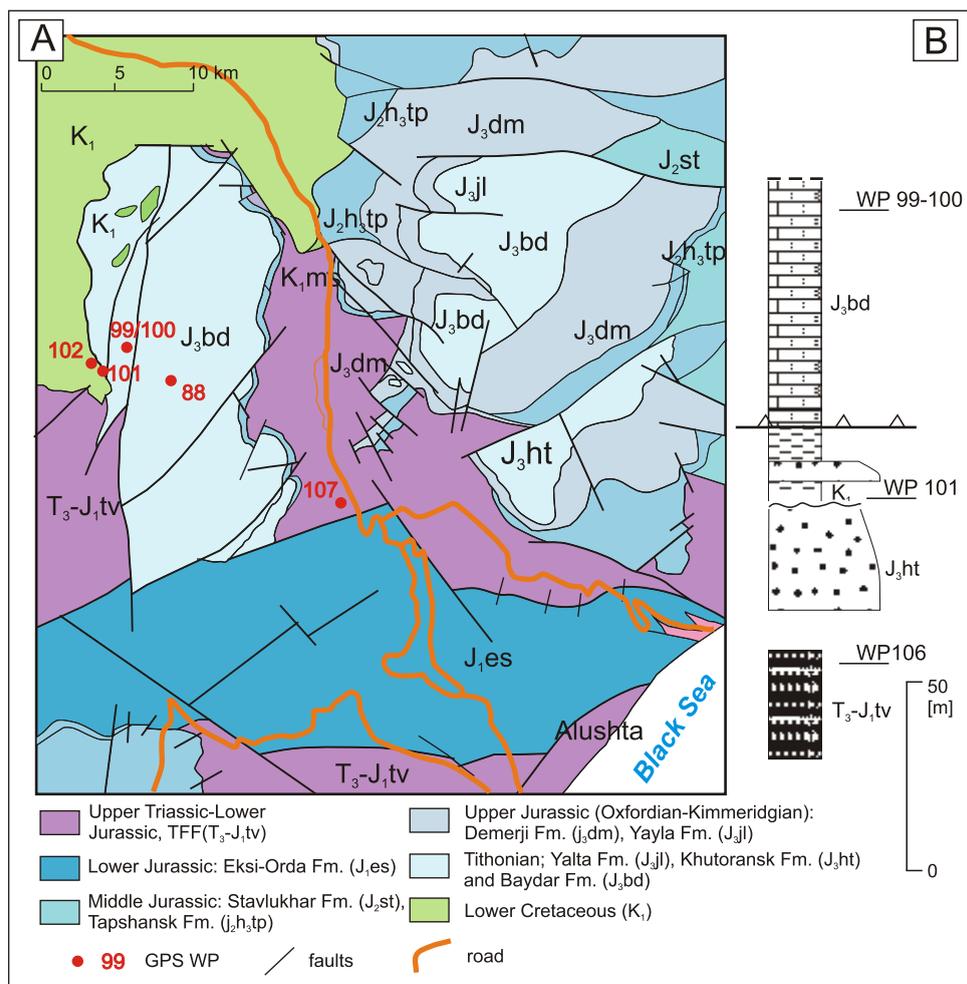


Fig. 11A – geological sketch-map of the Chatyr-Dag-Alushta area, based on [Bilecki \(2006b\)](#), with location of sampled sections; **B** – simplified lithostratigraphic profile with location of sampled sites

11A). The conglomerates have been included by [Pivovarov and Derenyuk \(1984\)](#) into the Callovian/Oxfordian, by [Yudin \(2009\)](#) into the Lower Cretaceous, and by [Popadyuk et al. \(2013\)](#) into the Neogene. Going up to the east, on a steep hillside, the variegated conglomerates are followed by thick beds of Oxfordian grey conglomerates ([Fig. 12C](#)). These conglomerates are overlain by highly tectonized dark grey marly shales that contain mainly pyritized microfossil pseudomorphs, not older than Albian (WP 101; [Appendix 1](#)). The Albian shales are overthrust by the Tithonian/Berriasian grey limestones ([Fig. 12](#)), steeply dipping to the east (85/51). Higher up, along the road to Mramorna Pechera (WP 99/100 and WP 88), karstified limestones of the Chatyr-Dag carbonate platform are exposed. These limestones contain Tithonian-Berriasian microfossils ([Appendix 1](#)). It needs to be highlighted that marly shales from WP 101 clearly correlate with the Albian (K₁a1-2) clays with fossils and siderites ([Pivovarov and Derenyuk, 1984](#)). These deposits are exposed also in the Salgir River Valley on the western margin of the Demerji Yayla carbonate platform. A few kilometres to the SE in the valley separating Demerji and Chatyr-Dag yaylas, at the petrol station (WP 107; [Figs. 11 and 12E](#)) in a cross-cut of a road, we found the south-dipping (190/40) dark grey thin-bedded flysch classified by [Pivovarov and Derenyuk \(1984\)](#) as the upper part of the TFF (T₃-J₁). However, we found relatively abundant microfossils, ostracods and

spines of sea urchins in sample WP 107 ([Figs. 11 and 12E](#)), clearly indicating Early Cretaceous (Neocomian) age. In a thin-section, foraminifera not older than Kimmeridgian were also observed. Similar flysch occurs near WP 108. In this case, the beds (dipping at 310/30) are exposed in a morphological depression located between the Chatyr-Dag (1527 m a.s.l.) and Demerji (1350 m a.s.l.; [Fig. 12F](#)) limestone massifs. This situation gives an impression that these flysch strata dip beneath the carbonate platforms (cf. [Popadyuk and Smirnov, 1991](#)). An interesting result was provided by sample WP 80 collected close to Yalta from grey calcareous mudstones. These deposits were regarded by [Pivovarov and Derenyuk \(1984\)](#) as the uppermost part of the Tauride Flysch (T₃-J₁) located beneath the carbonate platform. Sample WP 80 contains calcareous nannoplankton ([Appendix 1](#)), including *Watznaueria barnesae* (Black) Perch-Nielsen, which could be interpreted as not older than Middle Jurassic and not younger than Early Cretaceous.

Results of sampling along the road cross-sections. In addition to the previously described exposures, our research covered also the outcrops located along the roads in the western part of the CM ([Figs. 3 and 4](#)). In these areas, we recognized, among others, the Upper Jurassic/Lower Cretaceous microfacies (WP 71, 80, 81) typical of the carbonate platform ([Appendix 1](#)) NE of Yalta. In the Alushta region, we have acquired data on the Upper Triassic/Lower Jurassic TFF (WP 31,



Fig. 12. Relation of the Late Jurassic carbonate platform (Chatyr-dag Yayla) to its sedimentary basement

A – red continental conglomerates of TFF (Middle Jurassic?), WP 106; **B** – Oxfordian/Kimmeridgian? reddish and grey conglomerates, WP 105; **C** – breccia of the Aptian dark grey marly shales with blocks of Oxfordian/Kimmeridgian(?) conglomerates; **D** – Tithonian/Berriasian limestones of Chatyr-Dag Yayla, WP 99; **E** – Lower Cretaceous turbidites regarded as the Upper Triassic/Lower Jurassic deposits of TFF, Demerji Stream, near a petrol station, WP 107; **F** – Late Jurassic carbonate platform of Demerji Yayla – view from the west

32, 34, 35), located below the carbonate platform of the Demerji Yayla, and on the northern margin of the Dolhorukovska Yayla.

Eastern sector of the CM. Between the Sudak Bay and the Meganom Peninsula, along the shoreline and directly to the north, N-dipping, dark grey, thin- to medium-bedded turbidites are well-exposed (Figs. 3, 4 and 13). Towards the north, near Solnechna Dolyna, a range of hills exposes thin- to thick-bedded turbidites (Fig. 13D) overlain by conglomerates (Fig. 13E). The folded thick-bedded turbidites are also exposed near Feodosia (Fig. 13F). Further to the east, near Ordzhonikidze, the steep marine cliffs reveal a thick series of Lower Creta-

ceous (Hauterivian, see Sheremet et al., 2016a: point 43) thin-bedded flysch. In WP 170, we have documented a 4 m thick basalt sill that concordantly intercalated flysch deposits. In the Sudak area, we found Upper Jurassic/Lower Cretaceous foraminifera (in WP 153; Appendix 1) and the Upper Jurassic/Lower Cretaceous bioclastic grainstone near Kurortne (WP 158; Appendix 1). The foraminifera determinations confirm stratigraphic data of Sheremet et al. (2014) and Popadyuk et al. (2013). The thin-bedded flysch passes upwards into thick-bedded turbidites and debris-flow conglomerates with huge blocks of Upper Jurassic reef limestones, up to 2 km across (e.g.,



Fig. 13. Lithostratigraphic and sedimentary development of the Sudak Flysch Formation and overlying thick-bedded turbidites and conglomerates

A – Black Sea shore east of Sudak, composed of the Upper Jurassic/Lower Cretaceous flysch formations, view towards the Meganon Peninsula; **B** – steeply dipping medium- and thick- bedded flysch deposits; **C** – huge exposures of the Jurassic/Cretaceous flysch, view towards the NE; **D** – large conglomerate and sandstone exposures north of Solnechna Dolyna; **E** – a packet of thin-bedded flysch overlain by thick-bedded sandstones and conglomerates; example of a thinning- and fining-upward turbidite sequence; **F** – thick- and medium-bedded turbidites near Feodosia

[Khart-Kaya](#); see [Yudin, 2009](#)). These deposits are exposed between Pryvitne in the west and the Cap Kuuk-Atlama in the east, over a distance of at least 70 km. The width of the outcrops of these beds ranges between 2 km near Pryvitne to ~30 km at the Meganom meridian. These coarse clastic cone, underlain by distal turbidites in the south, is overlain by Lower Cretaceous marls and limestones in the north.

The age of this formation is Lower Cretaceous, not younger than Valanginian ([Sheremet et al., 2016a](#)).

Morske-Vesele-Novyi Svit sections (Figs. 14–17). These sections are located along the road P 29 from Morske to Sudak (Figs. 3 and 4). The Vesele section begins with the strongly folded flysch of Lower Jurassic ([Pivovarov and Derenyuk, 1984](#)) or Middle Jurassic ([Bilecki, 2006b](#)) age. These flysch deposits are well-exposed in the right side (S) of the road cross-cut (Figs. 14 and 16). They are represented by series of dark shales and micaceous mudstones with intercalations of NW-dipping, thin- to medium-bedded turbiditic sandstones which display palaeo-transport from the E (Fig. 16A–C). These deposits probably ex-

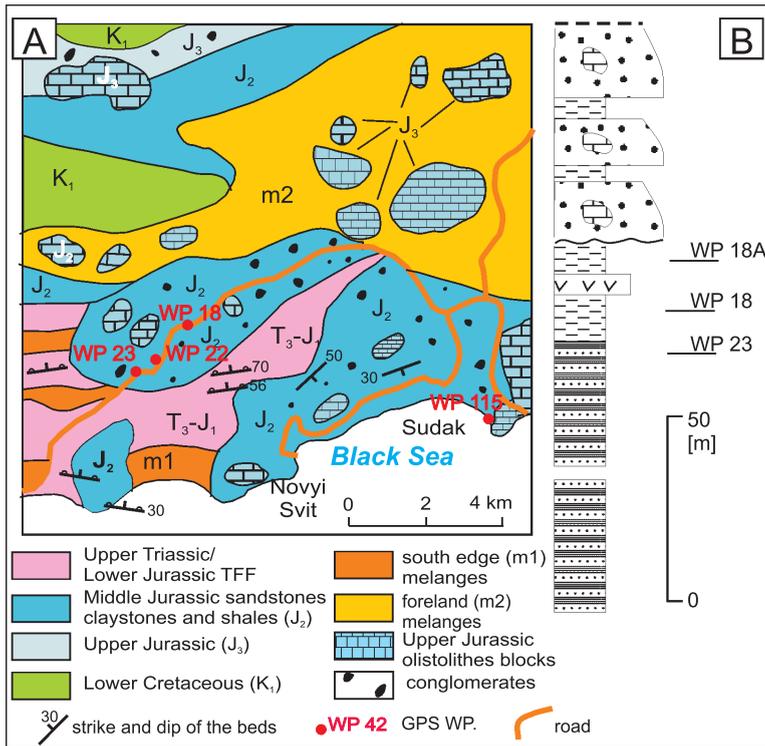


Fig. 14A – geological sketch-map of the Vesele and Novyi Svit area (based on Yudin, 2009) with location of the studied and sampled sections; **B** – simplified lithostratigraphic section with location of sampled sites

tend southwards to the Perchem-Kaya (576 m a.s.l.) with very thick, NW-dipping flysch series (Fig. 16D).

The sample collected in WP 22 (Fig. 14) was barren. Further to the west, within grey and beige micaceous mudstones exposed along the N side of the road, one of the samples (Fig. 13E; WP 23) contained foraminifera that suggest Late Triassic–Early Jurassic age (see Appendix 1). A few hundred metres further to the east, these flysch deposits are overlain by a thick conglomerate complex exposed on the left (N) side of the road (Fig. 15E) and dipping towards the NE. The age of these conglomerates has been differently interpreted: as Upper Callovian–Early Oxfordian by Pivovarov and Derenyuk (1984) and Bilecki (2006b) and as Middle Jurassic sandstones, mudstones and argillites with the Upper Jurassic reef limestone olistolith by Yudin (2009).

According to our observations, these deposits consist of thick-bedded, graded, channelized conglomerates, pebbly mudstones, and sedimentary breccias. They contain pebbles and large blocks of limestones with macrofossils and fragments of brachiopods. This coarse-grained complex shows a thinning-upward sequence with more sandstone intercalations upper in the section. The exact characteristics of the thick-bedded turbidites and debris-flow conglomerates with limestone blocks is shown in Figure 14B.

The conglomerates are composed of variously sized Upper Jurassic limestone blocks and boulders, supported by gravel/sandy/clay matrix. Towards the east, there are several very large limestone olistoliths, up to 1 km across (Fig. 13; see also Yudin, 2009). Thin-sections of these limestones from the lowermost part of the conglomerate complex contain the Oxfordian and Kimmeridgian microfossil assemblages (Appendix 1). It suggests that these conglomerates cannot be older than Kimmeridgian and younger than Berriasian. However, since the

fossils come from redeposited material, their precise age cannot be determined.

North of Vesele, in the pass near the cross-roads towards Sudak (Fig. 13; WP 18), there is a large block (5 x 3 m) of volcanites (Fig. 15F). This is a kind of Middle Jurassic or Upper Jurassic/Lower Cretaceous volcanic sill as a monadnock or olistolith block derived from the Upper Jurassic conglomerates. This block is underlain and overlain by dark grey mudstones which contain Upper Triassic/Lower Jurassic foraminifera at the base – WP 18 (Appendix 1) – and Upper Jurassic microfossils and calcareous nannoplankton at the top – WP 18A (Appendix 1). From the Vesele sections, Sheremet et al. (2014, 2016a) reported the Lower Cretaceous nannoplankton, not younger than Valanginian, collected from marly shales (points Nos. 59–61) located 50–60 m east (azimuth 81) of WP 18A.

In the Vesele section, along the northern side of the road, there are well-exposed different types of conglomerates and thick-bedded turbidites (Fig. 15A, B), matrix-supported debris flows (Fig. 15C), and chaotically organized conglomerates (Fig. 15D). In this section, we recognized deposits of different ages: both Upper Triassic–Lower Jurassic and Upper Jurassic/Lower Cretaceous (WP 23, WP 18 and 18A). There is similar situation with section WP 39 (Berehove). This documented that during the Late Jurassic/Early Cretaceous deposition the Late Jurassic/Early Cretaceous debris flows and turbiditic currents eroded the Lower Jurassic flysch sediments and transported to the Sudak Basin together with reworked microfossils.

From the Vesele section (WP 18), we continued our observations along the road to Novyi Svit (Fig. 17). North of the road we passed the Khart-Kaya (375 m a.s.l.), a very large block (1 km across) of Upper Jurassic limestones. According to Yudin (2009) the block is incorporated into mélangé (m2). It is highly probable that this block is one of the many large olistoliths in the Upper Jurassic/Lower Cretaceous debris-flow conglomerates. Deposits with huge olistoliths are well exposed on a cliff edge towards Novyi Svit (e.g., the Koba-Kaya cliff; Fig. 17A) – see the Callovian/Oxfordian carbonate reef massif (Nikishin et al., 2015b), and on the cliff close to the lighthouse in Novyi Svit (Fig. 17B). On the southern slope of the massif, along the road, and directly below the conglomerates, carbonate sedimentary breccia (Fig. 17C) is exposed. The limestone block contains large *Pecten* shells (Fig. 10D), and ammonite (Fig. 17E) and ?stromatoid casts. This suggests that they can represent a redeposited biohermal facies. One of the samples taken from grey shale intercalations (sample WP 115) yielded a relatively rich assemblage of Lower Cretaceous (Neocomian) foraminifera (Appendix 1). Just below the road, there are strongly disturbed grey-greenish mudstones devoid of microfossils and fragments of limestones, which probably represent sedimentary breccias, without mesostructures characteristic for breccias of tectonic origin. From this section, Sheremet et al. (2016a) reported Upper Jurassic/Valanginian calcareous nannoplankton (points 66 and 67).

Pryvitne-Krasnolisia transect (Figs. 18 and 19). In this area, our research was carried out along a local road over a distance of ~10 km. The cross-section begins ~7 km from the coastline of the Black Sea and runs northward through Pryvitne towards the main ridge of the CM, up to Krasnolisia (Bilohirsk direction). According to previous studies in this loca-



Fig. 15. Relation of the Early Cretaceous debris flow conglomerates to their flysch bedrock in the Vesele section

A – view from the road on the southern slope of Perchem-Kaya (576 m a.s.l.) with very thick, NW-dipping flysch series of TFF?; **B** – thin- to medium-bedded turbidites of TFF, roadcut; **C** – dark grey calcareous mudstones (sample WP 23); **D** – vertically dipping medium-bedded fine-grained sandstone, view on the lower surface with flute marks; **E** – ?Middle Jurassic/?volcanic olistolith (a few metres across) within dark grey shales (samples WP 18 and 18A); **F** – graded debris-flow conglomerates and thick-bedded sandstones of the basal part of the Upper Jurassic/?Lower Cretaceous transgressive series, northern side of road

tion (Pivovarov and Derenyuk, 1984; Bilecki, 2006b; Mileev et al., 2006; Afanasenkov et al., 2007; Yudin, 2009), the coastal plain, up to 8 km wide, is composed mainly of the TFF. According to Pivovarov and Derenyuk (1984), Upper Triassic-Lower Jurassic flysch deposits in this area are overlain by the Middle Jurassic flysch with intercalations of gravelites and lenses of coal. After Yudin (2009) the coastal band of the TFF (T_3 - J_2), ~3–4 km wide, is limited from the S and N by melange zones composed of the lower (T_3 - J_1) and upper (T_3 - J_2) parts of the

TFF, followed by a narrow zone of the Middle Jurassic sandstone/claystone flysch (J_2).

In this place, our transect (Fig. 18) starts with strongly tectonized black and dark grey shales, mudstones and thin- to medium-bedded sandstones (Figs. 18 and 19A, B). These beds are substantially similar to the upper part of the TFF (T_3 - J_2) and barren in microfossils (WP 122). In a conglomerate layer of WP 125 (Figs. 18 and 19C), we recognized a block of dark rudstone with the species of *Troglotella incrustans* Wernli and Fookes



Fig. 16. Upper Jurassic/Lower Cretaceous conglomerate series in the Vesele road section

A – fine conglomerates at the base of sub-vertically dipping thick-bedded turbidite sandstones; **B** – thick-bedded sandstone and laminated mudstones at the base of a few metres-thick sequence of channel deposits; **C** – submarine slump conglomerates capped by laminated mudstones; **D** – matrix-supported debris flow with well-rounded cobbles; **E** – poorly sorted matrix-supported conglomerates; **F** – chaotically organized matrix-supported conglomerate

and microproblematic *Koskinobullina socialis* (Cherchi and Schroeder) suggesting an age not older than Kimmeridgian. Upper Aptian calcareous nannoplankton has recently been reported from a site located ~2 km to the east of WP 125 (see Sheremet et al., 2016a: points 22 and 23, table 3). Higher up along our transect, folded dark flysch with intercalations of conglomerates is observed up to WP 134 (Fig. 18), where the flysch deposits are overlain by a very thick complex, up to 1000 m thick, of sedimentary breccias and conglomerates building up the main range of the mountains (Fig. 19D–E). They represent mainly various types of submarine slump deposits,

debris-flow deposits (debrites with large olistostromes of Upper Jurassic micritic limestones), as well as thick-bedded turbidites, which commonly display channelization. Conglomeratic sequences are separated by few turbiditic sequences with medium- to thick-bedded sandstones and dark grey mudstones or shales, which are few metres thick. The Pryvitne conglomerate complex is overlain by a sequence of thin- and medium-bedded sandstones, several tens of metres thick, with thin intercalations of shales (Figs. 18 and 19F). Microfossils identified in the investigated samples (WP 100 and 149) suggest a Tithonian–Berriasian age or more likely Berriasian age (see Appendix 1).



Fig. 17. Debris-flow thick-bedded conglomerates and olistoliths of Upper Jurassic reef limestones along the cliff in Novyi Svit

A – seashore cliff along a road to Novyi Svit; SW-dipping conglomerates with several huge blocks of rocks at the top (Koba-Kay – Callovian reef limestones; see [Nikishin et al., 2015b](#)); **B** – western view of the Novyi Svit seashore cliff, the Novyi Svit lighthouse, and a thick series of channelized Jurassic/Lower Cretaceous conglomerates; **C** – limestone block with a cast of brachiopod shell; **D** – cast of a Jurassic ?ammonite in a large limestone boulder of Jurassic/Lower Cretaceous conglomerates

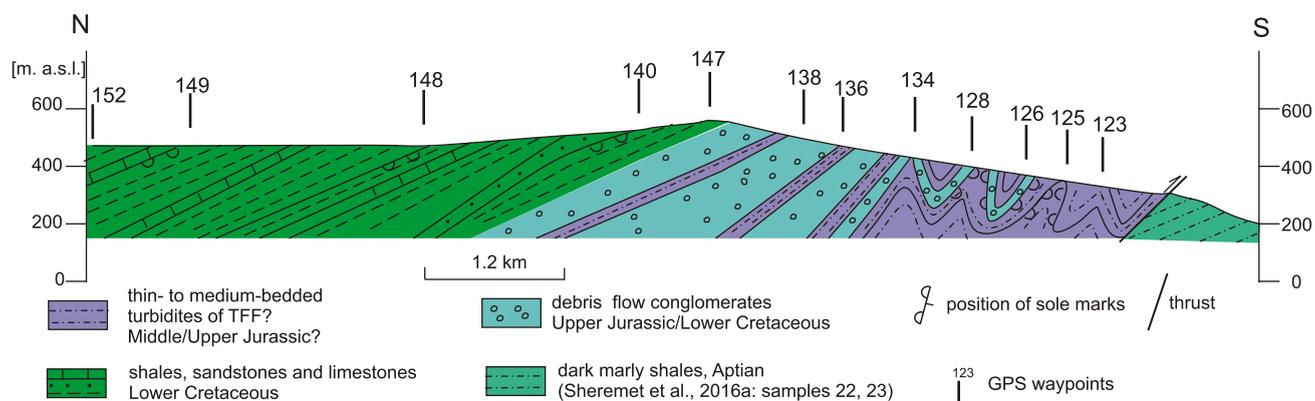


Fig. 18. Geological cross-section Pryvitne-Bilohirsk

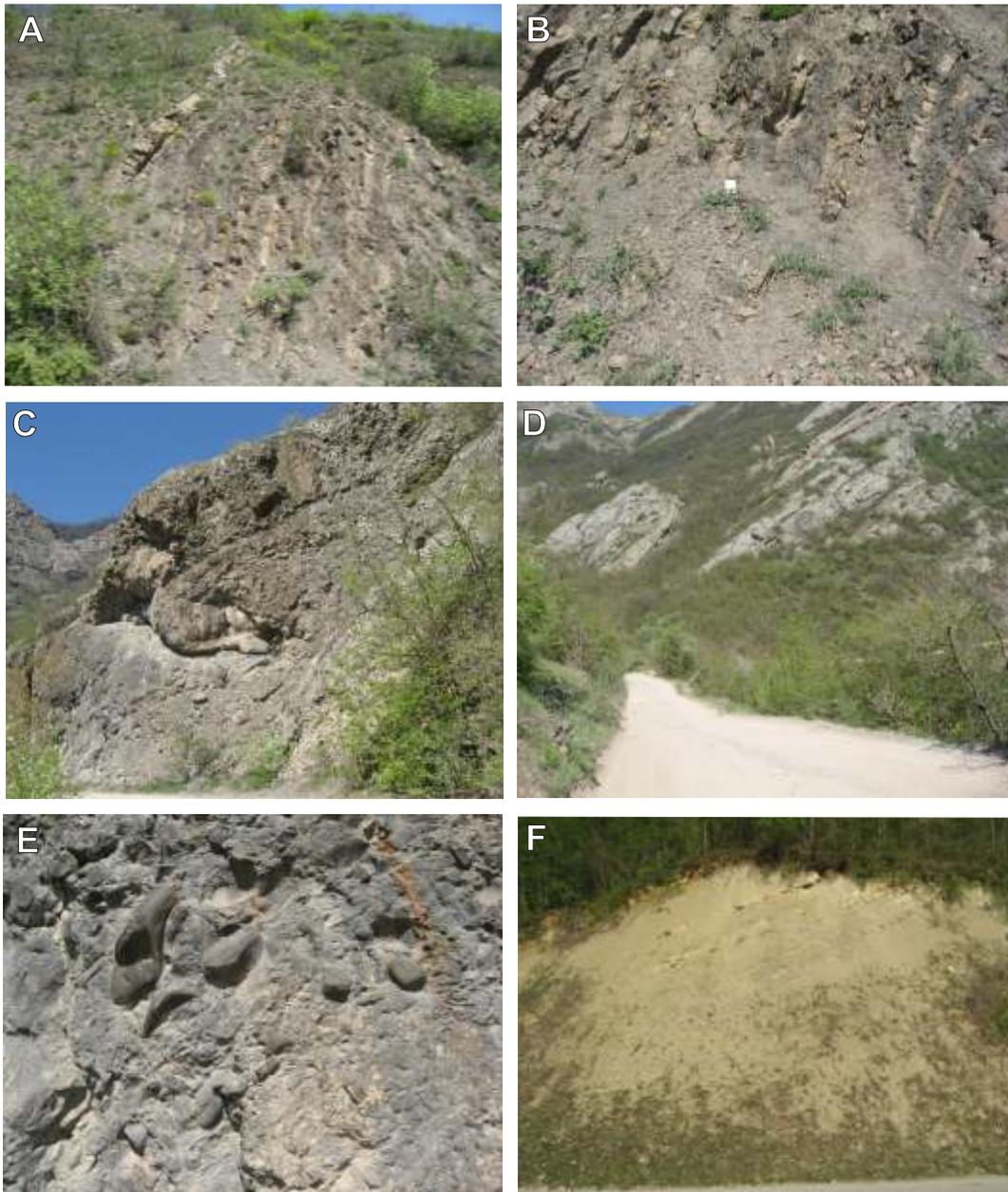


Fig. 19. Typical lithofacies along the Pryvitne-Bilohirsk transect

A – thin- to medium-bedded flysch of ?Taurida type, a narrow strongly deformed anticline (WP 123); **B** – ?Taurida-type flysch at the base of debris-flow conglomerates; **C** – thick-bedded conglomerates with boulders and blocks of limestones; **D** – fining-upward conglomerate sequence near the pass; **E** – well-imbricated boulders and cobbles of conglomerates with sandy/gravelly matrix; **F** – Cretaceous flyschoid deposits with limestone intercalations, directly above the top of conglomerates, behind the pass (WP 149)

Further along the profile there is a sequence of thin- to thick-bedded turbiditic sandstones and dark grey mudstones with sporadic intercalations of very thick channelized conglomerates. On the map of [Pivovarov and Derenyuk \(1984\)](#) these deposits are regarded as Tithonian/Berriasian. Recently, [Sheremet et al. \(2014, 2016a\)](#) included these beds into the Upper Jurassic/Valanginian. Our samples (WP 99a and b) confirm the Lower Cretaceous age (Lower Berriasian – sample 99a;

Upper Barremian – sample WP 99b; [Appendix 1](#)). Further towards the north, the next samples WP 151a and b, taken from a redeposited conglomerate block within grey mudstones, contain a foraminiferal assemblage of Tithonian age ([Appendix 1](#)). It ought to be stressed that these samples represent redeposited material and the Tithonian age is related to the primary age of sediments before subsequent reworking.

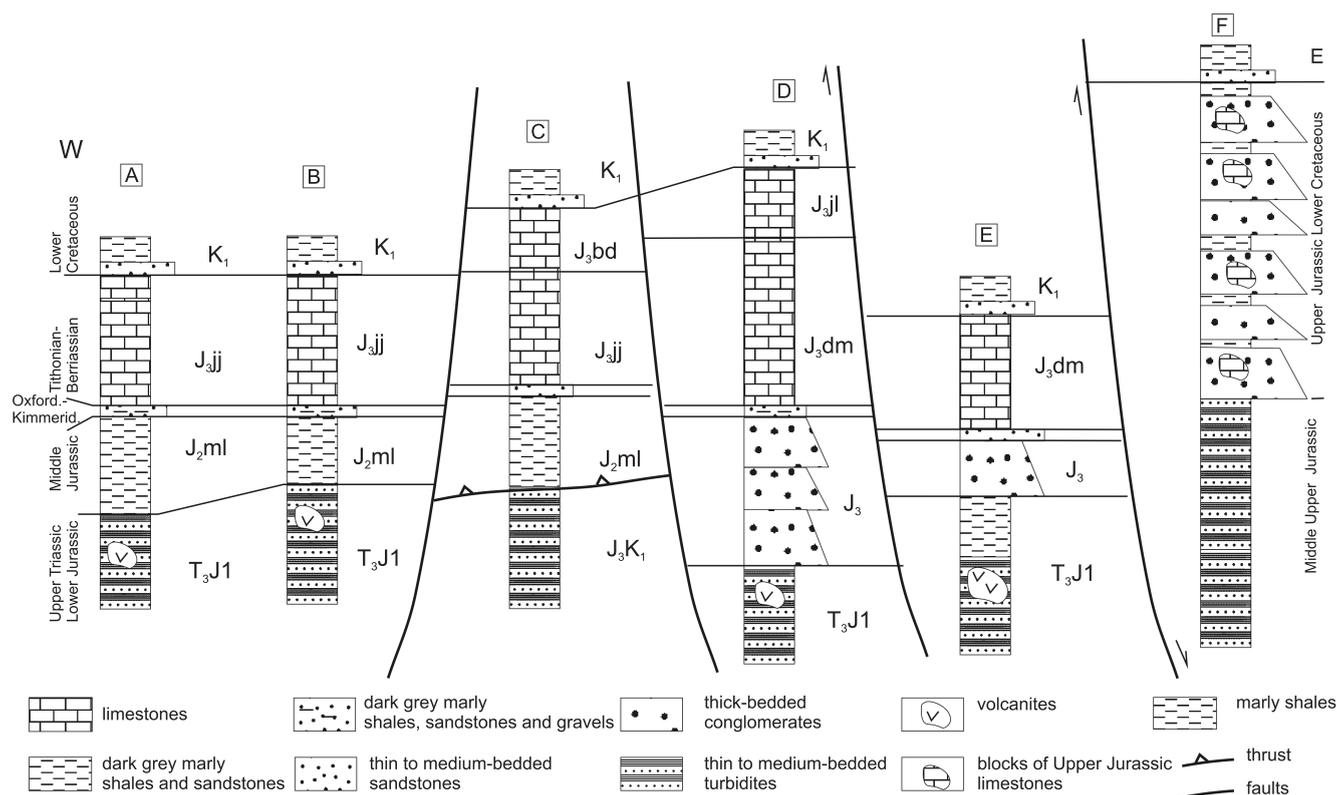


Fig. 20. Correlation of Mesozoic sediments along the Black Sea coast

A – southern termination of the Kacha Uplift; B – Laspi Area; C – Ay-Petri and Yalta massifs, Dimerji Yayla; D – Karabi Yayla; E – eastern sector of the CM, east of Pryvitne; F – eastern sector of the CM, Vesele-Novyi Svit-Sudak

INTERPRETATION

RELATIONSHIP OF THE TFF TO THE YOUNGER DEPOSITS OF THE CM

Our observations and published data on the relationship of the TFF with younger deposits indicate that in the NW sector of the CM (Kacha Uplift) up to the Alushta-Salgir-Simferopol Fault Zone, the TFF is transversively overlain by the Lower Cretaceous, mainly Hauterivian, deposits (Pivovarov and Derenyuk, 1984; Bilecki, 2006b; Yudin, 2009, Sheret et al., 2014, 2016a; see also Figs. 3 and 4). It suggests that this area was emerged and intensely eroded during the Late Jurassic/Berriasian. A different situation is observed along the western coastal part of the CM (Figs. 3, 4 and 20). Between the Sarych Cap and Berehove, strongly deformed TFF, followed by Middle Jurassic deposits on the elevation up to 250–300 m a.s.l.; occurs in a narrow zone. In some places, there are small sub-volcanic dykes and sills, related to the Middle Jurassic volcanism (Bilecki, 2006a). In this area, the TFF is overlain by the Middle Jurassic Melask Fm. followed by the Oxfordian/Kimmeridgian correlative horizon, ~50 m thick (see Oszczypko et al., 2012b, c). This unit could be partly correlated with both the Hurzuf (Bilecki, 2006a) and Sudak correlation horizons (see Leshchukh et al., 1999).

Towards the east, in the Berehove-Yalta uplifted block, we recognized the Upper Jurassic flysch (Lower Cretaceous according to Sheremet et al., 2016a), overthrust by the Upper Jurassic carbonate deposits of the Ay-Petri-Yalta Massif (Krajewski and Olszewska, 2007; Krajewski, 2010).

Between Yalta and Alushta, along the shoreline, the TFF again reveals numerous intrusions of the Middle Jurassic volcanites. The largest intrusion (3 x 4 km) of gabbro/basalts is located near Hurzuf (Ayu-Dag, see Bilecki, 2006b; Yudin, 2009). There are also large Middle Jurassic intrusions of gabbro/diabases and plagiogranites in this area (e.g., Kastel; Bilecki, 2006b; Solov'ev and Rogov, 2010).

In the post-Albian period, the Alushta-Salgir tectonic zone was transformed into the SE-dipping thrust fault that moved the Chatyr Dag Massif by at least 10 km to the west. East of this fault zone, the TFF narrows and then completely disappears near the village of Morske (Pivovarov and Derenyuk, 1984; Bilecki, 2006b; Yudin, 2009). Between the Sarych Cup and Alushta the TFF is overlain by the Middle Jurassic siltstone/claystone formations, 250–300 m thick (Fig. 20; see also Bilecki, 2006a, b). The lower part of the sequence belongs to the Belbek Fm. (S margin of the Kacha Uplift) and the Melaskaya Fm. (Laspi and Yalta/Ay-Petri sections), whereas the top of the sequence is included in the Ay-Vasil Formation.

East of Alushta, the position of the Middle Jurassic series is occupied by the Upper Jurassic conglomerates, up to 800 m thick (Lalomov, 2003, 2007). These conglomerates discordantly overlie the TFF and are covered by Tithonian/Berriasian carbonate platforms of the Dimerji Yayla (cf. Bilecki, 2006b). Similar conglomerates, described by Bilecki (2006b) as the Tapshan (J₂h3tp) or Khutoran beds (J₃ht), are also found below the Chatyr-Dag and Karabi-Yayla carbonate platforms (Fig. 20). In both sections, the lower, red part of the conglomerates is of continental origin. These deposits probably represent alluvial river system cones derived from the NW (granitoids from the Ukrainian Shield, see Lalomov, 2007). Upper in the section the

red conglomerates are replaced by grey debris-flow conglomerates deposited in a submarine coastal fan delta (Lalomov, 2007) or a Gilbert-type delta (Baraboshkin and Piskunov, 2010). The Demerji fan delta is a kind of half-graben cut by the Simferopol/Alushta Fault from the west, and edged to the east (Nikishin et al., 2015b).

Along the coastline, between the Sarych Cap in the west and Pryvitne in the east, the TFF (T₃-J₁), followed by Middle Jurassic and Oxfordian/Kimmeridgian deposits, are overlain by the Tithonian/Berriasian carbonate platform. The thickness of this platform ranges from ~500 m in the west (Sarych, Laspi), ~800 m in the Ay-Petri Massif, ~1300 m in Demerji, and ~500 m in Karabi yaylas in the east. The Tithonian/Berria-

sian carbonate platform (Zhabina, 2008; Zhabina and Anikeyeva, 2008) is regarded as a regional correlative horizon of the Main Ridge of the CM, transgressively overlain by the Valanginian/Hauterivian deposits. Near the village of Pryvitne, the Korabi carbonate platform disappears. On the map of Pivovarov and Derenyuk (1984), this boundary can be interpreted as a NW-SE scissor fault. In this interpretation, the NW wing of faults is occupied by the Valanginian-Hauterivian carbonate/marly deposits, while in the SE wing of the fault, the Jurassic/Cretaceous conglomerates and flysch occur. In a similar way, the map of Yudin (2009) can be interpreted. In the interpretation of Sheremet et al. (2016a), the fault zone has a NE-SW direction.

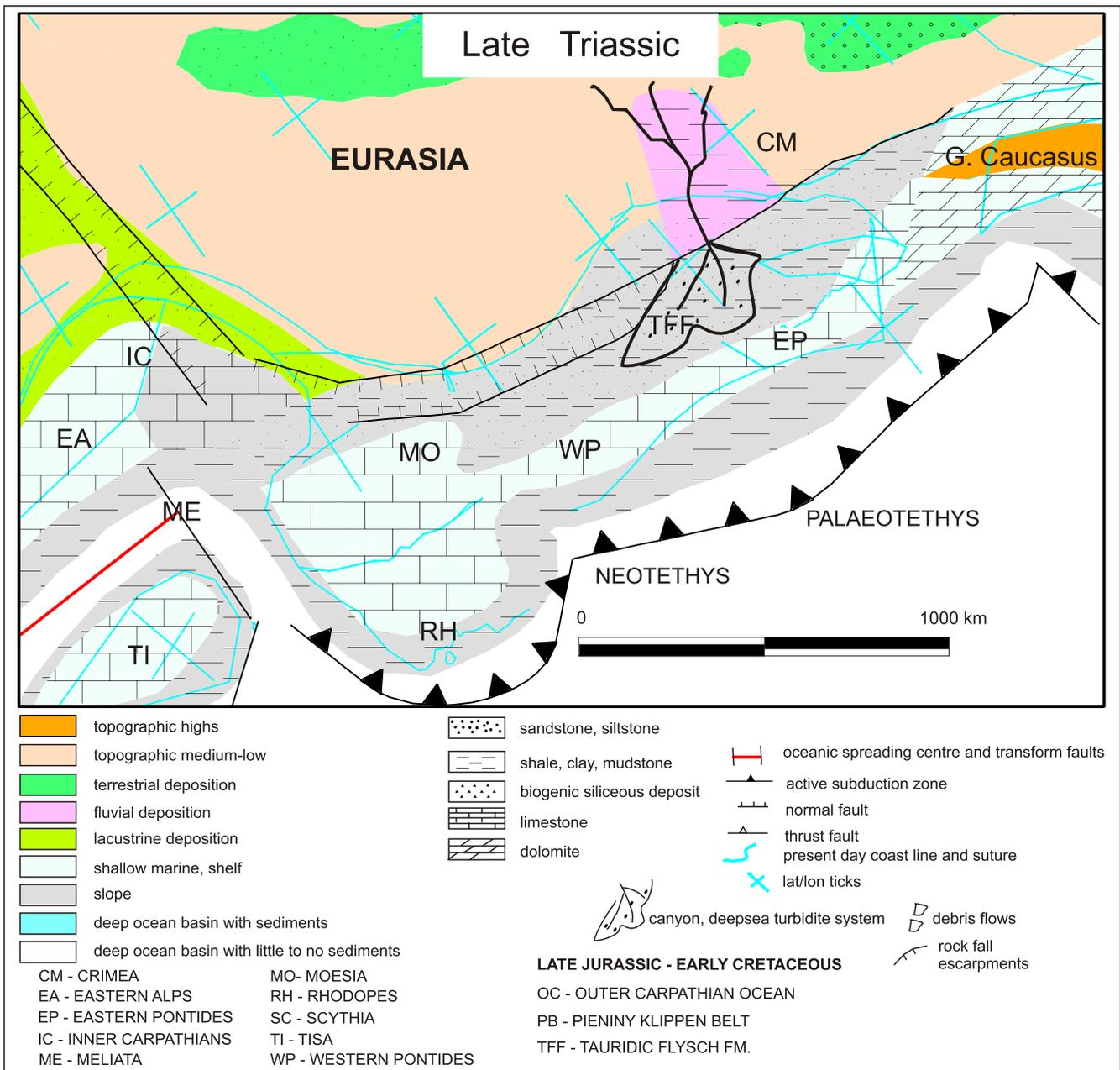


Fig. 21. The Late Triassic palaeotectonic position and lithofacies of the southern margin of Eurasia

Based on Golonka (2004, supplemented)

PALAEOGEOGRAPHICAL RECONSTRUCTION

During the Late Triassic/Early Jurassic (plate position at 225 Ma), the Taurida Flysch basin was located in the back-arc position (Golonka, 2004). This basin occupied the southern slope of the Scythian platform and the Pontide deep-water basin (Fig. 21). The measurements of palaeotransport directions in the Bodrak Valley show supply of clastic material from the NW. During the Early Jurassic (Nikishin, 2015b), marly/clay sediments were deposited in the northern, shallow-water part of the basin, locally followed by the accumulation of Lower/Middle Jurassic mudstones and claystones with coal-bearing intercalations (Pivovarov and Derenyuk, 1984; Bilecki, 2006a; Vergelska, 2016). This was followed by the Middle Jurassic folding, uplift and volcanic activity in the northern sector of the CM. According to Kruglov and Tsytko (1988), the folding and uplift were connected with the Early Cimmerian phase and took place only in the outer (WW) part of the Crimea Basin, while in the inner (SE) part of this basin, deep-water sedimentation persisted to the Early Cretaceous.

In the northwestern, folded and uplifted part of Crimea, erosion processes controlled the development of the river network, which supplied the Chatyr-Dag-Demerji alluvial cone,

with clastic material derived from erosion of the uplifted Scythian Platform (Lalomov, 2003, 2007). The width of this cone, could reach 50 km. During the Oxfordian marine transgression from the south, the alluvial cone in the north was gradually transformed into a marine fan delta. During the Kimmeridgian/Tithonian, this transgression resulted in the development of an extensive sea bay. Northwards (Demerji-Zuya), this bay might have reached a width of 60 km. Towards the west the bay probably narrowed to ~20 km. A carbonate platform developed in this bay and in the adjacent shelf area. High subsidence rate of this area in the period ~15 My allowed the deposition of carbonate sequence, up to 1500 m thick. At the same time, the present-day Kacha Uplift was probably still emerged and eroded.

It is unclear what happened at that time in the eastern sector of the CM. Perhaps, during the Middle Jurassic, parallel with the uplift of the north-western sector of the CM, the residual flysch basin moved eastwards of the Pryvitne, to the Sudak Trough. It was followed by the Late Jurassic/Early Cretaceous rifting (Stovba et al., 2013) and intense subsidence in the eastern sector of the CM, which obtained a connection with the sedimentary area of the Great Caucasus (Fig. 22). Simultaneously, a new source area appeared on the NW margin of the

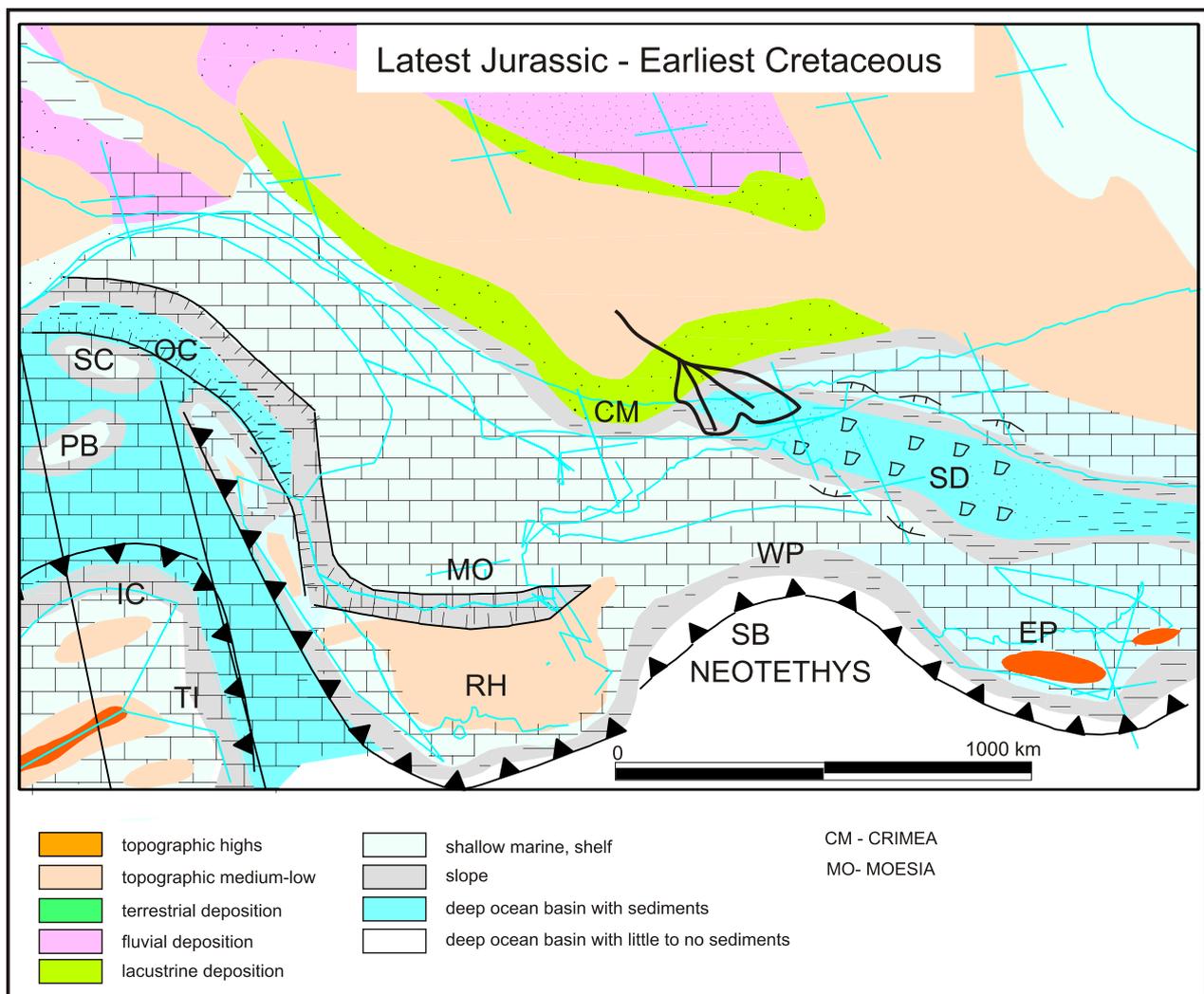


Fig. 22. The Late Jurassic-Early Cretaceous palaeotectonic position and lithofacies of the southern margin of Eurasia

Based on Golonka (2004, supplemented)

Sudak Trough. During the Late Jurassic and Early Cretaceous, that area supplied the basin with a huge amount of clastic material transported by turbidite and debris flows. At the same time, an active fault zone developed at the boundary between the eastern margin of the carbonate platform and the Sudak Trough. This zone generated significant landfalls of Upper Jurassic limestones derived to the Sudak Through as olistoliths and olistostromes. This resulted in progressive westward narrowing of the eastern sector of the carbonate platform, at least over a distance of ~10 km. Destruction of the carbonate platform was terminated with the beginning of the Valanginian/Hauterivian marine transgression.

DISCUSSION

Our results indicate the existence of at least two flysch formations in the CM: the Upper Triassic-Lower/Middle Jurassic and the Upper Jurassic/Lower Cretaceous ones. In addition, the Aptian/Albian flysch-like deposits might have been locally deposited. The oldest foraminiferal assemblages that contain the species *Thuramminoides metensis* (Terquem) and rare *Thalmanamina canningensis* Tappan were found in several samples of brown and dark grey ferruginous siltstones intercalated by turbiditic sandstones from the Bodrak Valley, commonly regarded as belonging to the TFF. These species are known only from the Late Triassic/Early Jurassic. No younger species have been found. Samples of the TFF also show no traces of reworked species. Two samples (WP 11, 12) from this locality contain stratigraphically significant calcareous dinocysts: *Nannoceratiopsis senex* and *N. gracilis*, which indicate Early Jurassic age. There is also one sample (WP 16) that contains *Walloclinium laganum*, characteristic for the Late Toarcian–Early Aalenian (see [Oszczypko et al., 2012c](#)).

To the south-east of the Kacha Uplift, three TFF samples (WP 32, 34, 35) of brown and dark grey ferruginous siltstones contain *Thuramminoides metensis* (Terquem) of Late Triassic/Early Jurassic age. A similar assemblage with *Thalmanamina canningensis* Tappan and *Hyperammina* aff. *pediformis* Scherp was found near the Husynyi Hotel (WP 39). This foraminiferal assemblage suggests an Early Jurassic age. Rocks of the same age were found also to the east, in the Vesele section (WP 18 and 23), within beige micaceous mudstone regarded as a Lower Jurassic part of the TFF.

Near Sanatorne and Laspi, along the western part of the Black Sea coast, we found dark grey flysch, significantly different from that of the Bodrak Valley. In this area (WP 39/40; [Figs. 1, 2 and 3B](#)) the foraminiferal assemblages typical of Late Triassic and Early Jurassic included *Hyperammina* aff. *pediformis* Scherp (WP 39) indicating Toarcian age. In addition, the TFF is overlain in this area by the Middle Jurassic flyschoid formations (Ay-Vasil and Belbek) with a total thickness of up to 500 m ([Fig. 20](#); see also [Bilecki, 2006a, b, 2007](#)). The above-described sequence of flysch and flyschoid sediments is overlain by the Oxfordian/Kimmeridgian transgressive deposits, identified at the base of the Tithonian/Berriasian carbonate platform ([Oszczypko et al., 2012b, c](#)). This confirms unequivocally the Upper Triassic-Lower/Middle Jurassic position of the TFF in this part of the CM. To the east of Yalta, the Middle Jurassic flyschoid deposits are replaced over a distance of ~25 km by a large submarine conglomeratic fan ([Fig. 20](#); see Upper Jurassic Conglomeratic Formation, UJCF of [Lalomov, 2007](#)) of uncertain age, but recently regarded as Oxfordian and Kimmeridgian-Tithonian ([Baraboshkin and Piskunov, 2010](#)).

A definitely different geological and stratigraphic interpretation of the Prokhladne area was presented by [Popadyuk et al. \(2013\)](#) who, based on small foraminifera, included the TFF of the Bodrak Valley into the Albian. That paper also provides information about a finding of the Albian-Cenomanian foraminifer *Gumbelina cenomanica* Agal in the Mender borehole at Prokhladne, at a depth of 94–200 m ([Yanin, 1976](#)). With this in mind, we want to recall that [Marcinowski and Najdin \(1976\)](#) reported the Upper Albian ammonites from several sections near Prokhladne and gave information about a borehole drilled in the training centre MGU (Geological Faculty of Moscow University). In this drilling, Upper Albian red marly mudstones occur down to a depth of 85 m, underlain by Lower Jurassic deposits of the Taurida Formation at a depth of 85–90 m.

East of the Karabi Yayla and north of Pryvitne, our investigations have confirmed the presence of another younger submarine conglomeratic fan system (Tithonian) deposited by different density currents, which can represent a coarse flysch sequence. The base of these conglomerates is clearly visible in both the Pryvitne and Vesele sections.

In the Privityne section, the conglomeratic sequence, not younger than Berriasian, is underlain by strongly deformed dark grey thin- to medium-bedded flysch, similar to the TFF but not older than Kimmeridgian (WP 122–125). Previously-mentioned flysch is regarded as Middle Jurassic (Pivovarov and Derenyuk, 1984) or Late Triassic–Early Jurassic in age ([Yudin, 2009](#)). Similarly, we can interpret the position of the volcanic block (WP 18) from the Vesele section, underlain and overlain by dark siltstones, as Lower Jurassic at the base (WP 18) and Upper Jurassic/Lower Cretaceous (WP 18A; [Appendix 1](#)) at the top. These siltstones are separated by a volcanic block. In such situation the Lower/Middle Jurassic foraminifera at the base of volcanites (WP 23 and 18) should be regarded as reworked.

In the Novyi Svit section, at the base of conglomerates with large blocks of Upper Jurassic reef limestone, there are Lower Cretaceous dark marly shales (WP 115) similar to that of the Sudak Flysch. The age of the Pryvitne and Vesele conglomerates, overlain by the Lower Cretaceous shaly flysch facies (WP 149, 99 and 151), may be estimated as Tithonian/Berriasian, while the Novyi Svit conglomerates may belong to the Lower Cretaceous.

At several localities in the eastern sector of the CM, calcareous nannoplankton not younger than Valanginian has recently been determined ([Sheremet et al., 2014, 2016a](#)). The same younger dates (Hauterivian and Barremian) were obtained by [Pivovarov and Derenyuk \(1984\)](#).

There are at least two flysch sequences within the CM: (1) upper Triassic–Lower/Middle Jurassic, known from the western sector of the CM as the TFF, and (2) Upper Jurassic/Lower Cretaceous, developed east of the Pryvitne-Bilohirsk line and typical for the eastern sector of the CM. The Upper Jurassic/Lower Cretaceous flysch of the Sudak Formation passes upwards into a thick unit of conglomerates and sandstones with blocks and large olistoliths of Upper Jurassic limestones, deposited by submarine avalanches and high-density turbiditic currents (Khart-Kaya Fm.). This sequence is terminated by the Lower Cretaceous flyschoid marly deposits.

Unclear is the geotectonic position occupied by a complex of dark marly claystones and turbidites, exposed along the road from Simferopol to Alushta. In the northern part of the area, [Pivovarov and Derenyuk \(1984\)](#) distinguished the Albian claystones that occupied a narrowing to the south bay (see also [Marcinowski and Najdin, 1976](#)). Recently, in the southern extensions of this bay, [Popadyuk et al. \(2013a, b\)](#) documented the Albian deposits, and [Sheremet et al. \(2014, 2016a\)](#) found Up-

per Aptian-Lower Barremian rocks. Further to the south, at the northern edge of the Chatyr-Dag Yayla (WP 101) and along a road (WP 107), we found the Albian dark marls and turbidites, formerly regarded as the TFF (Pivovarov and Derenyuk, 1984; Bilecki, 2006b; Yudin, 2009). In our opinion, the Aptian/Albian deposits recently found in the TFF area along the western edge of the Dolhorukovska Yayla could be related to the Aptian/Albian marine transgression onto the TFF (Kacha Uplift, see Marcinowski and Najdin, 1976; Pivovarov and Derenyuk, 1984). A similar stratigraphic position is occupied by the Upper Aptian-Albian deposits near Zelenohorye, and by the Barremian-Hauterivian rocks in Berehove, Yalta, and close to the Demerji Yayla (Sheremet et al., 2016a).

CONCLUSIONS

1. At least two flysch formations are found in the Crimea Mts.: the Taurida (Upper Triassic to Lower/Middle Jurassic) of the western sector of the CM, and the Upper Jurassic to Lower Cretaceous flysch of the Sudak Formation (eastern sector of the CM). The Upper Jurassic/Lower Jurassic flysch deposits has been also recognized near Berehove, the west of the Yalta. These deposits probably are prolonged along the shoreline towards the east.

2. Additionally, the Middle Jurassic flyschoid deposits were also accumulated (e.g., the Belbek and Ay-Vasil formations) in the western sector of the CM.

3. Along the Black Sea between Sevastopol and Alushta, above the TFF and beneath the Late Jurassic carbonate platform, the Upper Oxfordian/Kimmeridgian Laspi correlative hori-

zon has been documented. It is partly an equivalent of the Hurzuf and Sudak horizons.

4. At the base of the Late Jurassic carbonate platform (Chatyr-Dag, Demerji and Karabi) and above the TFF, there are the Middle/Upper Jurassic alluvial and delta fan conglomerates derived from the NW.

5. During the Late Jurassic/Early Cretaceous, the deep-water Sudak Basin developed to the east of Pryvitne, supplied with coarse-grained deposits sourced from the NW. These sediments were transported by debris and density turbiditic flows. It is not excluded that the deposits could provide the slope facies of the flysch basin.

6. The basin was simultaneously supplied with large blocks (olistoliths) of Upper Jurassic limestones, derived from destruction of the eastern edge of the Karabi carbonate platform.

7. Majority of melanges distinguished in the CM, due to the homogeneity of their material, are not true melanges, but rather strongly tectonized "broken formations", olistostromes and so-called "chaotic" sedimentary deposits.

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