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Research paper

The Black Sea basins structure and history: New model based on new deep penetration regional seismic data. Part 2: Tectonic history and paleogeography

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ABSTRACT

A new lithostratigraphy scheme has been compiled for the Western Black Sea Basin and a new geological history scheme from Middle Jurassic till Neogene is suggested for the entire Black Sea Region. Continental rifting manifested itself from the Late Barremian to the Albian while the time of opening of the basins with oceanic crust was from Cenomanian till mid Santonian; origination of the Western and Eastern Black Sea Basins took place almost simultaneously. During Cenozoic time, numerous compressional and transpressional structures were formed in different part of the Black Sea Basins. It is shown that in Pleistocene-Quaternary time, turbidities, mass-transport deposits and leveed channels were being formed in the distal part of the Danube Delta.

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1. Introduction

In the first paper, we presented and discussed the new seismic data for the Black Sea, which allowed us to clarify the sequences of the basins and improve our models for the paleogeography and tectonic history of the region. In this second paper, we discuss the seismic stratigraphy of the Black Sea, largely through the Western Black Sea Basin. On the basis of this revised version of the stratigraphy and new tectonic reconstructions, we attempt to reconstruct the paleotectonic and paleogeographic history of the Black Sea Region. This article is largely based on our fieldwork in Turkey, the Crimea and in the Greater Caucasus but we also incorporate field geology studies in Georgia, Romania and Bulgaria. Basement topography and key structural elements for the Black Sea Basins are shown on Figure 1 (for details see Paper 1).

2. Seismostratigraphic model for the Black Sea

Stratigraphic schemes for the Black Sea have already been presented in numerous publications (Tugolesov et al., 1985; Finetti et al., 1988; Robinson et al., 1996; Dinu et al., 2005; Afanasenkov et al., 2007; Shillington et al., 2008; Rangin et al., 2002; Khriachtchevskaia et al., 2009, 2010; Munteanu et al., 2011; Menlikli et al., 2009; Stovba et al., 2009; Tari et al., 2009; Stuart et al., 2011; Nikishin et al., 2009, 2010, 2012; Mityukov et al., 2012; Almendinger et al., 2011; Georgiev, 2012; TPAO/BP Eastern Black Sea Project Study Group, 1997; Gozhik et al., 2010). Based on the interpretation of new seismic data, we are suggesting a revised stratigraphic scheme for the pre-Oligocene section. Our scheme is an updated version of older works (Nikishin et al., 2003, 2009, 2012; Afanasenkov et al., 2007), grounded on the analysis of

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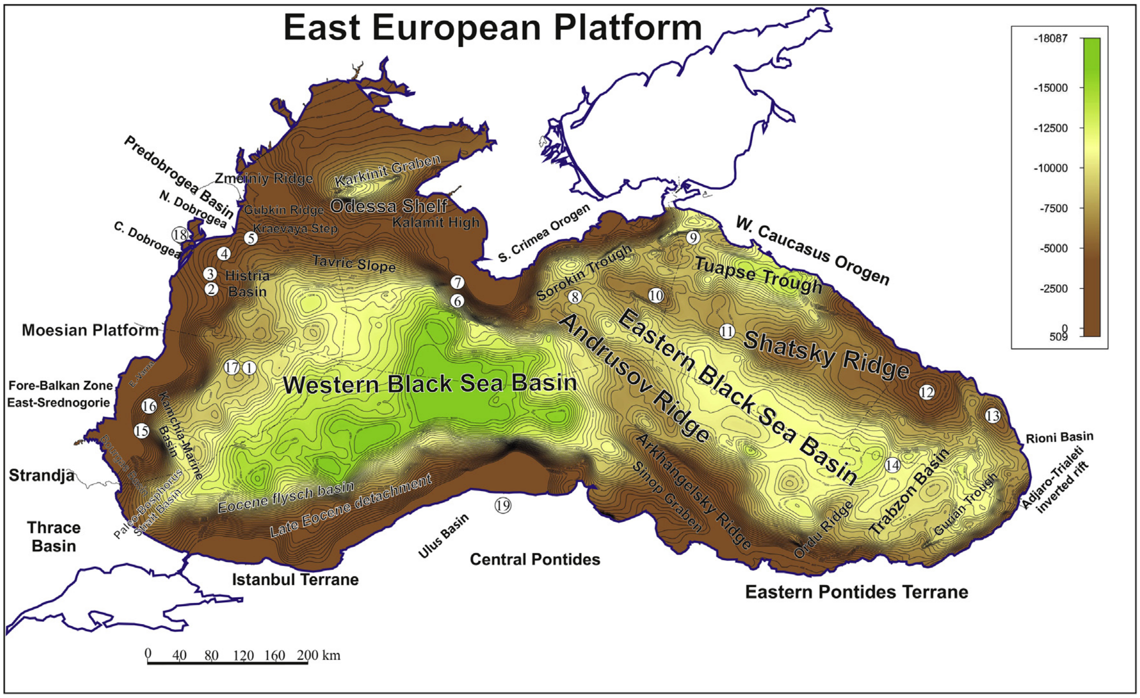

Figure 1. Basement topography of the Black Sea Basin (from Paper 1), and index map for the Black Sea Region. 1 – Polshkov Ridge, 2 – Tindala-Midia Ridge, 3 – Tomis Ridge, 4 – Lebada Ridge, 5 – Sf. Georg Ridge, 6 – Sevastopol Swell, 7 – Lomonosov Massif, 8 – Tetyaev Ridge, 9 – Anapa Swell, 10 – North Black Sea High, 11 – South-Doobskaya High, 12 – Gudauta High, 13 – Ochamchira High, 14 – Ordu-Pitsunda Flexure, 15 – Rezovo-Limankoy Folds, 16 – Kamchia Basin, 17 – East-Moesian Trough, 18 – Babadag Bassin, 19 – Küre Basin.

specific geological horizons and tectonostratigraphic units. Seismic data was discussed in Paper 1 where we presented 22 new regional seismic profiles. Here we analyze the main seismostratigraphic units and geological features along the three longest new regional seismic profiles (Figs. 2, 3, 4).

Corresponding to the fast drop of the sea level, the base Messinian erosional boundary can be clearly identified on most seismic lines (see Paper 1). In Neogene outcrop sections of the Taman region (Western part of the Great Caucasus), this event is dated as Middle Pontian (Rostovtseva, 2012), which approximately corresponds to the Late Messinian (Popov et al., 2006, 2010), or to the boundary between the Messinian and the Pliocene (Suc et al., 2011). The Messinian erosional event is detected on the Romanian Shelf as well, which is also dated as Mid Pontian (Suc et al., 2011; Munteanu et al., 2011, 2012).

On seismic lines, the top and bottom of the Maykop sequence are interpreted by different researchers as the bounding surfaces of a relatively monotonous package of sediments. Top and bottom of the Maykop sequence are dated by borehole data on the Ukrainian (Gozhik et al., 2010; Khriachtchevskaia et al., 2010) and Romanian (Dinu et al., 2005; Munteanu et al., 2011) shelves. Regionally, the upper boundary of the Maykop sequence corresponds to the end of

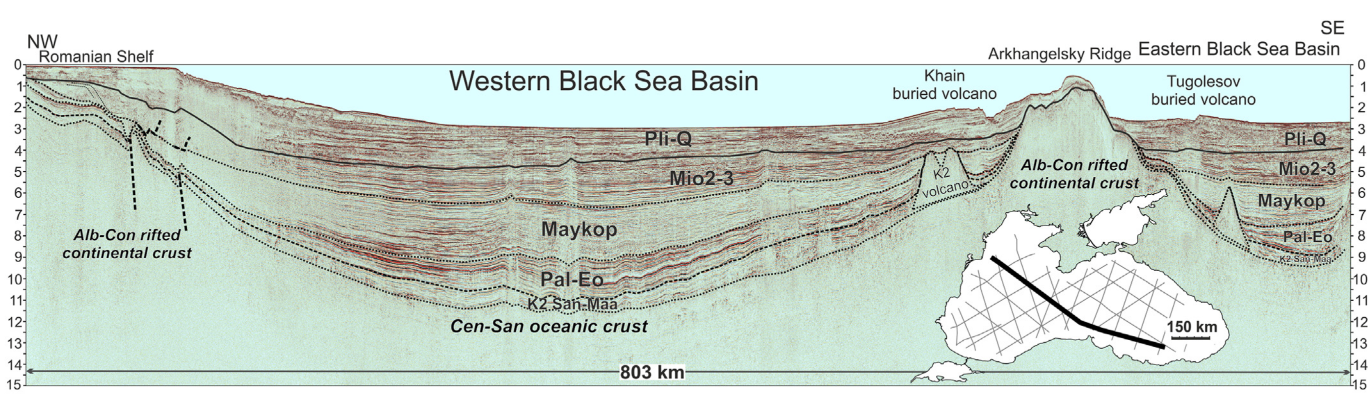

Figure 2. Geological interpretation of seismic line BS-160. This line is the longest in our project. The Arkhangelsky Ridge has no features of pre-Miocene sedimentary cover. Pre-Miocene levels could be composed of Cretaceous volcanics. Two big buried mountain-like highs could be recognized: Khain and Tugolesov. We propose a volcanic origin for these structures. The height of these structures is close to 2.5 s. They are covered by Maykopian deposits or even Mid Miocene deposits (the Khain structure). If these structures are volcanoes it means that till Early or Middle Miocene times the Black Sea was a deep-water basin with water depth in excess of 2 km. Abbreviations: K – Cretaceous, Apt – Aptian, San – Santonian, Maa – Maastrichtian, Pal – Paleocene, Eo – Eocene, Mio – Miocene, Pli – Pliocene, Q – Quaternary.

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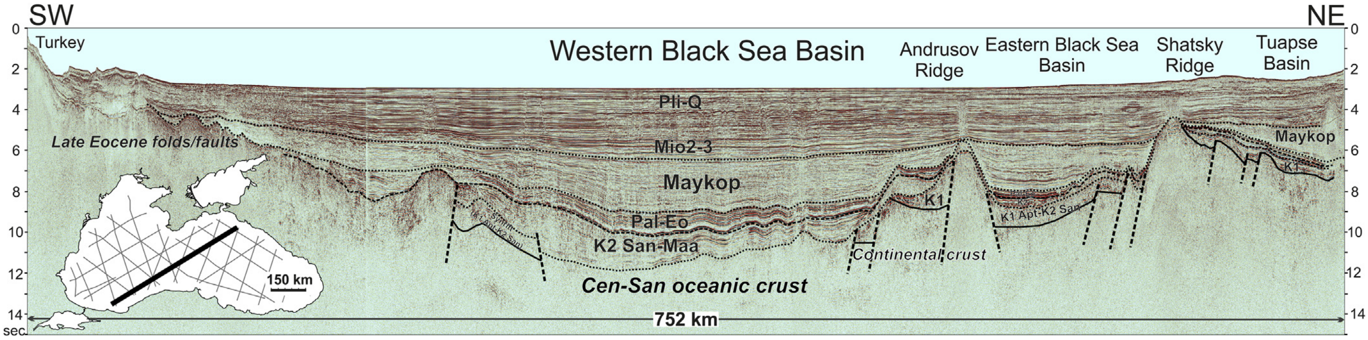

Figure 3. Geological interpretation of seismic line BS-210. This line crosses a number of major structures of the Black Sea Basin. The Shatsky Ridge is a tilted block as a peripheral bulge of the Tuapse flexural foredeep basin. The Tuapse Basin is a Maykopian flexural basin. The Eastern Black Sea Basin has rift-like structure. A few Early Cretaceous normal faults and tilted blocks could be recognized, including on the Andrusov Ridge. The continental slope of Turkey is covered by Maykopian and younger deposits. An Eocene foldbelt could be recognized below Maykopian deposits.

formation of the Tuapse and Sorokin flexural troughs, while the lower boundary corresponds to the start of their formation (Afanasenkov et al., 2007; Nikishin et al., 2009).

Below the Maykop sequence, a thick postrift unit is identified, which we date as Late Santonian-Eocene; we consider it coeval in the Eastern Black Sea Basin and in the Western Black Sea Basin. The time of end of rifting and oceanic crust spreading processes in the Black Sea is still disputed (Zonenshain and Le Pichon, 1986; Letouzey et al., 1977; Görür, 1988; Finetti et al., 1988; Okay et al., 1994; Robinson et al., 1996; Nikishin et al., 2003, 2012; Afanasenkov et al., 2007; Shillington et al., 2008, 2009; Stephenson and Schellart, 2010; Munteanu et al., 2011; Tüysüz et al., 2012; Okay et al., 2013).

According to our model, spreading of oceanic crust and regional rifting in the Black Sea was completed by Mid-Santonian time. The following data and observations support this assumption: (1) in Turkey's Central Pontides, Late Santonian deposits overlie transgressively and often discordantly all of the older sediments and they were formed after completion of normal faulting (Tüysüz et al., 2012); the same situation is observed in Crimea as well, where Late Santonian sediments overlie with slight erosion all the underlying sedimentary units and they were formed after the pre Late Santonian phase of uplift (Fig. 5) (Nikishin et al., 2008, 2012); (2) at a level mapped as the base of the Upper Cretaceous, some seismic lines indicate that the southwestern part of the Shatsky Ridge was relatively uplifted and formed the rift shoulder for the Eastern Black Sea Basin; subsidence of this rift shoulder started approximately at the end of the Late Cretaceous, hence in the Eastern Black Sea Basin the extension processes ended by that time; (3) large-size Cretaceous volcanoes seen on seismic lines north of the Pontides are supposedly of Late Santonian to Campanian age (see Paper 1); they were formed after completion of spreading of oceanic crust because according to our interpretation they occur stratigraphically on top of oceanic or transitional crust in the Western and Eastern Black Sea Basins; it means that oceanic crust spreading processes had terminated by the beginning of the Campanian.

Based on the following data, we interpret that large-scale rifting and spreading in the Western Black Sea and the Eastern Black Sea Basins started in Cenomanian time: (1) In the area of the Early Cretaceous Balaklava Graben of Southwestern Crimea (Nikishin et al., 2012, 2013), on the Odessa Shelf in the area of the Karkinit Graben (Khriachtchevskaia et al., 2010; Gnidec et al., 2010; Nikishin et al., 2012) and in the Central Pontides of Turkey (Yilmaz et al., 2010), Cenomanian deposits transgressively overlie Lower Cretaceous rift complexes. Hence in the area outside Eastern and Western Black Sea Basins the Albian to Cenomanian boundary corresponds to the rift-postrift boundary (break-up unconformity); after this event rifting and spreading of oceanic crust concentrated in the Black Sea Basins. (2) Seismic data over the Shatsky and Andrusov Ridges show that the main normal-fault formation took place during the Early Cretaceous, with the Upper Cretaceous transgressively overlying synrift deposits; hence, at the onset of the Late Cretaceous, rifting and spreading processes concentrated in the Western and Eastern Black Sea Basins.

Continental rifting around the Western and the Eastern Black Sea Basins took place synchronously with the spreading of oceanic crust in the Black Sea. For example, in the Western Pontides rifting is known to have taken place during the Turonian to Early Santonian (Tüysüz et al., 2012).

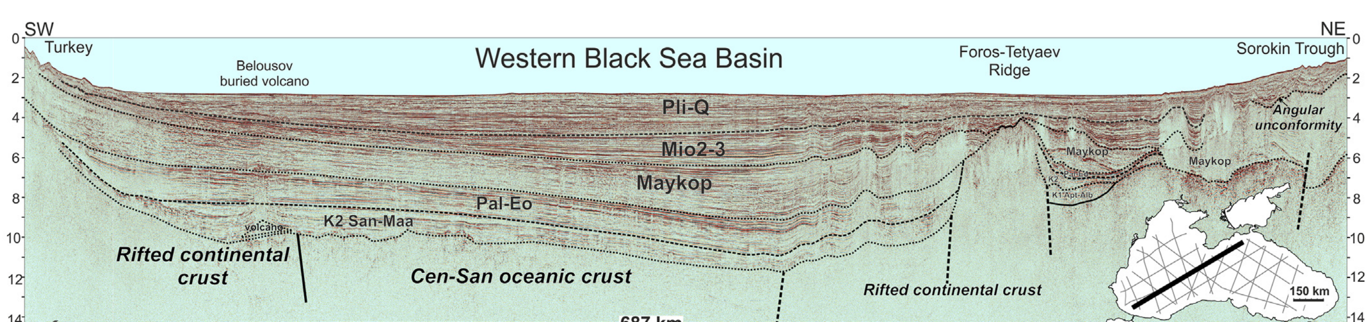

Figure 4. Geological interpretation of seismic line BS-220. The profile crosses the Western Black Sea Basin and the area of the Tetyaev Ridge. The Maykopian unit with thickness up to 2 s extends very close to the Turkish shoreline without change in thickness. We assume the Maykop sequence covered parts of the Thrace Basin in Turkey before the Neogene erosion.

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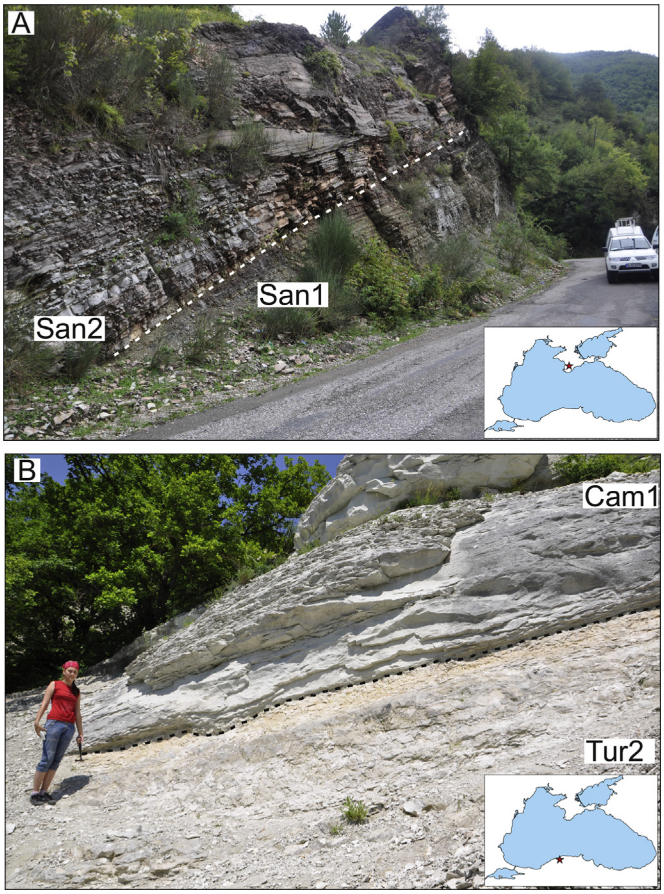

Figure 5. View of the intra-Santonian unconformity. A, Turabi Section, northern Turkey, Cide town region (Tüysüz et al., 2012). The Santonian2 unit is seen onlapping the underlying Coniacian-Santonian1 unit. B. Trudolyubovka Section, Southern Crimea, Bakhchisaray region; this Turonian/Campanian unconformity merges into an unconformity between the Lower and Upper Santonian some 8.6 km to the SW of this outcrop (Aksu-Dere Section; Nikishin et al., 2008).

Postrift deposits can be divided into an Upper Santonian-Maastrichtian (Upper Cretaceous) and a Paleocene-Eocene unit, though this boundary can only be drawn approximately. We recognize three geologically significant marker levels in the seismic data. 1) Buried volcanoes (see Paper 1) are interpreted to be of Campanian age (at least Late Cretaceous in age) and their bases definitely lie within the Upper Cretaceous sequence. 2) The turbiditic complexes of the Kamchia-Marine Foredeep Basin are dated onshore as Late Paleocene-Middle Eocene (Tari et al., 2009; Stuart et al., 2011; Georgiev, 2012); we are able to regionally trace this level along the grid of seismic lines. 3) Along the continental slope of the Western Pontides the turbiditic complex below the Maykop sequence is probably of Late Eocene age.

Continental rifting around the deep-water basins of the Black Sea took place mainly in the Late Barremian-Albian. We studied two rifts in the field – the Zonguldak Rift in the north of the Western Pontides and the Balaklava Rift in Crimea. The Early Cretaceous Zonguldak Basin was formed in Late Barremian-Albian (Yılmaz and Altiner, 2007; Masse et al., 2009) (Figs. 6, 7). While mainly developed onshore, its northern edge probably extends into the Black Sea. The Balaklava Graben is located in the area of Balaklava City in Crimea (Nikishin et al., 2012, 2013); it is filled with Aptian and Albian shales, debris flows and olistostromes (Figs. 8, 9).

The Karkinit Graben is located on the Odessa Shelf. It is well expressed on seismic lines (see Paper 1) and is penetrated by many wells (Gozhik et al., 2010; Khriachtchevskaia et al., 2010; Gnidec et al., 2010; Nikishin et al., 2012). It was formed in Late Barremian-Albian, with andesitic volcanites being present in the Late Albian (Gnidec et al., 2010).

Barremian-Albian synrift deposits also characterize of the Romanian Shelf (Munteanu et al., 2011).

On the whole, Late Barremian-Albian rifting is developed throughout the Black Sea shelves; we recognize at least two phases of rifting, the main rifting phase being of Albian (or Late Albian) age.

On the basis of these new data and interpretations, we propose a revised lithostratigraphy scheme for the Western Black Sea Basin (Fig. 10). For the Eastern Black Sea Basin, the lithostratigraphy scheme should coincide with this one in general.

3. Reconstruction of the Black Sea Region prior to the formation of the back-arc basins

Reconstructions for the opening of the Western and the Eastern Black Sea Basins have been presented by many researchers (Zonenshain and Le Pichon, 1986; Görür, 1988; Finetti et al., 1988; Okay et al., 1994; Robinson et al., 1996; Nikishin et al., 2003, 2012; Afanasenkov et al., 2007; Stephenson and Schellart, 2010). Our data show that both basins opened simultaneously in Cenomanian-Early Santonian time (though we do not exclude that within this time interval the Eastern Black Sea Basin opened first, followed by the Western Black Sea Basin).

In order to attempt a reconstruction of the Black Sea Region before the opening of the back-arc basins, one must know to what distance and in what direction the various bounding terranes have been displaced during the Cretaceous rifting phases. These include the Istanbul, Central Pontides, Eastern Pontides and Andrusov Ridge terranes. At places where we anticipate the presence of oceanic crust, 100% spreading took place, while where the Western and the Eastern Black Sea basins have a strongly thinned and rifted continental crust, we apply a 50% extension factor. Based on these two assumptions, we determined the area to be closed in the process of restoring the paleotectonic structure (Fig. 11a). Thereafter, we attempted to maximize the closure of this gap and drew up a paleotectonic reconstruction model of the Black Sea Region for the pre-Barremian time, i.e. for the time before back-arc basins formation started (Fig. 11b). It is obvious that our model is not completely accurate because it suggests the existence of large-size strike-slip faults and contains some gaps and overlaps. From the outset, the model contains several not quite valid assumptions about dimensions of the gap to be reconstructed and the model also does not assume ductile bends of blocks in the plan view. We have also excluded in the model the Trabzon Basin as an independent basin with its own kinematics of opening. Therefore this model should be considered as qualitative and approximate.

Wrench faults such as the West Black Sea Fault (Okay et al., 1994; Nikishin et al., 2003, 2012; Stephenson and Schellart, 2010) play a significant role in our model. We assume that the Ordu Fault played the main role in the course of the Eastern Black Sea Basin opening. Movement along the Trialeti Fault between the Eastern Pontides and the Shatsky Ridge led to the opening of the Trabzon Basin as a pull-apart basin.

A wrench fault also probably existed between the Central Pontides and the Eastern Pontides. We suggest to call it the Abana Fault; its role is perhaps exaggerated in our reconstruction and it is difficult to accurately show its position in Turkey.

4. Paleogeographical reconstructions for the Black Sea Region

Paleogeographical reconstructions for the Black Sea Region have already been presented in the series of special atlases (Vinogradov,

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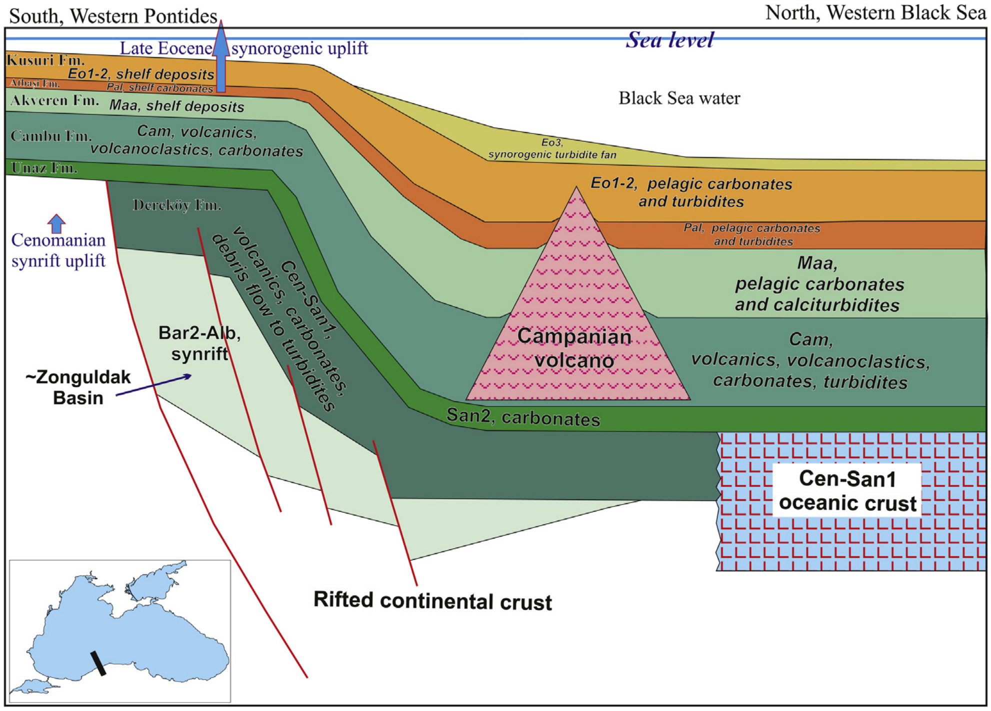

Figure 6. Late Eocene passive margin structure of the Western Pontides. The scheme is compiled using data in Yılmaz and Altiner (2007), in Masse et al. (2009), our own field data, and interpretation of seismic data presented in Paper 1. Bar – Barremian, Alb – Albian, Cen – Cenomanian, San – Santonian, Cam – Campanian, Maa – Maastrichtian, Pal – Paleocene, Eo – Eocene.

1961; Dercourt et al., 2000; Stampfli et al., 2001; Barrier and Vrielynck, 2008) and in numerous papers (for example Okay et al., 1994, 2001, 2013; Moix et al., 2008; Yilmaz et al., 2010). Here, we will mainly follow the reconstructions of Nikishin et al. (2003, 2012), though with considerable changes based on the interpretation of the new regional seismic lines; in this paper, we will focus on some basic new ideas.

4.1. Callovian-Early Oxfordian reconstruction (Fig. 12)

During Callovian-Early Oxfordian time, the Tethys (or Izmir-Ankara) ocean existed south of the Pontides. The Pontides were an active continental margin underlain by a subducting plate. Fragments of Callovian-Early Oxfordian volcanic arcs are known from Transcaucasia (Vinogradov, 1961; Topchishvili et al., 2006; Afanasenkov et al., 2007; Rolland et al., 2011; Nikishin et al., 2012) and from the Central Pontides (Okay et al., 2014). At that time, the opening of back-arc rift basins such as the Sudak Trough, Western Caucasus Trough and Eastern Caucasus Trough took place (Vinogradov, 1961; Afanasenkov et al., 2007; Nikishin et al., 2012). In Georgia, the large-size Kolkhida plateau basalt was under formation (Topchishvili et al., 2006).

The Black Sea Region was in a back-arc tectonic setting. Based on the interpretation of seismic lines, two types of settings can be identified as a minimum (Nikishin et al., 2012): (1) areas with platform sediments (the southern part of the Shatsky Ridge); (2)

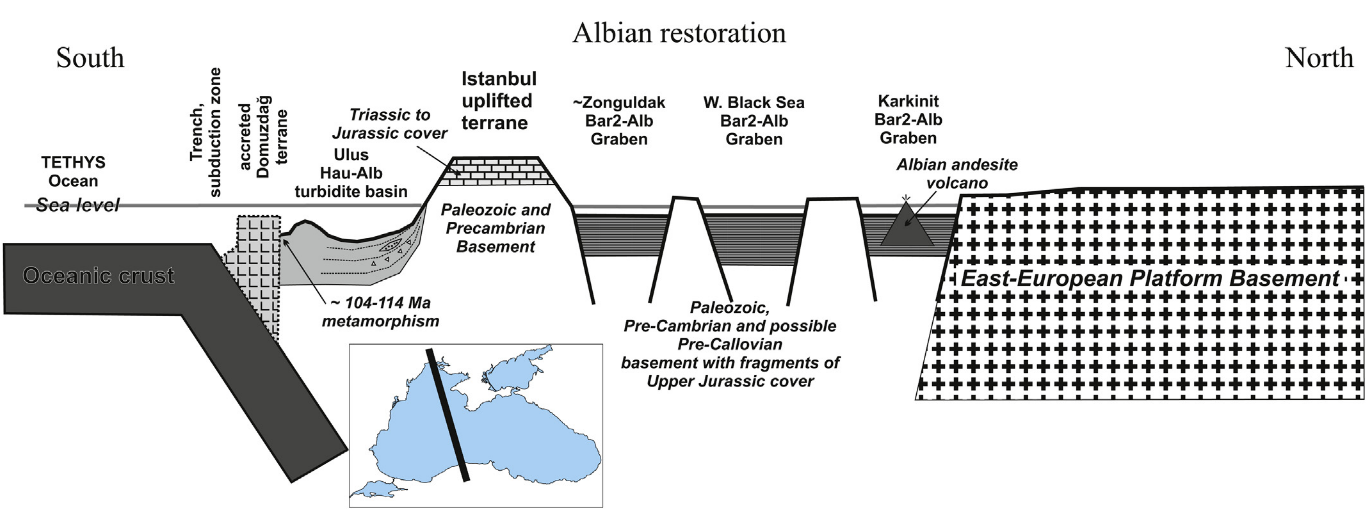

Figure 7. Albian Structure Restoration, Western Black Sea Basin. Data on metamorphism are from Okay et al. (2013). Hau – Hauterivian, Alb – Albian, Bar – Barremian.

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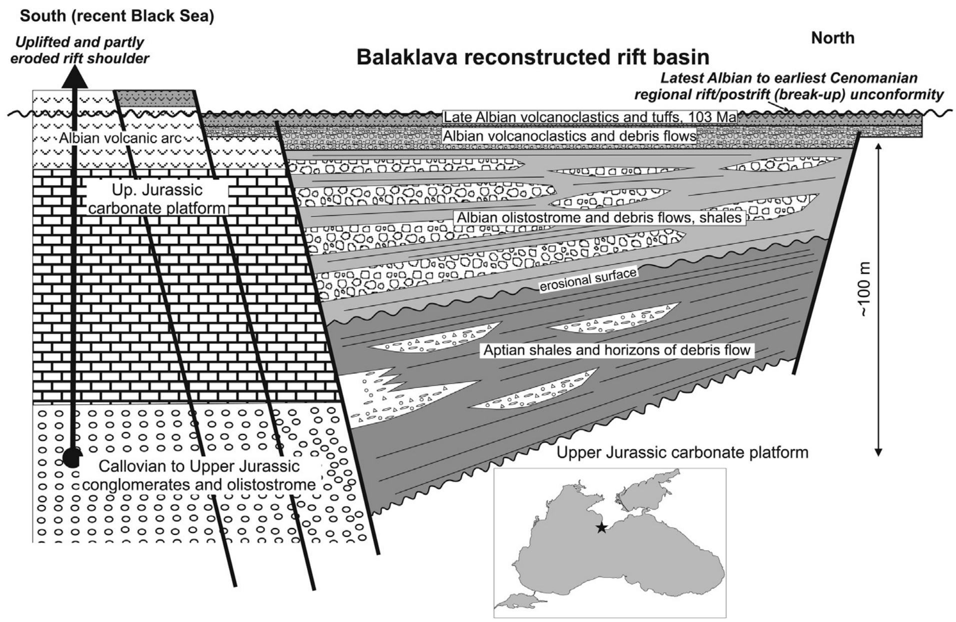

Figure 8. Balaklava Graben Restoration, southwestern Crimea region (not to scale). The restoration is based on our own field data. Zircon isotopic dating of Albian volcaniclastics yielded an age of 103 ± 1 Ma (Nikishin et al., 2013). Aptian and Albian ages are based on microfossil studies on our samples done by E.A. Scherbinina. A Latest Barremian age for the lowermost part of the section is not excluded.

deep shelf areas bounded by highs such as synrift horsts between graben-like depressions, where individual carbonate build-ups could grow. This area of the deep shelf probably experienced rifting synchronously with rifting in the Western Caucasus Trough.

New seismic data demonstrates some evidences of salt tectonics in the Gudauta High with a proposed Oxfordian salt horizon (Nikishin et al., in preparation).

4.2. *Kimmeridgian-Tithonian reconstruction (Fig. 13)*

Approximately the same tectonic setting persisted throughout the Kimmeridgian-Tithonian, with a volcanic arc known in Transcaucasia (Vinogradov, 1961; Topchishvili et al., 2006; Rolland et al., 2011; Nikishin et al., 2012). Late Jurassic subduction below the Pontides is documented by various authors (for example Ustaömer and Robertson, 2010; Akbayram et al., 2012; Okay et al., 2013). Most parts of the Black Sea Region experienced thermal subsidence with the formation of an extensive shelf carbonate platform. This platform is known to have extended over most parts of the Pontides (Okay and Sahinturk, 1997; Okay et al., 1994, 2013), the Moesian Platform, Southern Crimea, Georgia, Abkhazia and the northern slope of the Caucasus (Vinogradov, 1961; Topchishvili et al., 2006; Afanasenkov et al., 2007; Krajewski, 2010; Guo et al., 2011; Nikishin et al., 2012; Georgiev, 2012). Our new seismic data indicate that a carbonate platform was probably covering the southern part of the Shatsky Ridge, while individual carbonate reefal buildups formed in the northern, more deep-water part of the Shatsky Ridge; this confirms interpretations based on the previously acquired seismic lines (Afanasenkov et al., 2007; Nikishin et al., 2012). Reefal buildups were also formed along the margins

Figure 9. View of the Albian synrift section. Balaklava quarry, Crimea, Sevastopol region.

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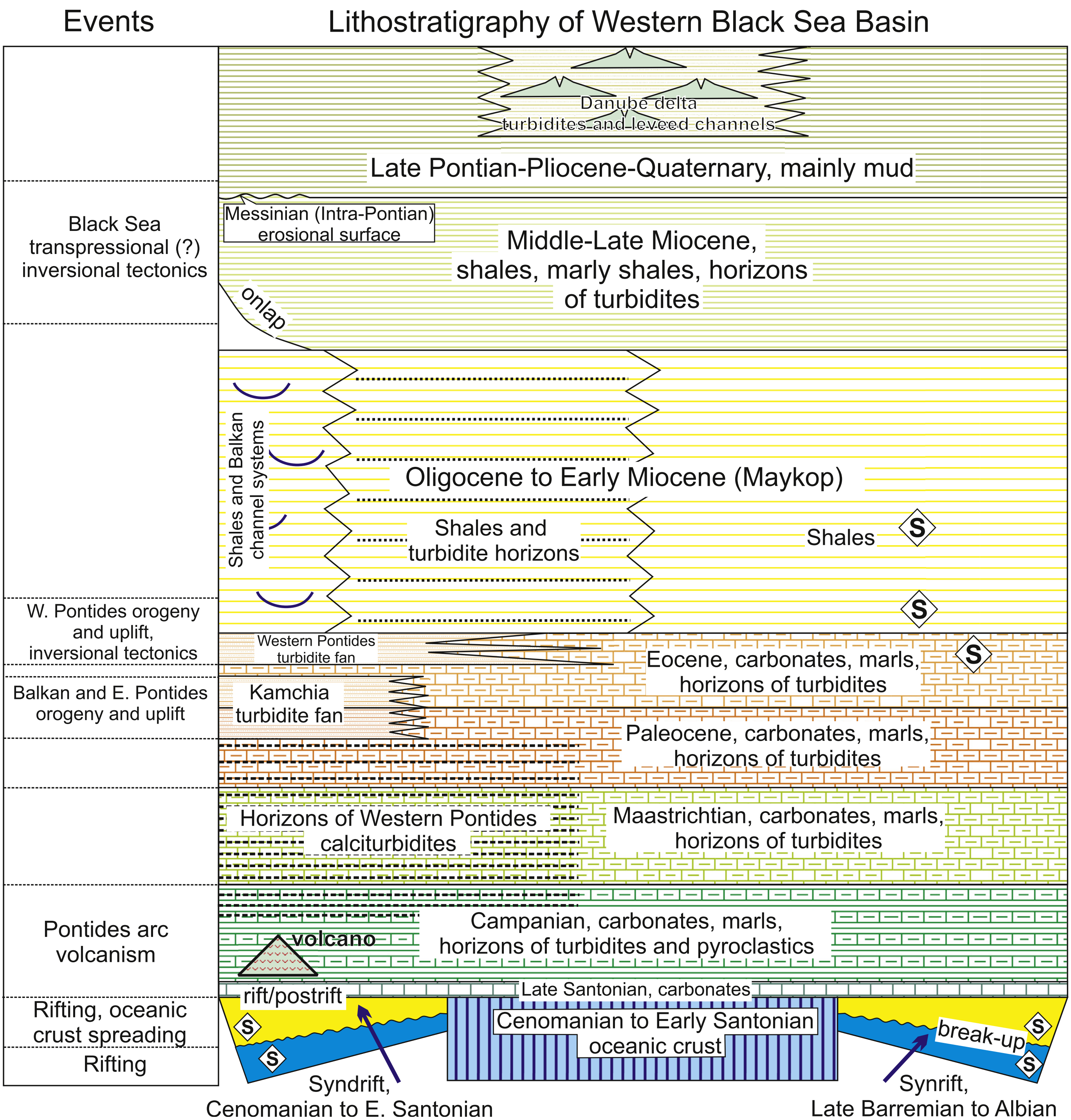

Figure 10. Western Black Sea Basin Lithostratigraphical Scheme. S – source rock.

of the Sudak and Western Caucasus deep-water troughs. Evaporites are known north of the Great Caucasus, in Georgia and in Abkhazia (Vinogradov, 1961; Topchishvili et al., 2006).

4.3. *Albian reconstruction (Fig. 14)*

The tectonic setting changed significantly in Late Barremian-Albian time, leading to the formation of the Karkinit, Histria, Zonguldak, Intra-Shatsky grabens and further hypothetical grabens located where the Western Black Sea Basin later developed; the Eastern Black Sea and Trabzon basins also began to be formed at that time. Albian volcanism took place in the area of the Karkinit Graben.

In Turkey, the Ulus Basin situated south of the Istanbul Terrane began its formation in Late Barremian time (Masse et al., 2009; Tüysüz et al., 2012). This basin is composed of flysch deposits with redeposited blocks (olistoliths) ranging in age from Paleozoic to Late Jurassic. The Ulus Basin has generally been considered as a graben, but this flysch basin was probably formed on the active continental margin of the Pontides between the trench and the onshore area of the rise of the Istanbul Terrane (Tüysüz, 1999; Okay

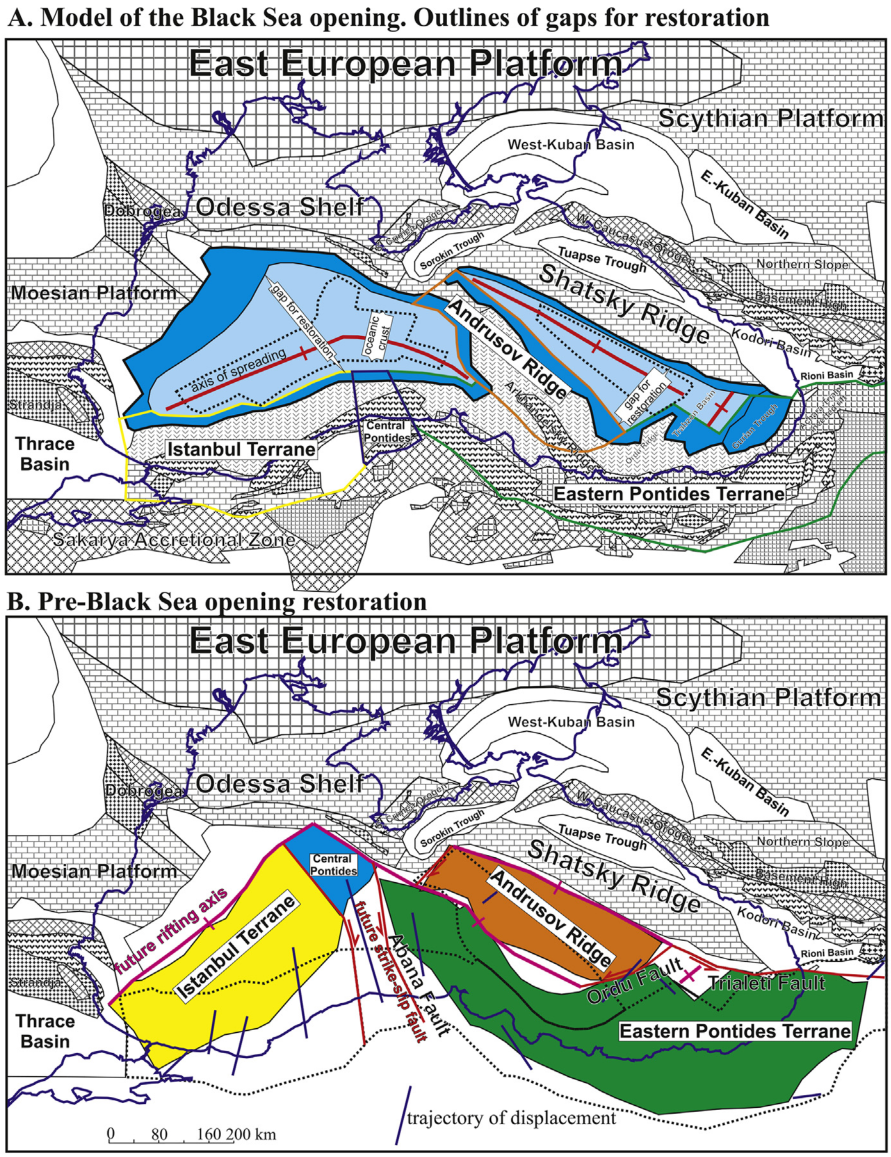

Figure 11. Pre-Black Sea Basin Opening Tectonic Structure Restoration. Figure A shows possible outlines of gaps in the restoration (see discussion in the text). Figure B shows the tectonic structure before the Black Sea Basin opening. Arrows show trajectories of displacements during the Black Sea Basin opening.

et al., 2013). Arguments supporting this interpretation include Albian metamorphic ages of 100–114 Ma (Okay et al., 2006, 2013) in the southern part of the Ulus Basin, while around 104 Ma old eclogites are present south of the Ulus Basin (Okay et al., 2006, 2013). These data support the existence of a subduction zone in Albian time. Okay et al. (2013) concluded that Albian metamorphism was connected with accretion of the Domuzdağ Plateau (Terrane).

A volcanic arc formed in Albian time. In Transcaucasia, Albian volcanism is known in the area of the Adjaro-Trialeti Zone (Vinogradov, 1961; Rolland et al., 2011; Nikishin et al., 2012). Albian tuffs with volcanic bombs and lapilli have been described in Balaklava, southwest Crimea (Shnyukov et al., 1997; Afanasenkov et al., 2007; Nikishin et al., 2012, 2013) and Albian volcanics are perhaps also present on the continental margin west of Sevalstopol in Crimea (Shnyukov et al., 1997; Shnyukova, 2013). Based on the interpretation of our seismic lines, Albian volcanoes can possibly be recognized on the Shatsky Ridge. All these observations indicate that an Albian volcanic arc was present in the area of Southwestern Crimea, and stretched into Transcaucasia (Nikishin et al., 2003, 2012, 2013); we propose calling it the Balaklava-Trialeti volcanic arc. Volcanism and the rifting were partly synchronous in Albian time.

4.4. *Cenomanian reconstruction (Fig. 15)*

In accordance with our correlations and earlier works (Nikishin et al., 2003, 2012), Cenomanian was the main epoch of opening of the Western Black Sea and the Eastern Black Sea back-arc basins. A Cenomanian volcanic arc is known from Transcaucasia (Vinogradov, 1961; Rolland et al., 2011; Nikishin et al., 2012). There is no data on Cenomanian magmatism in the Pontides; it apparently started later during mid-Turonian time. Cenomanian is a period of short erosion on the Western Pontides and it is the time of the rapid subsidence of the Sinop basin (Tüysüz, 1999). While the subduction zone was located south of the Pontides, different

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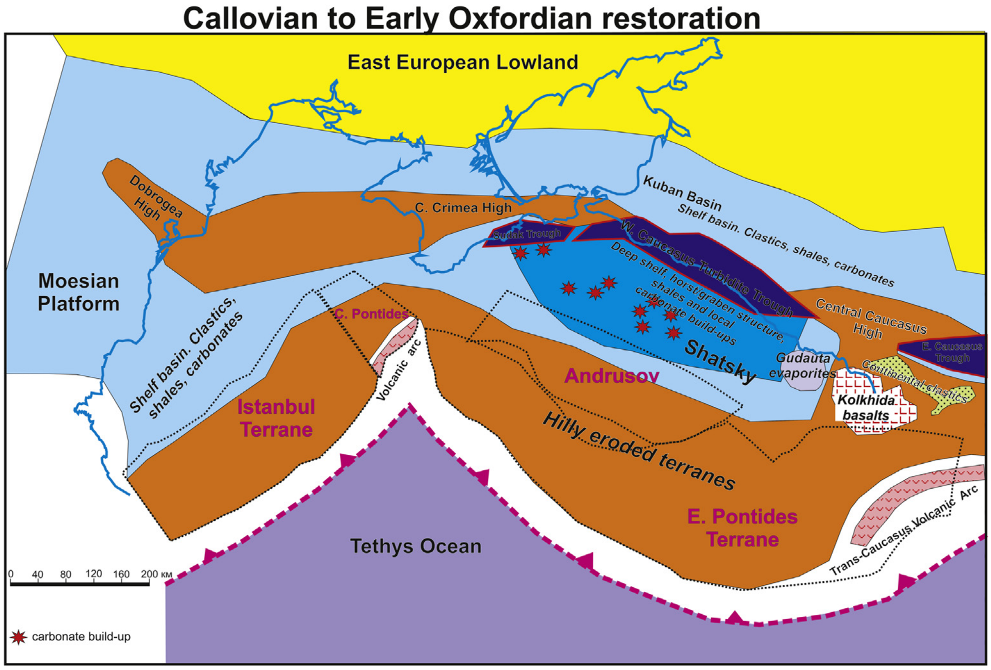

Figure 12. Callovian to Early Oxfordian paleogeographical scheme.

authors suggest different configurations (Okay et al., 1994; Tüysüz and Tekin, 2007; Yilmaz et al., 2010; Nikishin et al., 2012).

The Eastern Black Sea Basin was formed through rifting along the Albian Balaklava-Trialeti volcanic arc. The Western Black Sea Basin possibly started to form through rifting along the Cenomanian volcanic arc. Therefore, we do not exclude that the Western Black Sea Basin started to be formed somewhat later than the Eastern Black Sea Basin.

Our seismic lines show that the southwestern part of the Shatsky Ridge was probably relatively uplifted in Cenomanian time, when it formed the shoulder uplift for the rift of the Eastern Black Sea Basin. It is probable that the Andrusov Ridge was also relatively uplifted as the shoulder uplift of both the Western Black Sea and the Eastern Black Sea rifts.

4.5. *Campanian reconstruction* (Fig. 16)

Formation of the Pontides volcanic belt that stretched to the west into Bulgaria occurred dominantly in Campanian time; the subduction zone was located south of this belt (Okay et al., 1994,

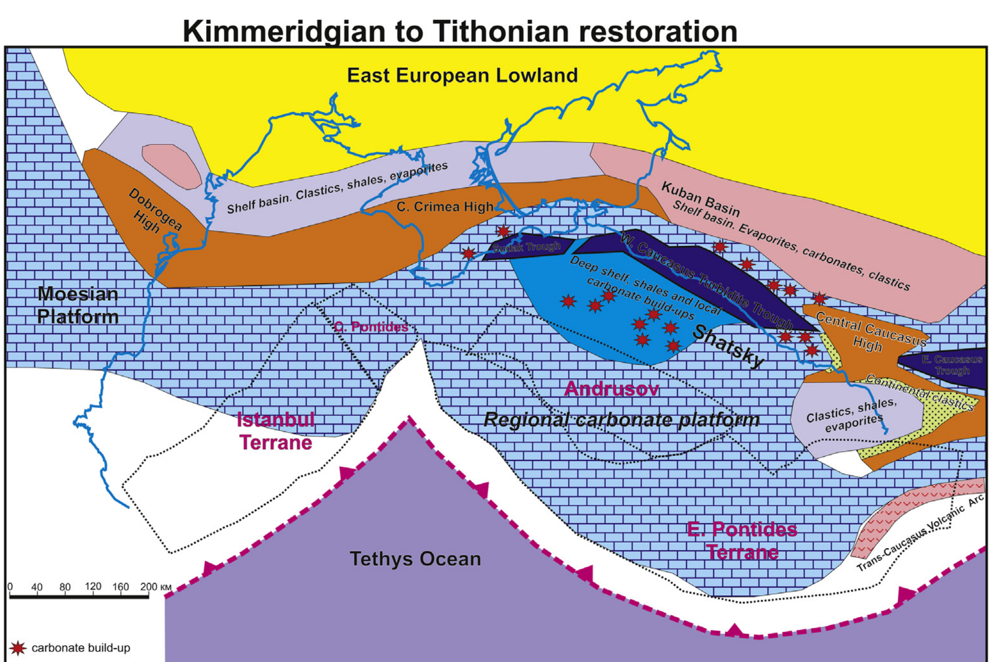

Figure 13. Kimmeridgian to Tithonian paleogeographical scheme.

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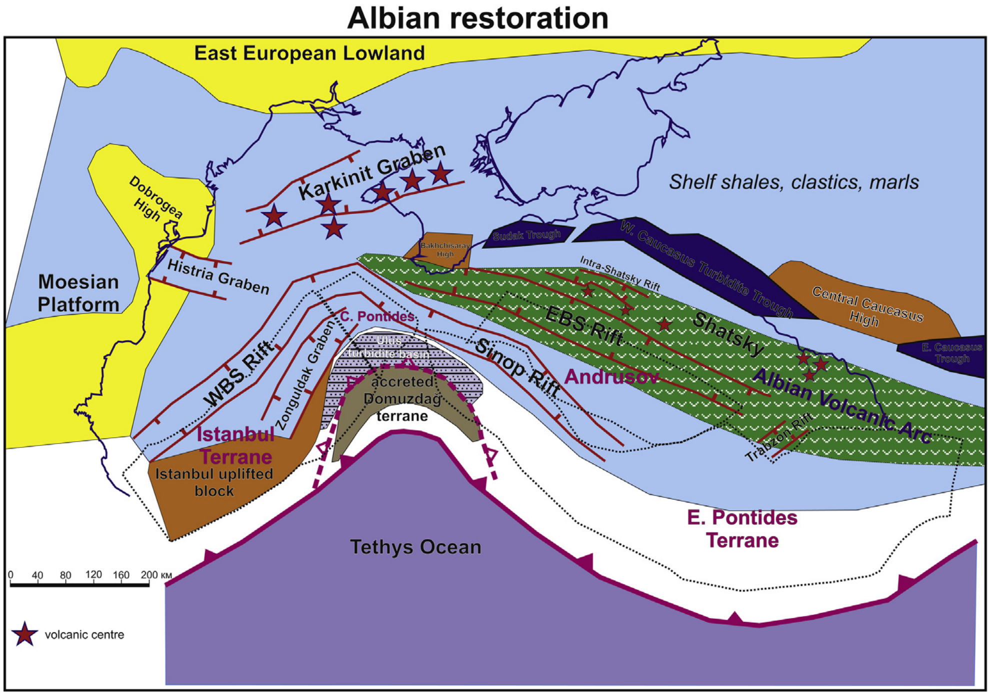

Figure 14. Albian paleogeographical scheme. WBS – Western Black Sea, EBS – Eastern Black Sea.

2013; Tüysüz et al., 2012; Georgiev et al., 2012). We assume that rifting and oceanic crust spreading processes had ended before the beginning of Campanian time. A belt of submarine volcanoes up to 1–2 km high was forming in the south of the Black Sea, north of the recent Pontides (Peri-Pontides volcanic arc, see Paper 1). Interpretation of the new seismic lines shows that at the end of the Late Cretaceous both the Andrusov and Shatsky Rises were being covered with a blanket of sediments and experienced general thermal subsidence, similarly to the deep-water Eastern Black Sea and the Western Black Sea basins.

4.6. Middle Eocene reconstruction (Fig. 17)

The main collisional processes in Northern Turkey and the full closure of the Izmir-Ankara Ocean took place approximately at the boundary of Paleocene and Eocene (Okay et al., 2001), while in

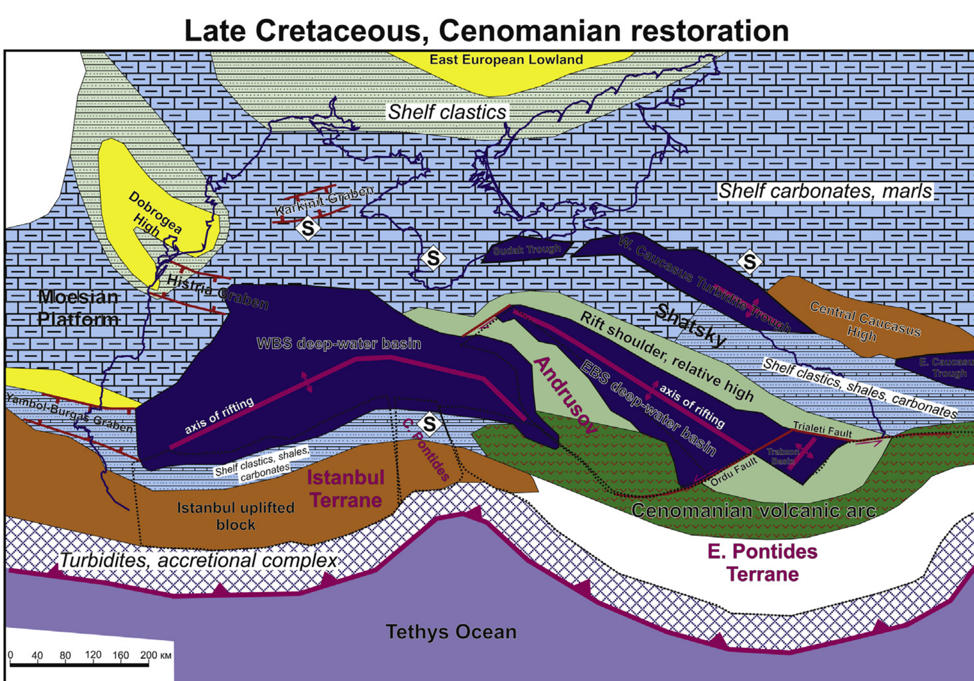

Figure 15. Cenomanian paleogeographical scheme.

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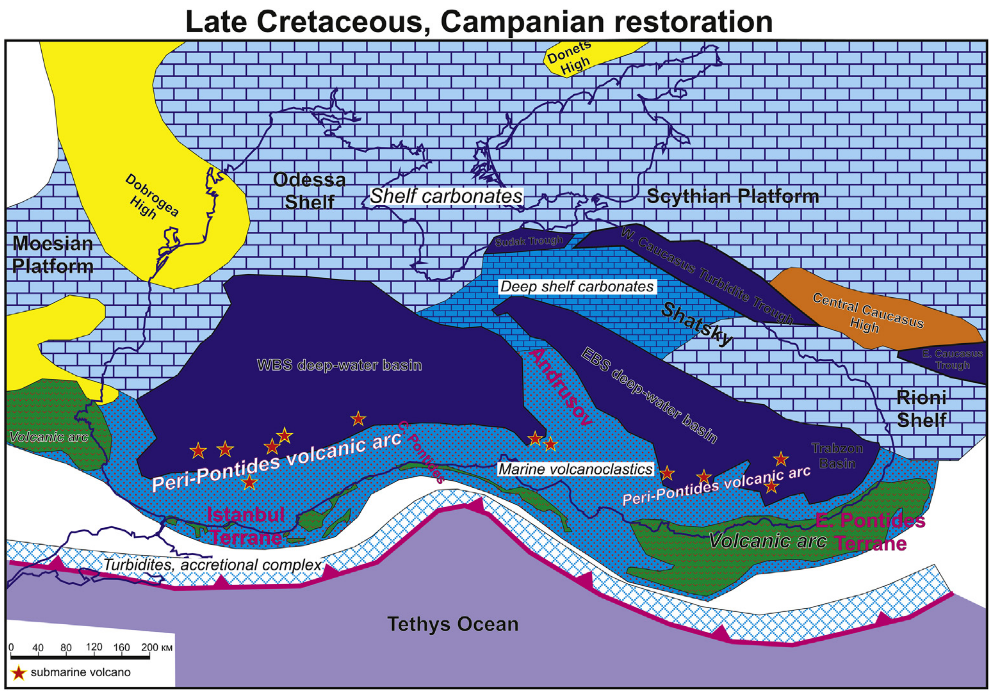

Figure 16. Campanian paleogeographical scheme.

Bulgaria these processes were completed later by the middle of Middle Eocene (Tari et al., 2009; Stuart et al., 2011; Georgiev, 2012).

In the Bulgarian part of the Black Sea, the Kamchia Foredeep and its offshore continuation was forming in front of the Srednogorie-Stranja orogeny; this foredeep basin is well recognizable offshore on our seismic lines.

In the northern part of Turkey and Transcaucasia numerous basins were forming in Mid Eocene time, which were being filled with volcanics, turbidites and carbonates. Calc-alkaline basaltic to dacitic volcanism widely manifested itself (Okay and Sahinturk, 1997; Topuz et al., 2011; Nikishin et al., 2012). These basins were forming in an extensional setting and they can be considered as rift basins (Topuz et al., 2011; Nikishin et al., 2012).

North of the Sea of Marmara the Thrace Basin was also forming as an extensional basin in Mid Eocene time (d'Atri et al., 2012); that basin was probably extending into the Black Sea.

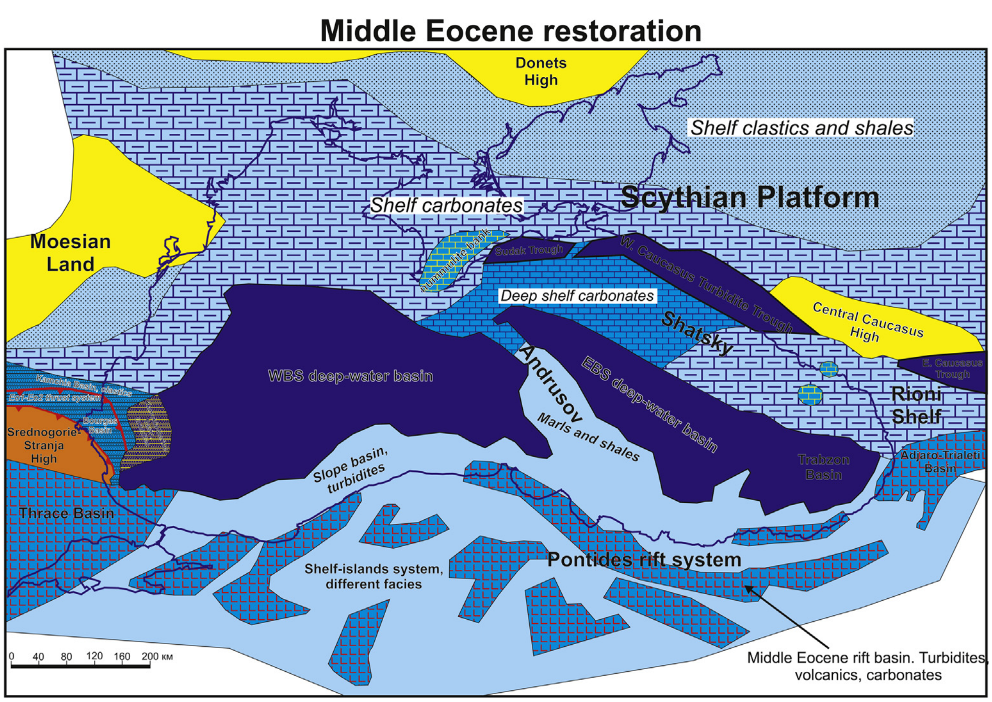

Figure 17. Mid Eocene paleogeographical scheme.

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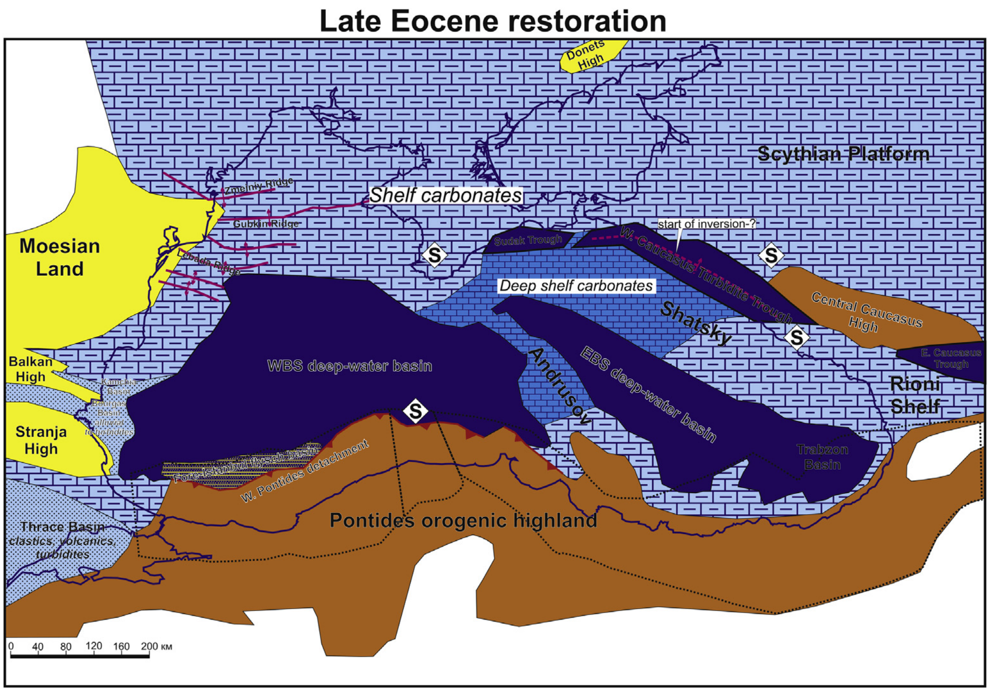

Figure 18. Late Eocene paleogeographical scheme.

The Black Sea basins experienced general thermal subsidence in Mid Eocene time.

4.7. *Late Eocene reconstruction (Fig. 18)*

In Late Eocene time the Western Pontides experienced a folding phase with a regional gentle-dip detachment at depths of 2–5 km and with a northward progradation of the folded system (Sunal and Tüysüz, 2002). Apatite fission-track thermochronology of the Western Pontides shows that uplift of the Western Pontides took place between the Late Lutetian and the Early Rupelian (43.5–32.3 Ma) (Cavazza et al., 2012). Synchronously with these events, we assume that a turbiditic (flysch) basin was forming in the Western Black Sea Basin north of the Western Pontides.

The Odessa and Romanian shelves areas were characterized by the formation of inversion structures.

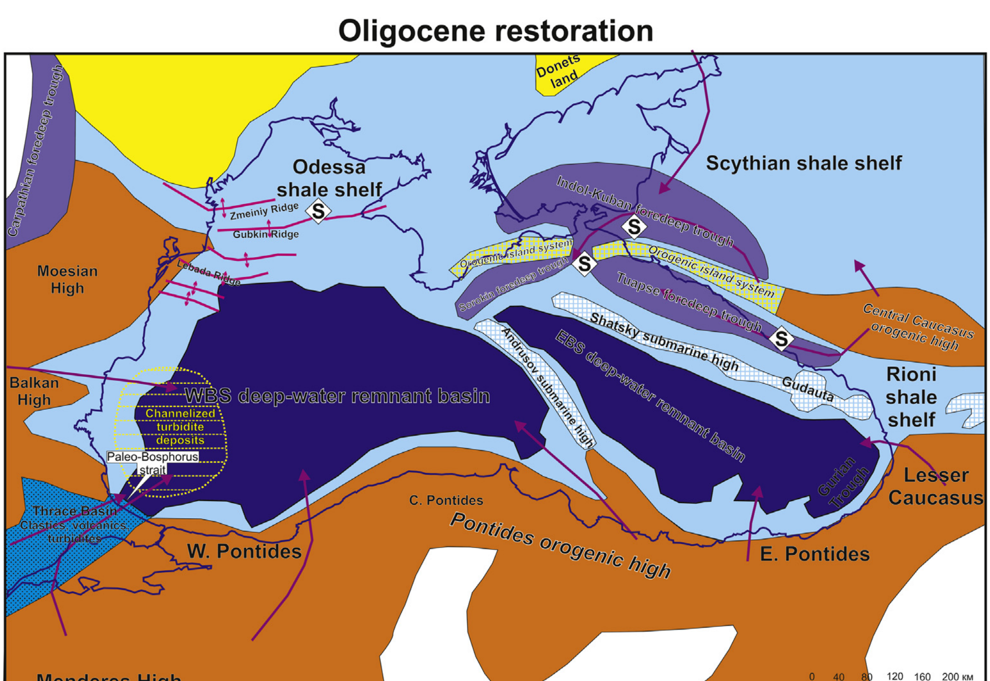

Figure 19. Oligocene Paleogeographical Scheme. Arrows show directions of clastic material transport.

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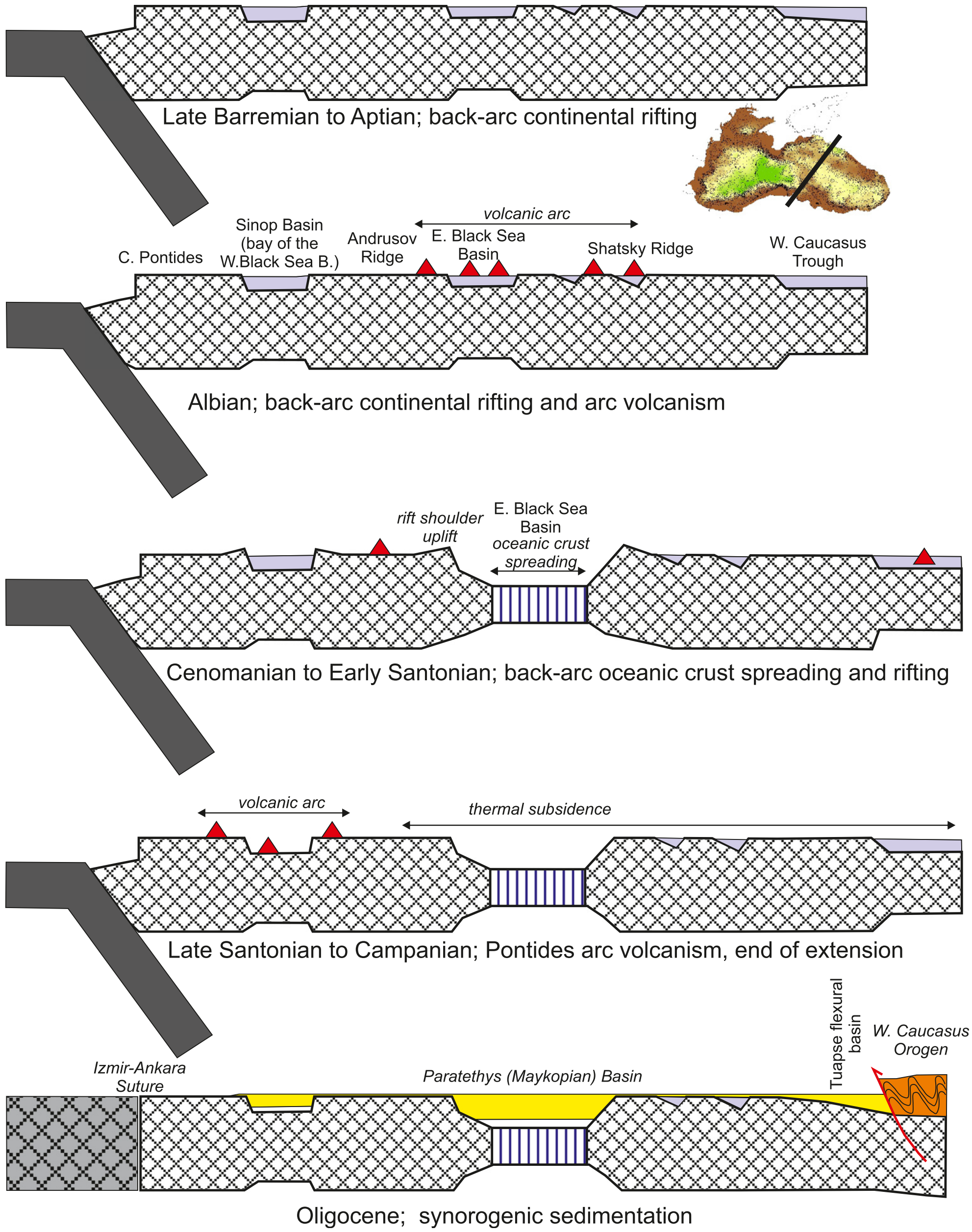

Figure 20. Conceptual cross-sections demonstrating the main geological events in the Black Sea Basin history. The Black Sea Basin region was in an above-subduction tectonic setting during Cretaceous time. Back-arc rifting started in Late Barremian-Aptian time and was followed by the development of an Albian volcanic arc before oceanic crust spreading started in the Cenomanian. The oceanic crust spreading terminated during the Santonian. This event was followed by the migration of a volcanic arc to the Pontides, reaching maximum volcanism in Late Santonian to Campanian. Maykopian (Paratethys) basin originated in a compressional regional setting.

At the end of the Eocene, the formation of the Pontide arch severed the open oceanic connection with the Tethys. Basins to the North (including the Black Sea area) experienced reduced oxygenation leading to the regional formation of the Kuma source rocks (Afanasenkov et al., 2007).

4.8. Oligocene reconstruction (Fig. 19)

A phase of global cooling took place at the boundary between the Eocene and the Oligocene (Bohaty et al., 2012); in the Black Sea Region this led to the replacement of carbonate sedimentation by argillaceous sedimentation.

At the Eocene – Oligocene boundary, the main phase of inversion of troughs took place in the Great Caucasus and in the south of the Crimea, leading to the formation of uplifted zones and island systems (Nikishin et al., 2012; Mityukov et al., 2012). High-rate subsidence of new sedimentary basins started synchronously with these inversion processes, forming the Tuapse, Sorokin and Indol-Kuban foredeeps. Clastic materials entered into these troughs mainly from the uplifts of the Great Caucasus but transport of sedimentary material probably proceeded from the East European Platform as well (Popov et al., 2004; Nikishin et al., 2012; Mityukov et al., 2012). The Pontides in Turkey were uplifted and were subjected to erosion (Popov et al., 2004; Cavazza et al., 2012; d'Atri et al., 2012) while further north the Balkan High and Moesian

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High were also uplifted (Vinogradov, 1961; Popov et al., 2004; Stuart et al., 2011).

In Oligocene time, the Western and the Eastern Black Sea basins, the Andrusov and Shatsky ridges were fully submerged. Dipping northward towards the Tuapse Basin, the Shatsky Ridge formed the peripheral bulge for the Tuapse Foredeep.

Based on the analysis of seismic facies, two Oligocene facies zones can be recognized in the Western and the Eastern Black Sea basins: clays were dominant in the north (transparent seismic facies), and clays with probable horizons of turbiditic sandstones are developed closer to the shores of Turkey and Bulgaria (brighter reflections on seismic).

The presence of numerous channels in Oligocene sediments slightly north of the recent Bosporus Strait points to the existence of a Paleo-Bosporus strait, through which large amounts of clastic material were transported into the Black Sea. It is therefore possible that a Bosporus Strait existed from Mid Eocene until recent time, and was active as a sediment entry point at least during individual epochs.

During the Oligocene the uplift of the Pontides orogenic area severed the open oceanic connection with the Tethys. Basins to the North (Paratethys Basin) experienced reduced oxygenation, leading to the regional formation of the Maykopian source rocks (Afanasenkov et al., 2007).

A conceptual model of the Black Sea Region history is shown on Figure 20.

5. Conclusions

1. The Eastern and Western Black Sea basins originated as back-arc structures. The main regional rifting phases took place during the Late Barremian to the Albian. Since Cenomanian to Mid-Santonian time, these basins were the site of oceanic crust spreading and large scale continental crust extension.
2. Starting in Late Santonian time, thermal subsidence affected the Andrusov and Shatsky continental terranes. Late Santonian to Eocene deposits consist of deep shelf condensed sediments.
3. New Paleocene and Eocene turbidite basins are recognized along the southern and southwestern parts of the Western Black Sea Basin. These turbidite basins originated as a result of compression, thrusting and uplifting of orogenic lands in Turkey and the Balkans.
4. Since Oligocene time the Black Sea deep-water basins were affected by rapid sedimentation and were infilled mainly by shales. Channelized systems are documented not far from the recent Bosporus strait indicating that the Bosporus area could have been a nearly permanent strait since Eocene to Recent time.
5. Based on the new seismic data, a revised stratigraphical scheme and a new set of paleogeographical maps were compiled.

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