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An offshore-onland transect across the north-eastern Black Sea basin (Crimean margin): Evidence of Paleocene to Pliocene two-stage compression

Yevgeniya Sheremet [a,b,*], Marc Sosson [b], Gueorgui Ratzov [b], Grigoriy Sydorenko [c], Zinoviy Voitsitskiy [c], Tamara Yegorova [a], Oleg Gintov [a], Anna Murovskaya [a]

[a] *Institute of Geophysics, National Academy of Sciences of Ukraine, Kyiv, Ukraine*
[b] *Université Côte d'Azur, CNRS, OCA, IRD, Géoazur, 250 rue Albert Einstein, Sophia Antipolis, 06560 Valbonne, France*
[c] *Technology Center of State Geophysical Company "Ukrgeofizika", Kyiv, Ukraine*

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ABSTRACT

The tectonic evolution of the Black Sea (BS) is a subject of debate, there are several unsolved questions: 1) the timing and the spatial progression of the BS basin opening and 2) the timing of Cenozoic shortening along the northern margin of the Eastern BS basin. The timing of the main compressional deformations, related to the inversion of the Greater Caucasus (GC) basin, is assumed to be Oligo-Miocene. However, Late Cretaceous/Early Paleocene shortening, linked to the final closure of the northern branch of the Neotethys, is also suggested. The Crimean Mountains (CM), to the north of the Eastern BS, is one of the key areas to investigate in order to fix the tectonic evolution of the BS. To precise the timing of the Cenozoic shortening of the Eastern BS, we focus on an integrated onshore/offshore transect from the Eastern CM to the Sorokin Trough (north of Eastern BS). We use newly collected stratigraphic and structural data from the Eastern CM, and a new interpretation of multichannel seismic lines. We define 1) the offshore seismic stratigraphy and constrain the relative chronology of deformations, 2) the age of seismic units by correlation of the seismic data with the Subbotina-403 well log, and 3) we construct an on-to-off shore transect of Eastern CM - northern Eastern BS region. Our results evidence a polyphased Cenozoic compression in the northern part of the Eastern BS: 1) Paleocene-Earliest Eocene and 2) Oligocene-Miocene (Maikopian). Normal faults appear to be related to a formation of the foreland basin, instead of evidencing the Eastern BS Cretaceous rifting. Finally, this study allows precising the shortening phases within Eastern CM and Eastern BS since the Early Paleocene, linking them to the Neotethys closure and the GC tectonic evolution.

1. Introduction

The Black Sea (BS) is one of the biggest isolated extensional basins in Europe. Its origin and evolution has been the object of investigations over the four last decades (Letouzey et al., 1977; Zonenshain and Le Pichon, 1986; Finetti et al., 1988; Okay et al., 1994; Robinson et al., 1996; Spadini et al., 1996; Nikishin et al., 1998, 2001; Cloetingh et al., 2003; Starostenko et al., 2004; Shillington et al., 2008; Stephenson and Schellart, 2010; Yegorova and Gobarenko, 2010; Meijers et al., 2010; Khriachtchevskaia et al., 2010; Okay et al., 2013; Yegorova et al., 2013 amongst others). According to these studies, the BS opened in back-arc position within the Eurasian Plate as the result of long-lived northward subduction of the Tethys oceanic plate (Adamia et al., 1981; Dercourt et al., 1986; Zonenshain and Le Pichon, 1986; Lordkipanidze et al., 1989; Okay et al., 1994; Robinson et al., 1996; Spadini et al., 1996; Cloetingh et al., 2003; Barrier and Vrielynck, 2008; Stephenson and Schellart, 2010; Hässig et al., 2013, 2016; Okay and Nikishin, 2015; Sosson et al., 2016). The closure of Northern Neotethyan domain produced the inversion of the BS and Greater Caucasus basins (see for a review Nikishin et al., 2015a, 2015b; Sosson et al., 2016). The main questions regarding BS basin evolution are the timing, which is estimated during the Early-Middle Cretaceous interval (Görür, 1988; Finetti et al., 1988; Dercourt et al., 1993; Hippolyte et al., 2010; Stephenson and Schellart, 2010; Nikishin et al., 2010, 2015a) and/or during the Paleocene (Robinson et al., 1996; Cloetingh et al., 2003), as well as the spatial progression of its opening. Furthermore, the timing of shortening within the BS northern margin is also debated. Generally, the timing of the compressional deformation is thought to be Oligo-Miocene, in relation

Abbreviations: BS, the Black Sea; GC, the Greater Caucasus; CM, the Crimean Mountains; SL, seismic lines.

* Corresponding author at: Institute of Geophysics, National Academy of Sciences of Ukraine, Kyiv, Ukraine
E-mail address: korngane@gmail.com (Y. Sheremet).

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to the Greater Caucasus (GC) orogeny as the inversion of the GC basin (Milanovsky and Khain, 1963; Milanovsky, 1991; Ershov et al., 1999, 2003, Nikishin et al., 1998, 2003; Khriachtchevskaia et al., 2010; Adamia et al., 2011; Espurt et al., 2014). However, Late Cretaceous/ Early Paleocene shortening due to the final closure of the Northern Neotethys ocean is also suggested (e.g. Sosson et al., 2016).

Despite the numerous studies of the BS based on seismic profiles (Finetti et al., 1988; Robinson et al., 1995, 1996; Yudin, 2008; Stovba et al., 2009, 2013; Khriachtchevskaia et al., 2010; Munteanu et al., 2012; Nikishin et al., 2015a, 2015b; Espurt et al., 2014; Suc et al., 2015; Sydorenko et al., 2016), the age correlation between studied areas and the corresponding tectonic stages are still debated. Structural connections between the GC and the Eastern BS basin (Angelier et al., 1994; Saintot and Angelier, 2002; Nikishin et al., 2010) as well as between Pontides and Eastern BS (Espurt et al., 2014) are well argued. The studied profiles evidence a mostly Cenozoic shortening phase for the Eastern BS. North of the Eastern BS, the Crimean Mountains (CM) is also one of the key areas to fix the tectonic evolution of the BS basin. Connection of tectonic structures described onland and offshore, crossing the Sorokin Trough (north of the Eastern BS), have been proposed by Yudin (2008), Mileev et al. (2009) and Yudin and Yudin (2014). However, recent works (Sheremet et al., 2016) contradict these interpretations, regarding the structures defined onland and the timing of deformation.

To precise the timing of the Cenozoic shortening of the Eastern BS, we focus on an integrated onland/offshore transect from the Eastern CM to the Sorokin Trough. We based this study on newly collected stratigraphic and structural data that redefined the timing of the Eastern CM deformations (Sheremet et al., 2014, 2016), and on a new interpretation of offshore multichannel seismic lines, which were provided by the State Geophysical Company "Ukrgeofizika" (Ukraine).

To precisely determine the timing of the Cenozoic shortening of the Eastern CM and of the northern part of the Eastern BS, we 1) define the offshore seismic stratigraphy and constrain the relative chronology of deformation, 2) define the age of seismic units by comparing the offshore data with a well log (Subbotina-403), and 3) construct an on-and-off shore transect from the Eastern CM to the Eastern BS region (the Sorokin Trough). Finally, this study allows precising the shortening of the Eastern CM and northern part of the Eastern BS since the Early Paleocene, linking it to the Neotethys closure and the GC tectonic evolution.

2. Geological settings

The BS basin is composed of Eastern and Western deep depressions filled with thick (up to 12–14 km) Mesozoic-Cenozoic sediments (Tugolesov et al., 1985; Finetti et al., 1988; Belousov and Volvovsky, 1989; Starostenko et al., 2004; Yegorova and Gobarenko, 2010). In contrast, the present-day topography of the sea floor reflects a single BS basin with a floor submerged at 2245 m at its deepest part (Ross et al., 1974).

2.1. Structures of the eastern BS

The Eastern BS basin is separated by the Mid-Black Sea High (Ridge) from the Western BS and considered to be somewhat younger (Paleogene) than the latter (Cretaceous) (Nikishin et al., 2003) (Fig. 1). It is much narrower and differs in regards to its dimensions, configurations, trends of tectonic units and thickness of sediments, which is up to 12 km (Tugolesov et al., 1985; Yegorova and Gobarenko, 2010). The Eastern BS presents a NW-SE elongation, and is parallel to the structures farther east of the GC Belt (Shatsky ridge and Tuapse trough offshore).

Most of the crust of the northern part of the Eastern BS is assumed to be Precambrian in age (Milanovsky, 1968; Görür, 1988; Stephenson and Schellart, 2010). The reinterpreted seismic refraction data in the north of the BS (Yegorova et al., 2010) evidence a very thick continental crust (up to 39 km, corresponding to the Scythian platform). This basement is composed, supposedly, of early Precambrian to early Mesozoic fragments of accreted terranes (Winchester et al., 2006; Pease et al., 2008; Stephenson and Schellart, 2010). The high velocity model of P-waves evidences a southward thinning of the crust of both sub-basins, which is interpreted as oceanic or much extended continental crust (Yegorova et al., 2010; Starostenko et al., 2004, 2016; Stephenson et al., 2004; Yegorova and Gobarenko, 2010).

2.2. Stratigraphy of the eastern BS basin

Based on deep seismic reflection data (Tugolesov et al., 1985; Finetti et al., 1988), a 3D diagram and stratigraphy of the BS basins (Shillington et al., 2008) allow the identification of the most significant structures of the Eastern BS (Fig. 1): to the north, the Sorokin Trough (ST), the Tuapse Trough (TT), and the Shatsky Ridge (SR); to the south, the Guriy Trough (GT) (southeastern limit of the Eastern BS) and the Mid Black-Sea Ridge (MBSR) composed from northwest to southeast of the Andrusov Ridge (approximately 200 km-long and 20–80 km-wide) and of the Arkhangelsky Ridge (about 450 km-long and from 10 to 60 km-wide) (Yegorova and Gobarenko, 2010). Onland, the Eastern BS is bounded northwards by the CM, and southwards by the Eastern Pontides (Fig. 1).

The thickness of the Cretaceous sediments ranges between 1.7 and 3–4 km depending on the authors (Finetti et al., 1988; Nikishin et al., 2003 with references to Tugolesov et al., 1985; Shillington et al., 2008). Beneath these series, the stratigraphy is not well constrained. The Paleocene-Eocene sediments (3 km thick) are characterized by a quiet thick, almost horizontal and flat layer interpreted as interlayered carbonates, terrigenous rocks (flysch complexes in the coastal troughs of the Western GC and Pontides), and volcanic rocks (Guriy Trough) (Tugolesov et al., 1985; Yegorova and Gobarenko, 2010; Shillington et al., 2008). The Oligocene-Lower Miocene sediments (Maikopian, approximately 4 km thick) fill the Sorokin and Tuapse Troughs, interpreted as syntectonic clays to siltstones related to the erosion of the GC (Tugolesov et al., 1985; Nikishin et al., 2015c). Strong alternations between sandstones and siltstones in the Miocene strata indicates gradual spatial changes in the sedimentation environment, with much thicker deposits in the Eastern BS than in the Western BS (in 1.5–2 times), reaching up to 3 km in the Guriy Trough (Tugolesov et al., 1985; Shillington et al., 2008; Stovba et al., 2009). The Quaternary deposits along the northern shelf of the Eastern BS (Kerch-Taman shelf) are terrigenous shales and siltstones over 3 km thick (Stovba et al., 2009; Yegorova and Gobarenko, 2010).

2.3. Tectonic evolution

The tectonic evolution of the Eastern BS was explained in light of offshore and onland data (Yudin, 2008; Mileev et al., 2009; Stovba et al., 2009; Nikishin et al., 2013; Nikishin et al., 2015a, 2015b, 2015c; Sydorenko et al., 2016) in relation to closure of the Tethys ocean (Letouzey et al., 1977; Zonenshain and Le Pichon, 1986; Görür, 1988; Okay et al., 1994; Robinson et al., 1996; Nikishin et al., 2003; Stephenson and Schellart, 2010) and the history of its long investigation is repetitively described (e.g. Sydorenko et al., 2016).

According to seismic reflection data, two stages of deformation are recognized for the tectonic evolution of the Eastern BS Basin: 1) Mesozoic (Cretaceous) extension, expressed in variety of high offset normal faults related to the opening of the BS (Nikishin et al., 2015a, 2015b); and 2) Cenozoic compression, accompanied by the inversion of the entire BS margin, featuring in distinctive thrusts and folds. The shortening within the northern flank of the Eastern BS is, classically, connected to the inversion of the GC basin (Nikishin et al., 2010; Yegorova and Gobarenko, 2010).

Moreover, onland data in the CM, an inverted section of the northwestern passive margin of the Eastern BS (e.g. Nikishin et al., 2001),