Tectonic Evolution of the Eastern Black Sea and Caucasus: an introduction

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Abstract: This Special Publication presents the results of 15 different studies in the Black Sea–Caucasus segment of the Alpine–Tethys orogenic realm. The main focus of these studies is the style and timing of key tectonic events occurring primarily during the area's post-Pangaean evolution. The methodologies encompass: geophysics, including active and passive crustal-scale seismology and common depth point reflection seismic profiling (both onshore and marine), palaeomagnetism and magnetostratigraphy; field geology, including biostratigraphic recorrelation; radiochronology; igneous rock geochemistry, including analyses of the obducted ophiolites; and low-temperature thermochronology. The geological record of the area is essentially one of sedimentary basins formed in an extensional back-arc setting and their subsequent compressional deformation during the closure of at least two branches of the Neotethys Ocean system.

Among the many goals of the DARIUS programme, based at the University of Paris VI (Université Pierre et Marie Curie) and chaired by Eric Barrier (CNRS, Université Pierre et Marie Curie), was the interpretation of the tectonic history of the sedimentary basins of the eastern Black Sea–Caucasus and surrounding areas. The programme also aimed to interpret the geodynamic processes governing the formation and deformation of these basins and the development of the related mountain belts. The *raison d'être* of DARIUS was to investigate the 6000 km long continuous orogenic belt running from Crimea–Anatolia in the west to the Tien-Shan in the east, through the Caucasus, northern Iran and Zagros. This scientific activity was loosely separated into regionally defined subgroups and this Special Publication reports some of the results of studies carried out by the DARIUS Caucasus Working Group in and on the margins of the eastern Black Sea, including Crimea and Turkey, and in the Caucasus domain between the Black and Caspian seas (Fig. 1).

Regional tectonic setting and issues in the eastern Black Sea–Caucasus realm

The sedimentary basins of interest in the study area are largely formed on top of and within the continental lithosphere of the Eurasian plate. The northern part of this pre-Black Sea pre-Caucasus Orogen lithosphere is represented by the so-called Scythian Plate (or Scythian Platform, although this terminology is neither well defined nor consistent in its usage; Fig. 1), which forms the crystalline basement north of the Crimea–Caucasus compressional belt (e.g. Saintot *et al.* 2006*a*). When and how the continental lithosphere of the Scythian Plate actually formed, and when it was accreted to the European craton to its north, have been poorly studied, but it is probable that it is at least as old as earliest Palaeozoic and, more likely, Precambrian (e.g. Gee & Stephenson 2006). Numerous large-scale studies of the European lithosphere using geophysical, thermal and/or geoid data to determine the lithospheric properties – such as the integrated strength – infer strong, cold lithosphere below most of the present day Black Sea (e.g. Tesauro *et al.* 2009) and presumably also the areas immediately to its east. An exception is the SE corner, adjacent to the Cenozoic magmatic province found in the Turkish eastern Pontides, which is an issue addressed in this volume.

The papers in this Special Publication deal with the evolution of the geology of the eastern Black Sea–Caucasus realm primarily during its post-Pangaean tectonic setting. Accordingly, only

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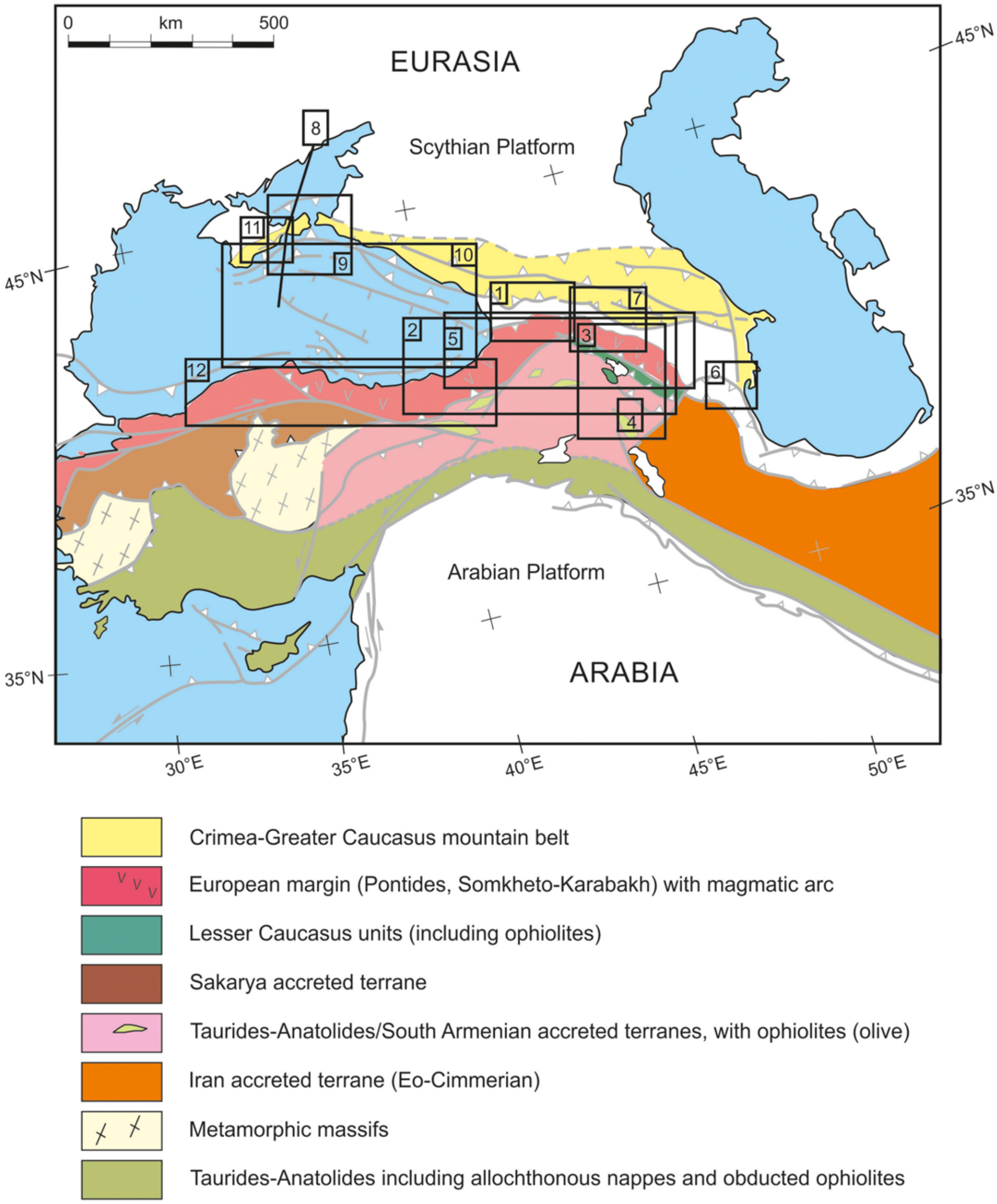

Fig. 1. Tectonic map of the Black Sea–Caucasus domain and surrounding areas, modified from Sosson *et al.* (2015), showing the field locations of studies reported in this Special Publication: 1, **Adamia *et al.* (2015)**; 2, **Hässig *et al.* (2015)**; 3, **Danelian *et al.* (2015)**, **Sahakyan *et al.* (2016)** and **Cavazza *et al.* (2015)**; 4, **Avagyan *et al.* (2016)**; 5, **Meijers *et al.* (2015)**; 6, **van der Boon *et al.* (2015)**; 7, **Alania *et al.* (2015)**; 8, **Starostenko *et al.* (2016)**; **Sydorenko *et al.* (2016)**; 9, **Gobarenko *et al.* (2015)**; 10, **Nikishin *et al.* (2015*b*)**; 11, **Sheremet *et al.* (2016*b*)**; and 12, **Hippolyte *et al.* (2015)**.

minor attention is given to its pre-Early Mesozoic history, which can be broadly correlated with the closure of what is known as the Palaeotethys Ocean (and its predecessors), in favour of the later Mesozoic and Cenozoic. During this time, the tectonic setting of the area can be characterized as one of general plate convergence as the Neotethys Ocean (or the branches of a Neotethys Ocean system) was subducted and eventually closed. The geological record documents the formation of sedimentary basins in an extensional back-arc setting through to the eventual compressional deformation (inversion) of these basins linked to the closure of the Neotethys Ocean and the processes and deformation associated with this closure. The inversion of the basins occurred in two main phases: the first was in the Cretaceous and, in this work, linked broadly to the closure of what is referred to as the northern branch of the Neotethys Ocean; and the second was in the Cenozoic, linked broadly to the closure of what is referred to as the southern branch of the Neotethys Ocean, which corresponds to the eventual suturing of the Arabian plate with Eurasia.

The main problems to resolve in the eastern Black Sea and Caucasus regions of the Alpine–Tethys belt are: (1) the evolution in space and time of the geodynamic processes (subduction, obduction and collisions) responsible for the closure of the northern and southern branches of the Neotethys Ocean and how these processes are related to the opening and inversion of back-arc basins in space and time in the realm of interest; (2) the timing and evolution of the extensional and syncompressional sedimentary basins; (3) the continuity of structures and their evolution in time between the eastern Black Sea, the Greater Caucasus, the Lesser Caucasus and those of the Taurides–Anatolides, Pontides belt and NW Iran; and (4) the evolution of Paratethys along this belt since the Eocene.

Contents of this Special Publication

This Special Publication includes 15 multidisciplinary studies covering topics in structural geology/tectonics, passive and active source seismology and seismic profiling, geochemistry, palaeontology, petrography, sedimentology and stratigraphy, reporting results obtained during the DARIUS programme and related projects in the eastern Black Sea and Caucasus realm. All are aimed at addressing the general issues highlighted in the preceding section. The papers are presented in two sections corresponding to the eastern 'Caucasus' and the 'Black Sea' parts of the Black Sea and Caucasus tectonic realm of interest. The first section mainly reports onshore geological studies from Georgia, Azerbaijan, Armenia and Iran. The second section reports onshore geological studies from the Black Sea margins of Crimea and Turkey and geophysical and other subsurface data from the eastern Black Sea and its northern margin. The papers are presented and discussed in generally chronological order (starting with the oldest) separately within each of these two sections.

The first section deals with the geology recorded from processes that largely occurred prior to and in the Cretaceous, which are linked to the closure of what is referred to here as the northern branch of the Neotethys Ocean. This section includes the results of new field mapping in Turkey, Georgia, Armenia, Azerbaijan and Iran, as well as palaeomagnetic, biostratigraphic, magnetostratigraphic and geochemical analyses. It opens with an overview of the tectonic history of this domain based on the geology of Georgia, including the Neoproterozoic–Palaeozoic crystalline and sedimentary basement of this area, which can be considered as part of the contiguous Eurasian plate from the point of view of subsequent Alpine–Tethys convergence and collision. This is followed by papers dealing with the Cretaceous emplacement of ophiolitic units during the closure of a northern branch of the Neotethys Ocean, suturing or juxtaposing the Taurides–Anatolides–South Armenian Microplate (TASAM) to Eurasia. A series of papers then addresses the structural styles and timing of Cenozoic compressional deformation related to the closure of a southern branch of the Neotethys Ocean (as it is called in this Special Publication), suturing the Arabian plate to Eurasia–TASAM.

The second section consists of papers dealing with the eastern Black Sea, documenting the mainly Cretaceous extensional tectonic regime in which the eastern Black Sea formed, as well as the subsequent Cenozoic compressional tectonic regime in which the margins and intra-basinal structures of the eastern Black Sea were (and are continuing to be) structurally inverted. This section starts with the results of new field observations and structural mapping in Crimea, including a revised stratigraphic correlation, and the Pontides of northern Turkey. This is followed by the characterization of the subsurface geology of the eastern Black Sea from seismic reflection profiling. It closes with crustal and upper mantle scale models of the Crimea–eastern Black Sea margin from controlled source and passive seismology, both of which illustrate complex regional crustal geometries consisting of ancestral structures and those developed during the Cretaceous extensional and Cenozoic compressional tectonic phases affecting this area.

'Caucasus' domain of the Eastern Black Sea–Caucasus tectonic realm

Adamia *et al.* (2015) contribute a general overview of the Phanerozoic tectonic history of Georgia and its contiguous eastern Black Sea (Fig. 1; area 1). As with the rest of the realm of interest in this Special Publication, it is a story of island-arc systems and back-arc basins on the southern, Tethyan, margin of the East European continent and magmatic activity linked to the subduction and obduction of crustal fragments as the deep marine basins were closed. These processes culminated with the collision of the African–Arabian and Eurasian plates and the consequent inversion of the intra-arc and back-arc basins into the present day Greater and Lesser Caucasus fold–thrust belts.

Hässig *et al.* (2015) discuss the earlier subduction of what is referred to as the northern branch of the Neotethys Ocean. This is marked by the Ankara–Erzincan–Sevan–Akera suture zone (Fig. 1; area 2). It displays unmetamorphosed ophiolites in tectonic slivers obducted over the northern edge of the South Armenian Block and the Taurides–Anatolides Platform margin (both areas representing the TASAM). The extensive database of these researchers supports a model in which these ophiolites, generally considered to consist of mid-ocean ridge basalts enriched in large ion lithophile elements, are derived from a single obducted nappe. Their emplacement is inferred to have taken place during the early Late Cretaceous, linked to an intra-oceanic north-dipping subduction zone in which the TASAM entered from the south, producing the obduction of the overriding oceanic plate.

Danelian *et al.* (2015) report a study of radiolarian faunas from the Cretaceous ophiolitic mélange that occurs in the Erakh area south of Yerevan, Armenia (Fig. 1; central part of area 3). They document new evidence of an Early Cretaceous (late Valanginian) age for the deep-water sediments in the Lesser Caucasus overlying submarine volcanic rocks of Late Jurassic age, which represent the northern branch of the Neotethys Ocean. This area is part of a branch of a deep marine basin, now closed and expressed as the Amasia–Sevan–Akera suture zone, and is part of the eastern segment of the longer suite of ophiolites studied by **Hässig *et al.* (2015)** and discussed by **Avagyan *et al.* (2016)**, which form the basement to Eocene sedimentary basins (**Sahakyan *et al.* 2016**).

Sahakyan *et al.* (2016) present a detailed petrological and geochemical study of Eocene magmatic rocks from the Lesser Caucasus area, Armenia (Fig. 1; area 3) and show how their results provide strong evidence for genesis within a subduction geodynamic environment. Specifically, these researchers argue that their results, put in a regional geodynamic context, suggest that the magmatism of this part of the Lesser Caucasus – consisting of both the Amasia–Sevan–Hakari suture zone (the Amasia–Sevan–Akera suture zone of **Danelian *et al.* 2015**) and the so-called South Armenian Microplate (the eastern part of TASAM, referred to by other researchers as the South Armenian Block) – formed in a back-arc setting north of a north-dipping subduction zone and prior to the closure of the southern branch of the Neotethys Ocean, marking the collision of the Arabian–Eurasian plates further to the south.

Avagyan *et al.* (2016) document the geology of the Khoy region in NW Iran (Fig. 1; area 4), primarily focusing on the Cenozoic convergent geodynamic processes in this area. The Khoy region is known for ophiolitic units that had earlier been obducted onto the South Armenian Block (the eastern part of TASAM) basement from the Amasia–Stepanavan–Sevan–Hakari suture zone (referred to as the Amasia–Sevan–Akera suture zone by **Danelian *et al.* 2015** and **Hässig *et al.* 2015**). These researchers present new stratigraphic and structural data on the style and timing of deformation. Volcanogenic and sedimentary Eocene strata unconformably overlie ophiolites and their Campanian–Maastrichtian–Paleocene cover deposits in a basin interpreted to have formed in a syn-orogenic, plate closure tectonic setting with the Khoy allochthonous ophiolites.

Meijers *et al.* (2015) deal with the specific northwards arc-shaped geometry of the Eastern Pontides–Lesser Caucasus fold–thrust belt, defined in earlier studies using palaeomagnetism as an orocline. Rocks of Late Cretaceous to Miocene age in Georgia and Armenia (Fig. 1; areas labelled 5) were sampled at 37 sites and integrated with other available data to test the orocline hypothesis and to constrain the timing of its formation. These researchers infer that, although the oroclinal structure was formed mainly during post-Paleocene compression (and here dominantly post-Eocene and pre-Miocene), some pre-existing curvature was also present before the Late Cretaceous.

Van der Boon *et al.* (2015) look in some detail at the Maikop Series (also spelt Maykop by some authors in this Special Publication), which is an important source rock in this area, deposited in a syn-compressional tectonic setting. Here, the oldest constituent formation of the Maikop Series in Azerbaijan has been dated by these researchers using magnetostratigraphy and biostratigraphy and they have determined that it is older than previously considered – Late Eocene in age rather than Oligocene. The location of this study is area 6 in Figure 1. Intrinsic to these researchers' deliberations are issues of tectonic v. glacio-eustatic controls on sea-level changes affecting the environmental controls on depositional setting. These researchers also report palaeomagnetic and geochemical results for the Eocene volcanic rocks that underlie the Maikop Series in Azerbaijan, with the cessation of this volcanism being considered as possibly central to the onset of the subsequent Maikopian depositional setting. The underlying Eocene volcanic rocks are part of a very long belt of similar rocks, which include those discussed by **Sahakyan *et al.* (2016)** and **Hippolyte *et al.* (2015)** and which continue to the SE through Iran.

Alania *et al.* (2015) focus on the latest stages of the Cenozoic compressional phase of tectonics in SE Georgia and adjacent parts of Azerbaijan (Fig. 1; area 7) by exploring the tectonic structures in the Miocene and younger subsurface formations revealed by seismic reflection profiling, rather than by outcrops of older formations. The study demonstrates that the Kura foreland fold–thrust belt of the eastern Greater Caucasus consists of fault-bend folds, fault-propagation folds and duplexes, and that deformation essentially continues to the present day, although it was most rapid around the end of the Miocene.

Cavazza *et al.* (2015), in the final paper of this section, present new apatite fission track data from the central Lesser Caucasus, which document a discrete phase of cooling/exhumation at 18–12 Ma (late Early–early Middle Miocene) as a result of the structural reactivation of a segment of the Late Cretaceous–Palaeogene Sevan–Akera suture zone (also discussed by **Hässig *et al.* 2015**; **Danelian *et al.* 2015**; **Avagyan *et al.* 2016**; **Sahakyan *et al.* 2016**). They point out that this is not consistent with the common view of the post-collisional tectonic style in this area being predominantly one of strike-slip movement, but with reactivation and exhumation focused along those segments of the older suture zone lying at high angles to the collision-induced far-field stress field. The location of this study is the northern part of area 3 in Figure 1.

'Black Sea' domain of the Eastern Black Sea–Caucasus tectonic realm

The first paper of the Black Sea domain is **Starostenko *et al.* (2016)**, which shows the Precambrian basement in its transition from the East European Craton to the Scythian Platform immediately north of the Black Sea. They describe the results of DOBRE2, a wide-angle reflection and refraction (WARR) profile that crosses the Azov Massif of the East European Craton, the Azov Sea, the Kerch Peninsula (the easternmost part of Crimea) and the northern East Black Sea Basin, thus traversing the entire Crimea–Caucasus compressional zone centred on the Kerch Peninsula (profile labelled 8 in Fig. 1). There is a significant change in the upper crustal lithology in the northern Azov Sea, indicating that the boundary between the East European Craton and the Scythian Platform and the depth of the underlying Moho discontinuity increases from 40 km beneath the Azov Massif to 47 km beneath the Kerch Peninsula. In the shallower parts of the WARR velocity model, DOBRE2 images the northern foredeep and the underlying successions of the Crimea–Caucasus compressional zone in the southern part of the Azov Sea.

A local seismic tomography study of this same area centred on the Kerch Peninsula and reported by **Gobarenko *et al.* (2015)** complements the **Starostenko *et al.* (2016)** geophysical study. The resulting three-dimensional P- and S-wave velocity models, for an area of *c.* 200 × 100 km (east–west and north–south, respectively) with a depth of *c.* 40 km (Fig. 1; area 9), suggest that the continental crust underlying the Crimea–Azov region north of the Black Sea margin is of different, cratonic, tectonic affinity than that underlying the northeastern part of the Black Sea. The uppermost mantle below the thin quasi-oceanic crust of the eastern Black Sea deep basin has been tentatively interpreted by **Gobarenko *et al.* (2015)** as representing serpentinized upper mantle of continental lithosphere exhumed during Cretaceous rifting and lithospheric hyperextension of the eastern Black Sea. The Crimea–Caucasus seismic zone, where earthquake foci deepen northwards, lies between the continental domains to the north and the crust underlain by anomalous upper mantle, suggesting that the latter is being thrust under the former in this intra-plate setting.

Nikishin *et al.* (2015*b*) link the onshore geology of the Crimean Peninsula with the subsurface geology of the eastern Black Sea, largely based on a set of regional seismic reflection profiles, and choose to discuss the Mesozoic and Cenozoic geological evolution of the area in terms of three stratigraphic mega-sequences: the Triassic–Early Jurassic; the Middle Jurassic; and the Late Jurassic–Eocene. By far the greatest attention is given to the last of these, which encompasses the key event of the formation of the eastern Black Sea basin, with an early extensional phase (graben formation according to these researchers) in the late Early Cretaceous, culminating with a magmatic event at the end of the Albian, and a main extensional phase in the early Late Cretaceous. The location of the study is area 10 in Figure 1.

Sheremet *et al.* (2016*b*) present important new findings that have important implications for understanding the geology of Crimea and its adjacent segment of the Black Sea (Fig. 1; area 11). These researchers, as part of a wide-ranging suite of field geological studies, dated rocks from the eastern Crimean Mountains using nannoplankton assemblages and documented that strata typically assigned to the Late Triassic in eastern Crimea are actually of Early Cretaceous age in this area. This leads to new interpretations of the structural relationships in Crimea and the timing of tectonic events. Evidence of the Cretaceous extensional tectonic regime responsible for the formation of the Black Sea is now clearly recognized onshore and, importantly, there was a tectonic shortening regime during the Paleocene–Early Eocene, before the main Middle Eocene limestone unconformity and subsequent compressional deformation, not mentioned by **Nikishin *et al.* (2015*b*)** in their offshore data.

Sydorenko *et al.* (2016) report a geological interpretation of a regional seismic reflection profile acquired along the same transect and in association with the DOBRE2 WARR profile (labelled 8 in Fig. 1) reported by **Starostenko *et al.* (2016)** and the resulting velocity model of the latter is superimposed on the former. The regional basin architecture from the Azov Sea, crossing the Kerch Peninsula into the Black Sea as far south as the eastern Black Sea deep basin, consists of a series of basement structural highs separating a series of sedimentary depocentres and is mainly a consequence of the compressional tectonic regime affecting the area since the Eocene. These researchers argue that two major sedimentary basins formed mainly during this time – the Sorokin Trough in the Black Sea and the Indolo-Kuban Trough in mostly the southern Azov Sea – formed as marginal troughs to the main Crimea–Caucasus inversion zone and are not, as such, flexural foreland basins in the traditional sense.

Hippolyte *et al.* (2015) present new nannoplankton ages for the western, central Pontides and eastern Pontides along the Black Sea margin of Turkey (Fig. 1; area 12) and have used these to refine the timing of tectonic events in this part of the study realm. These researchers infer that extensional subsidence, which can be considered as reflecting the Black Sea formation regime, migrated eastwards along the Pontides from the Barremian to the Paleocene, thus suggesting a younging towards the east. Syn-compressional basins in the Pontides suggest that contraction started at the beginning of the Eocene. **Hippolyte *et al.* (2015)** consider that the Eocene volcanism of the eastern Pontides, which form the eastern prolongation of the same (Eocene-aged) volcanic belt discussed by **Sahakyan *et al.* (2016)** and **van der Boon *et al.* (2015)**, is syn-collisional and they speculate that this may be related to the effects of the structure of the subducted slab.

Synthesis and summary

In the context of the regional objective of the DARIUS Caucasus Working Group, the papers in this volume have broadly clarified a series of tectonic questions relevant to the evolution of the Black Sea–Caucasus area as a whole.

Although there are several papers in this collection that in part address pre-Cretaceous geology and tectonics, the story of the Black Sea–Caucasus domain as discussed here essentially begins in the Cretaceous. The papers touching on pre-Cretaceous tectonic evolution include overview papers, such as **Adamia *et al.* (2015)** for the Caucasus domain as seen from Georgia, and papers addressing the eastern Black Sea domain (**Nikishin *et al.* 2015*b***) and its contiguous onshore geology in Crimea (**Sheremet *et al.* 2016*b***), the second of which deals with important issues of Mesozoic stratigraphy. There are also geophysical papers, in particular **Starostenko *et al.* (2016)**, whose authors recognize extensional structures and Late Palaeozoic, Permo-Triassic and Jurassic sedimentary basins in an upper crustal velocity model of the Black Sea domain.

In terms of the Cretaceous and younger evolution, the contents of this volume highlight a series of broadly correlative tectonic phases regionally affecting the study area. A widespread extensional regime, clearly occurring in the context of back-arc geodynamic processes within a plate tectonic zone of overall convergence, existed in much of the area during much of the Cretaceous (subsequent to earlier back-arc phases of extensional tectonics linked, for example, to the formation of the Greater Caucasus sedimentary basin in the area of the present Greater Caucasus mountains; e.g. Saintot *et al.* 2006*b*). The main extensional tectonics of the Black Sea occurred during this period (**Nikishin *et al.* 2015*b***, offshore; **Sheremet *et al.* 2016*b***, onshore Crimea; **Hippolyte *et al.* 2015**, southern margin of the eastern Black Sea).

The extensional tectonics of the Black Sea are due to the northwards subduction of the Neotethys Ocean below Eurasia. To the south, a secondary intra-oceanic northwards subduction zone was active within the Neotethys plate (**Hässig *et al.* 2015**) and this induced the opening of the Ankara–Erzincan–Sevan–Akera back-arc basin within the northern branch of the Neotethys Ocean (e.g. Sosson *et al.* 2010, 2015). Progressively, this basin subducts beneath Eurasia (**Hässig *et al.* 2015**), involving the NW–SE-trending spreading centre of the back-arc basin (Hässig *et al.* 2016; Sosson *et al.* 2015). It is suggested that the oceanic spreading centre moved along and entered the subduction trench progressively from west to east, leading to rifting of the Black Sea.

Any direct genetic link between the Cretaceous Black Sea and the northern branch of the Neotethys Ocean is speculative and unwarranted. However, the subduction of the northern branch of the Neotethys Ocean is the main cause of the back-arc extension of the Black Sea (cf. Sosson *et al.* 2015). According to stratigraphic and radiochronological data, obduction in the northern branch of Neotethys started during the early Late Cretaceous (**Hässig *et al.* 2015**), followed by collision between the

TASAM and Eurasia in latest part of the Cretaceous and early Paleocene. In this regard, for example, **Meijers *et al.* (2015)** infer post-Paleocene shortening in the eastern Pontides–Lesser Caucasus area superimposed on an earlier phase of shortening of Late Cretaceous age, but none in the intervening period. It is noted, however, that **Hippolyte *et al.* (2015)** suggest – but on the basis of inference rather than direct observation – that extension in the eastern Black Sea continues into the Paleocene, something that is not consistent with the studies of **Sydorenko *et al.* (2016)** and **Nikishin *et al.* 2015*b*** (also cf. Nikishin *et al.* 2015*a*).

Certainly, beginning at some point in the Paleocene, the whole study area probably entered a period of shortening on the regional scale, culminating in its present day tectonic configuration. **Sheremet *et al.* (2016*b*)** document from field geology that the onset of compression in the Black Sea domain (in any case, its northeastern segment) was in the late Paleocene. There is also good evidence of a compressional regime in this area in the Eocene (cf. Khriachtchevskaia *et al.* 2010; Sheremet *et al.* 2016*a*) in contiguous offshore regions, although they indicate that the most intense period of shortening began later. Significant volcanic activity also occurs in the Eocene in the study area, as reported by **Sahakyan *et al.* (2016)** in the Lesser Caucasus and **Hippolyte *et al.* (2015)** in the eastern Pontides. The former researchers consider this magmatism to be immediately 'pre-collisional', whereas the latter refer to it as syn-collisional, taking into account the regional setting inferred elsewhere.

Cavazza *et al.* (2015) also mention that the widely evidenced Paleocene–Eocene compressional event may represent an early pre-collisional phase, with the latest Eocene, but mainly the Oligocene–early Miocene, being the time of the main collisional phase. Collision in this case is between Arabia and Eurasia with the closure of the southern branch of Neotethys, the earlier subduction of which had driven back-arc extension to the north, probably including the Black Sea, in the Cretaceous. Oligocene–Miocene shortening is widely recognized throughout the study area, including by **Avagyan *et al.* (2016)** in the Khoy area of NW Iran and **Alania *et al.* (2015)** in the Kura fold–thrust belt in SE Georgia and Azerbaijan.

Alania *et al.* (2015) report the formation of Oligocene syn-compressional basins. This element of the tectonic evolution of the study area and the mechanism of formation of the Cenozoic sedimentary basins are documented elsewhere, specifically by **Sheremet *et al.* (2016*b*)** and **Sydorenko *et al.* (2016)** in the eastern Black Sea region and Crimea and by **Avagyan *et al.* (2016)** in Iran, **van der Boon *et al.* (2015)** in Azerbaijan and **Hippolyte *et al.* (2015)** in eastern Turkey. The syn-compressional basin succession is predominantly the Maykop Formation. Notably, **van der Boon *et al.* (2015)** suggest that the Maykop Formation, at least at their field area in Azerbaijan, where it is deposited directly onto Eocene volcanics, could be as old as Late Eocene, although it is normally considered to be Oligocene–Early Miocene in age. This is clearly a contentious interpretation that demands further study, but it emphasizes the close temporal link between volcanism and ocean closure in the study area and its relationship with syn-orogenic basin formation.

Cavazza *et al.* (2015) suggest a final (and contemporaneous) phase of the Arabia–Eurasia collisional process to have started in the Miocene, mainly expressed today as the active Anatolian Fault/westwards extrusion of Anatolia. **Gobarenko *et al.* (2015)** infer, however, that contemporary earthquakes on the northern margin of the eastern Black Sea provide evidence for continued underthrusting of Black Sea crust and lithosphere beneath the Crimean (Kerch) and Taman peninsulas. They also suggest from their local tomography velocity models that the underthrust Black Sea is not of oceanic affinity.

Thus, this synthesis of the DARIUS Black Sea–Caucasus Special Publication comes full circle, back to the origins of the Black Sea in the Cretaceous and its indirect association with the northern branch of the Neotethys Ocean, lost to the Ankara–Erzincan–Sevan–Akera suture zone. This raises important questions for future consideration about the crustal affinity of deep marine basins formed in back-arc settings generally – whether they are underlain by highly deformed and intruded lithosphere of continental affinity or whether they are the locus of the accretion of true oceanic crust and lithosphere at a newly formed mid-ocean ridge plate boundary, an important question for study in the Alpine–Tethys–Himalaya orogenic belt.

References

Adamia, S.A., Chkhotua, T.G. *et al.* 2015. Tectonic setting of Georgia–Eastern Black Sea: a review. *In*: Sosson, M., Stephenson, R.A. & Adamia, S.A. (eds) *Tectonic Evolution of the Eastern Black Sea and Caucasus*. Geological Society, London, Special Publications, **428**. First published on November 4, 2015, https://doi.org/10.1144/SP428.15

Alania, V.M., Chabukiani, A.O., Chagelishvili, R.L., Enukidze, O.V., Gogrichiani, K.O., Razmadze, A.N. & Tsereteli, N.S. 2015. Growth structures, piggy-back basins and growth strata of the Georgian part of the Kura foreland fold–thrust belt: implications for Late Alpine kinematic evolution. *In*: Sosson, M., Stephenson, R.A. & Adamia, S.A. (eds) *Tectonic Evolution of the Eastern Black Sea and Caucasus*. Geological Society, London, Special Publications,

428. First published on October 27, 2015, https://doi.org/10.1144/SP428.5

Avagyan, A., Shahidi, A. et al. 2016. New data on the tectonic evolution of the Khoy region, NW Iran. *In*: Sosson, M., Stephenson, R.A. & Adamia, S.A. (eds) *Tectonic Evolution of the Eastern Black Sea and Caucasus*. Geological Society, London, Special Publications, **428**. First published on April 7, 2016, https://doi.org/10.1144/SP428.13

Cavazza, W., Albino, I., Zattin, M., Galoyan, G., Imamverdiyev, N. & Melkonyan, R. 2015. Thermochronometric evidence for Miocene tectonic reactivation of the Sevan–Akera suture zone (Lesser Caucasus): a far-field tectonic effect of the Arabia–Eurasia collision? *In*: Sosson, M., Stephenson, R.A. & Adamia, S.A. (eds) *Tectonic Evolution of the Eastern Black Sea and Caucasus*. Geological Society, London, Special Publications, **428**. First published on October 27, 2015, https://doi.org/10.1144/SP428.4

Danelian, T., Asatryan, G., Sahakyan, L., Avagyan, A. & Galoyan, G. 2015. Radiolarian evidence for the age of chert blocks from the Upper Cretaceous ophiolitic mélange unit of the Erakh area, Armenia. *In*: Sosson, M., Stephenson, R.A. & Adamia, S.A. (eds) *Tectonic Evolution of the Eastern Black Sea and Caucasus*. Geological Society, London, Special Publications, **428**. First published on December 14, 2015, https://doi.org/10.1144/SP428.7

Gee, D.G. & Stephenson, R.A. 2006. European lithosphere – an introduction. *In*: Gee, D. & Stephenson, R. (eds) *European Lithosphere Dynamics*. Geological Society, London, Memoirs, **32**, 1–9. https://doi.org/10.1144/GSL.MEM.2006.032.01.01

Gobarenko, V., Yegorova, T. & Stephenson, R. 2015. Local tomography model of the northeastern Black Sea: intra-plate crustal underthrusting. *In*: Sosson, M., Stephenson, R.A. & Adamia, S.A. (eds) *Tectonic Evolution of the Eastern Black Sea and Caucasus*. Geological Society, London, Special Publications, **428**. First published on October 27, 2015, https://doi.org/10.1144/SP428.2

Hässig, M., Rolland, Y. & Sosson, M. 2015. From seafloor spreading to obduction: Jurassic–Cretaceous evolution of the northern branch of the Neotethys in the Northeastern Anatolian and Lesser Caucasus regions. *In*: Sosson, M., Stephenson, R.A. & Adamia, S.A. (eds) *Tectonic Evolution of the Eastern Black Sea and Caucasus*. Geological Society, London, Special Publications, **428**. First published on December 23, 2015, https://doi.org/10.1144/SP428.10

Hässig, M., Duretz, T. et al. 2016. Obduction of old oceanic lithosphere due to reheating and plate reorganization: insights from numerical modelling and the NE Anatolia–Lesser Caucasus case example. *Journal of Geodynamics*, **96**, 35–49.

Hippolyte, J.-C., Müller, C., Sangu, E. & Kaymakci, N. 2015. Stratigraphic comparisons along the Pontides (Turkey) based on new nannoplankton age determinations in the Eastern Pontides: geodynamic implications. *In*: Sosson, M., Stephenson, R.A. & Adamia, S.A. (eds) *Tectonic Evolution of the Eastern Black Sea and Caucasus*. Geological Society, London, Special Publications, **428**. First published on October 27, 2015, https://doi.org/10.1144/SP428.9

Khriachtchevskaia, O., Stovba, S. & Stephenson, R. 2010. Cretaceous–Neogene tectonic evolution of the northern margin of the Black Sea from seismic reflection data and tectonic subsidence analysis. *In*: Sosson, M., Kaymakci, N., Stephenson, R., Bergerat, F. & Starostenko, V. (eds) *Sedimentary Basin Tectonics from the Black Sea and Caucasus to the Arabian Platform*. Geological Society, London, Special Publications, **340**, 137–157. https://doi.org/10.1144/SP340.7

Meijers, M.J.M., Smith, B. et al. 2015. Progressive orocline formation in the Eastern Pontides–Lesser Caucasus. *In*: Sosson, M., Stephenson, R.A. & Adamia, S.A. (eds) *Tectonic Evolution of the Eastern Black Sea and Caucasus*. Geological Society, London, Special Publications, **428**. First published on October 27, 2015, https://doi.org/10.1144/SP428.8

Nikishin, A.M., Okay, A.I., Tüysüz, O., Demirer, A., Wannier, M., Amelin, N. & Petrov, E. 2015*a*. The Black Sea basins structure and history: new model based new deep penetration regional seismic data. Part 2: tectonic history and paleogeography. *Marine and Petroleum Geology*, **59**, 656–670.

Nikishin, A.M., Wannier, M. et al. 2015*b*. Mesozoic to recent geological history of southern Crimea and the Eastern Black Sea region. *In*: Sosson, M., Stephenson, R.A. & Adamia, S.A. (eds) *Tectonic Evolution of the Eastern Black Sea and Caucasus*. Geological Society, London, Special Publications, **428**. First published on October 27, 2015, https://doi.org/10.1144/SP428.1

Sahakyan, L., Bosch, D. et al. 2016. Geochemistry of the Eocene magmatic rocks from the Lesser Caucasus area (Armenia): evidence of a subduction geodynamic environment. *In*: Sosson, M., Stephenson, R.A. & Adamia, S.A. (eds) *Tectonic Evolution of the Eastern Black Sea and Caucasus*. Geological Society, London, Special Publications, **428**. First published on February 3, 2016, https://doi.org/10.1144/SP428.12x

Saintot, A., Stephenson, R., Stovba, S., Brunet, M.-F., Yegorova, T. & Starostenko, V. 2006*a*. The evolution of the southern margin of the Eastern Europe (Eastern European and Scythian platforms) from latest Precambrian–Early Palaeozoic to the Early Cretaceous. *In*: Gee, D. & Stephenson, R. (eds) *European Lithosphere Dynamics*. Geological Society, London, Memoirs, **32**, 481–505. https://doi.org/10.1144/GSL.MEM.2006.032.01.30

Saintot, A., Brunet, M.-F. et al. 2006*b*. The Mesozoic–Cenozoic evolution of the Greater Caucasus. *In*: Gee, D. & Stephenson, R. (eds) *European Lithosphere Dynamics*. Geological Society, London, Memoirs, **32**, 277–289. https://doi.org/10.1144/GSL.MEM.2006.032.01.16

Sheremet, Y., Sosson, M. et al. 2016*a*. An offshore–onland transect across the north-eastern Black Sea basin (Crimean margin): evidence of Paleocene to Pliocene two-stage compression. *Tectonophysics*, **688**, 84–100, https://doi.org/10.1016/j.tecto.2016.09.015

Sheremet, Ye., Sosson, M., Müller, C., Gintov, O., Murovskaya, A. & Yegorova, T. 2016*b*. Key problems of stratigraphy in the Eastern Crimea Peninsula: some insights from new dating and structural data. *In*: Sosson, M., Stephenson, R.A. & Adamia, S.A. (eds) *Tectonic Evolution of the Eastern Black Sea *and Caucasus*. Geological Society, London, Special Publications, **428**. First published on April 7, 2016, https://doi.org/10.1144/SP428.14

Sosson, M., Rolland, Y. *et al.* 2010. Subductions, obduction and collision in the Lesser Caucasus (Armenia Azerbaijan, Georgia), new insights. *In*: Sosson, M., Kaymakci, N., Stephenson, R., Bergerat, F. & Starostenko, V. (eds) *Sedimentary Basin Tectonics from the Black Sea and Caucasus to the Arabian Platform*. Geological Society, London, Special Publications, **340**, 329–352. https://doi.org/10.1144/GSL.MEM.2006.032.01.30

Sosson, M., Stephenson, R. *et al.* 2015. The Eastern Black Sea–Caucasus region during Cretaceous: new evidence to constrain its tectonic evolution. *Comptes Rendu Géoscience*, **348**, 23–32, https://doi.org/10.1016/j.crte.2015.11.002

Starostenko, V., Janik, T. *et al.* 2016. DOBRE-2 WARR profile: the Earth's upper crust across Crimea between the Azov Massif and the northeastern Black Sea. *In*: Sosson, M., Stephenson, R.A. & Adamia, S.A. (eds) *Tectonic Evolution of the Eastern Black Sea and Caucasus*. Geological Society, London, Special Publications, **428**. First published on February 3, 2016, https://doi.org/10.1144/SP428.11

Sydorenko, G., Stephenson, R. *et al.* 2016. Geological structure of the northern part of the Eastern Black Sea from regional seismic reflection data including the DOBRE-2 CDP profile. *In*: Sosson, M., Stephenson, R.A. & Adamia, S.A. (eds) *Tectonic Evolution of the Eastern Black Sea and Caucasus*. Geological Society, London, Special Publications, **428**. First published on May 23, 2016, https://doi.org/10.1144/SP428.15

Tesauro, M., Kaban, M. & Cloetingh, S. 2009. A new thermal and rheological model of the European lithosphere. *Tectonophysics*, **476**, 478–495, https://doi.org/10.1016/j.tecto.2009.07.022

van der Boon, A., Kuiper, K.F. *et al.* 2015. Onset of Maikop sedimentation and cessation of Eocene arc volcanism in the Talysh Mountains, Azerbaijan. *In*: Sosson, M., Stephenson, R.A. & Adamia, S.A. (eds) *Tectonic Evolution of the Eastern Black Sea and Caucasus*. Geological Society, London, Special Publications, **428**. First published on October 29, 2015, https://doi.org/10.1144/SP428.3