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Novel interpretation of the crustal structure and hydrocarbon evolution within the South Caspian and Kura sedimentary basins, Azerbaijan

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The South Caspian Basin, Lower and Middle Kura Basins, onshore Azerbaijan, and Georgia Upper Kura Basin are a genetically linked basin system created in a Mesozoic extensional setting with a complex Cenozoic sediment fill history. Delineating these basins shed new light on understanding the complex geodynamic history of the region between the Black Sea and the Caspian Sea and elucidate the petroleum prospectivity of the region.

Key data used for basin analysis were a series of regional isopach maps, temperature measurements from over 150 onshore and offshore boreholes in Azerbaijan, derived geothermal gradient data, and published surface heat flow data. Taken together, they allowed us to put some constraints on the crustal structure of an area where accurate temperature measurements are limited. An integrated set of offshore and onshore regional isopach maps for the key stratigraphic units from Jurassic to Pleistocene were created. The depth to basement and the crustal thickness across four seismic cross-sectionswere estimated and validatedvia interpretation of isopach maps and gravity and magnetic modeling.

The results encompass the area from the onshore Kura Basin in eastern Georgia to the offshore South Caspian. Several specific regions were differentiated, including a «cold» region in the South Caspian Basin. A reasonable correlation was established between basement depth, crustal thicknesses, and geothermal gradients. The tectonic boundary between these two basins controls the geothermal gradient change and therefore the hydrocarbon potential.

The western margin of the South Caspian Basin represents a long-standing crustal boundary between the South Caspian Basin oceanic crust of the South Caspian Basin and the thicker crust of the Kura basin of the island-arc origin. The Mesozoic evolution of these basins started as a result of an island arc extension in Mesozoic, followed by Cenozoic flexural overprint with rapid burial and significant sediment flux, thus creating suitable conditions for the development of a dynamic petroleum systems in the South Caspian Basin.

Key words: South Caspian Basin, Kura Basin, Azerbaijan, petroleum potential, crustal structure, isopach maps, crustal thickness, geothermal gradient.

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Introduction. The South Caspian Basin (SCB) is a unique basin and a depositional sink with unusually rapid subsidence [Abdullayev, 2019; Abdullayev, Huseynova, 2019; Guliyev et al., 2020a] and thickness of sedimentary fill reaching 20.5 km [Yusubov, Guliyev, 2021]. Petroleum systems in the SCB are highly dynamic due tohigh overpressures, high sedimentation rates, rapid source rock burial, and the continuing active generation and expulsion of hydrocarbons. The main source rocks are organic-rich shales of Oligocene-Miocene age [Narimanov, 1993; Inan et al., 1997; Abrams, Narimanov, 1997; Tagiyev et al., 1997; Katz et al., 2000; Feyzullayev et al., 2001; Guliyev et al., 2001, 2003; Sachsenhofer et al., 2018], capable of generating oil and gas up depths exceeding 13 km [Inan et al., 1997; Tagiyev et al., 1997; Huseynov, Huseynova, 2014; Huseynova, 2017, 2019; Huseynova, Huseynova, 2017; Huseynova, Afandiyeva, 2019; Goodwin et al., 2020]. The crustal structure and sedimentary fill of the SCB have been studied in detail using regional seismic reflection data [Yusubov, 2020; Yusubov et al., 2020, Yusubov, Guliyev, 2021; Guliyev et al., 2020a, b] and potential field and subsidence modeling [Glumov et al., 2004; Egan et al., 2009; Green et al., 2009; Abdullayev et al., 2017]. The recent discoveries of the giant Shah Deniz and Absheron gas-condensate fields added to the understanding of this prolific petroleum province [Goodwin et al., 2020]. The province covers both on- and offshore areas with different thermal regimes whose origin and extent need to be explained. The present study highlights the basin history that directly influenced hydrocarbon generation, such as the lateral distribution of formation temperatures and burial depths [Abdullayev et al., 2022].

Geodynamic Setting. The South Caspian and Kura Basins have a complex tectonic and stratigraphic history. Several magmatic complexes in the Greater Caucasus, Kura Basin, and the Lesser Caucasus formed between the Jurassic and Eocene [Alizadeh et al., 2017; Abdullayev et al., 2022]. Key tectonic elements of the region (Fig. 1) include Jurassic-age SCB, Absheron Ridge, Greater Caucasus Fold and Thrust Belt, Main Caucasus Thrust, Lesser-Caucasus Fold and Thrust Belt, Goycha-Hakari ophiolite zone, and Kura Basin. The Eastern Greater Caucasus continues east to Gobustan, Absheron Peninsula, and to offshore Absheron Ridge, which bounds the SCB from the north.

The Greater Caucasus Fold and Thrust Beltforms a barrier along the southern margin of the Scythian Platform from the Eastern Black Sea to the SCB [Bochud, 2011]. The Greater Caucasus Fold and Thrust Belt is an inverted relict of the deep-water Greater Caucasus Basin, formed as an elongated WNW-ESE trending rift basin located along the early Cimmerian suture, sub-parallel to the Neo-Tethys's margin [Blackbourn et al., 2021; Tari et al., 2021]. Kura Basin is divided into three subordinate sub-basins: 1) the Upper Kura basin or Kura-Gabyrry interfluve; 2) the Middle (Central) Kura basin, mostly occupied by the Yevlakh-Agjabadi Depression; 3) the Lower Kura basin separated from the Middle Kura by the volcanic Kurdamir-Saatly uplift and the West Caspian fault.

Trans-Caucasus Massif migration narrowed the Prototethys, creating a back-arc basin, a precursor to the Greater Caucasus Basin in the late Paleozoic [Ismail-Zadeh et al., 2020]. Subsequently, in the Mesozoic, oceanic lithosphere was obducted onto continental terrains, and the Somkheti-Garabagh magmatic arc was thrust over the Lesser Caucasus ophiolites [Khain, 1985] creating a complex terrain of magmatic arcs underlying the Kura foreland [Abdullayev et al., 2022].

By Oligocene, multiple episodes of collision occurred, including the ongoing shortening of the Kura Basin under the uplifting Greater Caucasus.It has also been linked to the northward movement of the Arabian Plate and the closure of Neotethys [Ismail-Zadeh et al., 2020; Abdullayev et al., 2022].

The Jurassic back-arc rifting was followed by a long period of passive margin deep-water sedimentation, culminating in rapid subsidence and sedimentation in the Late Cenozoic creating a thick sediment pile overlying oceanic-type crust [Egan et al., 2009; Green et al., 2009]. The sedimentary column in the South Caspian (Fig. 1, *a*) consists of a ~15 km thick Cenozoic succession overlying a 7—8 km thick Upper Jurassic-Cretaceous interval resting on the oceanic basement. The boundary between the oceanic crust of the SCB and the continental crust of the Kura Basin runs roughly through the south of the Absheron Peninsula [Abdullayev et al., 2022].

A regional 700 km long geoseismic cross-section running from the Upper Kura Basin of Eastern Georgia to the center of the SCB (Fig. 1, *b*) shows major thickening of the sedimentary cover from west to east [Glumov et al., 2004]. There is a corresponding abrupt transition in crustal thickness from a relatively thick continental crust beneath the onshore Kura Basin to the much thinner crust of oceanic affinity beneath the SCB (Fig. 1, *b*, *c*). At the northern boundary of the SCB there is a zone where the basement is interpreted to be oceanic crust subducted northwards below the Absheron Ridge [Green et al., 2009; Abdullayev et al., 2022].

Data sources and methodology. Many-sources went into the compilation of isopach maps which allowed to constructthe first regional geologic model. The model incorporates key bounding surfaces and stratigraphic units [Guliyev et al., 2001; Glumov et al., 2004; Abreu, Nummedal, 2007; Green et al., 2009; Bochud, 2011; Abdullayev et al., 2017; Blackbourn et al., 2021]. Temperature data was obtained from over 150 onshore and offshore wells, with depths ranging from 100 to 6000 m [Mukhtarov, 2004, 2018; Alizadeh et al., 2017]. Furthermore, maps of the geothermal field across Azerbaijan [Mukhtarov, 2018; Rustamov et al., 2004] and surface heat flow offshore and onshore were also employed [Tomara, 1979; Aliyev, Aliyev, 1995; Alizadeh et al., 2017; Zui, Mansouri Far, 2019]. The third type of data were gravity maps [Gadirov, 2002; Kadirov, Gadirov, 2014; Kadirov, 2000] and magnetic maps [Glumov et al., 2004; Eppelbaum, 2015; Alizadeh et al., 2017]. These maps were used to support the observations

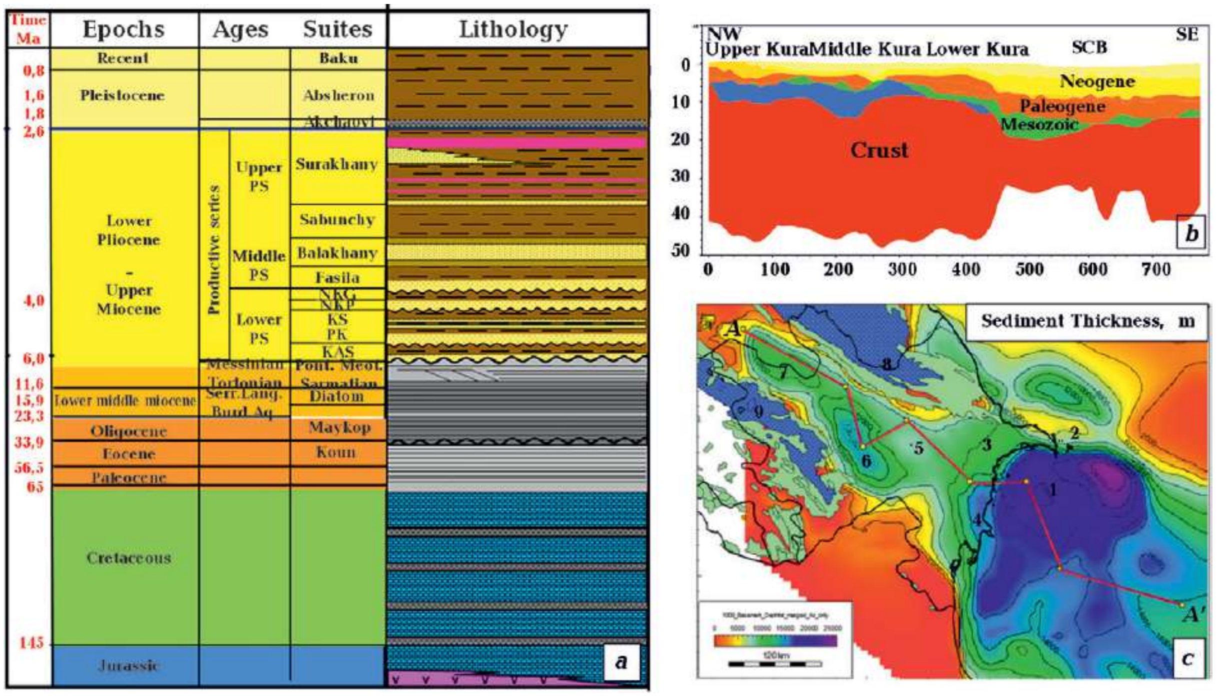


Fig. 1. Simplified SCB stratigraphic column, with local suites (*a*); regional NW-SE regional 700 km long cross-section extending from the Upper Kura basin to offshore SCB (*b*); Eastern South Caspian and Kura basins sediment thickness map with tectonostratigraphic areas (*c*): 1 — SCB, 2 — Absheron Ridge, 3 — Gobustan-Absheron Peninsula, 4 — Lower Kura Basin, 5 — Kurdamir-Saatly Uplift, 6 — Yevlakh-Agjabadi Depression (Middle Kura), 7 — Upper Kura (Kura-Gabyrry interfluve), 8 — Greater Caucasus Fold and Thrust Belt, 9 — Lesser Caucasus [modified from Abdullayev et al., 2022].

from sediment and crustal thickness maps in the general regional model [Abdullayev et al., 2022].

Results. ***Geothermal variations in the SCB and Eastern Azerbaijan.*** Fig. 2 shows how temperature varies with depth in different onshore regions in Azerbaijan and offshore SCB from our database of over 1000 measurement points referenced in the data sources section, with a maximum of c. 150 °C at depths of 5 up to 6.5 km. Temperatures show scatter, especially at depths where measurements are scarcer. The three trends highlighted on the graph show the SCB where temperatures increase slowly with depth, Upper Kura where they rise most rapidly with depth, and Lower Kura where the trend is almost an average of the two. Temperature trends vary greatly with depth because the geothermal gradient in the SCB and Kura Basin varies significantly both laterally and in character [Abdullayev et al., 2022].

Based on the geographical definition of oil and gas provinces adopted from Salmanov et al. [2015], the area is divided into eight geothermal gradient zones (shown in Fig. 3) [Abdullayev et al., 2022]:

– at the Absheron Ridge and on Absheron Peninsula, the effects of recent uplift and erosion are pronounced, and geothermal gradients vary widely (between 20 and 50 °C/km with a median value of 23 °C/km) and the variations between anticlines and synclines are significant;

– similar values of the geothermal gradient (between 18 and 30 °C/km) are recorded in the Gobustan area in the eastern part of the Greater Caucasus fold-and-thrust belt, where structural deformation continues to the present day;

– by contrast, in areas of sediment blanketing in the offshore SCB, the geothermal gradient is depressed and ranges between 14 and 20 °C/km;

– the geothermal gradient averages 23 °C/km in transitional zones in the nearshore and coastal areas (Nearshore Absheronon Fig. 3);

– in the Lower Kura Basin, the geothermal gradient ranges between 20 and 27 °C/km, averaging 21 °C/km;

– in the relatively flat-lying Middle Kura Basin, the geothermal gradient averages 24 °C/km. Some boreholes here produce thermal waters [Mukhtarov et al., 2015];

– in the Upper Kura Basin including eastern Georgia and the Kura-Gabyrry interfluve, the geothermal gradient averages 27 °C/km but locally exceeds 50 °C/km;

– in the North Absheron-Guba Depression, geothermal gradients are relatively low and do not exceed 23 °C/km.

Fig. 3 shows the distribution of these geo-

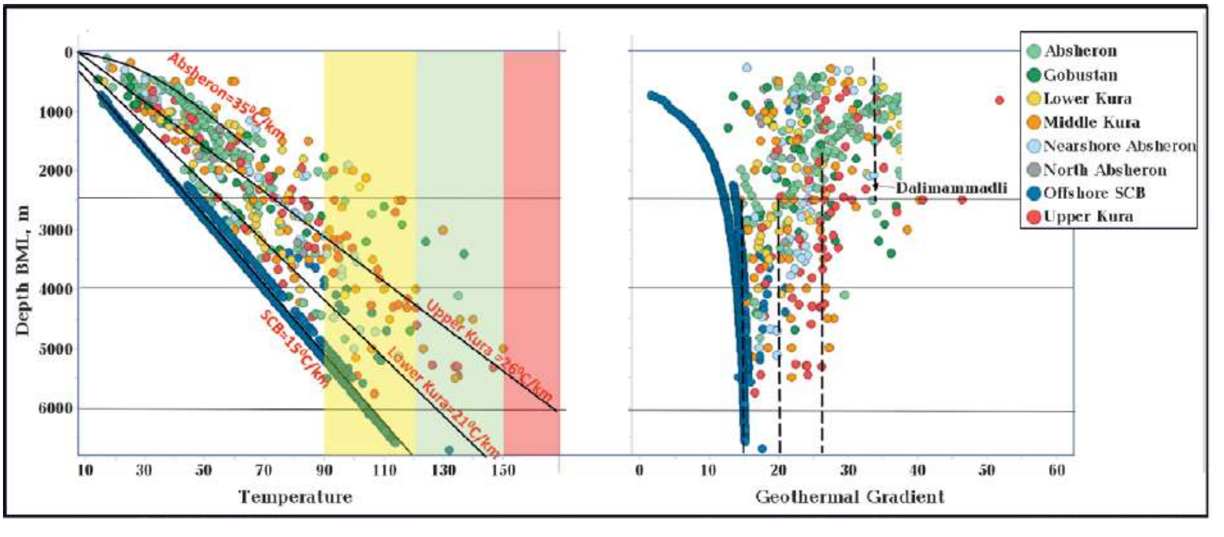


Fig. 2. Temperature measurements in the South Caspian and calculated geothermal gradient.Hydrocarbon generation windows are indicated in colored strips: yellow — oil window, green — wet gas window, pink — dry gas window [modified from Abdullayev et al., 2022].

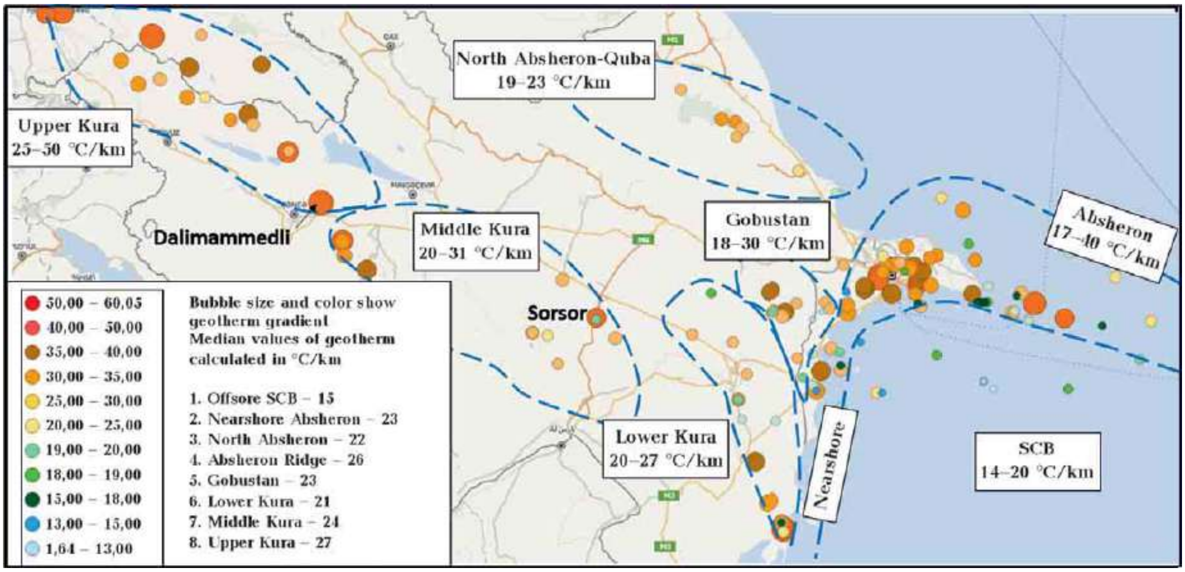


Fig. 3. Map of Azerbaijan and the adjacent offshore SCB showing geothermal gradient variation. Circle sizes indicate absolute values of averaged geothermal gradients, while the colors are related to group of geothermal gradients, defined in Absheron, Gobustan, Lower Kura, Middle Kura, Upper Kura, Nearshore Absheron, North Absheron, and offshore SCB [Abdullayev et al., 2022].

thermal gradient zones and highlights the zones of extreme temperature variations. The highest values (over 50 °C/km) were recorded in wells in the Upper Kura Basin and the foothills of the Lesser Caucasus (e.g. Dalimamedli and Gurzundag, Fig. 3). In some places in the Yevlakh-Agjabadi Depression and adjacent Saatly high, the temperature of «thermal» waters at the surface exceeds 90 °C [Mukhtarov, 2018].

Heat flow distribution. The surface heat-flow map resulting from integration of data from previous researches [Tamora, 1979; Aliyev, Aliyev, 1995; Alizadeh et al., 2017; Zui, Mansuri Far, 2019] demonstrates that the surface heat flow distribution in theon- and offshore Azerbaijan is uneven. While the onshore surface heat coverage is dense, the offshore heat flow is a sparse dataset with only a few measurement points. In areas devoid of active tectonic and volcanic activity, continental heat flow values strongly correlate with the type of the underlying crust. In general, granitic terrains have high surface heat flows, whereas many sedimentary rocks are associated with low heat flow. Regional heat flows are reduced in the Middle Kura Basin and range between 20 and 50 mW/m^2. By contrast, high heat flows (70 to 145 mW/m^2) are recorded in the Greater Caucasus, and in the Lesser Caucasus (around 100 mW/m^2). Significantly high heat flow exceeding 100 mW/m^2 in the southeastern area on the map corresponds to the Lesser Caucasus and Iranian Plateau. This area corresponds to the Alpine folding and active faulting accompanied by recent volcanic activity [Zui, Mansouri Far, 2019]. Variations in surface heat flow are related to lateral variations in radiogenic heat produced by the decay of long-lived radioisotopes found mostly in the granitic upper crust. Thus, the lateral heat flow variations show the Greater and Lesser Caucasus appear to pertain to a thick continental (granitic) upper crust, whereas the upper crust is attenuated or absent in the Kura Basin and the SCB where a thick overlaying sediment pile is found [Abdullayev et al., 2022].

Crustal structure modeling validation. The maps demonstratingdeep structures of the offshore SCB, Lower and Middle Kura Basins, including the Yevlakh-Agjabadi Depression, have been modified to incorporate a more recent depth-to-basement map centered in the SCB [Abdullayev et al., 2017]. The sediment and crustal thickness maps (Fig. 4) con-

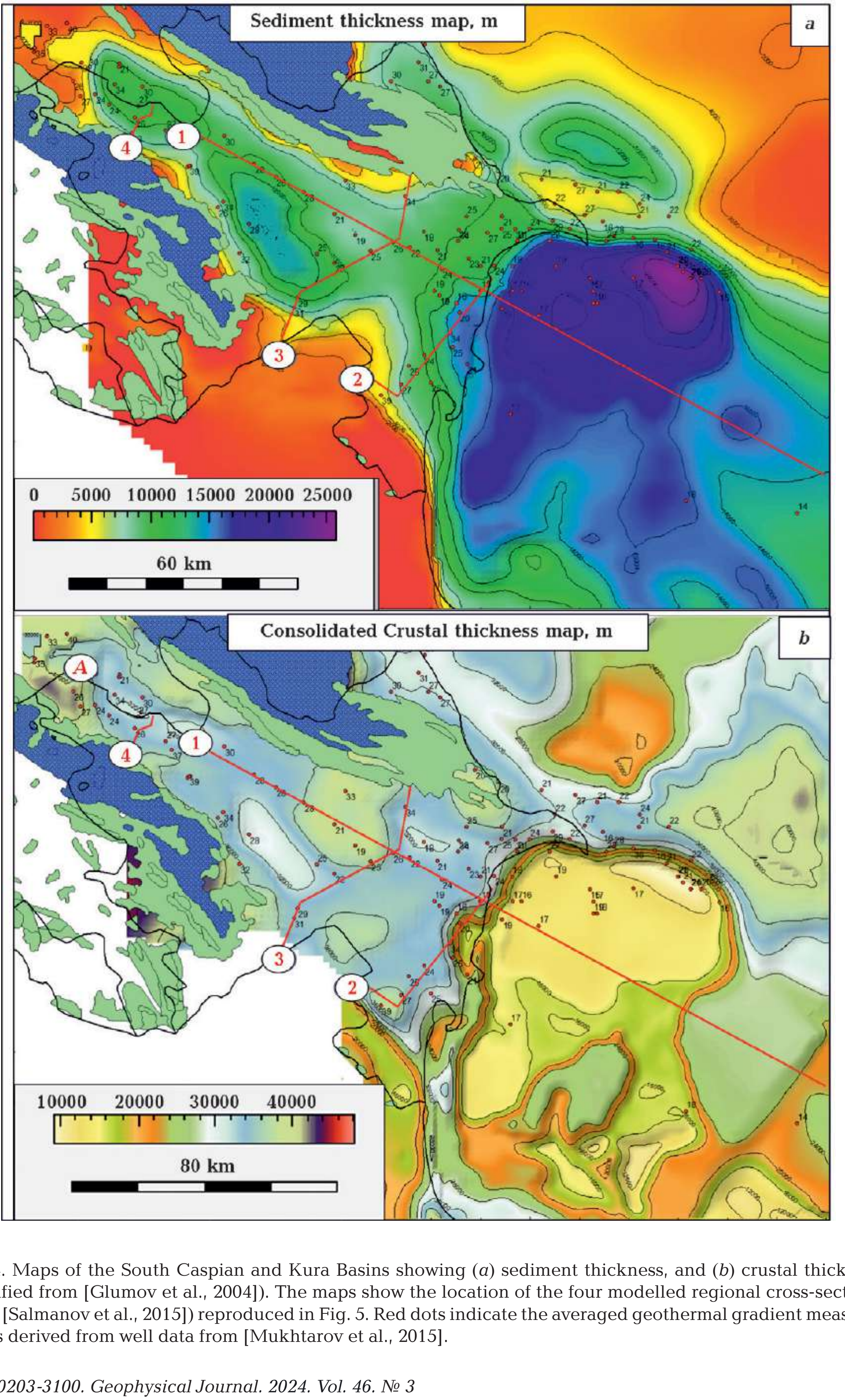
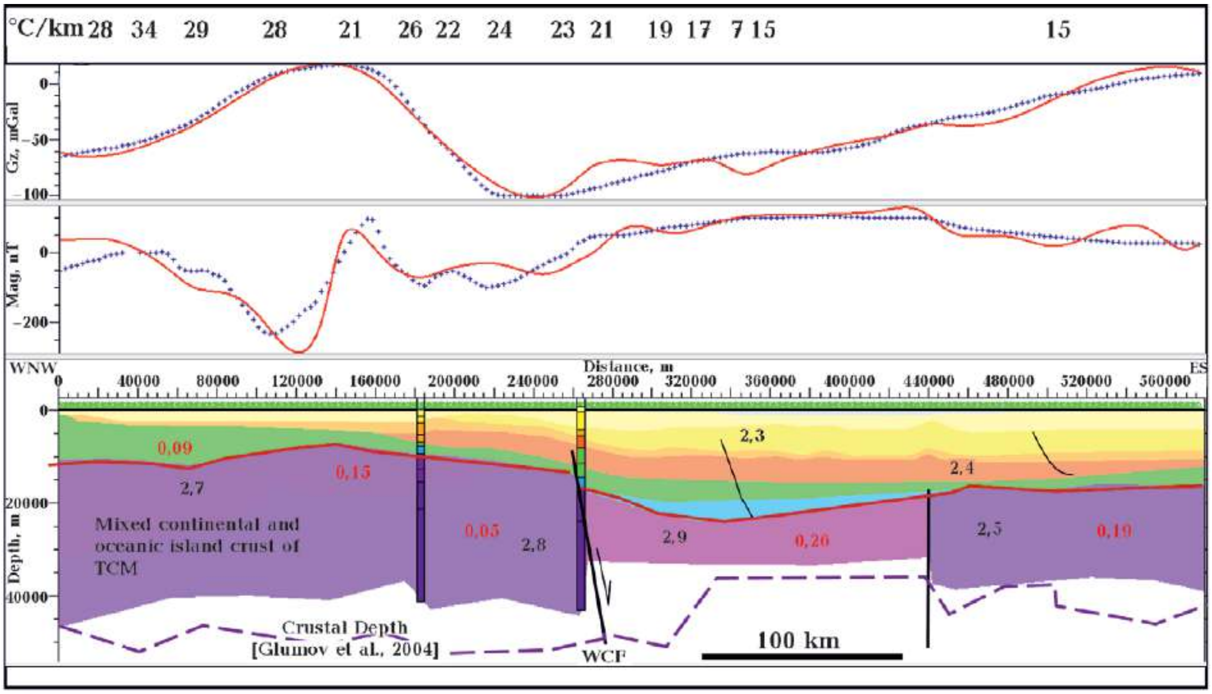
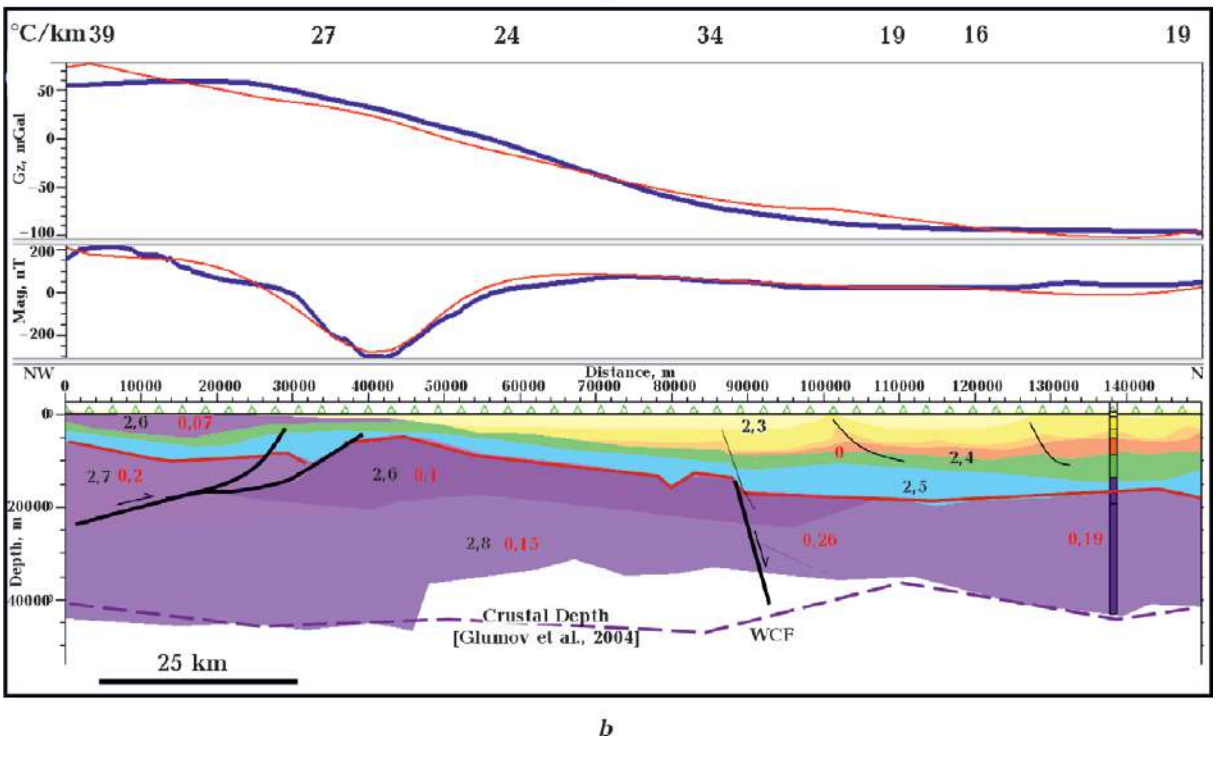


Fig. 4. Maps of the South Caspian and Kura Basins showing (*a*) sediment thickness, and (*b*) crustal thickness (modified from [Glumov et al., 2004]). The maps show the location of the four modelled regional cross-sections (from [Salmanov et al., 2015]) reproduced in Fig. 5. Red dots indicate the averaged geothermal gradient measurements derived from well data from [Mukhtarov et al., 2015].

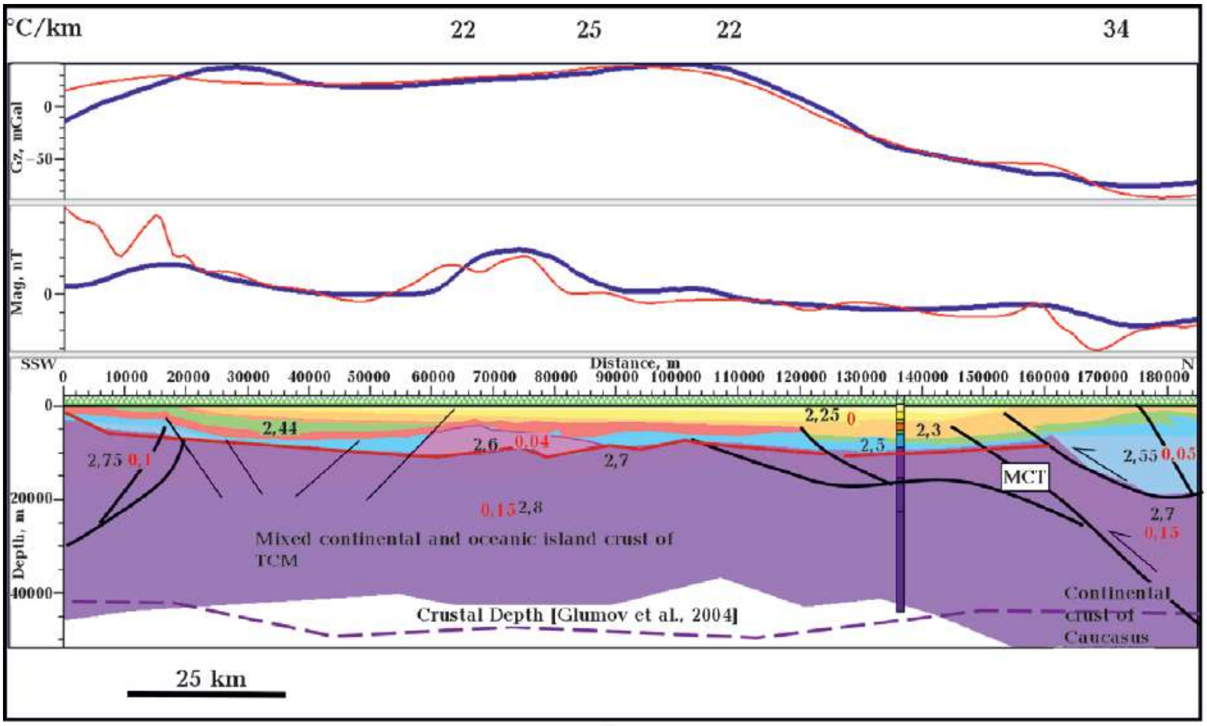


a



b

tain the profiles of the four seismic sections. In the northwestern part of the SCB, north of the Absheron Peninsula there is a gravity minimum with an amplitude reaching –125 mGal. The southern part of the basin is represented by a small isometric maximum of the gravity field (Safidrud and Godin uplift) and the majority of the offshore SCB is covered by a weak gravity minimum. On the border of SCB and Middle Kura Basins, a large Talysh-Vandam gravity maximum is found, with a magnitude of +80 mGal [Alizadeh et al., 2017] that extends 120 km to the west. This has been interpreted to indicate a deep-seated block of high-density material of either volcanic arc or basement origin [Mamedov, 1993]. The two



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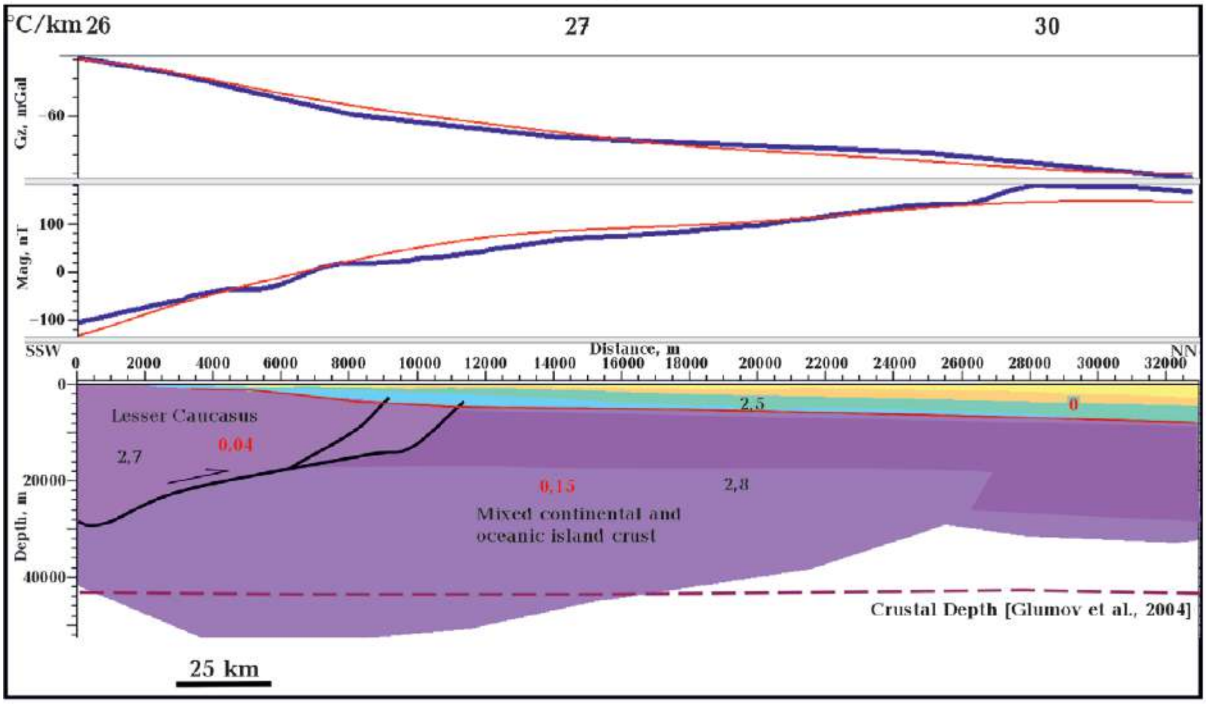

d

Fig. 5. Regional geoseismic sectionsthrough the territory of Azerbaijan. Profiles' locations are shown in Fig. 4: *a* — regional NW-SE 560 km long seismic section 1 extending through the Kura and SCB, *b* — regional seismic SW-NE 150 km long section 2 extending through the Lower Kura Basin, *c* — regional seismic SW-NE 190 km long section 3 extending through the Middle Kura Basin, *d* — regional seismic SW-NE 32 km long section 4 extending through the Upper Kura Basin. The profiles show the results of gravity and magnetic modelling (red lines — originalgravity and magnetic fields, blue lines — modelled gravity and magnetic fields) together with lateral variations in geothermal gradients and sediment depth. Black numbers on the sections are density (g/cm^3), red numbers are magnetic susceptibility.

large gravity minimums in the Lesser Caucasus (–130 mGal) and Greater Caucasus represent deep-seated mountain roots of low-density materials [Abdullayev et al., 2022].

The SCB has a smooth, positive magnetic field with intensity decreasing to the south. However, there are many local positive and negative anomalies in the western part of the basin and the Kura depression [Glumov et al., 2004] reflecting its complex structure, caused by intrusions of Mesozoic magmatic rocks [Eppelbaum, Khesin, 2012]. Two of the larger negative and positive magnetic anomalies both sit within the Talysh-Vandam gravity maximum, showing its heterogeneous nature [Abdullayev et al., 2022].

To investigate the crustal structure, heat flow values, and geothermal gradient variations in onshore Azerbaijan and offshore SCB, we used four regional geoseismic cross-sections (Fig. 5).

The NW-SE cross-section (Fig. 5, *a*) extends from the Kura Basin to the SCB. It crosses the boundary between the relatively thin, dense oceanic-type crust of the SCB and the attenuated continental crust of the Kura Basin. The significant gravity anomaly corresponds to a change from thick, low density crustal material to a thin oceanic-type crust with an overlying thick sedimentary column. The low-frequency part of the anomaly is related to the upper mantle.

Cross-section 2 (Fig. 5, *b*) extends from the Talysh Mountains to the NE through the Lower Kura Basin to the nearshore area south of the Absheron Peninsula and crosses several key tectonic boundaries. In the western part, the Saatly gravity maximum corresponds to volcanic intrusions [Alizadeh et al., 2017]. The 40 km thick crust is an indication of a change of crustal type between the South Caspian and the Lesser Caucasus. A significant lateral change exists from high geothermal gradients (39 °C/km) where the consolidated crust is about 34 km thick with a sediment thickness of 10 km, to areas where the gradient is less than 20 °C/km, where the consolidated crustal thickness is less than 10 km but the sediment thickness exceeds 15 km.

Cross-section 3 (Fig. 5, *c*) shows how gravity and magnetic fields vary from SW to NE across the Middle Kura Basin from the Sovetler and Muradkhanli fields towards the Kura lowlands and Gobustan. On this cross-section, the Yevlakh-Agjabadi Depression and the Saatly uplift are reflected by small positive Bouguer anomalies (30—10 mGal) which rapidly change to negative values. Modeling of this cross-section matches well with the relatively attenuated continental and island-arc crust, 20 km thick, which thickens to about 50 km in the Hercynyan basement of the Greater Caucasus. Glumov et al. [2004] showed that the crustal thickness below Yevlakh-Agjabadi Depression is around 40 km which the present modeling confirms, although it may be even more attenuated. Magnetic anomalies around the Saatly uplift are thought to be related to volcanic island-arc intrusives and uplift at a possible rifted margin [Alizadeh et al., 2017].

Finally, cross-section 4 (Fig. 5, *d*) crosses the Upper Kura Basin from SW to NE. The gravimetric modelling indicates that the consolidated crust may exceed 50 km beneath the volcanogenic sediments of the Lesser Caucasus origin and decreases in thickness to 35 km at the northern end of the cross-section. There is a significant magnetic anomaly in the SW part of the cross-section. Geothermal gradients in this part of the basin are closer to those of continental crust and vary between 34 and 30 °C/km. The modeled crustal thickness is more variable than that of Glumov et al. [2004] which is more uniform around 45 km [Abdullayev et al., 2022].

Discussion. ***Origin of the South Caspian and Kura basins.*** Different modes of accommodation and shortening between the subducting oceanic crust in the SCB and the thin-skinned fold-and-thrust belt could have been influenced by differences in crustal behavior as there is a transition from the continental lithosphere of the Kura basin to the oceanic lithosphere (with a thick sediment cover) of the SCB [Knapp et al., 2004; Reilinger et al., 2006; Vernant, Chery, 2006; Kadirov, Gadirov, 2014; Ismail-Zadeh et al., 2020]. Kadirov and Gadirov [2014] showed that a branch of the Greater Caucasus fold-and-thrust belt may follow the curved topographic break between the Kura basin and the Greater Caucasus and is linked to the deep-seated West Caspian Fault [Abdullayev et al., 2022].

A schematized geodynamic cartoon and map (Fig. 6) corresponding to the Middle Cretaceous modified from Adamia et al. [2017] and Hässig et al. [2017] show general features which could have influenced the present-day tectonic pattern [Abdullayev et al., 2022]. From this illustration of the narrative of the basin's origin several inferences can be made:

– the SCB formed at the northern boundary of Neotethys as a back-arc basin behind an island-arc chain [Zonenshain, Pichon, 1986; Abdullayev et al., 2017] at the same time and in continuity with the Great Caucasus Basin, making it a part of a genetically linked chain of basins;

– the SCB was separated from the Great Caucasus Basin by island arcs and by the complex terrain of the Transcaucasian Massif underlain by thicker continental crust;

– the depocenter in the Middle Kura Basin (including Yevlakh-Agjabadi Depression) is located between the two volcanic arc elements — the Somkheti-Garabagh and Artvin-Bolnisi belts [Adamia et al., 2017] and the buried Kurdamir-Saatly island-arc unit, which is a part of the Transcaucasian Massif. Its setting can therefore be described as an intra-arc basin;

– West Caspian Fault is located on the western edge of the Transcaucasian Massif on the eastern boundary of the SCB. It borders the Kurdamir-Saatly uplift on the west and follows its exact pattern, which coincides with the present-day plan-view shape of the partitioned Eastern Greater Caucasus [Ismail-Zadeh et al., 2020];

– an NW-SE trending crustal boundary must be present at the margin of the SCB and may represent a boundary between the rigid oceanic crust (Fig. 6, *c*) and the thicker Transcaucasian crust (possible transform boundary);

– some of these crustal boundaries are

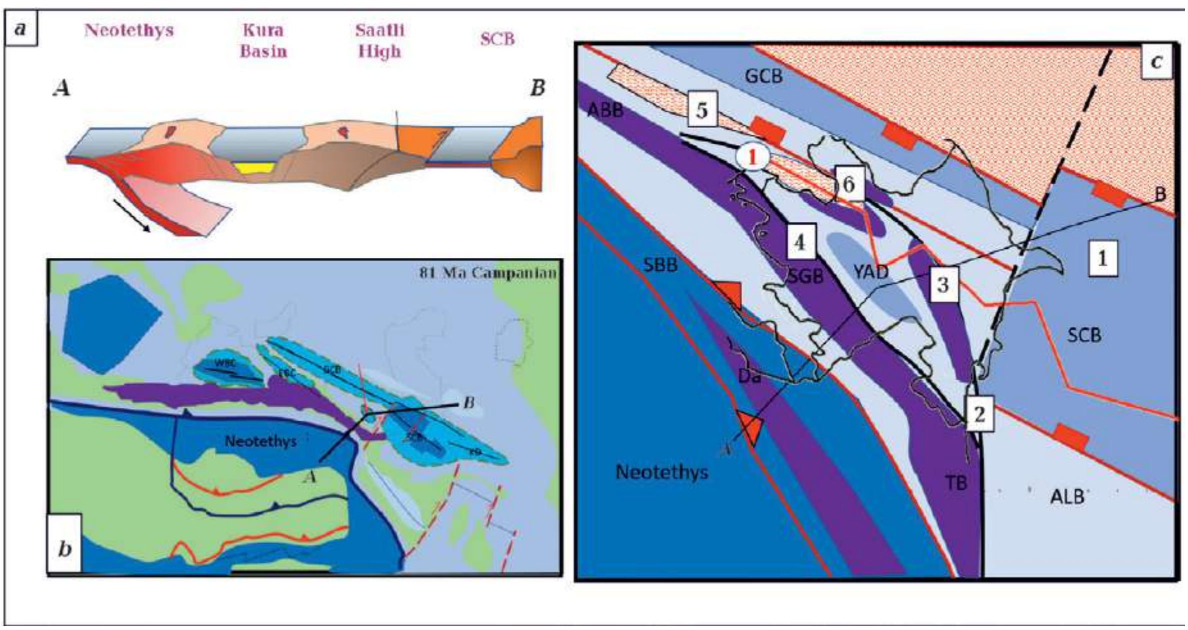

Fig. 6. Geodynamic sketch model of SCB and southern margin of Eurasia, Upper Cretaceous age based on Hässig et al. [2017] and presented as both cross-section and palaeogeographic map: *a* — A-B paleotectonic Upper Cretaceous cross-section, *b* — Paleogeographic map from Campanian (83 Ma), *c* — location of main tectonic boundaries in this period; *1* — Saatly buried high and magnetic anomalies; *2* — West Caucasus Fault; *3* — Vandam magmatic zone; *4* — Lesser Caucasus; *5* — Yevlakh-Agjabadi Intra-arc Depression. Line A-B represents a regional tectonic profile from the NeoTethys to the Caspian Basin. YAD —Yevlakh-Agjabadi Depression; SGB —Somkheto-Garabah Belt; ABB —Artvin-Bolnisi Belt; TB —Talysh Belt; ALB — Alborz Belt; SCB — South Caspian Basin; GCB — Greater Caucasus Basin [Abdullayev et al., 2022].

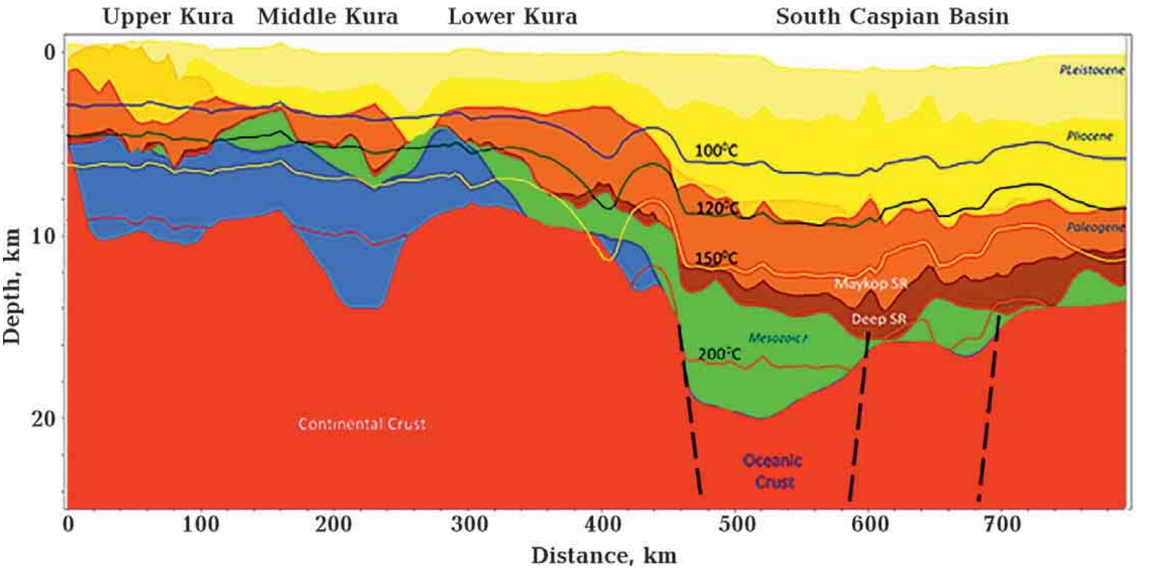

Fig. 7. NW-SE oriented 700 km geoseismic cross-section extending from the Upper Kura Basin to the offshore SCB with isothermal depth overlays (cross-section location is shown in Fig. 1).

now overlain by the flexural Kura foreland basin wedged between the Greater and Lesser Caucasus fold-and-thrust belts, which accommodates the shortening of the oceanic-type crust of the SCB which is being subducted northwards, beneath the Absheron Ridge.

Hydrocarbon potential. South Caspian is a unique basin with prolific source rocks and a dynamic petroleum system. Most of the Maikop and Diatom Formations contain gas-prone relatively modest-potential source rocks [Sachsenhofer et al., 2018]. Rich oil-prone source intervals are found in Maikop and Diatom with up 15.1 wt. % and Hydrogen index (HI) up to 612 mgHC/gC$_{org}$ [Feyzullayev et al., 2001]. Diatom Suite samples from the Kura Basin and wells close to Baku indicate increasing source rock potential basinwards with TOC increasing up to 7.8 % and HI values up to 708 mgHC/gC$_{org}$ [Feyzullayev et al., 2001]. Understanding the distribution of temperature gradients and their link to crustal parameters allowed us to update the NW-SE seismic section with an isothermal depth overlay calculated from trends calibrated using temperature data and a derived geotherm (Fig. 7). Isothermal surfaces are displayed on the cross-section, depth of the surfaces change across the boundary between the continental crust of the onshore Kura Basin and the different «oceanic-type» crust of the SCB. This boundary is located at around 500 km on the cross-section; isothermal values are abruptly displaced downwards at this location by about 4 km [Abdullayev et al., 2022].

A sharp increase in depth of the 120 °C isotherm along the boundary has significant implications for the thermal maturity of Oligocene-Miocene Maikop source rocks.

Diamondoids and gas isotope data from the offshore Shah Deniz and Azeri-Chirag-Gunashli fields petroleum analyses indicate a source rock interval that has attained thermal maturity of 1.5—2.0 % VRE [Goodwin et al., 2020]. Furthermore, rapid burial rates of the offshore SCB together with the low geothermal gradient have delayed the maturation of organic matter. Therefore, the modeled depth to the source rock interval is more than 13 km, making the SCB the location of one of the world's deepest active petroleum systems.

The offshore South Caspian Maikop source rock is oil-prone but a significant part of the generated oil has been cracked to gas [Goodwin et al., 2020]. Isotopically heavy oils from the offshore SCB fields suggest that the shallower Diatom Formation is in the oil window, whereas oils from the onshore Lower and Middle Kura Basins are isotopically lighter, suggesting that the shallow Diatom source rocks are immature [Guliyev et al., 2001]. This difference between the onshore and offshore areas is confirmed by mapping (see Fig. 7), where onshore Diatom source rock isotherm is on average above the 100 °C. Understanding this difference could play a role in segregating hydrocarbon prospective areas both onshore and offshore.

Some of the deepest parts of the actively generating source rock stratigraphy in the SCB can exceed or be at least equal to the active source rock depth limit of 16 km proposed by Pang et al. [2020]. Tectonic boundaries between the South Caspian and Kura Basins such as the West Caspian Fault zone serve as hydrocarbon prospectivity markers, with significantly greater potential in the offshore SCB where both deeper pre-Maikop and shallower Maikop source rocks become involved in the generation and expulsion of hydrocarbons [Abdullayev et al., 2022].

Conclusion. New insights at SCB and Kura basin formation, evolution, and hydrocarbon potential were achieved by integrating published structural maps and temperature observations into the existing tectonostratigraphic framework, and for the first time geological evolution of the offshore SCB and onshore Kura Basin, Azerbaijan were linked within a single map set. Delineating and linking these basins is key to understanding the geodynamic history between the Black Sea and Caspian regions, in a complex area overlooked by previous studies. One of the key observations is that there are several specific regions including «cold» South Caspian with a 20 km thick sedimentary succession, «intermediate» Lower Kura Basin, and «warm» Kura Basin (including Yevlakh-Agjabadi depression) with the crustal thickness of 20 to 25 km. The proposed evolution involves Mesozoic island arc extension origin for basins adjacent to the SCB. This was followed by SCB formation in Jurassic, with possible additional rifting in Eocene and flexural overprint in Tertiary. Inherited tectonic boundaries of the basin serve as markers for hydrocarbon prospectivity. In the deep and highlyprospective offshore SCB, source rocks generate hydrocarbons at a depth more than 13 km, whereas the onshore areas have a more limited hydrocarbon potential in Azerbaijan [Abdullayev et al., 2022].

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Нова інтерпретація структури земної кори та еволюція вуглеводнів у Південнокаспійському та Куринському басейнах

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Південнокаспійський басейн, Нижньокуринський і Середньокуринський басейни, що охоплюють територію суходолу Азербайджану та акваторію й Верхньокуринський басейн у Грузії, є генетично пов'язаною системою басейнів, утворених в умовах мезозойського розтягнення зі складною історією кайнозойського етапу осадонагромадження. Розмежування цих басейнів проливає нове світло на розуміння складної геодинамічної історії та нафтогазоносності Чорноморсько-Каспійського регіону.

Для аналізу басейнів використано регіональні карти ізопахіт, температурні виміри з більш як 150 свердловин на суші та в морі, дані щодо геотермічних градієнтів теплового потоку. Аналіз цих даних дав можливість уявити структури земної кори, навіть у тих районах, де точні виміри цих параметрів були обмежені. Побудовано інтегровані регіональні карти ізопахіт по основних стратиграфічних підрозділах від юрського періоду до плейстоцену. Інтерпретації карт ізопахіт, гравітаційного та магнітного моделювання підтвердили оцінки глибини залягання фундаменту та потужності земної кори за чотирма сейсмічними розрізами, що охоплюють територію суші Азербайджану та прилеглої акваторії.

За геотемпературним режимом у межах досліджуваної території, що охоплює басейн Верхньої Кури в Грузії та територію Азербайджану до узбережжя Південного Каспію і далі в море, виділено окремі райони, зокрема «холодний» Південнокаспійський басейн. Проведено кореляцію між глибиною залягання фундаменту, потужністю земної кори та геотермічними градієнтами. Тектонічна межа між цими басейнами контролює зміну геотермічного градієнта, що визначає вуглеводневий потенціал.

Західна околиця Південнокаспійської западини є довгою межею між океанічною корою Південнокаспійського басейну і потужнішою Куринською западиною острівного походження. Мезозойський етап еволюції цих басейнів розпочався в результаті розширення острівної дуги в мезозої, його наслідував кайнозойський флексурний етап зі значним привнесенням осадів і швидким їх похованням, що створило відповідні умови для розвитку динамічних нафтогазоносних систем у Південнокаспійському басейні.

Ключові слова: Південнокаспійський басейн, Куринський басейн, Азербайджан, нафтогазоносність, будова земної кори, карти ізопахіт, потужність земної кори, геотермічний градієнт.