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LATE PALEOZOIC – MESOZOIC TECTONIC EVOLUTION AND PROSPECTS OF HYDROCARBON EXPLORATION IN THE ALAKOL SEDIMENTARY BASIN (KAZAKHSTAN)

V.V. Korobkin, A.Ye. Chaklikov ✉, A.A. Ismailov, Zh.S. Tulemissova

Kazakh-British Technical University, 59 Tole bi St, Almaty 050000, Kazakhstan

ABSTRACT. Based on the analysis of stratigraphic, lithofacies, and geological and geophysical data, consideration is being given to the main stages in the formation of the basement and cover structures of the Alakol sedimentary basin. For this region, there was developed the substantiation of a scheme of tectonic zoning and there were proposed structural characteristics of faults and lithofacies features of the section. Evidence was found of a complex, multi-stage tectonic evolution. There were discovered potentially promising stratigraphic oil and gas complexes of the Late Paleozoic and Mesozoic. The deep-seated structure of the region is illustrated by a geological and geophysical section, spatially coincident with the "Turkestan" seismic profile. Based on the lithological and paleogeographic reconstructions, there were identified four major tectonic boundaries: Cambrian-Ordovician, Devonian-Carboniferous, Permian-Early Triassic, and Middle Triassic-Cretaceous. The correlation of the stratigraphic range of the hydrocarbon potential of the Alakol basin has been carried out. The criteria for forecasting hydrocarbon accumulations were substantiated.

KEYWORDS: Alakol basin; Junggar basin; tectonic and structural analyses; paleozoids; lithological-paleogeographic reconstructions; lithological-stratigraphic cross-section; stratigraphic correlation; hydrocarbon potential; probabilistic estimate

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Correspondence: Akhan Ye. Chaklikov, a.chaklikov@kbtu.kz

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1. INTRODUCTION

The Alakol basin (AB) is located in the southeast of the Kazakhstan segment of the Hercynian Junggar-Balkhash fold system [Bespalov, 1971; Koshkin, 1974; Zonenshain et al., 1990; Bekzhanov et al., 2000; Iskaziyev et al., 2015]. The AB is bounded peripherally by the Main Junggar (MJF) and Main Chingiz (MChF) regional faults (Fig. 1). The AB is the northwestern termination of the Junggar oil field in China [Wang, 1985; Zonenshain et al., 1990; Dobretsov, 2003; Xiao et al., 2009].

The AB is bounded on all sides by mountains comprised primarily of the Paleozoic (from Cambrian to Permian) ophiolite, island-arc and accretional complexes. The main tectonic elements of the Hercynian Junggar-Balkhash fold system are fault-bounded tectonic blocks. They consist of the fragments of the Proterozoic continental crust and Neoproterozoic-Paleozoic subductional-accretional complexes, often overlain by the Mesozoic sedimentary sequences (Fig. 1) [Wang, 1985; Zonenshain et al., 1990; Mossakovsky et al., 1993; Şengör et al., 1993; Didenko et al., 1994; Daukeev et al., 2002b; Windley et al., 2002, 2007; Dobretsov, 2003; Dobretsov, Buslov, 2007; Xiao et al., 2009, 2013; Ryazantsev et al., 2009; Bian et al., 2010; Korobkin, Buslov, 2011; Xiao, Santosh, 2014; Buslov, Cai, 2017; Gladkochub et al., 2018; Samygin, Kheraskova, 2019; Brunet et al., 2020; Sklyarov et al., 2020].

In the evolutional history of the study area, there are four large boundary intervals: Cambrian-Ordovician, Devonian-Carboniferous, Permian – Early Triassic, and Middle Triassic – Cretaceous. The Permian-Jurassic interval is associated with land subsidence and formation of up to 4 km thick sequence of sediments in the Alakol basin and the Junggar oil field of China as a whole.

Our studies are aimed at forecasting oil and gas potential of the Alakol basin. To do this, the correlation was performed between the stratigraphic range of hydrocarbon potential horizon in the AB and that in the Junggar basin of China. The prospects for the oil and gas content of the AB in the basement subsidence zones can be attributed to a number of factors: (1) a large thickness of the organic-rich Carboniferous, Permian, Triassic and Lower Jurassic deposits whose cross-section shows the presence of coals; (2) a step-like subsidence of the top basement, controlled by dynamics of the Main Junggar and Main Chingiz faults; (3) forecast hydrocarbon traps in the regional migration pathways. The method of structural analysis used herein as well as the lithological-stratigraphic studies would emphasize the scientific novelty of the present paper and

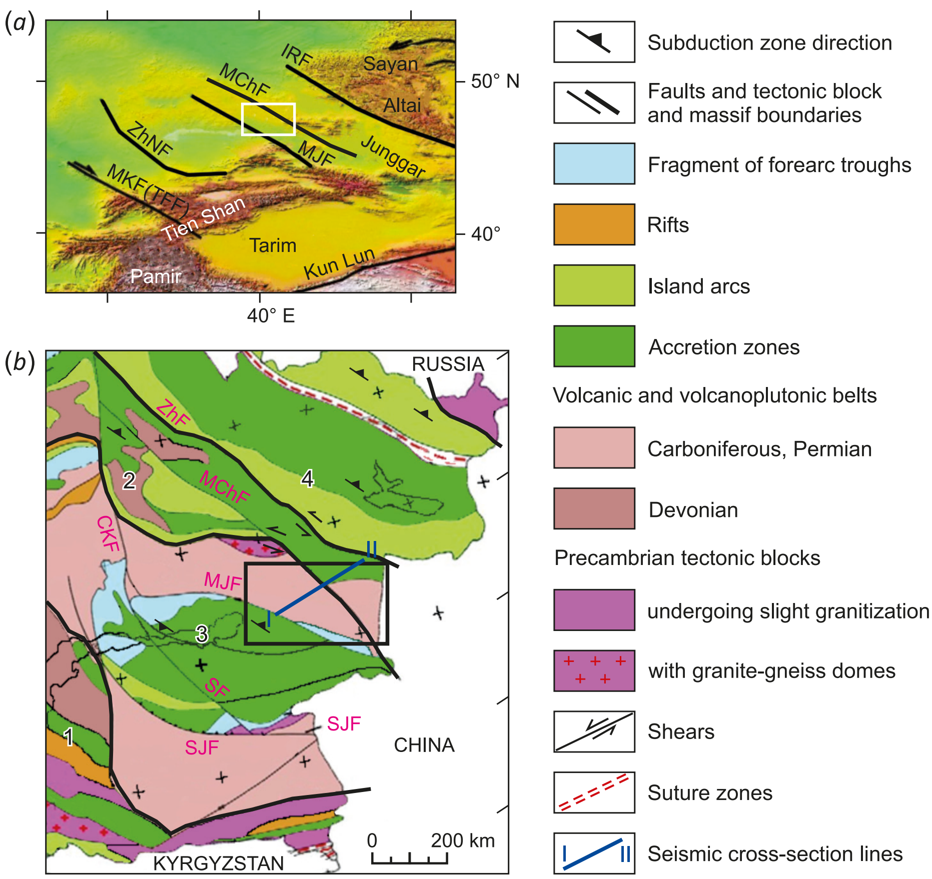

Fig. 1. A schematic diagram of the western segment of the Central Asian fold belt (*a*) and a schematic tectonic map of the eastern part of the Kazakhstan paleozoids, indicating the position of the main tectonic units (*b*).
Main faults: MKF – Main Karatau and TFF – Talas-Fergana, ZhNF – Dzhalair-Naiman, MJF – Main Junggar, MChF – Main Chingiz, IRF – Irtysh. Folded areas: Caledonian (Kazakhstan composite continent): 1 – Kokshetau – North Tien Shan, 2 – Chingiz-Tarbagatay; Hercynian: 3 – Junggar-Balkhash, 4 – Ob-Zaysan. The rectangle shows the contours of the Alakol basin and adjacent territories.

substantiate the criteria for forecasting of hydrocarbon accumulations.

2. STRUCTURE, LITHOLOGICAL-STRATIGRAPHIC CHARACTERISTICS AND PALEOGEOGRAPHIC RECONSTRUCTIONS OF THE ALAKOL BASIN AND ADJACENT AREAS

This section presents the results of the geological, tectonic, structural, stratigraphic and lithological-facial studies of the Alakol sedimentary basin. Based on the tectonic analysis (Fig. 1, 2) and lithological-paleogeographic reconstructions of the region (Fig. 3), there was identified a structural heterogeneity in the Earth's crust, represented by autonomously evolved tectonic blocks separated primarily by the Early Mesozoic strike-slip faults.

The AB is located on the boundary between two regional structures – Paleozoic Balkhash basin and Paleozoic Chingiz-Tarbagatay island-arc system (see Fig. 1, 2). To the west the AB basement is composed of the fragments of the Cambrian-Ordovician accretional complex, and to the northeast – of the Cambrian-Ordovician basalts changing upsection to andesibasalts of the island arc [Smirnov, Korobkin, 2003; Korobkin, Buslov, 2011; Kröner et al., 2014; Han et al., 2019]. The Upper Ordovician – Silurian section is composed of up to 3.5 km thick terrigenous and volcanogenic rocks (Fig. 4, 5).

At the end of the Silurian, there was a collision on the boundary of the Hercynian Ob-Zaysan oceanic basin which gave rise to the formation of variegated molasses and granite belt in the Main Chingiz fault zone (see Fig. 3). In the Early-Late Devonian (Frasnian), along the periphery of the Junggar-Balkhash and Ob-Zaysan oceans, there formed a system of island arcs (East Junggar and Zharma-Saur) and interarc basins [Daukeev et al., 2002b; Korobkin, Buslov, 2011]. At that time, during the collision process, there occurred the closure of the basin and the formation of the Central Kazakhstan orocline. The Junggar-Balkhash oceanic basin was bounded by the Central Kazakhstan volcanic belt.

In the Middle and Late Devonian, at the rear of the volcanoplutonic belt, there formed intermountain basins wherein were accumulated more than 5000 m thick continental lacustrine, lagoon and fluvial deposits [Kurchavov et al., 2000]. In the Famennian-Pennsylvanian, there was deformation in volcanic arcs which finally resulted in the occurrence of oroclinal bending and recurrence of its fragments along the strike-slip faults [Şengör et al., 1993; Windley et al., 2002; Buslov et al., 2003; Xiao et al., 2009; Bian et al., 2010; Korobkin, Buslov, 2011]. The most important events in formation of the pattern of strike-slip faults outlining a terrane collage were the Late Carboniferous right-lateral and the Late Permian left-lateral strike-slip displacements [Buslov et al., 2003; Xiao et al., 2009; Buslov, 2011; Korobkin, Buslov, 2011].

Termination of the process of collision in the Late Carboniferous and Permian caused the closure of the Junggar and Ob-Zaysan oceanic basins (see Fig. 3; Fig. 5). In the Ili-Balkhash area, there was an eruption of up to 6000 m thick lava flows of contrasting compositions. In parallel with the formation of collisional mountain ranges of Kazakhstan in the Permian there also has been formed the Junggar half-closed deep-water basin wherein flysch and bituminous shales with a total thickness of up to 5000 m were deposited (Fig. 5) [Korobkin, Smirnov, 2006; Xiao et al., 2009; Bian et al., 2010; Zou et al., 2012; Zong et al., 2015; Han et al., 2019].

In the Permian-Triassic, there finally formed the strike-slip pattern of the Central Asian fold belt which gave rise to the occurrence of strike-slip faults and rifts in the Tarim and Tien Shan. In a number of basins in Kazakhstan and China, such as Chu-Sarysu, Junggar and Tarim, there were deposited red-colored sediments [Daukeev et al., 2002b; Xiao et al., 2009; Han et al., 2019].

The Early Triassic Southern Dzungaria and Northern Pribalkhashye have been affected by orogenesis associated with powerful surface manifestations of volcanism. In the Middle Triassic, there has been a decrease in volcanic

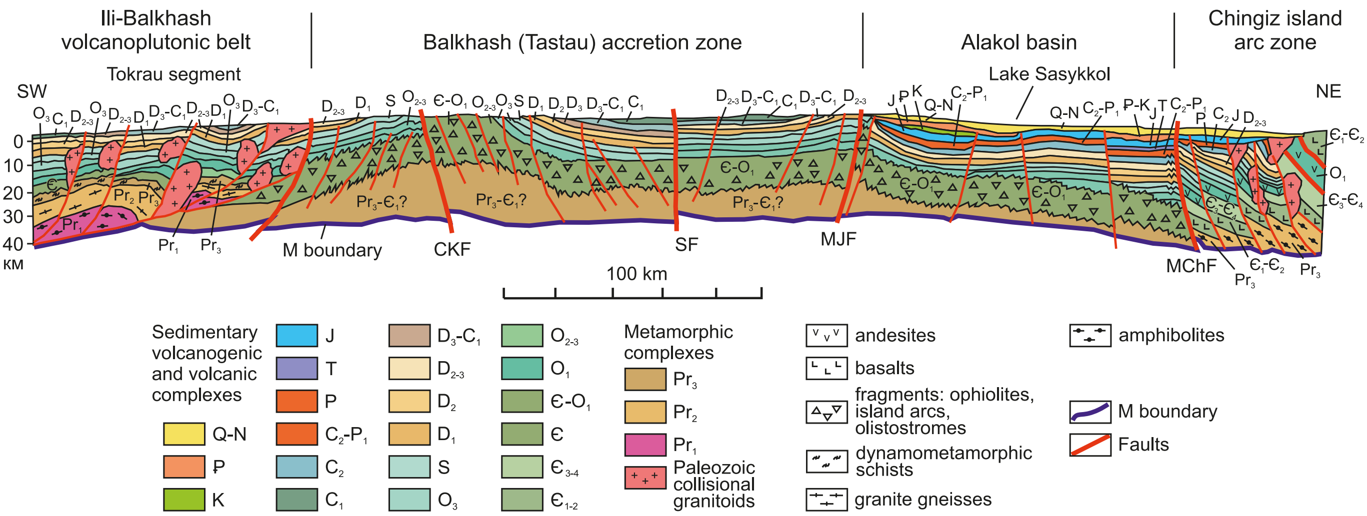

Fig. 2. A model of the deep-seated structure along the "Turkestan" and "Taldykorgan – Ust-Kamenogorsk" seismic profiles (fragment). Faults: CKF – Central Kazakhstan, MJF – Main Junggar, MChF – Main Chingiz.

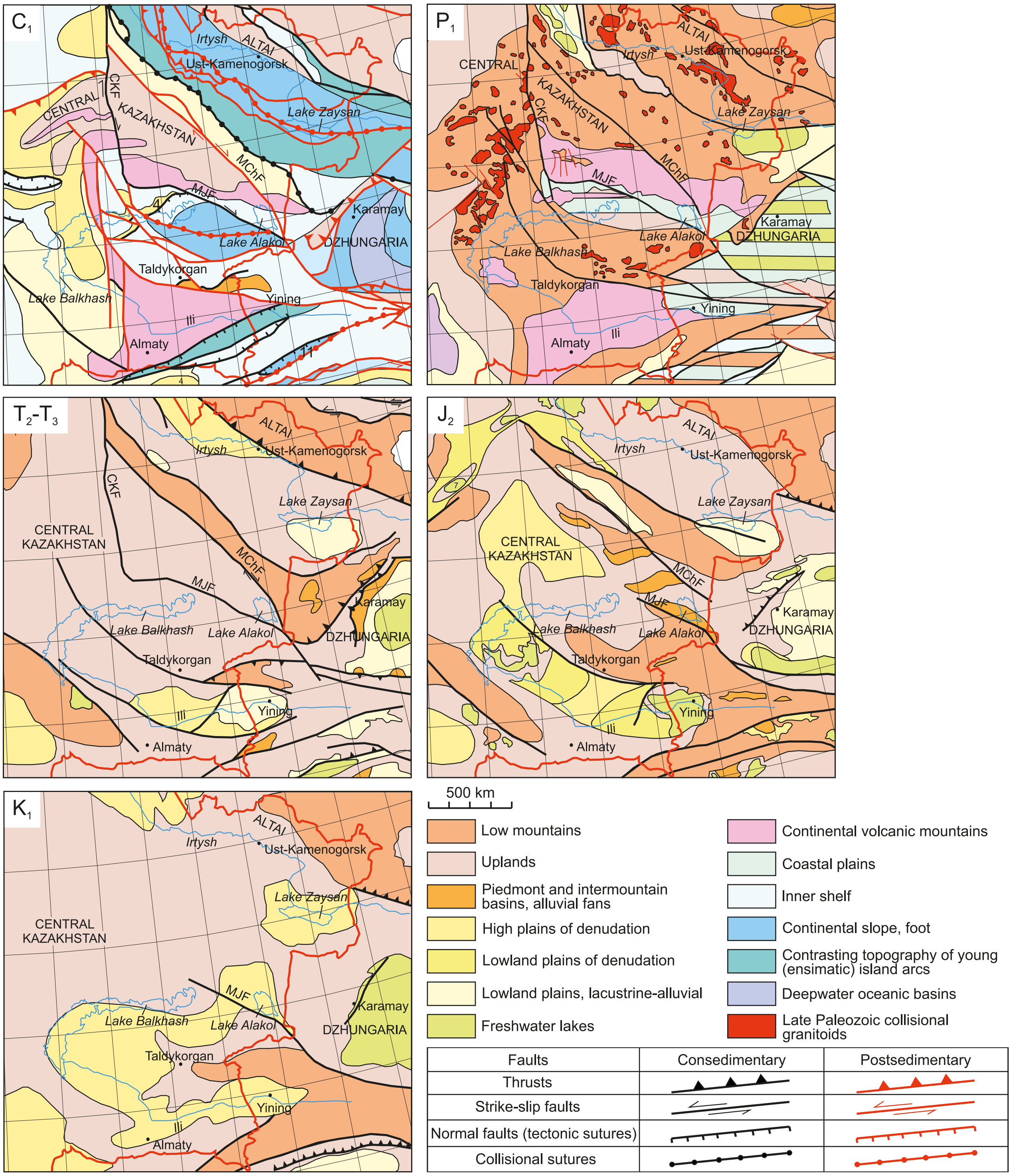

Fig. 3. Generalized lithological-paleogeographic maps of the East Kazakhstan and adjacent territories based on the data from [Daukeev et al.,2002b; Korobkin, Buslov, 2011]. Regional faults: MJF – Main Junggar; MChF – Main Chingiz; CKF – Central Kazakhstan.

activity, with the laterite weathering crust formed on the Paleozoic rocks [Korobkin et al., 2022]. The Late Triassic period is characterized by differential tectonic movements in the Alakol and Ili basins. The paleotectonic settings listed briefly (see Fig. 3; Fig. 5) show that the volcanogenic-sedimentary and sedimentary strata were formed in the zones of tectonomagmatic and tectonic activation of the Earth's crust. Shear dynamics of interaction of the main tectonic units caused large-amplitude strike-slip displacements there between [Windley et al., 2002; Buslov et al., 2003; Bian et al., 2010; Alexeiev et al., 2017].

The specialized structural studies [Buslov et al., 2003; Smirnov, Korobkin, 2003; Korobkin Smirnov, 2006; Feng et al., 2018] (see Fig. 1, 3; Fig. 5, 6) showed that such regional faults as Main Junggar, Central Kazakhstan, Main Chingiz and a number of others, bordering the main tectonic units

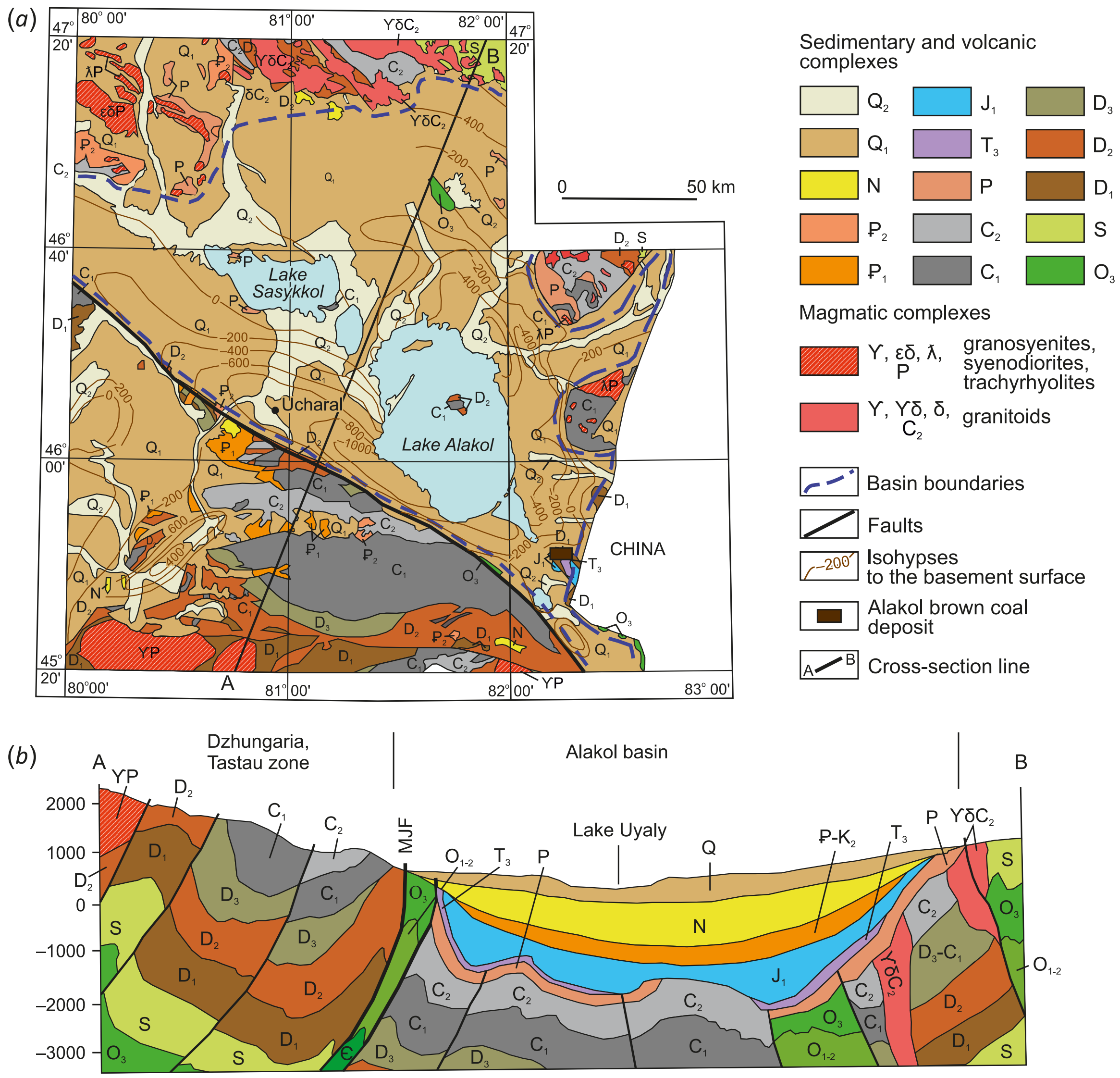

Fig. 4. A map of geological structure of the Alakol basin and adjacent territories after [Bekzhanov et al., 2000] (*a*) and geological cross-section along the A–B line (*b*).

of the Junggar-Balkhash fold system, are largely the left-lateral strike-slip faults [Windley et al., 2002; Buslov et al., 2003; Smirnov, Korobkin, 2003; Alexeiev et al., 2017; Ji et al., 2021]. In these faults, the left-lateral strike-slip component is determined based on the orientation of feathering faults and horizontal linearity (lb – structural-kinematic system of B. Zander, where structural-coordinate axes are: a – extension direction, b – fold axis, c – compression, ab – tectonic flow plane) [Rodygin, 2001]. The width of the zones of deformed rocks (mylonites, phyllonites) in the suture zone of the Main Junggar and Central Kazakhstan faults reaches a few hundred meters; in that of the Main Chingiz fault – one and more kilometers.

3. RESEARCH RESULTS

Tectono-structural framework of the AB is represented by the South Alakol, North Alakol and Yemel grabens, Ucharal and Sasykkol-Alakol horsts, and Urzhar monocline (Fig. 6) [Bekzhanov et al., 2000; Iskaziyev et al., 2015]. The South Alakol graben occupies the southwestern part of the basin and is linearly stretching northwestwards along the Main Junggar fault. The North Alakol graben, located in the northeastern part of the basin and also linear-shaped, is oriented at an angle relative to the Main Junggar fault. The grabens are divided by the Sasykkol-Alakol horst. In the eastern part of the basin, between the Arkaly and Arasantau mountains, there is the Yemel graben. In the northwestern part of the basin, on the continuation of the South Alakol graben, there is the Ucharal horst. In the northern part of the basin there is the Urzhar monocline, bounded by the Chingiz fault on the southwest (Fig. 6).

Lithological-stratigraphic characteristics of the AB are represented in Fig. 5. In the tectonic block south of the Alakol brown coalfield at the border with China (Fig. 6, 7), there are outcrops of 480 m thick conglomerates and sandstones containing remnants of the Carbonaceous-Permian flora. Upsection lie conglomerates, sandstones and siltstones of up to 750 m in thickness, related to undissected

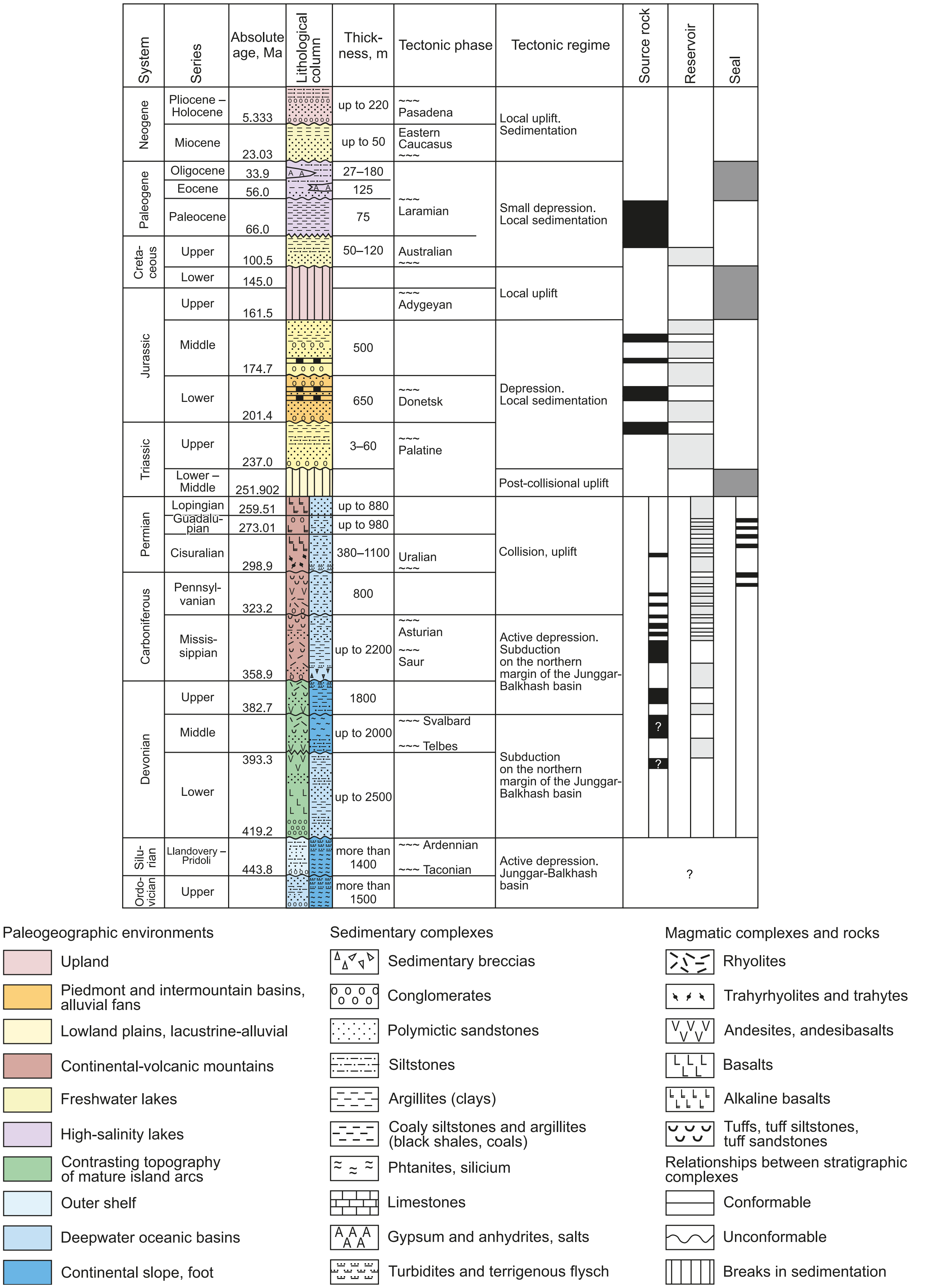

Fig. 5. Lithological and stratigraphic section of the Alakol basin with lithological and paleogeographic environment details. Shown here are source rocks, reservoirs and seals.

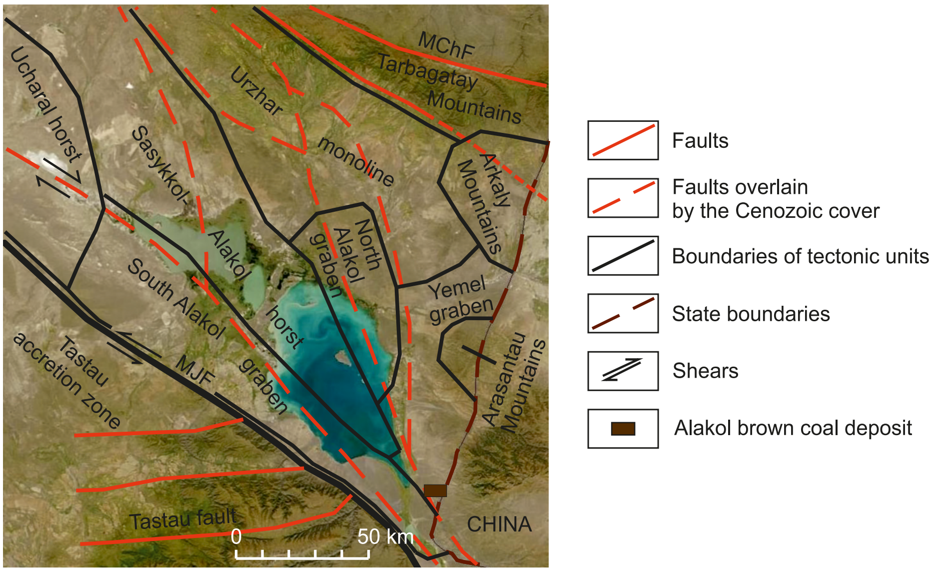

Fig. 6. A structural map of the Alakol basin. Regional faults: MJF – Main Junggar, MChF – Main Chingiz.

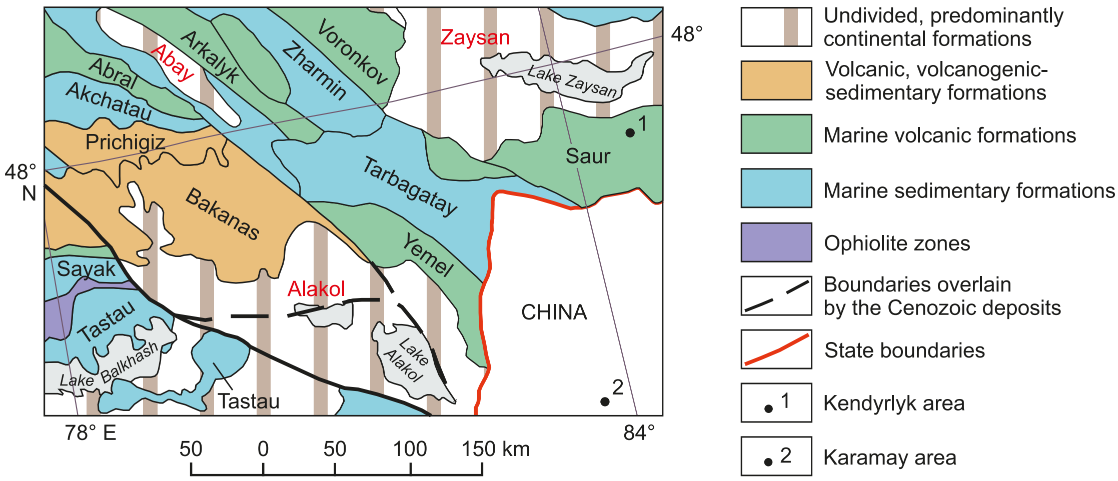

Fig. 7. Structural-facial zones without regard to palinspastic reconstructions of the Bakanas-Alakol region during the Carboniferous and Permian [Zholtaev et al., 2021].

deposits of the Lopingian and Guadalupian series. Next in the section is the Maylasary formation that rests on an erosional surface and has conglomerates, sandstones, and siltstones in its basal part and up to 550 m alkali rhyolites and tuffs in its upper part. The remnants of flora are indicative of both Middle Permian (Guadelupean series) and Early Triassic age of the deposits; the siltstone paleocomplex in the basal part is typical for the Middle Triassic [Zholtaev et al., 2021].

The Mesozoic complex, with a total thickness of 1500 m, is represented by terrigenous material of thin Triassic continental deposits and Jurassic coal-bearing rocks [Aubekerov et al., 2010; Zholtaev et al., 2021].

The Jurassic rocks of the AB are represented by the Uzunbulak formation. It is divided into two sub-formations, the lower of which (Hettengian–Sinemurian), with a coarser-grained texture, is represented by conglomerates, gritstones and sandstones 80–150 in thickness. The upper sub-formation (Pliensbachian) is composed of siltstones and argillites with interlayered conglomerates and sandstones up to 250 m thick. The age of the formation has been determined from the phyllopod shell and flora remains. The Cretaceous deposits of up to 120 m in thickness are represented by the remnants of the Sasykkol formation, ostracod-dated to the Upper Cretaceous [Bekzhanov et al., 2000; Zholtaev et al., 2021].

The Paleogene sediments are represented by salt deposits of lacustrine origin, composed of clays, siltstones and sands of up to 380 m in thickness [Aubekerov et al., 2010; Iskaziyev et al., 2015].

Mentions of hydrocarbon occurrences in the Northern Dzungaria of China can be found in a number of works [Hendrix et al., 1995; Cao et al., 2010; He at al., 2010]. Exploration and exploitation of oilfields showed that they are confined to the Triassic and Lower Jurassic deposits [Bian et al., 2010; Cao et al., 2010], which correlate well with the coeval deposits of the proven-reserve Alakol coalfield in Kazakhstan.

4. HYDROCARBON POTENTIAL

In the side parts of the AB, the occurrence depth of the Jurassic deposits does not exceed 1.5–2.0 km (see Fig. 4; Fig. 8). These deposits could not reach the maturity level of an active hydrocarbon generation (oil window zone). Their organic matter consists largely of flora remains, due to which the generation potential value cannot be high [Daukeev et al., 2002a]. In the axial parts of the AB, the Jurassic coal-bearing deposits occur at a depth of 3 km and more where they can generate hydrocarbons. We consider these deposits oil-and-gas source.

The Lower Jurassic coal-bearing strata of the Alakol field are 120 m thick (see Fig. 5; Fig. 9) and contain eight coalbeds, four of which are productive and minable. The average thickness of strata varies from 1.0 to 5.7 m. The coals are humic, changing from brown to black, and low-ash (an average of 6–10 % over the strata), related to low-sulfur

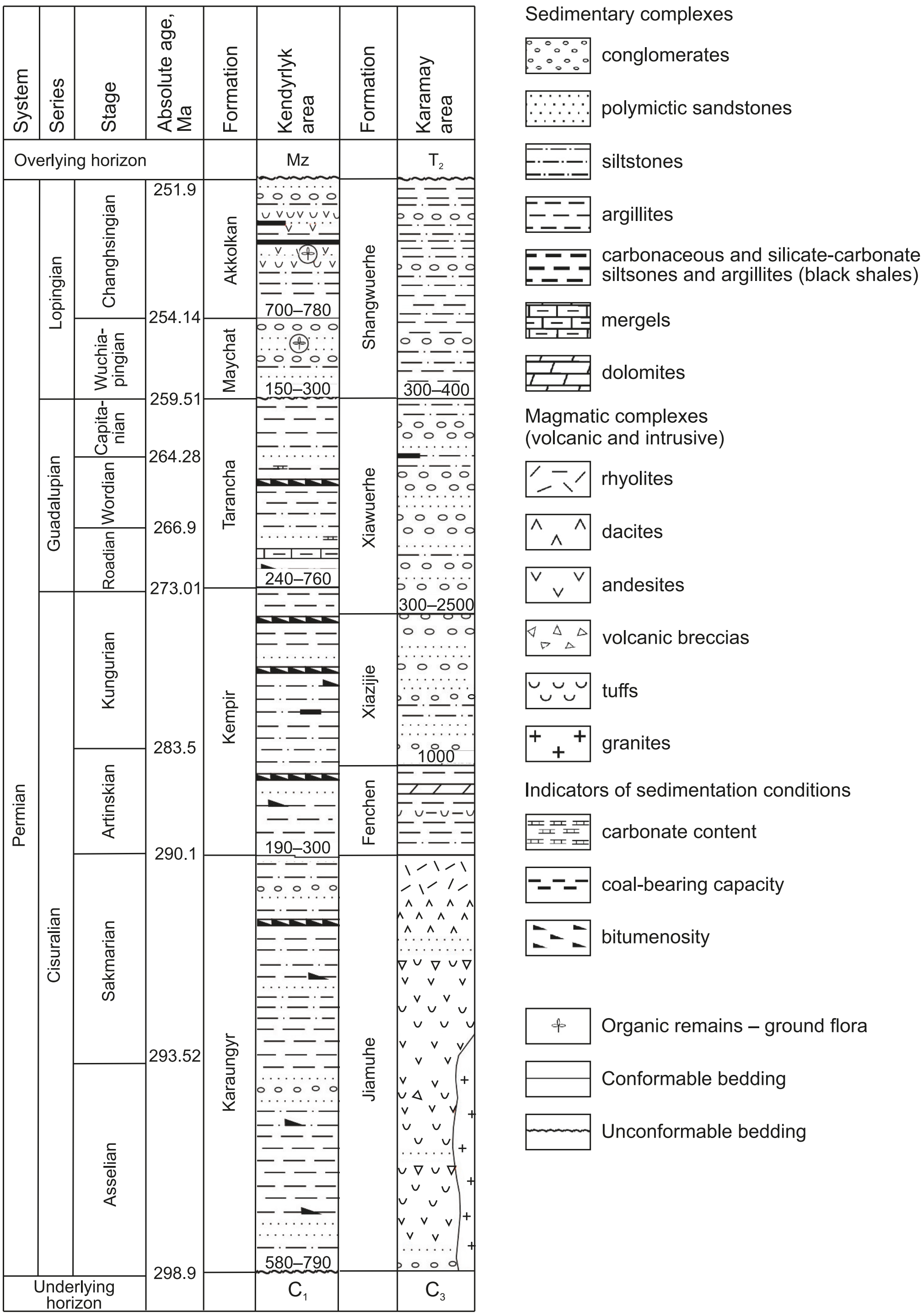

Fig. 8. Lithological-stratigraphic cross-section of the Kenderlyk (Zaysan basin) and Karamay (Junggar basin) areas.

and low-phosphorous. The coalfield's proven reserves total 47 million tons, of which about 8 million tons are suitable for open-pit mining [Azizov, Vlasov, 1997].

Hydrocarbon potential estimation of the Alakol sedimentary basin was based on parameter determination for forecasting reserves of the Upper Devonian – Carboniferous and Mesozoic complexes: 1) sedimentary basin area (see Fig. 3, 4), 2) source rock unit thicknesses (see Fig. 5), 3) organic matter content of source rock units, 4) source rock volumes (Table 1). The data on sedimentary basin areas resulted from lithological-paleogeographic and palinspastic mapping, the data on thicknesses were obtained from detailed lithological-stratigraphic studies.

The publications of Chinese geologists on the adjacent areas [Cao et al., 2010] were involved to use the data on organic matter content of the Upper Triassic – Jurassic [Azizov, Vlasov, 1997] and Paleogene [Iskaziyev et al., 2015] sediments. The forecast reserves were calculated using the volume-statistic method by L.G. Uiks's formula:

$$Q=qv\cdot V, \quad (1)$$

where Q – initial geologic resources, thousand tons; qv – bulk density of resources, t/m^3; V – sediment infill volume, km^3.

A probabilistic assessment of hydrocarbon potential of the AB (Table 1) was made based on the above-mentioned parameters in accordance with instructions for classification of reserves and prospective and forecast oil and hydrocarbon reserves in Kazakhstan [Akchulakov et al., 2002; Iskaziyev et al., 2015; Daukeev et al., 2002a; Zholtaev, Ozdoyev, 2010; Khisamov et al., 2018].

The Late Devonian – Early Carboniferous (Famennian-to-Mississippian) Alakol sedimentary basin in Kazakhstan, according to the lithological-paleogeographic reconstructions [Korobkin, Buslov, 2011; Iskaziyev et al., 2015; Korobkin et al., 2023], has an area of 20000 km^2 (approximate size 100×200 km), with a deposit thickness of 3 km.

The Mesozoic sedimentary complex, according to the lithological-paleogeographic reconstructions, comprises the southwestern portion of the Alakol basin and a latitudinal band along Lake Sasykkol. These structures, respectively

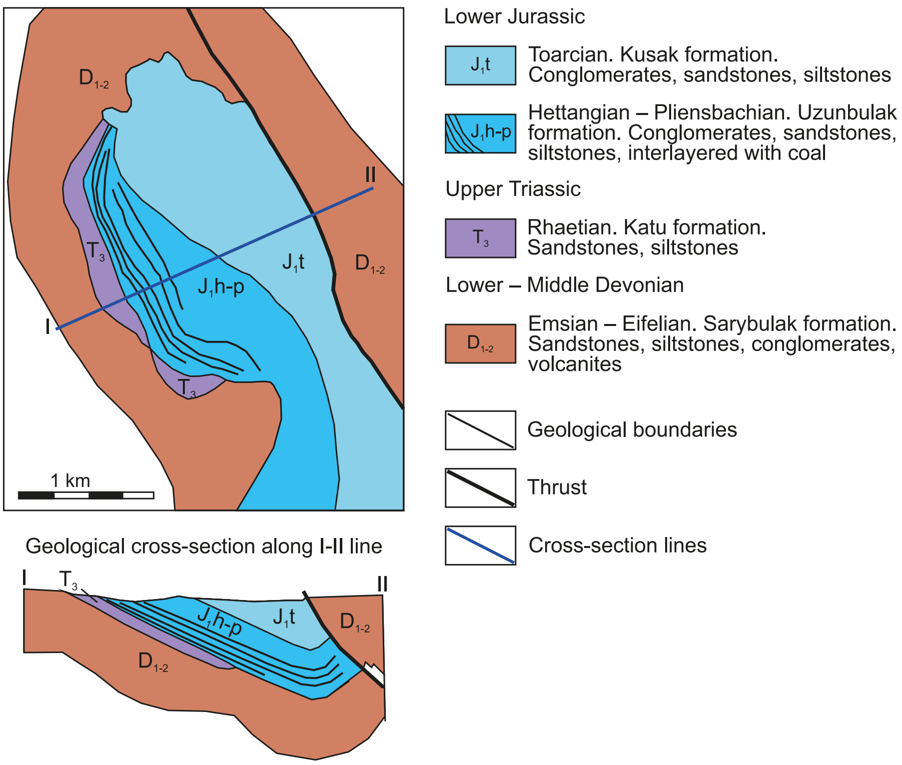

Fig. 9. The geological map and cross-section of the Alakol brown coalfield.

Table 1. Forecast hydrocarbon reserves of the Alakol basin

Zoning elements	Resource categories according to SCMR RK	Resource categories according to SPE–PRMS classification	Sedimentation volume, km3	Total resources, thousand tons	Stratigraphic range	Lithology of reservoirs
Kazakhstan sector of the Alakol basin	D_0 – possible reserves	P3 – possible reserves	60000	720000	D_3–C_1	terrigenous
			36900	442800	T_3–J–₽	terrigenous
			Total	1162800		

200 km and 150 km long and 50 km and 70 km wide, have areas 10000 and 10500 km^2, respectively, with a thickness of 2 km. The bulk density of resources, considering related assumptions, is estimated at 12000 tons per km^3 [Vassoevich, 1988].

Thus, the initial recoverable hydrocarbon reserves are estimated to be 1162800 thousand tons, the recoverable oil reserves make up one third of the forecast reserves.

5. DISCUSSION

Neither deep drilling nor geochemical surveys for forecasting the oil potential were conducted in the central parts of the AB. The Upper Devonian – Lower Carboniferous rocks of the AB lie at a depth of 2.5 km (horizon top) to 4 km and deeper (bottom). Consequently, they could reach the maturity level of an active hydrocarbon generation (gas window zone) and are potentially promising. The Paleozoic water-bearing deposits consist mostly of fresh infiltration waters with a mineral content of 1–2 mg/L. The water mineral content of the Jurassic, Cretaceous and Paleogene deposits is the same as mentioned above and increases to 20 g/L with increasing occurrence depth [Li, 1975; Daukeev et al., 2002a; Akchulakov et al., 2002; Iskaziyev et al., 2015; Zholtaev, Ozdoyev, 2010].

The AB is the result of the Late Paleozoic – Mesozoic crustal subsidence (see Fig. 3, 4) along large-amplitude oblique slips of the Main Junggar and Chingiz faults and exhibits insignificant vertical kinetics with a shallow basement occurrence. The deepest South and North Alakol troughs are filled by the Upper Paleozoic terrigenous deposits (see Fig. 3, 5)

Oil evidence may include oil-filmed water spouting from the well located 5 km north of Zharbulak. The names the local people gave natural springs and lakes are of interest because they contain information on the hues of water. "Kara" which means "black" – the color of hydrocarbons – is most commonly used in the names of localities: Karakuduk (Black Well), Karabulak (Black Spring), Karakol (Black Lake), Karasu (Black Water).

Exploration of the Junggar basin area showed that the Upper Devonian and Carboniferous rock units are of high oil and gas potential [Li et al., 2015; Zong et al., 2015; Zhu et al., 2022]. In the Carboniferous deposits of the Northwest China were discovered the Wucaiwan, Shixi, Kelameili and Chepaizi oil and gas fields, and a number of oil zones in the Karamay Field. The Permian rocks also have a high hydrocarbon potential. In the Zaysan basin, oil and mined bitumen are extracted from the Permian and Jurassic reservoir rocks. The Permian source rocks show a low degree of maturity. Paleogene gas is a product of oil and oil derivatives degradation. In the Zaysan basin, there were distinguished two oil-saturation and one gas-accumulation stages [Li et al., 2015; Zong et al., 2015; Zhu et al., 2022]. The first stage of hydrocarbon formation probably dates back to 207 Ma (Late Triassic) when the source rock fell within the temperature interval of oil window (depth 1.6–4.0 km, temperature 60-150 °C). Oil migrated into the Permian deposits, and oil reservoirs subsequently underwent biodegradation. Another oil migration occurred in the Upper Cretaceous (70–100 Ma ago) [Akchulakov et al., 2002; Iskaziyev et al., 2015].

6. CONCLUSION

Studies of the Late Paleozoic – Mesozoic tectonic evolution testify that the Devonian – Carboniferous – Permian, Jurassic and Paleogene reservoir rocks could accumulate hydrocarbons. Perhaps, a hydrocarbon potential of the Alakol basin is caused by the secondary hydrocarbon migration from the underlying terrigenous deposits.

The possible prospects of the Alakol basin for hydrocarbons in the basement subsidence zones are related to:

– increase in thickness of the Carboniferous, Permian, Triassic and Lower Jurassic organic-rich sedimentary deposits;

– subsidence of the stepped top of the AB basement, controlled by dynamics of the Main Junggar and Main Chingiz faults and their associated feathering faults at the collisional and post-collisional stages, which in turn gives rise to the formation of stratigraphic, lithological and structurally screened traps.

Features identified in the regional and local structure, lithological-paleogeographic conditions and lithological-facial and material composition of rocks in the Alakol basin allow to some extent to give an optimistic estimate of its hydrocarbon prospects. The foreseeable zones with traps are confined to the subsided parts of the grabens.

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8. CONTRIBUTION OF THE AUTHORS

All authors made an equivalent contribution to this article, read and approved the final manuscript.

9. DISCLOSURE

The authors declare that they have no conflicts of interest relevant to this manuscript.

10. REFERENCES

Akchulakov U.A., Zhylkaidarov I.S., Zholtaev G., Zhylkaidarov S.Ye., Paragulgov Kh.Kh., Rabinovich A.A., 2002. Methodological Guidelines for the Quantification of Inferred Hydrocarbon Resources of the Republic of Kazakhstan. Almaty, 72 p. (in Russian) [Акчулаков У.А., Жылкайдаров И.С., Жолтаев Г., Жылкайдаров С.Е., Парагульгов Х.Х., Рабинович А.А. Методическое руководство по количественной оценке прогнозных ресурсов углеводородного сырья Республики Казахстан. Алматы, 2002. 72 с.].

Alexeiev D.V., Bykadorov V.A., Volozh Yu.A., Sapozhnikov R.B., 2017. Kinematic Analysis of Jurassic Grabens of Soulthern Turgai and the Role of the Mesozoic Stage in the Evolution of the Karatau–Talas–Ferghana Strike-Slip Fault, Southern Kazakhstan and Tian Shan. Geotectonics 51, 105–120. https://doi.org/10.1134/S0016852117020029.

Aubekerov B.Zh., Cirelson B.S., Bykadorov V.A., Popov V.A., 2010. Peculiarities of the Geological Structure and Prospects of Oil and Gas Potential of the Mesozoic-Cenozoic Sedimentary Basins of Southern Kazakhstan. News of National Academy of Sciences of the Republic of Kazakhstan. Series of Geology and Technical Sciences 3, 131–140 (in Russian) [Аубекеров Б.Ж., Цирельсон Б.С., Быкадоров В.А., Попов В.А. Особенности геологического строения и перспективы нефтегазоносности мезозой-кайнозойских осадочных бассейнов Южного Казахстана // Известия НАН РК. Серия геологии и технических наук. 2010. № 3. С. 131–140].

Azizov T.M., Vlasov V.I., 1997. Coal and Oil Shale Basins and Fields of Kazakhstan. Mineral Resources of Kazakhstan. Almaty, 113 p. (in Russian) [Азизов Т.М., Власов В.И. Бассейны и месторождения углей и горючих сланцев Казахстана. Алматы, 1997. 113 с.].

Bekzhanov G.R., Koshkin V.Ya., Nikitchenko I.I., Smirnov A.V., Skrinnik L.I., 2000. Geological Structure of Kazakhstan: Explanatory Note to the Map in Scale 1:1000000. Academy of Mineral Resources of the Republic of Kazakhstan, Almaty, 396 p. (in Russian) [Бекжанов Г.Р., Кошкин В.Я., Никитченко И.И., Смирнов А.В., Скринник Л.И. Геологическое строение Казахстана: Пояснительная записка к карте масштаба 1:1000000. Алматы: Академия минеральных ресурсов Республики Казахстан, 2000. 396 с.].

Bespalov V.F., 1971. Geological Structure of the Kazakh SSR. Nauka, Alma-Ata, 363 p. (in Russian) [Беспалов В.Ф. Геологическое строение Казахской ССР. Алма-Ата: Наука, 1971. 363 с.].

Bian W., Hornung J., Liu Z., Wang P., Hinderer M., 2010. Sedimentary and Palaeoenvironmental Evolution of the Junggar Basin, Xinjiang, Northwest China. Palaeobiodiversity and Palaeoenvironments 90, 175–186. https://doi.org/10.1007/s12549-010-0038-9.

Brunet M., Sobel E.R., McCann T., 2020. Geological Evolution of Central Asian Basins and the Western Tien Shan Range. Geological Society of London Special Publications 427, 1–17. https://doi.org/10.1144/SP427.17.

Buslov M.M., 2011. Tectonics and Geodynamics of the Central Asian Foldbelt: The Role of Late Paleozoic Large-Amplitude Strike-Slip Faults. Russian Geology and Geophysics 52 (1), 52–71. https://doi.org/10.1016/j.rgg.2010.12.005.

Buslov M.M., Cai K., 2017. Tectonics and Geodynamics of the Altai-Junggar Orogen in the Vendian-Paleozoic: Implications for the Continental Evolution and Growth of the Central Asian Fold Belt. Geodynamics & Tectonophysics 8 (3), 421–427. https://doi.org/10.5800/GT-2017-8-3-0252.

Buslov M.M., Watanabe T., Smirnova L.V., Fujiwara I., Iwata K., de Grave I., Semakov N.N., Travin A.V., Kir'yanova A.P., Kokh D.A., 2003. Role of Strike-Slip Faults in Late Paleozoic – Early Mesozoic Tectonics and Geodynamics of the Altai-Sayan and East Kazakhstan Folded Zone. Russian Geology and Geophysics 44 (1–2), 49–75.

Cao J., Wang X., Wei D., Sun P., Hu W., Jia D., Zhao Y., 2010. Complex Petroleum Migration and Accumulation in Central Region of Southern Junggar Basin, Northwest China. Journal of Earth Sciences 21, 83–93. https://doi.org/10.1007/s12583-010-0004-5.

Daukeev S.Zh., Uzhkenov B.S., Abdulin A.A., Bespaev H.A., Vocalevsky E.S., Ljubetsky V.N., Mazurov A.K., Miroshnichenko L.A. (Eds), 2002a. Deep Structure and Mineral Resources of Kazakhstan. Oil and Gas. Vol. 3. Almaty, 248 p. (in Russian) [Глубинное строение и минеральные ресурсы Казахстана: Нефть и газ / Ред. С.Ж. Даукеев, Б.С. Ужкенов, А.А. Абдулин, Х.А. Беспаев, Э.С. Воцалевский, В.Н. Любецкий, А.К. Мазуров, Л.А. Мирошниченко. Алматы, 2002. Т. 3. 248 с.].

Daukeev S.Zh., Ushkenov B.S., Miletenko N.V., Morozov A.F., Leonov Yu.G., Futong W., Akhmedov N.A., Abdyllaev E.K. et al. (Eds), 2002b. Atlas of Lithology-Paleogeographical, Structural, Palinspastic and Geoenvironmental Maps of Central Eurasia. Scientific Research Institute of Natural Resources YUGGEO, Almaty, 132 p. (in Russian) [Атлас литолого-палеогеографических, структурных, палинспастических и геоэкологических карт Центральной Евразии / Ред. С.Ж. Даукеев, Б.С. Ужкенов, Н.В. Милетенко, А.Ф. Морозов, Ю.Г. Леонов, В. Футун, Н.А. Ахмедов, Э.Х. Абдыллаев и др. Алматы: Научно-исследовательский институт природных ресурсов ЮГГЕО, 2002. 132 с.].

Didenko A.N., Mossakovskii A.A., Pecherskii D.M., Ruzhentsev S.V., Samygin S.G., Kheraskova T.N., 1994. Geodynamics of the Centra Asian Paleozoic Oceans. Russian Geology and Geophysics 35 (7–8), 59–75 (in Russian) [Диденко А.Н., Моссаковский А.А., Печерский Д.М., Руженцев С.В., Самыгин С.Г., Хераскова Т.Н. Геодинамика палеозойских океанов Центральной Азии // Геология и геофизика. 1994. Т. 35. № 7–8. С. 59–75].

Dobretsov N.L., 2003. Evolution of Structures of the Urals, Kazakhstan, Tien Shan, and Altai-Sayan Region within the Ural-Mongolian Fold Belt (Paleoasian Ocean). Russian Geology and Geophysics 44 (1–2), 3–26.

Dobretsov N.L., Buslov M.M., 2007. Late Cambrian-Ordovician Tectonics and Geodynamics of Central Asia. Russian Geology and Geophysics 48 (1), 71–82. https://doi.org/10.1016/j.rgg.2006.12.006.

Feng J., Dai J., Li X., Luo P., 2018. Soft Collision and Polyphasic Tectonic Evolution of Wuxia Foreland Thrust Belt: Evidence from Geochemistry and Geophysics at the Northwestern Margin of the Junggar Basin. Journal of Geodynamics 118, 32–48. https://doi.org/10.1016/j.jog.2018.05.004.

Gladkochub D.P., Donskaya T.V., Stanevich A.M., Pisarevsky S.A., Zhang S., Motova Z.L., Mazukabzov A.M., Li H., 2019. U-Pb Detrital Zircon Geochronology and Provenance of Neoproterozoic Sedimentary Rocks in Southern Siberia: New Insights into Breakup of Rodinia and Opening of Paleo-Asian Ocean. Gondwana Research 65, 1–16. https://doi.org/10.1016/j.gr.2018.07.007.

Han S., Sang S., Liang J., Wang W., Zhang G., Wang S., 2019. Characteristics and Genesis of Diachronous Carboniferous Volcano-Sedimentary Sequences: Insights from Geochemistry, Petrology and U-Pb Dating in the North Junggar Basin, China. International Geology Review 61 (4), 404–423. https://doi.org/10.1080/00206814.2018.1428830.

He D., Chen X., Kuang J., Yuan H., Fan C., Tang Y., Wu X., 2010. Distribution of Carboniferous Source Rocks and Petroleum Systems in the Junggar Basin. Petroleum Exploration and Development 37 (4), 397–408. https://doi.org/10.1016/S1876-3804(10)60041-9.

Hendrix M.S., Brassell S.C., Carroll A.R., Graham S.A., 1995. Sedimentology, Organic Geochemistry, and Petroleum Potential of Jurassic Coal Measures: Tarim, Junggar, and Turpan Basins, Northwest China. AAPG Bulletin 79 (7), 929–959. https://doi.org/10.1306/8D2B2187-171E-11D7-8645000102C1865D.

Iskaziyev K.O., Karabalin U.S., Akchulakov U.A. (Eds), 2015. Atlas of Oil and Gas Bearing and Prospective Sedimentary Basins of the Republic of Kazakhstan. Astana, 97 p. (in Russian) [Атлас нефтегазоносных и перспективных осадочных бассейнов Республики Казахстан / Ред. К.О. Исказиев, У.С. Карабалин, У.А. Акчулаков. Астана, 2015. 97 с.].

Ji J., Wu K., Pei Y., Guo W., Liu Y., Li T., 2021. Fault Sealing Evaluation of a Strike-Slip Fault Based on Normal Stress: A Case Study from Eastern Junggar Basin, NW China. Energies 14, 1468. https://doi.org/10.3390/en14051468.

Khisamov R.S., Safarov A.F., Kalimullin A.M., Dryagalkina A.A., 2018. Probabilistic-Statistical Estimation of Reserves and Resources According to the International Classification SPE-PRMS. Georesources 20 (3), 158–164 (in Russian) [Хисамов Р.С., Сафаров А.Ф., Калимуллин А.М., Дрягалкина А.А. Вероятностно-статистическая оценка запасов и ресурсов по международной классификации SPE-PRMS // Георесурсы. 2018. Т. 20. № 3. С. 158–164]. http://doi.org/10.18599/grs.2018.3.158-164.

Korobkin V.V., Buslov M.M., 2011. Tectonics and Geodynamics of the Western Central Asian Fold Belt (Kazakhstan Paleozoides). Russian Geology and Geophysics 52 (12), 1600–1618. https://doi.org/10.1016/j.rgg.2011.11.011.

Korobkin V., Chaklikov A., Tulemissova Z., Samatov I., Dobrovolskaya Y., 2023. Results of the Study of Epigenetic Changes of Famennian–Tournaisian Carbonate Rocks of the Northern Marginal Shear Zone of the Caspian Syneclise (Kazakhstan). Minerals 13 (2), 249. https://doi.org/10.3390/min13020249.

Korobkin V., Samatov I., Chaklikov A., Tulemissova Z., 2022. Peculiarities of Dynamics of Hypergenic Mineral Transformation of Nickel Weathering Crusts of Ultramafic Rocks of the Kempirsay Group of Deposits in Western Kazakhstan. Minerals 12 (5), 650. https://doi.org/10.3390/min12050650.

Korobkin V.V., Smirnov A.V., 2006. Paleozoic Tectonics and Geodynamics of Volcanic Arcs in Northern Kazakhstan. Russian Geology and Geophysics 47 (4), 458–470.

Koshkin V.Ya., 1974. Tectonic Position of the Balkhash-Ili Hercynian Volcanic Belt. In: M.V. Muratov, A.A. Belov, L.P. Zonenshain et al. (Eds), Tectonics of the Ural-Mongolian Folded Belt: Proceedings of the Meeting. Nauka, Moscow, p. 86–92 (in Russian) [Кошкин В.Я. Тектоническое положение Балхаш-Илийского герцинского вулканического пояса // Тектоника Урало-Монгольского складчатого пояса: Труды совещания / Ред. М.В. Муратов, А.А. Белов, Л.П. Зоненшайн и др. М.: Наука, 1974. С. 86–92].

Kröner A., Kovach V., Belousova E., Hegner E., Armstrong R., Dolgopolova A., Seltmann R., Alexeiev D.V., Hoffmann J.E. et al., 2014. Reassessment of Continental Growth during the Accretionary History of the Central Asian Orogenic Belt. Gondwana Research 25 (1), 103–125. https://doi.org/10.1016/j.gr.2012.12.023.

Kurchavov A.M., Grankin M.S., Mal'chenko E.G., Zhukovskii V.I., Khamzin B.S., Mazurov A.K., Khamza S.Kh., 2000. Zoning, Segmentation, and Paleogeodynamics of the Devonian Volcanic Belt in Central Kazakhstan. Geotectonics 4, 32–43 (in Russian) [Курчавов А.М., Гранкин М.С., Мальченко Е.Г., Жуковский В.И., Хамзин Б.С., Мазуров А.К., Хамза С.Х. Зональность, сегментированность и палеогеодинамика девонского вулканического пояса Центрального Казахстана // Геотектоника. 2000. Т. 4. С. 32–43].

Li A.B., 1975. Tectonics and Prospects of Oil and Gas Potential of the Southern Kazakhstan. Nauka, Alma-Ata, 220 p. (in Russian) [Ли А.Б. Тектоника и перспективы нефтегазоносности Южного Казахстана. Алма-Ата: Наука, 1975. 220 с.].

Li D., He D., Santosh M., Ma D., Tang J., 2015. Tectonic Framework of the Northern Junggar Basin. Gondwana Research 27 (3), 1089–1109. https://doi.org/10.1016/j.gr.2014.08.015.

Mossakovsky A.A., Ruzhentsev S.V., Samygin S.G., Kheraskova T.N., 1993. Central Asian Fold Belt: Geodynamic Evolution and Formation History. Geotectonics 6, 3–33 (in Russian) [Моссаковский А.А., Руженцев С.В., Самыгин С.Г., Херасковa Т.Н. Центрально-Азиатский складчатый пояс: геодинамическая эволюция и история формирования // Геотектоника. 1993. № 6. С. 3–33].

Rodygin A.I., 2001. Dynamically Metamorphosed Rocks. Publishing House of the Tomsk University, 356 p. (in Russian) [Родыгин А.И. Динамометаморфические породы. Томск: Изд-во Томского университета, 2001. 356 с.].

Ryazantsev A.V., Degtyarev K.Ye., Kotov A.B., Sal'nikova E.B., Anisimova I.V., Yakovleva S.Z., 2009. Ophiolites and Island-Arc Complexes of the Zhalair-Naiman Zone and the Chu-Kendyktas Massif (South Kazakhstan): Position in the Structure, Substantiation of the Age and Setting of Formation. Doklady Earth Sciences 427, 902–906. https://doi.org/10.1134/S1028334X09060038.

Samygin S.G., Kheraskova T.N., 2019. Geological Structure and Stages of Tectonic Evolution of the Paleozoids of Kazakhstan. Lithosphere 19 (3), 347–371 (in Russian) [Самыгин С.Г., Хераскова Т.Н. Геологическое строение и этапы тектонической эволюции палеозоид Казахстана // Литосфера. 2019. Т. 19. № 3. С. 347–371]. https://doi.org/10.24930/1681-9004-2019-19-3-347-371.

Şengör A.M.C., Natal'in B.A., Burtman V.S., 1993. Evolution of the Altaid Tectonic Collage and Paleozoic Crustal Growth in Eurasia. Nature 364, 299–307. https://doi.org/10.1038/364299a0.

Sklyarov E.V., Lavrenchuk A.V., Fedorovsky V.S., Pushkarev E.V., Semenova D.V., Starikova A.E., 2020. Dismembered Ophiolite of the Olkhon Composite Terrane (Baikal, Russia): Petrology and Emplacement. Minerals 10 (4), 305. https://doi.org/10.3390/min10040305.

Smirnov A.V., Korobkin V.V., 2003. Tectonic Map of Kazakhstan in Scale 1:1000000 (Mapping Principles and Methods). News of National Academy of Sciences of the Republic of Kazakhstan. Series of Geology and Technical Sciences 2, 77–89 (in Russian) [Смирнов А.В., Коробкин В.В. Тектоническая карта Казахстана масштаба 1:1000000: (принципы и методика построения) // Известия НАН РК. Серия геологии и технических наук. 2003. № 2. С. 77–89].

Vassoevich N.B., 1988. Oil and Gas Potential of Sedimentary Basins. Selected Works. Nauka, Moscow, 260 p. (in Russian) [Вассоевич Н.Б. Нефтегазоносность осадочных бассейнов: Избранные труды. М.: Наука, 1988. 260 с.].

Wang H.Z., 1985. Atlas of the Paleogeography of China. Cartographic Publishing House, Beijing, China, 168 p.

Windley B.F., Alexeiev D., Xiao W.J., Kröner A., Badarch G., 2007. Tectonic Models for Accretion of the Central Asian Orogenic Belt. Journal of Geological Society 164 (1), 31–47. https://doi.org/10.1144/0016-76492006-022.

Windley B.F., Kröner A., Guo J., Qu G., Li Y., Zhang C., 2002. Neoproterozoic to Paleozoic Geology of the Altai Orogen, NW China: New Zircon Age Data and Tectonic Evolution. Journal of Geology 110 (6), 719–737. https://doi.org/10.1086/342866.

Xiao W.J., Santosh M., 2014. The Western Central Asian Orogenic Belt: A Window to Accretionary Orogenesis and Continental Growth. Gondwana Research 25 (4), 1429–1444. https://doi.org/10.1016/j.gr.2014.01.008.

Xiao W.J., Windley B.F., Allen M.F., Han C.M., 2013. Paleozoic Multiple Accretionary and Collisional Tectonics of the Chinese Tianshan Orogenic Collage. Gondwana Research 23 (4), 1316–1341. https://doi.org/10.1016/j.gr.2012.01.012.

Xiao W.J., Windley B.F., Huang B.C., Han C.M., Yuan C., Chen H.L., Sun M., Sun S., Li L., 2009. End-Permian to Mid-Triassic Termination of the Accretionary Processes of the Southern Altaids: Implications for the Geodynamic Evolution, Phanerozoic Continental Growth, and Metallogeny of Central Asia. International Journal of Earth Sciences 98, 1189–1217. https://doi.org/10.1007/s00531-008-0407-z.

Zholtaev G.Zh., Nikitina O.I., Zhaimina V.Ya., Seitmuratova E.Yu., Pirogov T.E., Ivanova N.I., Fazylov E.M., Musina E.S., Nigmatova S.A., Baishashov B.U., 2021. Modernization of the Phanerozoic Stratigraphic Schemes of Kazakhstan Based on the International Chronostratigraphic Scale – 2016–2021. LPP "378", Almaty, 139 p. (in Russian) [Жолтаев Г.Ж., Никитина О.И., Жаймина В.Я., Сейтмуратова Э.Ю., Пирогова Т.Е., Иванова Н.И., Фазылов Е.М., Мусина Э.С., Нигматова С.А., Байшашов Б.У. Модернизация стратиграфических схем фанерозоя Казахстана на основе Международной хроностратиграфической шкалы – 2016–2021. Алматы: ТОО «378», 2021. 139 с.].

Zholtaev G.Zh., Ozdoyev S.M., 2010. Prospects of Oil and Gas Potentials of the Alakol Sedimentary Basin. News of National Academy of Sciences of the Republic of Kazakhstan. Series of Geology and Technical Sciences 3, 122–127 (in Russian) [Жолтаев Г.Ж., Оздоев С.М. Перспективы нефтегазоносности Алакольского осадочного бассейна // Известия НАН РК. Серия геологии и технических наук. 2010. № 3. С. 122–127].

Zhu X., Shen C., Zhao B., Hu S., Ge X., Wang L., 2022. Multi-Stage Hydrocarbon Migration and Accumulation of Permian Petroleum System in the Zaysan Basin, NE Kazakhstan. Journal of Petroleum Sciences and Engineering 208, 109291. https://doi.org/10.1016/j.petrol.2021.109291.

Zonenshain L.P., Kuzmin M.I., Natapov L.M., 1990. Geology of the USSR: A Plate Tectonic Synthesis. American Geophysical Union, Washington, 242 p. https://doi.org/10.1029/GD021.

Zong R., Fan R., Gong Y., 2015. Advances in the Research on Carboniferous Deep-Water Marine Deposits in Western Junggar, Northwestern China. Geological Journal 50 (2), 111–121. https://doi.org/10.1002/gj.2532.

Zou C., Hou L., Tao S., Yuan X., Zhu R., Jia J., Zhang X., Li F., Pang Z., 2012. Hydrocarbon Accumulation Mechanism and Structure of Large-Scale Volcanic Weathering Crust of the Carboniferous in Northern Xinjiang, China. Science China Earth Sciences 55, 221–235. https://doi.org/10.1007/s11430-011-4297-8.