The Petroleum Geology of Kazakhstan*

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Introduction

Kazakhstan is a vast and varied country, extending for almost 3000 km from the Caspian Sea in the west to the Chinese border in the east. Its area of 2,727,300 km^2 is similar to that of Western Europe, and over 1/3 that of the contiguous United States. Much of the Republic comprises lowland semidesert and grassy steppe, which dominate in the part of the country lying west of the Aral Sea. To the east are more mountainous areas including the Kazakhstan plateau to the north, Tien Shan to the south, and the Altai mountains in the east.

Geologically the country is diverse. The Aral Sea overlies a north-south suture marking the position of the Uralian Ocean, which closed late in the Carboniferous. Much of Western Kazakhstan, therefore, corresponds to an ancient East European continental block with several Tethyan-accreted terranes. Eastern Kazakhstan is largely underlain by the Kazakh continental block, composed of a mosaic of Early Palaeozoic continental fragments, possibly of East Gondwanan affinity (Windley et al., 2007).

Western Kazakhstan

The Palaeozoic development of Western Kazakhstan is poorly understood owing to an almost complete absence of Palaeozoic outcrop except in the Southern Ural Mountains, with relatively few wells penetrating Palaeozoic basement. During the Mid-Palaeozoic, the region lay on the "southeastern" corner of the East European Platform adjacent to two closing oceans, the Uralian to the east and Palaeo-Tethys to the south. Various models have been proposed for the sequence of events leading to the closure of these two oceans, at the end-Palaeozoic and end-Triassic, respectively. Several existing models are based on studies of limited areas, and are difficult to reconcile with data from elsewhere in the region. The story is complicated by the presence of intra-continental rifts, such as the North Precaspian Rift, the Donets-Karpinsky-South Emba rift, and the Kuma-Manych-Karatau rift, with debate as to whether any or all of these represent former oceans or back-arc basins. Figure 1 attempts a simple model for the Palaeozoic development of Western Kazakhstan and surrounding areas. It is based on the "Occam's razor" principle of being the simplest model which accounts for the great majority of available data from over a wide area, but is far from definitive.

In terms of its hydrocarbon prospectivity, Western Kazakhstan can be divided into three broad provinces, the Precaspian Basin in the northwest (though the western flanks of the basin lie within Russia); Mangyshlak, the wide peninsular area bordering the East Caspian coastline; and Ustyurt, which lies between Mangyshlak and the Aral Sea. Oil and gas reservoirs in Mangyshlak are mostly Mesozoic, with Middle Triassic carbonates comprising the most prolific of several source rocks. The numerous fields here include giants such as Uzen, discovered in 1961 with an estimated STOIIP of around 8.4 billion barrels. The Triassic source rock does not extend beneath the extensive Ustyurt Plateau to the east, which largely explains its lower prospectivity, although some fields relying on various secondary sources do exist within Mesozoic and younger reservoirs.

The Precaspian Basin, 1000 km across (Figure 2), began to form during the Early to Middle Devonian. It was originally centred on an oceanic rift, the North Precaspian Rift, which failed but acted as the focus for basin subsidence. The basin geometry is also defined by thrust belts in the east (associated with Uralian closure) and south (associated with closure of the Donets-Karpinsky-South Emba rift). The apparently simple elliptical shape of the basin results from a complex interplay of tectonic factors, which in turn influenced the geometry of carbonate build-ups around the basin margins (darker-blue in Figure 2). The petroleum system within the Precaspian Basin is quite distinct from that of Mangyshlak and Ustyurt, depending primarily on the world-class Domanik (Upper Devonian) source rock, and the Lower Permian (Kungurian) salt, which forms a regional seal (Figure 3). These allowed giant fields to accumulate in Devonian-Carboniferous platformal and reefal carbonates, such as those hosting the massive Kashagan and Tengiz oil fields and the Karachaganak gas field (and the Astrakhan gas field in Russia). Kashagan has a STOIIP of perhaps 38 billion barrels (estimated up to ~13 billion barrels recoverable). The chief drawback is that the association of carbonate reservoirs with anhydrite in the seal has led to the development of high-sulphur hydrocarbons (e.g., around 19% H_2S in Kashagan). Occasional leakage through the seal has created a variety of Mesozoic fields within the Precaspian Basin, which though generally smaller than the sub-salt fields, tend to be low in sulphur.

Eastern Kazakhstan

The greater part of Kazakhstan lies east of the Aral Sea, and includes a number of diverse sedimentary basins (Figure 4 – but note that the basins of the Tien Shan range in the south, from Afghan-Tajik in the west to the Ili basins in the east, mostly belong to republics bordering Kazakhstan-Uzbekistan, Tajikistan and Kyrgyzstan). Field size and prospectivity are generally lower than in the West, but there are some large fields. These include Kumkol in the South Turgai Basin, with reported STOIIP in excess of 1 billion barrels, which together with similar fields nearby have a Jurassic reservoir, and trapping structures associated with the terminal splay of the long-lived regional strike-slip Talas-Fergana Fault (Moseley and Tsimmer, 2000). In contrast, the neighbouring Chu-Sarysu Basin hosts gas within Carboniferous reservoirs which developed on an extensive carbonate platform covering the West Kazakhstan Plateau. This carbonate system was the same age as that which rimmed the Precaspian Basin to the west, though it formed on the facing margin of the contemporary Uralian Ocean. Unfortunately, the absence of an equivalent to the oil-prone Domanik source rock, and less extensive seals, prevents Chu-Sarysu from being a Precaspian look-alike. However, outcrops of platform-margin deposits and associated reefs in the Bolshoi Karatau ridge, the uplifted southwestern edge of the Chu-Sarysu Basin, have been adopted as excellent surface analogues for the Precaspian reservoirs (e.g., Cook et al., 2002).

Each of the basins illustrated in Figure 4 has a distinct geological history, partly resulting from the complex plate-tectonic setting of the entire area, summarised in cartoon form in Figure 5. Many of these basins are, for various reasons, underexplored. There is no space to describe them all here, so one example has been selected, from the far east of Kazakhstan: the Zaisan Basin, straddling the border with China (Figure 4). It is described below.

The Zaisan Basin

Although lying geographically on the East Kazakhstan Plateau, geologically the Zaisan Basin is part of the Irtysh-Zaisan Belt associated with Mid-Carboniferous closure of the Ob-Zaisan ocean (Filippova et al., 2001), which led to collision of the Siberian and Kazakhstan continental terranes (Figure 5b). Part of the basin probably overlies crust with Siberian rather than Kazakh affinities. The basin is bounded in the north by the Altai and Kalby Mountains, and by the Saur-Tarbagatau Mountains in the south. The Chingiz-Tau Ridge separates the Zaisan Basin from the Junggar-Balkhash Zone of Central Kazakhstan. The basin is filled by Upper Cretaceous and Cenozoic continental deposits, over 1700 m thick (Figure 6), although hydrocarbons have been discovered within Palaeozoic (Lower Permian) basement. The centre of the basin is occupied by the freshwater Lake Zaisan.

The Zaisan Basin is divided into Northern, Central and Southern tectonic zones, each of which acted as a separate depocentre at different times. Deposition within the Southern Tectonic Zone occurred mainly during the Late Cretaceous and Eocene, in the Northern Zone during the Palaeocene, and in the Central Zone in the Eocene. Only since the Eocene has a substantial proportion of the basin, mainly towards the east, experienced uninterrupted deposition, probably in response to collision of the Indian continent to the south (Buslov, 2004). Deposition in the west began mainly during the Miocene. Lying within a tectonically unstable zone between the Kazakh and Siberian continental blocks and close to major strike-slip lineaments, the area has been subject to a series of tectonic adjustments caused by a variety of far-field and more proximal tectonic activity. Allen et al. (1995) consider that basin formation was initiated during the Late Permian to ?Early Triassic as an extensional structure within the broad sinistral shear zone. However, the precise sequence of tectonic events controlling the development of the various parts of the basin remains speculative.

Palaeozoic and Triassic Stratigraphy of the Zaisan Basin

The Palaeozoic underlying the Zaisan Basin includes Silurian and Devonian andesites and basalts overlain by Lower Carboniferous clastics and carbonates. Up to 2000 m of intermediate volcanic rocks accumulated within isolated troughs during the Mid-Carboniferous. These are presumably associated with volcanic arcs which developed as the Ob-Zaisan ocean closed.

The Late Carboniferous to the Late Triassic is represented by a mainly clastic succession divided into nine recognised formations approaching 5 km thick, although it is unlikely that this thickness was deposited in any one place. Sandstones, siltstones and claystones occur throughout, often with coals. The Lower Permian includes a unit of up to 720 m of grey sandstones and bituminous shales, and beds of limestone, marl, and gypsum occur higher in the Permian and into the Lower Triassic. A period of uplift and erosion occurred during the Mid-Triassic, and this was followed later in the Triassic by the onset of intense and deep weathering, which continued into the Early and, in places, the Late Cretaceous.

Cretaceous to Recent Stratigraphy of the Zaisan Basin

Upper Cretaceous and Cenozoic deposits crop out along the margins of the Zaisan Basin, where they are variably deformed and overlain by an impersistent Quaternary cover. They thicken into the basin centre, where they are less well-known. The best outcrops of these ages, up to 300-600 m thick, are observed within the foothills of the surrounding mountain belts. There is, however, no single locality where the entire succession has been penetrated by drilling, since deposition at any one time was concentrated in one or other of the depocentres.

Hydrocarbon Prospectivity of the Zaisan Basin

The prospectivity of the Zaisan Basin has been considered as moderately high, especially since the basin continues eastwards into China where oil is reported to have been encountered within Palaeozoic, Mesozoic, and Cenozoic horizons. Triassic oils in the Karamai field, for example, occur within a homoclinal structure sealed by an asphalt plug; fault sealing occurs at greater depth. The level of exploration within the Kazakh sector of the Zaisan Basin remains, however, fairly low.

Orudzheva and Obukhov (1988) state that oil shows occur in the Kenderlyk Sub-Basin in the southeast (Figure 6). Within the basin as a whole, two stratigraphic intervals are regarded as prospective. The older of these comprises the Upper Palaeozoic to Lower Mesozoic section. The TOC of the Upper Palaeozoic coals and bituminous shales is high in places, and the potential source rocks are reported to lie within the oil window. The younger prospective interval is the Cretaceous and Cenozoic, which is more widely developed.

The Central Tectonic Zone of the Zaisan Basin, and especially the Pre-Manrak and Pre-Saikan troughs, are regarded as prospective for oil. The Sarybulak Uplift occurs here at base-Cenozoic level. Khalimov et al. (1991) report that a stratigraphic well drilled to a depth of 4859 m on the Sarybulak structure, within the Central Tectonic Zone, discovered oil within the Permian in 1988. Testing over the 2960-2986 m interval within the Lower Permian yielded 2.3 m^3/day of highly viscous oil, high in tar but low in paraffins. This is reported to be similar to the oils found within the Chinese sector of the basin.

Geothermal studies indicate that the productive horizon has experienced temperatures of 130° C, over 60° C above the present temperature, which has been explained either by uplift and erosion, or by igneous activity. The accumulation is associated with a deep-rooted fault system, interpreted as indicating that it formed by upward migration of hydrocarbons from greater depth.

In summary, the Zaisan Basin holds a variety of potential reservoirs, especially within the Upper Palaeozoic to Lower Mesozoic and Upper Cretaceous to Pliocene sequences. Potential source rocks include the Lower Permian lacustrine shales and Triassic-Jurassic coal-bearing deposits. There appears to be an absence of regional seals, although local seals may be formed by intraformational lacustrine clays or evaporites.

The Zaisan Basin is described here simply as one example of the varied basins in Eastern Kazakhstan. The Republic as a whole offers geological opportunities for all players, from established supergiant fields in relatively mature provinces (drilling began in the Precaspian Basin late in the 19th century) to frontier exploration. The country inevitably presents numerous challenges, both for production and exploration, but some companies have already faced these risks and are being suitably rewarded.

Selected References

Allen, M.B., A.M. C. Sengör, and B.A. and Natal'in, 1995, Junggar, Turfan and Alakol basins as Late Permian to? Early Triassic extensional structures in a sinistral shear zone in the Altaid orogenic collage, Central Asia: Journal of the Geological Society, v. 152, p. 327-338.

Borovikov, L. I., and L.N. Krys'kov, 1963, Cambrian deposits in the Kendyktas mountains, Southern Kazakhstan [in Russian], *in* Material on the Geology and Natural Resources of Altai and Kazakhstan: Trudy VSEGEI, v. 94, p. 266-280.

Cook, H.E., V.G. Zhemchuzhnikov, W.G. Zempolich, et al. 2002, Devonian and Carboniferous carbonate platform facies in the Bolshoi Karatau, Southern Kazakhstan: Outcrop analogues for coeval carbonate oil and gas fields in the North Caspian Basin, Western Kazakhstan, *in* W.G. Zempolich and H.E. Cook, editors, Paleozoic Carbonates of the Commonwealth of Independent States (CIS): Subsurface Reservoirs and Outcrop Analogs: SEPM Special Publications, no. 74, p. 123-180.

Bakirov, A.B., and R.A. Maksumova, 2001, Tectonic evolution of the Tien-Shan lithosphere [in Russian]: Geology and Geophysics, v. 42/10.

Buslov, M.M., J. De Grave, and E.A. Bataleva, 2004, Cenozoic tectonics and geodynamic evolution of the Tien Shan mountain belt as response to India-Eurasia convergence: Himalayan Journal of Sciences, v. 2/4, p. 106-107.

Bykadorov, V.A.,V.A. Bush, O.A. Fedorenko, I.B. Filippova, et al., 2003, Ordovician-Permian palaeogeography of Central Eurasia: development of Palaeozoic petroleum-bearing basins: Journal of Petroleum Geology, v. 26/3, p. 325-350.

Filippova, I.B., V.A. Bush, and A.N. Didenko, 2001, Middle Palaeozoic subduction belts: The leading factor in the formation of the Central Asian fold-and-thrust belt: Russian Journal of Earth Sciences, v. 3/6, p. 405-426.

Khalimov, E.M., A.M. Silich, and A.N. Obukhov, 1991, Results of oil and gas exploration in the Zaisan Basin [in Russian]: Geologiya Nefti I Gaza, no. 10, p. 11-14.

Moseley, B.A. and V.A. Tsimmer, 2000, Evolution and hydrocarbon habitat of the South Turgai Basin, Kazakhstan: Petroleum Geoscience, v. 6, p. 125-136.

Orudzheva, D.S. and A.N. Obukhov, 1988, The Zaisan Basin [in Russian], *in* Tectonics, Formations and Hydrocarbons within Intermontane Basins: Nauka, Moscow, p. 92-103.

Windley, B.F., D. Alexeiev, W. Xiao, A. Kroner, and G. Badarch, 2007, Tectonic models for accretion of the Central Asian Orogenic Belt: Journal of the Geological Society, v. 164, p. 31-47.

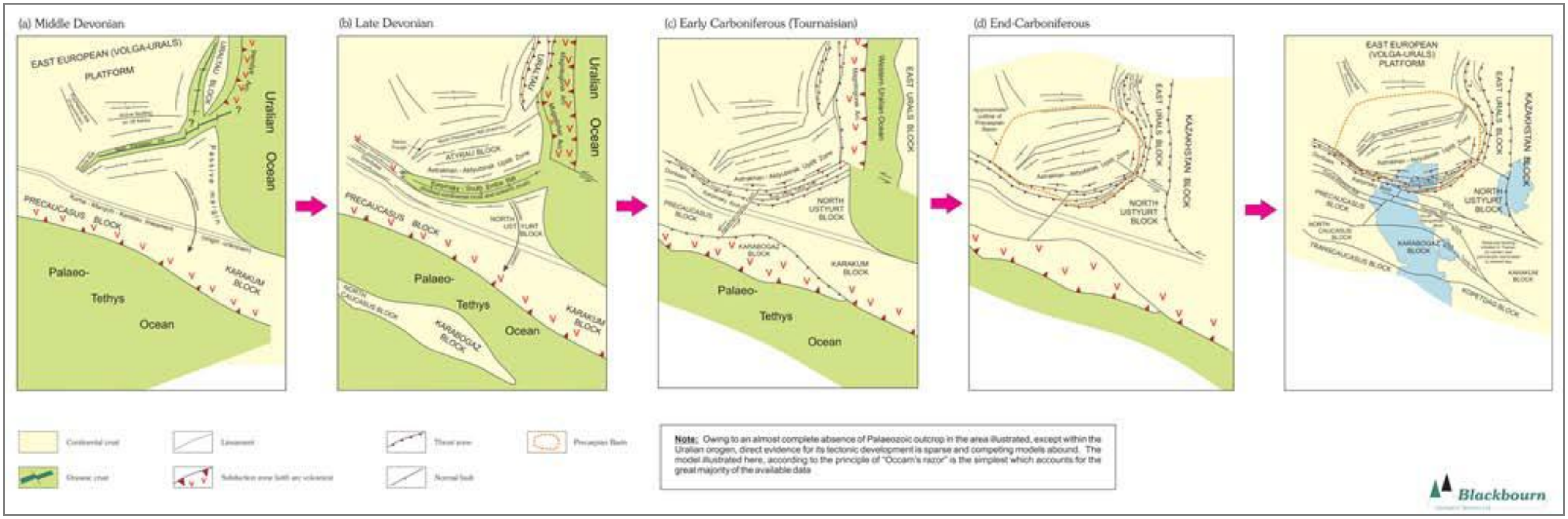

Figure 1. Simplified cartoon illustrating the formation of Western Kazakhstan and surrounding areas (part conjectural).

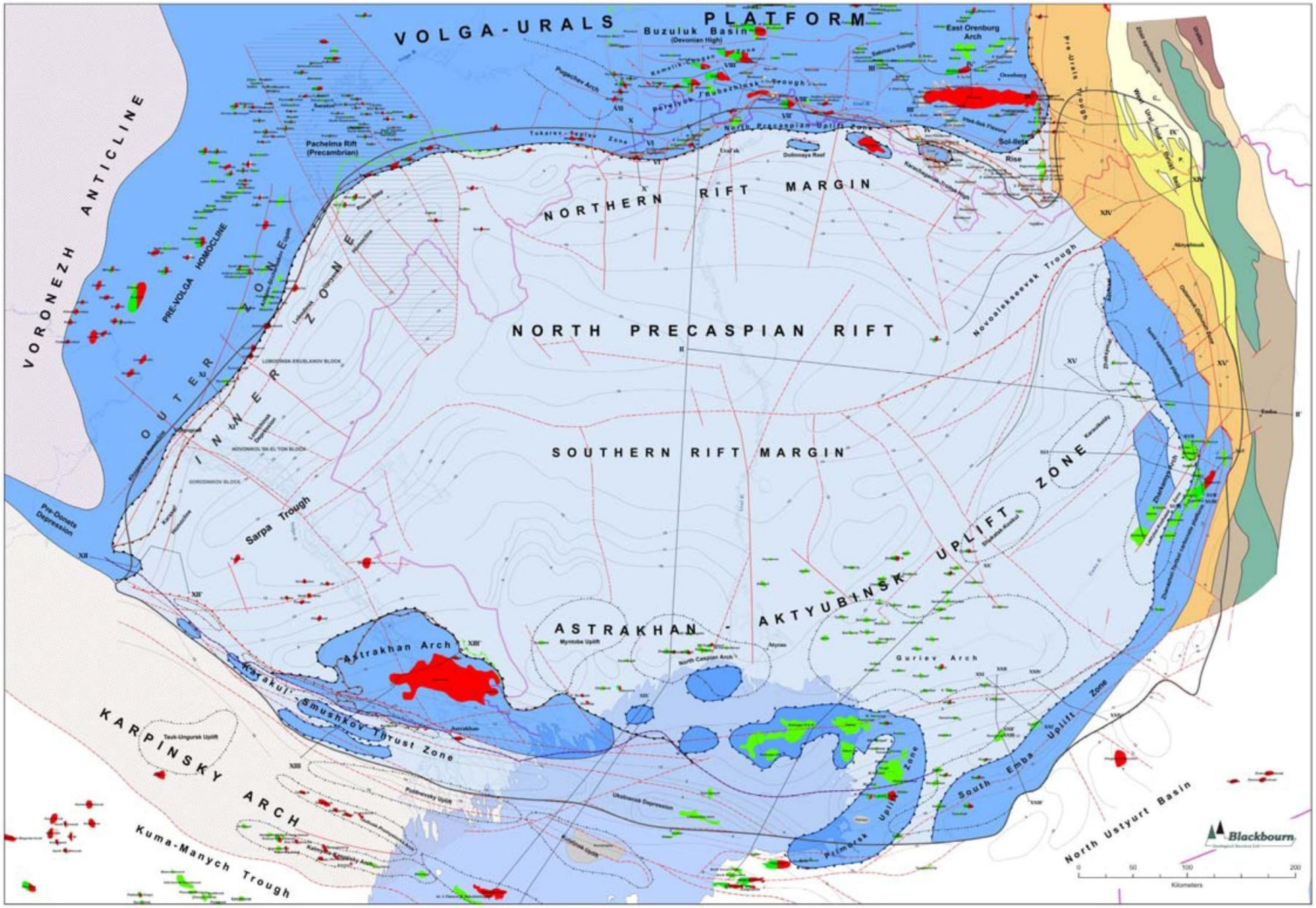

Figure 2. General map of structure, carbonate distribution, and nomenclature for the Precaspian Basin and surrounding areas. Location for south-north cross-section (I-I') in Figure 3.

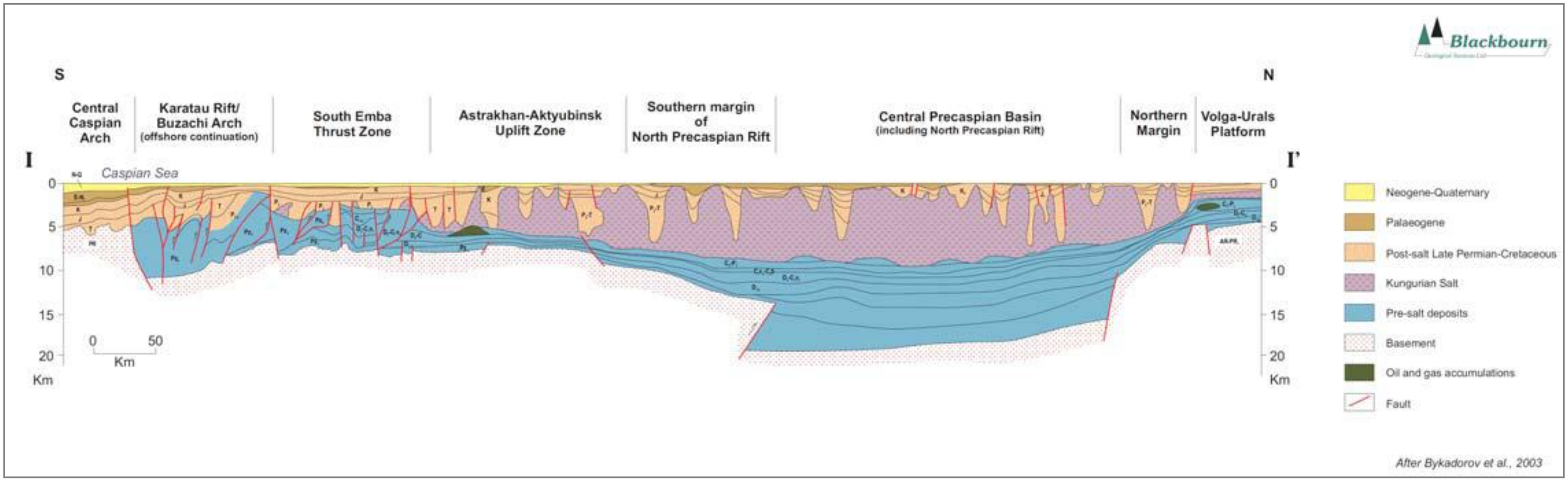

Figure 3. South-north cross-section through the Precaspian Basin, based on seismic data.

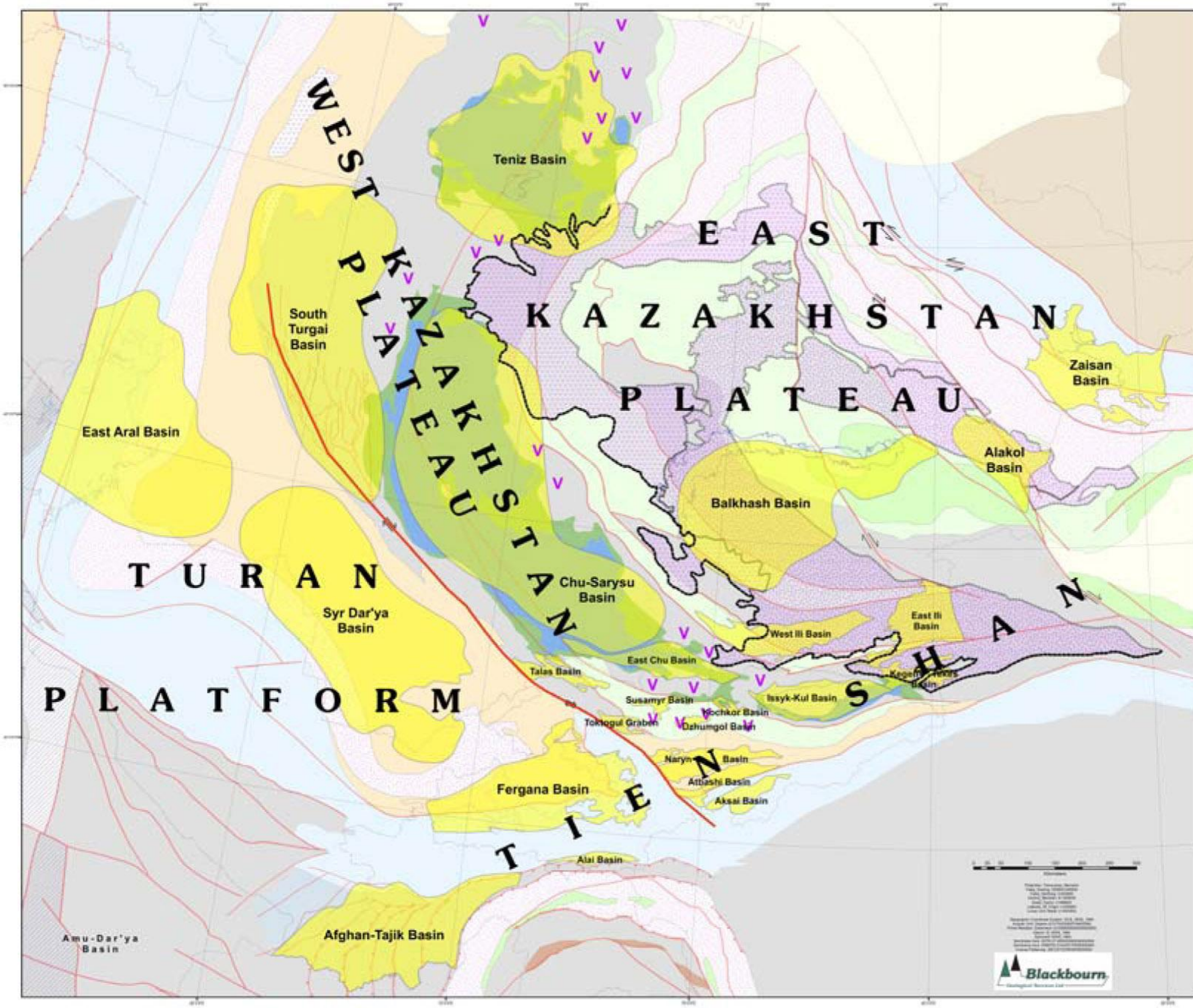

Figure 4. Location map of the known and prospective hydrocarbon basins of Southeast Central Asia.

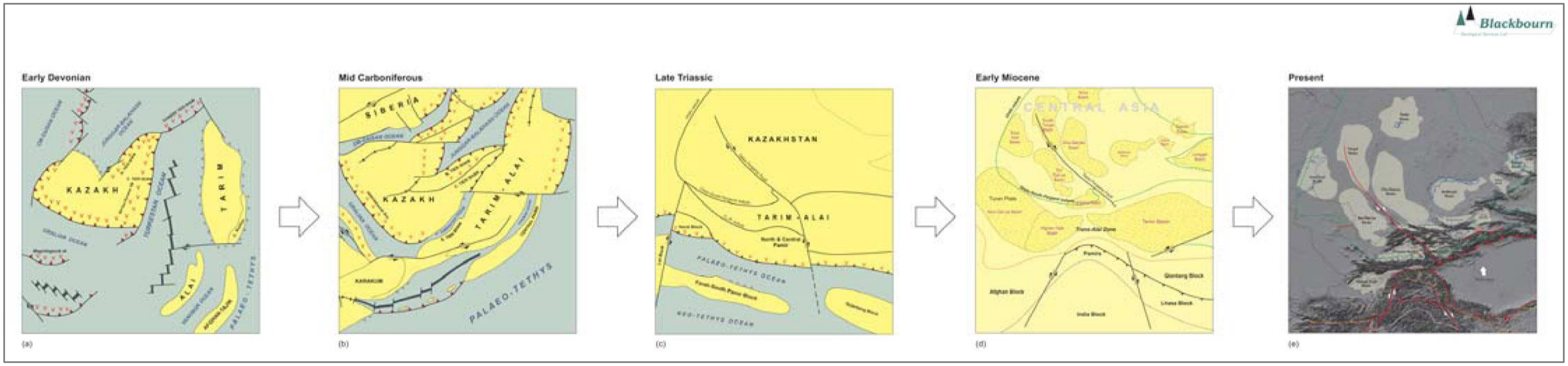

Figure 5. Simplified cartoon illustrating the formation of Eastern Kazakhstan and neighbouring areas of Central Asia (part conjectural).

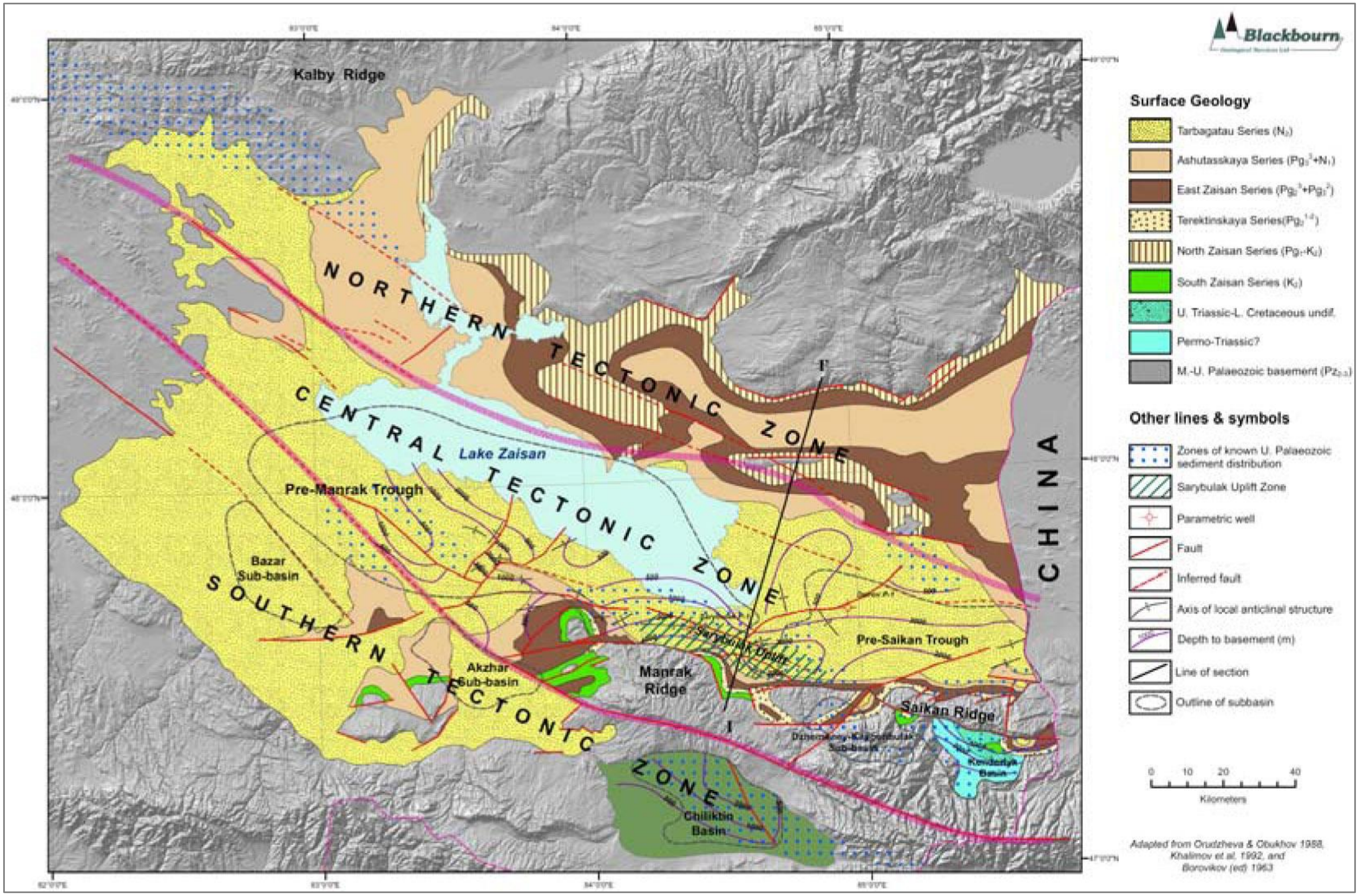

Figure 6. The Zaisan Basin: Outline map of the geology and structure.