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*UNLOCKING THE ASSETS: ENERGY AND THE FUTURE OF  
CENTRAL ASIA AND THE CAUCASUS*

GEOLOGY AND PETROLEUM POTENTIAL OF CENTRAL ASIA

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## Introduction

Central Asia, in particular the Caspian Sea area, is one of the oldest oil-producing regions in the world. Surface oil seeps in what is now Azerbaijan were known since 4 B.C., when Alexander the Great's soldiers used oil from shallow hand-dug wells (Abrams and Narimanov, 1997). The first oil well in history was drilled by a Russian engineer, F. N. Semyenov, in the Bibi-Eibat area of the Apsheron Peninsula in Azerbaijan in 1848 (Narimanov and Palaz, 1995). The first true offshore well was also drilled in Azerbaijan in 1924 from a wooden platform not far from Baku (Narimanov and Palaz, 1995).

Azerbaijan had the leading role in oil production in the former Soviet Union. Oil and gas exploration continues off the Azerbaijan coast and also in Kazakhstan and Turkmenistan. The discovery of large oil fields in the Caspian Sea and giant oil fields such as Tengiz and Karachaganak in Kazakhstan in the mid- and late 1980s showed that despite 150 years of oil production, the Central Asian region still contained significant amounts of oil and gas. It still does today.

In this study, we focus on the different geological basins located both directly within the Caspian Sea and in the surrounding areas. From the geological point of view, the territory of the Caspian Sea belongs to two different basins, the North Caspian and South Caspian (Figure 1). The Pricaspian Basin (alternative spelling, Precaspian) is another name for the North Caspian Basin. It includes the northern part of the Caspian Sea and the territory north of it, and is adjacent to the Volga-Ural province. The North Usturt Basin occupies the territory between the northern part of the Caspian Sea and the southern tip of the Ural mountain belt. The Mangyshlak Basin is located directly east of the Caspian Sea and south of North Usturt. The Amu-Darya Basin occupies eastern Turkmenistan and western Uzbekistan (Figure 1).

## The South Caspian Basin

The South Caspian geological basin contains the largest proven oil and gas resources in the Central Asian countries of the Caspian region. Azerbaijan, Kazakhstan, and

Turkmenistan have territory in the South Caspian Basin. Exploration activity in the basin started in the middle of the 19<sup>th</sup> century, and the geology of the basin is relatively well established.

The South Caspian Basin is 400 km across in the northwest-to-southeast direction and 900 m deep. It occupies the central part of a broader depression that includes the Kura Trough to the west and the coastal lowland of Turkmenia to the east. Two main folding ranges, the Great Caucasus and the Lesser Caucasus-Talesh-Elburz arc, surround the basin (Figure 1). The northern boundary of the basin is formed by the Apsheron-Balkanian sill, below which a periclinal termination of the Great Caucasus is buried. It can be traced to the eastern coast of the Caspian Sea to the Great Balkan Mountains, where Jurassic shales are exposed.

The South Caspian Sea basin is considered a Tertiary back-arc basin (Zonenshain & Le Pichon, 1986). The basin does not have a low-velocity crustal (granitic) layer. An oceanic-type crust underlies a sedimentary package 20 km thick. The relatively low geothermal gradient (about 1.5 ° C per 100 m) provides favorable conditions for the preservation of hydrocarbons at significant depths (up to 10 km).

Drilling on the South Caspian shelf in Azerbaijan and Turkmenistan revealed that thick (2,500-3,000 m) shallow-water sediments accumulated from the Late Jurassic to the Early Pliocene (Alikhanov, 1978). In Azerbaijan, shales and sandstones comprise most of the section, with flyshlike deposits found at two levels, in the Valanginian and Campanian-Maastrichtian. Tertiary deposits are represented by shales, including Eocene carbonate shales, carbonate-bituminous shales of the Maikopian suite (Oligocene-Lower Miocene), Middle and Upper Miocene shales and marles, and Meotian and Pont (Lower Pliocene) shales (Figure 2). This section of the Turkmenistan shelf consists mainly of basinal shale facies with local evaporites.

Significant change in sedimentation is observed in the Middle Pliocene with the accumulation of the oil-productive red suite. In Azerbaijan, these deposits lie transgressively on the Pont (Lower Pliocene) deposits. This oil-bearing suite is made of

sandstones and siltstone that are probably deltaic deposits of the paleo-Volga River (Alikhanov, 1978). The buried paleo-Volga valley of has been disclosed by seismic surveys in the central part of the Caspian Sea (Clarke, 1993). The thickness of the oil-productive suite varies from 1,500 to 3,500 m. It is overlapped by Upper Pliocene and Quaternary deposits up to 2,000 m thick (Figure 2). They comprise mainly clastics brought in by the Volga and small mountain rivers.

Seismic reflection profiles allow us to estimate the thickness of the units in the deeper parts of the basin where they have not been recovered by drilling (Figure 3). The reflector at the bottom of the Bakinian bed (Middle Pleistocene) is very distinct and can be traced across the basin. The thickness of the deposits overlying this bed varies from 0.5 km at the crest of anticlines to 2 km over synclines. The thickness of Upper Pliocene-Quaternary deposits over the oil-productive series varies between 3 and 6 km. The thickness of the oil-productive series is 5 to 6 km. The remaining 8 to 10 km of sediments are pre-Middle Pliocene.

Seismic profiles also show considerable deformation within the sedimentary package. A fold system that runs north/northwest-south/southeast and is 100 to 120 km wide occupies the western part of the South Caspian Sea basin. The folds are penetrated by numerous mud volcanoes.

Most of the known hydrocarbon fields in the South Caspian basin (Figure 4) are contained within siliclastic reservoirs within structural traps. Structural traps range from anticlinal folds to monoclines with various degree of reverse faulting and fracturing. Many structures are penetrated by mud diapirs and mud volcanoes. Most of the structures are located along clearly identifiable trends associated with underlying deep-seated faults that were inherited from the Mesozoic and reactivated during Cenozoic. Most hydrocarbons are located within fluvial-deltaic Middle Pliocene sediments (Productive series).

The Productive series can be subdivided into two distinct groups, early and late (Ruehlman, Abrams, & Narimanov, 1995). The early series is dominated by quartz and

minor sedimentary rock fragments typical of the Paleo-Volga province to the north. The late contains less quartz, more feldspar, and sedimentary and volcanic rock fragments more typical of sediments of Paleo-Kura in the west. Oil is also found in the Miocene Chokrak clastics and fractured Oligocene-Miocene Maikopian shales (Klosterman et al., 1997).

The unconsolidated nature of the Neogene sediments prevents extensive core recovery. By studying the sedimentary succession in the outcrops, it is possible to complement the core, well log, and seismic data (Reynolds et al., 1998). Traditionally, the Productive series is divided into a number of successions, or suites. The Kalin Suite is only known from subsurface samples and consists of coarse-grained sediments more than 300 m thick. The pre-Kirmaky Sand Suite lies directly over the Kalin Suite and is over 150 m thick. It has a thickness of 250-300 m and can be divided into a lower sand-prone unit and an upper argillaceous unit. The post-Kirmaky Suite is about 150 m thick, its base comprised of sandstone 35 m thick. The basal sandstone passes upward into a succession of gradually coarsening parasequences of mudstones, siltstones, and sandstones. The post-Kirmaky Clay Suite consists of mudstones and siltstones with thin sandstone beds. These rock types are arranged into stacked successions 9-15 m thick that coarsen toward the top (Reynolds et al., 1998). The Pereriva Suite is one of the most important producing intervals in the subsurface. It is particularly important in the Azeri, Chirag, and Guneshli fields, where its thickness is up to 110 m. Sandstones with conglomeratic sandstones at the base comprise the suite. Sandstones are characterized by poor sorting and giant cross-stratification indicating unidirectional southward paleocurrents. The rocks are interpreted as being deposited in a major fluvial or distributary channel system. The dramatic basal erosion surface is thought to reflect a major drop in base level and is considered a major sequence boundary.

The Balakhany Suite forms the main reservoirs of the fields located on the Apsheron Peninsula and is a major producing interval offshore. The sediments consist of fine-grained sandstone intervals and intervals of interbedded siltstone and sandstone. The Sabunchi Suite is an argillaceous succession over 190 m thick and characterized by decimeter-thick beds of mudstone, siltstone, and sandstone. The Surakhany Suite I is the

uppermost lithostratigraphic subdivision of the Productive series and typically consists of more than 400 m of mudstones, siltstones, and very thin, fine-grained sandstones.

## **The North Caspian (Pricaspian) Basin**

The North Caspian (Pricaspian) Basin is located on the southeastern margin of the Russian Platform and extends to the northern coast of the Caspian Sea (Figure 5). The topographic elevations are below sea level and can be as low as -24 m. Russia and Kazakhstan claim the territory within the North Caspian basin. A large part of the Russian Caspian shelf (southern part of the basin), however, is off limits for exploration because it is a sturgeon spawning ground.

The North Caspian is a pericratonic depression of the Late Proterozoic-Early Paleozoic age. It is bounded to the east by the Hercynian Ural Mountains and to the southeast and south by other orogenic belts. In the north, the basin is separated by the Voronezh Massif in the west and by the Volga-Urals Platform high in the north.

The North Caspian basin contains two supergiant fields, Tengiz and Karachaganak, and a large number of smaller fields. Tengiz and Karachaganak are isolated carbonate platforms (Figure 6) that consist of stacked sequences of Devonian-Middle Carboniferous and Devonian-Lower Permian carbonates, respectively (Cook, Zempolich, Zhemchuzhnikov, & Corboy, 1997).

The depth to reservoir of the Karachaganak, Tengiz, Astrakhan, and Zhanazhol fields varies from 3 to 5.2 km (Bagrintseva & Belozerova, 1990). The reservoirs qualify as shallow-water carbonate facies and reef buildups. The upper productive unit of the Zhanazhol field has a permeability up to 2 Darcies and a porosity of 25-28%. At Tengiz, the porosity is up to 18.6% for the pore-type reservoirs. The Karachaganak reservoirs are similar to those of Tengiz. Porosity varies from 7.5 to 18.7% and permeability varies from 1 to 98 md. The porosity of the Astrakhan field is 8-15% and permeability is 1-8 md. The complex facies architecture of the Tengiz and Karachaganak fields results in abrupt changes in porosity and permeability, a patchy distribution of reservoirs, and significant

thickness changes within the reservoirs. Many reservoirs have fractured or microfractured porosity. The bedded shallow-water carbonates of the Zhanazhol field display reservoir properties in the subsurface that are easier to predict. The intensive karstification in the upper part of the section caused the development of high-capacity cavity porosity.

Subsalt Paleozoic carbonates are widely distributed in the North Caspian depression and consist of Middle Devonian, Upper Devonian-Tournaisian, Upper Viséan-Lower Bashkirian, and Moscovian-Lower Permian sequences (Figure 8). The overall thickness is estimated at 1.7 km (Golov, Komissarova, & Nemtsov, 1990). Within the depression, carbonate platforms or banks occur on basement highs on the northern, eastern, and southern edges of the basin. An exception is the Devonian (Famennian)-"Middle" Carboniferous (Russian time scale) carbonate complex of the Karaton-Tengiz zone of highs that is located on the northern border of the Lower-Middle Paleozoic South Emba downwarp. The Paleozoic carbonate sequences are characterized by large, high relief (800-1,000 m) reefs or atolls that are reservoirs for Karachaganak, Kenkiyak, Zhanazhol, Tengiz, and possibly Astrakhan fields.

There is another ringlike belt of zones of probable hydrocarbon accumulation towards the interior of the basin (Golov et al., 1990). It is also most likely related to the large Paleozoic highs.

Most of the subsalt highs existed prior to the deposition of the Permian Kungurian salt. Maximum uplift movements were during the Late Carboniferous. The amplitudes were estimated as 300-400 m for the Karachaganak-Koblandin arch, about 500 m for the Yenbek and Zharkamys arches, 150-200 m for the Karaton-Tengiz zone of highs, and about 600 m for the Astrakhan arch.

The main hydrocarbon migration paths were updip from the more quickly subsiding parts of the depression. The reservoir fill occurred in multiple stages. First, the oil pools formed at the end of Paleozoic. Later, with further subsidence of the basin, gas was generated and entered oil-filled traps, changing the pools into gas-oil, gas-oil-condensate,

and gas. The northern, western and southwestern parts of the depression are gas prone, while the east and southeast are oil prone.

Field studies in the Karatau Mountains of Kazakhstan (Cook et al., 1997) describe rock sections that can be used as analogs for producing fields. They have defined several rock units.

The Frasnian and Famennian platforms (about 1,500 m thick) are reef-rimmed algal-stromatoporoid boundstones and rudstones. The platform interiors contain mud mounds, carbonate sands, cryptalgal laminites, and evaporitic laminites that are 10-100 m thick, and regionally extensive breccia that are 90 m thick. Basin margins contain carbonate turbidites and debris flow aprons. Tornasian carbonates up to 1,000 m thick form ramps of brachiopod-crinoid biostromes; ramp interiors have abundant tidal flat facies. Seaward ramp settings contain mud mounds 100 to 200 m thick and bioclastic turbidite aprons.

The Viséan and Serpukhovian platforms (up to 1,500 m thick) consist of slope mounds and grainstone-rimmed margins. The mounds consist of sponge-bryozoan-Tubiphytes-algae boundstone and cementstone (100-500 m thick); some mounds are interbedded with carbonate turbidite aprons. Grainstone-rimmed platform margins are characterized by cross-bedded ooidal-bioclastic sands, and platform interiors contain ooid, bioclastic, and phylloid algae sands and muddy facies. Bashkirian carbonate contain slope mounds of algae-brachiopod boundstone and cementstone (500 m) and platform margins and interiors of ooid, bioclastic, and phylloid algae sands.

## **The North Usturt Basin**

The North Usturt Basin has an area of 240,000 km<sup>2</sup> and is bounded on the north by the North Caspian Basin, on the northeast by the Mugodzar and Chelkar downwarps, on the east by the Aral-Kyzylkum zone of highs, and on the south by the Mangyshlak-Central Usturt system of highs (Figures 1, 9). On the west, the basin opens into the Caspian Sea.



Seismic data and drilling revealed folded basement in the North Usturt Basin covered by a package of sedimentary rocks up to 12 km thick. Several rock sequences have been defined within the sedimentary cover.

Carboniferous-Lower Permian carbonates and clastic rocks are found in the eastern part of the basin and are about 1,000 m thick. Lower Triassic redbeds and local volcanoclastics are 3,000 m thick on the Buzachi Peninsula. The section contains argillites within the redbeds that may serve as regional seals for lower reservoirs. The Middle Triassic section is mainly clastic with a thickness of up to 2 km. Two reservoirs with porosity up to 20% are present in the Kalamkas area. The Upper Triassic section is made of clastic rocks up to 600 m thick. They are similar to the Upper Triassic of the Prorva area of the North Caspian basin.

Overlying sediments have the following thickness: Jurassic , 150 m; Cretaceous, 2,500 m; Paleogene, 1200 m; and Neogene, 500 m.

The Triassic oil and gas play is composed of alternating sand-silt and clay beds 3 to 5 km thick. Sandstone reservoirs have up to 17% porosity and up to 30 md permeability. Oil has been found in the Triassic sediments in the Koltyk area.

The Middle-Upper Jurassic play is made of clays, argillites, siltstones, and sandstones with thickness varying from 200 to 1,000 m. Siltstone and sandstones form reservoirs and have 28-32% porosity and 1.5-2 darcies permeability. An Upper Jurassic clay-carbonate unit forms a seal. Commercial discoveries in the Jurassic have been made in the Karazhanbas, Severo-Buzachi, Kalamkas, Arman, Arystan, Karakuduk, Koltyk, Komsomol, and Vostochno-Karaturun fields.

The Lower Cretaceous (Neocomian) play is interbedded sands, silts, and clays that range in thickness from 150 to 850 m. The reservoirs are largely siltstones, and Aptian clays act as a seal. Commercial amounts of hydrocarbons have been discovered in the Karazhanbas, Severo-Buzachi, and Kalamkas fields.

The Eocene play is in the upper part of the Kuma Horizon and is represented by marls, siltstones, and clays. The reservoirs are siltstones that display porosity of 36% and 30 md permeability. The thickness is 10 to 30 m, and Eocene clays form the seal. Gas has been found in the five fields of the Chumyshty-Bazay group.

The distribution of reserves among the plays is the following: Middle-Upper Jurassic rocks contain over 60% of the oil and gas, Triassic rocks, 10%; the Lower Cretaceous section, 21%; and Eocene rocks, 8%.

## **The Mangyshlak Basin**

The Mangyshlak Basin (Figure 1) is located on the western part of the Turan epi-Paleozoic platform. Tectonic activity in the Riphean-Vendian era led to crustal tension and rifting, particularly the development of the Central Mangyshlak and Tuarkyr-Karaaudan rift systems (Murzagaliyev, 1996).

The Central Mangyshlak rift formed in Early Paleozoic time. Deep drilling showed that Paleozoic sediments consist of the Lower Permian and Carboniferous carbonate rocks and Upper and Middle Devonian and Lower Carboniferous clastics. The rift zone probably experienced some compression during pre-Permian times and then tension during the Late Permian and Early Triassic. The Mangyshlak and Usturt plates collided with the eastern European continent during the Early Cimmerian tectonic event. Tangential compression in the collision zone led to the formation of inversion highs with upthrust-overthrust activity. The result was a series of linear mega-anticlines and megasynclines. The rocks of the Permo-Triassic age are strongly deformed.

The Tuakyr-Karaaudan rift probably formed in the Early Paleozoic. Middle Paleozoic deposits are strongly deformed and contain basic and ultrabasic rocks of Devonian and Early Carboniferous age (Murzagaliyev, 1996). These ophiolites are probably fragments of older oceanic crust. They are overlain by red Permo-Triassic molasse composed of conglomerates and tuff and lava beds. The total thickness of the molasse is 4-5 km.

Exploration activity in the 1980s in the Mangyshlak Basin was aimed at Triassic and Jurassic rocks of the Zhetbay-Uzen structural step and Triassic rocks of the Peschanomys-Rakushech, Karadin, and Zhazgurlin tectonic zones of South Mangyshlak. Exploration targets were mainly anticlinal structures identified on seismic. Despite years of exploration in the central part of the south Mangyshlak basin, no significant hydrocarbon discoveries have been made. Exploration activity since 1990 has been targeting the Upper and Middle Triassic in the eastern part of the Sedendyk depression and the northern part of the Karagin saddle (Popkov, Rabinovich, & Timurziyev, 1992). Paleozoic rocks also may contain oil. A commercial discovery was made in Paleozoic reservoir rocks in the Oymash area. Other areas of the basin, such as the eastern Mangyshlak, the Uchkuduk depression, Buzuchi Peninsula, and the continuation of the Mangyshlak basin off the Caspian shore, have not been explored for oil and gas. Exploration in the eastern Mangyshlak and South Usturt has been disappointing; only one gas field (Kansuy) was discovered. Thick Jurassic and Cretaceous reservoirs and seals are disrupted at the crests of anticlines; the Triassic section is also strongly deformed.

Recent seismic surveys showed a connection between the Uchkuduk depression and the Zhazgurli depression of the southern Mangyshlak. This suggests that the Uchkuduk depression contains Middle and Upper Triassic oil and gas reservoirs similar to those in the southern Mangyshlak (Popkov et al., 1992).

There is an increasing amount of interest in the northern part of the Buzuchi Peninsula and offshore on the Caspian Sea shelf. Seismic surveys demonstrate that many onshore structures on the Buzuchi Peninsula extend into the Caspian Sea. A large, favorable structure of the Jurassic-Cretaceous age has been identified north of the Kalamkas anticlinal zone and west of Karazhanbas (Popkov et al., 1992).

## **The Amu-Darya Basin**

The Amu-Darya Basin extends over an area of 370,000 km<sup>2</sup> of eastern Turkmenistan and western Uzbekistan; another 57,000 km<sup>2</sup> are situated in neighboring countries, in particular northern Afganistan (Figures 1, 10). The southwestern border lies at the base of

the Kopet Dag, an Alpine mountain range. The Amu-Darya Basin lies within the Turanian plate, a feature that extends into the Caspian Sea and farther west into Europe as the Scythian platform. On the north, the basin is connected with the West Siberian platform through the Turgay depression.

The sedimentary section of the Amu-Darya Basin consists of Lower and Middle Jurassic coal-bearing clastics; Callovian-Oxfordian carbonates, including reef facies and Kimmeridgian and Tithonian carbonates and evaporites; Lower and Upper Cretaceous clastics; and Paleogene carbonates and clastics (Clarke, 1994). This section is commonly referred to as intermediate complex, and its thickness can be up to 10 km.

The Amu-Darya Basin has a complex tectonic structure (Figure 10). The Bukhara structural step occupies the extreme northeast of the basin and has a blocky shape created by large uplifts. The Permian-Triassic intermediate-complex rocks are absent here, as is the Kimmeridgian salt. The Chardzhou structural step also has a blocky shape as a result of the intersection of a northwest-trending Hercynian structure in the basement and a northeast-trending Alpine structure. Southeast of the Chardzou step is the Beshkent downwarp, where the thickness of the sedimentary is 6 km. It is bounded on the east by a system of overthrusts of the southeastern spurs of the Gissar Mountains.

The Khiva downwarp has a 4 to 5 km thick sedimentary rock cover, beneath which lies a graben filled with 3 km of Permian-Triassic deposits. The Beurdeshik structural step is located to the west of the Khiva downwarp and is a transitional feature to the Central Kara Kum arch farther west. This arch is interpreted as a microplate caught up in the Hercynian orogenic belt (Clarke, 1994).

The Malay-Bagadzha saddle is a structural high located between the Zaungiz downwarp on the west and the Karabekaul downwarp on the east. All three features are characterized by large uplifts. The Vostochno-Unguz zone of highs is a segment of the north-south Ural-Oman tectonic zone, a system of faults beneath which lie horsts and grabens. The central part of this system is the Aral-Murgab zone of rifts, which is more than 1,000 km long. The Rapetek arch is a narrow zone 12-15 km wide that extends 450

km across the Amu-Darya Basin and is associated with the Repetek-Kelif regional fault. Domes of Jurassic salts form the cores of anticlines located along this arch. In places, salt has reached the surface.

The Mary-Serakh zone of highs and the Uch-Adzhi arch are separated by the Bayram-Ali arch. These three structural elements are sometimes united into the Mary-Uch-Adzhi monocline, which dips southward and forms the north flank of the Murgab depression, a structural zone that also includes the Sandykachi zone of downwarps and the Severo-Karabil downwarps. The Badhyz-Karabil zone of highs is located immediately to the south. It is followed by the Kalaimor downwarp, which is largely in Afghanistan.

The Murgab depression occupies the space between the Repetek-Kelif regional fault on the north and the Badkhuz-Karabil zone on the south. The Bakhardok monocline south of the Central Kara Kum arch is a transitional feature that dips south into the Cis-Kopet Dag foredeep.

More than 130 gas, gas-condensate, and oil fields have been discovered in the Amu-Darya Basin. Of these, 60% are in western Uzbekistan and 40% in eastern Turkmenistan. There are three regional plays: Lower-Middle Jurassic clastic, Upper Jurassic carbonate, and Lower Cretaceous carbonate-clastic. There are also two local plays: Upper Cretaceous carbonate-clastic and Paleogene carbonate.

The Lower-Middle Jurassic play consists of sandstones, siltstones, argillites, and thin coal beds. Their thickness varies from 100 to 400 m. The reservoirs are not continuous and in general have low porosity. Seals are localized and are not favorable for large hydrocarbon accumulations. Fifteen gas and gas-condensate pools have been discovered on the Bukhara, Chardzhou, and Beurdeshek structural steps, and some oil pools have been found in this part of the section. This play is assessed as containing 15% of the undiscovered resources of the province and essentially is unexplored.

The Upper Jurassic play is made of limestones with a wide range of porosity and permeability. The thickness of the pay zones varies from 10 to 60 m. The thick Kimmeridgian evaporites form the seal. Beyond the margins of the evaporite,

argillaceous rocks act as seal, or in their absence, the hydrocarbons have migrated upward to form pools in the Cretaceous or to escape entrapment. Gas fields have been found on the Beurdeshik, Khiva, Zaunguz, and Chardzhou structural features. This play is assessed as carrying 56% of the undiscovered petroleum resources of the province.

The Lower Cretaceous-Cenomanian play includes carbonate-clastic deposits of the Neocomian-lower Aptian and predominantly clastic deposits of the upper Aptian, Albian, and Cenomanian. The section consists largely of sandstone 20-60 m thick, rare carbonates, and clays 10-200 m thick. Total thickness of the sedimentary package ranges from 700 to 1,600 m. A regional seal for this play is an upper Albian clay unit 100-130 m thick. In the central part of the basin, the Shatlyk Horizon of the upper part of the Hautervian Stage carries 90% of this play's discovered gas. The reservoir rock is a red sandstone that has good porosity and permeability. The reservoir beds of the hydrodynamically sealed, supergiant Dauletabad-Donmez gas field belong to the Shatlyk Horizon. This play hosts more than 50% of the discovered gas of the basin and 20% of the undiscovered petroleum resources.

A few small discoveries have been made in the Upper Cretaceous play of the Bukhara tectonic step and Central Kara Kum arch. Small pools have been found in Maastrichtian limestones in the Badkhyz-Karabil zone of highs. Four thin pays zone are recognized in the Upper Cretaceous of the Central Kara Kum arch in the Cenomanian and Turonian stages. They consist of fine-grained sandstones. Very large pools are present in the Upper Cretaceous in the Gazli field. Two gas-bearing horizons in the Cenomanian rocks contain 70% of the reserves of the field.

Small amounts of oil have been found in carbonates of the Paleogene play in the Karabil field of the Badkhyz-Karabil zone of highs. Reservoirs are both carbonates and sandstones, and the seal is an Eocene clay. The play is assessed to contain less than 10% of the undiscovered petroleum resources of the basin.

The Amu-Darya Basin is gas prone. Oil is found only as small pools in the Chardzhou and Bukhara gas-oil regions. Of the total assessed hydrocarbon resources in the basin, 4% is oil, and 96% is gas. The same ratio is assumed for the undiscovered resources.

The Yashlag area in the central part of the Murgab region is the most promising area for oil and gas exploration. The Late Jurassic basin here has adequate source beds and similar conditions to those of the northern basin's margin, where the Kukdumalak field has been discovered. O'Connor and Sonnenberg (1991) assess the undiscovered resources of this area at 120 trillion ft<sup>3</sup> of gas, 7 billion barrels of condensate, and 3-4 billion barrels of oil.

The northern part of the Chardzhou structural step potentially contains structural traps. Here the Lower Cretaceous deposits rest on an erosional surface above the Kimmeridgian-Tithonian beds. Facies changes and pinch-outs could be acting as potential reservoirs that trapped hydrocarbons migrating from deeper parts of the Jurassic basin of deposition.

There are a number of undrilled structures in the Bakhardok monocline and northern margin of the Cis-Kipet Dag foredeep. Three main plays are recognized here: Oxfordian, Tithonian, and Valanginian, with Tithonian being the most promising. The Lower-Middle Jurassic, Triassic, Permian, and Carboniferous section also may contain commercial amounts of hydrocarbons. New discoveries are also possible in the Mesozoic section in the Central Kara Kum arch despite the mature stage of exploration in the area. Southeastern Turkmenistan may contain significant gas and condensate reserves in the Upper Jurassic, both below and above the Upper Jurassic evaporite in the Murgab region.

According to the report by Ulmishek and Masters (1993), the entire Amu-Darya Basin contains 0.7 billion barrels of oil in identified reserves and 3 billion in undiscovered reserves. For gas, the cumulative production is 86 trillion ft<sup>3</sup>; identified reserves are 200 trillion, and undiscovered reserves are assessed at 75 trillion. Seventy-five percent of these gas reserves are found in Turkmenistan, and 25% in Uzbekistan.

## Comparison of the Caspian Region Oil and Gas Reserves to the World Hydrocarbon Reserves

Fossil fuels have been an inexpensive energy source for the entire 20<sup>th</sup> century. Crude oil is now the source of 38% of the world energy. Coal and natural gas provide 25% and 22% of world energy, respectively. All three fossil fuels (oil, gas, and coal) are nonrenewable resources and have been created through geologic time from solar energy.

The estimates of the world ultimate crude oil recovery range from 1,650 to 3,200 billion barrels, with most of the estimates between 2 and 3 trillion barrels (Edwards, 1997). According to the study by Petroconsultants (Marbo, 1996), the world is running out of cheap oil. The midpoint of world oil production is estimated to be around the year 2000. The world will then face a shortfall in supply and a permanent increase in the price of oil. By 2050 world oil production will be down to the 1950 level of 18 million barrels a day (Marbo, 1996).

Estimated world crude oil reserves were 1111 billion barrels of oil on January 1, 1994 (Energy Information Administration, 1995). World Oil (1997) estimated proven world total oil reserves at the end of 1996 at 1,160,102.6 million barrels. About 300 billion barrels of these reserves are suspect, added principally by Middle East OPEC producers from 1987 to 1990 to justify their production quotas (Ivanhoe, 1995). Future discoveries of oil are forecast at 1,005 billion barrels. World estimated ultimate recoverable conventional crude resources are the sum of cumulative production (720 billion barrels of oil), reserves (1,111 billion), and future discoveries and field growth (1,005 billion), totaling 2,836 billion barrels of oil.

World natural gas reserves are estimated to be 90 billion barrels, and estimated undiscovered natural gas liquids are estimated at 102 billion barrels (Masters, Root, & Attanasi, 1994). Gas is converted to oil equivalent using 6,000 ft<sup>3</sup> per barrel. World Oil (1997) estimated world proven natural gas reserves at 5,177,178.9 billion ft<sup>3</sup>.

The goal of Table 1 is to give a basic overview where the energy resources are located in the Central Asian republics. It was compiled from different studies of the amount of gas



and oil found in these nations. The majority of the data comes from Wood MacKenzie, a private consulting firm based in Scotland, while other sources are U. S. government studies and International Energy Agency reports. Each country is divided into either areas or geological basins (both indicated in bold type) or major fields. The estimated proven columns denote the remaining reserves that have been discovered, while the estimated possible columns show the amount of potential resources, including both the proven and the undiscovered. The total range of estimates for each country coming from different sources is listed in Table 2. As these ranges demonstrate, it is difficult to get an exact number for the amount of oil and gas reserves in Central Asia, but one can see the scale of resources that are available. Kazakhstan and Azerbaijan have the potential to become world suppliers of both oil and gas, and Turkmenistan has extensive gas resources .

The daily production figures of the Central Asia countries in 1995 are given in the Table 3. Azerbaijan had the largest production (183,000 barrels a day), and Uzbekistan was in the second place with 162,000 barrels a day. Kazakhstan was producing 128,000 barrels a day in 1995. Turkmenistan's daily production in 1995 equaled 79,000 barrels a day. Georgia, Kyrgystan, and Tajikistan were producing very small amounts of oil (less than 4,000 barrels a day). Combined daily production of the Central Asia region in 1995 was 560,000 barrels a day. Wood MacKenzie (1998) estimated combined current oil and condensate production in the region at 800,000 barrels a day. They also predict a fourfold increase in production to 3.1 million b/d by 2020. The forecast assumes the discovery of three Tengiz-size oil fields off the shore of Kazakhstan between 2000 and 2010 and one large offshore discovery in Turkmenistan.

Table 4 contains data on the proven oil and gas reserves by country reported by World Oil (1997) and data on the reserves of Azerbaijan, Kazakhstan, Turkmenistan, and Uzbekistan from this report. We took the highest estimates from the range of the proven resources for each country and compared them to the reserves of other countries with the proven oil and gas reserves exceeding 1 billion barrels of oil. The first two column represents ranking of countries in the descending order based on the amount of oil reserves. It is clear that Kazakhstan and Azerbaijan contain significantly larger amounts of oil than Turkmenistan and Uzbekistan, whose reserves do not exceed 1 billion barrels

of oil. Out of the four Central Asia countries, Kazakhstan has the oil reserves (22 billion barrels) that come closest to those of such countries as Norway (about 27 billion barrels), Libya (23.5 billion barrels), the United States (22 billion barrels), and Nigeria (about 21 billion barrels). It is interesting that even if we take the lowest estimate of the reserves (10 billion), Kazakhstan will still retain its place in the table, yielding only to Algeria with approximately 13 billion barrels of oil. Azerbaijan's oil reserves (6.5 billion barrels) put it in between Brazil (about 7 billion barrels) and Canada (5.5 billion barrels). Azerbaijan's oil reserves are also close to the estimated proven oil reserves of Malaysia (5.1 billion barrels), India (5 billion barrels), and the U.K. (5 billion barrels). The lower end estimate of Azerbaijan's proven oil is 3.6 billion barrels of oil. In this case, Azerbaijan's reserves are compatible with those of Egypt (3.7 billion), Australia (3.7 billion), Oman (3.6 billion), and Colombia (3.5 billion). It could be also compared to the reserves of Angola, but the reported reserves of Angola (3.6 billion barrels) do not reflect the string of billion-barrel discoveries offshore in 1997 that make Angola's reserves significantly larger.

The third and fourth columns of Table 4 show the ranking of the countries in descending order based upon the proven gas reserves. Turkmenistan has the largest amount of gas reserves out of the four Central Asia countries evaluated in this study. Turkmenistan's gas reserves are estimated at 93 to 155 trillion ft<sup>3</sup> of gas, which places Turkmenistan in between the U.S. (167 trillion) and Venezuela (142 trillion). Uzbekistan also contains significant gas reserves (70 to 106 trillion ft<sup>3</sup>). This number puts Uzbekistan in between Nigeria (110 trillion ft<sup>3</sup>) and Australia (83.5 trillion). Kazakhstan's highest estimated value of proven gas reserves is 83 trillion ft<sup>3</sup>, which puts Kazakhstan close to Australia (83.5 trillion) and Malaysia (79 trillion). Azerbaijan (16.5 trillion ft<sup>3</sup>) has significantly lower gas reserves. Azerbaijan's gas reserves are close to those of Yemen (17 trillion) and Brunei (13.5 trillion).

Table 5 summarizes the world distribution of hydrocarbons by region. The regions are ranked in the descending order, and the highest estimated values of proven reserves were used for Central Asia. The total proven oil and condensate reserves of Central Asia estimated in this study varies from 15 to 31 billion barrels, and the highest value is close

to the total amount of reserves of Western Europe (34 billion). However, Central Asian oil reserves are one twentieth of those of Middle Eastern countries and one fifth of the oil reserves of Eastern Europe ( which includes Russia). Central Asian gas reserves are in third place if we use the highest estimates for Central Asia (360 trillion ft<sup>3</sup> of gas). This number is close to the reserves of Africa (344 trillion ft<sup>3</sup> of gas). Gas reserves of Central Asia approximately equal one fifth of the gas reserves of Eastern Europe (which includes Russia) or the Middle East, and represent almost 7% of the world's total.

## Conclusions

The Central Asian region includes a number of petroleum basins that are different in their geological development, reservoir types, hydrocarbon types, and quantity of resources. The South Caspian, North Caspian (Pricaspian), North Usturt, Mangyshlak, and Amu-Darya geological basins contain hydrocarbon reservoirs. The territory of Azerbaijan includes part of the South Caspian basin. Kazakhstan's territory contains a part of the South Caspian and almost all of the North Caspian, Mangyshlak, and North Usturt basins. Turkmenistan's territory includes a part of the South Caspian basin and Amu-Darya. Uzbekistan's territory contains a large part of the Amu-Darya basin.

The South Caspian is a mature exploration basin with over 150 years of development. However, large known oil and gas fields are in the Caspian offshore (Guneshli, Chirag, Kyapaz) awaiting development. Detailed seismic surveying of the deeper parts of the Caspian offshore may reveal new untested structures that contain commercial quantities of hydrocarbons. At the moment, most of the Turkmenistan Caspian shelf, with more than 40 untested structures, remains relatively undrilled. Turkmenistan is also disputing the Kyapaz field, which was discovered by Azerbaijan. A number of exploration blocks were offered for bidding in September 1997. Turkmenistan postulates undiscovered reserves on its Caspian shelf at 3 billion metric tons (22 billion bbl) of oil and 4.8 trillion cubic meters (168 tcf) of gas.

The northern Caspian and northwestern Kazakhstan are also areas with large amounts of proven reserves and high potential for new discoveries. Almost three quarters of all the

Kazakhstan reserves are in two supergiant fields—the Tengiz (oil) and Karachaganak (gas). The recoverable reserves of Tengiz have been recently updated to 12 billion barrels of oil with an estimated 25 billion barrels of oil in place. Most of the fields in the northern part of the basin, such as Karachaganak, contain mostly gas with a small amount of oil.

The North Usturt and Amu-Darya basins have some potential in oil and gas exploration. Seismic surveys and extensive exploration programs are expected to reveal potential drilling targets. The Amu-Darya Basin contains mainly gas reserves with a minor amount of oil.

Kazakhstan is a leader among the Central Asian countries in the amount of proven reserves and the potential for new findings. It has 10 to 22 billion barrels of proven crude reserves and 53 to 83 trillion ft<sup>3</sup> of gas. Kazakhstan's territory is the largest among the Central Asia countries and contains four different geological basins. Those basins remain largely unexplored even though current exploration activity is high.

Azerbaijan has the second largest reserves among the Central Asian countries. It is a mature oil and gas country and will remain an important producer for decades. The new large discoveries, if made, would be confined to the deep water in the Caspian offshore.

Turkmenistan has large gas reserves (95 to 155 trillion ft<sup>3</sup> of gas). A large territory of Turkmenistan remains unexplored. It is quite possible that important discoveries will be made onshore and offshore in the part of the South Caspian basin that belongs to Turkmenistan.

Uzbekistan does not have a significant amount of oil but contains large amounts of gas (70 to 105 trillion ft<sup>3</sup>). It also has a large territory that has not been well explored for oil and gas.

The total proven oil reserves of the Central Asian countries were estimated in this study as ranging from 15 to 31 billion barrels, and proven gas reserves estimates vary from 230

to 360 trillion ft<sup>3</sup> of gas (Table 2). Central Asian reserves represent approximately 2.7% of the world total proven oil reserves and 7% of the world gas reserves.

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