Assessment of Undiscovered Technically Recoverable Conventional Petroleum Resources of Northern Afghanistan

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ABSTRACT

Using a geology-based assessment methodology, the U.S. Geological Survey–Afghanistan Ministry of Mines and Industry Joint Oil and Gas Resource Assessment Team estimated mean volumes of undiscovered petroleum in northern Afghanistan; the resulting estimates are 1.6 billion barrels (0.2 billion metric tons) of crude oil, 16 trillion cubic feet (0.4 trillion cubic meters) of natural gas, and 0.5 billion barrels (0.8 billion metric tons) of natural gas liquids. Most of the undiscovered crude oil is in the Afghan-Tajik Basin and most of the undiscovered natural gas is in the Amu Darya Basin.

Four total petroleum systems were identified, and these were subdivided into eight assessment units for the purpose of this resource assessment. The area with the greatest potential for undiscovered natural gas accumulations is in Upper Jurassic carbonate and reef reservoirs beneath an impermeable salt layer in relatively unexplored parts of northern Afghanistan. The Afghan-Tajik Basin has the greatest potential for undiscovered crude oil accumulations, and these are potentially in Cretaceous to Paleogene carbonate reservoir rocks associated with thrust faulting and folding.

INTRODUCTION

Crude oil, natural gas, and natural gas liquids/condensate (collectively called "petroleum") resources are important for the redevelopment of Afghanistan's infrastructure. One of the results of more than two decades of strife in Afghanistan is a shortage or absence of energy required to improve living conditions. Food, clothing, shelter, heat, sanitation, and industry, in general, depend on the availability of energy. The presence of petroleum resources has long been known in Afghanistan but these resources were exploited only to a limited extent. Improved living and economic conditions in Afghanistan require increasing the availability of energy, particularly by exploitation of Afghanistan's petroleum resources.

The U.S. Geological Survey (USGS) cooperated with the Afghanistan Ministry of Mines and Industry to assess the potentially undiscovered technically recoverable conventional petroleum resources of Afghanistan. Funding for this effort was provided by the U.S. Trade and Development Agency.

The assessment is based on the geologic elements of a total petroleum system, which include (1) source-rock presence, maturation, petroleum generation, and migration; (2) distribution and quality of reservoir rocks; and (3) character of traps and time of formation with respect to petroleum migration. Data from detailed studies of geochemistry, petroleum geology, geophysics, and tectonics combined with historical exploration and production analyses were used to aid in the estimation of the number and sizes of undiscovered petroleum accumulations.

Much of the petroleum resource potential of Afghanistan and all of the known crude oil and natural gas reserves are in northern Afghanistan, located in parts of two petroliferous geologic basins — the Amu Darya Basin to the west and the Afghan-Tajik Basin to the east (fig. 1). In addition to previous exploration, this study shows that potential still exists for additional crude oil and natural gas discoveries in northern Afghanistan.

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TRANSLITERATION

Most geographical and geological names for northern Afghanistan were transliterated directly from Dari to English by geologists with the Afghanistan Ministry of Mines and

Industry and used in this report. Geographical and geological names for neighboring Turkmenistan, Uzbekistan, and Tajikistan used in this report are transliterations from Russian. Some obvious discrepancies in the spelling of names among countries are observed in this report. For example, the word for pilgrim is spelled “Khoja” for Afghanistan, but spelled “Khodzha” for Turkmenistan, Uzbekistan, and Tajikistan.

REGIONAL GEOLOGY

The Amu Darya and the Afghan-Tajik Basins are located in desert and semi-desert areas of Turkmenistan, southwest Uzbekistan, southeastern Tajikistan, and northern Afghanistan (fig. 1) (Ulmishek, 2004). The two basins encompass approximately 87,000 square kilometers (34,000 square miles) in those portions that lie within Afghanistan. The Amu Darya Basin is west of the Afghan-Tajik Basin, and they are separated from one another by the southern subsurface extension of the Southwestern Gissar meganticline and spur. The Amu Darya and the Afghan-Tajik Basins occupy a narrow zone between the Amu Darya River to the north and west, the Alburz-Marmul fault, North Afghan High, and Bande Turkestan Range to the south. The east boundary is the Hindu Kush and Badakhshan.

Northern Afghanistan has pre-Jurassic basement unconformably overlain by Jurassic to Paleogene oil- and gas-bearing terrigenous and carbonate rocks, which in turn are unconformably overlain by Neogene orogenic continental clastics (Kulakov, 1979;

Brookfield and Hashmat, 2001). Many minor unconformities represent erosion during orogenies in adjacent folded regions (Kulakov, 1979).

The Afghan-Tajik Basin and the Amu Darya Basin formed a single Mesozoic to Paleogene sedimentary basin that existed until Neogene time (Ulmishek, 2004). Collision of the Indian plate with the Eurasian plate at that time uplifted the southern portion of the basin and divided the northern portion into the Amu Darya and Afghan-Tajik Basins. Pre-Neogene basin history and stratigraphy of the Amu Darya and Afghan-Tajik Basins are similar, consisting of (1) Paleozoic to Triassic basement complex, (2) Jurassic to Paleogene sedimentary cover, and (3) Neogene to Holocene orogenic clastics (Orudzheva and Kornenko, 1991; Dastyar and others, 1990; VNIGNI, 2005a) (fig. 2).

The basement in both basins comprises peneplaned fold structures composed of continental and oceanic blocks accreted during Late Paleozoic tectonism (Dastyar and others, 1990) and consist of intensely deformed and partially metamorphosed sedimentary rocks at depths of 4 to 16 kilometers (Kulakov, 1979; Orudzheva and Kornenko, 1991). A Permian to Triassic transitional complex, up to 2,500 meters thick, overlies the pre-Permian section (Orudzheva and Kornenko, 1991). Undifferentiated Permian and Triassic marine carbonate and clastic rocks that pass into redbeds fill grabens in the basement (Kulakov, 1979; Orudzheva and Kornenko, 1991).

The Jurassic to Paleogene sedimentary cover is divided into four intervals: (1) Lower to Middle Jurassic continental to paralic clastic rocks, (2) upper Middle to Upper Jurassic marine carbonate and evaporite rocks, (3) continental Neocomian clastic rocks and redbeds, and (4) Aptian to Paleogene marine carbonate and clastic rocks (Orudzheva and Kornenko, 1991). Clastic sediments become increasingly more continental derived during late Paleogene time (Orudzheva and Kornenko, 1991).

Neogene to Holocene orogenic clastics were deposited as a result of tectonic deformation related to the collision of the Indian plate with the Eurasian plate, which began in latest Oligocene time (Orudzheva and Kornenko, 1991; Ulmishek, 2004).

Basin History

The Afghan part of the Amu Darya and the Afghan-Tajik Basins is located on the extreme southeastern part of the Turan platform of the Eurasian plate, and is bounded on the south and southeast by the Harrirud fault system (Kulakov, 1979; Dastyar and others, 1990; VZG, 2004).

The evolution of the Amu Darya and Afghan-Tajik Basins involved the movement of the Eurasia, Africa, and Indian continental plates (VNIGNI, 2005a). Rocks in these two basins record the tectonic history of the Tethys region (VNIGNI, 2005a). The major tectonic events are (1) late Carboniferous to Early Permian compression with the closing of the

Paleotethys Ocean, (2) Late Permian to Triassic continental breakup with extensional rifting, (3) Late Triassic collision of Cimmerian blocks with Eurasia and associated deformation of the southern Eurasian margin, (4) Early Jurassic to beginning of the Middle Jurassic extension, (5) Late Jurassic(?) to Early Cretaceous formation of island arcs, passive margins, and post-rift sags resulting in marine transgression, (6) Late Cretaceous(?) to early Paleogene movement of micro continents in the Neotethys Ocean, and (7) Cenozoic compression resulting from the closing of the Neotethys Ocean and collision of continents and micro continents (VNIGNI, 2005a). Most of sedimentary basins along the Eurasian plate were formed over aulacogens, grabens, and triple junctions (VNIGNI, 2005a). The main basin-fill deposits include syn-rift, post-rift sag, and passive margin (VNIGNI, 2005a). The structural and stratigraphic development of the Amu Darya and the Afghan-Tajik Basins is summarized in Figure 2.

Two major structures that influenced crude oil and natural gas occurrence developed in northern Afghanistan during Mesozoic and Cenozoic time; the Parapamiz-Bande Turkestan Range (a mountainous foldbelt), located in the southern and central parts of the northern Afghanistan; and the Murgab depression of the Amu Darya Basin, located in the northern part of the area (fig. 3) (Dastyar and others, 1990; VZG, 2004). The Parapamiz-Bande Turkestan may have been a rift basin formed on the Eurasian plate behind a magmatic arc of the Hindu Kush and Parapamiz (Brookfield and Hashmat, 2001; Ulmishek, 2004). A thick section of Permian and Triassic clastic, carbonate, and volcanic rocks, up to several kilometers thick, filled the rift basin, but was uplifted and deformed in Late

Triassic time by Cimmerian orogenesis (Dastyar and others, 1990; Ulmishek, 2004). A stable passive margin developed over the area and the fold belt was subsequently peneplaned, subsided, and overlain by Jurassic to Paleogene rocks (Dastyar and others, 1990; Ulmishek, 2004).

The Murgab depression is part of the Amu Darya Basin and is presently subsiding as indicated by Neogene and Quaternary rocks unconformably overlying, with a sharp contact, older rocks with thicknesses are up to 2,000 meters (Kulakov, 1979). The Murgab depression subsided more than the Parapamiz-Bande Turkestan Range (Dastyar and others, 1990). The block structure of the Amu Darya Basin consists of a series of diagonal and east to west faults along which some parts of the basin have been uplifted and others subsided, including the Kalaimor-Kaisar Depression, Badkhyz-Karabil Uplift, North Karabil-Dauletabad Depression (northern Badkhyz depression), Maimana Step, and Uchadzhi High (Kulakov, 1979). Neogene to Holocene tectonism deformed much of the area, but with a pattern that generally follows pre-Jurassic structural grain (Ulmishek, 2004).

Almost all of the deformation in northern Afghanistan began in the Miocene with the collision of the Indian plate into the Eurasian plate (Brookfield and Hashmat, 2001). The collision of the Indian plate with the Eurasian plate occurred in three phases, based on tectonic, structural, magmatic, and geochronologic data (Treloar and Izatt, 1993). The first phase involved suturing of the Kohistan-Ladakh-East Nuristan island arc to south Eurasia about 100 million years ago (Cretaceous) (Treloar and Izatt, 1993). The second phase involved the collision of the Indian plate with the Eurasian plate about 55 million years ago (Paleogene) (Treloar and Izatt, 1993). The third phase was the collision of the Indian plate with the Turan plate (Afghan Block) during the Pliocene (Treloar and Izatt, 1993).

The Afghan-Tajik Basin was deformed by the northward protrusion of the Pamir block beginning in late Oligocene time and continuing to present (Orudzheva and Kornenko, 1991; Ulmishek, 2004; VNIGNI, 2005a). The Pamir block was translated northward by at least 100 kilometers relative to the Turan platform and rotated by at least 30 degrees as a result of rotation of the Indian Plate (Thomas and others, 1996). Compression and subhorizontal or gently plunging east to west shortening occurred and a series of anticlinoria and synclinoria, trending generally north to south, were produced that are underlain by thrust faults with the principal detachment surface along Upper Jurassic salt (Loziyev and others, 1984; Orudzheva and Kornenko, 1991; Leith and Alvarez, 1985; Thomas and others, 1996; Ulmishek, 2004; VNIGNI, 2005a). Fault heaves increase in magnitude from south to north indicating counter-clockwise rotation (Thomas and others, 1996). Rotations increase in magnitude from west to east (Thomas and others, 1996). Crustal shortening ranges from 50 to 90 kilometers; 20 to 60 percent (fig. 4) (Thomas and others, 1996; VNIGNI, 2005a). The thrusts flatten with the depth and continue into but not through the evaporite interval (VNIGNI, 2005a). The allochthonous slabs moved relative to the autochthon base on one or multiple surfaces (which converge to a common fault surface) (VNIGNI, 2005a). Subsalt Jurassic deposits do not participate in the thrusting and likely have platform-type structure similar to that of the southwestern Gissar spur (VNIGNI, 2005a). Synclinoria were filled with thick orogenic sediments during upper Neogene and Quaternary time; up to 5,000 meters in the Afghan-Tajik Basin with decreasing thickness westward into the Amu Darya Basin (Orudzheva and Kornenko, 1991; Ulmishek, 2004; VNIGNI, 2005a). The Alburz-Marmul strike-slip fault separates the Afghan-Tajik Basin from the North Afghan High to the south. Elongate north to south trending structures of the Afghan-Tajik Basin are truncated by the Alburz-Marmul fault, having vertical displacement of approximately 4 kilometers (Bratash and others, 1970; Ulmishek, 2004). The Alburz-Marmul fault has a Neogene to Holocene oblique strike-slip component (Brookfield and Hashmat, 2001) and elongate structures of the Afghan-Tajik Basin might have been deformed by dragging along the fault.

The thrusting does not extend across the Southwest Gissar spur and meganticline into the Amu Darya Basin (Ulmishek, 2004). Only local uplift of blocks occurred in the Amu Darya Basin as a result of the collision (Orudzheva and Kornenko, 1991).

Principal Present-Day Structural Elements

Only the southern margins of the Amu Darya and Afghan-Tajik Basins occupy northern Afghanistan. The Amu Darya Basin deepens to the northwest into Turkmenistan, becoming a large structural depression surrounded by mountain ranges to the south and basement highs to the north (Ulmishek, 2004). The Afghan-Tajik Basin deepens northward into Turkmenistan and Uzbekistan, becoming a structural depression having a north to south trending depocenter, surrounded by mountain ranges to the north and east, and by basement highs to the south.

Most present-day structures and faults were developed by Neogene to Holocene tectonic events, which formed new structures and reactivated and modified older structures (Brookfield and Hashmat, 2001; Ulmishek, 2004). The present-day structural elements are shown on Figure 3. Older Mesozoic to Paleogene structures were influenced by Triassic to Jurassic rifting and include inversion uplifts in rifts, such as the Maimana step; and over-rift sag depressions, such as the Amu Darya Basin (Brookfield and Hashmat, 2001; VNIGNI, 2005a).

Amu Darya Basin

The basement of the Amu Darya Basin has a fault-block structure (Ulmishek, 2004). A large number of the faults border main structural units of the basin, separating smaller uplifted and subsided blocks (Ulmishek, 2004). "The faults either extend upward into the sedimentary cover or are expressed as flexures" (Ulmishek, 2004). "Many of the structures are arranged into linear anticlinal zones along the faults" (Ulmishek, 2004). Little information is available on the existence of pre-Neogene structures (Ulmishek, 2004). Some structures in adjacent areas experienced continuous uplift in Neogene time whereas others were buried under younger rocks (Ulmishek, 2004).

The Amu Darya Basin consists of subordinate depressions and uplifts of varying degrees of expression. Structures in northern Afghanistan and adjacent areas include the Murgab depression, Obruchev depression, North Karabil-Dauletabad depression, Andkhoy uplift, Akhchin step, Sheberghan block, Maimana step, Badkhyz-Karabil uplift, and Repetek zone.

Murgab depression

The Murgab depression is a large depression located mostly in Turkmenistan and includes several smaller structural elements (VZG, 2004). The structural elements of this depression that are in Afghanistan include the Obruchev and Dauletabad depressions; Andkhoy uplift and its extensions the Yashlar-Andkhoy and Shakhmolla arches, which divide the Obruchev and North Karabil-Dauletabad depressions; Maimana step and its extension, the Badkyz-Karabil uplift (VZG, 2004). These structures are expressed as regional gravity anomalies in geophysical surveys (VZG, 2004).

Obruchev depression is bounded on the south by the Andkhoy uplift and Akhchin step, and bounded on the north by the Repetek zone (VZG, 2004). On the gravity map, the depression is expressed as a large negative anomaly (VZG, 2004). The depth of burial to the top of Kimmeridgian to Tithonian evaporites approaches 4 to 5 kilometers (VZG, 2004).

North Karabil-Dauletabad depression is bounded on the south by the Maimana step and on the north by the Andkhoy uplift (Seradzhi, 1988, 1993; VZG, 2004). The top of the

Kimmeridgian to Tithonian evaporites has not been penetrated, but is supposed to occur beneath the base of the Neocomian, which is at a depth of 3 to 3.6 kilometers (VZG, 2004). The thickness of the sedimentary section decreases eastward (VZG, 2004).

Badkhyz-Karabil uplift is an elongate basement high with a thin sedimentary cover that extends westward from the Maimana step in Afghanistan to the Kopet Dag area of Turkmenistan and Iran. Triassic, Jurassic, and lowermost Cretaceous rocks are absent on top of the uplift and on the Maimana step, and the Paleozoic basement is overlain by Hauterivian or Barremian clastic rocks. The Badkhyz-Karabil uplift bounds the southern margin of the Murgab depression.

North Afghan High

The North Afghan High is a highland with elevations locally exceeding 2,500 meters (Ulmishek, 2004). Triassic and Jurassic rocks are absent on the crest of the high but are present on the slopes (Ulmishek, 2004). The basement is exposed in the southeastern part and is overlain by Cretaceous to Paleogene rocks at depths of 1,200 to 1,500 meters in western parts (Bratash and others, 1970; Ulmishek, 2004). On the north, the North Afghan High is bounded by the Alburz-Marmul sinistral strike-slip fault. Along this fault, the basement of the North Afghan High is downthrown into the Afghan-Tajik Basin to the north (Bratash and others, 1970; Ulmishek, 2004).

Andkhoy uplift is a buried western protrusion of the North Afghan High. The Andkhoy uplift is expressed as a positive gravity anomaly 65 kilometers long and 20 to 30 kilometers wide on the gravity map (VZG, 2004). The uplift is orientated west-to-east and includes several simple subordinate structures (VZG, 2004).

Akhchin step is a basement high along the northern margins of the Andkhoy uplift and North Afghan High.

Maimana step is a basement high with a thin sedimentary cover that includes a group of anticlinal folds that divide smaller depressions (VZG, 2004). The strike of the arch is generally east to west and is expressed as relatively elevated values of gravity on the gravity map (VZG, 2004). The Maimana step is along the flank of the North Afghan High and is the updip continuation the Badkhyz-Karabil uplift.

Repetek zone

The Repetek zone is the largest intrabasinal fault zone of the Amu Darya Basin, extending west to east from Turkmenistan into northern Afghanistan south of the Uzbekistan border (Ulmishek, 2004; VNIGNI, 2005b). The zone marks the northern boundary of the Murgab depression and consists of a series of faults apparently with a dextral strike-slip component that caused salt diapirism, the intensity of which decreases from east to west (Ulmishek, 2004; VNIGNI, 2005b). Salt domes are of Upper Jurassic salt and have amplitudes as high as 1,000 meters along the eastern part of the Repetek zone (Ulmishek, 2004). Subsalt Jurassic rocks in this zone are not as deformed as the complex steeply folded suprasalt rocks (VNIGNI, 2005b). Vertical offset is approximately 1,500 meters on the eastern portion of the zone and decreases westward (VNIGNI, 2005b).

Kushka depression and Kushka zone

The Kushka zone of folds is an anticlinal zone in southernmost Amu Darya Basin that lies on the western plunge of the Parapamiz-Bande-Turkistan range (Ulmishek, 2004; VNIGNI, 2005b). The zone is separated from the Badkhyz-Karabil uplift and Maimana step by the east to west trending Kalaimor/Kaisar depression, which is filled with Cretaceous and Paleogene rocks (Ulmishek, 2004; VNIGNI, 2005b). Upper Jurassic rocks are absent in both the anticlinal zone and the depression, and Lower Cretaceous rocks unconformably overlie Lower to Middle Jurassic coal-bearing clastic rocks.

Parapamiz-Bande Turkestan range

The present-day Parapamiz range is a Triassic volcanic arc. The Bande Turkestan is most probably a back-arc rift. Both were closed, inverted, and deformed by collision of the Central Afghanistan (Helmend) block (microcontinent) at the end of Triassic time.

The strong but relatively short-lived downwarping of the Harrirud fault system in the Triassic led to accumulation of thick, extensively developed terrigenous-volcanic deposits (north of the fault system), which were intensely folded at the end of the Triassic (Sborshchikov and others, 1974). Triassic clastic sediments were deposited in a narrow inland sea (Safdari, 1991). Slavin (1970) interprets the Bande Turkestan section as a northern part of a single trough that includes the Parapamiz section. A very thick, up to 9,000 meter, Triassic section of volcanic rocks (three volcanic intervals, 600 to 6,500 meters) is present in the Parapamiz mountains (Slavin, 1970). The Triassic section in the Bande Turkestan mountains is thinner, with Middle and Upper Triassic flysch-like rocks or black mudstone about 3,000 meters thick (Slavin, 1970). At the end of the Late Triassic, terrigenous coals and thin coal interbeds were deposited in a littoral marine plain with lagoons and swamps (Safdari, 1991). Early Cimmerian deformation was most intensive in the Bande Turkistan area (Safdari, 1991).

Harrirud fault zone

The Harrirud fault zone is a Triassic sutural structure that separates the Turanian block of the Eurasian plate to the north from continental blocks of Gondwanian origin and related structures to the south (fig. 5) (Sborshchikov and others, 1974; Safdari, 1991). In Neogene time, the structure was reactivated and became a dextral strike-slip fault in a general pattern of escape tectonics related to compression from the collision of the Indian plate.

Southwest Gissar Meganticline and Spur

The Southwest Gissar Meganticline and Spur separate the Afghan-Tajik Basin from the Amu Darya Basin. Only the extreme southern limb of the meganticline is located in Afghanistan, which includes limbs of the Khamyab, Khan Tepe, and Kleft anticlines (Dastyar and others, 1990). Southwest Gissar spur is structurally different from the rest of the Afghan-Tajik Basin and might have formed by mixed thrust and block tectonics (Kravchenko and others, 1990). The spur is a tectonic (Neogene) uplift that is thrust on margins of both the Afghan-Tajik and Amu Darya Basins. The southwest Gissar spur is delineated by the outcrops of Cretaceous rocks beneath Quaternary sediments in the extreme western part of the Afghan bank of the Amu Darya River (Dastyar and others, 1990). The Hercynian basement and Jurassic rocks are exposed in the highest part of the uplift.

Alburz-Marmul fault

The Alburz-Marmul fault lies between the Afghan-Tajik Basin to the north and the North Afghan High to the south. The Alburz-Marmul fault may be left-lateral transpression zone (Thomas and others, 1996).

Afghan-Tajik Basin

The Afghan-Tajik depression is located on a zone of intense negative gravity anomalies (VNIGNI, 2005a). The thickness of the earth's crust in the Afghan-Tajik depression changes from 45 kilometers in the most of the depression to 55 to 60 kilometers along the eastern margin (VNIGNI, 2005a). The Afghan-Tajik depression is an area of deep downwarping, whereby the basement is at a depth of 10 to 15 kilometers or more as determined by geophysical methods (VNIGNI, 2005a). The basement cannot be mapped because of poor resolution of the geophysical methods employed (VNIGNI, 2005a). Marginal structural steps, uplifted as much as 3 to 8 kilometers, surround the Afghan-Tajik depression (VNIGNI, 2005a). The major steps include the Dushanbe and Baysun steps, and the North Afghan High (VNIGNI, 2005a).

Suprasalt post-Jurassic sedimentary cover of the basin was detached along Jurassic salt in Neogene time and deformed into a series of thrust anticlinoria and synclinoria. In anticlinoria, Paleogene rocks are commonly exposed on the surface whereas synclinoria are filled with several kilometers of Neogene to Quaternary continental clastic deposits. Complex fold-thrust structures are present in the sedimentary cover within the depression (VNIGNI, 2005a). These structures are typically ridge-like anticlinal folds with thrust fault-cut cores (VNIGNI, 2005a). The structure of allochthonous plates in the depression is not well understood (VNIGNI, 2005a). Thrust fault surfaces and allochthonous plates were folded in some places (VNIGNI, 2005a). Parts of these folds can be traced into the allochthonous plates at different levels, and the frontal parts of the plates in anticlines are commonly accompanied by buried underthrust anticline uplifts (VNIGNI, 2005a). Autochthonous subsalt plates were subthrust under the southwest Gissar spur and under the Pamir range (Kravchenko and others, 1990). The internal structure of the autochthonous plate is virtually unknown.

In the center of the Afghan-Tajik Basin, thick allochthonous slabs bury Jurassic subsalt deposits to depths inaccessible to drilling, 8 to 12 kilometers (VNIGNI, 2005a). Subsalt Jurassic deposits are much shallower, 2 to 3.5 kilometers only on the uplifted steps where either the thickness of allochthonous slabs decreases (such as at Gadzhak field on the

Baysun step) or the structural style changes from thrusting to block-folding (such as at Komsomolsk field on the Dushanbe step) (VNIGNI, 2005a).

Only 5 wells drilled in the Afghan-Tajik Basin reached depths of 4.5 to 5 kilometers, (Krylov, 1980). Two wells encountered Neogene rocks of subthrust sheets (Krylov, 1980; Kravchenko and others, 1990; VNIGNI, 2005a). On Aktau and North Kurgancha structures of Tajikistan, Upper Jurassic salt was penetrated (Krylov, 1980).

The sedimentary cover within the inner part of the Afghan-Tajik Basin consists of three allochthonous synclinal zones: (1) the Surkhan megasyncline and Mazar i Sharif basin, (2) the Vakhsh megasyncline, and (3) the Kulyab megasyncline (or Badakhshan Foredeep) (VNIGNI, 2005a). These synclinal zones are divided by (1) the Kafirnigan meganticline, and (2) the Obigarm meganticline (VNIGNI, 2005a). The anticlinal zones are breached and cores of salt and suprasalt intervals of Late Jurassic to Paleogene age crop out (VNIGNI, 2005a). The northeastern extremity of anticlinoria is complex and contains mainly imbricate allochthonous-sheet structures, where anticlinal folds are most closely spaced (Loziyev, 1976). Synclinoria contain synclinal folds and compressed anticlines with sharp crests (Loziyev, 1976).

In synclinoria of the Afghan-Tajik Basin, anticlines in the northern parts have regularly oriented dip of axial planes with the steep limbs broken by reverse faults with throws of 2.5 to 3.5 kilometers; folds become imbricate where throws are large. Structures in the southern parts of synclinoria of the Afghan-Tajik Basin have differing axial dips, crests commonly contain grabens, and limbs have symmetrical, sharp folds (Loziyev, 1976).

In anticlinoria of the Afghan-Tajik Basin, Neogene rocks unconformably overlie eroded anticlinal crests down to the Cretaceous section (Loziyev, 1976). The depth of erosion decreases southward to the Paleogene section (Loziyev, 1976). The unconformity is absent in synclines and in the Surkhan Darya megasyncline, where the Neogene section is in normal stratigraphic succession (Oligocene and early Miocene) and early folding was synsedimentary (Loziyev, 1976). Folding might have been noncontemperaneous over the Afghan-Tajik Basin; proceeding from northwest to southeast (Loziyev, 1976). Folding is less pronounced in the synclinoria, where it lagged somewhat and did not develop unconformities in the cores of local anticlines (Loziyev, 1976). A pronounced unconformity is present at the base of the Holocene section in the Afghan-Tajik Basin as indicated by the eroded crests of anticlines in synclinoria (Loziyev, 1976).

Imbricate structures are best developed in the northeastern parts of the anticlinoria in the Afghan-Tajik Basin and originated at the beginning of Neogene time as indicated by pre-Neogene unconformity truncating the crests of anticlinal folds (Loziyev, 1976). Structures in the southern parts of synclinoria of the Afghan-Tajik Basin developed at the beginning of Holocene time, where pre-Holocene unconformity exists on anticlinal folds, but does not exist in synclinoria (Loziyev, 1976).

Loziyev (1976) recognized two main structural styles in the Afghan-Tajik Basin: (1) Isombay folds, which involve a thick salt bed as a detachment surface but the bed has no independent structure-making significance and (2) Kulyab folds, which incorporate salt in the structures as diapirs and flows.

Surkhan megasyncline and Mazar i Sharif basin contains Mesozoic to Cenozoic rocks approximately 7 or 8 kilometers thick in northern Afghanistan (Dastyar and others, 1990). Gravimetry indicates that the megasyncline is divided into two parts by a fault boundary running longitudinally through Mazar i Sharif. The eastern part contains gravity highs and lows that trend north to south, representing long, narrow, intensely faulted anticlines with steep limbs. The anticlines include the Gunj, Mohammad Jandagar, and Aita Tepa structures. Anticlinal structures to the west are broader, less elongate, less intensely faulted, and have gentler dipping limbs. An extension of the Repetek zone is expressed by the Sanduqli anticlinal structure to the west (Dastyar and others, 1990). Salt diapirism is observed along the Repetek zone farther west in Turkmenistan (VNIGNI, 2005a).

Kafirnigan meganticline is situated east of the Surkhan megasyncline and is divided into two parts by the Mir Ali trough (Dastyar and others, 1990). The eastern part of the Kafirnigan meganticline is topographically more elevated than the western part (Dastyar and others, 1990).

Vakhsh megasyncline is deepest south of Qunduz, where the top of the folded basement is buried under 7.5 to 8 kilometers of Neogene and Quaternary deposits (Dastyar and others, 1990). Kukushkin and Ramazanova (1989) show that thrust sheets cover older pre-Kulyab structures on the west side of the Vakhsh depression in Tajikistan.

Obigarm meganticline is the easternmost anticlinorium of the Afghan-Tajik Basin and situated between the Vakhsh and Kulyab synclinoria.

Kulyab megasyncline (or Badakhshan foredeep) is the easternmost major present-day structural element in the Afghan-Tajik depression of northern Afghanistan. The Kulyab megasyncline is a foredeep basin filled with thick Neogene to Quaternary orogenic clastic sediments (Dastyar and others, 1990).

Kokchin graben is an orthorhombic depression on the eastern edge of the Afghan-Tajik Basin along the Badakhshan, containing up to 17 kilometers of Neogene and Quaternary molasse (Dastyar and others, 1990). The origin of the graben is not well understood.

Tectonic Development

The basement of the Afghan-Tajik and Amu Darya Basins is known from outcrops in the Tian Shan in the north and the Parapamiz-Bande Turkestan range in the south. The northern Tian Shan is the uplifted part of the Caledonian basement of central Kazakhstan.

The southen Tian Shan, called the Gissar range, includes the Hercynian ophiolite suture, Carboniferous volcanic arc, and large massifs of post-collisional granitoids. In the Parapamiz-Bande Turkestan range, pre-Jurassic rocks are composed of four tectono-stratigraphic intervals: (1) Ordovician? to Lower Devonian passive margin interval developed on oceanic crust, (2) Upper Devonian to lower Carboniferous magmatic arc and ophiolites developed on the passive margin, (3) lower Carboniferous to Permian rift and passive margin intervals, (4) Triassic continental magmatic arc (Brookfield and Hashmat, 2001).

In the basins, the basement is overlain by Upper Triassic to Cenozoic sedimentary rocks, which are more than 16 kilometers thick in the Afghan-Tajik Basin as evidenced by geophysical data (VNIGNI, 2005a). A significant part of the section, up to 7 kilometers of continental rocks, was deposited from the Oligocene to Holocene (VNIGNI, 2005a).

Paleozoic

The basement of the Amu Darya and Afghan-Tajik Basins was probably formed by the accretion of various tectonic terranes during the Hercynian tectonic event (late Carboniferous to Permian) based on extrapolation of the basement composition of the basin margins into the deeper parts of the basins (Ulmishek, 2004). The closing of oceanic basins and concomitant tectonic activity involving the collision of microplates during the late Carboniferous to Early Permian time most likely occurred along the southern edge of Eurasian plate at the modern southern Tian Sh n and northern Pamir ranges (Ulmishek, 2004; VNIGNI, 2005a). The Hercynian tectonic event involved two Precambrian continental microplates. The Karakum microplate is northernmost and extends eastward into the Tian Shan north of the Gissar range. The Karakum microplate may have included the Tarim block in northwest China (Zonenshayn and others, 1990; Ulmishek, 2004). The southern microplate is the Tajik. Gravity and magnetic geophysical surveys indicate that the Tajik microplate underlies the Afghan-Tajik Basin and extends into the Amu Darya Basin (Maksimov, 1992; Ulmishek, 2004). Ophiolites in the central part of the Gissar range are located along the collision zone between the Karakum and Tajik microplates (Ulmishek, 2004). The Amu Darya Basin basement farther west includes various oceanic blocks containing basic volcanic rocks of Carboniferous age (Ulmishek, 2004).

Triassic

Subduction of Paleo-Tethyan lithosphere under the southern margin of Eurasia began in Triassic time. In Afghanistan, this subduction resulted in formation of the Parapamiz continental volcanic arc and back-arc rifting of the Turanian plate. The largest rift was formed in Bande Turkestan, but the presence of other rifts under thick post-Triassic rocks is probable. At the end of the Triassic or earliest Jurassic, the Paleo-Tethys was closed and the Helmend block of Gondwanian origin (Leven, 1997) collided with the Eurasian margin. The collision resulted in intense but short-lived early Cimmerian deformation of the margin and inversion of Bande Turkestan. Uplift of marginal highs (North Afghan High, Maimana step, and Badkhyz-Karabil uplift) is most likely related to this collision. The collision and deformation completed the formation of the economic basement for petroleum exploration of the Afghan-Tajik and Amu Darya Basins.

Jurassic

Jurassic rocks unconformably overlie Triassic and older rocks in the Amu Darya and Afghan-Tajik Basin (Dzhalilov and others, 1982; Dastyar and others, 1990; Ulmishek, 2004; VNIGNI, 2005a). During the Early to Middle Jurassic in northern Afghanistan, a crust containing kaolinite formed by weathering of Triassic volcanic rocks under hot and humid climatic conditions (Dastyar and others, 1990). Most of the Lower Jurassic interval older than Toaracian is not recognized in the Amu Darya and Afghan-Tajik Basin (Dzhalilov and others, 1982).

Jurassic rocks are buried 6 to 7 kilometers below upper Mesozoic and Cenozoic rocks in the Afghan-Tajik Basin (Bebeshev and Makarov, 1989). Although the Jurassic section was not penetrated by drilling in the Afghan-Tajik Basin, lithologic descriptions were made from outcrops in the surrounding mountains (Dzhalilov and others, 1982; Polyansky, 1989). The most complete Jurassic section is exposed in the western part of the Afghan-Tajik Basin and consists of marine and continental deposits (Dzhalilov and others, 1982). Five depositional stages are identified. (1) During late Early Jurassic to early Middle Jurassic time, high relief surrounded the Afghan-Tajik Basin and fluvial, lacustrine, and swamp depositional environments existed that resulted in the deposition of commercial coal deposits (Bebeshev and Makarov, 1989; Dzhalilov and others, 1982). (2) A sea-level rise occurred during the Aalenian to Bajocian time whereby paralic sediments were deposited consisting of alternating marine and continental sandstone, siltstone, and mudstone up to 300 meters thick (Bebeshev and Makarov, 1989; Dzhalilov and others, 1982). (3) Marine transgression continued during the Bajocian to Bathonian time and deltaic sediments were deposited in the northern part of the Afghan-Tajik Basin grading southward into more argillaceous shallow-marine deposits (Egamberdyev, 1981; Bebeshev and Makarov, 1989). Marine rocks include marine mudstone, marl, and limestone, up to 150 meters thick and the deltaic rocks are potential petroleum reservoirs (Bebeshev and Makarov, 1989; Dzhalilov and others, 1982). (4) Maximum marine transgression occurred during Callovian to Oxfordian time resulting in a carbonate system with the deposition of carbonates up to 650 meters thick (Bebeshev and Makarov, 1989; Dzhalilov and others, 1982). (5) The final stage occurred during Kimmeridgian to Tithonian time with the deposition of anhydrite, halite, and mudstone, up to 1,000 meters thick (Bebeshev and Makarov, 1989; Dzhalilov and others, 1982). In the eastern part of the Afghan-Tajik Basin, the Jurassic section consists mainly of continental deposits up to 2,200 meters thick (Dzhalilov and others, 1982).

The Early to Middle Jurassic was a time of intercontinental rifting, accompanied by development of horst and graben and inter-graben zones (early stage) and above-rift downwarpings or sags with flooding to create shallow marine basins, interior seas, and embayments (later stage). The region can be divided into the Turan, Karakum, Afghan, Amu Darya, and Pamir blocks, based on the locations of the horst and graben zones

(VNIGNI, 2005a). An Early Jurassic graben exists in northern Afghanistan on the Badkhyz-Karabil uplift and Maimana step (Ulmishek, 2004). Other such Early Jurassic grabens may also exist (Ulmishek, 2004).

Boundaries of the blocks are marked by changes in sediment thickness and by presence of volcanogenic deposits (VNIGNI, 2005a). During Early Jurassic time, rifting resumed along the earlier-formed rift system (VNIGNI, 2005a). During the Triassic, rifting was most active in the western part of the region (VNIGNI, 2005a). From Early to Middle Jurassic time, however, rifting was most active in eastern parts of the region, involving the Turan and Karakum blocks (VNIGNI, 2005a). The formation of Early to Middle Jurassic rifts in central Asia was initiated by rapid spreading of the Eurasia and Africa continents, with the spreading center in the Neotethys Ocean (VNIGNI, 2005a). The rift system extended hundreds of kilometers through the Caucasus, the south of Kopet Dag, and northern Afghanistan (VNIGNI, 2005a). Parts of the rift system are probably buried under allochthonous plates (VNIGNI, 2005a). Separate fragments of the rift system are marked by flysch deposits and have been identified in northern Afghanistan (VNIGNI, 2005a). The Early to Middle Jurassic rift system, having a northwest strike, is clearly traced along the northern flank of the Amu Darya depression (VNIGNI, 2005a). In central parts of the Amu Darya depression, similar structures were identified by seismic data (VNIGNI, 2005a). The increase of the salt thickness along the Repetek fault serves as an indirect indicator of the possible presence of a rift system (VNIGNI, 2005a).

During the Early Jurassic, the topography of the Afghan-Tajik Basin was dissected, hilly, and in some places, mountainous (Timofeev and Polyansky, 1985; Polyansky, 1989). This topography existed at the Darvaz-Alay and south Tian Shan mountains, and was the provenance for alluvial deposits and peat bogs (Timofeev and Polyansky, 1985). A band of alluvial-deltaic, in places, lagoonal coastal environments covered northern Afghanistan and part of the Afghan-Tajik Basin, the Kugitang, southern Darvaz, and the Gissar Range (Polyansky, 1985; Egamberdyev, 1987).

The Lower Jurassic section in northern Afghanistan consists of mainly continental deposits, which include conglomerate, sandstone, siltstone, mudstone, and carbonate rocks, with coals and detrital bauxite (Egamberdyev, 1987; Dastyar and others, 1990; VNIGNI, 2005a). Thick fine- to coarse-grained terrigenous rocks with coal overlie weathered Triassic rocks in northern Afghanistan (Dastyar and others, 1990). Tuffs and volcanic rocks are present in the Lower Jurassic section near Pul i Khumri in the eastern part of northern Afghanistan (Dastyar and others, 1990). The Lower Jurassic section crops out on slopes of Gissar and Darvaz ranges, where it is coarse grained and includes conglomerate and sandstone (VNIGNI, 2005a). In the northern part of the Afghan-Tajik Basin, the Jurassic section consists of Lower Jurassic coal-bearing deposits overlapped by banded sandstone (Dzhalilov and others, 1982). Younger Jurassic deposits are not observed (Dzhalilov and others, 1982).

Starting in Bajocian time, above-rift depressions, or sags, formed, becoming intercontinental marine basins connected to the Neotethys Ocean (VNIGNI, 2005a). By the end of Bajocian time, rifting began to cease along the Karakum and Turan plates (VNIGNI, 2005a). Dissected by rifts, the edges of blocks started to subside under the weight of the sedimentary cover (VNIGNI, 2005a). In the Afghan-Tajik Basin, sediment provenance is the Gissar range and local uplifts (Egamberdyev, 1987). Bajocian-age rocks directly overlay basement rocks on one of the local uplifts (Egamberdyev, 1987). A Jurassic paleoarch may have existed in the present-day Vakhsh and Kafirnigan area (Volos and others, 1982).

Alluvial, lacustrine, swamp, and deltaic terrigenous peat-bearing and coastal marine carbonate-terrigenous sediments were deposited in northern Afghanistan during the Middle Jurassic. Sediment source was from early Jurassic dissected uplands along the northern borders (Polyansky, 1985; Timofeev and Polyansky, 1985). The Middle Jurassic section in northern Afghanistan contains conglomerate, sandstone, carbonaceous mudstone, and coal (Dastyar and others, 1990; VNIGNI, 2005a). Sediments become more marine upward (Egamberdyev, 1987) and become more carbonaceous toward the west (VNIGNI, 2005a).

The Lower and Middle Jurassic section laps onto basement highs (Ulmishek, 2004). Beds in the lower part of the section pinch out on the slopes of the highs (Ulmishek, 2004). The Lower and Middle Jurassic section is absent on the Badkyz-Karabil uplift and Maimana step (Ulmishek, 2004). Lower and Middle Jurassic rocks are present in both north and south of these uplifts in Afghanistan, but the thickness is known only along the margins and does not exceed several hundred meters (Ulmishek, 2004).

Tectonic events during the Late Jurassic to Early Cretaceous include: (1) marine transgression and broadening of the marine embayment along the periphery of the Neotethys Ocean into a sea that occupied the Amu Darya Basin; (2) collision of island arcs with microcontinents at the northern edge of the Neotethys Ocean, particularly along the Turan and Karakum plates resulting in uplift and alternating marine and continental sedimentary sections; (3) changing depositional environments and bioherm development along margins of plates and blocks; (4) connection of deep marine water between the Amu Darya and Kopet Dag areas; (5) marine transgression and regression in the Amu Darya Basin resulted from longitudinal and transverse tectonic movement of blocks (VNIGNI, 2005a).

The Neotethys Ocean reached maximum size at the end of Late Jurassic time (VNIGNI, 2005a). A marine transgression advancing from the north and northwest, from the Turan sea basin, flooded the single pre-Neogene combined Amu Darya-Afghan-Tajik Basin at the end of Bathonian time (Dastyar and others, 1990). The Parapamiz-Bande Turkestan area of northern Afghanistan remained above sea level (Dastyar and others, 1990; VNIGNI, 2005a). The deepest part of the sea was in the center of the depression and seemingly corresponded to the Repetek fault, Obruchev depression, and the southern part of the Afghan-Tajik Basin (VNIGNI, 2005a). The Amu Darya sea deepened from the northwest to the southeast (VNIGNI, 2005a). A broad shelf was located to the north and south of sea along the Badkhyz-Karabil uplift, Maimana step, Andkhoy uplift, Akhchin step, and Afghan-Tajik Basin (VNIGNI, 2005a). Reefs developed on the margins of the relatively deep-water basin. Reef development is expected in the northern part of the Kafirnigan and Obigarm zones, and in the Baysun zone of the Afghan-Tajik Basin (Kravchenko and others, 1990).

In the northern part of the Afghan-Tajik Basin, such as at the Dushanbe step, Oxfordian through Tithonian sediments may not have been deposited (Dzhalilov and others, 1982). Upper Jurassic deltaic sediments were observed along the Darvaz range, indicating that the coastline might have existed along the Gissar range, central Tian Shan, and Darvaz range (Timofeev and Polyansky, 1985).

At the northern edge of Neotethys Ocean, in present-day Afghanistan and Iran, a northward dipping subduction zone with associated island arcs was formed in Late Jurassic time (Boulin, 1988; VNIGNI, 2005a), as indicated by the presence of calci-alkalic extrusive rocks (VNIGNI, 2005a). Interaction of island arcs with margins of continental plates probably occurred on the southern edge of the Kabul and North Pamir blocks (VNIGNI, 2005a). he northern edge of Tethys was bordered by island arcs, which collided one-by-one with the Iran, Central Afghanistan, and North Pamir blocks, resulting in the inversion of rifts and undeveloped passive margins, and uplift of eastern regions of central

Asia (VNIGNI, 2005a). The collisions only weakly affected the Turan and Karakum plates (VNIGNI, 2005a). Tectonic movements continued during Kimmeridgian to Hauterivian time, forming inversion uplifts in synclines and depressions, such as the Uchadzhi high (VNIGNI, 2005a). The Late Jurassic to Early Cretaceous embayment, which occupied the Amu Darya Basin, and the Karakum and adjacent microplates, was dissected by uplifts and became shallow or completely retreated, as in the North Pamir area (VNIGNI, 2005a).

Marine transgression began in latest Bathonian or early Callovian time (Ulmishek, 2004). A basal mudstone unit was deposited followed by deposition of carbonate rocks of the Kugitang suite (Ulmishek, 2004). During Callovian and Oxfordian time, a complex of barrier reefs, pinnacle reefs, and atolls formed along the shelf edge and in marginal areas of the deep-water basin (Ulmishek, 2004). The sedimentary section decreases in thickness from the shelf margin toward the nearshore zone, and the section pinches out at the basin margin (Ulmishek, 2004). The Callovian to Oxfordian shelf sequence is composed of various shallow-water facies; including oolitic, detrital, and algal limestones and dolomitic limestones; small nearshore Callovian carbonate buildups; argillaceous limestones and marls; and local beds of anhydrite in the middle to upper Oxfordian section (Ulmishek, 2004). Siliciclastic material is present and is locally dominant along the basin margins (Ulmishek, 2004).

The thickest and most hydrocarbon-productive rocks in the Amu Darya Basin part of northern Afghanistan are middle and upper Oxfordian limestones associated with reefs

(Ulmishek, 2004). The reef complex contains much of the discovered natural gas reserves and most of the estimated undiscovered natural gas resources (Ulmishek, 2004).

The deep-water basinal facies is poorly known because it is deeply buried and has been penetrated in only a few wells in Turkmenistan and Uzbekistan (Ulmishek, 2004). The lower and middle Oxfordian section is composed of dark-gray, thin- to medium-bedded, bituminous, argillaceous limestone (Ulmishek, 2004). The upper Oxfordian section consists of black, thinly laminated, highly organic-rich argillaceous limestone and calcareous mudstone and siltstone with an admixture of volcanic ash (Fortunatova, 1985; Ulmishek, 2004). These rocks, which contain ammonites and other planktonic fossils, are characterized by high readings on gamma-ray logs and are known collectively as the radioactive bed (Ulmishek, 2004). Where drilled, the total thickness of the Upper Jurassic carbonate sequence in the basinal facies is about 200 to 250 meters (Ulmishek, 2004).

The reefs and associated rocks observed on the northeast margin of the Amu-Darya Basin and at outcrops along the southwest Gissar spur provide stratigraphic information that can be used to infer the structure and distribution of reefs and carbonate shelf elsewhere in the basin (Ulmishek, 2004). Reefs and associated rocks provide important hydrocarbon reservoirs on the Chardzhou step in Uzbekistan (Ulmishek, 2004). The section consists of middle Callovian thin- to medium-bedded, dark-gray, argillaceous limestones, which were deposited before reef growth (Ulmishek, 2004). Upper Callovian to middle Oxfordian reefs, up to 50 meters high and including coral and algal-bryozoan reefs, and associated detrital limestone overlie the argillaceous section (Abdullaev, 1999; Ulmishek, 2004). Both the reefs and underlying argillaceous carbonate section on the Chardzhou step produce crude oil and natural gas (Ulmishek, 2004).

Major reef development took place during late Oxfordian and probably early Kimmeridgian time when the sea was deepest (Ulmishek, 2004). Semicircular barrier reefs developed that separated the shelf from the deep-water basin (Ulmishek, 2004). Three linear zones of barrier reefs developed through time (Mirzoev, 1985; Khudaykuliev and others, 1989). A main upper Oxfordian barrier reef and shelfal reefs are present in the Gaurdak-Kugitang area of the Chardzhou step (Khudaykuliev and others, 1989). The barrier reef zone extends westward and southwestward from the Chardzhou step where it separates the extensive northern shelf from the deep-water basin (Ulmishek, 2004). The exact location of the reef zone is not well known because few wells have penetrated below the Upper Jurassic salt in that area (Ulmishek, 2004). Additionally, pinnacle reefs inside basinal facies have not been reliably identified, probably because of great depths, but their presence is inferred on the basis of limited drilling and seismic data (Maksimov and others, 1986; Abdyllaev and others, 1991; Ulmishek, 2004). Farther southwest, the barrier reef plunges to depths exceeding 5 kilometers, and its location is not known (Ulmishek, 2004).

The location and morphology of the reef zone along the south margin of the Amu Darya Basin are poorly known (Ulmishek, 2004). Upper Jurassic carbonates are at depths exceeding 4 kilometers, and the quality of seismic data available in the former Soviet Union was inadequate to map the reef bodies below the thick evaporites (Ulmishek, 2004). Oxfordian limestone and dolomitic limestone of probable reef origin were penetrated by a few wells between the Dauletabad and Shatlyk fields in Turkmenistan (Amanniyazov and Nevmirich, 1985; Ulmishek, 2004). Wells in the Dauletabad field penetrated back-reef facies (Allanov and others, 1985; Ulmishek, 2004). Reefs in this area were also inferred from seismic data, but the morphology of the reef bodies is unclear (Ulmishek, 2004). Seismic data indicate that the Upper Jurassic structure of the southern slope of the Murgab depression consists of two linear uplifted blocks trending west to east, merging with the Andkhoy uplift in northern Afghanistan, and separated by a structural low (O'Connor and Sonnenberg, 1991; Ulmishek, 2004). The uplifted blocks, the Yashlar-Andkhoy and Shakhmolla arches, are apparently covered by carbonate bank deposits that contain reefs (Kleshchev and others, 1991; Ulmishek, 2004). Barrier reefs may be located along the block margins and basinal facies probably fill the low areas (Ulmishek, 2004). The barrier reef extends eastward into northern Afghanistan (Ulmishek, 2004). The reef is located northwest and north of the North Afghan High along the Andkhoy uplift, but its exact position farther east is not known (Ulmishek, 2004). On the crest of the North Afghan High, the entire Upper Jurassic section is absent due to nondeposition, and Cretaceous rocks unconformably overlie the Paleozoic basement or thin Lower to Middle Jurassic and (or) Triassic rocks (Bratash and others, 1970; Ulmishek, 2004).

The barrier reef of the Chardzhou step was dissected into segments 4 to 8 kilometers long by tidal channels 50 to 100 meters deep and from a few hundred meters to 1.5 kilometers wide (Goryunov and Ilyin, 1994; Ulmishek, 2004). The channels are filled with, and overlain by, younger evaporites that provide seals for the trapping of hydrocarbons in the barrier reef complex (Ulmishek, 2004). A number of solitary pinnacle reefs and atolls formed in deeper water (Ulmishek, 2004). The reefs are commonly surrounded by carbonate forereef talus deposits (Ulmishek, 2004). A transition from the barrier reef to basinal facies is observed (Ulmishek, 2004). The reef-carbonate section grades basinward into highly organic-rich, thinly bedded black mudstone with ammonites, which covers the basin floor and overlaps some of the reefs (Khudaykuliev and others, 1989; Ulmishek, 2004). Some reefs most likely drowned during the sea-level maxima (Ulmishek, 2004). Back-reef deposits developed landward from the reef zone and consist of various shallow-water carbonates interbedded with anhydrite (Ulmishek, 2004). Farther landward, the carbonate section includes siliciclastic material derived from adjacent land (Ulmishek, 2004).

The Kugitang suite is one of the major petroleum reservoirs in northern Afghanistan and has been relatively well explored in the Turkmenistan and Uzbekistan portions of the Amu Darya Basin (VNIGNI, 2005b). Most discovered pools have been in barrier and solitary reefs (VNIGNI, 2005b). Local reef knolls may have existed (VZG, 2004). To the north and west, clay-carbonate deposits of the same age were most likely deposited in relatively deeper water (VZG, 2004). The thicknesses of the reef rocks are up to 400-500 m (600 meters in Uzbekistan) and sharply decrease down to 100 to 150 meters for the deep water sediments (VZG, 2004). The reef zone is hypothetically located at northern slopes of the Andkhoy uplift and to the east of Etym Tag and Kohi Alburz (VZG, 2004). Back-reef deposits are observed in Jer Koduq, Assk, Bashi Kurd, Juma, Zigdali, Khuja Bulan, and Gul Tepe wells (VZG, 2004). Reefal (lagoonal and apron) are observed in Etym Tag and Khuja Goger Dak wells (VZG, 2004). Fore-reef deposits are observed in some crude oil and natural gas wells (VZG, 2004).

During Kimmeridgian to Tithonian time in northern Afghanistan, the sea became shallower and more saline, resulting in deposition of red to variegated terrigenous deposits and evaporite rocks under hot and dry climatic conditions (Dastyar and others, 1990). Evaporites of the Kimmeridgian to Tithonian Gaurdak Formation overlie older Upper Jurassic carbonate rocks in the central part of the Amu Darya Basin where the formation is more than 900 meters thick in deeper parts of the basin (Ulmishek, 2004). The Gaurdak Formation extends into the Afghan-Tajik Basin, where it is poorly known because of its deep burial in synclinoria and complex structure in anticlinoria (Ulmishek, 2004). The formation is absent on the North Afghan High (Ulmishek, 2004).

The Upper Jurassic salt basin was an evaporite lagoon separated from the Tethys Ocean by the barrier of the Karabil-Badkhyz uplift and its eastern continuation (Mirzoev, 1985). The southern boundary of the salt basin is sharp and follows large faults, including those along the Karabil-Badkhyz uplift and Alburz-Marmul fault (Mirzoev, 1985). In the Kopet

Dag foldbelt, Upper Jurassic evaporites and red beds of the Amu-Darya basin grade into bedded marine limestones in the Kimmeridgian part of the section and into massive limestones and dolomites with inclusions of anhydrite in the Tithonian part (Amanniyazov, 1989; Ulmishek, 2004). These shallow-water carbonate rocks, probably partly of reef origin, separated open Tethyan Ocean to the south from the Amu Darya salt basin to the north (Ulmishek, 2004). The salt basin was limited on the west by the Serakh sill, along the Ural-Oman lineament, separating open sea on the west from saline lagoon on the east (Mirzoev, 1985). The Karabil-Badkhyz uplift was structurally raised in the late Oxfordian and eroded while sedimentation continued to the north of the uplift (Mirzoev, 1985).

Generally, the Gaurdak Formation consists of two salt (halite) layers that are underlain, and also separated, by anhydrite strata (Ulmishek, 2004). A thinner (15 meters or less) anhydrite bed lies at the top of the formation (Ulmishek, 2004). Both lower and middle anhydrites include carbonate beds that are mostly limited to the marginal parts of the basin (Ulmishek, 2004). Thickness of the lower anhydrite is commonly less on top of the reefs, but increases on the reef slopes (Goryunov and Ilyin, 1994; Ilyin and Fortunatova, 1988; Ulmishek, 2004). Thicknesses of the anhydrite bed, which adjoins the reefs, are used as an exploration tool for identifying the location of reef bodies in Turkmenistan and Uzbekistan (Vakhabov, 1986; Goryunov and Ilyin, 1994; Ulmishek, 2004). However, zones of thick anhydrite have seismic characteristics similar to that of underlying carbonates and hinder interpretation of seismic data (Ulmishek, 2004).

The lower salt layer fills the topographic irregularities inherited from Oxfordian time; it is thin or absent on top of the reefs and on the back-reef shelf and thickens abruptly over Oxfordian deep-water deposits (Ulmishek, 2004). The upper salt layer is less variable, being several hundred meters thick in the central basin area and thins gradually toward the basin margins (Ulmishek, 2004). Both salt layers locally contain anhydrite beds and potassium salt beds (Ulmishek, 2004). In the marginal zone of the Gaurdak Formation, the salt completely pinches out, and the formation is composed of alternating carbonate and anhydrite beds with a variable amount of clastic material (Khudaykuliev, 1986; Ulmishek, 2004).

The thickness of the upper salt and anhydrite layers along the Andkhoy uplift generally increases from the east to the west (VZG, 2004). The thickness of the lower salt, the middle anhydrite, and the blanket anhydrite are uniform (VZG, 2004). Variation in the thickness probably resulted from the growth of local structures during Kimmeridgian to Tithonian time as evidenced by the thinning and pinching out of all units of this section in wells on crests of the structures (VZG, 2004). Such variations are observed at Juma, Etym Tag and Khuja Goger Dak (VZG, 2004). At Etym Tag and Khuja Goger Dak, the upper salt pinches out and the section is represented by anhydrite with interlayers of red-brown clays (VZG, 2004). In the Obruchev depression, the thickness of the section varies considerably from full pinch out at Chekh Che to 256 meters at Jangali Kalan (VZG, 2004).

Over almost the entire area of its distribution, salt of the Gaurdak Formation is not deformed by halokinesis (Ulmishek, 2004). The only exception is a narrow linear zone, which extends along the Repetek fault, having a strike-slip component, where the salt is deformed into domes (Ulmishek, 2004). Halokinetic deformation along the Repetek zone in northern Afghanistan may provide migration pathways and traps for hydrocarbon accumulations. Salt stocks are observed in the northern part of the Hindu Kush sector of faults, south of the USSR boundary (Nikonov, 1975).

Evaporites of the Gaurdak Formation are conformably overlain by the Karabil Formation, which is composed of red clastic rocks (VZG, 2004). The boundary between the Jurassic and Cretaceous remains speculative; different geologists place it at the base or at the top of the Karabil suite. Fossil ostracods in the red beds indicate these rocks were probably deposited in a lagoonal to alluvial environment (Ulmishek, 2004). The formation, commonly believed to be late Tithonian or late Tithonian to earliest Berriasian in age (Beznosov and others, 1987), is absent in marginal parts of the basin (Ulmishek, 2004).

The Upper Jurassic interval is similar to deposits of the same age in the Amu Darya Basin (VNIGNI, 2005a). In the Amu Darya Basin, carbonate rocks are distinguished and traced from those deposited on shallow marine shelf to those deposited on the continental slope and basin (VNIGNI, 2005a). The Upper Jurassic interval in the Afghan-Tajik Basin is poorly studied (VNIGNI, 2005a). Rocks of the interval are penetrated by wells only in the Southwest Gissar spur, Surkhan-Darya syncline and Dushanbe depression (VNIGNI, 2005a). Several fields were discovered and produce from this interval, including Adamtash, Gumbulak, and Gadzhak (VNIGNI, 2005a). In the center of the Afghan-Tajik Basin, carbonates of the upper part of the interval have not been penetrated by wells (VNIGNI, 2005a). Based on regional reconstructions, the depth of burial of the interval in the Afghan-Tajik Basin is 4.5 to 7 kilometers (VNIGNI, 2005a). Limestone is likely the predominant rock type in the central part of the basin but becomes more clastic along the eastern edge of the basin at the southwestern Darvaz, where the rocks are predominantly calcareous sandstone, mudstone, and siltstone (VNIGNI, 2005a). The clastic sediments were deposited in marine conditions above reefal depressions (VNIGNI, 2005a).

Cretaceous

The tectonic activity that occurred along the Turan platform during Kimmeridgian to Hauterivian time slowed during Barremian to Coniacian time (VNIGNI, 2005a). Orogens that were created by island arc accretion onto the microcontinents were intensively eroded (VNIGNI, 2005a).

Presence of Upper Jurassic and Lower Cretaceous limestone within the Karakum, Turan, Caucasus, North Caucasus, and Iran areas indicate that they were located in an equatorial climatic zone (VNIGNI, 2005a). Redbeds deposited during Early Cretaceous time, such as the Karabil suite, indicate arid conditions (VNIGNI, 2005a). The main source of sediment was from unroofing of structural highs in eastern regions of central Asia, northern Afghanistan, and North Pamir (VNIGNI, 2005a).

Most of the Lower Cretaceous section in eastern central Asia was deposited under arid continental conditions with some shallow marine and lacustrine deposition (Ulmishek, 2004; VNIGNI, 2005a). Lakes occupied large depressions and marine transgressions are identified.

The Lower Cretaceous interval conformably overlies the Jurassic interval in the central parts of the Amu Darya and Afghan-Tajik Basins (Dzhalilov and others, 1982; Pashaev and others, 1993; Ulmishek, 2004). Lower Cretaceous rocks unconformably overlie Paleozoic to Upper Jurassic rocks on the Amu Darya and Afghan-Tajik Basin margins (Dzhalilov and others, 1982; Ulmishek, 2004). In the Amu Darya Basin, the Lower Cretaceous section is composed of continental clastic rocks with interbeds of lagoonal and marine clastic rocks higher in the section (VNIGNI, 2005b). In the Pul i Khumri region of northern Afghanistan, Lower Cretaceous rocks unconformably overlie Middle Jurassic rocks (Dastyar and others, 1990). In the foothills of the western Hindu Kush range, Lower Cretaceous-age red coarse sandstone and conglomerate directly overlie Triassic and older rocks (Dastyar and others, 1990). The thickness of Lower Cretaceous rocks decreases toward the periphery of the Amu Darya Basin as lower stratigraphic units consecutively pinch out (VNIGNI, 2005b).

The thickness of Lower Cretaceous rocks in northern Afghanistan ranges up to 300 meters on the east and up to 850 meters on the west (VZG, 2004). Maximum thickness of the

Lower Cretaceous section is in an east-to-west depression along Amu Darya River before it turns to the north. The depression has an abrupt south slope and a gentle north slope. In the Kushka area, the Lower Cretaceous section is 345 meters thick at Karachop Field and 290 meters thick at Islim Field.

In the eastern part of the Amu Darya Basin, the section consists of lagoonal to continental red and variegated clastics with beds of dolomite, anhydrite, and salt (halite) (Ulmishek, 2004). Fine to coarse terrigenous rocks from several to 1,000 meters thick were deposited under hot and dry climatic conditions in northern Afghanistan (Dastyar and others, 1990). A prominent sandstone interval in the Neocomian section is the Hauterivian Qezeltash sandstone, also called Shatlyk sandstone, which contains the largest gas reserves in Turkmenistan (Ulmishek, 2004). Qezeltash (Shatlyk) sandstone is of deltaic origin and is present in the western and central areas of the Murgab depression and slopes (Tashliev and others, 1985; Ulmishek, 2004). The bed is composed of red and brown sandstones with interbedded mudstone layers (Ulmishek, 2004). In the eastern part of the Murgab depression and northwestern Afghanistan, sandstone of the Qezeltash bed grades laterally into a 20 to 60 meter thick salt mixed with sand grains (Bratash and others, 1970; Pashaev and others, 1993; Kryuchkov, 1996; Ulmishek, 2004).

In the Afghan-Tajik Basin, the Lower Cretaceous interval contains variegated clastic rocks, including sandstone and mudstone with subordinate limestone and anhydrite interbeds (VNIGNI, 2005a). Red beds increase to the east, with thicknesses ranging from 800 to 1,200 meters (VNIGNI, 2005a).

Along the southwestern slope of the Gissar Range, basal red-colored sandstone has a thickness of up to 220 meters (VNIGNI, 2005a). The Hauterivian section is sandy and has a thickness of 120 meters (VNIGNI, 2005a). The Barremian to Aptian section consists of gypsum-bearing mudstones with rare layers of dolostone, having a total thickness up to 270 meters (VNIGNI, 2005a). The Albian section contains more marine sediments, including gray and red-colored marine limestone and arkosic sandstone, with large concretions. The thickness ranges from 160 to 400 meters (VNIGNI, 2005a).

To the east, in the direction of Darvaz range, sediments of the Lower Cretaceous section were deposited in continental environment (VNIGNI, 2005a). The clastic rocks are coarser grained and some conglomerate is present. Toward the Pamir range, the Lower Cretaceous clastic rocks appear to be orogenically derived.

The sea transgressed into the Amu Darya Basin during late Barremian time, depositing limestone in the basin center and red marl and mudstone eastward (Ulmishek, 2004; VNIGNI, 2005b). Barremian rocks provide a seal for crude oil and natural gas accumulations in Lower Cretaceous reservoirs (VNIGNI, 2005b). Upper Barremian to middle Aptian section consists of lagoonal to marine deposits (Dzhalilov and others, 1982). Aptian- to Albian-age rocks include marine mudstone, siltstone, and sandstone with some middle Aptian carbonate beds (Kariev, 1978; Dzhalilov and others, 1982; Ulmishek, 2004; VNIGNI, 2005b).

In Late Cretaceous time, the Turan Sea covered most of northern Afghanistan except for some small areas of the Parapamiz-Bande Turkestan Uplift (Dastyar and others, 1990). Upper Cretaceous rocks consist mainly of clastic terrigenous sediments deposited in a marine basin (VZG, 2004; VNIGNI, 2005b). Some geologists believe that the Kafirnigan anticlinorium of the Afghan-Tajik Basin was formed over a pre-Tertiary high similar to the Central Karakum arch (Egamberdyev and Mayvandi, 1992). In the late Albian to Santonian, a sea was to the west of this high and a lagoon was to the east (Egamberdyev and Mayvandi, 1992).

The Upper Cretaceous interval conformably overlies Lower Cretaceous rocks in the Afghan-Tajik Basin part of northern Afghanistan (Dzhalilov and others, 1982).Upper Cretaceous sediments were deposited in more marine conditions (VNIGNI, 2005a) and consist of marine, lagoonal, and continental deposits (Dzhalilov and others, 1982). The deposits include gray-colored sandstone and mudstone. Limestone and marl become more abundant in the upper part of the section (VNIGNI, 2005a). Short marine regressions occurred as indicated by the presence of variegated lagoonal and continental interbeds (Dzhalilov and others, 1982). Maximum thickness of the interval is at the basin center and to the east, thinning northward (Dzhalilov and others, 1982). The thickness ranges from 800 to 1,100 meters (VNIGNI, 2005a).

Upper Cretaceous rocks in the Amu Darya Basin are dominantly marine and grade eastward from carbonate into clastic rocks consisting of mostly mudstone and siltstone in the central basin and coarser clastic rocks on the basin margins (Tashliev and others, 1985; Ulmishek, 2004). Minor limestone and marl beds are present in the Campanian and Maastrichtian strata (Ulmishek, 2004).

Maximum marine transgression occurred during Maastrichtian to Paleocene time in northern Afghanistan (Dastyar and others, 1990). Carbonate reef-associated rocks were deposited at the Parapamiz-Bande Turkestan area and northern Afghanistan (Dastyar and others, 1990). Clastic rocks up to 600 meters thick were deposited farther west in the Amu Darya Basin-Murgab depression of Afghanistan (Dastyar and others, 1990).

In the Amu Darya Basin of eastern Turkmenistan, on the Karabil uplift, the top of the Upper Cretaceous, including Campanian rocks, was deeply eroded before Paleogene time. In eastern Turkmenistan, the Upper Cretaceous is 1,000 to 1,200 meters thick with few carbonate beds. However, Upper Cretaceous carbonate beds are present in the Badkhyz area and in the preserved part of the section on the Karabil high (anonymous).

Paleogene

Marine conditions continued through most of the Paleogene in the then combined Amu Darya and Afghan-Tajik Basin. Approach and collision of the Arabian, Iranian, and

Hindustan continental plates into the Eurasian plate that closed the Neotethys Ocean occurred 25 to 30 million years ago in the late Paleogene. Uplift, marine regression, and deposition of continental sediments by the close of the Paleogene resulted from these collisions (VNIGNI, 2005a).

In the southeastern part of the Afghan-Tajik Basin, in southwest Darvaz and Pul i Khomri, and in more eastern areas of Afghanistan, a full transition from marine to nearshore to continental rocks in the Upper Cretaceous to Paleogene interval is observed (Melamed and others, 1988). Along the rest of the eastern margin, such a transition is not observed, and marine Paleogene borders older rocks along reverse faults (Melamed and others, 1988). Nearshore Paleogene deposits are observed 50 to 70 kilometers north of the basin boundary, on the Turkestan Range (Melamed and others, 1988).

Paleogene (Paleocene to middle Oligocene) rocks are at the top of the sedimentary fill of the Amu Darya basin. Lower Paleocene (Danian) clastics and carbonates are preserved only in the southern areas of the Amu Darya Basin and in the Afghan-Tajik Basin. Lower Paleogene rocks were removed by pre-middle Paleocene erosion elsewhere. Paleogene rocks conformably overlie Cretaceous rocks in northern Afghanistan (Dastyar and others, 1990). In the Afghan-Tajik Basin, evaporites are predominant in the lowermost Paleocene interval (Dzhalilov and others, 1982).

The middle and upper Paleocene rocks (Ghory or Bukhara Formation) are predominantly shallow-water carbonates, although some beds of clastic rocks and anhydrite are present (Ulmishek, 2004). The proportion of clastic rocks increases northward and northwestward, whereas anhydrite beds and anhydrite inclusions in other rock types are present mainly in the southern areas of the Amu Darya Basin (Ulmishek, 2004).

The Eocene to middle Oligocene section is composed mainly of gray and variegated mudstone and siltstone, with sandstone commonly present in the southern part of the basin (Ulmishek, 2004). Carbonate rocks and marl are present throughout the section, being more abundant in the western areas (Ulmishek, 2004). Beds of basalt, andesite, and tuff have been penetrated by wells in the upper Eocene section of the Badkhyz-Karabil uplift and Maimana step (Ulmishek, 2004). Paleogene rocks are more than 2 kilometers thick in the Kopet Dag foredeep, 500 to 800 meters thick in the Murgab depression, and only tens to a few hundred meters thick in the basin marginal areas (Ulmishek, 2004).

Eocene rocks conformably overlie Paleocene rocks over most of northern Afghanistan and represent the last marine conditions (Dastyar and others, 1990). An erosional unconformity is observed only at the Parapamiz-Bande Turkestan range (Dastyar and others, 1990). The Eocene section of northern Afghanistan is up to 850 meters thick and contains fine-grained terrigenous rocks deposited in slightly differentiated shallow normal marine conditions (Dastyar and others, 1990).

The lower Eocene Suzak section is widely distributed across central Asia (VZG, 2004). The Suzak section consists of mudstone containing abundant organic material, from 100 to 150 meters thick (VZG, 2004). In the Afghan-Tajik Basin, the Suzak section consists of homogenous gray, greenish-gray mudstone with bituminous mudstone beds, 50 to 200 meters thick (Minakova and others, 1975; Dastyar and others, 1990; VNIGNI, 2005a). Organic-rich Suzak beds are most likely source rocks for crude oil accumulations in the Afghan-Tajik Basin.

The lower part of the Givar horizon of the Suzak section, the Kaptar beds, is gray and dark-gray non calcareous to slightly calcareous mudstone (Buzurukov and others, 1978; Davidzon and others, 1982). The mudstone commonly becomes calcareous in the central and southern parts of the basin (Babkov and others, 1972) and sandy to the northeast and east (Davidzon and others, 1982). Combustible bituminous mudstone or oil shale 0.2 to 1.6 meters thick, commonly about 0.5 meters thick, and containing phosphorites and pyrite (and marcasite?) concretions is present in the lower half, particularly to the south (Babkov and others, 1972; Buzurukov and others, 1978; Davidzon and others, 1982). Phosphorite concretions range in size from 2 to 5 centimeters and pyrite crystals are as large as 2 to 3 centimeters (Babkov and others, 1972; Pokryshkin, 1981). Ferruginous nodules have also been observed (Dzhalilov and others, 1982). Kaptar beds contain fossils of the Istymtau fauna, which indicate lack of oxygen (Davidzon and others, 1982). The sea is assumed to have been deep, especially on the south where bathyal conditions probably occurred (Babkov and others, 1972). Some corals and mollusks are present eastward and nummulites and discocyclines fossils are found only at the top of the bed (Davidzon and others, 1982). At the type section, the Kaptar beds are approximately 20 meters thick (Davidzon and others, 1982). Lenses with numerous large pelecypods have also been observed (Babkov and others, 1972).

Baymin beds, in the upper part of the Givar horizon of the Suzak section, are greenish-gray calcareous mudstone (Buzurukov and others, 1978; Davidzon and others, 1982). Marl beds up to 2 to 2.5 meters thick are present in the middle and upper parts of the section (Babkov and others, 1972). At the western part of the Afghan-Tajik Basin, Baymin beds are bluish-gray calcareous mudstone with fossil foraminifera and mollusks (Davidzon and others, 1982). The Baymin beds are approximately 46 meters thick (Davidzon and others, 1982). The Baymin beds become a monotonous greenish-gray, calcareous mudstone eastward (Davidzon and others, 1982). Farther east, at the Kafirnigan megaanticline and Vakhsh megasyncline, division of the Givar horizon into the Kaptar and Baymin beds is difficult (Davidzon and others, 1982). The section consists of gray and bluish-gray mudstone, but grades to siltstone to the northeast (Davidzon and others, 1982). An oil shale bed 0.5 meters thick is present in the type section at Vakhsh Ridge (Davidzon and others, 1982).

At the easternmost part of the Afghan-Tajik Basin, the Darvaz area, the Givar horizon is 6 to 13 meters thick (Davidzon and others, 1982). The section consists of greenish-gray, calcareous mudstone and sandstone with phosphorite concretions and glauconite grains

(Davidzon and others, 1982). Although this is a proximal area of Givar deposition, thin oil shales are present (Davidzon and others, 1982). A 0.6 meter thick bed of oil shale and 1.2 meter thick conglomerate bed are present at the type section (Davidzon and others, 1982). Sandy, fissile (called "paper") mudstone 0.7 meters thick is exposed at the bottom of the section (Davidzon and others, 1982).

At the Kortau structure in northern Afghanistan, the bottom of the Suzak section is a bituminous mudstone bed consisting of 10 meters of brownish-green mudstone with light-gray marl layers and *Gryphea* fossils (Ivanov and others, 1963). Higher, five meters of gypsum with layers of thin-bedded marl with bitumen smell is present (Ivanov and others, 1963). Above is 4.5 meters of light-gray marl with bitumen (Ivanov and others, 1963). In cores from Konduz(?) well #1, at 815 to 837 meters from the subthrust, gray thin-bedded bituminous marls with chips of gypsum are present (Ivanov and others, 1963). The overlying mudstone bed is composed of dark-gray to greenish mudstone with pyrite crystals to several centimeters and concretions of marl (Ivanov and others, 1963). The thickness of this bed is 113 meters (Ivanov and others, 1963). The uppermost bed in the Suzak section is sandstone, 81 meters thick (Ivanov and others, 1963).

At the Khanabad structure in northern Afghanistan, the basal Suzak bituminous bed is composed of white gypsum with numerous thin, up to 1 meter thick layers of bituminous marl with oil stains (Ivanov and others, 1963). The overlying bed consists of gray mudstone 59 meters thick that is sandier than those at the Kortau structure (Ivanov and others, 1963). A two meter thick bed of brown to black paper oil shale is present in the upper part of the gray mudstone bed (Ivanov and others, 1963). The upper sandstone bed consists of massive, fine-grained, greenish-gray sandstone (Ivanov and others, 1963). The uppermost bed in the Suzak section is sandstone, 30 meters thick (Ivanov and others, 1963). The presence of sandstone and gypsum in the Suzak section of both the Kortau and Khanabad structures indicates that the eastern part of northern Afghanistan was a proximal area of the Suzak basin.

Bituminous marl and marly limestone of middle Eocene (Lutetian) age are observed in northern Afghanistan, near Madar on the North Afghan High (Schmitz and Weippert, 1966). The rocks are 8 to 15 meters thick and contain up to 0.7 percent oil-like bitumen (Schmitz and Weippert, 1966). Bituminous rocks having similar ages and depositional facies are observed near Kala i Kurchi (Maimana Province) and Tashkurgan in northern Afghanistan (Schmitz and Weippert, 1966).

Eocene flammable mudstone covers all Uzbekistan and Tajikistan except for the Gissar and Darvaz Ridges where it is limited to small areas (Khaimov, 1986). Everywhere, the flammable mudstone is in the lower part of the Suzak unit, 1.5 to 5 meters from the bottom (Khaimov, 1986). The bed is generally 0.5 to 1.35 meters thick, but can reach 1.8 meters (Khaimov, 1986). The mudstone covers an area of 36,200 square kilometers (Khaimov, 1986). The mudstone consists of clay, carbonate, and organic matter in an average proportion of 5:3:2 (Khaimov, 1986). The same bed covers the Kyzylkum basin, where its thickness is 0.75 to 1.4 meters (Khaimov, 1986). The beds crop out in three areas: (1) Uchkyr-Kulbeskak, south of Bukhara, (2) Baysun step near the southwest Gissar spur, where the bed is 0.4 to 0.9 meters thick and having 28 percent organic matter and 4.5 percent sulfur; and (3) Urtabulak, where the organic matter contains 7.65 to 8.08 percent hydrogen (Khaimov, 1986). A chart of stratigraphy of Paleogene rocks in the atlas "Geology of the USSR" (Tulyaganov, 1972) shows two sections of Suzak beds in Uzbekistan, one at the town of Guliob where 0.3 meters of flammable bituminous mudstone is exposed and another at Baysun Mountain, where 0.8 meters are exposed. Black mudstone interbeds were penetrated by wells northeast and east of Tamdytau and in the Bukhara depression near Karaulbazar town and north of Kassan town in the Amu Darya Basin. A full Paleogene section is exposed in the Chil-Darya anticline along the southwest Gissar spur in Uzbekistan, where the Bukhara beds are a black bituminous limestone 140 meters thick and the Suzak beds are black, bituminous, bedded marl 17 meters thick (Popov and others, 1962). Paleogene black shales and marls also present in Turkestan and the Isfarin-Khanbad area (Popov and others, 1962).

The Turan Sea regressed northward at the end of the Paleogene resulting in the emergence of a dissected continental landscape and deposition of terrigenous rocks over most of northern Afghanistan (Dastyar and others, 1990). The Parapamiz-Bande Turkestan range continued to rise and the Amu Darya Basin-Murgab Depression continued to subside. The Amu Darya Basin-Murgab depression remained submerged until the end of the Paleogene, possibly under fresh water lacustrine conditions (Dastyar and others, 1990). Volcanism occurred at the Parapamiz-Bande Turkestan area resulting in the deposition of intermediate to basic porphyry volcanics (Dastyar and others, 1990).

In the Afghan-Tajik Basin, a slight tilt of the Kafirnigan meganticline to the east and only gentle platform structures were present during Paleogene time through the Oligocene, until the end of Sumsar deposition (Volos and Makhkamov, 1969). In Sumsar time, the area west of Kafirnigan River was uplifted, as indicated by the absence of the Sumsar Formation (Volos and Makhkamov, 1969).

Structural movements of the Amu-Darya Basin and presumably the Afghan-Tajik Basin during the basinal stage of development (Jurassic through Paleogene) are characteristic of block-type platform tectonics (Ulmishek, 2004). Structural highs, such as the Badkhyz-Karabil uplift, Maimana step, North Afghan High, and smaller uplifts experienced slower subsidence and occasional positive movements that resulted in local disconformities and the absence of parts of the sedimentary sequence (Ulmishek, 2004). Maximum subsidence took place in the central parts of the basins (Ulmishek, 2004).

Neogene

Tectonic events of Neogene time were responsible for much of the present-day geological structure and traps for oil and gas accumulations in the Amu Darya and Afghan-Tajik Basins (Brookfield and Hashmat, 2001; VNIGNI, 2005a). During this time, the Neotethys Ocean closed by the convergence of the Eurasia and India plates. Accretion of the Arabian, Iranian and Hindustan plates onto Eurasia deformed and reactivated the boundaries between adjacent microplates. The creation of an orogenic epiplatform in eastern central Asia resulted, forming fold belts and overthrust nappes of the Kopet Dag and thrust faults in the Afghan-Tajik Basin (VNIGNI, 2005a). Block boundaries, such as at the Repetek zone were reactivated, resulting in flowage, thickening, and diapirism of Jurassic evaporites, erosion, inversion of aulacogens and grabens, and transform movements along Alburz-Marmul and Amu Darya faults. Northwestwardly movement of the Pamir block at the end of the Neogene resulted in thrust faulting of the suprasalt section of the Afghan-Tajik Basin (VNIGNI, 2005a).

Orogenic movements in mountain ranges bordering the Amu Darya Basin began in late Oligocene time, and tectonism progressively increased through the Pliocene and into the Holocene (Ulmishek, 2004). Although Neogene thrusting from the east did not extend into the Amu Darya Basin, the compression led to active tectonic movements (Ulmishek, 2004). East-west-trending faults, mainly with dextral slip, were formed in northern Afghanistan (Brookfield and Hashmat, 2001; Ulmishek, 2004). The Repetek zone strike-slip fault, which inherited a Jurassic or older fault zone in the Murgab depression was formed at this time (Ulmishek, 2004). All local structural uplifts along the eastern and southern basin margins were produced during this stage of tectonic deformation (Ulmishek, 2004). Anomalously high formation pressure in southeastern Amu Darya Basin is associated with this movement (VNIGNI, 2005a).

The collision of a protusion on the Pamir block of Hindustan into the Turan block during Miocene to Quaternary time tectonically reactivated and split the Eurasian plate into several blocks, including the Pamir, Afghan, and Tajik (Ulmishek, 2004; VNIGNI, 2005a). The Upper Jurassic to Cenozoic suprasalt sedimentary section in the Afghan-Tajik Basin was uplifted, thrusted, and folded forming anticlinoria and synclinoria (Ulmishek, 2004; VNIGNI, 2005a). The most intense deformation of the allochthon happened in the east where, the basement was most likely subject to uplift and overthrusting (VNIGNI, 2005a). The Afghan-Tajik Basin was bounded on the north and south by strike-slip faults, including the Ilyak, Alburz-Marmul, and Mirzavalan faults, which were rift zones in the Early to Middle Jurassic (VNIGNI, 2005a). Strike-slip faults were accompanied by thrust faulting in the Afghan-Tajik Basin (VNIGNI, 2005a).

The main stage of collision between the Indian plate and the Afghan Block occurred during Pliocene time (Treloar and Izatt, 1993). Sedimentation occurred during intense tectonic movements resulting in great variability of composition, thickness, and stratigraphic completeness of the sections (VNIGNI, 2005a). Orogenic movements became intensive during Neogene time in northern Afghanistan (Dastyar and others, 1990). The Amu Darya Basin-Murgab Depression of northern Afghanistan rapidly subsided relative to the Parapamiz-Bande Turkestan Uplift and was filled initially with fine terrigenous sediments that became progessively coarser through time (Dastyar and others, 1990).

Neogene deformation in the Amu Darya Basin is marked by a widespread pre-late Oligocene unconformity (Ulmishek, 2004). Upper Oligocene to lower Miocene deposits are marine to lagoonal, mostly fine-grained clastic rocks with beds of gypsum and coquina (Ulmishek, 2004). Clastic material was derived primarily from platform provenances rather than from orogenic uplifts (Ulmishek, 2004). The middle Miocene and the lower part of the upper Miocene section on the eastern part of the Amu Darya Basin consist of coarse continental clastic deposits derived from the rising mountains to the south and southeast (Ulmishek, 2004). The upper Miocene to Quaternary section over the entire Amu Darya Basin is composed of lacustrine and alluvial orogenic clastic deposits (Ulmishek, 2004). The upper Oligocene to Quaternary section is 1 to 1.5 km thick in the Murgab depression and adjoining areas (Ulmishek, 2004).

The thickness of the Neogene to Quaternary section in the Afghan-Tajik Basin, and northern Afghanistan is 2 to 7 kilometers (Dzhalilov and others, 1982; Egamberdyev and Mayvandi, 1992; VNIGNI, 2005a). In the Darvaz area of Tajikistan, the Neogene section is most complete with a thickness of approximately 5 kilometers (Dzhalilov and others, 1982). Neogene rocks unconformably overlie older rocks in northern Afghanistan (Dastyar and others, 1990).

In the Afghan-Tajik Basin, a very thick Oligocene to Miocene continental molasse overlies the marine Paleogene (Nosov, 1972). The total thickness of the Neogene interval ranges from 1.2 to 3 kilometers (VNIGNI, 2005a). The section contains reddish mudstone with sandstone at the base that grade upward to sandstone and conglomerate (VNIGNI, 2005a). The grain size and thickness of the deposits increase to the east and north-east (Nosov, 1972). On the east side of the Afghan-Tajik Basin, gypsum appears in the base of the Neogene (VNIGNI, 2005a). In central parts of synclines and at flanks of megasynclines, Neogene and upper Oligocene deposits overlap Paleogene, Cretaceous and Paleozoic rocks transgressively and uncomformably at different horizons (VNIGNI, 2005a).

Maximum thickness of the Miocene section is on the east along Darvaz (Nikolayev, 1990). In northern Afghanistan, the Pliocene section covers a large area and overlies, with sharply expressed unconformity, the Miocene down to Upper Jurassic rocks (VZG, 2004). Neogene unconformities vary in number from 1 to 2 and possibily 3 and their age varies from pre-Neogene (Oligocene) to pre-Pleistocene in southern Tajikistan (Kukhtikov and Vinnicheuko, 1994; VNIGNI, 2005a). Older unconformities are observed in the Peter I Range (Kukhtikov and Vinnicheuko, 1994). The upper Miocene Tavildarin Formation transgressively overlies Paleozoic, Mesozoic, Paleogene, and lower Miocene rocks (Nikolayev, 1990). The pre-Pliocene (pre-Karanak Formation) unconformity is less expressed than the pre-upper Miocene unconformity and is not present everywhere as determined by seismic profiles (Nikolayev, 1990). Another unconformity is at the base of upper Pliocene Polizak Formation, which is well expressed on the eastern margin (up to 90 degrees) but only a few degrees to horizontal at the basin center (Nikolayev, 1990). Above is another unconformity below the upper Pliocene to Pleistocene (to 0.75 million years ago) and younger Kulyab Formation, which lies near horizontally and deformed only near faults (Nikolayev, 1990). The pre-Kulyab unconformity is well seen on seismic profiles (Nikolayev, 1990). Interpretation of a seismic section shows orogenic clastic sediments onlapping and overlapping a fold in Paleogene rocks in the southern part of the Kafirnigan meganticline (Nikolayev, 1990).

Quaternary

The Vakhsh thrust fault is an important feature in the tectonic history of the Afghan-Tajik Basin because it cuts a number of northwestern-oriented structural zones (Kleshchev and others, 1993). The estimated total approximately north to south movement along the cis-Pamir system of thrusts is 180 to 300 kilometers (Kleshchev and others, 1993). Along the slopes of Darvaz range, Hindu Kush, and Zaalay mountains, depositional facies change from marine, gray-colored rocks, to red beds, mudstone, and carbonate, to sandstones and conglomerates (Kleshchev and others, 1993). This change indicates that no significant overthrust of the Afghan-Tajik Basin by the Pamir block occurred (Kleshchev and others, 1993).

The Amu Darya Basin-Murgab depression of northern Afghanistan continued to subside relative to the Parapamiz-Bande Turkestan range during Quaternary time (Dastyar and others, 1990). River terraces were formed at different levels throughout northern Afghanistan during Quaternary time (Dastyar and others, 1990). In the Afghan-Tajik Basin, terraces are locally deformed (Loziyev, 1976).

The maximum thickness and most fully developed Pliocene to Quaternary sections are in the central part of Afghan-Tajik Basin (Nikolayev, 1990). The Yavan-1 well drilled through over 5 kilometers of molasse and the age at total depth was only lower Miocene Baldzhuan Formation (Nikolayev, 1990).

Stratigraphy

A lithostratigraphic column on Figure 6 summarizes the stratigraphy of the Amu Darya and Afghan-Tajik Basins.

Basement

Basement rocks are a folded complex of the Paleozoic and Triassic rocks, which are exposed in the Tian Shan and Pamir range (VNIGNI, 2005a). The rocks include crystalline schists, quartzites, marls of the middle Paleozoic, and volcanogenic argillaceous rocks of the upper Paleozoic (VNIGNI, 2005a).

The taphrogenic Triassic section is commonly deformed and partially metemorphosed in outcrops around the Afghan-Taji and Amu Darya Basins. Although undeformed rocks of this age may be present beneath the Jurasic to Cenozoic sediments in the inner parts of the basins, the rocks are over mature with respect to petroleum generation and considered here as an economic basement for petroleum production.

Kanonin Formation

Upper Permian to Triassic rift-fill deposits comprise the base of sedimentary cover and consist of marine clastics and carbonates, and volcanic rocks, grading to red-colored orogenic clastic sediments and redbeds in some areas (Loziyev, 1976; VNIGNI, 2005a).

The Lower Triassic section in northern Afghanistan is approximately 1,000 meters thick and consists of conglomerate overlain by dolostone, siltstone, sandstone, volcanic rocks, and tuff (Dastyar and others, 1990). Near Doab, Lower Triassic rocks are over 400 meters thick and include thin limestone beds unconformably overlain by conglomerate, dark mudstone, siltstone, sandstone, volcanic rocks, and tuff (Dastyar and others, 1990).

The Middle Triassic section in northern Afghanistan is approximately 1,000 meters thick and consists of mudstone, limestone, and sandstone (Dastyar and others, 1990). Near the Hindu Kush range, Middle Triassic rocks are thicker (4,700 meters) and include thick beds of intermediate and acidic volcanic rocks and tuff (Dastyar and others, 1990).

The Upper Triassic section in northern Afghanistan consists of sandstone, conglomerate, mudstone, and siltstone, with some volcanic rocks (Dastyar and others, 1990). The Triassic section is deformed, metamorphosed, and cut by Early Jurassic granitic intrusions along the foothills of the western Hindu Kush and Parapamiz ranges (Dastyar and others, 1990).

The Rhaetian sequence is recognized in the eastern part of the Maimana step where it is from 350 to 1,400 meters thick (Sarwary, 1990). The sequence consists of intermediate and acid volcanic rocks with a small amount of terrigenous sedimentary rocks (Sarwary, 1990). The volcanic rocks include andesite porphyry, rhyolite, and dacite (Sarwary, 1990).

The Triassic section is known in two areas of the Afghan-Tajik Basin, one in the South Tian Shan area and the other in the western piedmont of the Pamir range (Dzhalilov and others, 1982). The south Tian Shan section contains weathered Upper Triassic rocks unconformably overlying Paleozoic rocks (Dzhalilov and others, 1982). Farther south, the section contains 2 kilometers of presumed Lower Triassic coarse continental redbeds of the ***Khanakin suite*** (Kanonin Formation) (Dzhalilov and others, 1982). The Khanakin suite probably continues southward and underlies younger rocks throughout the Kafirnigan meganticline and Vakhsh megasyncline areas (Dzhalilov and others, 1982). The Lower Triassic section along the Pamir range is similar to those of northern Afghanistan (Dzhalilov and others, 1982). The section is up to 1.5 kilometers thick and includes sandstone and conglomerate of the ***Vasmikukh suite***, marine clays of the ***Alikagar suite***, and continental conglomerate of the overlying presumed Middle Triassic ***Iokundj suite*** (Dzhalilov and others, 1982). Upper Triassic rocks are not recognized in this area (Dzhalilov and others, 1982).

Lower to Middle Jurassic

The Triassic to Lower Jurassic interval in the northeastern Afghan-Tajik Basin contains a thick Upper (?) Triassic to Lower Jurassic volcanic section, which is similar to that of the southern Bande Turkestan (Polyansky, 1973). Both volcanic sections were probably deposited along the southern basin boundary before deformation.

Lower to Middle Jurassic rocks contain continental clastic rocks with coal. Thick fine- to coarse-grained continental rocks with coal (***Sayghan Series***) overlay a kaolinitic crust that developed on older Triassic volcanic rocks in northern Afghanistan (Dastyar and others, 1990).

Subdivisions of the Jurassic interval in the Afghan-Tajik Basin of Tajikistan include the upper Toarcian to lower Bajocian ***Gurud*** coal-bearing continental section, 20 to 200 meters thick; (2) Bajocian ***Gring*** coal-bearing continental section; (3) Bajocian ***Degibadam-Tangiduvalia*** alternating marine and continental sandstone, siltstone, and mudstone, up to 300 meters thick; and (4) ***Shkeldarin*** varigated mudstone (Dzhalilov and others, 1982). A regional unconformity exists at the base of the transgressive deposits of the upper Bajocian Baysun suite (Dzhalilov and others, 1982).

The Baysun suite (Bathonian to Callovian) unconformably overlies formations of the Upper Triassic to older Jurassic(?), and is onlapped by an argillaceous-carbonate member of the Kugitang suite (VZG, 2004). The Baysun suite in the Amu Darya Basin is composed of dark gray mudstone, marl, and clayey limestone up to 200 meters thick

(Dzhalilov and others, 1982; VNIGNI, 2005b). The section contains sandstone and the thickness decreases and pinches out toward the Amu Darya Basin edges (VNIGNI, 2005b). Variegated and red clays with sandstone interlayers representing lagoonal and continental deposits overlay the Baysun suite to the south (VZG, 2004). Thickness ranges from about 60 to 140 meters, thickening southward (VZG, 2004). The distribution of the lithologic composition and the thickness of the Baysun suite rocks indicate deposition in shoal open shelf conditions with fluctuations in water depth (VZG, 2004). The presence of sandstone and conglomerate containing poorly rounded dolostone fragments indicate that the provenance was apparently located within the limits of the modern North Afghan High (VZG, 2004). Lagoonal conditions existed behind a barrier-reef or bar-reef system as evidenced by about 100 meters (by thickness of the lagoonal member) of sulphate mineral-bearing, variegated terrigenous deposits, presumably of early Callovian age, that overlie the Baysun suite in some wells (VZG, 2004). The reef system (lower Callovian) is assumed to be north and north-west of Khuja Bulan Field, in the area of Khuja Goger Dak and Etym Tag Fields and the Andkhoy uplift (figs. 3 and 7) (VZG, 2004). Reef and reef-apron sediments are represented by sandy, oolitic, and detrital-carbonate bearing limestone and dolostone (VZG, 2004).

In the southwest Gissar meganticline and spur and Surkhan megasyncline (fig. 3), sediments in the upper Bathonian to lower Callovian section (Baysun Formation) are marine, thin-bedded mudstone with some carbonates containing ammonites and other fauna (Egamberdyev, 1987). The section is 20 to 50 meters thick and could serve as a seal for petroleum accumulations (Egamberdyev, 1987).

From late Bathonian through Oxfordian time, a uniform carbonate section deposited in a slightly differentiated shallow-water sea of normal salinity was deposited is present in northern Afghanistan (Dastyar and others, 1990).

Kugitang suite (Callovian-Oxfordian) is represented by mainly carbonate deposits of an Upper Jurassic barrier-reef system, which extends west-to-east (Dastyar and others, 1990; VZG, 2004). The section is composed of thick limestone deposited in deep basin, reef, and shelf environments (VNIGNI, 2005b). In northern Afghanistan, the lithologic distribution indicates deposition in lagoonal and tidal-flat environments to the south, shelfal bioherms and barrier reefs farther to the north (Etym Tag Field and Kohi Alburz wells), and basinal deposition is presumed beyond (forereef deposits observed in Barbulaq 1) (fig. 7) (VZG, 2004). Two members are identified in the Kugitang suite, a lower terrigenous-carbonate member and an upper carbonate member (VZG, 2004).

The terrigenous-carbonate member represents a transition of depositional environments from lagoonal/back reef to the south and west (Jer Koduq Field), a presumed barrier reef system (Khuja Goger Dak and Etym Taq Fields), and basinal to the north (fig. 7) (VZG, 2004). Thickness of the member increases from about 60 meters along the Andkhoy uplift to up to 139 meters northward toward deeper parts of the basin (VZG, 2004). Rocks representing the lagoonal/back reef depositional environment include gray to dark-gray limestones and brown-gray, fine-grained dolostones with mudstone layers, having cavernous porosity (VZG, 2004). Closer to the presumed barrier reef, the member consists of partially dolomitized limestone with interlayers of gray and dark-gray mudstone, siltstone, and sandstone (VZG, 2004). Northward of the barrier reef, the member consists of dark-gray to black marl, containing beds of breccia-like sediments and dolostone. These rocks represent deposition in a relatively deeper part of a paleobasin, probably in a zone of the lower slope basinward of the presumed barrier reef (VZG, 2004).

Carbonate member is composed of dark-gray dense, reefal limestone and dolostone (VZG, 2004). The upper portion consists of mostly microcrystalline to fine-grained dolostone, with partings and inclusions of anhydrite (VZG, 2004). The member becomes thicker northward, from about 70 meters in the south to up to about 440 meters (Kohi Alburz wells 2 and 3) (VZG, 2004). In the south (Faiz Abad, Zamarud Sai, Bazar Kami, Qash Qari, Aq Sai, Gul Tepe, and Angut structures, fig. 7), the carbonate member is thin or absent due to erosion during pre-Valanginian time and nondeposition on uplifted basement of the North-Afghan High and Maimana step, which were positive structural elements during the Kugitang time (VZG, 2004).

The upper Oxfordian ***Khodzhaipak Formation*** of western and southern Uzbekistan was deposited as a basinal facies of the main reef complex, but overlaps some reefs

(Akramkhodzhaev and Egamberdyev, 1981). The formation is a very thinly bedded alternation of mudstone, marl, limestone, and rare siltstone of gray to black color (Akramkhodzhaev and Egamberdyev, 1981). These rocks are most likely a source for petroleum (VNIGNI, 2005a).

In drilled areas of the Afghan-Tajik Basin, the Upper Jurassic Callovian to Oxfordian interval consists of light- and dark-gray limestone (VNIGNI, 2005a). The thickness of this interval ranges from 200 to 700 meters, averaging 400 meters (VNIGNI, 2005a). The ***Gissar layers*** comprise the lower part of the interval and consist of massive bituminous limestone, about 700 meters thick, with thick beds of mudstone and sandstone (VNIGNI, 2005a). In the northern and western parts of the basin (Baysun step and the junction of the Dushanbe step with Kafirnigan and Obigarm meganticlines), the interval probably has a reefal origin, but to the south, the limestone may have been deposited in relatively deep water (VNIGNI, 2005a). In the east, limestone is replaced by calcareous sandstone of the ***Zarbuz suite*** (Dzhalilov and others, 1982; VNIGNI, 2005a). The age of the Zabuz Formation is probably Callovian to Oxfordian as indicated by spores and pollen (Luchnikov, 1973). In the Darvaz area, the Zarbuz Formation consists of well sorted calcareous sandstone ranging in thickness from 165 to 220 meters in the lower part of the section and of alternating sandstone and mudstone in the upper part (Luchnikov, 1973). The sediments were deposited in a submarine delta and on a shallow shelf to the south (Luchnikov, 1973). The total thickness ranges from 450 meters on the south thinning to 210 meters in the north (Luchnikov, 1973).

In the northern part of the Dushanbe step (fig. 3), the Upper Jurassic is thin, ranging from 5 to 15 meters thick (VNIGNI, 2005a). The section consists of terrigenous clastic rocks, sandy limestone, and anhydrite. In the Darvaz area, the Upper Jurassic section is 150 to 300 meters thick and is composed of mudstone, marl, and sandstone with salt beds (VNIGNI, 2005a).

Gaurdak suite (Kimmeridgian-Tithonian) in northern Afghanistan consists of a lower anhydrite unit and an upper salt and anhydrite unit (Dastyar and others, 1990; VZG, 2004). The age of the Gaurdak suite southwest of the Gissar spur is determined as Kimmeridgian by fauna of marine pelecypods and gastropods for the lower part and Tithonian for the upper part (VZG, 2004). The distribution of evaporites of the Gaurdak suite is controlled by the North Afghan and Maimana arches and the northwestern edges of the basin (fig. 3) (VZG, 2004). Salt pinches out north of Jer Koduq and Etym Tag Fields (VZG, 2004). The pinch out can be traced eastward to the north of Kohi Alburz (VZG, 2004). The salt is absent in the Chekh Che area, apparently because of the presence of reefal buildup in this region (VZG, 2004). The thickness generally increases from the south to the north, exceeding 1,000 meters in the Obruchev depression (VZG, 2004). Later, in the Kimmeridgian to Tithonian time, the depression was filled by evaporites (VZG, 2004). Thickness of non-eroded deposits of the Gaurdak suite where they are covered by the Karabil suite argillaceous rocks, in the Sheberghan oil-and-gas-bearing region, abruptly changes from 159 meters at Etym Tag Field to 671 meters at Kortamash Field (VZG, 2004).

At Jer Koduq Field, a Valaginian sandstone transgressively onlaps an eroded surface (pre-Valanginian of the lower anhydrite unit (VZG, 2004).

To the east of the Sheberghan area, in the Afghan-Tajik Basin, the lateral equivalent of the Gaurdak suite consists of about 250 meters of variegated gray and brown mudstone and siltstone with layers of gypsum and anhydrite (VZG, 2004). The upper part contains a layer of white and rose gypsum 34 m thick, which is overlain by red mudstone ranging in thickness from several meters to 70 meters (VZG, 2004). A basal conglomerate of Neocomian age unconformably overlies the Gaurdak suite (VZG, 2004). Southeast of the city of Talikan, gypsum, anhydrite and halite of the Gaurdak suite crops out as diapirs (fig. 7) (VZG, 2004). The thickness of the suite in this region is more than 150 meters but can reach 400 meters and more in the diapirs (VZG, 2004).

The Gaurdak suite provides a regional seal for crude oil and natural gas accumulations in the Amu Darya Basin (VNIGNI, 2005b).

Anhydrite member (lower anhydrite) consists of anhydrite and gypsum, with some limestone and dolostone beds (VZG, 2004; VNIGNI, 2005b). The anhydrite is dense, firm, and fractured (VZG, 2004). The dolostone is fine-grained to microcrystalline (VZG, 2004). The thickness of the anhydrite member decreases on the apex and crests of presumed reef buildups, such as the barrier reef at Etym Tag and local pinnacle reefs at Jangali

Kalan and Chekh Che (VZG, 2004). The thickness increases sharply along the reef slopes into deeper parts of the basin (VZG, 2004).

Salt-anhydrite member consists of anhydrite, gypsum, halite, and sylvite (in the central part of the Amu Darya Basin) containing various amounts of carbonate and terrigenous material (VZG, 2004; VNIGNI, 2005b). The most complete sections of the salt-anhydrite member are known on the Andkhoy uplift, where four distinct beds were identified by borehole logging data (VZG, 2004). These beds are, from the bottom to the top, lower salt, middle anhydrite, upper salt and blanket anhydrite (VZG, 2004). Similar beds are observed in the south part of the Chardzhou step of Uzbekistan (VZG, 2004).

In the Afghan-Tajik Basin, the Kimmeridgian-Tithonian section comprises the upper part of the Jurassic interval and consists of dolomitic limestone, gypsum, and anhydrite at the base and evaporite deposits, which are covered by mudstone at the top (VNIGNI, 2005a). Where drilled on the basin margins, the section consists of a lower salt interval, a middle anhydrite interval, and an upper red-colored mudstone interval. The thickness ranges from 100 to 900 meters, with an average thickness of 600 meters.

In the Afghan-Tajik Basin, the Kimmeridgian to Tithonian evaporite-bearing mudstone is called the ***Sarymak*** (***Sarynamak***) Formation (Dzhalilov and others, 1982). In the Darvaz foothills of the Afghan-Tajik Basin, the Kimmerdgian to Tithonian Sarynamak Formation consists of red mudstone, siltstone, thin sandstone beds, and gypsum beds with rare lenses of salt (Luchnikov, 1973). To the south, the formation consists of pure gypsum 635 to 675 meters thick with andesite and tuffs 70 to 90 meters thick. To the north, the formation consists of mudstone with two gypsum beds 7 and 13 meters thick with salt lenses 1.5 to 17 meters thick and up to 17 meters long observed in outcrops. The total thickness of the formation ranges from 150 to 800 meters or more.

Karabil suite (Berriasian (or upper Tithonian)-Valanginian) is composed of lagoonal and continental sediments (VZG, 2004). The formation is divided into a lower red-colored argillaceous member and an upper member consisting of cross-bedded red-colored sandstone with conglomerate containing cobble-sized rock fragments (Dastyar and others, 1990; VZG, 2004; VNIGNI, 2005b). The age of the Karabil suite is Berriasian to Valanginian (VZG, 2004) or late Tithonian to Berriasian (VNIGNI, 2005b). The thickness of the lower member increases west and northwest from 17 meters at Khuja Goger Dak Field to 140 meters at Kortamash to a maximum of 485 meters at Jangali Kalan Field (fig. 7) (VZG, 2004). On structures of the Andkhoy uplift, the thickness ranges from 70 to 120 meters. Lateral thickness changes are most likely associated with halokinesis and basin accommodation (deepening) during Karabil and subsequent times. In the Afghan-Tajik Basin, the Karabil suite consists of red mudstone, siltstone, and sandstone with sparse freshwater fauna, up to 300 meters thick (Dzhalilov and others, 1982). The Karabil suite is conglomeratic in the northern part of the Afghan-Tajik Basin and pinches out in the southern Gissar (Tian Shan) range (Dzhalilov and others, 1982). In the Darvaz area of the

Afghan-Tajik Basin, the Tithonian(?) Karabil Fm consists of purple and red well sorted sandstone (Luchnikov, 1973).

Almurad suite (Valanginian-Hauterivian) overlies the Karabil suite and consists of continental, lagoonal and, to a lesser degree, marine sediments (Kariev, 1978; VZG, 2004). A minor marine transgression occurred at this time, during which limestone was deposited in the western part of the Amu Darya Basin and dolostone and anhydrite in the eastern part (VNIGNI, 2005b). The Almurad suite is composed of red mudstone, siltstone, sandstone, gypsum, anhydrite, limestone, and dolostone (Dastyar and others, 1990). Three members are observed in a complete stratigraphic section (VZG, 2004). The lower two-thirds of the suite are made up of red-colored silty mudstone (VZG, 2004). An interlayer of dolostone with marine fauna of Hauterivian age is the middle member (VZG, 2004). The upper part is brownish-red mudstone interbedded with gypsum (VZG, 2004). In the Afghan-Tajik Basin, the Almurad suite consists of red mudstone, gypsum, dolostone, and siltstone up to 120 meters thick and thins northward (Dzhalilov and others, 1982).

Qezeltash suite (Hauterivian-Barremian) overlies the Almurad suite and is laterally extensive (VZG, 2004). In northern Afghanistan, as well as in neighboring territories of Uzbekistan and Tajikistan, the Qezeltash suite consists of continental deposits having two red-colored, variegated and green-colored siltstone and mudstone, with beds of conglomerate (Egamberdyev and Mayvandi, 1992; VZG, 2004). The lower unit is finer grained, whereas the upper unit is coarser grained and thicker (VZG, 2004). The thickness of the entire suite reaches 200 meters (VZG, 2004). In the Afghan-Tajik Basin, the Qezeltash suite consists of red sandstone and siltstone with sparse freshwater fauna (Dzhalilov and others, 1982; Dastyar and others, 1990).

The Qezeltash suite is assigned to the Hauterivian and Barremian Stages based on the stratigraphic position between underlying Hauterivian rocks and overlying rocks containing early Aptian ammonites, as well as the correlation of it with Barremian deposits of the Shekhitlin suite in more western parts of the Amu Darya Basin (VZG, 2004).

Nearshore marine and paralic conditions with development of sand bars occurred throughout the Amu Darya Basin in Hauterivian time (Mirzoev, 1985). Well sorted quartzose sandstone of the Qezeltash suite, called the Shatlyk sandstone, was deposited in central and southeast parts of the Amu Darya Basin (VNIGNI, 2005b).

In Turkmenistan, provenances of the lower Hauterivian sandstones, including the Shatlyk sandstone, are from the southeast and north (Balkuliev, 1991). Here, the Shatlyk sandstone was deposited in a brackish- water basin (Balkuliev, 1991). Shatlyk sand (Bayramali Formation) is of deltaic origin in southeast Turkmenistan and contain the principal gas reserves of the country (Tovbina and Tashliev, 1983).

The Shatlyk section in the Afghan-Tajik Basin contains a sandy to argillaceous salt bed 40 to 50 meters thick (Pashaev and others, 1993). Pashaev and others (1993) suggest that the source for the salt was to the northeast, where the Hauterivian directly overlies the salt-bearing Jurassic section. The salt basin opened to the southeast where the salt is clean (Pashaev and others, 1993).

Okuzbulak suite (Lower Aptian) The Qezeltash suite grades upward into the Okuzbulak suite (VZG, 2004). This suite consists of limestone and marl with poorly preserved ammonites. Upper beds of the suite comprise argillaceous evaporites. The thickness of the suite ranges from 170 to 200 meters. The age was established recently as lower Aptian.

In the Afghan-Tajik Basin, the Okuzbulak suite consists of lagoonal to marine mudstone, gypsum, and coquina in the lower part grading upward to lagoonal gypsum and red mudstone (Dzhalilov and others, 1982; Dastyar and others, 1990). The marine section thins eastward and is replaced by more proximal deposits consisting of massive sandstone overlying red mudstone and siltstone up to 250 meters thick (Dzhalilov and others, 1982).

Kaligrek suite (Aptian) In northern Afghanistan, the Kaligrek suite is an alternating multi-colored sandy argillaceous unit with interbedded marl and limestone (Dastyar and others, 1990; VZG, 2004). The thickness ranges from 50 to 100 meters.

In the Afghan-Tajik Basin, the Kaligrek suite consists of marine sandstone, limestone, and mudstone up to 60 meters thick (Dzhalilov and others, 1982). The marine section is replaced to the east and northeast by more proximal deposits consisting of red and gray massive sandstone and siltstone (Dzhalilov and others, 1982).

Karakuz suite (Aptian) In the Afghan-Tajik Basin, the Karakuz suite consists of marine sandstone, mudstone, and conglomerate from 15 to 120 meters thick (Dzhalilov and others, 1982). The marine section is replaced to the east by more proximal deposits consisting of continental sandstone and mudstone (Dzhalilov and others, 1982).

The **Albian Stage** has three units in northern Afghanistan: (1) a lower sandy to silty unit up to 150 m thick assigned to the lower Albian, (2) a middle sandy calcareous unit about 70 meters thick assigned to the middle Albian, and (3) an upper calcareous argillaceous unit assigned to the upper Albian (VZG, 2004; VNIGNI, 2005b). Sandstone in the middle unit (middle Albian) is a good reservoir rock (VZG, 2004). The sandstone is gas bearing at Etym Tag and Khuja Goger Dak Fields and oil bearing at Angut Field (fig. 7). Albian reservoir rocks pinch out and laterally grade into clays, argillaceous siltstone, and marl on the Akhchin step, Andkhoy uplift and Maimana step (fig. 3).

The **Aulat Formation** is the name given to the Albian section of the Afghan-Tajik Basin (VNIGNI, 2005a). The Albian section is composed of limestone, mudstone, siltstone, and sandstone. The upper portion of the upper Aptian to lower Albian interval in northern Afghanistan consists of calcareous sandstone and mudstone overlain by dark gray to black mudstone (Dastyar and others, 1990).

Derbent suite (lower Albian) In the Afghan-Tajik Basin, the Derbent suite consists of mudstone up to 75 meters thick passing into continental sandstone and mudstone of the Mingbatman suite containing a freshwater fauna (Dzhalilov and others, 1982).

Luchak suite (middle Albian) In the Afghan-Tajik Basin, the Luchak suite consists of organogenic limestone, mudstone, and marl from 100 to 150 meters thick (Dzhalilov and others, 1982; Dastyar and others, 1990). The section is transgressive across the Mingbatman suite and reached the Darvaz area (Dzhalilov and others, 1982).

Akkapchigai suite (upper Albian) In the Afghan-Tajik Basin, the Akkapchigai suite consists of mudstone and sandstone from 40 to 110 meters thick (Dzhalilov and others, 1982). The section grades eastward into variegated gypsum-bearing sandy mudstone with brackish water fauna of the Dzhetymtaus suite (Dzhalilov and others, 1982).

Shirabad suite (upper Albian) In the Afghan-Tajik Basin, the Shirabad suite consists of green sandstone and gypsum up to 50 meters thick (Dzhalilov and others, 1982; Dastyar and others, 1990). Eastward, at southwest Darvaz, the section is replaced by up to 110 meters of red sandstone of the Khozretish suite (Dzhalilov and others, 1982).

Rocks of the **Cenomanian Stage** are divided into a lower sandy siltstone unit and an upper limestone unit, with a combined thickness of 50 to 300 meters (VZG, 2004).

In the Amu Darya Basin, the lower Cenomanian section contains sandstone and limestone overlain by mudstone and siltstone. The middle Cenomanian section is composed of sandstone and limestone and the upper Cenomanian section is composed of dark gray to black mudstone (VNIGNI, 2005b).

In the Afghan-Tajik Basin, the Cenomanian section becomes thicker from west to east. The section consists of mudstone, sandstone, argillaceous limestone, and gypsum to the west, with thickness ranging from 65 to 100 meters. To the east, the section consists of evaporite, limestone, sandstone, and conglomerate, with thickness ranging from 180 to 220 meters (VNIGNI, 2005a).

Three Cenomanian sequences are identified in the central part of the Afghan-Tajik Basin (Mamadzhanov, 1968). In the lower sequence, limestone and dolomite are in the eastern areas, calcareous siltstones are in the central basin, and coarser clastic deposits are in northern areas. The nearshore part of the marine basin was in the northwestern part of the basin where limestones with beds of siltstone and shale are present. Limestone with some mudstone is present to the southeast. To the south of the basin, near Tuyuntau and Aryktau, a thick (up to 80 meters) limestone without clastic material is present (fig. 7). The second sequence consists of gypsum in the northeast part of the basin and gypsiferous mudstone with limestone beds in the northwestern and southeastern parts. The overlying

Turonian section consists of thick marine mudstone with a rich fauna. Four Cenomanian suites in the Afghan-Tajik Basin are recognized by Dzhalilov and others (1982).

Tjubegatan suite (Cenomanian) In the Afghan-Tajik Basin, the Tjubegatan suite consists of nearshore and shelf mudstone, coquina, and sandstone 50 to 80 meters thick, becoming slope and basinal sediments eastward (Dzhalilov and others, 1982).

Karikansai suite (Cenomanian) In the Afghan-Tajik Basin, the Karikansai suite consists of mostly of 70 to 130 meters of mudstone to the west, becoming coarser and red in places eastward, consisting of siltstone and sandstone with gypsum (Dzhalilov and others, 1982).

Tagara suite (Cenomanian) In the Afghan-Tajik Basin, the Tagara suite consists of sandstone, detrital and oolitic limestone 30 to 50 meters thick with rudistids in western areas (Dzhalilov and others, 1982; Dastyar and others, 1990).

Gazdahana suite (Cenomanian) In the Afghan-Tajik Basin, the Gazdahana suite consists of dark gray mudstone with coquina interbeds 25 to 95 meters thick with limestone of the Idzhudarin suite replacing mudstone in eastern areas (Dzhalilov and others, 1982).

The **Turonian Stage** section consists of fossiliferous argillaceous rocks, predominantly mudstone, with marl and limestone beds (VZG, 2004). These rocks are assigned to lower and upper Turonian based on fossils. The maximum thickness is about 430 meters on the Andkhoy uplift.

In the Afghan-Tajik Basin, the lower Turonian section is calcareous with marl, sandstone, green mudstone, and limestone (Dastyar and others, 1990; VNIGNI, 2005a). The thickness is 30 to 200 meters on the west and 15 to 45 meters on the east (Darvaz). The Upper Turonian section is similar to the lower Turonian section but with increasing limestone to the east. Reddish mudstone and gypsum are present in the upper part of the section. The thickness varies from 15 to 45 meters on the east to 50 to 80 meters on the west.

Talhab suite (lower Turonian) In the Afghan-Tajik Basin, the Talhab suite consists of dark gray mudstone with marl interbeds near the base 10 to 120 meters thick (Dzhalilov and others, 1982).

Dazgiriak suite (upper Turonian) In the Afghan-Tajik Basin, the Dazgiriak suite is 10 to 55 meters thick and consists of green mudstone with marl and coquina interbeds (Dzhalilov and others, 1982).

Muzrabat suite (upper Turonian) In the Afghan-Tajik Basin, the Muzrabat suite consists of gray mudstone with limestone and gypsum interbeds 34 to 45 meters thick in western areas and red siltstone and sandstone with thicker gypsum and brackish water fauna to the east (Dzhalilov and others, 1982).

Rocks of the **Coniacian Stage** consist of dark-gray mudstone containing gypsum with interlayers of fossiliferous limestones (VZG, 2004). Rich fauna in these rocks allows the section to be divided into lower and upper sub-stages. Fossils at the base of the section belong to the lower Coniacian sub-stage. The maximum thickness is up to 110 meters. A marly and calcareous argillaceous member assigned to the upper Coniacian sub-stage is a regional marker bed. A gas pool with condensate is found in this unit on the Etym Tag structure. The thickness of this unit ranges from several meters to 65 meters.

Modun suite (Coniacian) In the Afghan-Tajik Basin, the Modun suite consists of mudstone with coquina interbeds 50 to 1,000 meters thick (Dzhalilov and others, 1982). Carbonate interbeds become thicker eastward.

Akrabat suite (Coniacian) In the Afghan-Tajik Basin, the Akrabat suite consists of gray mudstone with pale gray marl and limestone interbeds 50 to 70 meters thick (Dzhalilov and others, 1982). Carbonate interbeds become thicker eastward.

The **Santonian Stage** section is eroded over a significant part of the area. The rocks are predominantly argillaceous of variable thickness, ranging from 50 to 186 meters (VZG, 2004).

In the Afghan-Tajik Basin, the lower part of the Santonian section contains marine sediments, including limestone, mudstone, siltstone, and sandstone at the base (Dastyar and others, 1990; VNIGNI, 2005a). The upper part was deposited in a lagoonal environment and consists of mudstone, gypsum, and sandstone. The thickness, from west to east, is 90 to 220 meters in southern Gissar, 50 to160 meters at the Vakhsh megasyncline and Kafirnigan meganticline, and 50 to 180 meters in the Darvaz foothills.

Kattakamysh suite (Santonian) In the Afghan-Tajik Basin, the Kattakamysh suite consists of gray ferruginous mudstone 110 to 200 meters thick in southwestern areas (Dzhalilov and others, 1982). To the north and east, the suite consists of a lower mudstone with limestone and siltstone interbeds 40 to 75 meters thick overlain by variegated siltstone and sandstone with gypsum interbeds 50 to 100 meters thick. The lower part is mostly limestone in far eastern areas.

Campanian Stage Sedimentation was relatively continuous throughout the Upper Cretaceous until the end of the Upper Campanian (VZG, 2004). At this time, a significant part of the North Afghanistan region was uplifted and previously deposited Upper Cretaceous sediments were eroded. Preserved sections of the lower Campanian consist of interbedded mudstone, sandstone, and coquinoid limestone, with thickness ranging from 40 to 80 meters (Dastyar and others, 1990; VZG, 2004).

In northern Afghanistan, upper Campanian rocks are divided into two members, a sandy argillaceous member up to 580 meters thick and a carbonate member (Dastyar and others, 1990; VZG, 2004).

Upper Campanian rocks in northern Afghanistan transgressively overlie rocks of various Cretaceous and Jurassic ages and have a clastic-rich (transgressive lag?) base (Bratash, 1969; Dastyar and others, 1990).

In the Afghan-Tajik Basin, the Campanian interval is composed of limestone and mudstone (VNIGNI, 2005a). The thickness is up to 130 meters in the Dushanbe step, 5 to 220 meters in Vakhsh-Kafirnigan region, and 50 to 300 meters in the Darvaz zone. The Campanian is composed of organogenic limestone 30 to 110 meters thick east of the Vaksh River (Dzhalilov and others, 1982).

Sarykamish suite (Campanian) The Sarykamish suite consists of gray mudstone and siltstone with coquina interbeds 15 to 140 meters thick in the Afghan-Tajik Basin (Dzhalilov and others, 1982).

Daralitau suite (Campanian) In the Afghan-Tajik Basin, the Daralitau suite consists of gray-blue mudstone and siltstone with coquina interbeds 90 to 200 meters thick west of the basin center, and mudstone with coquina interbeds and bluish-gray marl 10 to 25 meters thick in eastern areas (Dzhalilov and others, 1982).

Ghory suite (Campanian to Paleogene) The Ghory suite represents a continuous series of rocks from the upper Campanian to the Thanetian Stage of the Paleocene (VZG, 2004). The thickness of the Ghory limestone ranges from 150 to 170 meters on the Maimana step to 640 meters on the Shiram structure (fig. 7). The carbonate member of the upper Campanian together with limestone of the Maastrichtian constitute the lower part of a thick carbonate series of the Ghory suite. In the Amu Darya Basin, upper Maastrichtian section contains limestone with rudists (VNIGNI, 2005b).

The Ghory Formation (Maastrichtian to Paleocene) in northern Afghanistan is 150 meters thick on the Maimana step and at Jangali Kalan Field, 640 meters thick at Sheram structure, 500 to 600 meters thick at the Qunduz area, and 920 meters thick at the eastern margin of the Afghan-Tajik Basin (at Dakhanitor or Dahanishor) (Bratash, 1969).

In the Afghan-Tajik Basin, the Maastrichtian consists of mainly limestone (VNIGNI, 2005a). Sandstone is present in the southwestern Gissar spur. The thickness changes from west to east, from 15 to 30 meters in foothills of the Gissar range, to 10 to 60 meters in the Kafirnigan meganticline, to 50 to 170 meters in the Vakhsh megasyncline. In the Dushanbe step, the Maastrichtian is not identified (VNIGNI, 2005a).

Udantau suite (Maastrichtian) In the Afghan-Tajik Basin, the Udantau suite consists of gray and variegated sandstone and siltstone 60 to 90 meters thick in western parts of the basin, and bluish-gray limestone and organogenic limestone 25 to 90 meters thick in the central and eastern parts of the basin (Dzhalilov and others, 1982; Dastyar and others, 1990).

Bulgary suite (Maastrichtian) In the Afghan-Tajik Basin, the Bulgary suite consists of limestone, arenaceous limestone, and coquina 10 to 50 meters thick (Dzhalilov and others, 1982; Dastyar and others, 1990).

Bukhara series (Paleocene) Paleogene deposits are more complete in the northeastern and northwestern regions of Afghanistan (VZG, 2004). Paleogene sediments were deposited in lagoonal and marine conditions. The thickness of the Paleocene deposits increase from northwest to southeast from 150 to 650 meters. The section increases in thickness from 40 meters at the basin edge to 350 meters toward the central part of the basin. In the Afghan-Tajik Basin, the Bukhara member consists of light- and dark-gray limestone with anhydrite from 150 to 200 meters thick (VNIGNI, 2005a).

The Bukhara series to some extent corresponds to upper massive limestone of the Ghory suite (VZG, 2004). Three members are identified in the Bukhara series of the Amu Darya and Afghan-Tajik Basins, the lower ***Tabakchin*** or ***Akdzhar***,(carbonates), the middle ***Aruktau*** or Shiram (anhydrite), and the upper ***Karatag*** (carbonates and clastics) (Kreydenkov and Ashurov, 1971; VZG, 2004; VNIGNI, 2005a).

The ***Akdzhar member*** is a section in the middle of the Ghory suite consisting of laminated limestone (VZG, 2004). In the Afghan-Tajik Basin, the member consists of white and red anhydrite with interlayers of mudstone and dolostone from 100 to 200 meters thick (VNIGNI, 2005a). In the Afghan-Tajik Basin, the Akdzhar member consists of gypsum, dolostone, and red mudstone, with interbeds of red sandstone and siltstone in some areas, from 10 to 250 meters thick, which conformably overlies Maastrichtian limestone throughout much of the area with some exceptions (Dzhalilov and others, 1982). The Tabakchin member of the Afghan-Tajik Basin consists of limestone, rare dolostone, and gypsum (Dzhalilov and others, 1982). The Tabakchin in the south-central part of the basin contains normal marine fossils and many nummulites, which compose most of the rock in the upper part of the section (Kreydenkov and Ashurov, 1971). To the west (southwest Gissar spur), east, and north (Kaplaukyr complex), the fauna are not as abundant because of abnormal salinity conditions (Kreydenkov and Ashurov, 1971).

The Aruktau member of the Afghan-Tajik Basin consists of gray calcareous mudstone and marl, in places grading into limestone and is overlain by gypsum with rare interbeds of dolostone (Dzhalilov and others, 1982).

The Karatag member of the Afghan-Tajik Basin consists of gray marl and argillaceous limestone and calcareous mudstone (Dzhalilov and others, 1982).

Eocene The Eocene stratigraphic interval is divided into four sections, the Suzak, Alay, Turkestan, and Talikan (includes Rishtan, Isfarin, and Khanabad beds) (Dastyar and others, 1990; VZG, 2004; VNIGNI, 2005b).

The ***Suzak section*** is early Eocene in age and includes the ***Givar horizon***, which is divided into the ***Kaptar beds*** in the lower part and ***Baymin beds*** in the upper part. The Suzak section is most complete in the Afghan-Tajik Basin. In the Afghan-Tajik Basin, distal Suzak beds are grayish green mudstone and proximal beds are composed of sand and silt material (Babkov and others, 1972; Dzhalilov and others, 1982). The Suzak mudstone is rich in illite and montmorillonite and ranges in thickness from 10 to 180 meters, thinning to the east and northeast (Pokryshkin, 1981). To the east and northeast, the mudstone becomes more calcareous, and beds of sandstone and carbonate rocks appear (Buzurukov and others, 1978). The mudstone beds pass into sandstone toward the south (Babkov and others, 1972). The change from Bukhara sediments to Suzak mudstone was caused by a general deepening of the basin and not any paleogeographic event (Kreydenkov and Ashurov, 1971).

The ***Alay section*** is middle Eocene in age and consists of interbedded limestone, marl, green mudstone and sandstone (Dastyar and others, 1990; VZG, 2004). The thickness ranges up to 130 meters. The Alay section in the Afghan-Tajik Basin consists of gray and dark-gray limestone and reddish mudstone 30 to 200 meters thick (VNIGNI, 2005a). Lagoonal limestone (with some concentrations of shells), mudstone, sandstone, and gypsum are present in the central part of the basin (VNIGNI, 2005a). The section becomes more terrigenous toward the west and northwest, closer to mountains (VNIGNI, 2005a). The total thickness ranges from 30 to 120 meters (VNIGNI, 2005a).

Dzhalilov and others (1982) divide the lower Eocene stratigraphic interval of the Afghan-Tajik Basin into the ***Jukar*** and ***Beshkent horizons***. The Jukar horizon consists of variegated calcareous mudstone, marl, limestone, coquina, and sandstone, with interbeds of dolostone and gypsum to the west and interbeds of red mudstone, siltstone, and sandstone eastward (Dzhalilov and others, 1982). This horizon is assumed to be equivalent to the Alay section. The Beshkent horizon is composed of the ***Gandzhin layers*** and the overlying Turkestan section (Dzhalilov and others, 1982). The Gandzhin layers consist of gray calcareous mudstone with interbeds of marl, coquina, limestone, and sandstone up to 60 meters thick and are probably laterally equivalent to the Alay section.

Commercial phosphate deposits are present in upper Alay beds of the Afghan-Tajik Basin (Pokryshkin, 1981). Upper Alay phosphorites are clasts in sandstone (grain size to 3 millimeters) and phosphatized fossils (Pokryshkin, 1981).

The ***Galachagar Series*** of the Parapamiz-Bande Turkestan range consists of intermediate to basic porphyry volcanic rocks that are from 210 to 1,410 meters thick (Dastyar and others, 1990).

The ***Turkestan section*** is lowermost upper Eocene in age (VZG, 2004). The Turkestan section is eroded over much of northern Afghanistan, but is preserved in the Afghan-Tajik Basin near the towns of Konduz and Kholm, and at the Maimana step (Badkhyz-Karabil uplift of northwestern Afghanistan) (VZG, 2004). In the Afghan-Tajik Basin of northern Afghanistan, the section consists of interbedded variegated sandstone, siltstone, and mudstone 80 to 120 meters thick (Dastyar and others, 1990; VZG, 2004). The section at the Maimana step is significantly different, consisting of sandstone interbedded with mudstone, marl, and beds of basalt and tuff with a thickness of about 160 meters (Dastyar and others, 1990; VZG, 2004).

In the Afghan-Tajik Basin, the Turkestan section consists of greenish-gray mudstone and mudstone, 50 to 140 meters thick (Dzhalilov and others, 1982; VNIGNI, 2005a).

Talikan suite The overlying Talikan suite is uppermost upper Eocene in age and consists of variegated mudstone with sandstone and limestone interlayers (VZG, 2004). Over a significant portion of the Afghan-Tajik Basin, the Talikan suite is divided into the ***Rishtan***, ***Isfarin*** and, ***Khanabad members*** (VZG, 2004). In northern Afghanistan, these members are identified only in outcrops along the Amu Darya River (VZG, 2004).

In the Afghan-Tajik Basin, the Rishtan, Isfarin and, Khanabad members are present only in the central part of the region and are mainly mudstone with some sandstone and minor limestone (VNIGNI, 2005a). The Rishtan member is 80 to 200 meters thick and consists of red mudstone and white anhydrite (VNIGNI, 2005a). The Isfarin and Khanabad members consist of greenish- and bluish-gray mudstone up to 100 meters thick (VNIGNI, 2005a).

The ***Tochar horizon*** in the Afghan-Tajik Basin consists of a lower sandstone member with mudstone, coarse-grained sandstone, and white gypsum up to 40 meters thick (Dzhalilov and others, 1982). The upper member consists of mudstone, siltstone, and sandstone with coarse-grained sandstone lenses up to 175 meters thick (Dzhalilov and others, 1982). The amount of detrital material and red beds decrease westward (Dzhalilov and others, 1982).

The ***Kushan horizon*** of the Afghan-Tajik Basin consists of gray mudstone up to 175 meters thick with rare interbeds of limestone, coquina and, near the top, reddish-brown mudstone (Dzhalilov and others, 1982).

The top of the Eocene interval is eroded in the Afghan-Tajik Basin, with the brown and red mudstone and sandstone of the ***Sanglak horizon*** preserved only in the eastern part of the basin (Dzhalilov and others, 1982).

The Oligocene is largely absent (eroded) in southern Uzbekistan and northern Afghanistan (Egamberdyev and Mayvandi, 1992).

Sumsar section The Sumsar section is Oligocene in age and unconformably overlies the Turkestan section over much of the southeastern Amu Darya Basin (VZG, 2004). The

Sumsar section is composed of marine and continental sandstone and silty argillaceous rocks, ranging from 30 to 74 meters thick (VZG, 2004; VNIGNI, 2005b).

In the Afghan-Tajik Basin, the Oligocene interval is called the **Bol'dzhua suite** and has two members (Dzhalilov and others, 1982). The lowermost member is the ***Sumsar member*** and consists of red-colored marine mudstone 150 meters thick (VNIGNI, 2005a). The Sumsar member is overlain by the ***Shurysay member***, which consists of red-colored gypsiferous mudstone, sandstone, and siltstone, ranging from 200 to 250 meters thick (VNIGNI, 2005a).

In the Afghan-Tajik Basin, the lowermost member, called the ***Hissarak member***, unconformably overlies older Paleogene rocks and consists of alternating bluish and greenish-gray sandstone and reddish-brown mudstone, siltstone, and sandstone up to 130 meters thick (Dzhalilov and others, 1982). Stromatolitic limestone and gypsum intercalations are present in some areas (Dzhalilov and others, 1982).

The Shurysay member in the Afghan-Tajik Basin unconformably overlies the Hissarak and Sanglak horizons (Dzhalilov and others, 1982). The Shurysay member consists of alternating brown and red mudstone, sandstone, and siltstone with gypsum and less common limestone up to 190 meters thick (Dzhalilov and others, 1982).

Neogene rocks overlying the Sumsar section include continental lacustrine, fluvial, deltaic, and lacustrine-marine sediments (in the west) (VZG, 2004; VNIGNI, 2005b). The formation of the Neogene red-colored and gray-colored continental ororgenic clastic rocks took place under the conditions of intense downwarping of the earth crust and of active mountain building (VZG, 2004). Rare fossil fauna and flora allow this interval to be divided into the Shefai and Koshtangin suites (VZG, 2004). Neogene deposits are part of an orogenic complex represented by continental sediments in the Afghan-Tajik Basin (Dzhalilov and others, 1982).

Shefai suite The Shefai suite is composed of interbedded conglomerate with bright-red calcareous mudstone, sandstone and siltstone up to 660 meters thick (Dastyar and others, 1990; VZG, 2004).

Balzuan suite The lower Miocene Balzuan suite in the Afghan-Tajik Basin is subdivided into the ***Kamoli*** and ***Childara members*** (Dzhalilov and others, 1982).

In the Afghan-Tajik Basin, the Kamoli member unconformably overlies Shurysay and Hissarak rocks and consists of massive and coarse laminated sandstone with rare interbeds of mudstone, siltstone, and conglomerate ranging from 180 to 310 meters thick (Dzhalilov and others, 1982). The overlying Childara member consists of red sandstone and siltstone from 175 to 800 meters thick (Dzhalilov and others, 1982).

Koshtangin suite The most complete sections of the overlying Koshtangin suite are in northeastern Afghanistan (VZG, 2004). The Koshtangin suite is quite similar in lithologic composition to the Shefai suite, but the Koshtangin suite differs in the presence of more conglomerate, with orange-brown color in the bottom part of the section (Dastyar and others, 1990; VZG, 2004). The thickness ranges greatly, from 600 to 2,800 meters (VZG, 2004). Limestone interbeds are present between Sheberghan and Kholm (fig. 7) (Dastyar and others, 1990). In northern Afghanistan, the Koshtangin conformably overlies the Shefai suite to the east, but unconformably overlies it to the west (Dastyar and others, 1990).

Kingou and **Tavildara suites** In the Afghan-Tajik Basin, the upper Miocene interval is divided into the Kingou and Tavildara suites (Dzhalilov and others, 1982).

The Kingou suite is present only in the eastern part of the Afghan-Tajik Basin and consists of gray and red-brown sandstone, siltstone, and mudstone with lenses of coarse-grained sandstone and conglomerate ranging from 230 to 1,500 meters thick (Dzhalilov and others, 1982). The Tavildara suite consists of coarse and massive laminated gray and "lilac" sandstone and conglomerate up to 2,500 meters thick (Dzhalilov and others, 1982). Fossil flora indicates desert conditions at the time of deposition (Dzhalilov and others, 1982).

Rustak suite The Rustak suite occurs at the base of the Pliocene section and occupies vast areas in the eastern part of the Amu Darya Basin (VZG, 2004). Basal layers of the suite are composed of conglomerate (VZG, 2004). Above the basal layers, the section consists of uneven alternating siltstone, gray-colored poorly sorted sandstone, conglomerate (VZG, 2004). The thickness ranges from 2,000 to 3,000 meters (VZG, 2004).

Kokchin suite The Kokchin suite is a thick clastic section consisting of alternating gray sandstone, sandy siltstone and mudstone (Dastyar and others, 1990; VZG, 2004). The suite has extreme variations in thickness, from several hundreds of meters to 7,000 meters (VZG, 2004). The Kokchin suite grades unconformably into conglomerate-sandstone rocks of the ***Keshm suite*** (VZG, 2004).

Keshm suite The Keshm suite consists of coarse-grained, cross-bedded sandstone and conglomerate (VZG, 2004). Mudstone is rare (VZG, 2004). The thickness may reach 4,000 meters (VZG, 2004).

Karanak suite (Pliocene) the Karanak suite of the Afghan-Tajik Basin consists of red-brown and pale brown siltstone and clay-rich sandstone with interbeds of conglomerate and some gypsum, ranging from 30 to 1,130 meters thick (Dzhalilov and others, 1982). Conglomerate content increases towards the basin margins (Dzhalilov and others, 1982).

Polizak suite (Pliocene) In the Afghan-Tajik Basin, the Polizak suite consists of gray sandstone, intercalations of gray, red-brownish-gray, and red-brown mudstone and siltstone, and interbeds and lenses, ranging from 190 to 490 meters thick (Dzhalilov and others, 1982). The upper Pliocene **Kuruksay suite** overlies the Polizak suite (Dzhalilov and others, 1982). In the Amu Darya Basin, mostly gray- and brown-colored rocks occur in the upper part of the Pliocene section (VZG, 2004).

Kulyab suite (Quaternary) Quaternary deposits are present at the top of the sedimentary cover, ranging in thickness from 1,000 to 1,700 meters (VZG, 2004). In the Afghan-Tajik Basin, the oldest Quaternary deposits are sand, mud, and conglomerate (VNIGNI, 2005a). The lower Quaternary Kulyab section is 600 to 1,000 meters thick and is probably of lacustrine origin. The Kulyab section is slightly deformed and unconformably overlies older rocks (VNIGNI, 2005a). Younger Quaternary sediments consist of alluvial sand, mud, loess, and massive debris flows. Quaternary eolian deposits are widely present in the Amu Darya Basin (VNIGNI, 2005b).

TOTAL PETROLEUM SYSTEMS

Afghanistan has five major sedimentary basins with petroleum exploration potential, the Amu Darya, Afghan-Tajik, and Herat (Tirpul) Basins (fig. 3); and and on the Helmund (Gelmend or Sistan) and Katawaz (Kundar-Urgan) blocks (fig. 5). The Amu Darya Basin in the northwest of Afghanistan contains known petroleum reserves and the Afghan-Tajik Basin to the northeast has undrilled structures in prospective areas (fig. 7). Natural gas is Afghanistan's major known petroleum resource and is found in Mesozoic and Cenozoic sediments (Nathan Associates Inc., and Louis Berger International, Inc., 1992; Economic and Social Commission for Asia and the Pacific, 1995).

Four total petroleum systems were identified in this study; eight assessment units were defined within these total petroleum systems for the purpose of resource assessment (table 1, figs. 8 through 11). Three of these total petroleum systems are parts of a pre-cursor single pre-Neogene total petroleum system that was located mainly in the Amu Darya Basin but extended into the Afghan-Tajik Basin. The total petroleum systems are (1) Amu Darya Jurassic-Cretaceous, (2) Kalaimor-Kaisar Jurassic, (3) Afghan-Tajik Jurassic, and (4) Afghan-Tajik Paleogene.

Thermally mature source rocks of Jurassic age charged predominantly carbonate reservoirs with natural gas below a thick (up to 800 meters) salt seal. Clastic reservoirs of Cretaceous age (above the Jurassic section) are charged with natural gas and crude oil where the salt is absent. A younger Paleogene total petroleum system overlies the Jurassic System in the Afghan-Tajik Basin. Here, the Jurassic and Paleogene total petroleum systems are separated by thick Jurassic salt in thrust-fault sheets. The Paleogene total petroleum system is oil-prone whereas the Jurassic total petroleum systems are gas-prone.

Elements of the Amu Darya Jurassic-Cretaceous Total Petroleum System and the Afghan-Tajik Jurassic Total Petroleum System include Lower to Middle Jurassic carbonaceous mudstone and coal and Upper Jurassic basinal marine mudstone source rocks; Upper Jurassic carbonate and Lower Cretaceous clastic reservoirs; Upper Jurassic evaporites and Lower Cretaceous mudstones seals; and Mesozoic and Cenozoic structures and reef-related traps. The third, Kalaimor-Kaisar Jurassic Total Petroleum System includes only Lower to Middle Jurassic carbonaceous mudstone and coal source rocks; Lower to Middle Jurassic and Lower Cretaceous clastic reservoirs and Upper Cretaceous carbonate reservoirs; intraformational Jurassic, Cretaceous, and Paleogene mudstones seals; and Mesozoic- and Cenozoic-age structures as traps.

The Paleogene Total Petroleum System has not been previously recognized in the Afghan-Tajik Basin. The source rocks for crude oil in this basin have not been identified by previous studies. This system is composed of lower Eocene basinal marine mudstone source rocks; Upper Cretaceous to Paleogene reservoirs; lower Eocene and upper Paleogene mudstone seals; and Neogene compressional structures associated with Himalayan orogenesis as traps. Evaporite-evacuation sites (areas where evaporite is absent) might have allowed local mixing of Jurassic-sourced petroleum with Paleogene-sourced petroleum. Anticlinal structures in the eastern part of the basin are eroded and some are breached, resulting in biodegradation and leakage of petroleum.

Another unnamed total petroleum system includes Lower to Middle Jurassic carbonaceous mudstone and coal on the North Afghan High where coalbed gas accumulations may be present. The presence and extent of the Lower to Middle Jurassic section on the North Afghan High are unknown and consequently the coalbed gas resources were not assessed in this total petroleum system.

The eight assessment units were defined with homogeneous geologic traits and exploration efforts that constitute sufficiently homogeneous populations for resource assessment. All assessment units are located within Afghanistan.

Geochemistry

Petroleum has not been produced from the Afghan-Tajik part of northern Afghanistan but petroleum is produced across the border in neighboring Uzbekistan and Tajikistan. The source rocks for the crude oil have not been definitively identified. Jurassic source rocks of the Amu Darya Basin exist beneath thrust sheets, but are deeply buried and have been subjected to gas-generation temperatures. Although these rocks were suspected to be the source of petroleum in the Afghan-Tajik Basin, their great burial depth below the impervious Upper Jurassic salt precludes the sourcing of suprasalt reservoirs except where salt may be absent. Organic-rich Eocene-age Suzak (also called Givar) mudstone has been described by geologists for many years. Based on petroleum-generation models and geochemical analyses of source rock extracts and crude oils conducted at the USGS, the Suzak mudstone may be the source of oil in the Afghan-Tajik Basin. USGS data indicate the existence of this previously unrecognized Paleogene oil-prone total petroleum system.

Basin-subsidence curves and PETROMOD one-dimensional petroleum-generation models were constructed for this study based on rock thicknesses derived from two regional cross sections. One cross section represents northern Afghanistan and the other represents southern Tajikistan. Profiles from cross sections through synclines were used for modeling. One interval is immediately west of the Afghanistan Gunj structure and the other is between the Tajikistan Aryktau and Khodzha Kazian structures (locations on map on fig. 7). Thicknesses of the individual rock-time intervals were measured directly from the cross sections and amounts of erosion were estimated by calculating the difference between the measured thickness of each profile and the maximum thickness in the same or nearby locations along the cross section. Basin-subsidence curves were then constructed from these thicknesses (fig. 12). In addition, because late Neogene and Quaternary tectonic events greatly influenced the maturation of source rocks and timing of petroleum expulsion and accumulation, the deposition and erosion history of Quaternary deposits at the nearby mouths of the Vakhsh and Pyandzh Rivers (located between the two profiles) was incorporated into the basin-subsidence curves.

The basin-subsidence curves are reasonably similar to one another and to a curve constructed by Yakovets (1976). Some differences in subsidence rates and ages of pre-Quaternary unconformity result from different rock-unit groups between the two original cross sections. The pre-Quaternary uplift event and resulting unconformity, as well as three erosional events during the Quaternary, are shown by both curves. The age of the pre-Quaternary and pre-Neogene erosional events are shown to be a few million years older on the northern Afghanistan curve. These discrepancies do not significantly change the interpretation of the overall basin subsidence and basinal heat-flow histories.

A postulated basinal heat flow was used in the PETROMOD model, which was determined from basin models developed by McCabe (USGS, 2006, personal communication). The Afghan-Tajik Basin was an intracratonic rift sag basin throughout most of the Cretaceous and Paleogene and a foreland basin since late Neogene (Miocene) time. Typically, heat flow in rift sag basins range from 35 to 65 milliwatts per square meter (McCabe, USGS, 2006 personal communication). A mean heat flow for rift sag basins of 50 milliwatts per square meter was used in this study for both basin types. Typically, higher heat flows are associated with foreland basins (up to 100 milliwatts per square meter), but because subsidence and high sedimentation rates occurred very recently, the lower heat flow was assumed to account for non-equilibrated temperatures.

Geothermal gradients for three depth intervals within the Afghan-Tajik Basin reported by Gotgilf and others (1969) were incorporated to calibrate the temperatures used in the model. The gradients are 25 degrees C per kilometer for the Neogene interval, 32 degrees C per kilometer for the Eocene to Oligocene interval, and 20 degrees C per kilometer for the Paleocene interval. These geothermal gradients are consistent with those reported by Krylov (1980) for the Afghan-Tajik Basin; 24 to 30 degrees C per kilometer to 4.5 kilometers depth and 25 to 29 degrees C per kilometer to 6 to 7 kilometers depth.

A surface temperature of 20 degrees C was assumed for the entire basin history. The gradients provide approximate temperatures of 108 degrees C at 3,531 meters depth, 117 degrees C at 3,816 meters depth, and 164 degrees C at 6,164 meters depth for the Afghanistan section and 150 degrees C at 5,200 meters depth, 163 degrees C at 5,600 meters depth, and 209 degrees C at 7,900 meters depth for the Tajikistan section. Paleo-geothermal gradients were matched to the measured vitrinite reflectance values. Vitrinite reflectance was measured by the USGS from two wells in the Afghan-Tajik Basin of northern Afghanistan that are located along the cross section used to construct the basin-subsidence curve. The vitrinite-reflectance samples are from Upper Cretaceous to lower Paleogene rocks (Bukhara beds, 2,658 to 2,667 meters) of the Balkh # 1 well and Lower to Upper Cretaceous rocks (Barremian to Campanian, 2,935 to 2,942 meters depth) of the Sanduqli #1 well. The mean and standard deviation of the vitrinite reflectance values are 0.94 percent and 0.14 (3 samples) for the Balkh well samples and 1.53 percent and 0.23 (5 samples) for the Sanduqli samples.

The PETROMOD model indicates that the Eocene Suzak mudstone was thermally mature and in an oil-generation temperature regime (oil window) by early Neogene time, thereby supporting the hypothesis of the existence of a Paleogene total petroleum system in the Afghan-Tajik Basin (fig. 13). Late Neogene and Quaternary tectonic events uplifted some areas to place the Suzak mudstone above the oil-generation conditions. The model indicates that the Suzak mudstone becomes mature at depths of 2,470 meters in

Afghanistan and 3,200 meters in Tajikistan. A map of the present-day distribution of thermal maturation of Suzak mudstone in terms of burial depth was constructed from the model (fig. 14).

Many crude oil, natural gas, and source rock samples have been collected from wells, fields, and outcrops in northern Afghanistan and Tajikistan to relate crude oil and natural gas to postulated source rocks (fig. 7). Additionally, results of geochemical analyses of crude oil and source-rock extracts from the Uzbekistan part of the Amu Darya Basin by British Petroleum (BP) as reported by VNIGNI, (2005a) are used for comparative purposes. Biomarker and stable carbon isotope analysis of crude oil and source rock extracts demonstrate different petroleum systems. A database of the analytical results is provided in the appendix, but a summary and interpretations are given in this part of the text. Crude oil families, source-rock type, maturity, and relative aerobic/anoxic conditions of the water-sediment interface during source-rock deposition interpreted from these data indicate that crude oil in the Amu Darya Basin is different from that of the Afghan-Tajik Basin. Although geochemical correlation of the proposed Paleogene source rock with crude oil in the Afghan-Tajik Basin is inconclusive, at present, the geochemical character of the extracts from these rocks more closely resemble that of the Afghan-Tajik crude oils than the Amu Darya crude oils.

Outcrop samples of Suzak mudstone from northern Afghanistan and southern Tajikistan, along with core samples from Qunduz #3 well of northern Afghanistan, and Khodzhasartis

#18, Kyzylsu #5, and Tanapchi #5 of Tajikistan were analyzed to determine crude oil source potential (fig. 7). Samples collected from outcrops in the Afghan-Tajik Basin are poor due to extreme weathering (fig. 15). Only a few outcrop samples and core samples of the Suzak mudstone contained enough organic matter to be adequately analyzed geochemically, although many more samples provided total organic carbon, vitrinite reflectance, and pyrolysis information (fig. 16). Most of the samples have mean vitrinite reflectance values between 0.9 and 1.5 percent, indicating that the organic matter is thermally mature and within the realm of of crude oil generation. Two samples have vitrinite reflectance values of approximately 2 percent, capable of natural gas generation. One aberrant sample probably contains reworked (recycled) vitrinite with a reflectance value of 5.6 percent.

Total organic carbon content of Suzak mudstone outcrop samples is generally low, averaging approximately 0.4 weight percent (fig. 16). Only two outcrop samples contain total organic carbon greater than 1 weight percent, both approximately 1.3 weight percent. Two Suzak mudstone core samples from the Qunduz #3 well of northern Afghanistan (fig. 7) have total organic matter contents of 13.9 and 19.7 weight percent, indicating that these rocks are capable of generating petroleum.

Results from pyrolysis analysis (Rock-Eval) indicate that the two core samples are thermally immature (Tmax less than 435 degrees C), never buried deeply enough to be in the temperature regime for crude oil generation (fig. 16). Additionally, most of the Suzak mudstone outcrop samples were found to be thermally immature as well. Organic matter in two outcrop samples, however, is highly mature to post mature (Tmax greater than 465 degrees C).

Pyrolysis analysis of the Suzak mudstone also indicates that most of the outcrop samples contain natural gas-prone type III kerogen (fig. 16). The Qunduz #3 well core samples and a few outcrop samples contain crude oil-prone type II kerogen.

Crude oil samples from Tajikistan oil-producing fields of the Afghan-Tajik Basin, Ghory reservoir rocks in Kaldar #1 well core (northern Afghanistan), and extracts from Suzak mudstone from outcrops and the Qunduz #3 well were analyzed to determine source rock potential (figs. 7 and 17A through K). Crude oil samples from the Amu Darya (Angut, Aq Darya, and Qash Qari Fields) and Herat Basins (Ahmad Abad well) of northern Afghanistan, as well as the results of BP's geochemical analysis of crude oil and extracts from the Uzbekistan part of the Amu Darya Basin (Chardzhou Step) were included for comparative purposes (fig. 17A).

Crude oil and crude oil extract samples tend to cluster when plotted with respect to the relative proportions of saturates, aromatics, and polar fractions (fig. 17B). Samples from Kaldar #1 and Qunduz #3 wells contain the greatest proportion of polar constituents. All but two of the Tajikistan crude oil samples plot together. The Amu Darya and Herat Basin samples from Afghanistan have similar proportions of each fraction. One Tajikistan sample has a composition similar to the Afghanistan Amu Darya samples. The Uzbekistan Amu Darya samples generally contain greater proportions of aromatic hydrocarbons, but one sample is rich in saturate hydrocarbons and is classified by BP as a condensate (from the Shurtan #1 well).

The crude oil and extract samples are differentiated with respect to stable carbon isotope data for saturated and aromatic hydrocarbon fractions (fig. 17C). Suzak mudstone extracts from the Qunduz #3 well core samples contain saturate and aromatic fractions that are isotopically light in terms of carbon 13 to carbon 12 ratios (greater than -30 per mil or parts per thousand, delta ^{13}C). Samples from both the Afghanistan and Uzbekistan parts of the Amu Darya Basin contain similar isotopic compositions. Most of the Tajikistan samples and Kaldar #1 samples contain similar isotopic compositions, heavier than those of the Amu Darya Basin samples. The Herat Basin sample is also isotopically similar to the Tajikistan samples. Two Tajikistan samples (Shaambari and Khodzhamumyn Fields), however, are isotopically lighter than the others.

Tajikistan crude oil is different from that of the Afghanistan Amu Darya samples with respect to sulfur content and crude oil density (as API gravity) (fig. 17D). The Takjikistan crude oils generally contain smaller amounts of sulfur and have lighter API gravities than the Amu Darya samples (all from Angut Field). Two Tajikistan crude oils, from Kichikbel and Akhbashadyr Fields, are different from the other samples having higher percentages of sulfur (6 to 7 percent) and heavier (11 to 14 degrees API). These two crude oil samples are interpreted to be water washed and partly biodegraded. The character of chromatographs supports this interpretation and evidence exists that perhaps more than one episode of migration, remigration, and biodegradation occurred.

Tajikistan crude oil is different from that of the Afghanistan Amu Darya samples with respect to sulfur content and the ratio of pristane to phytane (fig. 17E). As with crude oil density, crude oil samples from Kichikbel and Akhbashadyr Fields of Tajikistan are different from the other Tajikistan samples having much smaller pristane to phytane ratios (because of biodegradation?) as well as greater sulfur content. A crude oil sample from Herat Basin is different from the others, having a low pristane to phytane ratio (0.3)

Based on the relative proportions of the C27, C28, and C29 sterane biomarkers, crude oils from the Tajikistan fields are slightly different from the Afghan crude oils of the Amu Darya and Herat Basins, having a greater C29 content (fig. 17F, samples from the Uzbekistan part of the Amu Darya Basin are not included because data are unavailable). Extracts from the Qunduz #3 samples appear to be more similar to the Tajikistan samples than the other Afghanistan samples. One Afghanistan crude oil of the Amu Darya Basin, from Aq Darya Field, has a composition quite different from the other Amu Darya Basin samples.

Crude oil samples from the Tajikistan part of the Afghan-Tajik Basin, one of the Kaldar #1 samples, and the Herat Basin sample were most likely sourced from organic-rich clastic-rich mudstone, based on the C22/C21 and C29/C30 sterane ratios (fig. 17G). Also based on these ratios, crude oil samples from the Afghanistan part of the Amu Darya Basin were most likely sourced from organic-rich, fine-grained carbonate rocks. Two of the Kaldar #1 samples most likely had a clastic source rock based on C29/C30, but C22/C21 indicates that a carbonate source-rock component may have existed.

Source rocks for the Tajikistan crude oils and source rocks from cores and outcrops were most likely deposited in disoxic conditions based on C35/C34 (fig. 17H). Source rocks for the Kaldar #1, Herat Basin, and Afghanistan part of the Amu Darya Basin crude oils were most likely deposited in anoxic conditions as indicated by C35/C34.

Grouping of crude oil samples and extracts are also observed in the relations of diasterane and sterane ratios with respect to C29/C30 sterane ratio (fig. 17I) and pristane to phytane ratio (fig. 17J).

The C27 18a trisnorhopane to C27 17a trisnorhopane ratios (Ts/Tm) for the samples indicate that extracts from the outcrop and core samples of the Afghan-Tajik Basin, Kaldar #1, and the Herat Basin were derived from thermally immature source rocks (Ts/Tm less than 0.5) (fig. 17K). The Tajikistan and Afghanistan Amu Darya Basin crude oils were derived from thermally mature source rocks. Two Tajikistan crude oils, from Kichikbel and Akhbashadyr Fields, have low Ts/Tm probably as a result of water washing and biodegradation.

Oils in Paleogene reservoirs of the Dushanbe step and Afghan-Tajik Basin have iC_{19} to iC_{20} ratios of 0.81 to 1.74 and vanadium to nickel porphyrine ratios of 3.22 to 1.63 (Safranov and others, 1986). Non-biodegraded oils in Paleogene reservoirs of the Kulyab megasyncline are light, low sulfur, and the gases are wet (heavy hydrocarbon content of 9.75 to 12.64 percent) with 0.16 to 0.26 percent hydrogen sulfide (Safranov and others, 1986). In the Kulyab megasyncline, oils in Eocene reservoirs are not biodegraded and gas is mainly methane with high amounts of carbon dioxide and nitrogen (Safranov and others, 1986). Paleocene oils are paraffinic, heavy (density of 0.929 to 0.962 grams per cubic centimeter or 16 to 21 degrees API gravity), and contain abundant resins but few asphaltenes (1.5 to 10 percent) (Yakovets and Gotgilf, 1969). Sulfur content ranges from 1.92 to 4.33 percent and paraffin content ranges from 3.5 to 18.65 percent in these oils (Yakovets and Gotgilf, 1969). These oils have a paraffinic-naphthenic base (Yakovets and Gotgilf, 1969). Porphyrine content is high with dominant vanadium concentrations (Yakovets and Gotgilf, 1969). Alay oils (Shaambary and Lyalmikar Fields) are also paraffinic, similar to the Paleocene oils, but with a lighter hydrocarbon fraction (Yakovets and Gotgilf, 1969). Sulfur content ranges from 0.26 to 2.10 percent (Yakovets and Gotgilf, 1969). Small amounts of porphyrines are present, therefore nickel is in greater concentrations than vanadium (Yakovets and Gotgilf, 1969).

A water sample from the Paleogene (Ghory) reservoir flowing from the Gunj #2 well was analyzed for traces of hydrocarbons. The water is classified as sodium-calcium-sulfate composition, containing 773 parts per million sodium, 758 parts per million calcium, and

2,520 milligrams per liter sulfate. Other constituents include 1,590 milligrams per liter chloride, 249 parts per million magnesium, 37 parts per million silicon, 34 parts per million potassium, 31 milligrams per liter nitrate, 15 parts per million strontium, and minor concentrations of bicarbonate, bromine, fluoride, boron, lithium, and barium. The composition indicates that this water is a mixture of formation water associated with sulfate-rich evaporites and meteoric water. Meteoric water probably invaded from a recharge area approximately 75 kilometers to the south along the Alburz-Marmul fault where Ghory beds crop out.

Mineralization of water is not clearly related to depth in the Afghan-Tajik Basin (Safranov and others, 1983). At Khaudag Field, Tajikistan, formation water from Paleocene rocks at 160 meters contains 190 grams per liter of total dissolved solids (Safranov and others, 1983). At Dzeyrankana Field, Tajikistan, formation water from Paleocene rocks at 2,000 meters contains 5 to 10 grams per liter of total dissolved solids (Safranov and others, 1983). Crude oils are found associated with both low salinity waters with sulfates and with high salinity waters (Safranov and others, 1983).

In the Dushanbe step and North Afghan High, mineralization of water in Jurassic reservoirs is only 20 to 40 grams per liter compared to 250 to 400 grams per liter elsewhere (Safranov and others, 1986). Water in Eocene reservoirs are of different mineralization (20 to 100 grams per liter) having a complex chemical composition and low gas saturation in water (Safranov and others, 1986).

In Amu Darya Basin crude oil fields, such as Angut, formation waters have potassium carbonate and potassium sulfate compositions indicating meteoric-water invasion (Seregin and others, 1982).

AMU DARYA BASIN

Amu Darya Jurassic-Cretaceous Total Petroleum System (115401)

Discovery History:

Fifteen fields have been discovered in the Amu Darya Basin part of Afghanistan since 1957, the most recent discovered in 1984; seven are oil fields and eight are gas fields. Only about 3 of the gas fields are currently producing.

As a result of the discovery of petroleum accumulations in neighboring Uzbekistan and Turkmenistan, some oil companies began geologic studies of northern Afghanistan (particularly in the Amu Darya Basin) beginning in the 1930s (VZG, 2004). Exploration was conducted by gravimetric and magnetic mapping, drilling of shallow core holes, and reflection seismic surveys (Ulmishek, 2004). An evaluation of high petroleum potential resulted from work by England Exploration Company, which was corroborated by studies made later by R. Schlumberger in 1948 (VZG, 2004). Petroleum exploration started in northern Afghanistan in the middle to late 1950s with the drilling of shallow core wells at the Angut structure by the Swedish company Diamante in 1958 (VZG, 2004). Evidence of crude oil and natural gas was observed in Lower Cretaceous rocks (VZG, 2004). Crude oil was first discovered at Saripul in 1959. The first major crude oil field, Angut, was discovered in 1967, where some oil wells gushered and several thousand barrels per year of crude oil were produced (Nathan Associates Inc., and Louis Berger International, Inc., 1992). Five more oil fields have been discovered since Angut; the most recent field is Zamarud Sai, discovered in 1978. Crude oil production increased by about 20 percent per year through the 1970s (Nathan Associates Inc., and Louis Berger International, Inc., 1992). Crude oil is presumed to have been trucked to the USSR during the early 1970s, but later, the Soviets built two pipelines from the USSR to supply the needs of their military forces during their occupation of Afghanistan, as well as their Afghan government client (Nathan Associates Inc., and Louis Berger International, Inc., 1992). Crude oil production all but ceased following the Soviet military withdrawal in the 1980s. Starting in 2000, small volumes of crude oil were produced from Angut Field and processed in a "primitive" refinery in Sheberghan to make fuel. As of 2006, discovered recoverable crude oil in northern Afghanistan is reported to be approximately 75 million barrels (10 million metric tons) with approximately 0.2 million barrels (0.03 million metric tons) produced (data from Gustavson and Associates, 2005, VZG, 2004).

During exploration for crude oil in the 1960s and 1970s, several large natural gas fields were discovered. Etym Tag (1960) and Khuja Goger Dak Fields (1961), both near Sheberghan in Jowzjan Province, were among the first to be discovered. Several more large natural gas fields were discovered during the 1970s and early 1980s in this area (Nathan Associates Inc., and Louis Berger International, Inc., 1992). The most recent discovery was Bashi Kurd Field in 1984. The annual production of natural gas in 1983 was 100.6 trillion cubic feet (2,850 million cubic meters) per year (Economic and Social Commission for Asia and the Pacific, 1995). As of 2006, discovered recoverable natural gas in northern Afghanistan is reported to be approximately 5 trillion cubic feet (142 million cubic meters) with approximately a little over 2 trillion cubic feet (56 billion cubic meters) produced (data from Gustavson and Associates, 2005, VZG, 2004). Natural gas production began in 1967 with Khuja Goger Dak Field (Nathan Associates Inc., and Louis Berger International, Inc., 1992; VZG, 2004). Approximately 80 percent of the natural gas was piped 200 kilometers to the USSR (Nathan Associates Inc., and Louis Berger International, Inc., 1992; Economic and Social Commission for Asia and the Pacific, 1995). The remaining natural gas was delivered to a 28,000 kilowatt thermal power plant and 100,000 tonnes-per-year nitrogen fertilizer plant in Mazar i Sharif (Nathan Associates Inc., and Louis Berger International, Inc., 1992; Economic and Social Commission for Asia and the Pacific, 1995; VZG, 2004). In 1976, construction began on a gas-refining facility to remove sulfur from natural gas produced at Jer Koduq Field (the Jardak Desulfurization Project) (Nathan Associates Inc., and Louis Berger International, Inc., 1992; VZG, 2004). The facility was placed in operation in 1978 (Nathan Associates Inc., and Louis Berger International, Inc., 1992). Reports since 1979 indicate that natural gas shipments to the USSR reached over 100 billion cubic feet (3.5 billion cubic meters) per year (Nathan Associates Inc., and Louis Berger International, Inc., 1992). By 1985, seven natural gas fields and six oil fields were discovered in Afghanistan (Economic and Social Commission for Asia and the Pacific, 1995). Khuja Goger Dak gas field, Jer Koduq gas field, and Qash Qari oil field are the largest discoveries to date in this basin. Major producing reservoirs are in the Upper Jurassic Kugitang carbonates and Lower Cretaceous terrigenous rocks (Economic and Social Commission for Asia and the Pacific, 1995). In the early 1990s, natural gas production and shipments to the USSR were terminated (Nathan Associates Inc., and Louis Berger International, Inc., 1992; VZG, 2004). In 1999, the Afghan Gas Enterprise restored the only remaining pipeline, which runs between Jer Koduq Field and Mazar i Sharif (VZG, 2004).

About 370 wells have been drilled in northern Afghanistan, based on data obtained mainly from the Afghanistan government. Although the exact number is not known, over 100 of these wells are classified as exploration and over 200 are classified as development. Of the 100 or so exploration wells, most are probably outpost and new-pool wildcat wells rather than new-field wildcat wells because many fields contain more than one, and up to several, of these wells.

Of the 370 or so wells, most were drilled in the Amu Darya Jurassic-Cretaceous Total Petroleum System; 270 were drilled in the Afghanistan Jurassic Evaporite Basin Margin (11540107) Assessment Unit and 48 were drilled in the superimposed Afghanistan Jurassic Evaporite Basin Subsalt Carbonates (11540105) and Afghanistan Jurassic Evaporite Basin Suprasalt Anticlines (11540106) Assessment Units. Twenty-seven wells were drilled on the North Afghan High along the edge of the Afghanistan Jurassic Evaporite Basin Margin (11540107) Assessment Unit. These wells tested dry (petroleum absent) and were used to delineate the assessment unit boundaries.

Estimates of recoverable crude oil and natural gas in discovered fields made through time by various organizations generally are not significantly different from one another (fig. 18). Estimates of the recoverable crude oil and natural gas (field sizes) with respect to discovery year are shown in Figure 19 to provide insight into the discovery history. Improvements in current recovery efficiency will most certainly result in re-estimation of volumes of petroleum that might be produced from those fields.

Petroleum Occurrence:

Most of the discovered petroleum in Afghanistan is in the Amu Darya Basin. The accumulations are in structures, some expressed in topographic relief (fig. 20), on and along the Akhchin step (Jangali Kalan, Etym Tag, and Khuja Goger Dak natural gas fields), Andkhoy uplift (Juma, Bashi Kurd, and Jer Koduq natural gas fields), the western flank of the North Afghan High (Khuja Bulan natural gas field; Angut, Aq Darya, Qash Qari, Bazar Kami, and Zamarud Sai crude oil fields), and Maimana step (Alli Gul crude oil field). One accumulation on the Akhchin step (Chekh Che natural gas) and two along the flank of the North Afghan High (Saripul crude oil and Sha Karak natural gas) may also be fields, but are not formally recognized as such to date (AMMI, 2002, Gustavson and Associates, 2005). All of these accumulations exist either below Upper Jurassic salt or where salt is absent. Large petroleum accumulations have not yet been found above Upper Jurassic salt (Kingston, 1990; Kingston and Clarke, 1995).

The main trapping configurations for petroleum are associated with compressional structures and include (1) Upper Jurassic carbonate rocks sealed by evaporites (Khuja Goger Dak, Jer Koduq, Juma, Jangali Kalan, Bashi Kurd, Etym Tag Fields); (2) Lower Cretaceous fine-grained continental sandstone sealed by Aptian to Albian mudstone (Khuja Goger Dak, Jer Koduq, Etym Tag, Khuja Bulan, Qash Qari, Zamarud Sai, Aq Darya, Angut, Alli Gul, and Bazar Kami Fields); and (3) potential Upper Cretaceous to Paleocene carbonate rocks sealed by Paleogene mudstone (fig. 21) (Brookfield and Hashmat, 2001). The latter may be more important for the Afghan-Tajik Basin.

The Akhchin step and Andkhoy uplift are both westward extensions of the North Afghan High. The Andkhoy uplift is structurally higher than the Akhchin step. Upper Jurassic salt is thin on the Akhchin step but is absent on parts of the Andkhoy uplift. Natural gas accumulations, therefore, exist in Lower Cretaceous reservoirs on the Andkhoy uplift as a result of salt absence. These highs were positive features during the Late Jurassic, on and along where reef and reef-associated carbonate rocks were deposited. The reef trend extends westward into Turkmenistan along the Yashlar-Andkhoy and Shah Mala (Shakhmolla) arches, then northward into Uzbekistan and wraps around the southwestern Gissar spur. The trend might also extend eastward from the Akhchin step and Andkhoy uplift along the northern flank of the North Afghan High into the Afghanistan portion of the

Afghan-Tajik Basin. The possibility exists for pinnacle reefs and fore-reef talus having reservoir potential for petroleum accumulations to have been deposited in more basinal settings, north of these positive features. Alternatively, reef-associated petroleum accumulations might also extend around a possible paleo-embayment south of the Andkhoy uplift, wrapping around to follow the northern flank of the Maimana step and continuing westward.

Jurassic and Lower Cretaceous sections thin and pinch out along the western flank of the North Afghan High where the Jurassic evaporite basin margin once existed. On the Angut and Sheram structures on the western flank of the North Afghan High, crystalline basement, Paleozoic, Triassic, and Jurassic rocks were penetrated by well bores (Akhmedzyanov and others, 1973). Crystalline basement rocks consist predominantly of highly metamorphosed rocks including gneiss with some volcanic rocks, schist and quartzite (Akhmedzyanov and others, 1973). The Paleozoic section consists of carbonates and terrigenous deposits of Silurian to Devonian age from 500 to 600 meters thick, Carboniferous terrigenous deposits of up to 600 to 800 meters thick, and Permian carbonates approximately 1,500 meters thick (Akhmedzyanov and others, 1973). Triassic rocks unconformably overlie older rocks in the Angut, Aabdan, and Kariz structures (Akhmedzyanov and others, 1973). Dark Triassic sandstone and mudstone of less than 100 meters thick are on the Kariz structure, but red continental clastic deposits, 39 to 88 meters thick, are on the Angut structure (Akhmedzyanov and others, 1973). Up to 400 meters of green and dark to black sandstone, mudstone, and coal comprise the Lower to

Middle Jurassic section (Akhmedzyanov and others, 1973). Upper Jurassic rocks consist of red terrigenous rocks with rare anhydrite interbeds less than 100 meters thick in the San Charak (Sangcharak) area (Akhmedzyanov and others, 1973).

The Badkhyz-Karabil uplift and Maimana step are important for exploration of sulfur free gas in Cretaceous reservoirs in Turkmenistan (Smirnov and others, 1980). The Maimana step is structurally higher than the Badkyz-Karabil uplift and the stratigraphic section is less complete (fig. 22) (Smirnov and others, 1980). An escarpment about 700 to 1,500 meters high is located between the Maimana step and Badkyz-Karabil uplift in Turkmenistan (Smirnov and others, 1980). Jurassic and Hauterivian rocks are absent on Maimana step (Smirnov and others, 1980). The Maimana step contains three parallel elongate structures: (1) southwestern, called Kurukbeli arch, Jekda Lak line with the Turkmenistan Khwaja Gugert Dag structure; (2) central, Khuja Qul line with the Qara Babi structure; and (3) northeastern, Qara Qul line with the Dervezekem structure (Smirnov and others, 1980). The base of sedimentary cover has an average dip of 2° (Smirnov and others, 1980). In most uplifted area at Khwaja Gugert Dag Field, the base is 1 kilometer deep but is 5 kilometers deep on the northern slope of the structure (Smirnov and others, 1980). Significant structural changes took place during pre-Ghory unconformity (Smirnov and others, 1980). The eastern part of the area was uplifted and the southwestern slope formed (Smirnov and others, 1980). Amplitudes of structures progressively increase at unconformities, increasing 1.5- to 1.7-fold from Lower to Upper Cretaceous, indicating that structures were developing during Cretaceous time (Kravchenko and Ivanova, 1997).

Callovian to Oxfordian and some Lower Cretaceous intervals pinch out completely under the pre-Barremian unconformity and are absent on the North Afghan High and Maimana step (Aleshina and Bluket, 1967; Smirnov and others, 1980; Kravchenko and Ivanova, 1997). Transgressive sandstone lies at the base of the Barremian where Hauterivian deposits are absent and Barremian rocks directly overlay Triassic rocks (Kravchenko and Ivanova, 1997). The sedimentary section substantially decreases from west to east (Kravchenko and Ivanova, 1997). The section becomes thinner mostly because of pre-Neogene, pre-Ghory, and pre-Barremian erosion, and to a lesser degree, syn-sedimentary nondeposition (Kravchenko and Ivanova, 1997). The amount of pre-Ghory erosion becomes less farther east to Alli Gul Field (Kravchenko and Ivanova, 1997).

Some reservoirs are present in the Barremian interval and are locally present in other Cretaceous sections on the Badkyz-Karabil uplift and Maimana step (Smirnov and others, 1980). In Turkmenistan, good reservoirs are present in upper Paleocene Bukhara beds, which are 180 to 200 meters thick with an average porosity of 22 percent and permeability of 44 millidarcies (Smirnov and others, 1980). Eocene mudstone is the seal and the mudstone ranges from 400 to 600 meters thick (Smirnov and others, 1980).

The Kurukbeli arch (fig. 7) forms the southern margin of the Badkyz-Karabil uplift and Maimana step. Natural gas reserves (including C1 and C2 reserve categories) along the Kurukbeli arch in Turkmenistan exceed 3,531 billion cubic feet (100 billion cubic meters)

(Melikhov and others, 1997). The fields include Kurukbeli, East Kurukbeli, West Kurukbeli, and Karabil Fields (Melikhov and others, 1997). In Afghanistan, approximately 3.5 million barrels (0.5 million tonnes) of recoverable crude oil was discovered in Alli Gul Field in a sandstone bed overlying basal Aptian mudstone (Smirnov and others, 1980; Kravchenko and Ivanova, 1997; AMMI, 2002, VZG, 2004). Natural gas production is from clastic and carbonate reservoirs of Hauterivian, lower Barremian, lower Aptian, and Paleocene ages (Melikhov and others, 1997). Natural gas and presumably the crude oil migrated from the Murghab Depression to the north onto the arch (Melikhov and others, 1997). Melikhov and others (1997) assessed natural gas resources of the Badkyz-Karabil uplift and westernmost structures of the Maimana step in Turkmenistan (fig. 7), such as Dervezekem, Lekker, Khwaja Guger Dag, at 7 trillion cubic feet (200 billion cubic meters). Two other structures (Khuja Seplan and Jekda Lak) in Afghanistan were drilled but are considered nonproductive. Khuja Seplan contained carbon dioxide-rich natural gas. Liquid crude oil was observed in cores of Aptian siltstone in the Jekda Lak #1 well (Kravchenko and Ivanova, 1997). Crude oil seeps were reported along the fault bounding the Maimana step on the south (Kravchenko and Ivanova, 1997). Potential stratigraphic traps, primarily in the Shatlyk unit, might be present along the northern slope of the the Badkyz-Karabil uplift and Maimana step (Smirnov and others, 1980). Jurassic reefs located along the slope of the Badkhyz-Karabil uplift may exist providing potential reservoirs (Smirnov and others, 1980).

Source Rocks:

The principal source rocks in this total petroleum system are Lower to Middle Jurassic coaly continental to marine mudstone and coals and Upper Jurassic (primarily Oxfordian) anoxic basinal black mudstone (Seregin and others, 1982). The source-rock section is thin or absent on marginal highs, but the section thickens to several hundred meters basinward. Both source rocks are separated from Cretaceous reservoirs by a regional, undeformed salt seal.

Maximum penetrated thickness of the Lower to Middle Jurassic interval in the southeastern part of the Amu Darya Basin is about 200 meters (Seregin and others, 1982). The Lower to Middle Jurassic coaly mudstone contain from several tenths (0.7) to as much as 4.3 weight percent of total organic carbon (averaging 1.5 weight percent) with Type III kerogen and thin coals (Seregin and others, 1982; Seradzhi, 1988; 1993). Ulmishek, (2004) reported values as high as 2.5 weight percent. Upper Jurassic basinal black mudstone (Khodzhaipak Formation) has not been penetrated by wells in Afghanistan but is known from paleogeographically similar areas in adjacent Uzbekistan where it is a few tens of meters thick and contains from 6 to 8 weight percent and as much as 15 weight percent, total organic carbon and type II kerogen (Akramkhodzhaev and Egamberdyev, 1981; Ulmishek, 2004). Thickness of the mudstone ranges up to 70 meters and produces a high gamma-ray response on well logs (Akramkhodzhaev and Egamberdyev, 1981). In northern Afghanistan, Late Jurassic marine sediments contain total organic matter contents from 0.22 to 1.2 weight percent (Seradji, 1993). Carbonate rocks deposited in reef and lagoon environments have total organic matter contents from 0.3 to 0.4 weight percent (Seradji, 1993). Petroleum contribution from possible organic-lean Cretaceous source rocks is minimal.

According to a British Petroleum geochemical analyses of crude oil and condensate from the Shurtan #1 and North Urtabulak #1 wells of Uzbekistan, and selected Upper Jurassic source-rock extracts reported in VNIGNI (2005a), possible major source rocks are Lower to Middle Jurassic mudstone. Deposition of these oil-source rocks is possibly associated with restriction of the basin prior to or during the deposition of the Kimmeridgian to Tithonian evaporite section. These rocks sourced much of the gas and gas-condensate in Upper Jurassic carbonate and clastic reservoirs. Other source-rock intervals may also exist in the basin, such as Kimmeridgian to Tithonian mudstone deposited before or during evaporite deposition. Differing analytical results from the North Urtabulak #1 crude oil and the Shurtan #1 condensate indicate at least two different source rocks are present in the basin or different depositional facies of the same source rock.

Before this study, Seradzhi (1988) indicated that no detailed geochemical data existed for Lower and Middle Jurassic rocks in Afghanistan. Lower to Middle Jurassic rocks are considered the most likely source for natural gas in the Amu Darya Basin, whereas, based on carbon isotope analysis, Upper Jurassic rocks are considered the major crude oil source (Abduazizov, 1976).

Crude oils in Hauterivian reservoirs of the Angut and Aq Darya Fields are saturated with carbon dioxide (82 to 96 percent) and only 1.42 to 17.17 percent of the natural gases are hydrocarbons (mostly heavy gas) (Safranov and others, 1986). The vanadium to nickel porphyrine ratio is 0.66 in oils in Hauterivian and Aptian reservoirs (Safranov and others, 1986). Condensate in Lower Cretaceous reservoirs of Etym Tag Field is light (density of 0.846 grams per cubic centimeter or 36 degrees API gravity), low sulfur content (0.53 percent), and paraffinic (5.09 percent) (Yakovets and Gotgilf, 1969). No resins or asphaltenes are reported (Yakovets and Gotgilf, 1969). The condensate has a paraffinic to naphthenic base (Yakovets and Gotgilf, 1969).

Hauterivian reservoirs produce high-density, high-sulfur oil at Angut, Aq Darya, and Qash Qari Fields, with densities up to 0.915 grams per cubic centimeter (23 degrees API gravity) and 2.12 to 6.4 percent light hydrocarbon fractions at 200 degrees C (Economic and Social Commission for Asia and the Pacific, 1995). Lower Albian reservoirs contain lighter, lower sulfur oil, with densities from 0.822 to 0.843 grams per cubic centimeter, 11.3 to 31 percent light hydrocarbon fractions at 200 degrees C, and 2 to 7 percent paraffin (Economic and Social Commission for Asia and the Pacific, 1995).

Condensates in Upper Jurassic reservoirs of Etym Tag and Khuja Goger Dak Fields are heavy, from 0.8 to 0.85 grams per cubic centimeter, because of the low gasoline fractions, no more than 7 cubic centimeters per cubic meter (Turanov and others, 2004). Oil from the oil leg of Jer Koduq Field is also heavy, from 0.89 to 0.92 grams per cubic centimeter

(Turanov and others, 2004). Oil flows, some with water, were obtained in Jer Koduq Field and from the bottom part of gas pools in the Sha Karak and Juma Fields (Turanov and others, 2004).

Natural gas in most Afghanistan fields of the Amu Darya Basin consists of dry methane containing 0.005 to 6 percent hydrogen sulfide (Economic and Social Commission for Asia and the Pacific, 1995; this study). Natural gas samples were collected from Khuja Goger Dak (well #15) and Jer Koduq (wells #21 and #62) Fields. The natural gases are thermogenic and the Khuja Goger Dak samples are interpreted to be of higher maturity than the Jer Koduq samples based on molecular and isotopic compositions. Natural gas from Khuja Goger Dak Field contains approximately 86 percent methane having a $\delta^{13}C$ value of -27.6 per mil whereas gas from Jer Koduq contains 90 to 93 percent methane having a $\delta^{13}C$ value of -31.1 per mil. The $^{1}H/^{2}H$ ratios for these two samples are between -157 and -160 per mil. Natural gas of 92.4 percent methane is reported from a Hauterivian pool in Khuja Bulan Field and 98.6 percent from an Aptian pool at Khuja Goger Dak Field (Economic and Social Commission for Asia and the Pacific, 1995). Natural gas in Hauterivian reservoirs of the southeastern Amu Darya Basin is drier than natural gas in Upper Jurassic reservoirs (Seregin and others, 1982).

Unlike the northern Amu Darya Basin, natural gas with greater than 1 percent sulfur is ubiquitous in southern areas (Solovyev and others, 1996). Sulfur is widespread in free gas and in waters along the pinch-out of Jurassic evaporates (Solovyev and others, 1996).

Natural gas resources with variable hydrogen sulfide concentrations are identified in Upper Jurassic carbonates at Juma, Bashi Kurd, Jangali Kalan, and Jer Koduq fields (Economic and Social Commission for Asia and the Pacific, 1995). Hydrogen sulfide content in the Khuja Goger Dak and Jer Koduq gases is low, from 0.07 to 0.18 percent. Hydrogen sulfide content in Hauterivian gases increases toward faults (Seregin and others, 1982).

Maturation:

Both Lower to Middle and Upper Jurassic source-rock suites are deeply buried and are within the gas-generation window and are at high stages of maturity. The source rocks were buried to the upper limit of petroleum generation at 2 kilometers, with a temperature of 90 degrees C and a geothermal gradient of 45 degrees C per kilometer at the close of the Early Cretaceous (Seradzhi, 1988; Seradji, 1993). This paleogeothermal gradient was also assigned for the backarc pull-apart basin at this same time (Brookfield and Hashmat, 2001). In the Late Cretaceous and Paleogene, the Lower to Middle Jurassic rocks were buried to 3,500 meters and heated to 120 degrees C, well within the zone of oil generation (Seradji, 1993). The geothermal gradient of 34 degrees C per kilometer calculated from the data given in Seradji (1993) is consistent with present-day geothermal gradient of approximately 34.6 degrees C per kilometer in producing wells of northern Afghanistan (Brookfield and Hashmat, 2001). An initial stage of crude oil generation was followed by a later stage of catagenic natural gas generation, which displaced oil (Turanov and others, 2004). Oil fields along the Jurassic evaporite basin margin were preserved because late

Tertiary faulting prevented later-generated natural gas migration to these areas (Turanov and others, 2004).

The generation area for hydrocarbon accumulations in northwestern Afghanistan was in the Murgab depression (Turanov and others, 2004). Turanov and others (2004) suggest that two stages of expulsion occurred; the first stage expelled oil with little gas and the second stage involved high temperature-derived gas. As a result of the two expulsion stages, three areal zones of hydrocarbon accumulations formed, a zone of crude oil pools, of both natural gas and crude oil (as oil legs) pools, and natural gas pools (Turanov and others, 2004). Crude oil pools are only in areas where no natural gas pools are present in underlying rocks (Turanov and others, 2004). Natural gas fields in Cretaceous reservoirs are only in areas where natural gas pools are also present in Upper Jurassic reservoirs (Turanov and others, 2004).

Based on the geothermal gradients of the Amu Darya Basin, the crude oil generation window (mesocatagenesis stage 1, mesocatagenesis stage 2, and probably mesocatagenesis stage 3) begins at depths of 2,200 to 2,500 meters with paleotemperatures of 90 to 105 degrees C and increases to 140 degrees C at 2,200 to 4,000 meters and deeper (Seregin and others, 1982). Maximum Neogene erosion on uplifts in southeastern Amu Darya Basin is estimated at 300 to 500 meters; resulting in cooling by 5 to 20 degrees C (Seregin and others, 1982). In fields of the Amu Darya Basin, the present-day geothermal gradient changes stepwise with depth from 24 to 25 meters per degree C

(40 degrees C per kilometer) to a depth of 1,000 meters, 35 meters per degree C at 1,000 to 2,500 meters (42 degrees C per kilometer; 103 degrees C at 2,500 meters), and to 40 to 45 meters per degree C deeper than 2,500 to 3,000 meters (12 degrees C per kilometer; 109 degrees C at 3,000 meters) (Seregin and others, 1982).

Commercial crude oil and natural gas resources may possibly be found in Jurassic and Cretaceous rocks, which are separated by Upper Jurassic salt in the basin center but not at the basin margin (Economic and Social Commission for Asia and the Pacific, 1995). The precise mechanism of migration from the source to the reservoirs above the salt is not clear. A possible model, known from the giant Dauletabad-Donmez field in adjacent Turkmenistan, includes vertical migration beyond the pinch-out boundary of the salt formation and following lateral migration basinward to traps (Ulmishek, 2004). Shows are observed at the surface in Lower Cretaceous rocks on the southeastern margins of the Amu Darya Basin (Seregin and others, 1982). The existence of “windows” in salt, which provide pathways for vertical migration, in the salt-dome area along the Repetek Zone is possible, which would allow vertical charging of Lower Cretaceous suprasalt reservoirs.

Reservoir Rocks:

The main reservoir rocks are Upper Jurassic (Callovian to Oxfordian) Kugitang carbonates that include probable barrier and pinnacle reef facies, and Gissar sandstone and carbonates.

Upper Jurassic carbonate reservoir rocks of the Kugitang and Gissar suites in the Amu Darya Basin are natural gas-bearing and range in thickness from 224 meters at Jer Koduq to 380 meters and more at Khuja Goger Dak (Seradji, 1993). Reservoir properties are variable with total porosity from 5 to 11 percent and effective porosity from 3 to 7 percent (Seradji, 1993; VZG, 2004). Microfractures in these rocks are 0.01 to 0.08 millimeters wide. Fields that produce from Upper Jurassic reservoirs include Jangali Kalan, Jer Koduq, Juma, Etym Tag, Bashi Kurd, and Khuja Goger Dak (Seradji, 1993). Gas shows have been observed in anhydrites and limestones of the Gaurdak Formation (Seregin and others, 1982).

Cretaceous clastic reservoir rocks in the Amu Darya Basin are also important and include those of Hauterivian, Aptian, Albian, Cenomanian, and Turonian to Senonian ages (Seradji, 1993). The Hauterivian Qezeltash (Shatlyk) Formation is the main oil- and gas-bearing reservoir, containing more than 90 percent of the discovered Cretaceous oil and gas, and ranges from 150 to 200 meters thick (fig. 23) (Seradji, 1993). Porosity ranges from 10 to 23 percent, averaging 14 to 20 percent, and permeability from a few tens to 600 millidarcies, averaging 100 to 150 millidarcies (Seradzhi, 1988, 1993; VZG, 2004). Fields that produce from Hauterivian reservoirs in northern Afghanistan include Khuja Goger Dak (natural gas), Etym Tag (natural gas), Jer Koduq (natural gas), Khuja Bulan (crude oil and natural gas), Angut (crude oil), Aq Darya (crude oil), Qash Qari (crude oil), Bashi Kurd (crude oil), and Zamarud Sai (crude oil) (Seradzhi, 1988, 1993; Economic and Social Commission for Asia and the Pacific, 1995).

Other possible reservoir rocks in northern Afghanistan include Lower to Middle Jurassic clastic rocks, having effective porosity up to 15 percent and permeability up to 228 millidarcies (Seradzhi, 1988). Reservoir quality in these rocks decreases with depth and basinward because of an increase in clay-mineral content and decrease in grain size (Seradzhi, 1988).

Traps:

All known fields are in structural traps, particularly broad anticlines, related to the Neogene compressional event (Brookfield and Hashmat, 2001). Undiscovered fields are expected in structural traps, in reefs, or combination of the two.

The main tectonic event that affected petroleum accumulation in the Amu Darya Basin was the development of Neogene to Quaternary structures whereby depressions continued to subside and blocks continued to be uplifted (Seradji, 1993). Local uplift decreased pressure that promoted phase separation of water-dissolved natural gas into free natural gas to form new natural gas accumulations (Seradji, 1993).

Almost all of the petroleum traps are anticlinal (Seradzhi, 1988). Petroleum accumulations in Hauterivian reservoirs are present only in areas where the Gaurdak evaporite unit is absent (Seradzhi, 1988). Pinchout traps are inferred in the zone where Jurassic strata pinch out, such as that along the southern edge of the North Karabil-Dauletabad depression (Seradzhi, 1988). Along the Afghan High, Lower to Middle Jurassic deposits pinch out first, followed by the Upper Jurassic deposits (Seradzhi, 1988). Crude oil and natural gas accumulations in Upper Jurassic reefal carbonates may exist (Seradzhi, 1988). Seradzhi (1988) shows on a map, the salt pinchout line along the margins of the North Karabil-Dauletabad depression. Seradzhi (1988) shows in a cross section from the North Karabil-Dauletabad depression toward the North Afghan High (from Jangali Kalan to Angut Fields) that Middle to Upper Jurassic rocks pinch out first and that overlapping Upper Jurassic rocks pinch out farther north, leaving only the potential for the existence of stratigraphic traps.

Horsts in southeastern Turkmenistan, such as at Dauletabad and Kurukbeli, originally formed in the Early Jurassic during Aalenian time (Yanena and Mamedov, 1982). Uplift and formation of weathering crust on top of the Triassic occurred later during Early Jurassic to Middle Jurassic time (Yanena and Mamedov, 1982). The thickness of Upper Jurassic rocks is up to 300 meters (Yanena and Mamedov, 1982). General subsidence occurred during the Early Cretaceous with onlapped (overlap) sediment thicknesses from 600 meters in the north to 300 meters in the south (Yanena and Mamedov, 1982). Some structures formed during the Late Cretaceous by differential movements, causing a general tilt of the Amu Darya Basin to the north and west, with sediment thicknesses ranging from 200 to more than 1,000 meters (Yanena and Mamedov, 1982). East to west tilting continued into the Paleogene with sediment thicknesses ranging from 200 to 500 meters in east to 1,200 to 1,300 meters in the west, but no northern tilt occurred during that time (Yanena and Mamedov, 1982). A reversal in the tilting occurred from the Neogene to Quaternary time and as a result, sediments range in thickness from 300 to 500 meters in the west to 500 to 1,000 meters in the southeast and to 1,500 to 1,600 meters in the northeast (Yanena and Mamedov, 1982).

Seals:

The principal regional seal is the Kimmeridgian to Tithonian Gaurdak Formation, composed of salt and anhydrite with local carbonate beds (Kingston, 1990; Kingston and Clarke, 1995; Ulmishek, 2004). In the Amu Darya Basin of northern Afghanistan, the Gaurdak Formation ranges in thickness from 130 to 180 meters (Seradzhi, 1988). Gaurdak evaporites are the seals for petroleum accumulations at Khuja Goger Dak, Etym Tag, Juma, Jangali Kalan, and Bashi Kurd Fields (Seradzhi, 1988).

An extensive Barremian to Aptian mudstone is the seal for Qezeltash Formation reservoirs and is 130 to 150 meters thick in northern Afghanistan (Seradzhi, 1988; Ulmishek, 2004). Barremian mudstone is the seal for accumulations at Khuja Goger Dak, Etym Tag, Khuja Bulan, Jer Koduq, Angut, Aq Darya, and Qash Qari Fields (Seradzhi, 1988). Aptian mudstone is the seal for accumulations at Khuja Goger Dak, Etym Tag, Alli Gul, and Qash Qari Fields and Albian mudstone seals accumulations at Angut, Aq Darya, Khuja Goger Dak, and Etym Tag Fields (Seradzhi, 1988).

Intraformational Albian and Cenomanian mudstone seals gas pools in other reservoirs (Seradzhi, 1988). The Paleogene Suzak Formation mudstone provides seal for Ghory reservoirs.

Assessment Units:

Assessment units in the Amu Darya Jurassic-Cretaceous Total Petroleum System of Afghanistan are defined by stratigraphic position above or below the Upper Jurassic salt. The Afghanistan Jurassic Evaporite Basin Subsalt Carbonates Assessment Unit (11540105) encompasses Upper Jurassic carbonate and reef reservoirs below the salt seal. This assessment unit has higher potential for undiscovered natural gas resources than the other assessment units within this total petroleum system. The Afghanistan Jurassic Evaporite Basin Suprasalt Anticlines Assessment Unit (11540106) encompasses predominantly Cretaceous sandstone reservoirs associated with anticlinal structures above the salt seal. This assessment unit has relatively low potential for undiscovered petroleum resources. The Afghanistan Jurassic Evaporite Basin Margin Assessment Unit (11540107) is located where Jurassic salt is absent and extends up the North Afghan High where maximum petroleum migration is projected. This assessment unit is the most explored and contains the greatest number of known accumulations and volumes of discovered crude oil and natural gas.

Assessment Results: The Amu Darya Basin has the least overall geologic uncertainty with respect to petroleum occurrence in northern Afghanistan. Source rocks are known and the geology and sizes of discovered fields are known in much of the basin. However, interpretations of the presence and location of traps, particularly Jurassic reefs, from seismic profiles and other geophysical surveys of northern Afghanistan are questionable because of poor resolution and older technology.

Discovery-history graphs of only Afghanistan fields are not sufficient to use for size estimates because of the small number of discoveries (eight gas fields and seven oil fields). Therefore, the sizes of fields discovered throughout the entire Amu Darya Basin rather than just the assessment units were analyzed to provide information on the expected sizes of undiscovered fields (fig. 24). Two hundred and thirteen natural gas fields have been discovered in the basin. The overall median field size is 134 billion cubic feet. Considering reserve growth, the overall median size is 203 billion cubic feet. The median field sizes chosen for input to the resource calculations are somewhat smaller, 80 billion cubic feet, to express the concept that discovered field sizes are well known to decrease through time and that the accumulations are smaller in Afghanistan than in other parts of the Amu Darya Basin. Without the old large fields of Turkmenistan, which do not represent the geology of the Afghanistan accumulations (such as Dauletabad-Donmez Field), the largest field is approximately 8 trillion cubic feet.

The Afghanistan Jurassic Evaporite Basin Subsalt Carbonates Assessment Unit has the greatest potential for undiscovered gas than other assessment units, but it also has the greatest uncertainty as indicated by the ranges in number, sizes, and estimated resources. Both source and reservoir rocks are present below and sealed by the Upper Jurassic salt, creating a condition conducive for a significant number of accumulations, some being very large, should traps exist. But this is only one possible geologic scenario. In another scenario, reservoir rocks and traps may have only limited areal distributions, resulting in a smaller number of accumulations. The very skewed distributions of estimated number and sizes express the combination of the two scenarios (fig. 25). The mean undiscovered natural gas volume is almost 5.5 trillion cubic feet (0.2 trillion cubic meters) with a range from an F95 of about 2 to an F5 of over 11 trillion cubic feet.

A 50 percent chance of an accumulation exceeding the minimum specified size was assumed to exist in the suprasalt assessment unit. Should accumulations exist, this assessment unit has relatively low potential for undiscovered natural gas because the Upper Jurassic salt inhibits migration from the Upper Jurassic source rocks to the Lower Cretaceous reservoirs. The lower potential is expressed by the estimated small number of undiscovered fields. Should natural gas migrate through salt-evacuation sites or diapirs, the sizes of the largest accumulations could be quite large, as expressed by our estimate of field sizes going up to 4 trillion cubic feet.

Without geologic risk, the mean of the undiscovered natural gas volume is a little over 0.5 trillion cubic feet (14 billion cubic meters) with a range from an F95 of 0.1 to an F5 of 1.7 trillion cubic feet. With the 50% geologic probability, the mean of the undiscovered natural gas volume is only a third of a trillion cubic feet (9 billion cubic meters) with a range from an F95 of 0 to an F5 of 1.3 trillion cubic feet.

The Afghanistan Evaporite Jurassic Basin Margin Assessment Unit is the most explored and contains the greatest number of known accumulations and volumes of discovered crude oil and natural gas. A number of fields greater than the suprasalt assessment unit was estimated for the basin margin assessment unit because more reservoirs are available for petroleum charge. In addition, more structures for traps may be available due to the proximity to reactivated older structures and the presence of a carbonate shelf with reef-associated traps surrounding these older structures. The sizes of the accumulations are expected to be smaller because the assessment unit represents the updip part of the Amu Darya Basin and seals are poorer. The seals are thinner proximal mudstone rather than thick basinal mudstone or salt. The mean of the undiscovered natural gas volume is about 1.2 trillion cubic feet (34 billion cubic meters) with a range from an F95 of 0.3 to an F5 of 2.6 trillion cubic feet.

Crude oil has been produced from this assessment unit. Parameters estimated for the assessment-input variables are shown in Figure 26. A small number (4) of undiscovered crude oil fields was estimated as most likely because of the limited area for crude oil accumulation and the small number of discoveries in one of the more explored areas of northern Afghanistan. However, the distribution is skewed to a maximum of 10 in order to express the degree of uncertainty in our geologic understanding of the areal distribution of crude oil accumulations. The estimated size distribution of undiscovered crude oil fields reflects the sizes of discovered fields (compare with fig. 19). The maximum size of 100 million barrels of oil expresses great uncertainty and the possibility that the largest crude oil field may not have yet been discovered. A mean of about 73 million barrels (10 million metric tons) of crude oil is estimated to be undiscovered.

KALAIMOR-KAISAR BASIN

Kalaimor-Kaisar Jurassic Total Petroleum System (115402)

Discovery History:

Three wells were drilled in the Afghanistan Kushka Zone (11540201) Assessment Unit. Although no discoveries were reported, structures extend into Turkmenistan where natural gas fields have been discovered. These fields include Morgunovka, Islim, Karachop, and Mangan.

Recoverable natural gas of Islim, Karachop, and Morgunovka Fields combined are approximately 350 billion cubic feet (10 billion cubic meters) (Melikhov and others, 1997; IHS Energy, 2005). Flowing natural gas is reported in Karachop Field (Dmitriev and others, 1990). Undiscovered natural gas resources are not large and are probably concentrated in the Kushka area (Melikhov and others, 1997). Potential for natural gas resources may also be present in the Adylbek area, where Middle Jurassic sandstone pinches out along the north slope of the Kalaimor depression (Melikhov and others, 1997).

Petroleum Occurrence:

On the south slopes of the Maimana step and North Afghan High, the thickness of the Mesozoic to Cenozoic section is small and mainly composed of continental, lagoonal, and nearshore coarse clastic rocks (Aleshina and Bluket, 1967). Beds of the Upper Jurassic rocks, including Callovian to Oxfordian beds, and a number of Cretaceous and Paleogene horizons are absent in the Kushka zone of uplifts and in the Bande Turkestan range (Aleshina and Bluket, 1967). Cretaceous sandstone reservoirs directly overlie Lower to Middle Jurassic source rocks in the Kushka zone. Petroleum is likely to occur in sandstone pinchouts and Cretaceous to Paleogene carbonate rocks on or along structural highs, and perhaps along the southern margin of the Maimana step in the Kalaimar-Kaisar depression (figs. 7 and 9).

Source Rocks:

The principal source rocks are probably Lower to Middle Jurassic continental to marine coaly clastics (total organic carbon content as much as 2.5 weight percent) with some coal beds in the lower part. The source rocks are estimated to be natural gas-prone.

Maturation:

Lower to Middle Jurassic source rocks are probably thermally mature with respect to petroleum generation. These rocks are buried to depths of about 3 kilometers on the anticlinal uplifts and significantly deeper in depressions filled with thick Neogene to Quaternary rocks.

Reservoir Rocks:

Reservoir rocks in fields of Turkmenistan that are close to the country boundary are present in the section from the upper part of the Middle Jurassic to the Maastrichtian (Ghory Formation). The Ghory reservoirs are composed of carbonate rocks; other reservoir rocks are clastics. Reservoir rocks at Karachop Field include Maastrichtian to Danian sandstone and Ghory Formation carbonate rocks, with porosity ranging from approximately 6 to 12 percent and permeability from 5 to 150 millidarcies (Bratash and others, 1970; Selab, 2006, Afghanistan Ministry of Mines and Industry, personal communication). Reservoir rocks at Islim Field include Middle Jurassic and Lower Cretaceous (Neocomian) sandstone with approximately 4 to 8 percent porosity and up to 50 millidarcies of permeability, and Turonian carbonate rocks with approximately 6 percent porosity and 10 millidarcies of permeability (Bratash and others, 1970; Selab, 2006, personal communication). Dmitriev and others (1990) state that reservoirs in Islim and Karachop Fields have porosity from 3 to 6 percent and permeability from 3 to 7 millidarcies.

Traps:

All discovered productive traps in Turkmenistan are local anticlinal uplifts. New discoveries are expected in undrilled anticlines and, possibly in the pinch-out zone of Lower to Middle Jurassic clastics along the boundary of the assessment unit with the Maimana step.

Seals:

Seal rocks are most likely intraformational mudstone, with Barremian- to Albian-age mudstone acting as a regional seal. Suzak beds also provide a regional seal and range from 20 to 140 meters thick (Dmitriev and others, 1990).

Assessment Units:

The Afghanistan Kushka Zone Assessment Unit (11540201) encompasses the entire Kalaimor-Kaisar Jurassic Total Petroleum System within Afghanistan. The assessment unit encompasses the Kalaimor-Kaisar, Nurbelek, and Kalarin depressions and bounding uplifts forming the western plunge of Bande Turkestan. A fault bounding the Jekda Lak anticline on the south marks the boundary with the Maimana step. In the north, the assessment unit extends to the country boundary of Afghanistan. The Bandigandao Ridge provides the eastern boundary, and the Siakh-Bubak and Siad-Kohe ranges bound the southern edge of the assessment unit.

Assessment Results: A small number of undiscovered small fields are estimated for this assessment unit, estimated to contain about 436 billion cubic feet (12 billion cubic meters) of natural gas (fig. 27). Four undiscovered natural gas fields were estimated as most likely because of the small number of mapped structures. However, the distribution is skewed to a maximum of 10 in order to express the degree of uncertainty in our geologic understanding of the areal distribution of natural gas accumulations. The estimated size distribution is based on the sizes of fields in the Kushka Zone of Turkmenistan.

NORTH AFGHAN HIGH

The potential for coalbed methane resources in Lower to Middle Jurassic clastics exists on the flanks of the North Afghan High. The principal source rocks of the Amu Darya and Afghan-Tajik Basins are absent on the North Afghan High except possibly in some yet unidentified areas on its slopes where Lower to Middle Jurassic rocks may be present (fig. 28). If present, Lower to Middle Jurassic coal (source rock) probably occurs at relatively shallow depths, but the coals could have reached thermal maturity earlier in geologic history, before late Tertiary uplift of the North Afghan High. Additionally, the coals could provide the necessary nutrients for the generation of biogenic gas. Most potential reservoir rocks are basal Neocomian clastics that unconformably overlie the basement or Triassic rocks. The coals are probably not thick enough to serve as producing reservoirs. The traps are local anticlinal uplifts. No regional seals in the section are known and many structures are eroded down to Upper Cretaceous rocks. No assessment units were delineated on the North Afghan High in this study.

AFGHAN-TAJIK BASIN

The Afghan-Tajik Basin is located in the northern and northeastern part of Afghanistan and consists of more than 10 kilometers of Mesozoic and Cenozoic strata (Economic and Social Commission for Asia and the Pacific, 1995). Commercial petroleum production is from Upper Jurassic and Cretaceous reservoirs on marginal structural steps, and Paleogene reservoirs in the basin center. Oil production in Tajikistan is from Cenozoic reservoirs and natural gas is produced from older reservoirs (Economic and Social Commission for Asia and the Pacific, 1995). The oil is heavy, with densities from 0.94 to 0.97 grams per cubic centimeter (Economic and Social Commission for Asia and the Pacific, 1995). Petroleum resources in Cretaceous to Paleogene and Upper Jurassic subsalt reservoirs appear promising in the Afghanistan part of the basin, including those in thrust-fault zones and buried reef complexes, which are difficult to penetrate because of depth and presence of thick salt.

Present-day structures and fields discovered in Tajikistan and Uzbekistan are shown in Figure 7 and the geologic model for petroleum occurrence is shown in Figure 9.

The Afghan-Tajik Basin was open to the west during Jurassic, Cretaceous, and Paleogene time and no thinning of sedimentary sections is observed along the eastern boundary (Dzhalilov and others, 1982). Lower to Middle Jurassic coal-bearing continental sediments were deposited in alluvial-lacustrine humid coastal plains and had much the same distribution as the present-day basin (Dzhalilov and others, 1982). All marine transgressions starting since the Middle Jurassic were from the west (Dzhalilov and others, 1982). In the Late Jurassic, the sea flooded the entire western and central parts of the basin, but did not extend to the north farther than the southern flank of the Gissar range (Dzhalilov and others, 1982). In the Early Cretaceous, the northern boundary of the Afghan-Tajik Basin extended to the east and arid deltaic conditions were present. The epicontinental sea occupied the basin only five times and extended east of the Vakhsh River only in Albian time (Dzhalilov and others, 1982). The basin axis extended east-to-west and was located along the present-day Amu Darya and Pyandzh rivers (Dzhalilov and others, 1982). A continental depositional regime was established in Oligocene time and uplift of basin margins began, ending with mountain building during Pliocene time (Dzhalilov and others, 1982).

Well data from Cretaceous rocks in 4 petroleum fields of the western Kulyab depression in southwestern Tajikistan indicate a possibility that the Afghan-Tajik Basin had moved relative to the southern Tian-Shan range and that the Darvaz area was the southern, not the eastern margin of the pre-Neogene Afghan-Tajik Basin (fig. 4) (Andreyev and Fursov, 1986).

Afghan-Tajik Jurassic Total Petroleum System (115601)

Discovery History:

Only 21 wells have been drilled in the Afghanistan portion of the Afghan-Tajik Basin, none of which penetrated Jurassic rocks. Likewise, no wells drilled in the Tajikistan portion of the basin penetrated Jurassic rocks, except on Dushanbe step and southwest Gissar spur, along the edges of the basin, where Upper Jurassic salt is absent.

Petroleum Occurrence:

As a result of Neogene compressional stacking, the favorable Jurassic carbonate play is buried to great depths in the Afghan-Tajik Basin and is probably is natural gas-prone (Orudzheva and Kornenko, 1991). Largest predicted discoveries are expected on Jurassic subsalt reef buildups (Orudzheva and Kornenko, 1991). Generation of crude oil from Jurassic source rocks began in Albian and Cenomanian time (Orudzheva and Kornenko, 1991), but this crude oil most likely cracked to natural gas because of the great burial depths.

Although no discoveries have been made in the main part of the Afghan-Tajik Basin, natural gas produced from the Uzbekistan Gadzhak Field may provide information on natural gas in this total petroleum system. The Gadzhak Field produces from Upper Jurassic carbonates and Karabil Formation sandstone (Grinenko, 1982). Well 8 tested natural gas in fractures in the lower Gaurdak anhydrite (Grinenko, 1982). The natural gas is wet, contains little sulfur and carbon dioxide, and contains 14.9 percent hydrogen (Grinenko, 1982). The natural gas is probably from Lower to Middle Jurassic source rocks, not Upper Jurassic rocks (Grinenko, 1982).

Based on the depth of the Bukhara interval, from 5.5 to 6.5 kilometers in synclines, and thickness calculations, subsalt deposits are at depths of 9 to 12 kilometers (VNIGNI, 2005a). These depths are confirmed by direct seismic reflections from subsalt deposits in the Yava zone, at 4.2 to 4.3 seconds (VNIGNI, 2005a). Subsalt deposits are at a depth of more than 8 kilometers in the area of the Gardanyushti structure (VNIGNI, 2005a).

Source Rocks:

The principal source rocks are Lower to Middle Jurassic coaly continental to marine clastics and coals, and Upper Jurassic (primarily Oxfordian) anoxic basinal black mudstone.

The Lower to Middle Jurassic section of the Afghan-Tajik Basin center is believed to be 600 to 700 meters thick (Safranov, 1988). Dominant components of coals known from marginal sections within the Lower to Middle Jurassic section of the Afghan-Tajik Basin are vitrinite, semifusinite, and leiptinite (1 to 5 percent) and contain type III kerogen (Safranov, 1988). The total organic matter content in Lower to Middle Jurassic mudstone of the Afghan-Tajik Basin is approximately 2 weight percent (Safranov, 1988).

Several Lower to Middle Jurassic coal-bearing formations were drilled in wells along the southwest Gissar spur (Akramkhodzhaev, 1982). Lower to Middle Jurassic rocks were drilled at depths of 800 to 1,200 meters (Akramkhodzhaev, 1982). Total organic carbon contents range from a few tenths to 4 weight percent (Akramkhodzhaev, 1982). Much secondary (migrated) bitumen is present in all of the rocks (Akramkhodzhaev, 1982). Akramkhodzhaev (1982) calculated that one million metric tons of natural gas could be generated per square kilometer and from up to 10,000 metric tons of crude oil per square kilometer from these coal-bearing intervals.

Upper Jurassic sediments that were deposited under weak reducing conditions in reefal depressions are possible source rocks (VNIGNI, 2005a). Oxfordian to Kimmeridgian (Khodzhaipak Formation) black, radioactive, bituminous, thinly laminated, ammonite-bearing limestones are known in the Gaurdak area of the southwest Gissar spur area (Amanniyazov and Nevmirich, 1985; Egamberdyev and Mayvandi, 1992).

Maturation:

Both Lower to Middle and Upper Jurassic source rocks are buried within the natural gas-generation window and have been in this maturity zone since at least Late Cretaceous time. The source rocks are buried to 2 to 3.5 kilometers on the uplifted structural steps along the basin margins and probably to 12 kilometers in the basin center by allochthonous thrust sheets and thick Neogene to Quaternary fill.

Lower to Middle Jurassic rocks today are in the gas window (mesocatagenesis stages 2 and 3 to apocatagenesis stage 1) (Safranov and others, 1983). Generation of crude oil started in Cretaceous time in the central area of the Afghan-Tajik Basin and reached a maximum in Eocene time when the rocks were in crude oil-generation window (Safranov, 1988). The rocks were in crude oil-generation window when deposition of Neogene orogenic clastic sediments started to accumulate and this burial resulted in their reaching the natural gas-generation window (Safranov, 1988).

Reservoir Rocks:

Possible reservoir rocks include Jurassic carbonates near the margin of the basin and possibly some Upper Jurassic clastic rocks. Reservoir quality of these carbonates deteriorates basinward, as the carbonate rocks become more argillaceous. Based on data from adjacent areas, Lower to Middle Jurassic clastics lose their reservoir quality at depths greater than 3 to 3.5 kilometers due to compaction and diagenesis. One gas field having reservoirs in the Upper Jurassic interval is located at the Surkhan megasyncline on the Baysun step (VNIGNI, 2005a). Three small fields in the Dushanbe area of Tajikistan produce Jurassic gas from Tithonian reservoirs, but reservoir quality decreases basinward because of deep burial (Kingston, 1990; Kingston and Clarke, 1995).

Permeable horizons are connected to fractured limestones, reef bodies, forereef talus slopes, and tidal bars (VNIGNI, 2005a). Lower Jurassic sandstone in the Afghan-Tajik basin has low porosity ranging from 5 to 10 percent and permeability of a few millidarcies (Egamberdyev, 1987). A small possibility of reservoir rocks with adequate reservoir quality in the deeper parts of the basin, but would have to include Jurassic carbonates and possibly some Upper Jurassic clastic rocks.

Traps:

Possible traps include subsalt anticlinal structures and, possibly stratigraphic traps in the pinch-out zone of Jurassic clastics along the basin margin.

Seals:

Upper Jurassic evaporites might provide a regional seal for petroleum accumulations. The regional seal may be present only on the western part of the basin, whereas argillaceous limestone and mudstone would provide local seals in the eastern part of the basin (VNIGNI, 2005a).

Assessment Units:

Two assessment units are defined, both below thrust sheets and the Jurassic salt. The Afghanistan Subsalt Oxfordian Shelf Assessment Unit (11560101) encompasses potential reservoirs of carbonate and clastic rocks deposited on a shelf along the southern margin of the Afghan-Tajik Basin, and structures that developed before Neogene thrust faulting and folding. Reservoir rocks of the Afghanistan Subsalt Basinal Facies Assessment Unit

(11560102) are more argillaceous than those deposited on the shelf, are buried to greater depths, and have low potential for petroleum accumulations.

The Afghanistan Subsalt Oxfordian Shelf Assessment Unit encompasses an area in the Afghanistan portion of the Afghan-Tajik Basin and covers an undelineated Late Jurassic (Oxfordian) shelf. This assessment unit is defined to separate reservoir rocks deposited on the shelf having a high probability of hydrocarbon accumulations from basin rocks having a lower probability. The assessment unit includes subsalt Jurassic rocks, which occur in the autochthon below detached and folded Cretaceous and Cenozoic rocks.

The Afghanistan Subsalt Basinal Assessment Unit encompasses an area in the Afghanistan portion of the Afghan-Tajik Basin that is part of an as-yet undelineated Late Jurassic basin. The assessment unit is defined to separate reservoir rocks deposited on the shelf having a high probability of hydrocarbon accumulations from basin rocks having a lower probability. The assessment unit includes subsalt Jurassic rocks, which occur in the autochthon below detached and folded Cretaceous and Cenozoic rocks.

Assessment Results:

Parameters estimated for the input variables are shown in Figure 29. The estimated number of undiscovered natural gas fields is based on the density and areas of mapped structures. The area of the Afghanistan Subsalt Oxfordian Shelf Assessment Unit is one-fourth that of the Afghanistan Subsalt Basinal Facies Assessment Unit where potential reservoirs are deeper and presumably of poorer quality. One-fourth of the structures of the Afghanistan Subsalt Basinal Facies Assessment Unit were assumed to have potential accumulations, thereby resulting in the same estimated number of undiscovered fields. A very skewed undiscovered size distribution was estimated based on natural gas field sizes of Jurassic accumulations in the Amu Darya Basin. A wide range of undiscovered field sizes was chosen because many different structural and stratigraphic traps may exist in each assessment unit.

Despite the same estimated number and sizes of undiscovered fields, different probabilities of geologic occurrence were assigned. The Afghanistan Subsalt Oxfordian Shelf Assessment Unit was given an 80 percent geologic probability whereas the Afghanistan Subsalt Basinal Facies Assessment Unit was given only 50 percent for the assessment unit. Without risk, the mean of the undiscovered gas volume is a little over 1.5 trillion cubic feet (42 billion cubic meters) with a range from an F95 of 0.3 to an F5 of 3.7 trillion cubic feet. With the 80% geologic probability, the mean of the undiscovered natural gas volume in the Afghanistan Subsalt Oxfordian Shelf Assessment Unit is 1.2 trillion cubic feet (34 billion cubic meters) with a range from an F95 of 0 to an F5 of 3.5 trillion cubic feet. With the 50% geologic probability, the mean of the undiscovered natural gas volume in the Afghanistan Subsalt Basinal Facies Assessment Unit is 0.8 trillion cubic feet (23 billion cubic meters) with a range from an F95 of 0 to an F5 of 3 trillion cubic feet.

Afghan-Tajik Paleogene Total Petroleum System (115602)

Discovery History:

Crude oil has been discovered and is produced in the Afghan-Tajik Basin in Tajikistan. Although no discoveries have been made in Afghanistan to date, crude oil shows were observed in some wells on Gunj and Qunduz (Kortau) structures. Twenty-one wells were drilled in the Afghan-Tajik Basin part of northern Afghanistan. Because of technical problems mostly related to overpressure, many of these wells did not penetrate the objectives or were not tested and completed.

Petroleum Occurrence:

The Afghan-Tajik Paleogene Total Petroleum System is crude oil-prone (Orudzheva and Kornenko, 1991). Few wells have penetrated Cretaceous rocks of the Surkhan megasyncline; most wells terminate just below the Paleocene section (Egamberdev and Abdullaev, 1993).

Source Rocks:

The principal source rock is organic-rich mudstone beds of the Eocene Suzak interval (Knodur and others, 1992). Total organic carbon content in thin (0.5 to 2 meters) organic-rich beds in neighboring Tajikistan is typically 11 to 19 weight percent, but up to 48 weight percent, and have high gamma ray well-log responses (Buzurukov and others, 1978; Ergashev, 1983; Khaimov, 1986; Egamberdyev and Mayvandi, 1992). In other lower Suzak rocks of both Afghanistan and Tajikistan, the total organic carbon contents range from 0.5 to 3.5 weight percent (Ergashev, 1983; Egamberdyev and Mayvandi, 1992). The organic matter is type II (marine) kerogen. The organic-rich mudstone has a hydrogen content of 7.65 to 8.08 percent (Khaimov, 1986). No terrestrial organic matter is observed (Khaimov, 1986). Resin content is 10 percent and sulfur content is 4.5 percent (Khaimov, 1986).

Thick green to dark gray Suzak mudstone, up to 130 meters thick, was deposited in a deep marine basin (Egamberdyev and Mayvandi, 1992). Suzak organic-rich mudstone beds are commonly 1.5 to 5 meters above the base of the Suzak interval (Khaimov, 1986). The organic-rich mudstone beds are present throughout the Amu Darya and Afghan-Tajik Basins, but are present only in small areas in the Gissar and Darvaz ranges (Khaimov, 1986).

In the Baysun and southwest Gissar areas, Paleogene black mudstones (Suzak Formation) were drilled in two synclines (Ergashev, 1983). Black mudstones in the two wells were 323 and 107 meters deep having thicknesses of 1.2 to 1.5 meters, respectively (Ergashev, 1983). In southern Uzbekistan, Suzak beds include mudstone with organic-rich beds to the south and mudstone and sandstone to the north (Atkhamor and Kasymov, 1967). In the Khaudag Field, crude oil shows are observed in Suzak beds along fractures and are syngenetic (high resin and asphaltene content, only 34% oil fraction) (Atkhamor and Kasymov, 1967).

Total organic carbon content in intervals other than Suzak is typically low, but the Aptian to Albian section has total organic carbon content up to 18 weight percent (Egamberdyev and Mayvandi, 1992). Organic matter in this section is mainly of terrestrial origin (Egamberdyev and Mayvandi, 1992). Other mudstones in the section has total organic carbon contents from 0.3 to 3.46 weight percent and type III (terrestrial) kerogen (Egamberdyev and Mayvandi, 1992).

Maturation:

In the deepest area of the Afghan-Tajik Basin, Paleogene rocks are at the onset of crude oil generation (catagenic zones between protocatagensis stage 3 and mesocatagenesis stage 1) (Knodur and others, 1992). In synclines, the Suzak source rock reached the crude-oil generation window during Neogene time. The source rocks are buried by thick Neogene to Quaternary clastics and by thrust sheets of Cretaceous and Cenozoic rocks.

Based on elemental composition of kerogen, Paleogene rocks in the Surkhan and Vakhsh megasynclines are in the oil window (middle grades of catagenesis) at depths of 4 to 5 kilometers, and the principal potential is in subthrust zones, in synclines (Volos and others, 1982).

In the Vakhsh megasyncline and Kafirnigan meganticline, on the Kichikbel and Akbashadyr structures, the average geothermal gradients are, for the Neogene interval, 2.5 degrees C per 100 meters; for the Oligocene to Eocene interval, 3.2 degrees C per 100 meters; and for the Paleocene interval, 2 degrees C per 100 meters (Gotfilf and others, 1969). The average geothermal gradient is slightly higher for the Gissar meganticline and Vakhsh megasyncline at 3 degrees C per 100 meters (Gotfilf and others, 1969). At 4.5 kilometers, bottom-hole temperatures vary from 110 degrees C at South Aktau to 135 degrees C at Aktau and North Kurgancha (Krylov, 1980). A temperature of 175 degrees C is calculated for depths of 6 to 7 kilometers (Krylov, 1980).

Anomalously high formation pressure (overpressure) is present in some structures, such as the Karadum Anticline, which extends into Afghanistan. Overpressure is local rather than regional (Bratash and others, 1970).

In the Afghan-Tajik Basin, only the Paleogene and Upper Cretaceous rocks are in the oil-window zone (Yakovets, 1976). Underlying rocks are in the gas window (Yakovets, 1976).

Reservoir Rocks:

The primary potential reservoir rocks are the Upper Cretaceous to Paleogene Ghory suite carbonates (fig. 30). Paleogene and Neogene clastic reservoirs are probably of secondary importance. Cretaceous reservoir rocks may have potential only in structural positions where they could be charged by Eocene Suzak source rocks. Migration of gas from the underlying subsalt Jurassic petroleum system is possible locally, although no signs of migration of fluids from Jurassic source rocks have been observed (Safranov, 1988).

Reservoir properties of Paleogene carbonate rocks in Tajikistan improve from east to west mainly because of increasing amounts of dolomite (Knodur and others, 1992).

In Beshtentyak Field, carbonate reservoir rocks have porosities from 0.5 to 16.2 percent; low porosity (less than 3 percent) rocks account for 75 percent. Higher porosity rocks in the Ghory suite (Bukhara member) are poorly characterized. Matrix permeability is very low even in high porosity rocks.

Traps:

Possible primary traps are anticlines and faults associated with anticlines (fig. 31). Most of the crude oil and natural gas accumulations have been discovered in "blanket-crest traps" (Orudzheva and Kornenko, 1991). Many anticlines in the upper thrust sheets are deeply eroded, and conditions for preservation of hydrocarbons are poor. Structural traps in synclines and lower thrust sheets have better potential. The youngest tectonically sealed traps in the Afghan-Tajik Basin were formed by the end of the Pliocene and the beginning of the Quaternary (Knodur and others, 1992). Traps are present in synclinal zones (tectonically sealed), among anticlinoria, but the best traps are in overthrust zones of the Vakhsh zone (Knodur and others, 1992).

Stratigraphic traps may exist in the Afghan-Tajik Basin based on the discovery of stratigraphic and fault traps in Beshtentyak and North Kurgancha Fields (Makhkamov and others, 1985). The most favorable traps are those sealed by salt diapirs in the Cretaceous and Paleogene intervals of the Obigarm and Kulyab meganticlines in eastern parts of the basin (Makhkamov and others, 1985). Structures produced by salt tectonics are observed in the Afghan-Tajik Basin near the town of Taloqan in northern Afghanistan (Dastyar and others, 1990) and salt diapirs in southern Tajikistan (Loziyev, 1976).

Seals:

Seal rocks include Suzak mudstone and intraformational Paleogene and Neogene mudstone (Safranov and others, 1983).

Assessment Units:

The Afghanistan Western Suprasalt Gentle Folds Assessment Unit (11560201) and the Afghanistan Eastern Suprasalt Thrusts and Folds Assessment Unit (11560202) are both stratigraphically above the Upper Jurassic salt but differentiated with respect to the intensity of deformation within potential structural traps. The Afghanistan Western Suprasalt Gentle Folds Assessment Unit is located on a basement structural step that inhibited intense Neogene deformation thereby having larger, unbroken structures with a high potential for petroleum resources.

The Afghanistan Western Suprasalt Gentle Folds Assessment Unit encompasses Cretaceous and Cenozoic rocks of the area where Neogene to Quaternary deformation was not as intense as in areas farther east. The area coincides with a structural step as indicated by gravimetric surveys. The area extends from the eastern edge of the southwest Gissar spur meganticline to the western edge of intensive Neogene to Quaternary folding within the Surkhan synclinorium. The southern boundary of the assessment unit is along the Alburz-Marmul fault zone.

Afghanistan Eastern Suprasalt Thrusts and Folds Assessment Unit comprises Cretaceous and Cenozoic rocks in an area of intensive Neogene to Quaternary folding from anticlinal ridges of the eastern Surkhan synclinorium to the Hindu Kush and Badakhshan ranges in the east. The southern boundary is along the Alburz-Marmul fault zone.

Fifteen wells were drilled in the Afghanistan Eastern Suprasalt Thrusts and Folds Assessment Unit and six in the Afghanistan Western Suprasalt Gentle Folds Assessment Unit.

Assessment Results: The Afghan-Tajik Basin has the greatest geologic uncertainty in this study. No seismic surveys have been conducted in northern Afghanistan and only surveys using old technology having poor resolution were made in Tajikistan. The geology is known primarily from surface mapping. The geologic model of petroleum occurrence used in this study was constructed using analogues.

Although oil and source-rock samples were collected throughout the basin and analyzed for this study, no definitive oil-source rock correlations have yet been made. Source rocks for the oil are inferred and the petroleum system is poorly defined. In addition, the geology and sizes of discovered fields are poorly known. The elements of Jurassic total petroleum system, as well as subthrust structures below the salt are poorly known.

Despite discoveries in Tajikistan, random success throughout exploration history and poorly known field sizes make exploration and discovery history analysis inadequate to use for assessment of northern Afghanistan. Therefore analogs were used in addition to structure/prospect maps to aid in the estimation of the number and sizes of undiscovered accumulations.

An assessment unit in the North Caucasus was chosen as an analog because it has similar but well understood geology and is mature with respect to exploration. As with the Afghan-Tajik Basin, this analogue has an allochthonous section above a salt detachment surface; compressional anticlines, folds, and thrusts; and salt-induced structures. In addition, the source rock age, reservoir rock age, and structural timing are similar.

Figure 32 shows cross sections through this analogue assessment unit. The Terek-Sunzha thrust belt (fig. 32A) is in the western part of the assessment unit, has a salt detachment surface, and is where most of the oil accumulations exist. Both the source rock (Oligocene to Miocene Maykop Formation) and reservoir rocks (Upper Cretaceous to Miocene) are above the Jurassic salt detachment surface, as in the Afghan-Tajik Basin. The Dagestan thrust belt (fig. 32B) has a mudstone detachment surface and is in the eastern part of the North Caucasus assessment unit. These cross sections show that where salt is present, only a small number of thrust sheets are expected to be stacked; typically two (A) whereas multiple imbricate thrust sheets are stacked where salt is absent (B).

Analysis of the discovery history of the North Caucasus assessment unit analog (fig. 33) indicates that about 30 oil discoveries were made and decreasing in size through time of discovery as expected. The largest field sizes are roughly 500 to 800 million barrels. Most of the sizes are below 100 million barrels. The median field size is between 10 and 20 million barrels.

Structures and prospects on maps in the Afghan-Tajik Basin were counted to aid in our estimation of the number of undiscovered accumulations. Only about 40 percent of the structures are assumed to be mapped, some undrilled structures may not be prospects, and some drilled "dry" structures may actually be fields. Traps are expected in both allochthons and subthrusts.

The Afghanistan Western Suprasalt Gentle Folds Assessment Unit is postulated to have a smaller number of larger fields, whereas the Afghanistan Eastern Suprasalt Thrusts and Folds Assessment Unit should have a larger number of smaller fields because of the larger area and a greater degree of deformation (figs. 34 and 35).

The largest accumulation in the Afghanistan Western Suprasalt Gentle Folds Assessment Unit was assumed to not yet have been discovered and a size larger than the analog was estimated to express uncertainty (3 billion barrels). Despite the large maximum estimated size, the expected largest crude oil accumulation is only about 300 million barrels because of the small number of fields estimated.

The estimated sizes for the Afghanistan Eastern Suprasalt Thrusts and Folds Assessment Unit are more like the Middle Caspian Foldbelt-Foothills Assessment Unit analog.

The mean of the undiscovered crude oil volume in the Afghanistan Western Suprasalt Gentle Folds Assessment Unit is over 600 million barrels (over 80 million metric tons) with a range from an F5 of 90 to an F95 of 1,800 million barrels. Although larger accumulations may be discovered in this assessment unit, most of the undiscovered crude oil is estimated to be in the Afghanistan Eastern Suprasalt Thrusts and Folds Assessment Unit.

The mean of the undiscovered crude oil volume in the Afghanistan Eastern Suprasalt Thrusts and Folds Assessment Unit is almost 900 million barrels (123 million metric tons) with a range from an F5 of 280 to an F95 of 1,600 million barrels. The distribution is considerably less skewed and the range is narrower than for the Afghanistan Western Suprasalt Gentle Folds Assessment Unit, reflecting the wider range of numbers and larger numbers of accumulations with a narrower size distribution.

A small number of natural gas fields was estimated for the Afghanistan Western Suprasalt Gentle Folds Assessment Unit because of the small areal extent of the assessment unit and few mapped structures. Should a natural gas field exist the size could be quite large, which is expressed by a maximum of 1,500 billion cubic feet of natural gas in the estimated undiscovered field-size distribution. Although an undiscovered field-size distribution that is the same as for the Afghanistan Jurassic Evaporite Basin Margin Assessment Unit of the Amu Darya Basin was estimated, this distribution was chosen to express trap volume without a salt seal in allochthons, as well as natural gas generation from a marginally mature source rock.

In comparison with the Afghanistan Western Suprasalt Gentle Folds Assessment Unit, a larger number of smaller natural gas fields was estimated for the Afghanistan Eastern Suprasalt Thrusts and Folds Assessment Unit. Natural gas accumulations are postulated to exist in highly compartmentalized subthrust structures. Smaller field sizes were estimated to reflect smaller compartments and the possibility of leakage through faults and fractures in these intensely deformed structures.

Conclusions

Using a geology-based assessment methodology, the U.S. Geological Survey–Afghanistan Ministry of Mines and Industry Joint Oil and Gas Resource Assessment Team estimated mean volumes of undiscovered petroleum in northern Afghanistan. Units for assessment were delineated, and geologic risk was assigned to these assessment units. Number and sizes of undiscovered petroleum accumulations were estimated and given ranges of uncertainty. The results of the assessment are probability distributions of the volumes of undiscovered crude oil, natural gas, and natural gas liquids/condensates.

The resulting estimated mean volumes of the probability distributions are 1,596 million barrels or 219 million metric tons of crude oil, 15,687 billion cubic feet or 444 billion cubic meters of natural gas, and 562 million barrels or 77 million metric tons of natural gas liquids (table 1). The greatest volume of undiscovered crude oil is estimated to be in the Afghanistan Eastern Suprasalt Thrusts and Folds Assessment Unit (11560202). The greatest volume of undiscovered natural gas is estimated to be in the Afghanistan Jurassic Evaporite Basin Subsalt Carbonates Assessment Unit (11540105).

Development of Afghanistan's petroleum resources is needed for the continued economic recovery of the country. This development will likely take several forms starting with verification of reserves through recompletion or twinning of existing wells in producing fields to increase production and collect data. The viability of petroleum resources in the Afghan-Tajik Basin should be demonstrated with regional seismic surveys followed up by appropriate exploratory wells.

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Appendicies

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APPENDIX 1

Assessment input forms

APPENDIX 2

Assessment results reports

APPENDIX 3

Description of assessment methodology

UNDISCOVERED PETROLEUM RESOURCES

USGS Methodology for the Assessment of Undiscovered Technically Recoverable Conventional Petroleum Resources (modified from Schmoker and Klett, 2003)

Conventional accumulations, as recognized by the USGS for purposes of resource assessment, are defined by two key geologic characteristics: (1) they occupy limited, discrete volumes of rock bounded by traps, seals, and down-dip water contacts, and (2) they depend upon the buoyancy of crude oil or natural gas in water for their existence; floating bubble-like in water. Because of these properties, conventional accumulations are commonly assessed in terms of the sizes and numbers of discrete accumulations (for example, individual crude oil and natural gas fields). This section describes the fundamental concepts supporting the U.S. Geological Survey "Seventh Approximation" model for resource assessments of conventional accumulations.

The Seventh Approximation model provides a strategy for estimating volumes of undiscovered petroleum (crude oil, natural gas, and coproducts) having the potential to be added to reserves in some (specified) foreseeable future time span. For purposes of this model, undiscovered petroleum is that which is postulated from geologic knowledge and theory to exist outside of known accumulations, and which resides in accumulations having sizes equal to or exceeding a stated minimum volume. Undiscovered petroleum volumes include initial accumulation sizes as they are perceived at the time of discovery, as well as any reserves anticipated to be added as these discoveries are developed and produced.

The Seventh Approximation does not attempt to predict volumes of petroleum that will actually be discovered in a given future time span. To do so would require full knowledge of future petroleum economics and exploration technologies, and the extent of exploration effort that will be conducted in the area being assessed. Rather, the Seventh Approximation is used to estimate volumes of petroleum having *potential*, from a geologic standpoint, to be discovered in a specified time frame.

To begin an assessment of undiscovered conventional resources using the Seventh Approximation, the volume of rocks to be assessed is apportioned into reasonably homogeneous subunits. These subunits are divisions of total petroleum systems, termed assessment units. Assessment units are considered and assessed individually.

The assessment of an area requires (1) choice of a minimum accumulation size, (2) assignment of geologic risk, and (3) estimation of the number and sizes of undiscovered accumulations in the assessment area. The combination of these variables yields probability distributions for potential additions to reserves. Computer programs are used in conjunction with the Seventh Approximation to calculate resource estimates. However, assessment results are controlled by geology-based input parameters supplied by knowledgeable geologists, as opposed to projections of historical trends.

Documentation for the World Petroleum Assessment 2000 (U.S. Geological Survey World Energy Assessment Team, 2000) described the Seventh Approximation in considerable detail, as well as operational procedures and practical considerations associated with its implementation. The reader is referred to that reference for more detail than is provided here.

The uncertainties associated with the variables required for an assessment of undiscovered conventional resources are considerable, leading to a substantial range of possible input values. Many of the variables that make up the set of input data are therefore represented by probability distributions rather than by single (point) values. Resource forecasts derived from these input data are also represented by probability distributions.

The probability distributions for some input variables show the uncertainty of a fixed but unknown value, whereas other probability distributions represent input variables that have a naturally occurring range of values. F_{100} (minimum), mode, and F_0 (maximum) fractiles are the input parameters estimated for all variables, except size whereby the F_{50} (median) is recorded for the central tendency. These parameters are represented by probability distributions. These parameters are not specifically linked to a particular type of probability distribution (for example, lognormal). The choice of probability-distribution type is an operational decision that is not constrained by the basic Seventh Approximation assessment model. For this assessment, a truncated, shifted lognormal distribution is used for the sizes of undiscovered accumulations, and triangular distributions are used for all other input variables represented by probability distributions.

The essence of the assessment procedure is as follows:

(1) A minimum accumulation size (field size or pool size), expressed as barrels of oil for oil accumulations and barrels of oil equivalent for gas accumulations, is chosen for the assessment unit. Petroleum in accumulations expected to be smaller than the minimum size is not considered to be a significant resource within the specified forecast span and is excluded from the assessment.

(2) Probabilities for the occurrence of adequate charge, adequate rocks, and adequate timing for at least one undiscovered accumulation of minimum size or greater are assigned to the assessment unit; this defines the geologic risk.

(3) The number of undiscovered oil accumulations and the number of undiscovered gas accumulations in the assessment unit that are greater than or equal to the minimum size are estimated.

(4) Sizes of these undiscovered crude oil accumulations and undiscovered natural gas accumulations are estimated. Size estimates include both the reserves estimated at the

time of discovery and anticipated reserve additions as accumulations are exploited after discovery (reserve growth).

(5) For undiscovered oil accumulations, ratios of natural gas/crude oil and natural gas liquids/natural gas are estimated. For undiscovered natural gas accumulations, the ratio of total liquids/natural gas is estimated. These ratios are used to assess the coproducts associated with crude oil in crude oil accumulations and with natural gas in natural gas accumulations.

The combination of individual geologic probabilities, number of undiscovered accumulations, sizes of undiscovered accumulations, and coproduct ratios yields probability distributions for potential additions to reserves of crude oil, natural gas, and coproducts in the assessment unit.

An important aspect of this assessment procedure is that historical exploration and discovery patterns serve only as a starting point for the assessment forecast, and they are not necessarily projected as characteristic of future exploration and development trends. With historical data as a point of reference, input parameters can be chosen to reflect perceived impacts of future change, such as improved technologies and newly developed geologic concepts, as well as the recognition that the larger fields in an assessment unit tend to be found first.

Four input-data elements in addition to those discussed in the previous section are recorded at the assessment-unit level.

(1) Identification Information

Identification information includes the assessor's name, the date of the assessment meeting at which input data were discussed and reviewed, and the names and numerical codes of the region, province, total petroleum system, and assessment unit. Brief notes relevant to the assessment can also be recorded.

(2) Characteristics of Assessment Unit

These input data, although not essential elements of the assessment model, provide information that is useful for the resource-assessment process.

Classification of the assessment unit as crude oil prone or natural gas prone, based on the criteria that the overall natural gas/crude oil ratio of an crude oil-prone assessment unit is less than 20,000 cubic feet of natural gas/barrel of crude oil, and that of a natural gas-prone assessment unit is greater than or equal to 20,000 cubic feet of natural gas/barrel of crude oil.

Number of discovered crude oil accumulations and natural gas accumulations of minimum size or larger, and the median sizes of three sub-groups of these accumulations – the first-third discovered, the second-third discovered, and the third-third discovered (or first-half and second-half discovered if the number of fields is small).

A classification of the exploration maturity of the assessment unit – as established, frontier, or hypothetical – is also made, based on the number of discoveries equal to or exceeding minimum size. Established (>13 accumulations discovered) and frontier (1-13 accumulations discovered) assessment units are known to have all the geologic elements necessary for at least one petroleum accumulation of minimum size. Additionally, established assessment units have a sufficient number of discovered accumulations for historic field- or pool-level data to be of help in postulating properties of undiscovered accumulations. Hypothetical assessment units have no discovered accumulations, and their assessment is therefore more speculative than for established and frontier assessment units.

(3) Selected Ancillary Data for Undiscovered Accumulations

These data establish a modest set of information useful for economic and environmental analyses of assessment results. They do not contribute directly to assessment calculations. Ancillary data for undiscovered conventional crude oil accumulations are estimates of API gravity of crude oil, sulfur content of crude oil, drilling depth, and water depth (if applicable). Ancillary data for undiscovered conventional natural gas accumulations are estimates of inert-gas content, carbon dioxide content, hydrogen sulfide content, drilling depth, and water depth (if applicable).

(4) Allocations of Assessed Undiscovered Resources

These input data consist of percentages necessary to allocate assessed undiscovered conventional resources to various land entities of interest within the assessment unit, as well as to the offshore portion of each entity, if applicable. Such land entities could include, for example, surface and mineral ownerships, special use categories of state and federal lands, or ecological zones.

Undiscovered petroleum resources estimated for assessment units can be aggregated to total petroleum systems, geologic provinces, and regions. If the assessment units or other areas are assumed to be dependent, that is having a +1 correlation coefficient, the fractiles of the calculated resources may be added to provide the probabilistic estimates of the petroleum resources of northern Afghanistan. In addition, aggregation assuming dependency maintains a broader uncertainty range.

APPENDIX 4

One page geologic summaries

USGS PROVINCE: Amu Darya Basin (1154)

GEOLOGISTS: T.R. Klett and G.F. Ulmishek

TOTAL PETROLEUM SYSTEM: Amu Darya Jurassic-Cretaceous (115401)

ASSESSMENT UNIT: Afghanistan Jurassic Evaporite Basin Subsalt Carbonates (11540105)

DESCRIPTION: Assessment unit encompasses Jurassic rocks of the basin area in boundaries of the Gaurdak salt formation (Kimmeridgian to Tithonian). Known fields are located dominantly in northern areas of the assessment unit; the rest of its area is mostly undrilled. The assessment unit is characterized by the presence of the regional salt seal that generally prevents vertical migration of hydrocarbons into post-Jurassic rocks. As a result, most fields contain pools only in Upper Jurassic (Callovian to Oxfordian) carbonates beneath the salt. Several natural gas fields discovered to date in northern Afghanistan are in this assessment unit.

SOURCE ROCKS: The principal source rocks are Lower to Middle Jurassic coaly continental to marine clastics and coals and Upper Jurassic (primarily Oxfordian) anoxic basinal black mudstone. The source rock section is thin on marginal highs, but thickens to several hundred meters basinward. Both source rocks are separated from Cretaceous reservoirs by a regional, undeformed salt seal. The clastic rocks contain from several tenths to as much as 2.5 weight percent of total organic carbon with Type III kerogen and thin coals. Upper Jurassic basinal black mudstone (Khodzhaipak Formation) has not been penetrated by wells in Afghanistan but is known from paleogeographically similar areas in adjacent Uzbekistan where it is a few tens of meters thick and contains as much as 15 weight percent total organic carbon and type II kerogen.

MATURATION: Both Jurassic source rock suites are in the gas window and are at high stages of maturity.

RESERVOIR ROCKS: The main reservoir rocks are Upper Jurassic (Callovian to Oxfordian) carbonates that probably include barrier and pinnacle reef facies.

TRAPS: All known fields are in structural traps. Undiscovered fields are expected in structural traps, in reefs, or combination of the two.

SEALS: The principal regional seal is the Kimmeridgian to Tithonian Gaurdak Formation composed of salt and anhydrite with local carbonate beds.

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USGS PROVINCE: Amu Darya Basin (1154)

GEOLOGISTS: T.R. Klett and G.F. Ulmishek

TOTAL PETROLEUM SYSTEM: Amu Darya Jurassic-Cretaceous (115401)

ASSESSMENT UNIT: Afghanistan Jurassic Evaporite Basin Suprasalt Anticlines (11540106)

DESCRIPTION: Assessment unit encompasses Cretaceous and younger rocks of the basin area in boundaries of the underlying Upper Jurassic evaporite formation. A regional salt seal between Jurassic source rocks and potential Cretaceous reservoirs hampers vertical migration of hydrocarbons. No hydrocarbon accumulations have been discovered in this assessment unit, and potential for finding gas accumulations is related to migration through windows in the salt.

SOURCE ROCKS: The principal source rocks are Lower to Middle Jurassic coaly continental to marine clastics and coals and Upper Jurassic (primarily Oxfordian) anoxic basinal black mudstone. The contribution from possible organic-lean Cretaceous source rocks is minimal, if any. The precise mechanism of migration from the source to the reservoirs is not clear. A possible model, known from the giant Dauletabad-Donmez field in adjacent Turkmenistan, includes vertical migration beyond the pinch-out boundary of the salt formation and following lateral migration basinward to traps. The existence of windows in salt, which are suitable for vertical migration, in the salt-dome area along the Repetek-Kelif fault is also possible.

MATURATION: Both Jurassic source rocks are in the gas window and have resided in the high maturity zone since at least Late Cretaceous time.

RESERVOIR ROCKS: Principal reservoir rocks are sandstone of the Hauterivian Qezeltash Formation (also spelled Kyzyltash; stratigraphically equivalent to the Shatlyk Formation of Turkmenistan), but other Cretaceous reservoir rocks are also present.

TRAPS: Accumulations will most likely be found in structural traps.

SEALS: The Qezeltash Formation reservoirs are sealed by an extensive Barremian to Aptian mudstone. Intraformational mudstone beds may seal gas pools in other reservoirs.

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USGS PROVINCE: Amu Darya Basin (1154)

GEOLOGISTS: T.R. Klett and G.F. Ulmishek

TOTAL PETROLEUM SYSTEM: Amu Darya Jurassic-Cretaceous (115401)

ASSESSMENT UNIT: Afghanistan Jurassic Evaporite Basin Margin (11540107)

DESCRIPTION: Assessment unit consists of Jurassic through Cenozoic rocks along major structural highs located south and east of the pinch-out zone of Upper Jurassic salt. The structural highs include the Akhchin step, Andkhoy high, Maimana step and smaller adjacent structures. Many of the gas and all oil fields discovered to date in northern Afghanistan are in this assessment unit.

SOURCE ROCKS: The principal source rocks are Lower to Middle Jurassic coaly continental to marine clastics and coals and Upper Jurassic (primarily Oxfordian) anoxic basinal black mudstone. The source rock section is thin or absent on marginal highs, but thickens to several hundred meters basinward. Hydrocarbon contribution from Lower Cretaceous organic-lean mudstones, if any, is minimal. Apparently, hydrocarbon accumulations were formed by updip lateral migration to traps from Jurassic source rocks that occur in depressions adjacent to this assessment unit.

MATURATION: In the depressions adjacent to this assessment unit, both Jurassic source rocks are in the gas window and have resided in the high maturity zone since at least Late Cretaceous time.

RESERVOIR ROCKS: The Hauterivian Qezeltash Formation sandstone (also spelled Kyzyltash; stratigraphically equivalent to the Shatlyk Formation of Turkmenistan), several tens of meters thick, contains most of the oil and gas reserves. The gas contains little or no sulfur. The sandstone has high porosity and permeability. The second important reservoir rock interval is Upper Jurassic (Callovian to Oxfordian) shallow-shelf carbonates that contain sour gas. Other Cretaceous reservoir rocks are of secondary importance.

TRAPS AND SEALS: Most of discovered productive traps are anticlinal uplifts. Structural traps are expected to contain the majority of resources. Pinch-out zones of Jurassic and lower Neocomian clastics and carbonates on the northern slope of the Maimana Step may contain stratigraphic and combination traps.

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USGS PROVINCE: Amu Darya Basin (1154)

GEOLOGISTS: T.R. Klett and G.F. Ulmishek

TOTAL PETROLEUM SYSTEM: Kalaimor-Kaisar Jurassic (115402)

ASSESSMENT UNIT: Afghanistan Kushka Zone (11540201)

DESCRIPTION: Assessment unit encompasses the Kalaimor-Kaisar, Nurbelek, and Kalarin depressions and separating uplifts forming the western plunge of Bandi-Turkestan. A fault bounding the Dzhikdalek anticline on the south marks the boundary with the Maimana High. In the north, the assessment unit extends to the state boundary of Afghanistan. The Bandigandao Ridge provides the eastern boundary, and the Siakh-Bubak and Siad-Koh ranges bound the southern edge of the zone.

SOURCE ROCKS: The principal source rocks are probably Lower to Middle Jurassic continental to marine coaly clastics (total organic carbon content as high as 2.5 weight percent) with some coal beds in the lower part. The source rocks are largely gas-prone.

MATURATION: Lower to Middle Jurassic source rocks are buried to depths of about 3 kilometers on the anticlinal uplifts and significantly deeper in depressions filled with thick Neogene to Quaternary rocks and are considered mature for natural gas generation.

RESERVOIR ROCKS: Reservoir rocks in drilled fields of Turkmenistan that are close to the country boundary are present in the section from the upper part of the Middle Jurassic to the Maastrichtian (Ghory Formation). The Ghory reservoirs are composed of carbonate rocks; other reservoir rocks are clastics.

TRAPS AND SEALS: All discovered productive traps in Turkmenistan are anticlinal uplifts. New discoveries are expected in undrilled anticlines and, possibly in the pinch-out zone of Lower to Middle Jurassic clastics along the boundary of the assessment unit with the Maimana Step.

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USGS PROVINCE: Afghan-Tajik Basin (1154)

GEOLOGISTS: T.R. Klett and G.F. Ulmishek

TOTAL PETROLEUM SYSTEM: Afghan-Tajik Jurassic (115601)

ASSESSMENT UNIT: Afghanistan Subsalt Oxfordian Shelf (11560101)

DESCRIPTION: Assessment unit encompasses an area in the Afghanistan portion of the Afghan-Tajik Basin to cover an undelineated Late Jurassic (Oxfordian) shelf. Assessment unit is defined to separate reservoir rocks deposited on the shelf having a high probability of hydrocarbon accumulations from basin rocks having a low probability. The assessment unit includes subsalt Jurassic rocks, which occur in the autochthon below detached and folded Cretaceous and Cenozoic rocks.

SOURCE ROCKS: The principal source rocks are Lower to Middle Jurassic coaly continental to marine clastics and coals and Upper Jurassic (primarily Oxfordian) anoxic basinal black mudstone.

MATURATION: Both Jurassic source rocks are in the gas window and have resided in the high maturity zone since at least Late Cretaceous time. The source rocks are buried to depths of 2 to 3.5 kilometers on the uplifted structural steps along the basin margins and probably as deep as 12 kilometers in the basin center by allochthonous thrust sheets and thick Neogene to Quaternary fill.

RESERVOIR ROCKS: Possible reservoir rocks include Jurassic carbonates near the margin of the basin and possibly some Upper Jurassic clastic rocks. Reservoir quality of these carbonates deteriorates basinward, the carbonate rocks becoming more argillaceous. Based on data from adjacent areas, Lower to Middle Jurassic clastics lose the reservoir quality at depths greater than 3 to 3.5 km due to compaction and diagenesis. Three small fields in the Dushanbe area of Tajikistan produce Jurassic gas from Tithonian reservoirs, but reservoir quality decreases basinward because of increasing burial depth.

TRAPS AND SEALS: Possible traps include subsalt anticlinal uplifts and the pinch-out zone of Jurassic clastics along the basin margin. Upper Jurassic evaporites provide a regional seal.

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Bratash, V.I, Yegupov, S.V., Pechnikov, V.V., and Shelomentsev, A.I., 1970, Geologiya i neftegazonosnost severa Afganistana (Geology and petroleum potential of northern Afghanistan), Trudy VNIGNI, v. 80, Nedra, Moscow, 288 p.

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USGS PROVINCE: Afghan-Tajik Basin (1154)

GEOLOGISTS: T.R. Klett and G.F. Ulmishek

TOTAL PETROLEUM SYSTEM: Afghan-Tajik Jurassic (115601)

ASSESSMENT UNIT: Afghanistan Subsalt Basinal Facies (11560102)

DESCRIPTION: Assessment unit encompasses an area in the Afghanistan portion of the Afghan-Tajik Basin and covers an undelineated Late Jurassic basin. Assessment unit is defined to separate reservoir rocks deposited on the shelf having a high probability of hydrocarbon accumulations from basin rocks having a low probability. The assessment unit includes subsalt Jurassic rocks, which occur in the autochthon below detached and folded Cretaceous and Cenozoic rocks.

SOURCE ROCKS: The principal source rocks are Lower to Middle Jurassic coaly continental to marine clastics and coals and Upper Jurassic (primarily Oxfordian) anoxic basinal black mudstone.

MATURATION: Both Jurassic source rocks are in the gas window and have resided in the high maturity zone since at least Late Cretaceous time. The source rocks are buried to depths of 2 to 3.5 kilometers on the uplifted structural steps along the basin margins and are probably as deep as 12 kilometers in the basin center covered by allochthonous thrust sheets and thick Neogene to Quaternary fill.

RESERVOIR ROCKS: Low possibility of reservoir rocks with adequate reservoir quality exists in this assessment unit, but would include Jurassic carbonates and possibly some Upper Jurassic clastic rocks. Reservoir quality of the carbonates deteriorates basinward, becoming more argillaceous, and Lower to Middle Jurassic clastics loose the reservoir quality at depths greater than 3 to 3.5 km due to compaction and diagenesis.

TRAPS AND SEALS: Possible traps include subsalt anticlinal uplifts. Upper Jurassic evaporites provide a regional seal.

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USGS PROVINCE: Afghan-Tajik Basin (1154)

GEOLOGISTS: T.R. Klett and G.F. Ulmishek

TOTAL PETROLEUM SYSTEM: Afghan-Tajik Paleogene (115602)

ASSESSMENT UNIT: Afghanistan Western Suprasalt Gentle Folds (11560201)

DESCRIPTION: Assessment unit encompasses Cretaceous and Cenozoic rocks of the area where Neogene to Quaternary deformation was not as intense as in areas farther east. The area coincides with a structural step indicated by gravimetric surveys. The area extends from the eastern edge of the southwest Gissar spur meganticline to the western edge of intensive Neogene to Quaternary folding within the Surkhan synclinorium. The southern boundary is along the Alburz-Marmul fault zone.

SOURCE ROCKS: The principal source rock is organic rich mudstone of the Eocene Suzak beds. Total organic carbon content in thin (0.5 to 2 meters) bituminous beds of neighboring Tajikistan is typically 11 to 19 weight percent, but up to 48 weight percent. In other lower Suzak rocks of both Afghanistan and Tajikistan, the total organic carbon content ranges from 0.5 to 3.5 weight percent. The organic matter is type II kerogen.

MATURATION: In synclines, the Suzak source rocks were in the oil window during Neogene time. The source rocks are buried by a thick fill of Neogene to Quaternary orogenic clastics.

RESERVOIR ROCKS: The primary potential reservoir rock is the Upper Cretaceous to Paleogene Ghory carbonates. Paleogene and Neogene clastic reservoirs are probably of secondary importance.

TRAPS AND SEALS: Possible primary traps are anticlines and faults associated with anticlines. Seal rocks include Suzak mudstone and intraformational Paleogene and Neogene mudstone.

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USGS PROVINCE: Afghan-Tajik Basin (1154)

GEOLOGISTS: T.R. Klett and G.F. Ulmishek

TOTAL PETROLEUM SYSTEM: Afghan-Tajik Paleogene (115602)

ASSESSMENT UNIT: Afghanistan Eastern Suprasalt Thrusts and Folds (11560202)

DESCRIPTION: Assessment unit encompasses Cretaceous and Cenozoic rocks of an area of intensive Neogene to Quaternary folding from anticlinal ridges of the eastern Surkhan synclinorium to the Hindu Kush and Badakhshan ranges in the east. The southern boundary is along the Alburz-Marmul fault zone.

SOURCE ROCKS: The principal source rock is organic rich mudstone of the Eocene Suzak beds. Total organic carbon content in thin (0.5 to 2 meters) bituminous beds of neighboring Tajikistan is typically 11 to 19 weight percent, but up to 48 weight percent. In other lower Suzak rocks of both Afghanistan and Tajikistan, the total organic carbon content ranges from 0.5 to 3.5 weight percent. The organic matter is type II kerogen.

MATURATION: In synclines, the Suzak source rock was buried to within the oil window during Neogene time. The source rocks are buried by thick Neogene to Quaternary clastics and by thrust sheets of Cretaceous and Cenozoic rocks.

RESERVOIR ROCKS: The primary potential reservoir rock is the Upper Cretaceous to Paleogene Ghory carbonates. Paleogene and Neogene clastic reservoirs are probably of secondary importance. Cretaceous reservoir rocks may have potential only in structural positions where they could be charged by Eocene Suzak source rocks. Migration of gas from the underlying subsalt Jurassic petroleum system is locally possible.

TRAPS AND SEALS: Possible primary traps are anticlines and faults associated with anticlines. Seal rocks include Suzak mudstone and intraformational Paleogene and Neogene mudstone. Many anticlines in the upper thrust sheets are deeply eroded, and conditions for preservation of hydrocarbons are poor. Structural traps in synclines and lower thrust sheets have better potential.

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Bratash, V.I, Yegupov, S.V., Pechnikov, V.V., and Shelomentsev, A.I., 1970, Geologiya i neftegazonosnost severa Afganistana (Geology and petroleum potential of northern Afghanistan), Trudy VNIGNI, v. 80, Nedra, Moscow, 288 p.

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APPENDIX 5

Seismic survey report

Seismic Component – Northern Afghanistan

A 3-person USGS team visited Sheberghan in Afghanistan with the primary goal to recover as much previously recorded digital seismic data as possible for use in the assessment. A personal computer and the necessary software was purchased and delivered to the seismic processing lab in Sheberghan, Afghanistan for the purpose of transcribing 9-track magnetic field and processed tapes onto DVDs. Upon arrival however, it quickly became apparent that rescuing data from the magnetic tapes would prove to be difficult to impossible. Under proper storage conditions, magnetic tapes can have a lifespan of up to 100 years. During the previous decades of war, the tapes were not stored under conditions of ideal temperature and humidity. None of the tapes examined had data that were recoverable. All magnetic tapes examined had metal oxide flaking problems causing the 9-track tape drive to continuously lose tracking position and go offline. We therefore decided to scan as many paper seismic sections as possible and then later convert the scanned images into the industry standard SEG-Y format, thus making the digital data available for possible future use on interpretation workstations. Final stacked sections were scanned and recorded on DVD for 19 selected seismic profiles during our stay in Sheberghan.

Figure 1 is a location map showing all the seismic profiles recorded through 1988. Figure 2 shows a location map of the 19 seismic profiles selected for scanning and later conversion to SEG-Y for this study.

Many of the 19 profiles were selected on the basis that they were recorded over major geologic structures and existing gas fields (fig. 3). The remaining profiles were selected primarily because they were most readily available at the time. Shown in Figures 4 through 6 are three representative seismic profiles recorded over the Jangali Kalan gas field depicted in Figure 3 as profiles A-A′, B-B′, and C-C′. As can be seen from these images, the data quality is not sufficient for high-resolution stratigraphic interpretation, but the quality suffices to allow delineation of gross geologic structures. Future work in northern Afghanistan should entail the acquisition of modern, multi-channel, higher resolution seismic data with particular emphasis on the Afghan-Tajik Basin as most if not all of the seismic data in northern Afghanistan has been previously recorded in the Amu Darya Basin.

Figure 1. Seismic lines recorded in northern Afghanistan through 1988.

Figure 2. Highlighted in red seismic profiles scanned and converted to SEG-Y format.

Figure 3. Selected seismic profiles recorded over geologic structures (pink) and known gas fields (orange).

Figure 4. Profile 88335 recorded over the Jangali Kalan gas field in northern Afghanistan.

Figure 5. Profile 88329 recorded over the Jangali Kalan gas field in northern Afghanistan.

Figure 6. Profile 85102 recorded over the Jangali Kalan gas field in northern Afghanistan.