Evaluation of salt-section and interpretation of wells in the Kashagan field, Southern part of Pre-Caspian depression, Kazakhstan

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Received ; revised

Pre-Caspian basin has been formed from Paleozoic to Cenozoic time and the Kashagan field is situated in the southern part of Pre-Caspian depression in the Southern flung of Astrakhan-Aktyubinsk elevation system of basal complex and associated with Tengiz-Kashagan interbasin carbonate platform. Platform is composed of separate carbonate early Carboniferous blocks resting on the common Devonian (late Fransian-Fammenian) carbonate base. Four of them are: Kashagan, Kashagan South-West, Aktote and Kairan are located on the Caspian shelf and Karaton, Tengiz and Korolev on the coastal line of the eastern Caspian. Depositions of Devonian through to Elephantine inclusive were penetrated in Kashagan. Maximum section penetrated during drilling was 5172 m in KE-1. Pre-salt and post-salt units separated by thick Kungurian of Lower Permian salt-bearing section were identified in the well log. Description of the tectonics of the field was based on 3D seismic and drilling data from KE-1, KE-2, KE-3, KE-5 for East Kashagan and 2D seismic for West Kashagan where one well KW-1 was drilled. 3D seismic data provided more detailed information about geology of the structure, facies distribution and main layer thicknesses, and allowed a more accurate interpretation of tectonic faulting.

Introduction

The Kashagan oil field is located in the northern Caspian Sea, western Kazakhstan (Figure 1). Kashagan field is one of the largest oil fields discovered in the last 30 years. It is a large, isolated carbonate bank, one of the biggest buildups in an archipelago that characterized the Pre-Caspian Basin from the Devonian to the Carboniferous and that now hosts large hydrocarbon reserves (Zempolichal., 2002b; Zempolich, 2005). Kashagan reservoir has a complex depositional and stratigraphic framework, which experienced multistage diagenetic and tectonic evolution. This supergiant field was discovered in 2000 by the Offshore Kazakhstan International Operating Company (OKIOC) consortium (Agip, Shell, Exxon Mobil, Phillips, Inpex, KMG, British Gas, BP Amoco, Statoil, and Totalfina). Structure was successfully tested by the Kashagan East-1 and Kashagan West-1 exploration wells, which penetrated a nearly 400-m(1312-ft)- thick oil column in Carboniferous platform carbonates. The oils 46°API and contains 16%H2S. Field is covered by a three dimensional seismic survey shot in 2001–2002. By the end of 2008, Agip Kazakhstan North Caspian Operating Company N.V. (AKCO) (operating company from 2001 until 2008) had drilled 2 exploration, 10 appraisal, and 11 development wells and had cut more than 2000m (6562 ft) of cores in 15 wells (Figure 2). The
Kashagan buildup is approximately 75 km (47 mi) in length and 35 km (22 mi) in width; it is subdivided into an eastern platform (Kashagan East) and a western platform (Kashagan West) connected by a narrow neck (Figure 2). Top of the structure is a seismic horizon correlatable throughout the Pre-Caspian depression that corresponds to the top of the Carboniferous Bashkirian limestone. Platform margin is characterized by a narrow rim elevated up to 250 m (820 ft) higher than the platform interior and best

Developed in Kashagan East (Figures 1, 2), the platform flanks are steep, sloping up to 25°, with the northern slope being steeper than the southern slope (Figure 3). In the southern Pre-Caspian Basin, main phase of carbonate deposition ranged from the late Visean to Bashkirian.

Majority of the precipitation occurs during spring and autumn with the annual level exceeding 250 mm at times. Strong winds are typical for the area: In winter prevailing winds are easterly and northeasterly, in summer westerly and north westerly. Snow blizzards in winter and sand storms and dry hot winds are fairly frequent. Development of the field will take place in very complicated geological environment with abnormally high reservoir pressure and H2S content. Consortium intends to re-inject produced raw gas into the reservoir to increase the oil recovery and reduce the production of sulphur (Barker, A. and Croasdale, K. R., 2004). All this imposes very strict environmental constraints related to every sphere of operational activities both offshore and onshore. Development plan envisages construction of artificial islands and platforms for producers and injectors (vertical and directional).

Geological setting

Kashagan field is situated in the southern part of Pre-Caspian depression in the Southern flung of Astrakhan-Aktyubinsk elevation system of basal complex and associated with Tengiz-Kashagan interbasin carbonate platform (Fig.2). Platform is composed of separate carbonate early Carboniferous blocks resting on the common Devonian (late Fransian-Fammenian) carbonate base. Four of them are: Kashagan, Kashagan South-West, Aktote and Kairan are located on the Caspian shelf and Karaton, Tengiz and Korolev on the coastal line of the eastern Caspian. Depositions of Devonian through to Elephantine inclusive were penetrated in Kashagan. Maximum section penetrated during drilling was 5172 m in KE-1. Pre-salt and post-salt units separated by thick Kungurian of Lower Permian salt-bearing section were identified in the well log. Figure 3 showing a cross section of the area.
Methods and Material

Extensive field exploration and appraisal activities continued during 2003 – 2005:

- Three new wells were drilled in East Kashagan (KE-4, KE-6, KE-A-01), another three are being drilled (KE-A-02, KE-A-03, KE-5-01).
- Gravimetry survey was carried out.
- West Kashagan 3D seismic survey was completed.
- PSTM 3D data processing and interpretation and integrated seismic and gravimetry data interpretation performed.
- New well data acquired: Core, cuttings, logs, well test results.

As a result of these studies new data was obtained to extend the knowledge of the geology of the field including the number and boundaries of the facies, reservoir rocks and reservoir properties. The new information allowed to update and to increase the reliability and quality of the built previously geomodel. Core analysis and well test, reservoir fluid physical properties data was accumulated and reviewed. A vast amount of laboratory studies and experiments was performed to forecast the behavior of the reservoir fluid during the development of the field. All the above allowed to estimate STOOIP and reserves based on the model. Later the estimated oil in place and reserves were officially approved and registered in the State Book of Balance of RoK.

Stratigraphy

Pre-Salt

Upper Devonian deposits were penetrated by two wells:
Deposits are composed of recrystallized algal-pelloid very tight partially dolomitized WST/PST. In Devonian KE-1 penetrated a fairly thick porous zone which could be the result of the karstification due to the significant drop of the sea level at the end of Devonian. Thickness of Upper Devonian interval penetrated by KE-1 is 325m. Carboniferous system is represented stratigraphically, though not in full, by Lower and Middle series of: Turnesian, Visean and Serpukhovian of Lower Carboniferous and Bashkirian of Middle Carboniferous.

Turnesian was partially penetrated by KW-1, KE-3, KE-5, KE-A-01 and fully by KE-1. In this section the deposits of Malev, Upinsky, Cherepezyk, Kizelovsky and Kosvinsky were identified. Generally Turnesian part of the section is a zone of Eustatic Sea level elevation. In the lower part of the interval biofacies typical of the shallow water platform or low energy near tidal lagoon often associated with fine textured PST, WST, saturated pelloids, clots and chunks are quite frequent. Intensive micritization of skeletal grains in this section does not allow accurate identification. In the upper part of
the section these facies are replaced by grainier lithofacies typical for the higher energy open platform palaeoenvironment. The thickness of Turnesian deposits is approximately 220 m.

**Visean** is represented by Kozhimsky suprahorizon and Oksky subhorizon. Thin carbonate deposits (pellet with streaks of algal bodies) are widely spread in the Lower Visean as a result of the Seven seas rise and extension of the transgression on the platform. Lower Visean deposits (Kozhimsky supra-horizon) are represented by pelloid WST/PST, GST, less often by BST. The rocks are silicified in places and have low porosity.

**Tulsky** is composed of bioclastic, crinoidal, crinoidal-brachiopodal limestone interbedded with streaks of vitric tuff. Facies of bioherms represented by small algal and crinoidal-algal bioherms could be found also. Towards the top of the section facies typical of low energy platform prevail. High radioactive zone (HRZ) represented by interbedded tuffous argillites is identifies. This member serves as a regional plug and borderline between Oksky and Tulsky horizons represented by shale and marl. Its thickness varies between 25.2m (KE-4) and 91.4m (KW-1).

**Oksky deposits** of Upper Visean are composed of limestone WST/PST partially recrystallized and silicified. Base Upper Visean is characterized by shale and shale-marl limestone with streaks of volcanogenic-clastic deposits (HR marl facies). The thickness of the Oksky supra-horizon varies across the platform from 216 m (KE-6) to 295.8 m in KE-4.

**Serpukhovian** is represented by organogenic-clastic limestone WST and PST, to a lesser degree by GST, BST, bioclastic algal, re-crystallized, and porous. In the rim area it is represented by vuggy limestone. The thickness of the deposits in the platform varies from 31m (KW-1) to 49.m (KE-5). In the rim the thickness in KE-2 is 38.2 m, but in the well KE-4 it increases to 101.9 m. Middle Carboniferous is represented by Bashkirian which is overlaid by Lower Permian with a regional nonconformity, and its thickness varies within an extremely wide range. The thickness of the deposits alters, and they are represented by bioclastic and oolithic GST and PST with a small amount of bitumen in bioclasts and pores with streaks of alagal limestone re-crystallized in the top section. On the whole Bashkirian rocks show enhanced porosity. Practically the entire section is characterized by interparticle and intraparticle porosity, in some places mouldic porosity is present. At the top of the section the pore volume is increased due to the dissolution process. The overall thickness of Bashkirian is 78-127 m. The reflector P2 is found in the top Bashkirian. Permian formation with a deep stratigraphic nonconformity is situated on the eroded surface of Carboniferous. Permian is represented by two series: Lower and Upper, the latter being poorly defined from the Lower Triassic. Lower Permian is divided into pre-salt Artinskian and Kungurian salt. Artinskian is composed by two
members. The top consists of shale, limestone and argillites; the bottom is represented mainly by argillous rocks. The thickness of Artinskian is around 74 m. The reflector P1 is associated with the top presalt.

**Salt section**

Partially eroded surface of the Artinskian limestone-argillite is overlaid by Kungurian sulphate-halogenic sediments. Salt thickness varies from around 100 m in intercupolar areas to several kilometers in the anticline folds of the salt domes (KE-1 –1054m, KW-1 – 2056 m, KE-2 – 1000m, KE-3 – 99 m, KE-4 – 313 m, KE-5 – 1430 m and KE-6 penetrated 1762 m of salt).

**Post-salt section**

Poorly defined Permian-Triassic sediments are represented mainly by brownish, reddish shale and argillites with the streaks of limestone, marl and anhydrite. In the top the streaks of light grey and grey siltstone, sandstone and argillite are present. Maximum thickness reaches over 800 m. Upper Triassic is represented by grey and greenish shale with the streaks of siltstone, sand aleurite and sandstone. The thickness is around 150 m.

Jurassic is represented by terrigenous-carbonate series of all the three sections situated on the eroded surface of Triassic. Lower and Middle Jurassic are composed of interbedded shale, sandstone, and argillite with occasional streaks of coarsely fragmented material with inclusions of coal and pyrite. Thickness of the deposits is 491-640 m. Upper Jurassic consists of carbonate-terrigenous sediments of Oxford and limestone series of Volzhsky age. Upper Jurassic thickness is 280-327 m. Cretaceous series consisting of upper and lower sections overlays the eroded surface of Jurassic. Lower section is represented by Neokomsky supra-horizon, Aptsky and Albsky horizons of sand-shale series. Lower Cretaceous is 590-920 m thick.

Reflector III is found in Neokomsky base. The upper series consisting of Cenoman, Turonian-Congaksy, Santonian, Campan and Maastrichtian is composed of shale interbedded with sand and sandstone replaced by limestone towards the top of the section and transforming into a mixture of marl, chalk, clay and argillite. Thickness is 398 m (KE-4) – 500 m (KW-1). Unconformable Palaeogenic and Neogenic sediments are found in various horizons of Upper Cretaceous and are represented by interbedding of sand, sandstone, with thin seams of gypsum. Thickness of the sediments ranges between 91 and 216 m.
Stratigraphic/structural model

Seismic Data
Geomodel structure has been built using the December 2004 seismic interpretation. Interpretation was carried out using 3D Pre-Stack Time Migration (PreSTM) post processed for both East and West Kashagan and comprises the following:
- H400, top Bashkirian
- H600, top Visean III
- H660, top Visean II TST
- H700, base HRZ
- Environment of Deposition (EoD) polygons.
The fault polygons are taken from the May 2003 seismic interpretation. A total of 143 faults were interpreted based on the following 3D seismic data:
1. East: Pre-Stack Time Migration
2. West: On board processing
Figures 7 and Figure 8 show the map of the H400 horizon with all the interpreted faults and the reference EoD map.

Fault Modelling

The total fault population, 143 faults, could not be incorporated into the 3D geological model. This was due to a problem of:
1. Cell size i.e. faults with a horizontal spacing less than 500m could not be included in the simulation grid. To minimise upscaling error (“smearing” of properties) the fault model in the simulation grid is the same as the geomodel which has 167m cells.
2. Grid distortion. The grid distortions occurred due to a combination of the large number of faults, cells and sub-grids. The number of faults was therefore reduced using a combination of the following criteria:
- Fault length (measured using fault polygons). The longer faults were preferentially selected.
- Fault throw (maximum fault throw measured using the FRACA software). Longer fault throws were preferentially selected.
- Fault spacing. Faults incorporated in the geomodel must have a minimum spacing of 500m. The screening reduced the number of faults to 66 (Fig. 7). The selected faults generally consist of events
recognized both at the H400 and H700 seismic horizons, suggesting the persistence of these discontinuities across the entire reservoir thickness.

**Layering**

Layering employed in the 2004 geomodel is based on the 4th order shallowing upward cycles. Cycles control both facies distribution and the distribution of petrophysical properties. The description of each cycle and the correlation across the platform was performed using core descriptions, petrographic thin sections and log data. Figure 9 illustrates an example of a 4th order modal cycle. There are 63 4th order sequences interpreted in Kashagan. In order to reduce the final number of layers those sequences having petrophysically homogeneous characteristics have been grouped.

The 6 sequences of Serpukhovian 1 described only in KE4 (Fig. 9) for details on grouped sedimentological cycles). The final number of sequences used in the geological model is 53. The complete list of geomodel layers and their correspondence with the official nomenclature of sedimentological 4th order cycles are shown in Figure 9. For the modeling these sequences were further proportionally subdivided in geostatistical layers with average thickness ~0.5m.

**Stratigraphic Modeling**

In order to propagate the 4th order layering into the inter-well areas stratigraphic modelling was performed (using IRAP-RMS). The 4th order layers were generated using the following input data:

1. Four interpreted seismic horizons; H400, H600, H660 and top HRZ.
2. 4th order tops from well data.
3. The full (143) fault population.

The intermediate horizons have been interpolated conformable to the interpreted seismic horizons. The intermediate layers were proportionally created maintaining a dominantly constant layering thickness in the interior which thickens into the rim (where Unit 1 reservoir thickens, see Fig.10). There are a number of 4th order cycles with a limited areal extension and/or variable thickness which are captured in the layering:

1. The Upper Bashkirian sequence is characterized by an erosional event that is responsible for the irregular distribution of 4th order cycles.
2. The Bashkirian Maximum Flooding Surface is absent in the rim according to control points in KE2 & KE4.
3. There is an increase in thickness of Serpukhovian 1 in KE4 relative to all other wells (including KE2), and is absent in KE3. The maximum thickness observed in KE4 (72.6m) is interpreted as outer-shelf. The increase in thickness and favourable comparison with analogue data (Tengiz) has been used to propagate an increase in thickness of Serpukhovian 1 in the outer-shelf of Kashagan East (Fig. 12).

Conclusions

The study area Kashagan field is one of the largest oil fields discovered in the last 30 years. Kashagan field of 820 km² belongs to Atyrau region and is situated in the North-East sector of the Kazakhstan part of the Caspian Sea. Kashagan field is situated in the southern part of Pre-Caspian depression in the Southern flung of Astrakhan-Aktyubinsk elevation system of basal complex and associated with Tengiz-Kashagan interbasin carbonate platform. Climate of the area is continental: Cold winter and hot summer. Snow cover generally settles in the middle of November and stays till the end of March. Extensive field exploration and appraisal activities continued during 2003 – 2005 from drilling new wells, gravimetry survey, 3D seismic survey of the well and PSTM 3D data processing and interpretation. As a result of these studies new data was obtained to extend the knowledge of the geology of the field including the number and boundaries of the facies, reservoir rocks and reservoir properties. The study area is composed of Upper Devonian deposits were represented by two wells this is pre-salt section; salt section structurally is anticline folds and Permian-Triassic sediments these are Post-salt section. In the final the tectonic structure of the area are recorded. By 2D and 3D seismic data relatively long tectonic faults along the boundaries of the carbonate platform transformed into a series of relatively short tectonic faults of the same trend. In East Kashagab small fault network is generally limited by south and south-east rim of the platform margin. Fairly extensive tectonic faults of West Kashagan identified by 2D seismic are interpreted based on 3D seismic as a series of short tectonic faults of the same strike.

References


Figure

Fig. 1: Map of the area.

Fig. 2: Structural-tectonic map of Caspian region.

Fig. 3: Cross section of Caspian Sea and Kashagan field.

Fig. 7: Kashagan top reservoir depth map.

Fig. 8: Environment of deposition description for the reference case.

Fig. 9: Figure a. shows all faults before selection and b. shows faults implemented in the geomodel after selection (66 in total).

Fig. 10: Schematic representation of a 4th order modal cycle.

Fig. 11: Above tables show the 4th order cycles have been merged to obtain the geomodel layering.

Fig. 12: Cross-section through Kashagan East showing the input seismic horizons and modelled 4th order layers.