HYDROCARBON POTENTIAL OF THE YELLOW SEA KUNSAN BASIN WESTERN KOREA OFFSHORE

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The Yellow Sea is surrounded by the mainland Chinese continent and the Korean peninsula. Two major sedimentary basins are situated in the Yellow Sea: The North and South Yellow Sea Basin. The basins developed in the North Yellow Sea from west to east, include Jiaolai Basin, Bohai Bay Basin, the North Yellow Sea Basin in China and the West Korea Bay Basin in North Korea.

The South Yellow Sea Basin is subdivided into the Northern and Southern South Yellow Sea Basins by a central uplift area. The Northern South Yellow Sea Basin included the North Basin in China and Kunsan Basin in South Korea and the Southern South Yellow Sea Basin developed the Subei Basin, the South Basin in China and Heuksan Basin in South Korea (Figure 1). Commercial oil discoveries have been made in the Bohai Bay basin, the Subei basin and the South Basin in China. However, no commercial discovery has been made in the South Yellow Sea Basins in South Korea yet.

Petroleum exploration in the South Yellow Sea in South Korea dates back to the 1970s and led to the awarding of exploration concessions to several international oil companies, Gulf Oil, Texaco, Marathon Oil and Shell (Blocks I, II and III). These concession blocks cover approximately 117,320 square kilometers. By 2004, a total of 33,784 L-km of 2D seismic data had been acquired in this area. Five wells were drilled (Figure 2). Most of the wells were drilled in the eastern portions of the Northern South Yellow basin and the Kunsan Basin. So far no well has been drilled in the Heuksan Basin.

The sedimentary successions in the Kunsan basin can be subdivided into three distinct tectono-stratigraphic units : Pre-Cretaceous, Cretaceous to Early Tertiary (Paleocene) and Tertiary (Eocene to Plio/Pleistocene). The Late Cretaceous and possible Paleocene shales are considered as the most probable source rocks in the basin, while the younger Paleocene and Eocene fluvial-deltaic rocks appear to be the likely reservoirs. This paper is mainly focused on the hydrocarbon potential of the Korea portion of the Northern part of South Yellow Sea Basin, that is the Kunsan Basin.

Geological Setting

The evolution of the basins within the Yellow Sea was controlled tectonically by the NE-SW orientated Tan Lu Fault in eastern China. The South Yellow Sea Basin developed on the Yangtze Platform of the South China Block mainly during the Cretaceous and Tertiary time. It is known to be an intracratonic pull-apart basin with a general E-W orientation. Transtensional boundary faults along its northern and southern flanks are thought to be the result of relative left-lateral movement. Secondary strike-slip fault movements during the Late Jurassic along the Tan Lu Fault led to the formation of small-scale rift basins in the South Yellow Sea Basin and these were extended into pull-apart basins as sinistral strike-slip faulting continued into the Paleogene.

During the Late Eocene the Indo-Sinian Orogeny caused the reversal of the movement of the Tan Lu Fault. As a result, the South Yellow Sea basin was folded and inverted tectonically by a N-S oriented compression. Accordingly, the sedimentary strata of the basin were uplifted and eroded from Oligocene into the Early Miocene, although some sediments were deposited in limited areas of the basin during the Early Miocene. The basin subsided again during the Middle Miocene and widespread sediment deposition was continued. A marine transgression during the Late Pleistocene led to a change in the general depositional environment to the continental shelf conditions that prevail today.

The Yellow Sea area was subjected to compressional tectonic movements due to the subduction of the South China Block under the North China Block from Jurassic Period onwards. A large-scale strike-slip basin developed during the Late Jurassic – Cretaceous. It contains predominantly alluvial to fluvial and lacustrine sediments. The South Yellow Sea Basin entered a new stage with the development of separate half-grabens in the Paleogene and a unified pan-like depression in the Neogene(Zhang et al., 1989).

Maximum regional subsidence of the basin occurred in the Early-Middle Eocene. In the Late Eocene the rate of subsidence decreased; sedimentation was under shallow lacustrine and eventually ceased altogether when compressional tectonic movements caused uplift and erosion and led to a depositional hiatus. During the early Miocene time, little sedimentation took place in the basin, but from the Middle Miocene onwards regional subsidence again led to widespread subsidence. The Late Miocene deposits are missing from the succession in places. The basin was once again uplifted in the Early Pliocene.

Subsidence followed in the Late Pliocene, and the basin finally succumbed to marine deposition during the Pleistocene.

The Kunsan Basin is divided into eight structural elements (Figure 3). There are four sub-basins or sags and four basement high block areas or massifs. The sags include: the North Sag, the East Sag, the West Sag and the South Sag. The East and West Sags appear to be genetically related and may be considered a single depression with a minor structural high dividing the features. The massifs include the Northeast Massif, the North Central Massif, the South Central Massif and the Southern Margin Massif.

The North Sag is relatively shallow and poorly defined with its northwest to southeast margin. The area is relatively unfaulted.

The East Sag shows the largest and deepest basinal feature. It lies in the southeastern part of the area and trends northwest to southeast with a southeast plunge that terminates against the Southern Basin Margin Massif. The West Sag appears to be a continuation of the East Sag confined by the same high blocks. The portion of the sag within the area is aerially very limited and relatively shallow. This sag may be more significant in both size and depth in the Chinese area.

The South Sag may also be subdivided into two sub-areas designated as the Southwest Sub-sag and the South Central Sub-sag. The South Central Sag is an aerially small but very deep sub-basin located along the southern margin. The feature is traversed by numerous normal and reverse faults with a general northwest to southeast trend. This sub-sag is bounded on its southern margin by the Southern Basin Margin Massif.

Regional Stratigraphy and Depositional Facies

The Kunsan Basin has been tested by five exploratory wells. The geologic age of the succession penetrated in the wells ranges from pre-Cretaceous carbonates and metasediments to Plio/Pleistocene marine section A section of Cretaceous age was encountered at all five wells and the thickest section was penetrated in the Kachi-1 well. Although over 2,000 meters of this section was penetrated in this well, the cretaceous section seen here is incomplete, as it is eroded and overlain unconformably by the Miocene. This Miocene Unconfirmity may be related to the Sanduo Movement recorded in the offshore China (Figure 4).

The Cretaceous succession is divided into four sequences; the Late Jurassic to early Cretaceous, the Early Cretaceous, the Late Cretaceous and the Late Cretaceous to Early Paleocene.

The Late Jurassic to Early Cretaceous is represented by a typical basal section of syn-rift sediments, including volcanoclastics and dominantly beds of siltstones and mudstones. The Early Cretaceous section is composed of interbedded siltstones and mudstones, and thin sandstones. The section is changed to calcareous dolomites in the upper part of the Early Cretaceous sequence. The Late Cretaceous sequence is dominated by mudstones interbeded with thin siltstone, sandstones and limestones. The overall Cretaceous appears to be an upward transition from alluvial sediments through fluvial to shallow lacustrine and finally semi-deep lacustrine deposits.

The overlying Late Cretaceous to Early Paleocene sequence was penetrated in three wells, Haema-1, IIH-1x and IIC-1x, with considerable lithologic variations. In the Haema-1 well, the sequence is composed of a claystone overlying the granitic basement, with thick sandstone as well as aphanitic andesite. In other wells, it is represented by interbedded sandstones, siltstones and mudstones. Such lithologic diversity may indicate the localized differential depositional environments.

The overlying Eocene sequence has been penetrated in the Haema-1, IIH-1XA and IIC-1X wells. The lithology is represented by interbedded sandstone, siltstone and shale, locally dolomitic and calcareous. Depositional environments are interpreted to be transitional from fluvial through alluvial to a shallow lacustrine environment.

The Neogene sediments is separated from the underlying strata by an angular unconformity(the middle Miocence unconfimity)and is composed of mostly unconsolidated sandstone, claystone and siltstone and brecciated sandstone, deposited in fluvial and marsh environments.

Petroleum System

Source Rock

A major uncertainty in the hydrocarbon potential of Block I, II and III is the presence or absence of source rock.

The TOC value from 2,000 meters to 2,700 meters of the IIH-1Xa well is about 1 percent. This interval corresponds to the Lower Eocene and Paleocene. The samples around 1,100 meters of the Kachi-1X, upper Cretaceous, shows 0.5 percent of TOC values. The type of organic matter in the two intervals could not be grouped to Type II, because the depositional environment of these intervals is lacustrine. Possible organic matter types in the Kunsan basin are III and I. Geochemical modeling was carried out based on these results and paleogeothermal gradient.

Generally, five well evaluation results show us lower than 0.5 percent TOC value and lower than 0.4 mgHC/g Rock S2 value except the two intervals.

The upper limits of maturation zone are 1,000 meters in the Inga-1 well, 1,200 meters in the Kachi-1x and 2,250 meters in the Haema-1 well. So, the maturation level in the basin should be deeper than 2,200 meters, a sufficient level.

Possible sources can be expected in the Paleocene and the Late Cretaceous based on the Chinese exploratory well data.

Reservoir Rock

Information about the reservoir potential of the basin is based on observations from the five wells drilled. These observations are combined with the seismic data to present a picture of the possible reservoir quality strata in the area.

While the well information is incomplete there are several constants known from the wells. The depositional environment of the five wells is fluvial plain to shallow lacustrine. In addition, the II H-1Xa well also appears to have some alluvial influx. The sediments are poorly sorted and show evidence of minimal transport, indicating that they were deposited near the source area. In spite of this, the sediments are medium to fine or very fine-grained clastic material.

Porosities from the wells are low to moderate in range. In the Haema–1 well the porosities from the 1320 to 2440 meter depth interval are from 2 percent to a high of 15 percent but below 1670 meters the porosity decreases below 6 percent. The IIC-1X well has the highest porosity in the range of 10 to 15 percent whereas the IIH-1Xa well shows the overall lowest porosity at about 5 percent.

Permeabilities are uniformly quite low in all the wells. This is interpreted to be the result of early cementation with quartz or calcite or the presence of abundant clays in the pore throats. The combination of poor sorting, substantial diagenesis and the inclusion of large amounts of clay minerals and volcanic rock fragments in the strata, influence the reservoir quality. The most favorable potential for good reservoir quality sandstone in this basin would be anticipated in the areas least affected by tectonic activity.

Adding to the poor potential for these sediments as reservoir rocks is the interbedding of volcanics in the Cretaceous portion of the Heama-1, Kachi-1 and Inga-1 wells (Figure 5). The presence of these volcano-clastic rocks indicate that much of this older section has been baked resulting in the alteration of much of the clay fraction.

Seal

Results from the five wells drilled in the basin show that thin mudstones are common in both the Cretaceous and Tertiary sections. These mudstones could become effective top seals for reservoir quality strata. However, due to their likely poor lateral continuity, most of these mudstone units are expected to act as only local top seals for the potential reservoirs.

The Late Cretaceous section encountered in the Katchi-1 well and the Eocene section seen in the Haema-1 well contain significant mudstones that are believed to be lacustrine in nature. These may be expected to provide adequate sealing capacity where they should be best developed near the basin depocenter (Figure 5). This top seal capacity is expected to be greatly reduced in the margins of these basins due to lateral lithofacies changes. The Paleocene, Eocene and possibly Early Oligocene sections penetrated in the

IIC-1X and IIH-1XA and Inga-1 wells may explain the lack of hydrocarbon accumulations in these wells. Basinward from these well locations, more favorable seals may be anticipated.

HYDROCARBON POTENTIAL

Several of the previous wells drilled tested fairly substantial but relatively young structural features. It is clear that these features postdate hydrocarbon generation and migration in the basin and do not form effective traps. This is notably the case for the Kachi-1 well, which while testing substantial older, Cretaceous age strata, drilled a very young structure that is evidently still somewhat active. In other cases, the wells tested off-structure or where the structural trap may not have been present.

Regarding source rock, none of the five wells encountered favorable section, although there are some indications that the maturity level necessary to generate hydrocarbons was reached in the area. The Late Cretaceous and possible Plaeocene shales are considered the most likely source rocks in the basin (Figure 6).

Finally, the issue of reservoir rocks must be addressed. The five wells all encountered shaley to interbedded, poorly sorted sands and volcanoclastics which would not be considered good reservoir material. However, these wells were drilled in hindsight locations where the reservoir rock was less favorable to develop. This basin does have several areas that may have been the depocenters for well-sorted lacustrine sands in a lacustrine delta environment. Notably, two areas draw interest for further evaluation, namely the East Sag and Southwesthern Sub-sag. It is thought that these areas have not been adequately tested.

East Sag

The combination of the findings cited above lead to negative conclusions concerning much of the area. However, there are two areas in which the results of the previous five wells have not supplied the answers as to the exploration potential. The first of these lies in the vicinity of the Inga-1 well. This well was drilled on an intra-basinal high and tested a Cretaceous feature. However, the well encountered a thick Palecene section. This younger section climbs from this location to the northwest-northeast and to the west. There is a potential for updip stratigraphic traps and some structural traps along the margin of the east sag.

The stratigraphic play identified is a deltaic complex in the Middle Upper Eocene. It transitions to a fan system on the west flank of the basin. The seismic data shows a delta build-up with focused point source deposition on the basin margin that changes character and becomes thin into the basin. Conversely, from the east the deposition is more line-sourced into the basin. This pattern is similar to the pattern of half-graben depositional pattern from the Subei-basin. This view offers a possibility that a similar depositional system with good source rock and reservoir rock potential could be developed in the basin.

Southwest Sub-sag

There are three structural traps in the Southwest Sub-sag area. They are all traps in close proximity indicating similar source rock and reservoir potential as well as trap timing. Play one is a downthrown three-way structural trap(Figure 7). At the top of the Paleocene horizon, this feature is a abroad southwesterly plunging nose with a small crestal four-way closure, cut by a northwest to southeast, down-to-the-west fault.

Displacement along the fault ranges from minimal, increasing to over 50 meters. The structure has about 200 meters height of structural closure.

Support for source rock potential is based on two possibilities. There is a local source potential from the underlying Cretaceous section. The second play type is an upthrown three-way fault closure structural trap. At the top of the Paleocene horizon, this trap is a long yet narrow closure, highside to a bifurcating down-to-the-northeast normal fault pair. The fault displacement ranges from less than 50’ to over 250’ and the trap has about 150’ of structural closure. At the top of the Cretaceous horizon, the trap is bounded by a single down-to-the-northeast fault but the fault displacement is quite variable.

The third play in the Southwest Sub-sag area is an upthrown three-way fault closure structural trap. At the top of the Cretaceous horizon this trap is a very elongated yet narrow closure, highside to a northwest to southwest trending normal fault with variable displacement. At the top of Paleocene mapping horizon the structure is subdivided by a saddle, which results in two smaller but significant closures.

CONCLUSION

On the basis of integrated analyses of the geological and geophysical data of South Korea and China, the Kunsan Basin has a good condition to form lacustrine sand reservoir and source rocks, mainly with the Late Cretaceous and Paleocene shale. The faults developed well in this area and these faults could act as an important passage of petroleum migration.

Two areas of significant lead potential have been recognized in this basin. In both areas, they target the Upper Cretaceous and Lower to Middle Tertiary sections.

The first of these lies in the designated East Sag. The Cretaceous and possible Paleocene strata may provide both source rock and reservoir rock for hydrocarbon potential in this moderate-sized basin. The second prospective area is the structurally complex sub-basin downthrown to the northeast of the Kachi-1 well in the Southwestern Sub-sag. This area appears to have both an Upper Cretaceous and a Lower Tertiary section that is found in both stratigraphic trapping and upthrown structural closures within a series of down-to-the-northeast normal faults.

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