Play Analysis of the Gamtoos Basin, off the south coast of South Africa – from concept to portfolio

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Workshop 10: Play Analysis – From Concept to Portfolio

1. Introduction

The Gamtoos Basin, off the south coast of South Africa, remains underexplored. Between the late 1970’s and early 1990’s, 10 wells were drilled (Figure 1) in under 200m water depth. SOEKOR well completion reports identified five wells in the eastern portion of the basin, close to the Gamtoos Fault, which encountered oil and gas shows. These shows are strong indicators of an active petroleum system within the Gamtoos Basin. The aim of this analysis is to identify, risk and rank the main petroleum aspects resulting in defining potential petroleum plays.

The onshore-offshore Gamtoos basin is one of five Mesozoic sedimentary sub-basins of the greater Outeniqua Basin situated along the southern margin of South Africa. Development of the Outeniqua Basin began during the mid Jurassic (Figure 2) due to the rifting, between east and west Gondwana, giving rise to several graben and half-graben over an area that is presently the South African southern margin.

The Gamtoos Basin is underlain and bound by Palaeozoic meta-sedimentary rocks of the Cape Supergroup (Figure 3), which comprises the rifted basement subcrop highs offshore, called the St. Francis Arch and Recife Arch (Figure 1). Basin development occurred over four phases (Figures 2 and 3) according to Broad et al. (2006):

- The Rift or Synrift 1 phase (Oxfordian to Valanginian)
- Early rift-drift or Synrift 2 phase (Valanginian to Hauterivian)
- Late rift-drift or Transitional Phase (Hauterivian to early Albian)
- And the Drift phase (Albian to present)
2. Source

Four major source intervals have been identified within 8 wells. The Kimmeridgian (KIM) and Tithonian (TI) (Figure 2) source rocks formed during the Synrift 1 stage of basin formation and appears to be the major source intervals within the southern basin area. They were mostly developed within upper to lower slope environments by anaerobic bottom conditions.

The Kimmeridgian source has dry-gas to oil-prone shales whereas the Tithonian source has oil-prone to wet-gas and dry-gas shales. Valanginian (VA) to Hauterivian (HA) age source intervals formed during the Synrift 2 stage.

This coincides with other global rift successions formed during two major anoxic events, the Late Valanginian Weissert and Latest Hauterivian Faraoni Events (Jenkyns, 2010). These source intervals comprise dry-gas to wet-gas shale intervals.

3. Reservoir

Potential reservoir intervals were identified in various wells. Major intervals include the Kimmeridgian to Tithonian, Berriasian (BE) to Valanginian and Aptian (AP) to Albian (AL) intervals (Figure 2). The main
Kimmeridgian sandstone in wells Ha-A1 and Ha-K1 is characterised by upper to lower slope, tight to porous deposits below 3500m depths with a thickness net range of 40-100m.

The Tithonian interval, in Ha-A1, Ha-G1 and Ha-K1, contains upper slope to transitional environment deposits within 2000-3500m depths with a net thickness ranging between 40 and 140m. The Berriasian to Valanginian is a wide reservoir range that can be separated into three intervals of thin deposits in Ha-A1, Ha-B2, Ha-D1, Ha-G1, Ha-I1, and Ha-N1.

The depositional environments of the Gamtoos Basin can be divided into continental to transitional and transitional to inner/outer shelf with net thicknesses from 10m to 150m at depths between 1000m and 3000m. Good quality canyon-fill (Gamtoos Canyon) reservoirs of Late Aptian to Albian age were encountered in wells Ha-G1 and Ha-K1. These range in net thickness of 40m to 60m.

4. Play Fairway Analysis Method

A play is a geographically or stratigraphically delimited area, such as the Gamtoos Basin, where common geological factors combine, in the order that petroleum accumulation can occur (Allen and Allen, 2005). The method of play fairway analysis strives to identify, risk and rank sweet spot areas, where the stratigraphic model and components of the potential reservoir, source or charge, traps and seal culminate to provide an effective petroleum play (Figures 4 to 7). It supports the risking exercise which is essential to assess areas, leads and prospects by creating a framework based on all the data as well as sound regional assumptions. This framework assists in ranking prospects within the same play while ensuring consistency, which finally highlights the most prospective areas.
4.1 Reservoir Risk of Synrift 1a
Criteria:
- Low risk (0.9) in areas proximal to wells with sandstone interbeds thicker than 10m and sandstones where fair porosity was detected.
- An overburden of more than 4750m are classified to be of medium reservoir risk. Permeability of these sands is impacted negatively by high burial depth.
- Arenaceous content as intersected in four wells consistently ranged between 22 and 42%.
- Thus no high reservoir risk can be allocated at the earliest stage of basin formation and rifting of the Gamtoos Basin.

4.2 Charge Risk of Synrift 1a
Criteria:
- Low risk (highlighted in blue) areas proximal to the confirmed Kimmeridgian source.
- An overburden of >2500m proves expulsion using 3°C/100m for geothermal gradient within Kimmeridgian Source.
- Gas shows exhibited in Ha-K1, Ha-B2 and Ha-D1.
- Distal areas having favourable migration routes, and up-dip from the Kimmeridgian source kitchen are interpreted as medium charge risk areas (highlighted in olive green).
- Distal areas with no identified migration route to the source kitchen are interpreted as high risk charge areas (highlighted in yellow).

4.3 Seal Risk of Synrift 1a
Criteria:
- Low seal risk (0.9) proximal to wells where gas shows were confirmed.
- Medium seal risk (0.5) where the overburden is calculated to have >800m overburden.
- High seal risk (0.1) where the overburden is <800m.
- Lateral extent of the seal is a major risk factor.

4.4 Geological Risk of Synrift 1a
The geological risk or geological probability of success (P_g) comprises the product of the preceding three risk elements.
- The P_g of this interval depicts the lowest risk zone (0.7 to 0.8) which avoids the deepest part of the Gamtoos Basin due to excessive burial depth, which negatively impacts on reservoir quality, but is favourable to the source kitchen.
- Ten of the twenty-one Synrift 1a leads were identified as low risk.
- The four largest leads are considered high risk, as they are distal from control points and have to rely on longer migration pathways.
Firstly, the gross envelope of the potential play or package that contains the reservoir facies was mapped (Figure 4). It can be regarded as the easiest element to map as it is supported by the most data. It also provides the target for drilling and a geological overview of the play fairway.

The presence of individual traps is usually not considered at the play level, but does form part of the prospect-specific risk. It is important, however, to note that the extent of an effective regional top seal (Figure 6) or mature source kitchen can also be used as the starting point for delineating a play fairway.

The play risk varies according to the actual or perceived variations of the different elements of the play. By mapping out and superimposing these variations, the inter-relationships between the different elements of the play are determined. The play fairway is subdivided into areas with different characteristics (play-risks). Areas considered high risk were colour coded in yellow and were labelled with a numerical value of 0.1 (10%). Medium and low risk areas were colour-coded in olive green and blue respectively and these were respectively labelled as 0.5 (50%) and 0.9 (90%) (Table 1).

Maps for charge, reservoir and seal were superimposed to produce a geological risk map (Figure 7) for all of the fairways, e.g. Synrift 1a below, which quantifies the geological probability of success (Pg) across the area. Risking of Synrift 1a is discussed in detail below.

**4.1 Reservoir Risk of Synrift 1a**

Different assumptions were used to categorize and define high, medium and low risk of each element (Figure 4). The first play fairway (Synrift 1a) was analysed, where the reservoir risk is interpreted to be low risk (0.9) in areas proximal to wells with sandstone interbeds thicker than 10m and sandstones where fair porosity was detected. All sandstones with an overburden of more than 4750m are classified to be of medium reservoir risk. Permeability of these sands is impacted negatively by high burial depth. Likewise, all areas distal to the wells (control points) will automatically be categorised as medium reservoir risk areas. The arenaceous content as intersected in four wells consistently ranged between 22 and 42%. Thus it was assumed that no high reservoir risk can be allocated at the earliest stage of basin formation and rifting of the Gamtoos Basin.

**4.2 Charge Risk of Synrift 1a**

The charge risk (Figure 5) is interpreted to be low risk (0.9 and highlighted in blue) in areas proximal to the confirmed Kimmeridgian source. Expulsion is proven with an overburden of 2500m plus for proven source sequences, such as the Kimmeridgian and Hauterivian source rocks. This is calculated from the geothermal gradient of 3 degrees Celsius per 100m of overburden registered in most of the Gamtoos Basin wells. Sandstones in these areas also exhibited gas shows, which confirms an active petroleum system.
More distal areas with favourable migration routes, and up-dip from a proven source kitchen are interpreted as medium charge risk areas (0.5 and highlighted in olive green). The untested deepwater territory is modelled to contain both Kimmeridgian and Hauterivian source sequences, but its distal location puts this into the medium charge risk category. The most distal areas with no identified migration route to the source kitchen are interpreted as high risk charge areas (0.1 and highlighted in yellow).

4.3 Seal Risk of Synrift 1a

The assessment of seal risk (Figure 6) for Synrift 1a uses the following assumptions:

- Low seal risk (0.9) proximal to wells where gas shows were confirmed,
- Medium seal risk (0.5) where the overburden is calculated to be more than 800m and
- High seal risk (0.1) where the overburden is less than 800m.

4.4 Geological Risk of Synrift 1a

The geological risk or geological probability of success is illustrated in Figure 7 above and comprises the product of the preceding three risk elements. The Pg of this interval depicts the lowest risk zone (0.7 to 0.8) which avoids the deepest part of the Gamtoos Basin due to excessive burial depth, which negatively impacts on reservoir quality, but is favourable to the source kitchen.

Ten of the twenty-one Synrift 1a leads were identified as low risk within this play. The four largest leads are considered high risk, as they are distal from control points and have to rely on longer migration pathways. This risking was applied in the deterministic as well as the probabilistic assessment of the individual leads. It was also customised or amended for each trap.

5. Results

Six play types were identified (Table 2) with a total of 80 leads, ranked from low to high risk. Major trapping mechanisms include basin-bounding faults, domal closures, plunging anticlines, tilted fault blocks, horst structures and stratigraphic among other trap types.

<table>
<thead>
<tr>
<th>Play type</th>
<th>Age</th>
<th>Low Risk</th>
<th>Medium Risk</th>
<th>High Risk</th>
<th>Total Leads</th>
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<td>10</td>
<td>0</td>
<td>11</td>
<td>21</td>
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<td>Synrift 1b</td>
<td>Kimmeridgian to Early Tithonian (P3)</td>
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<td>2</td>
<td>3</td>
<td>9</td>
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<tr>
<td>Synrift 1c</td>
<td>Early Tithonian (P3) to Mid Berriasian (P1)</td>
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<td>5</td>
<td>1</td>
<td>9</td>
</tr>
<tr>
<td>Synrift 1d</td>
<td>Mid Berriasian (P1) to Late Berriasian (J1)</td>
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<td>7</td>
<td>7</td>
<td>14</td>
</tr>
<tr>
<td>Synrift 1e</td>
<td>Late Berriasian (J1) to Early Valanginian (1Ae1)</td>
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<td>10</td>
<td>15</td>
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<tr>
<td>Synrift 2</td>
<td>Early Valanginian (1Ae1) to Late Hauterivian (6Ae1)</td>
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<td>0</td>
<td>12</td>
<td>12</td>
</tr>
</tbody>
</table>

Table 2: A summary of the six play fairways that led to a portfolio of 80 new leads within the various Synrift successions of the Gamtoos Basin.

Examples illustrated in Figures 8 to 9 include leads 1-7, 1-8 and 1-14 of the Synrift 1a play, where the minimum, most likely and maximum postulated gas-water-contacts (GWC) are shown. Numerous attractive leads have been identified within the Gamtoos Basin (Figure 10), with the presence of source intervals at various levels within the Synrift succession.
Figure 8: Two fault bound leads identified in Synrift 1a package of the Gamtoos Basin

Figure 9: Synrift 1a lead displaying domal closure, in close proximity to the main Gamtoos Fault

Figure 10: Synrift leads identified throughout the Gamtoos Basin, displayed on the backdrop of the overlying structural depth surface
6. Conclusions

Risk factors such as trapping style and migration, play an important role in identifying viable leads with the major risk being seal occurrence and integrity. The Synrift 1a package poses the least risk having an active petroleum play identified by oil and gas shows in 4 wells. The leads are found at levels greater than 3000m below sea level within the depocentres of the basin.

References


