Click to view slides of oral presentation.

Implications of Sequence Stratigraphic Models of the Gamtoos Basin for Its Petroleum Potential*

Anthea C. Davids[1] and Chantell B. Van Bloemenstein[1]

Search and Discovery Article #11170 (2018)**
Posted July 22, 2019

*Adapted from extended abstract prepared for oral presentation given at 2018 AAPG International Conference and Exhibition, Cape Town, South Africa, November 4-7, 2018.
 DOI:10.1306/11170Davids2018

[1]Petroleum Agency SA, Cape Town, South Africa (davidsa@petroleumagencysa.com)

Abstract

The Gamtoos Basin along the south coast of South Africa reveals various stratigraphic sequences deposited during the Synrift (Davids et al., 2018). Rifting commenced during the Late Jurassic and continued until the early Valanginian in this basin. Catuneanu (2002) advocated careful analysis and a thorough understanding of all controls on sedimentation, when carrying out sequence stratigraphic interpretations rather than applying rigid theoretical models in an inflexible fashion.

During this study, the method proposed by Abreu et al. (2010; 2014), where stratal geometries of the seismic character within various packages assisted with the identification of highstand, lowstand and transgressive sequence tracts / sets, was applied. Marking the various terminations / lapouts also aided in the identification of the various surfaces. The portion between the mid-Tithonian (P3) and early Valanginian (1At1) has been mapped using existing seismics and data from wells Ha-A1, Ha-B2, Ha-H1 and Ha-K1. The seismic character and gamma ray log curve played important roles in identifying aggradational, progradational, retrogradational and degradational stacking patternsand the possible geological depositional environment (GDE), as well as systems tracts. Environments of deposition in wells and various observations on seismic transects were compared to verify highstand, lowstand and transgressive sequences identified during this study.

It was again proven that the conceptual framework of the interpreter remains key in making the correct correlations between well log cross sections and seismics (Catuneanu, 2002). Drilling was historically carried out on the basis of minimal, relatively poor-quality 2D data within the Gamtoos Basin and in many cases terminated away from the traps or off-structure. With the availability of more recently acquired seismics in the area, it has become possible during this study to better delineate several potential targets for hydrocarbon exploitation in this basin. This underexplored sub-basin of the Outeniqua Basin remains a highly prospective region, where oil and gas shows were identified in 50% of the 10 drilled wells. Several source rock intervals were intersected during drilling and modelled by Davids et al. (2018). It is thus proposed that more 2D and 3D seismic data sets are acquired to upgrade the portfolio of leads identified in this area.

Introduction

This study is a culmination of an integrated study on the sedimentology, structure, basin evolution, geochemical data, and play fairway analysis of the offshore Gamtoos Basin of South Africa. The study area is located between the Recife Arch and St Francis Arch (Figure 1). The study comprises the detailed analysis of the stacking patterns identified in seismic and well data to support the systems tracts, geological environment of deposition, and evolution of the basin. Sequence stratigraphy and biostratigraphy were some of the invaluable tools used to coordinate this study. The general integrated workflows (Figure 2) enabled the identification of the main petroleum aspects of the basins, which resulted in defining of potential petroleum plays, their maturity, and a portfolio of leads or prospects (Davids et al., 2018).

Geological background

The Late Mesozoic Gamtoos Basin comprises a half graben formed as a result of the strike slip movement along the Agulhas Falkland Fracture Zone (AFFZ) (Figure 3) during separation of the African and South American plates (Broad et al., 2006). The basin forms part of a series of half grabens that extend southwards into the greater Outeniqua Basin. The basin lies both onshore and offshore and is underlain by meta-sedimentary rocks of the Cape Supergroup. Roux and Davids (2016) proposed that the basin's structure developed from north to south in various splay directions. Basin development occurred over four phases:

- Synrift 1 (Oxfordian to Valanginian) comprises transitional and shallow to deep marine sediments and overlies basement.
- Synrift 2 (Valanginian to Hauterivian) comprises deep water claystones.
- Late rift-drift or transitional (Hauterivian to early Albian) comprises marine claystones and turbidites.
- The Drift phase (Albian to present) comprise marine claystone, turbidites and shelf sandstones.

Stratigraphy and Play Elements of the six play fairways throughout the Synrift

Reservoir intervals were identified in various wells of the Gamtoos Basin. Figure 4 illustrates the major intervals which were identified in the Synrift 1a to 1e and Synrift 2 plays. The Kimmeridgian sand is characterized by upper to lower slope, tight to porous deposits below 3500m in wells Ha-A1 and Ha-K1. These reservoirs have a thickness of 40-100 m (Davids et al., 2018). The Tithonian comprises upper slope to transitional deposits within the interval from 200 to 2500m below surface with a net thickness of 40 to 140m. The Berriasian to Valanginian has a wide reservoir range, separated into three intervals of thin deposits. Some continental to transitional to inner / outer shelf depositional environments with net thicknesses of 10-150m can be identified throughout the basin, with good quality canyon fill reservoirs of late Aptian to Albian age, up to 40-60m thick.

Mapping Terminations and Identifying Sequence Stratigraphy Surfaces

During this study the terminations (Catuneanu, 2002) were mapped and the methodology of Neal and Abreu (2009) was deemed best to delineate the various packages (Figure 5). Sedimentological analysis through well and seismic integration of facies and events was conducted by investigating the boreholes and various transects within the Gamtoos Basin. All the well formation tops identified through paleontological studies of the basin were used to calibrate the seismic data set (McMillan et al., 1997 and McMillan, 2003). Some dip and strike sections are used to support the analysis of the sequence stratigraphy of the basin. As per the method proposed by Abreu et al. (2010; 2014), the stratal geometries of the seismic character within the various packages interpreted aided in the identification of highstand (HST / HSS), lowstand (LST / LSS) and transgressive systems tracts or sequence sets (TST / TSS).

Within the wells and seismic profiles the highstand systems tracts (HST) typically display aggradational, followed by progradational then degradational (APD) internal geometry. Lowstand systems tracts typically display one or more sets of progradational then aggradational (PA) internal geometry. Transgressive systems tracts are characterized by backstepping / retrogradational (R) internal geometry of the seismic character. In addition to showing the events (ages), marking the terminations on the seismic transects also aided in the identification of the various surfaces and systems tracts (Figures 6, 7, 8, 9, and 10). Downlaps (green arrows) onto the maximum flooding surfaces (MFS) in addition to the stratal geometry within the packages aided in their identification, while truncation due to erosion and onlap (red or black arrows) aided in the identification of the sequence boundaries. The backstepping / retrogradational character within the transgressive sequence (blue arrows) aided in the identification of the transgressive systems tract (TST).

These packages display low to medium amplitude reflectors of a parallel and continuous nature. The lowstand systems tracts, LST5 to LST8 are marked by incised channels at the base of the packages with possible sandy infill displaying slightly higher amplitudes. In well Ha-A1 a general fining upward (Figure 10) depositional environment is observed with siltstones to a more clayey content. The channels broaden and flatten higher-up in the stratigraphy. Generally the TSTs are thinner with the exception of TST8. These are marked by retrogradational packages and higher continuous seismic amplitudes. Above HST10 is SB9.1 (red line) and marked in well Ha-A1 (Figure 9) but for the purposes of this study the packages before the regional erosive surface (stippled line) were not identified due to low resolution on the seismic section.

Gamtoos Basin Modelling

During this integrated study, six real well models incorporated rifting heat flow with an initial spike during rifting and a gradual decay of the heat flow through time to present day. Pseudo wells were also used to model the maturity of the source rocks. This rift basin has provided the ideal geological setting for the deposition of at least three source rocks identified in certain wells across the basin, including the Kimmeridgian, Tithonian and Valanginian / Hauterivian intervals. The maturity of these source rocks varies across the basin.

Play Fairway Mapping

A total of 80 leads were ranked from low to high risk (Table 1) throughout the Synrift 1a to 1e and Synrift 2 sequences (Davids et al., 2018). Major traps include basin-bounding faults, domal closures, tilted fault blocks, horst structures and plunging anticlines. Both stratigraphic, structural and combination traps were identified throughout the Gamtoos Basin.

Numerous attractive leads were identified within the Gamtoos Basin, with source rock present at various intervals of the Synrift sequence. Risk factors, such as migration, trapping style, are important in identifying viable leads. Seal occurrence and integrity pose the major risk in the basin. The Synrift 1a succession poses the lowest risk as four wells displayed oil and gas shows in this play. Davids et al. (2018) lists some examples of the leads found in the Synrift 1a Play, although more have been catalogued.

Conclusions

This Gamtoos study derived great value from the integration of geosciences, starting from the collection of well and seismic data, biostratigraphy, geochemistry, sedimentological studies through to petroleum systems modeling and play fairway analysis, which culminated in the identification of leads and prospects.

Sequence stratigraphy was an integral tool to discern between the various geological events. Various sequence boundaries (SBs) were identified from basement to the Late Cenozoic; they generally separate lowstand systems tracts (LSTs) from the underlying highstand systems tracts (HSTs). Laterally, toward the proximal part of the basin the transgressive surface (TS) overlies the lowstand systems tracts (LSTs) and in turn is overlain by the transgressive systems tracts (TSTs). Within the sediment packages of the TSTs we observe the backstepping of parasequences within the systems tract. This is then followed by the maximum flooding surface (MFS) which overlies the TST, which in turn is overlain by the highstand systems tract (HSTs), where the parasequence sets of the HST clearly exhibit downlap onto the MFS.

It is possible to identify these various cycles of:

- The Lowstand Systems Tracts / Sequence Sets which display Progradation-Aggradation (PA) in addition to onlap onto the SB, with some incised valley fill observed under the Transgressive Surface (TS).
- The Transgressive Systems Tracts / Sequence Sets clearly display fining upward trends / Retrogradation (R) and backstepping of the shoreline on seismics as the depositional sequences moved more landward, under the Maximum Transgressive Surface (MTS / MFS).
- The Highstand Systems Tracts / Sequence Sets display Aggradation-Progradation-Degradational (APD) internal seismic geometry in addition to downlap onto the MFS and is generally bound at the top by the SB. The degradational portion of the HST can be generally lower than the aggradational and progradational portion of the tract / set as there is more channelling or downwasting of sediments, before the start of the next Lowstand, when more accommodation is created farther offshore.

There is potential to improve the identification of the various surfaces on the seismic profiles and especially on the various well logs in order to improve the sequence stratigraphic model of the basin. The sedimentary environments of deposition can also be expanded upon by conducting more specialized studies into the wells, cores, petrographic analysis and existing, new, or reprocessed seismic data. Work can be expanded to seismic attribute analysis, detailed facies mapping to aid the construction of 4D models of the Gamtoos Basin in terms of its tectono-stratigraphy and petroleum systems. While providing a coordinated approach to interrogating large amounts of data over a number of years, the study also presented technical challenges as it required numerous software packages and application of various geoscience disciplines.

References Cited

Abreu, V., J.E. Neal, K.M. Bohacs, and J.L. Kalbas, editors, 2010, Sequence Stratigraphy in Siliciclastic Systems – the ExxonMobil Methodology, Atlas and Exercises: SEPM concepts in sedimentology and palaeontology, no. 9, 226p.

Abreu, V., K. Pederson, J. Neal, and K. Bohacs, 2014, A simplified guide for sequence stratigraphy: Nomenclature, definitions and method: William Smith Meeting 2014: The Future of Sequence Stratigraphy: Evolution or Revolution?: The Geological Society, London, p.10-11.

Broad, D., E. Jungslager, I. McLachlan, and J. Roux, 2006, Offshore Mesozoic basins, *in* M.R. Johnson, C.R. Anhaeusser, and R.J. Thomas, editors, The Geology of South Africa:. Geological Society of South Africa, Johannesburg/Council for Geoscience, Pretoria, p. 553-557.

Catuneanu, O., 2002, Sequence stratigraphy of clastic systems: Concepts, merits, and pitfalls: Journal of African Earth Sciences, v.35, Geological Society of Africa Presidential Review no. 1, p. 1-43.

Davids, A.C., C.B. Van Bloemenstein, and J. Roux, 2017, Play analysis of the Gamtoos Basin, off the south coast of South Africa – from concept to portfolio: European Association of Geoscientists and Engineers Conference and Exhibition 2017 – Workshop 10 Poster WS10-P03, 1.

Davids, A.C., C.B. Van Bloemenstein, J. Roux, and C.J. Campher, 2018, A Geoscientific Analysis of the Hydrocarbon Potential of the Offshore Gamtoos Basin, South Africa: Petroleum Agency SA, Cape Town, 193p.

McMillan, I.K., 2003, Foraminiferally defined biostratigraphic episodes and sedimentation pattern of the Cretaceous drift succession (early Barremian to late Maastrichtian) in seven basins on the South African and southern Namibian continental margin: South African Journal of Science, v. 99, p. 537-576.

McMillan, I.K., G.J. Brink, D.S. Broad, and J.J. Maier, 1997, Late Mesozoic sedimentary basins off the south coast of South Africa, *in* R.C. Selley, editor, Sedimentary Basins of the World: The African Basins: Elsevier, Amsterdam, p. 319-374.

Neal, J., and V. Abreu, 2009, Sequence stratigraphy hierarchy and the accommodation succession method, Geology, v. 37/9, p. 779-782, doi: 10.1130/G25722A.1.

Roux, J. and A.C. Davids, 2016, Structural evolution of the Gamtoos Basin, based on 2D seismic data: International Geological Congress, Poster, 1.

Acknowledgements

The authors would like to thank the Petroleum Agency SA for permission to publish these results.

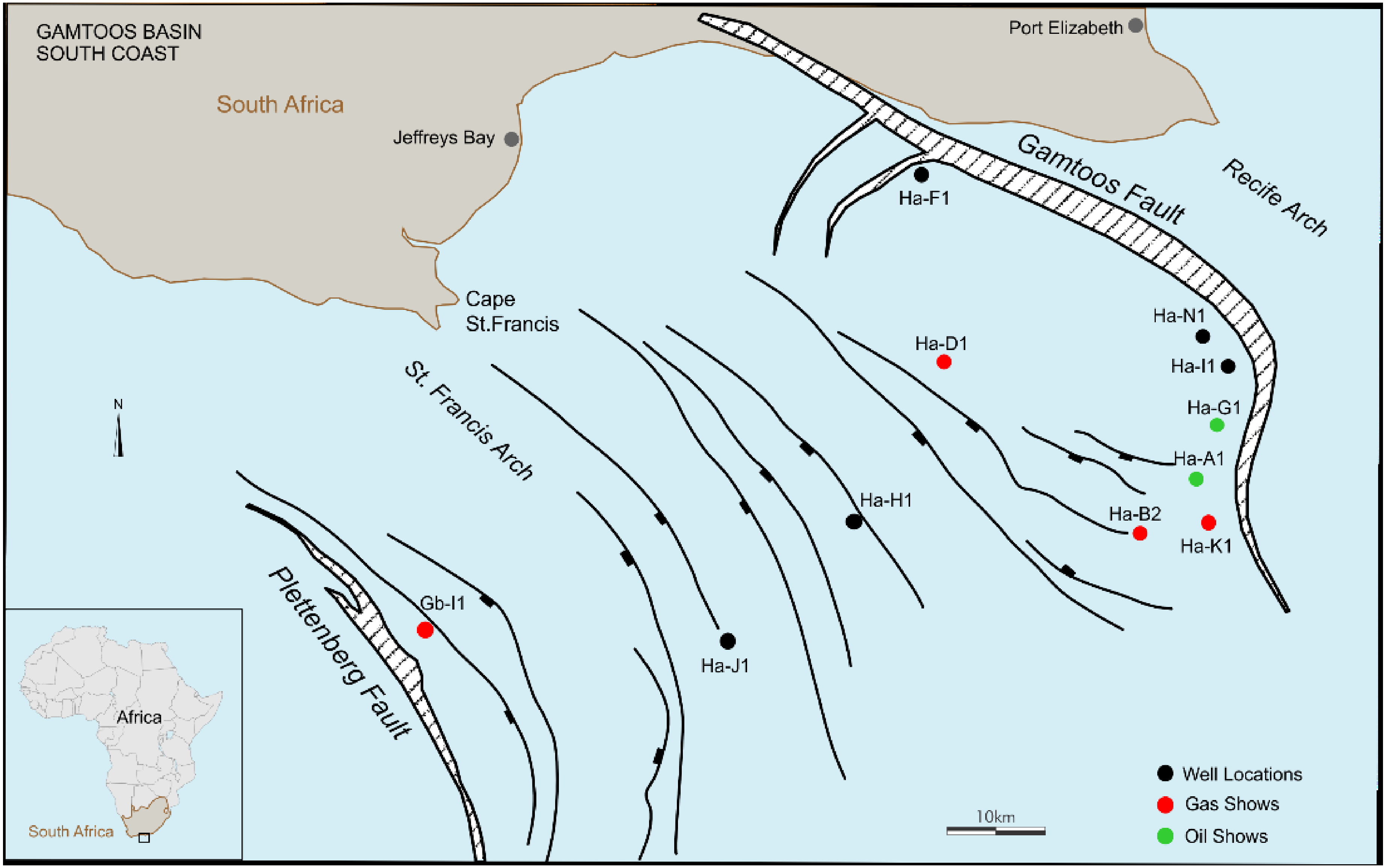

Figure 1. The location of the Gamtoos Basin, off the south coast of South Africa, showing hydrocarbon shows at six wells, including the well in the Pletmos Basin. Adapted from Broad et al. (2006).

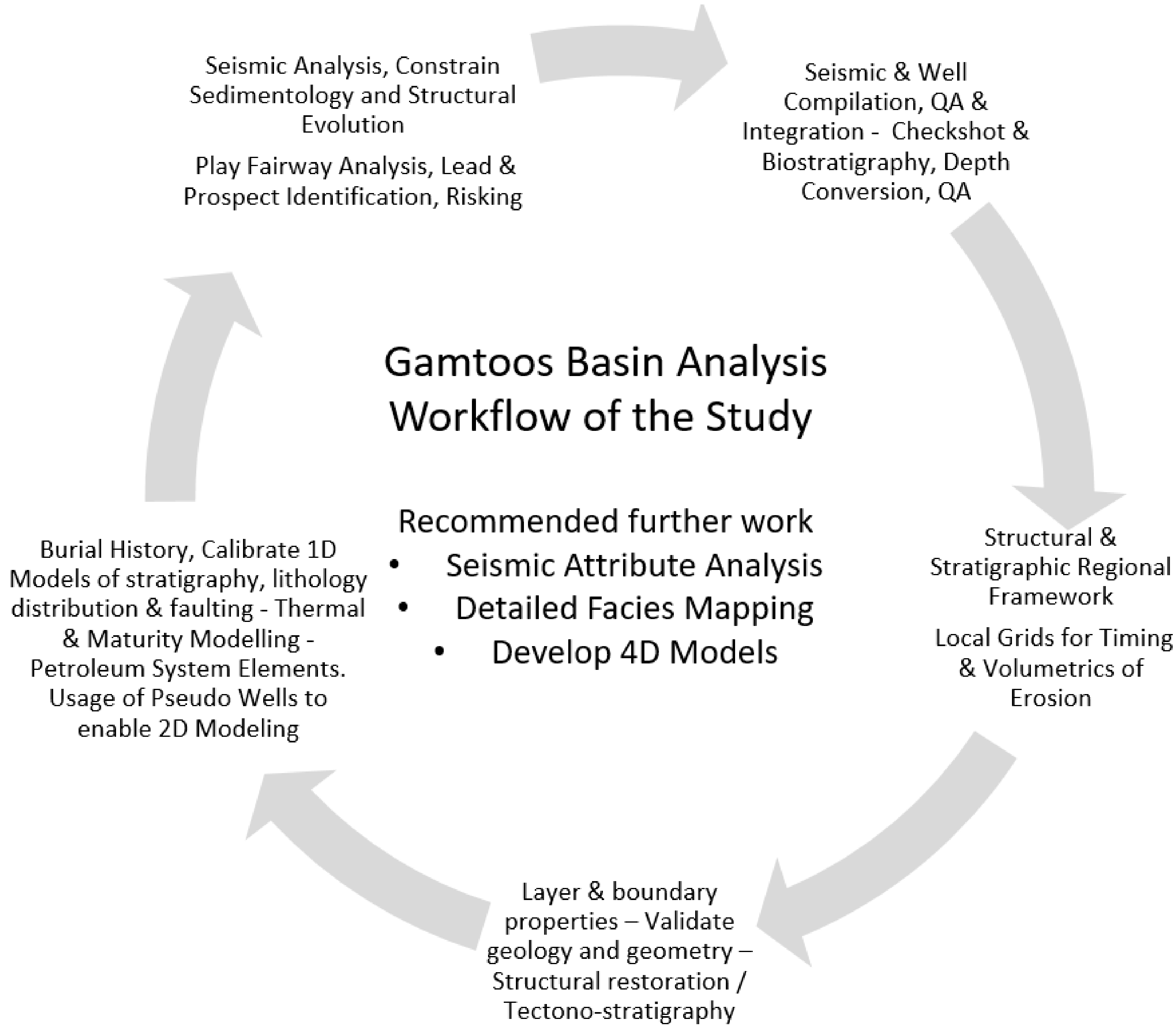

Figure 2. An integrated workflow utilized for modeling basin-scale petroleum systems of the Gamtoos Basin, offshore South Africa.

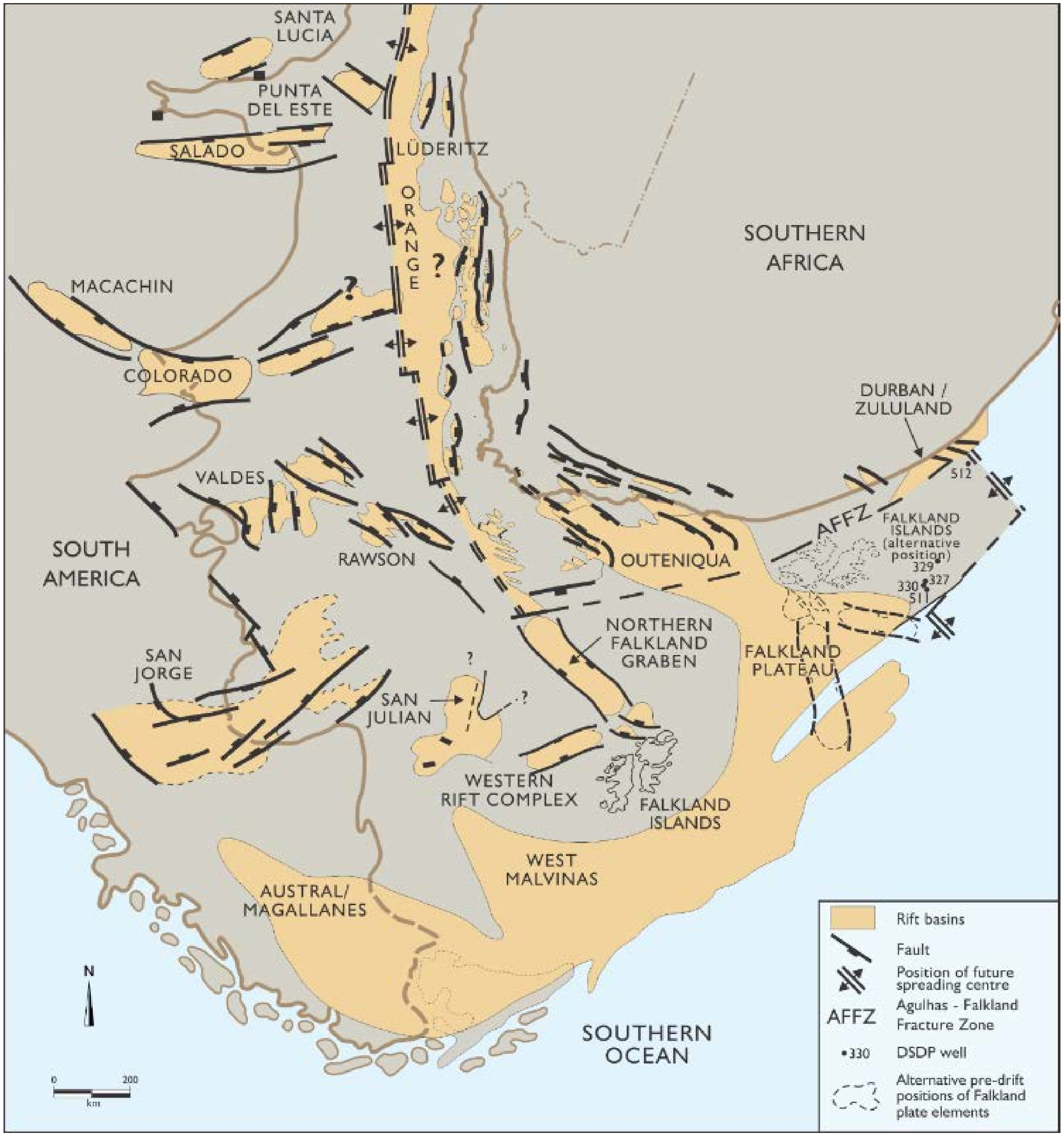

Figure 3. Conceptual pre-breakup reconstruction (Broad et al., 2006).

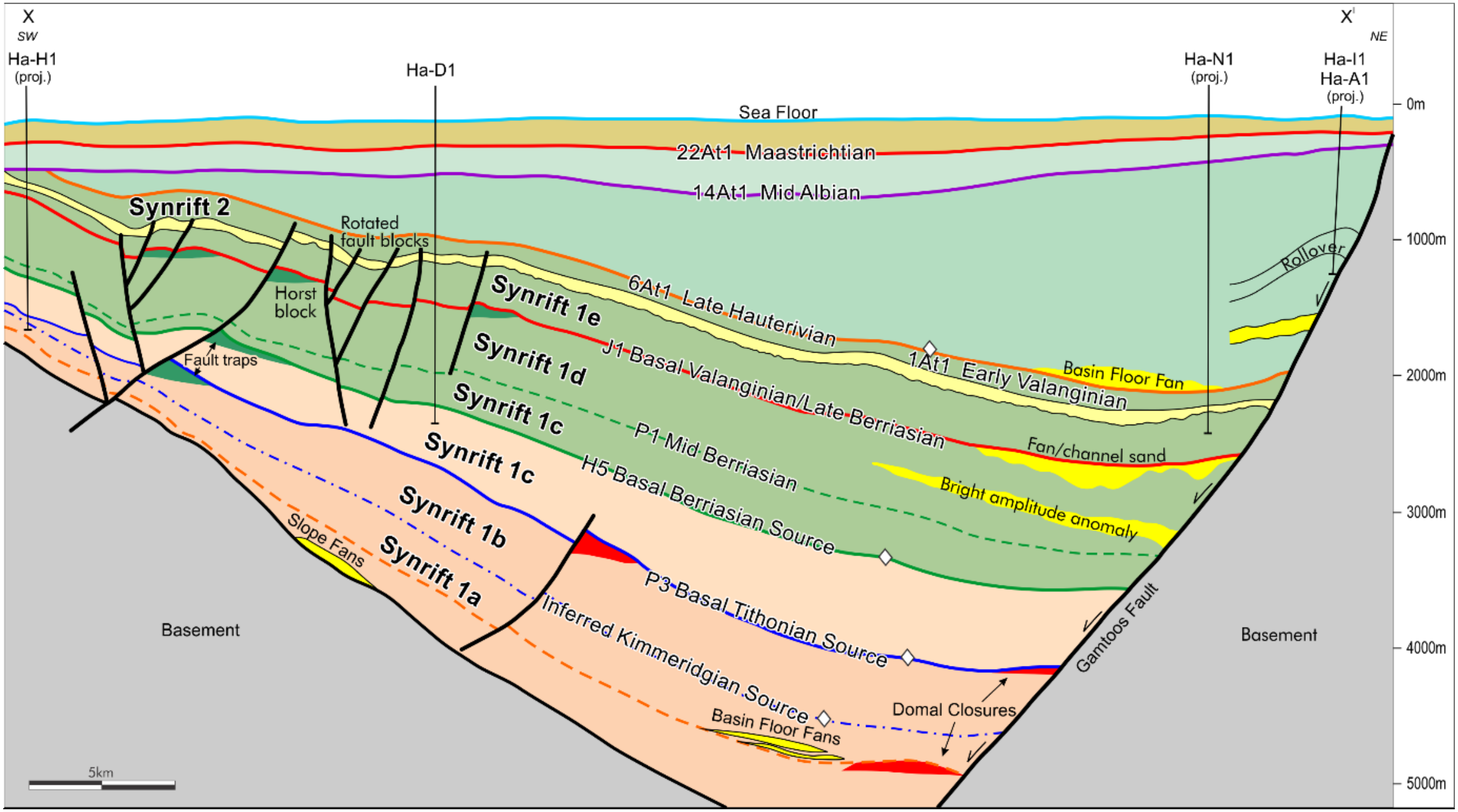

Figure 4. Stratigraphy and Play Elements of the Gamtoos Basin throughout the Synrift 1 and 2 successions (Davids et al., 2017).

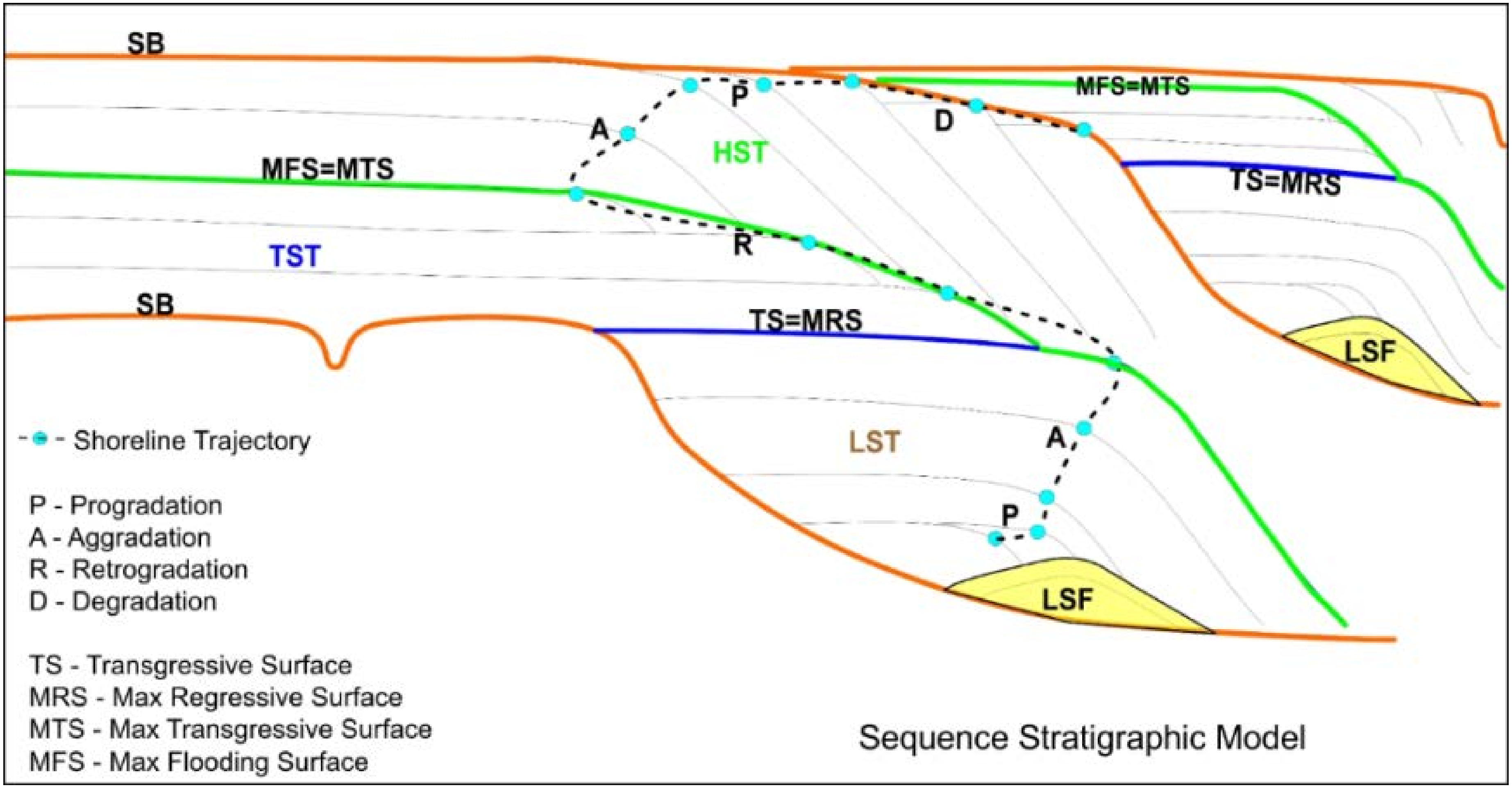

Figure 5. Accommodation stacking successions illustrating the various components of systems tracts and their accompanying sedimentation patterns (after Abreu et al., 2010).

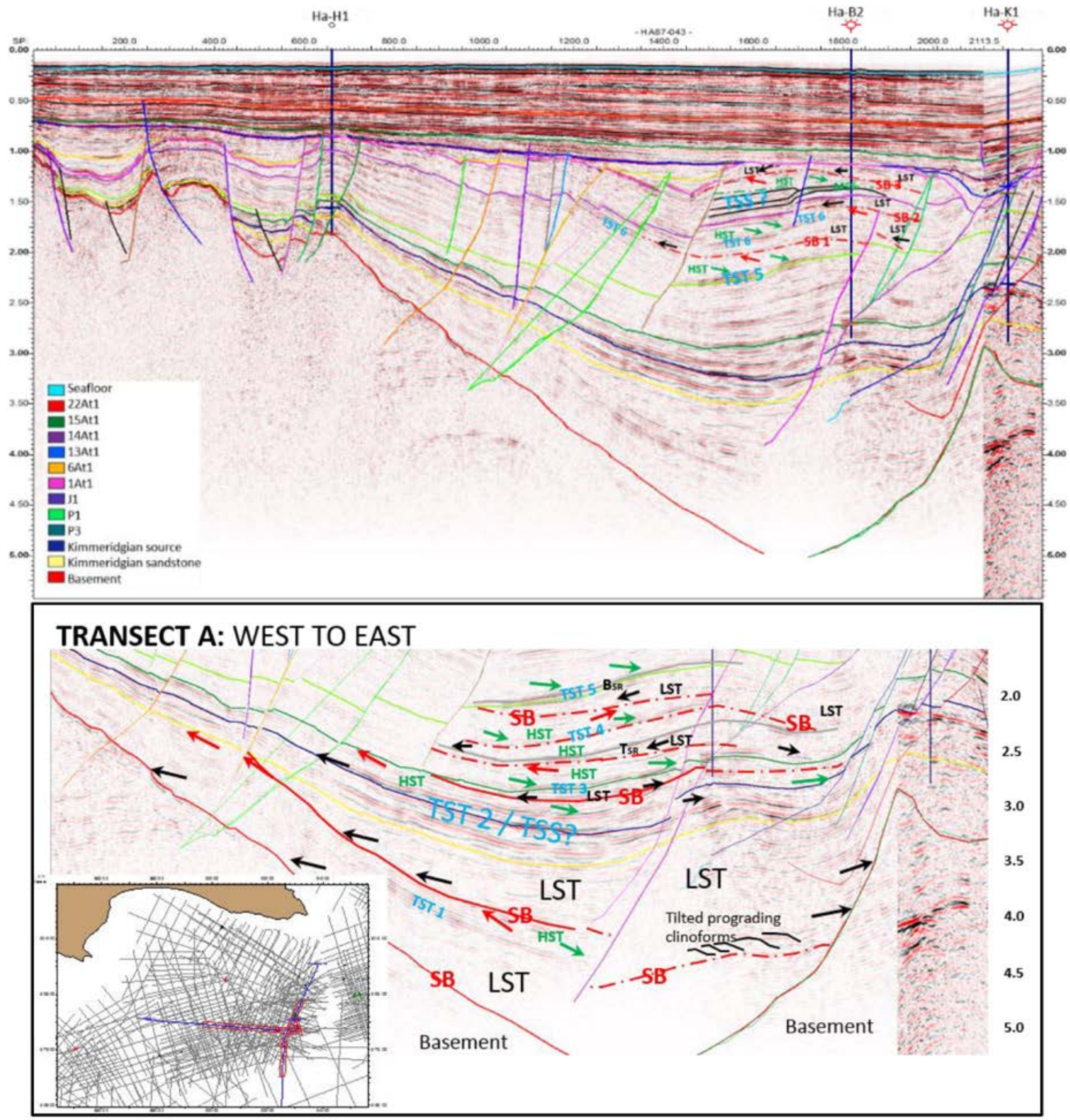

Figure 6. An interpreted 2D line showing the interpreted events in a strike orientation with more detailed termination mapping of the basal section below (Davids et al., 2018).

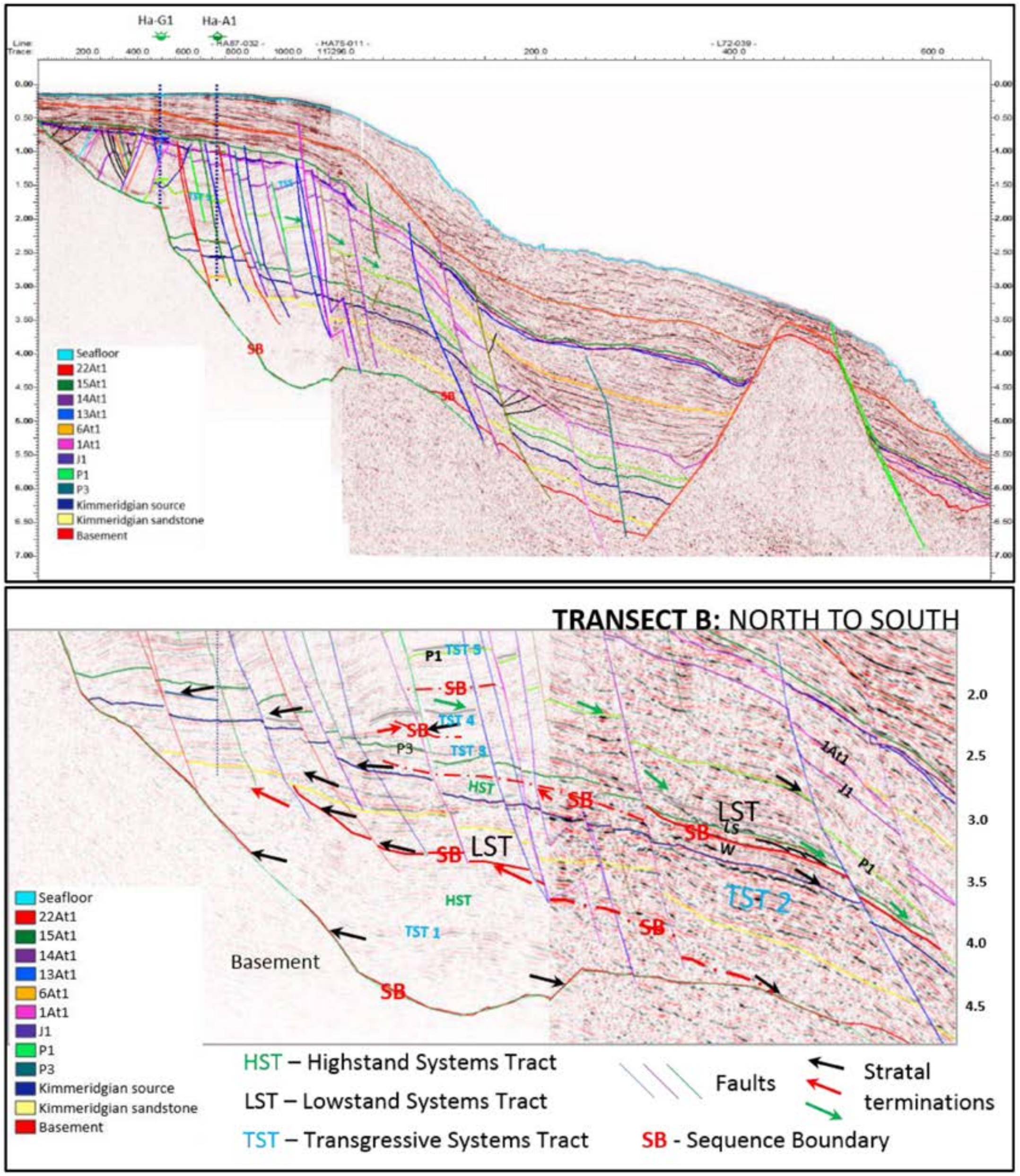

Figure 7. An interpreted 2D line showing the interpreted events in a dip orientation with more detailed termination mapping of the basal section below (Davids et al., 2018).

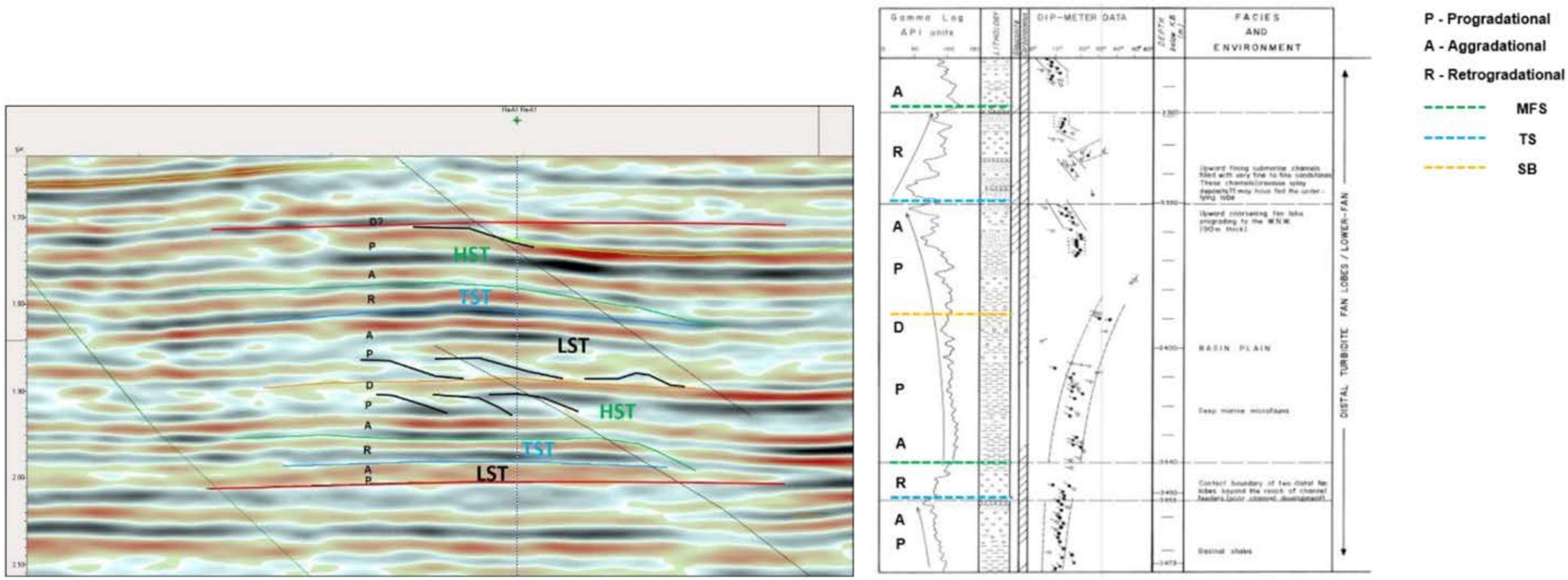

Figure 8. Seismic section and gamma ray log curve from well Ha-A1 illustrating the sequence sets in the Mid Berriasian section of the Gamtoos Basin (Davids et al., 2018).

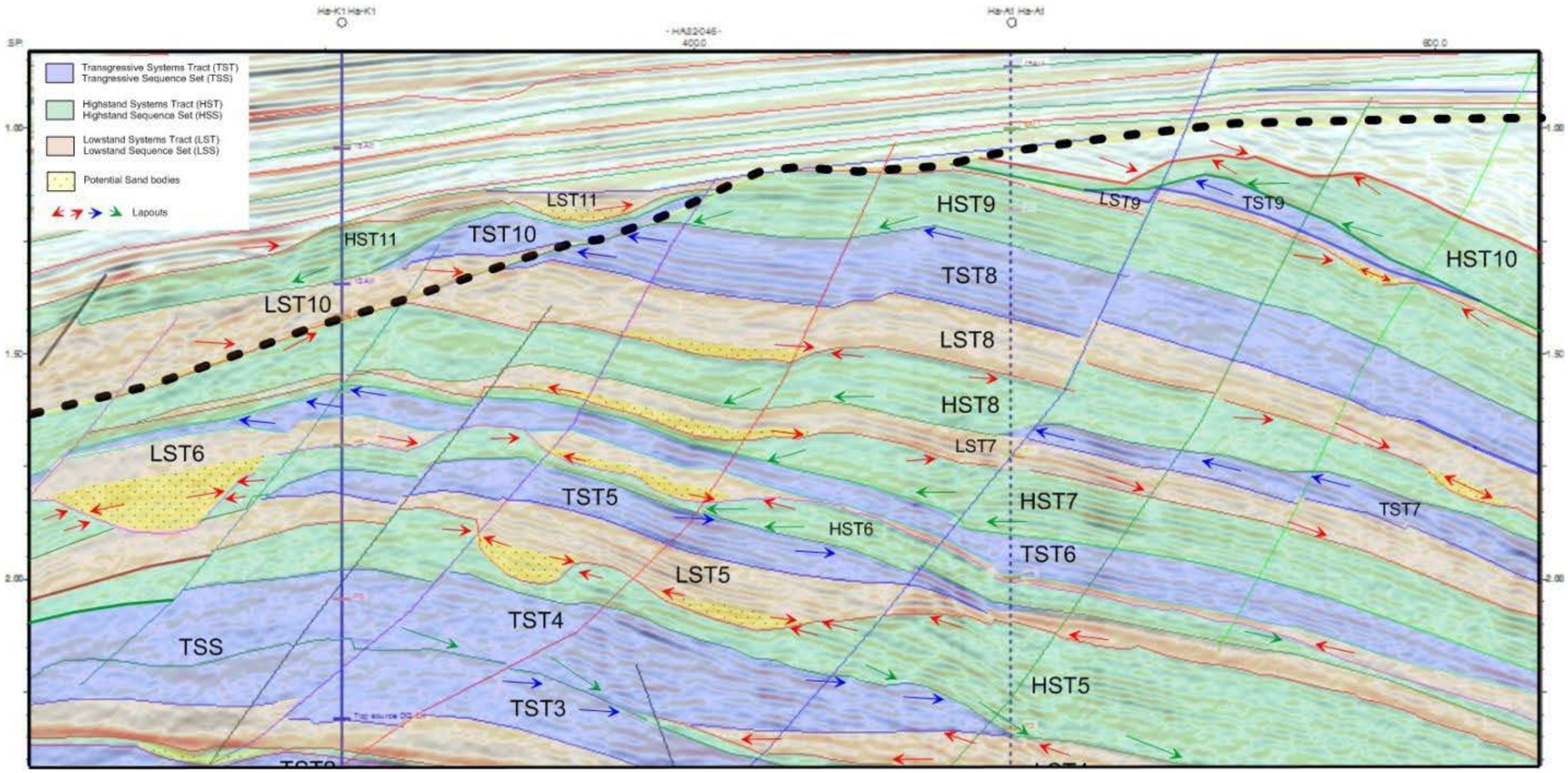

Figure 9. Interpreted seismic section illustrating the progradational, aggradational, degradational and retrogradational cycles of the lowest portion across wells Ha-K1 and Ha-A1, displaying the interpreted maximum flooding surfaces (green), sequence boundaries (SB in red), transgressive surfaces (blue) and terminations (from transgressive systems tract 3 (TST3) to highstand systems tract (HST11) (Davids et al., 2018).

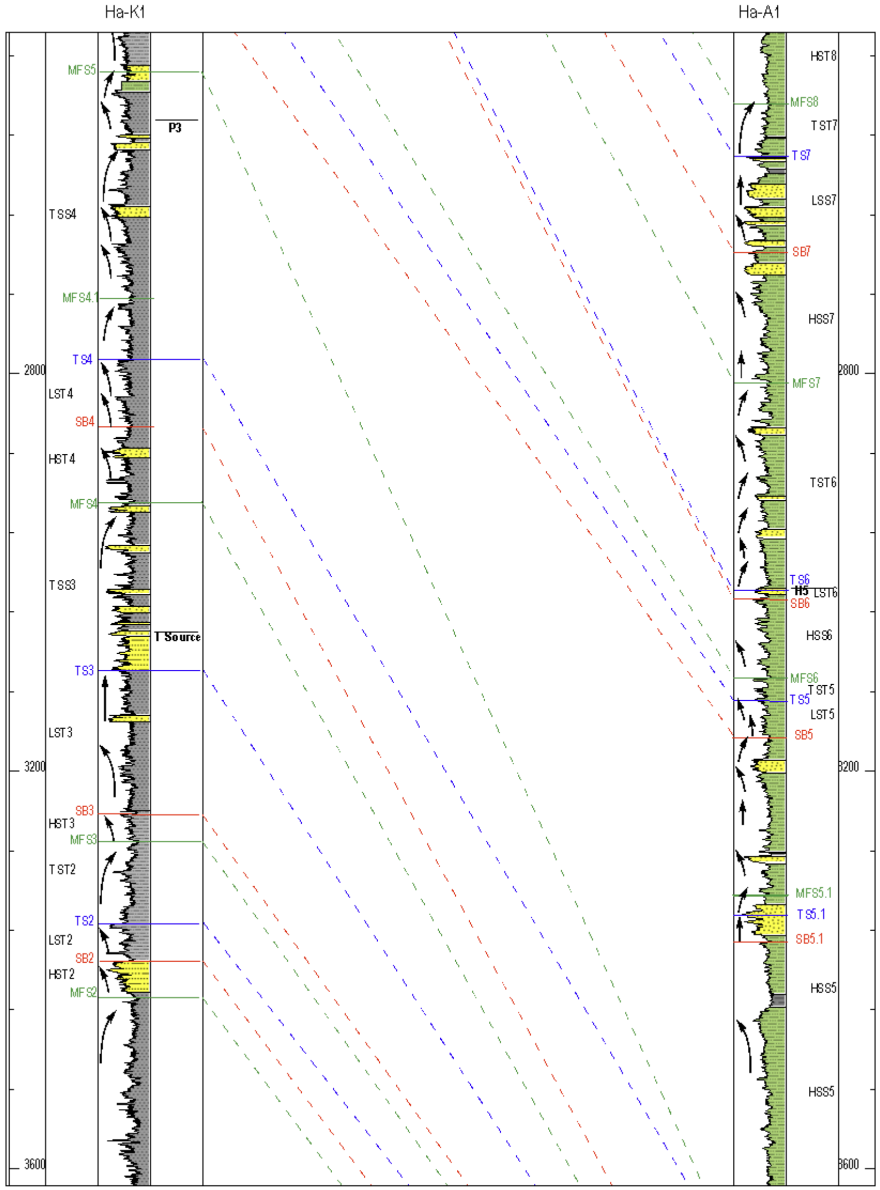

Figure 10. Gamma ray log curve illustrating the prograding, aggrading and retrogradational cycles of the lower portions of wells Ha-K1 (left) and Ha-A1 (right) across the Jurassic sequences, displaying sequence boundaries, transgressive surfaces and maximum flooding surfaces (from below MFS2 to MFS5 in Ha-K1 and from below SB5.1 to MFS8 in Ha-A1). (Davids et al., 2018).

Table 1: Low to High Risk Leads identified over the 6 Synrift plays in the Gamtoos Basin					
Play Type	**Age**	**Low Risk**	**Medium Risk**	**High Risk**	**Total Leads**
Synrift 1a	Basement to Kimmeridgian Source	10	0	11	21
Synrift 1b	Kimmeridgian to Early Tithonian (P3)	4	2	3	9
Synrift 1c	Early Tithonian (P3) to Mid Berriasian (P1)	3	5	1	9
Synrift 1d	Mid-Berriasian (P1) to Late Berriasian (J1)	0	7	7	14
Synrift 1e	Late Berriasian (J1) to Early Valanginian (1At1)	0	5	10	15
Synrift 2	Early Valanginian (1At1) to Late Hauterivian (6At1)	0	0	12	12

Table 1. Low- to high-risk leads identified over the 6 Synrift plays in the Gamtoos Basin.

Click to view slides of oral presentation.