PSThe Internal Seismic Character of the Gamtoos Basin's Upper Valanginian to Upper Hauterivian Syncline Fill Sequences and the Potential for a Hydrocarbon Play*

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Abstract

The Gamtoos Basin is located within the greater Outeniqua Basin off the southern coast of South Africa. Initial rifting commenced during the Late Jurassic and continued up until the Early Valanginian. There are two distinct tectonic regimes that have influenced the formation of the Synrift phases within the Gamtoos Basin. Synrift I and II described by Broad et al. (2006), focused on the tectonic regimes that influenced the sedimentation. Paton and Underhill (2004) refer to these phases as Principal Synrift and Late Synrift and distinguish them as mega-sequences governed by crustal anisotropy.

Accommodation space developed in response to movement on the Agulhas-Falkland Fracture Zone. As a result of this movement the Gamtoos Fault, in plan view, trends SE-NW from the onshore portion of the basin and makes an almost 90° bend offshore, continuing in a general north-south trend (Paton and Underhill, 2004). The main Gamtoos depocentre is thus not only as a consequence of the growth of the Gamtoos Fault but also due to the occurrence of folding (Paton and Underhill, 2004). This fold-fault system trending across the basin has produced various concave structures giving rise to mini-depocentres. A depocentre along the Gamtoos Fault, also referred to as the Late Valanginian to Late Hauterivian canyon by Davids et al. (2018), created a "mini-basin" whereby several features as well as possible source rocks and seals have been interpreted, using seismic stratigraphy methods. In this study potential reservoir and trap configurations have been identified, using seismic / sequence stratigraphy methods by observing stratal terminations and lapouts (Catuneanu, 2006). Then seismic facies were examined, using external geometries, the internal seismic character and seismic amplitude and frequency identification. Structures within the synclinal fill packages have been interpreted throughout the basin in variable extents and provide insights into sediment-transfer zones prior to being sediment-filled. Several leads have been identified by analysing the petroleum system elements.

The Gamtoos Basin, being under-explored, holds many key elements for an active petroleum system justified by oil and gas shows / fluorescence in many wells. Channels and canyons have fed valuable accretion packages, as mapped during this study, to the deeper reaches of the basin. This emphasizes the hydrocarbon potential with leads identified in this study, thus enhancing the prospectivity of this subbasin.

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The internal seismic character of the Gamtoos Basin's Upper Valanginian to Upper Hauterivian syncline fill sequences and the potential for a hydrocarbon play

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1. Introduction

The Gamtoos Basin forms part of a series of sub basins within the greater Outeniqua Basin of the southern coast of South Africa. This basin extends onshore and is bounded to the east by the Recife Arch, to the west by the St. Francis Arch and to the south by the Diaz Marginal Fracture Ridge (DMFR). The Gamtoos Basin is an underexplored basin (Figure 1). A total of ten boreholes have been drilled between the 1970s and 1980s. Five of these boreholes yielded oil or gas shows along the western part of the Gamtoos Fault (Figure 1).

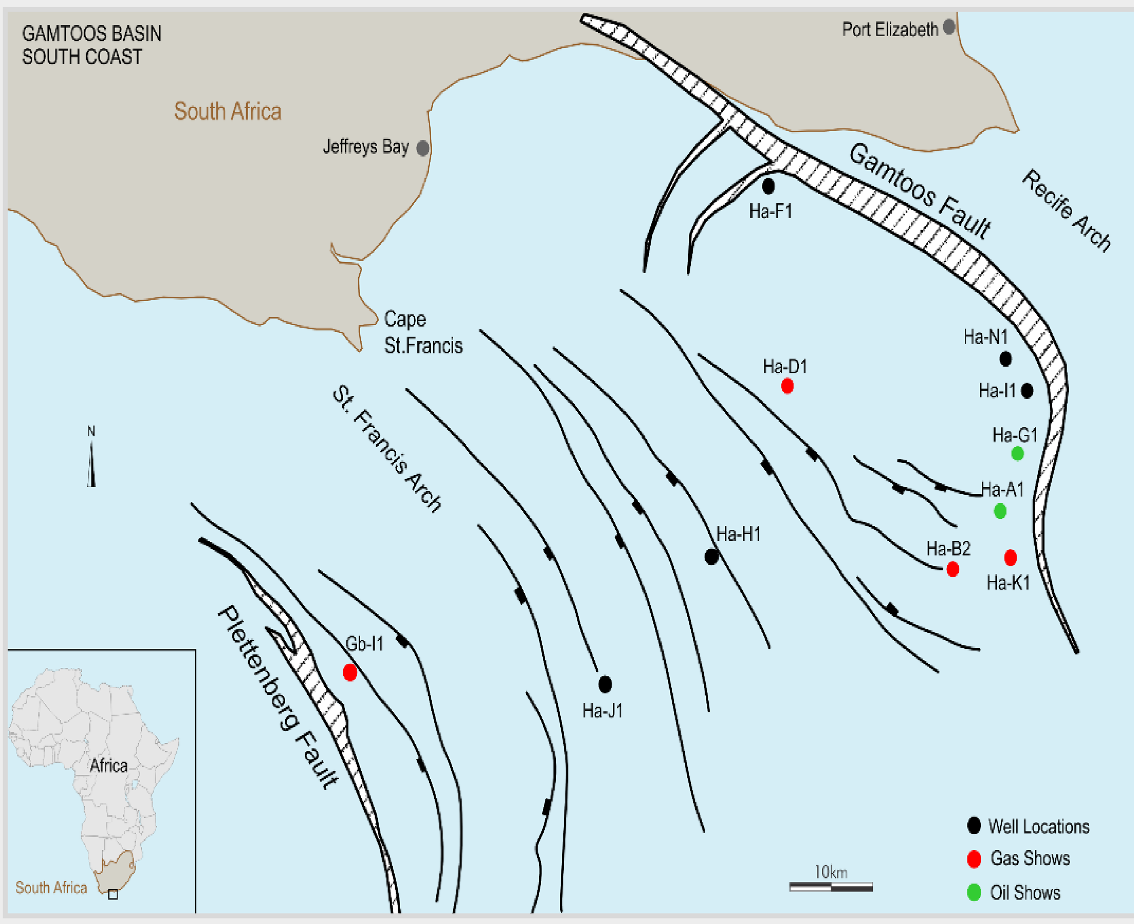


Figure 1: The Gamtoos Fault was at its most active strike-slip stage during the Late Valanginian to Early Barremianin the Gamtoos Basin. Adapted from Broad (1990), Broad *et al*. (2006 and De la Cruz (1981)

The Gamtoos Basin experienced four phases of basin evolution:

- Rift or Synrift I phase (Oxfordian to Early Valanginian),
- Early rift-drift phase or Synrift II (Early Valanginian to Late Hauterivian),
- Late rift-drift phase or Transitional (Late Hauterivian - Mid Albian) and,
- Drift phase (Mid Albian - Present).

(Malan, 1993; Burden *et al*., 1994 and McMillan *et al*., 1997)

2. Tectonic Regimes and Sedimentary responses

There are two distinct tectonic regimes that have influenced the Synrift phases within the Gamtoos Basin. During the first phase (Kimmeridgian to Early Valanginian), normal extension occurred forming half-graben structures that were filled by predominantly Cape Supergroup metasediments of fluvio-lacustrine and inner shelf environments (Figure 2). The second phase (Early Valanginian to Late Hauterivian) represents the dominance of dextral (right-lateral) strike-slip movement along the AFFZ. This caused the truncation of pre-existing structural trends of the Permo-Triassic Cape Fold Belt. Mostly deep marine claystones and thin-bedded turbidites were deposited during this period.

The arcuate trend of the Gamtoos Fault (Figure 1) is most likely inherited, during these phases, from the structural grain of the underlying orogenic Cape Fold Belt (De Swardt and McLachlan, 1982) and later from movement on the Agulhas-Falkland Fracture Zone (AFFZ). Synrift I and II described by Broad *et al*. (2006), focused on the tectonic regimes that influenced the sedimentation (Figure 3 and 4). Paton and Underhill (2004) refer to these phases as Principal Synrift and Late Synrift and distinguish them as mega-sequences governed by crustal anisotropy.

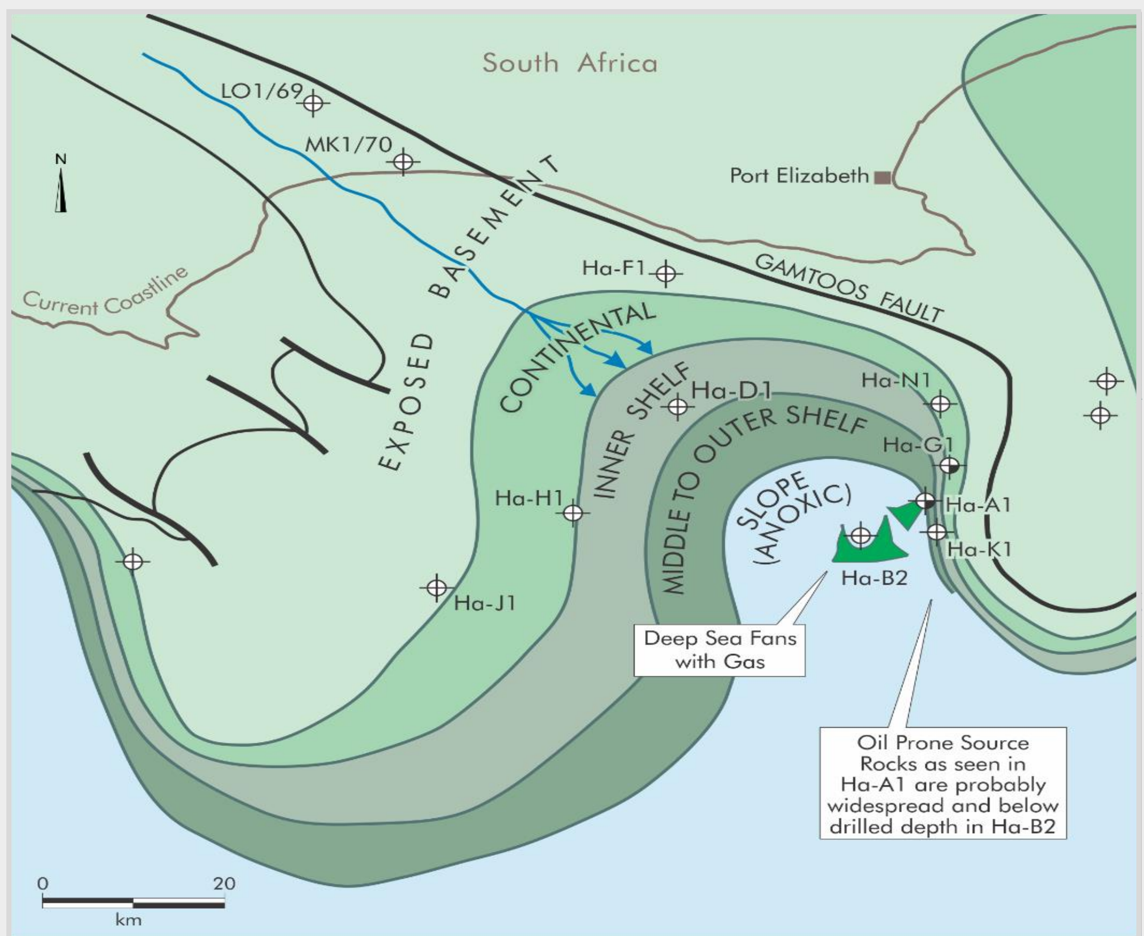


Figure 2: Depositional environments of Synrift I during the Kimmeridgian (After SOEKOR, 1986)

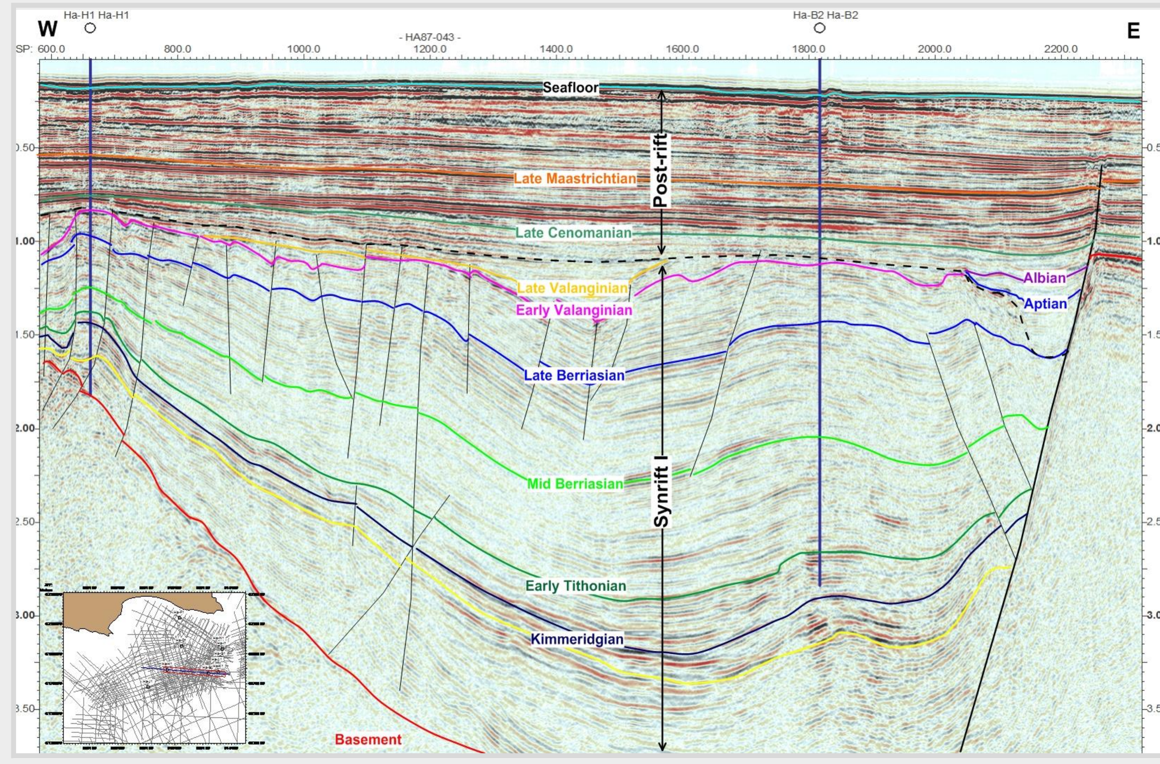


Figure 3: East-West section of the Gamtoos Basin mega-sequences of Synrift I and II from Kimmeridgian to Late Hauterivian (after Broad *et al*., 2006).

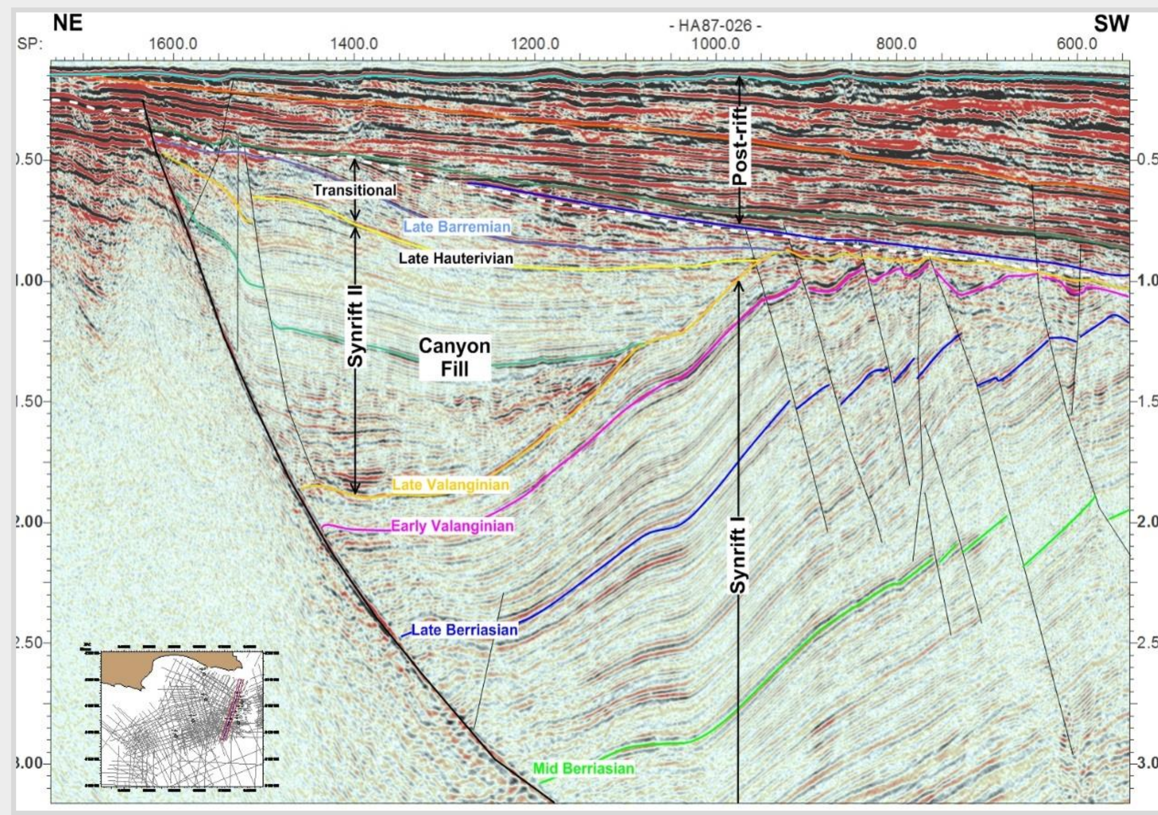


Figure 4: North-South section depicting the Synrift II mega-sequence from Late Valanginian to Late Hauterivian predominantly along the Gamtoos Fault (after Broad *et al*., 2006)

Synrift II is characterised by a period of extensive erosion and canyon formation (Broad *et al*., 2006) from the Early Valanginian to Late Hauterivian age, as illustrated in Figure 4. The Gamtoos Canyon is restricted mostly adjacent to the northern portion of the Gamtoos Fault and is infilled by shelf and slope sediments which transported large volumes into the Southern Outeniqua Basin (Thomson, 1999). These restricted sequences are characterised by two distinct depositional styles, the lowermost overlain by a uniform package of about 400m. The uppermost Hauterivian package reaches a thickness of up to 890m. The sediments change from grey to dark claystones due to the lower anoxic slope to outer/middle shelf environment (Paton and Underhill, 2004).

3. Study Area

The study area covers approximately ~1600km2 along the northern NW-SE trending portion of the Gamtoos Fault (Figures 5 and 6).

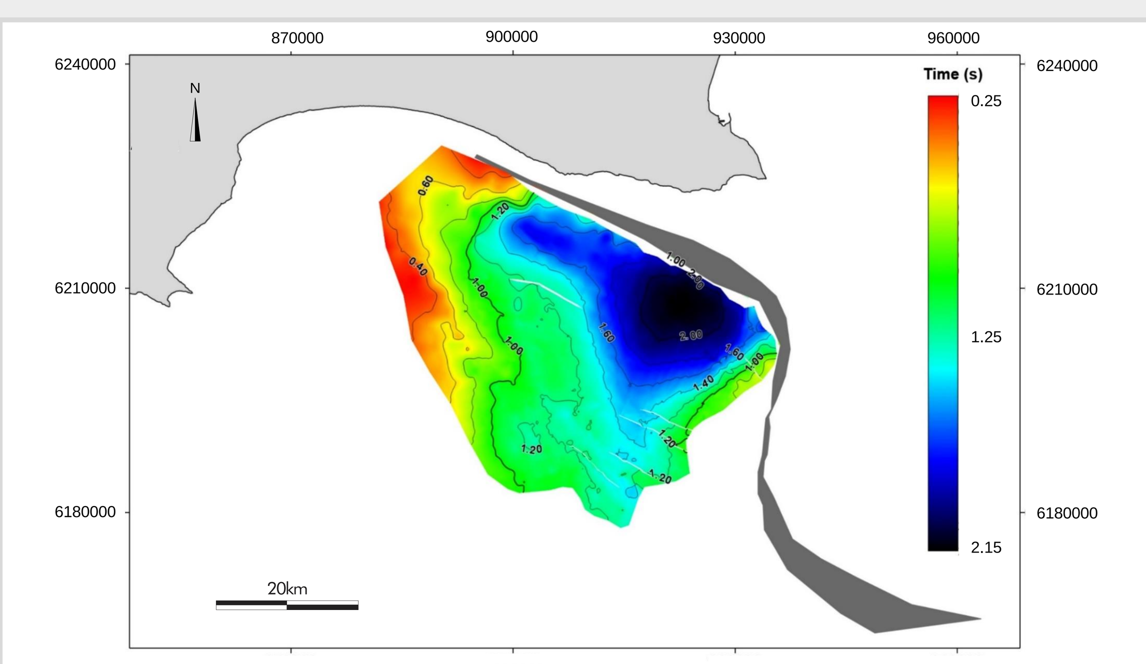


Figure 5: The synclinal fill package basal structure of the Late Valanginian to Late Hauterivian Canyon as viewed in 2D

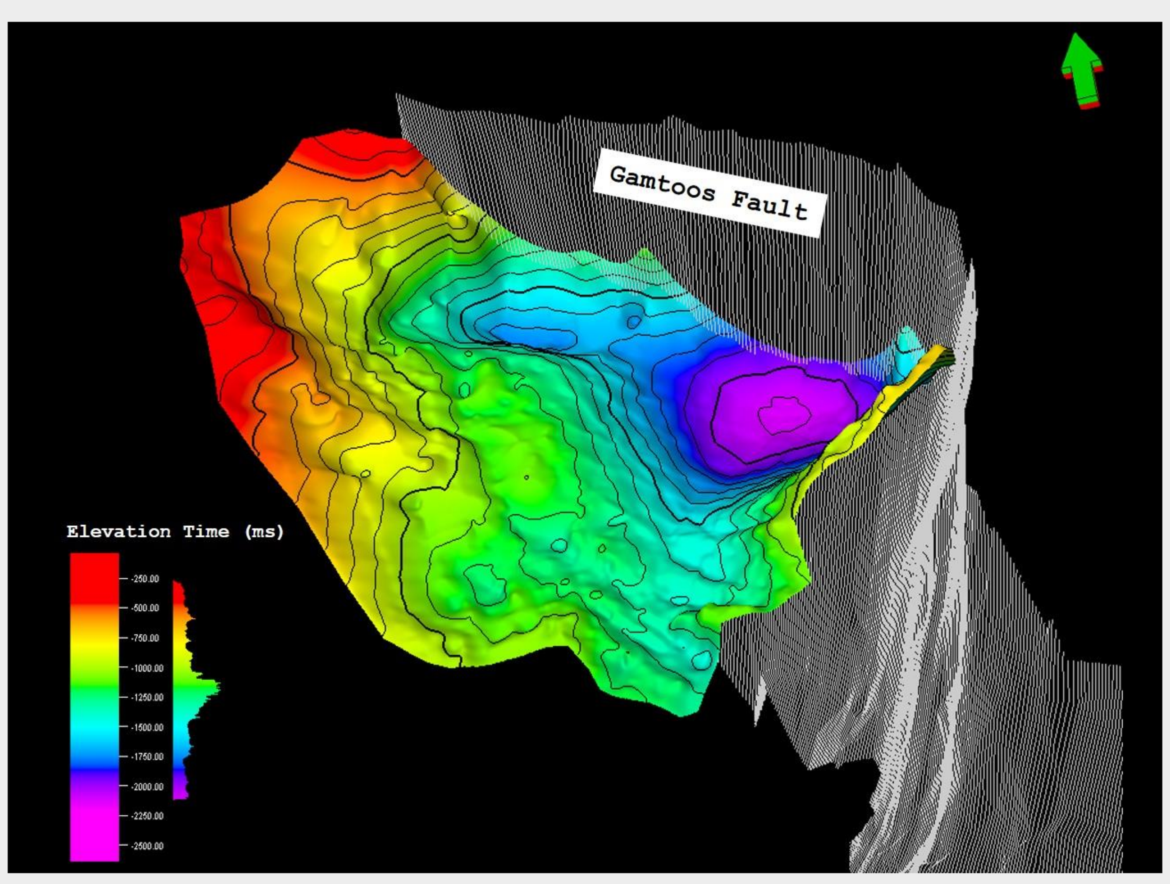


Figure 6: The synclinal fill package basal structure of the Late Valanginian to Late Hauterivian Canyon as viewed in 3D

The fill packages occur above the 1At1 unconformity of Early Valanginian age within the main Gamtoos depocentre. These are characterised by a change in fill direction and are considered to be greatly influenced by the major strike slip movement on the AFFZ.

4. Seismic Stratigraphy methods

This synclinal depocentre is thus not only a consequence of the growth of the Gamtoos Fault but also due to underlying folding (Paton and Underhill, 2004) as a mechanism of compensating the strike-slip movement. This fold-fault relationship trending across the basin has produced various upward concave structures giving rise to mini depocentres or synclinal fill structures. A synclinal structure along the Gamtoos Fault, also regarded as the Late Valanginian to Late Hauterivian canyon by Davids *et al*. 2018, created a "mini basin" whereby several features as well as possible source rocks and seals have been interpreted using seismic stratigraphy methods. In this study potential reservoir and trap configurations have been identified using seismic / sequence stratigraphy methods by observing stratal terminations / lapouts and the geometric relationships of successions (Catuneanu, 2006) as illustrated in Figures 7a and b.

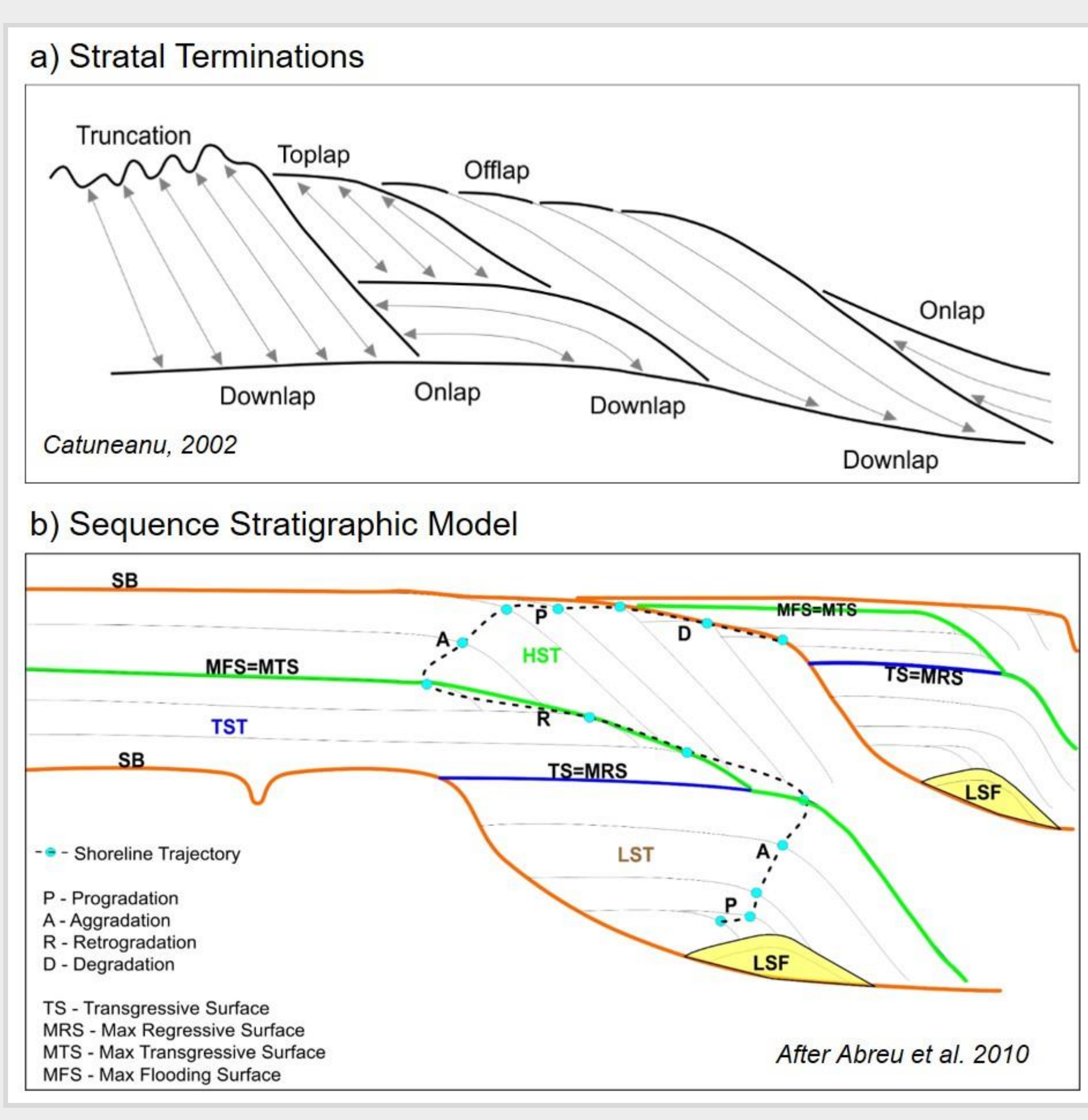


Figure 7: a) Stratal terminations used to illustrate accommodation stacking successions with b) various components of systems tracts and their accompanying sedimentation patterns.

Seismic facies were examined using both external and internal geometries. These assisted in classifying stratal termination patterns into respective configurations (Figure 8). The internal seismic character was identified using reflection characteristics of amplitudes, frequency and continuity. Structures within the synclinal fill packages have been interpreted throughout the basin to variable extents and provide insights into sediment-transfer zones prior to being sediment-filled.

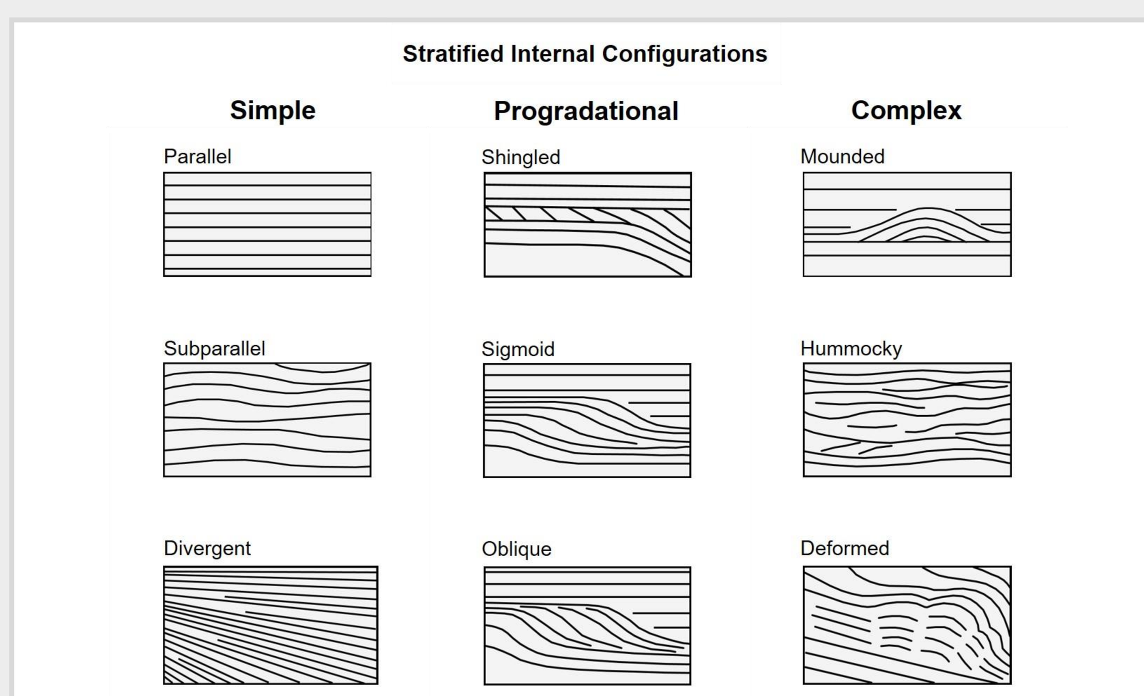


Figure 8: The internal reflection configuration assisted with systems tracts identification (courtesy of AAPG Archives http://archives.aapg.org/slide_resources/schroeder/11b/index.cfm)

5. Petroleum Elements

Well Ha-D1 is located on the southern flank of the canyon and wells Ha-F1 and Ha-N1 to the south of the Gamtoos Fault, west and east respectively (Figure 1). The following petroleum elements were deduced from well completion reports:

Well name	Ha-D1	Ha-F1	Ha-N1	Risk
Source age	Late Valanginian - Hauterivian	Late Valanginian - Hauterivian	Late Valanginian - Hauterivian	
Source depth range (m)	1088-1230 ~130m	1944-2080 ~136m	1960-1980 ~20m	
TOC (%)	1,1 – 1,7 WG-OP	1 – 1,6 DG-WG	0,7 -1,3 DG-OP	
Reservoir, %N/G	Trace , <2%	Trace , <2%	Tight , <21%	
Trap	Stratigraphically-dependent	Stratigraphic & fault assisted	Stratigraphic & fault assisted	
Migration	Fault-dependent	Fault-dependent	Fault-dependent	
Seal	Poorly developed	Good lateral seal required	Good lateral seal required	

WG – Wet Gas DG – Dry Gas OP – Oil-Prone

Low Medium High

6. Evidence of a syncline

Figures 9 and 10 show the possibility of an eroded limb of a syncline structure. As the Gamtoos Fault continued to grow, erosion caused the upper-most missing section to most-likely deposit within the canyon itself. Tight to porous potential reservoir rocks have been identified in various wells for the strata found below 1At1. This could pose as a potential input source for reservoir sequences along the Gamtoos Fault within the canyon.

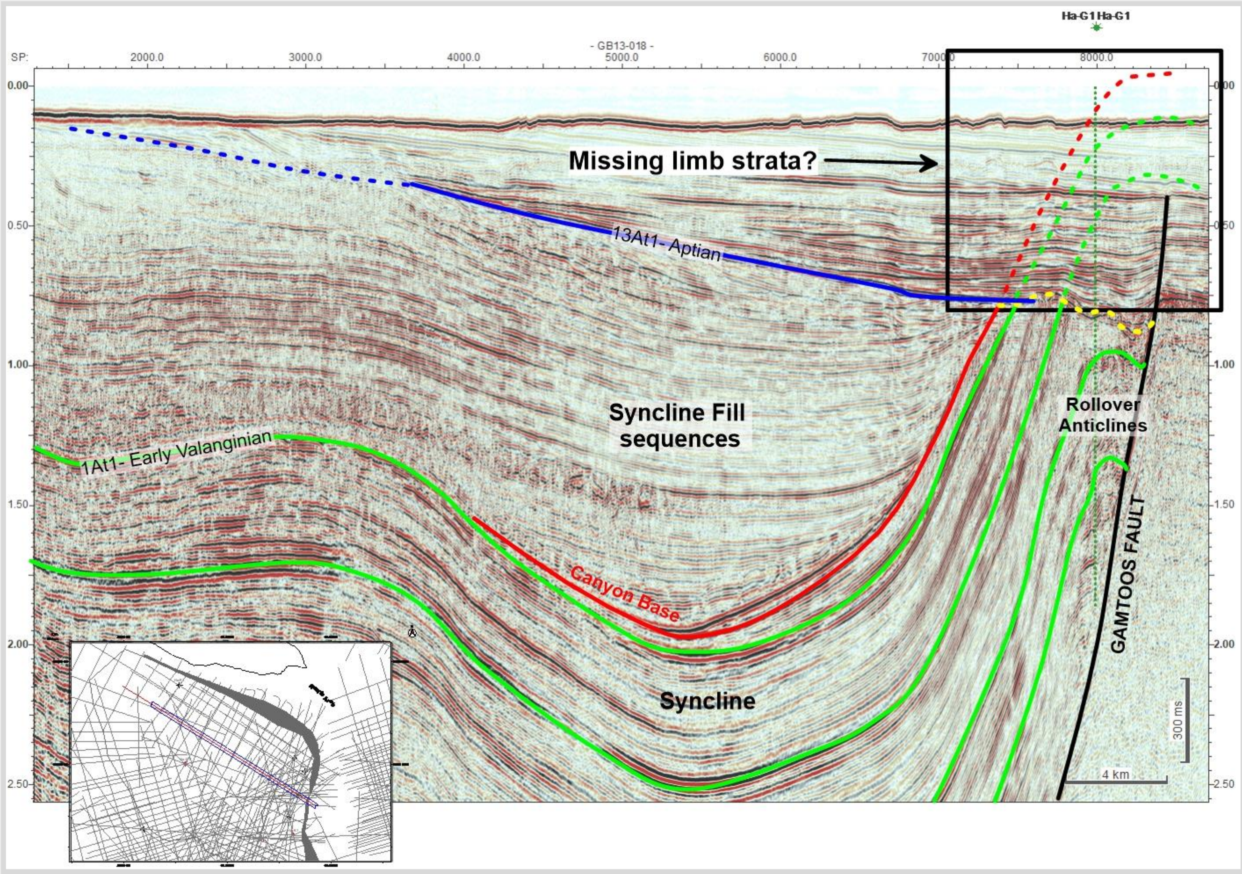


Figure 9:
The Early Valanginian (1At1) and its underlying strata appear to have been subjected to folding on a regional scale. The timing of this event is critical to determine the potential missing strata which have been eroded. If this occurred as a syntectonic sedimentation event, it could be valuable for the reservoir potential of the canyon. The inferred missing strata have been vertically exaggerated for illustrative purposes.

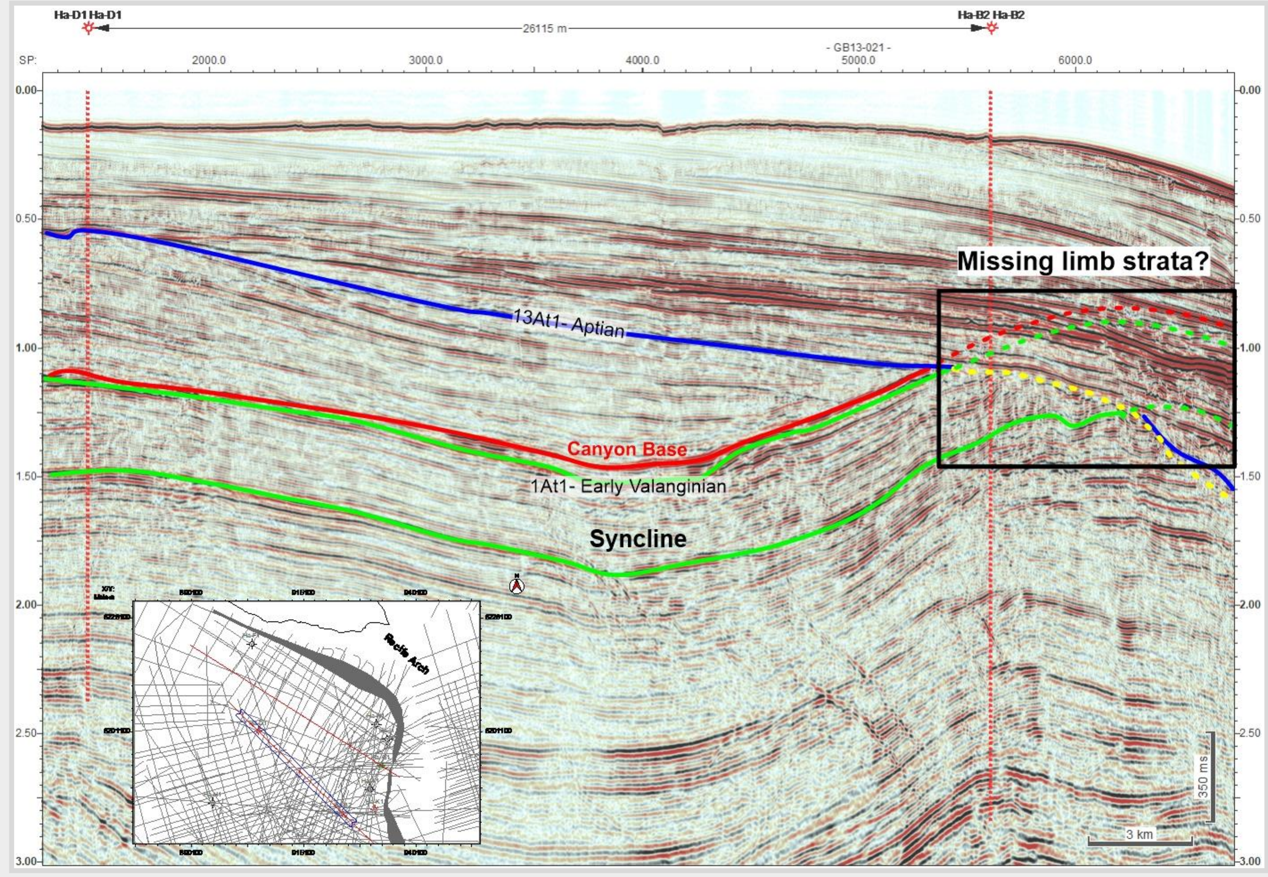


Figure 10:
The southern flank of the canyon, as illustrated, shows a shallower syncline structure with possible eroded limb strata. This missing strata appear to have been deposited towards the southern portion of the basin. This poses good potential for reservoir strata to be fed into the deeper parts of the basin. The inferred missing strata have been vertically exaggerated for illustrative purposes.

7.1 Systems Tracts with relative seismic character and facies

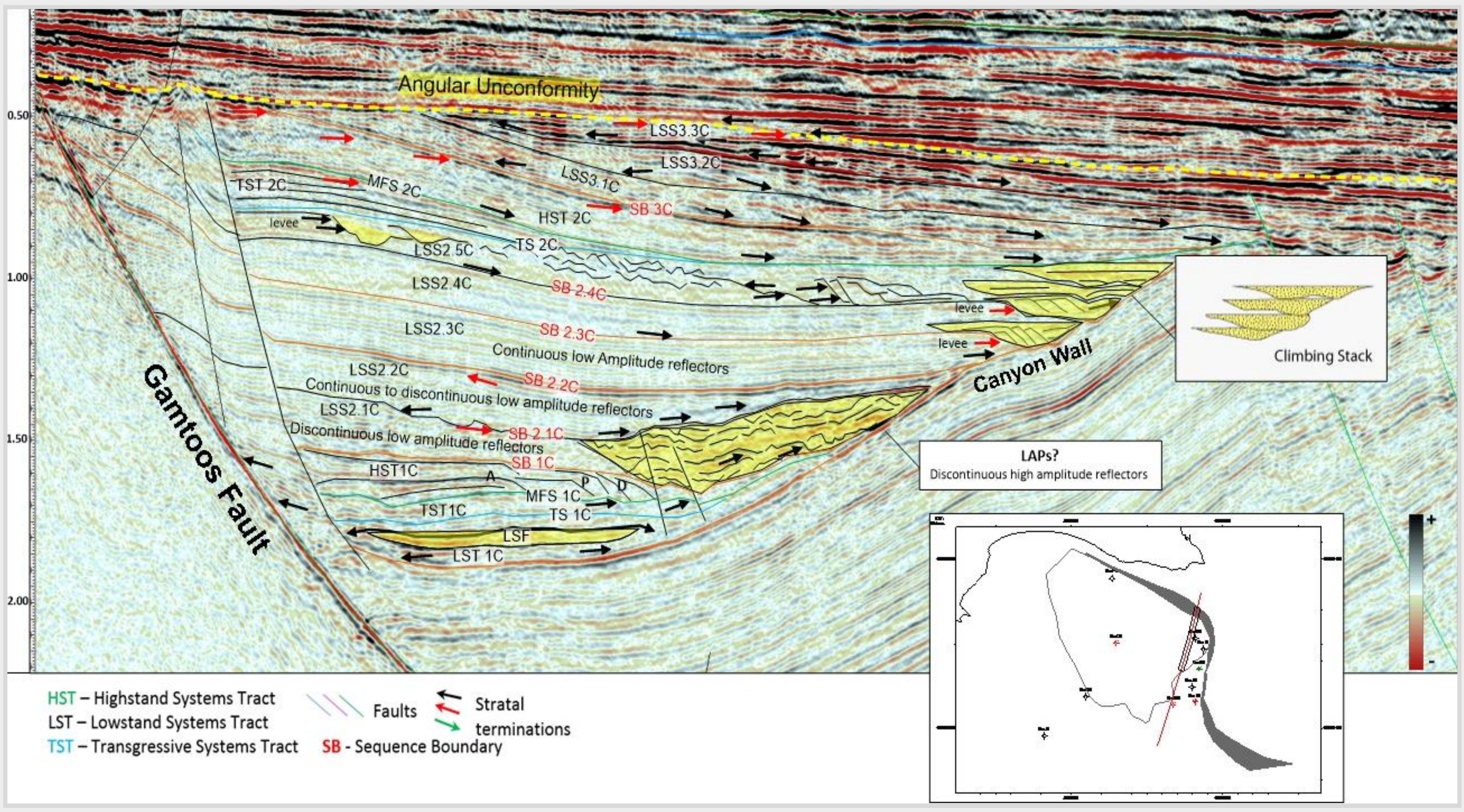


Figure 11: Seismic features identified using external geometries and internal configurations to deduce relevant systems tracts (after Davids *et al.*, 2008).

Summary table of systems tracts with associated seismic character

Various seismic features have been identified within the canyon area. A lowstand system at the base of the syncline fill sequences has the potential for good reservoir (Figure 11). Also identified are climbing stacked channels along the eastern portion of the canyon wall displaying lateral accretion as well as the flank of a lateral accretion package (Figure 11).

Systems Tract	Seismic Configuration	Seismic Texture		External Shape	Terminations	Seismic Facies (+ / -)	Interpreted Seismic Profiles
		Amplitude	Continuity				
LSS2.5C	Hummocky to disrupted	Moderate	Chaotic	Sheet	Truncation downlap		
Stacked channels	Oblique to sigmoid	Moderate to high	Continuous	Channel	Truncation downlap onlap		Passive Active
LSS2.2C – LSS2.4C	Parallel	Moderate to high	Continuous	Sheet	Onlap		SB
LSS2.1	Subparallel to hummocky	Moderate to high	Semi-continuous to chaotic	Sheet – channel shape	Onlap truncation		SB SB
HST1C	Oblique	Moderate to high	Semi-continuous	Sheet - wedge	Downlap, offlap		SB MFS
TST1C	Subparallel	Low to moderate	Variable	Wedge	Toplap		MFS
LST 1C	Subparallel	Moderate to high	Continuous	Lens	Onlap		Canyon Base

7.2 Facies of sequences and lateral accretion packages (LAPs)

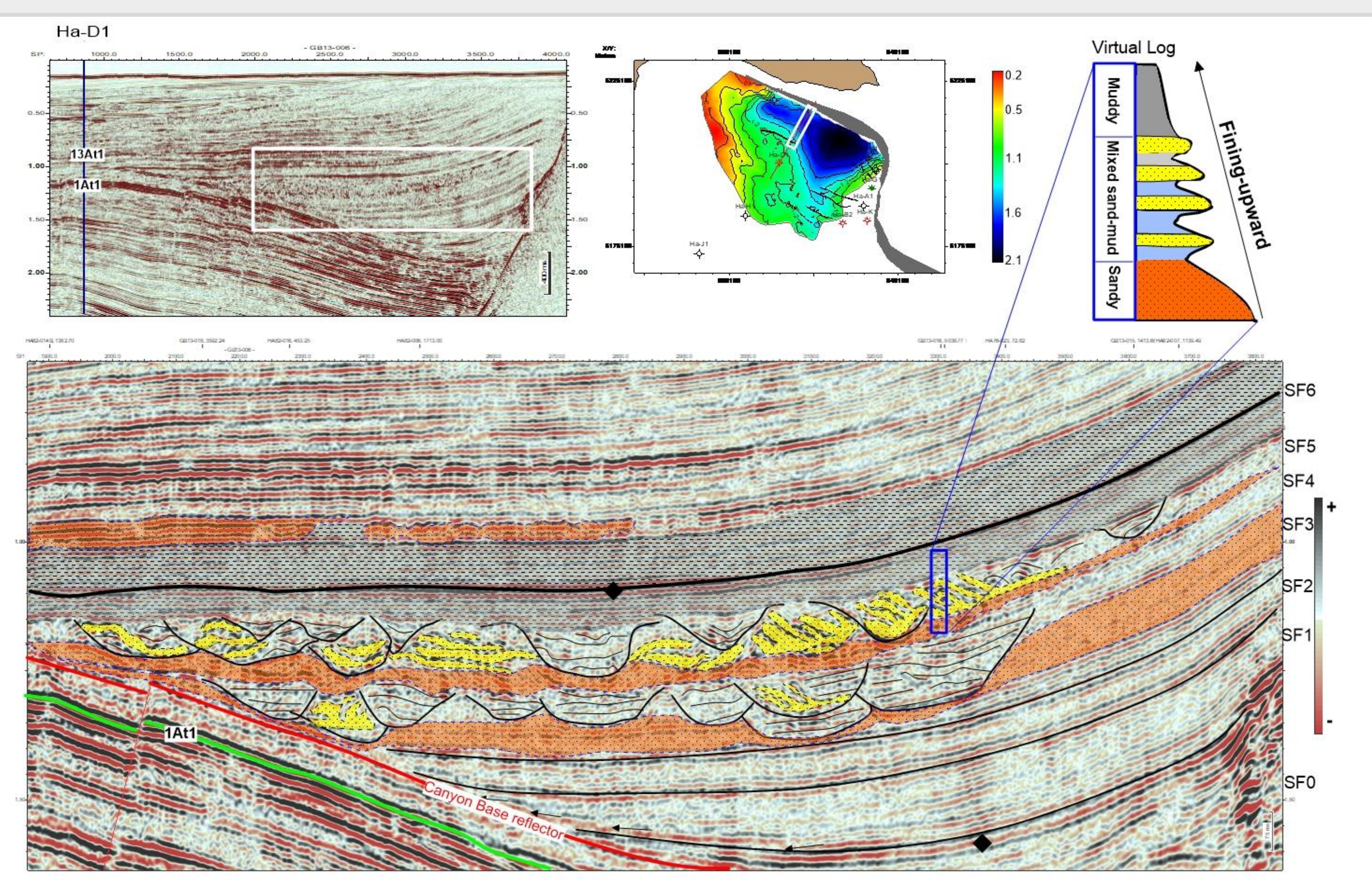


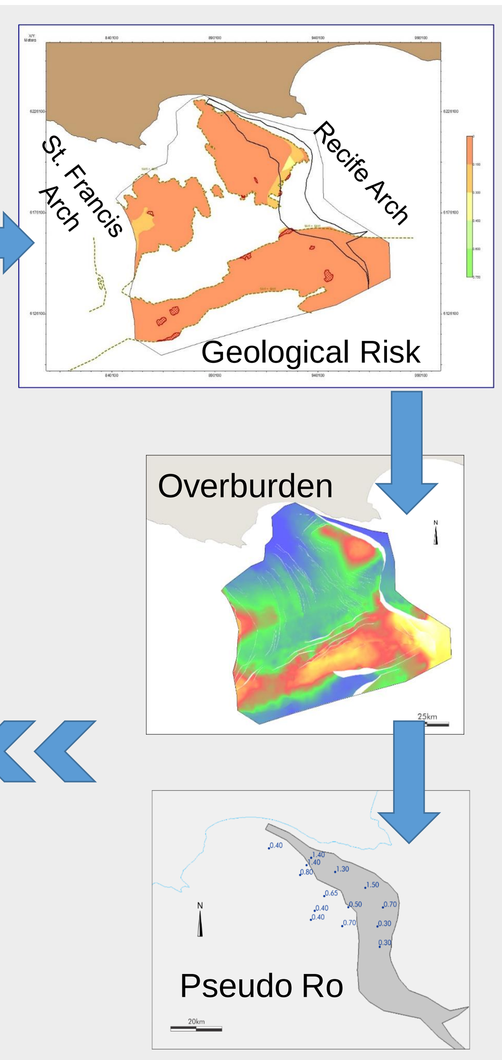
Figure 12: A large area demonstrating lateral accretion packages having channel cutting/migrating features.

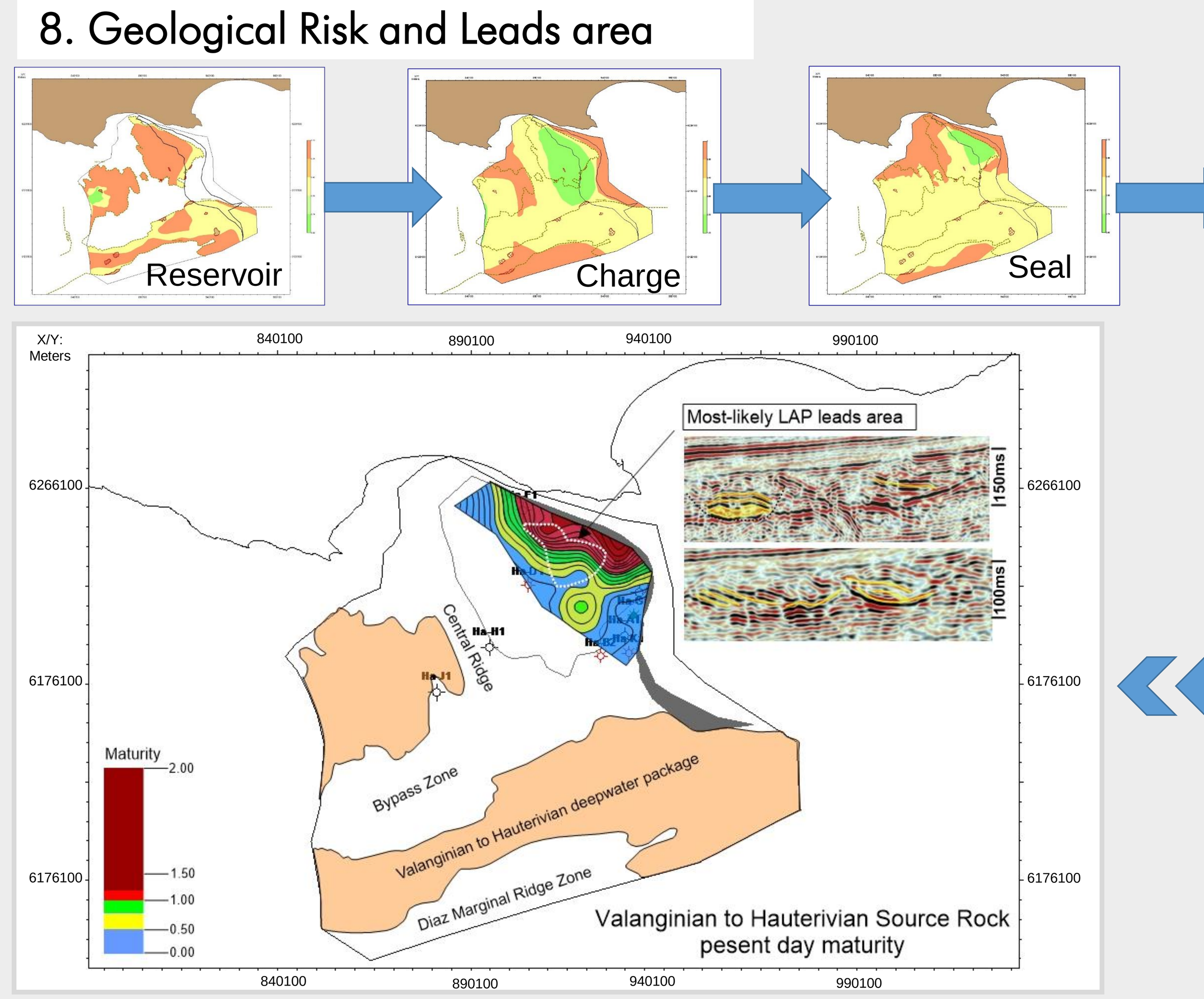
Summary table of facies packages SF0 to SF6

The most notable feature within the synclinal fill sequences is large lateral accretion complexes, also referred to as Lateral Accretion Packages (LAPs) with associated migrating channels. These are characterised by moderate to high amplitude and shingled to hummocky configurations displaying possible sandy accretions (Figure 12). These migrate across the canyon and if connected could hold good reservoir potential (Abreu *et al.*, 2003).

Facies	Seismic Configuration	Seismic Texture			External Shape	Inferred Interpretation	Seismic Facies (+ / -)	Interpreted Seismic Profiles
		Amplitude	Frequency	Continuity				
SF6	Parallel	Moderate to high	Low	Continuous	Sheet	Possible seal due to muddy seismic character		
SF5	Oblique to hummocky	Moderate to high	Variable	Chaotic	Complex Channel	Sand-filled LAPs interbedded with muds		
SF4	Parallel to oblique	Moderate to high	Variable	Semi-continuous to chaotic	Complex Channel	Sand-filled and mud-filled channels		
SF3	Hummocky	Moderate to high	Moderate	Semi-continuous	Lens	Turbidite sands and muds eroded by channels		
SF2	Shingled	Moderate to high	Moderate	Continuous to disrupted	Sheet	Horizontal sheet muds		
SF1	Parallel	Low to moderate	Moderate to low	Continuous	Sheet	Dipping sheet muds		
SF0	Parallel to subparallel	Moderate to high	Low	Continuous	Sheet	Possible source sequences due to anoxic conditions		S

8. Geological Risk and Leads area





Reservoirs and seals were mapped along with potential migration areas and overburden to deduce the Geological Risk. Petroleum systems modelling for the Late Valanginian to Late Hauterivian deduced that the potentially most mature area lies within the canyon depocentre along the Gamtoos Fault. LAPs have been identified within this area and pose great potential for reservoir and trap systems. Factors required to de-risk prospectivity include richer source, connected reservoir sands, lateral seals and strong stratigraphic trapping mechanisms.

9. Summary

- The Gamtoos Basin, being under-explored, holds many key elements for an active petroleum system which have thus far been justified by oil and gas shows / fluorescence in many wells. Channels and canyons have acted as valuable conduits, as mapped in this study, to the deeper basin areas.
- A LAP complex covering an approximate area of 200km^2 has been identified within the synclinal fill sequence package which could further de-risk reservoir within the canyon area. These display a seismic character relative to interbedded sands and muds of migrating stacked channels and sand accretion.
- Climbing channel stacks on the eastern flank of the canyon wall has the potential for additional reservoir sands.
- Identified source potential in wells on the flanks of the canyon suggests a potentially richer source towards the canyon depocentre and maturity modelling inferred greater potential in the deeper depocentre.
- Seal mechanisms pose the most risk and a very strong lateral seal component is needed to sufficiently trap hydrocarbons.
- This study has highlighted potential within the Gamtoos Basin not previously identified.

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