PSS Sequence Stratigraphy of the Post-Jurassic in the Algoa and Gamtoos Basins: Implications for Hydrocarbon Potential in the Eastern Cape, South Africa*

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Abstract

Sequence stratigraphy is a modern branch of stratigraphy commonly used in the petroleum industry, to understand the depositional history of a basin. As common with young disciplines, terminology is inconsistently used by different schools of thought to define stratigraphic surfaces and group strata, resulting in multiple sequence stratigraphic models that interpret the same data differently. Using the Algoa and Gamtoos Basins as a case study, this investigation is building a modern sequence stratigraphic framework by integrating available vintage dataset to test the robustness of selected sequence stratigraphic models. Although a working petroleum system was proven in the Algoa and Gamtoos Basins of South Africa, seismic and well data acquired to date yielded limited exploration success. This limitation has prevented the development of contemporary basin development models for the Algoa and Gamtoos region. Based on vintage data by Soekor E&P (Pty.) Ltd. and preliminary sequence stratigraphic studies, New Age Global Energy Company, reported in 2018 that the offshore Algoa Canyon, syn-rift Gamtoos Basin, and Outeniqua Basin slope plays contain ~510 MMboe (million barrels of oil equivalent) resources. The ultimate goal of this ongoing project is to understand the basin formation mechanisms and the hydrocarbon prospectivity, offshore Port Elizabeth, South Africa. To achieve this, using desktop-based Petrel and/or Hampson-Russell software, the following objectives are being addressed:

- 1. Analyse and interpret the geological record in the Algoa and Gamtoos Basins, firstly by using basic principles of stratigraphy and process sedimentology (i.e., independent of any sequence stratigraphic school of thought).
- 2. Understand the mechanisms (autocyclic and/or allocyclic) responsible for seismic reflector geometries and sequence generation in these south east basins.
- 3. Compare sequence boundaries and geometries observed in the dataset to stratigraphic boundaries and geometries defined by different sequence stratigraphic models in the study area and its broader vicinity, in the eastern Outeniqua Basin.
- 4. Use relevant sequence stratigraphic models to predict facies distribution in the basins, by testing the robustness of current models and highlighting their advantages and limitations.
- 5. Attempt to develop a robust predictive tool for facies distribution away from well control and hydrocarbon plays (i.e., build gross depositional environment models).

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6. Provide recommendations on how sequence stratigraphy can be used in similar regions to this study.

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Sequence stratigraphy of the post-Jurassic in the Algoa and Gamtoos Basins: implications for hydrocarbon potential in the Eastern Cape, South Africa

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INTRODUCTION

This study is based on well log and seismic survey data from the Algoa and the Gamtoos Basins of South Africa (Fig. 1), and aims to build a basin evolution model for the region by:

1. Applying the principles of stratigraphy and sedimentology;

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- 2. Understanding the relative importance of autocyclic and allocyclic processes in the generation of basin-filling successions;
- 3. Developing a predictive tool for facies distribution away from well control with the aid of gross depositional environmental (GDE) maps;
- 4. Testing the robustness of different sequence stratigraphic models against the existing well and seismic data in these basins.

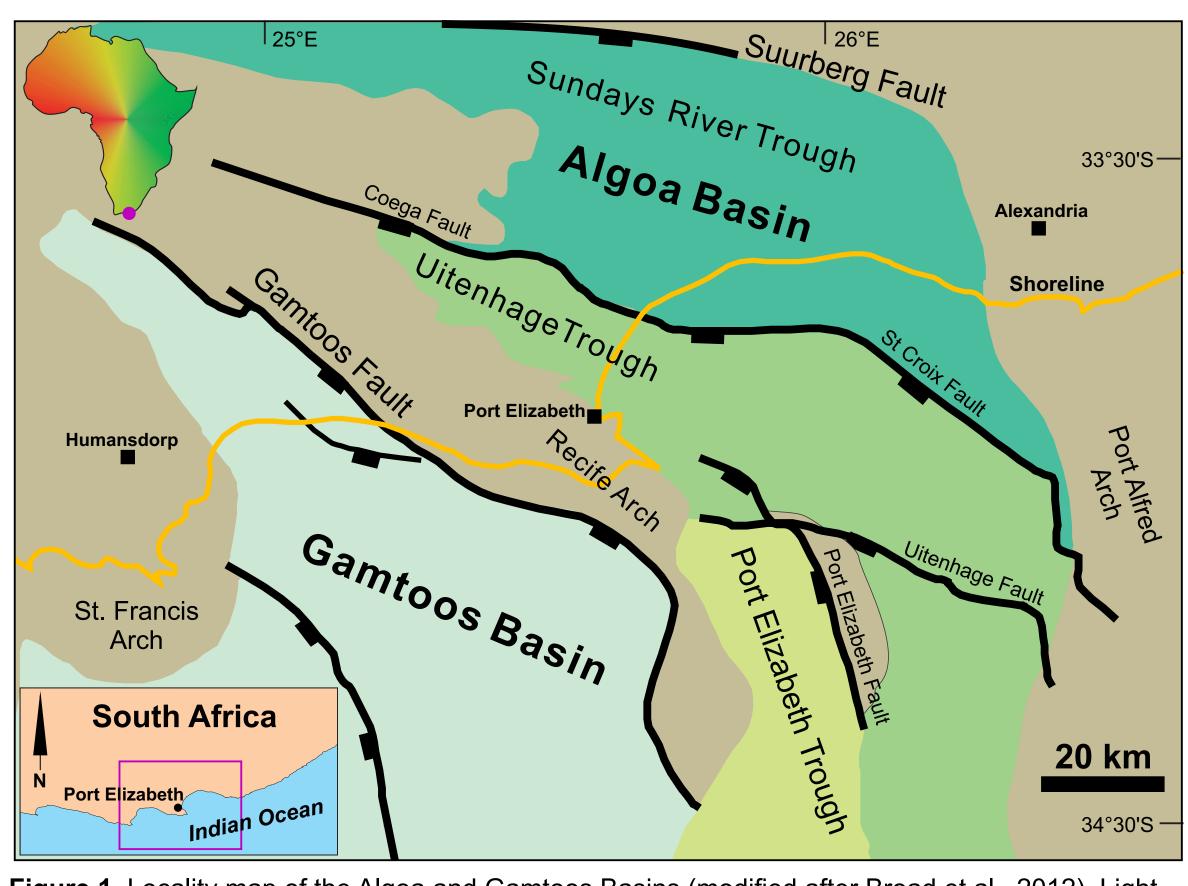


Figure 1. Locality map of the Algoa and Gamtoos Basins (modified after Broad et al., 2012). Light brown for shallow basement.

PROBLEM STATEMENT

- 1. Unlike other more established branches of stratigraphy (e.g., litho-, bio, chrono-, magnetostratigraphy), sequence stratigraphic terminology is in the process of being formalised (Catuneanu et al., 2011).
- 2. Different schools of thoughts still inconsistently define stratigraphic surfaces and group strata, and this can result in erratic interpretations of the same rock unit.
- 3. The concept of multiple sequence stratigraphic models (Fig. 2) is also often misunderstood (Catuneanu, 2002, 2006; Catuneanu et al., 2011). These models were established independently in separate basins, therefore, they best fit the observations from basins similar to the original basins (Catuneanu, 2002; 2006).

	Sequence Events model and stages	Depositional Sequence I	•		Depositional Sequence IV	Genetic Sequence	T-R Sequence
	HNR		HST	early HST	HST	HST	RST
	end of T T	ence	TST	TST	TST	TST	TST
— allile —	end of R LNR	Sequence	late LST (wedge)	LST	LST	late LST (wedge)	MRS
	end of RSL fall		early LST (fan)	late HST	FSST	early LST (fan)	RST
	onset of RSL fall- HNR	CC	HST	early HST	HST	HST	
• 1	sequence boundary systems tract boundary within-sequence surface within-systems tract surface Sequence boundary onset of regression RSL fall end of RSL fall						

Figure 2. Multiple sequence stratigraphic models (Catuneanu et al., 2011, p. 176).

GEOLOGICAL SETTING

The Algoa and Gamtoos Basins are a series of grabens and half-grabens along the SE coast of South Africa (Figs. 1, 3). Their genesis is linked to the break-up of Gondwana (e.g., Dingle et al., 1983; McMillan et al., 1997). Their petroleum potential has been recognized (e.g., Broad, 1990) but lacks a systematic evaluation rooted in modern sequence stratigraphy.

The Uitenhage Group (Fig. 3) unconformably rests on pre-Lower Jurassic units, and comprises the Jurassic-Early Cretaceous syn-rift succession, namely the Enon, Kirkwood and Sundays River Formations. The post-rift succession is broadly assigned to the Algoa Group.

The regional structural trend is controlled by the Permo-Triassic Cape Fold Belt (i.e., pre-existing structural planes, late superimposed dextral deformation - Bate and Malan, 1992; McMillan et al., 1997; Broad et al., 2012).

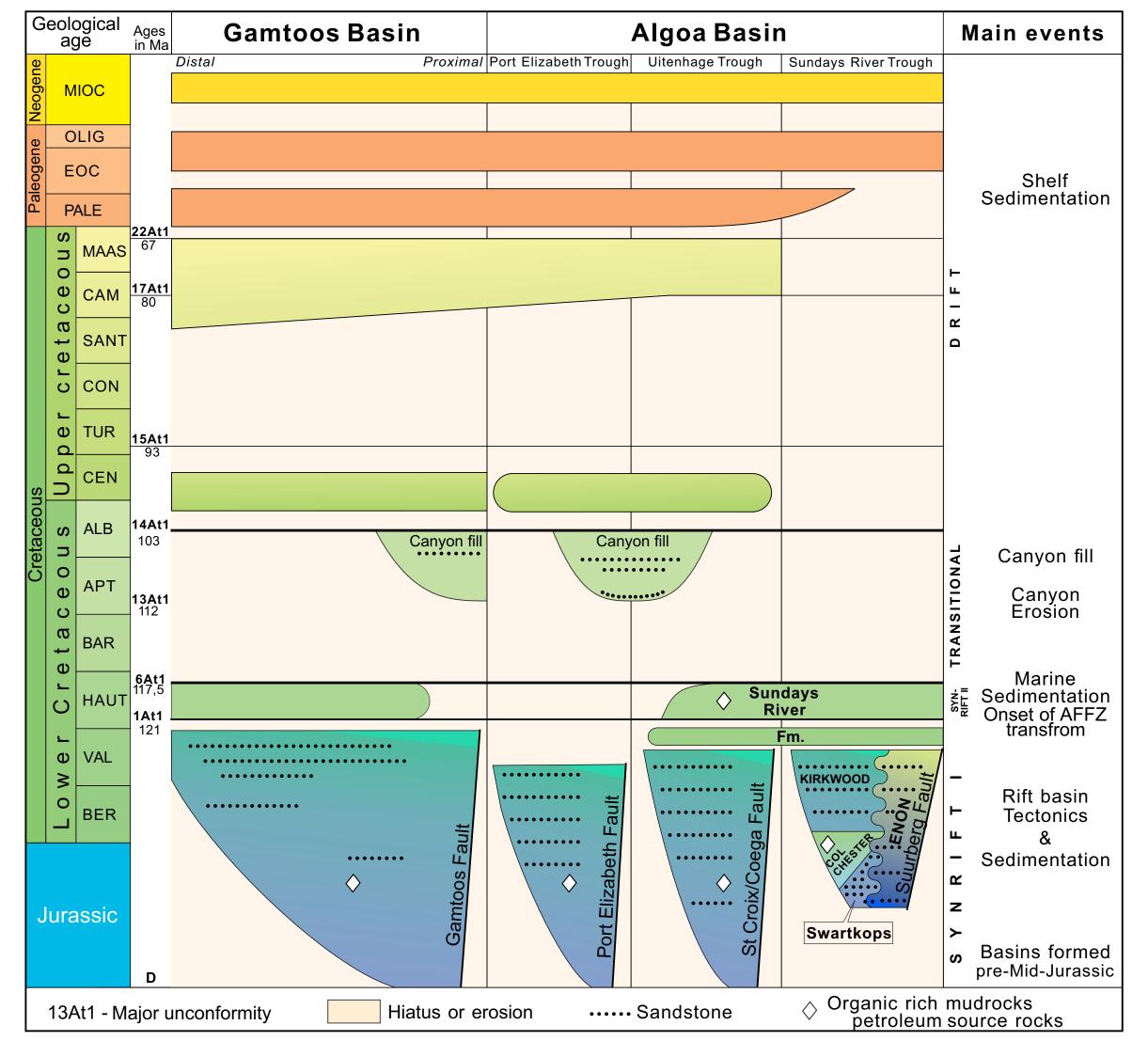


Figure 3. Stratigraphic succession and major geological events in the Algoa and Gamtoos Basins (modified from McMillan et al., 1997; Broad et al., 2012).

METHODOLOGY

- ⇒ Quality check (QC) seismic lines for processing and acquisition artefacts;
- ⇒ If formation tops are not provided, use biostratigraphy or petrological studies from core and/or outcrop to identify major sequence boundaries;
- ⇒ Calibrate well information with seismic data in the seismic-to-well-tie process;
- ⇒ Correlate wells chronostratigraphically if suitable data is available; ⇒ Identify faults, depositional trends on wireline logs (and outcrop if
- available) and stratal termination on seismic profiles to establish the major sequence boundaries; ⇒ Use stratal terminations and stacking patterns to infer local shoreline
- trajectories; ⇒ Evaluate the relative importance of autocyclic and allocyclic
- processes for sediment supply and accommodation space creation; ⇒ Infer relative sea level changes by assessing the relative rate of changes in local tectonics and eustatic sea level;
- sedimentation rates, and assign system tracts that best fits the observations;

⇒ Assess the interplay between changes in the relative sea level and

- ⇒ Compare observed sequence boundaries and geometries within system tracts to those in different sequence stratigraphic models;
- ⇒ Propose an explanation for potential discrepancies;
- ⇒ Use analogues to explain why a sequence model was chosen, and; ⇒ Use the model that fits best the data to predict facies distribution in the

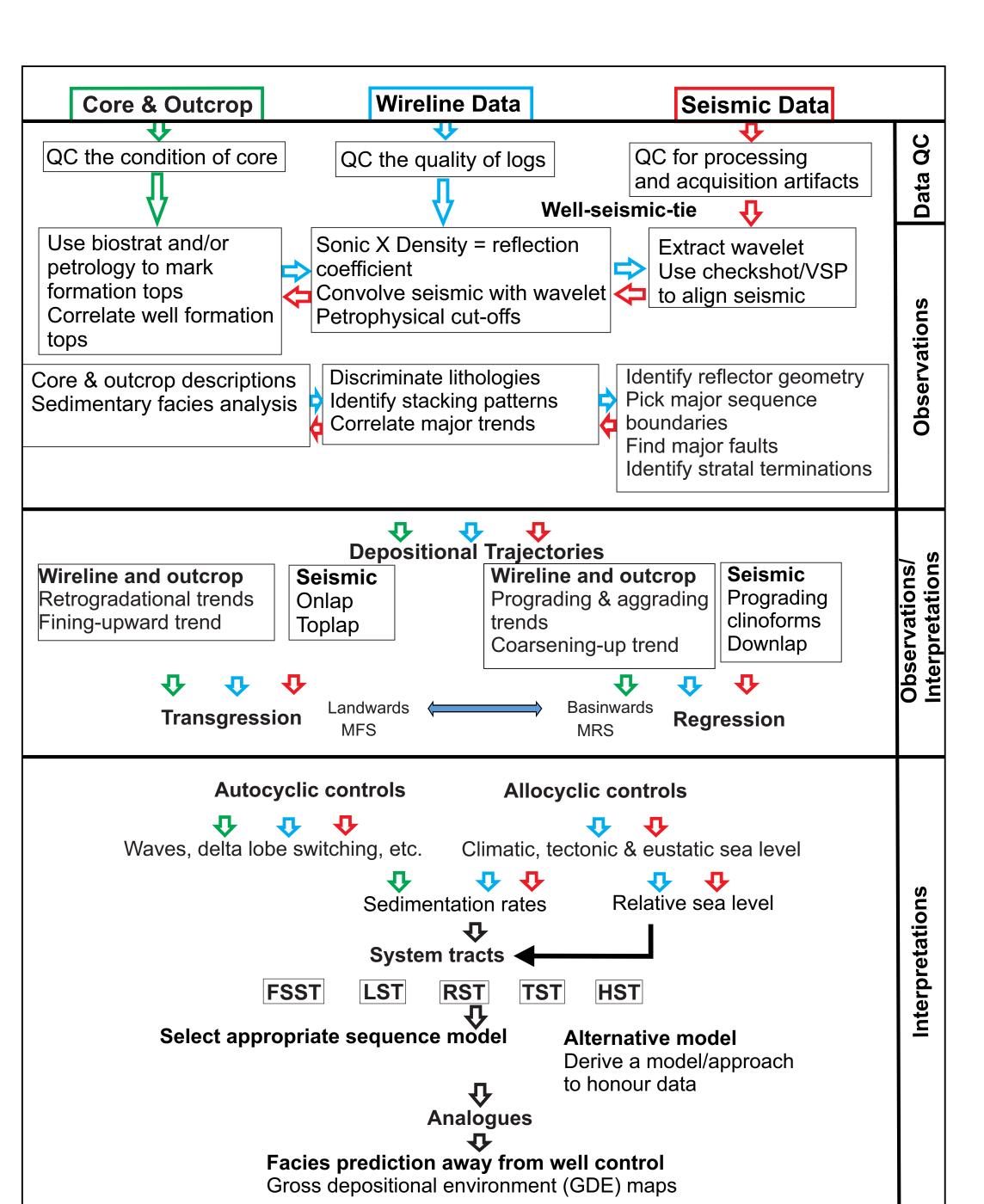
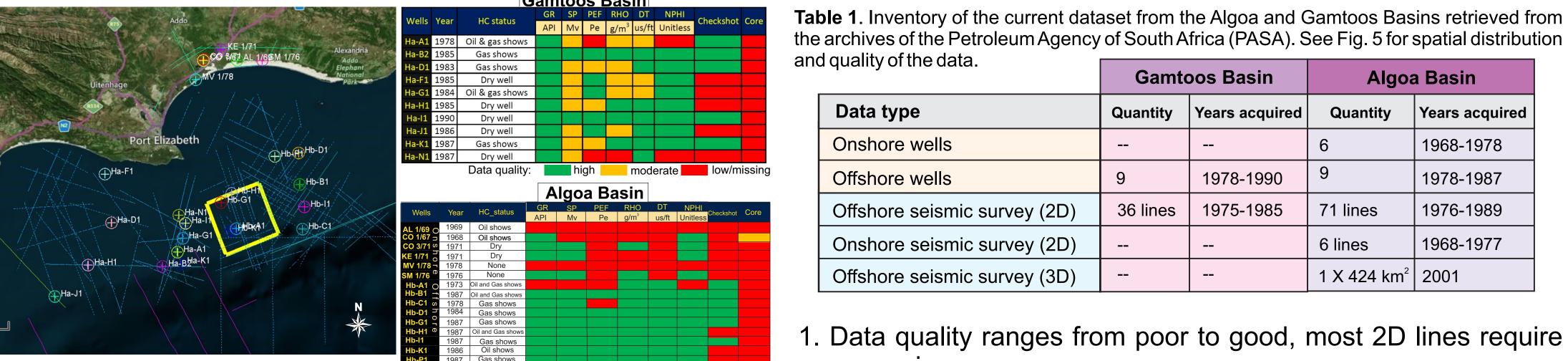


Figure 4. Workflow for sequence stratigraphic interpretation and facies prediction.

DATASET



reprocessing. Figure 5. Spatial distribution of the dataset from the Algoa and Gamtoos Basins used in this study (left). Quality of the well data from the Gamtoos and Algoa Basins (right).

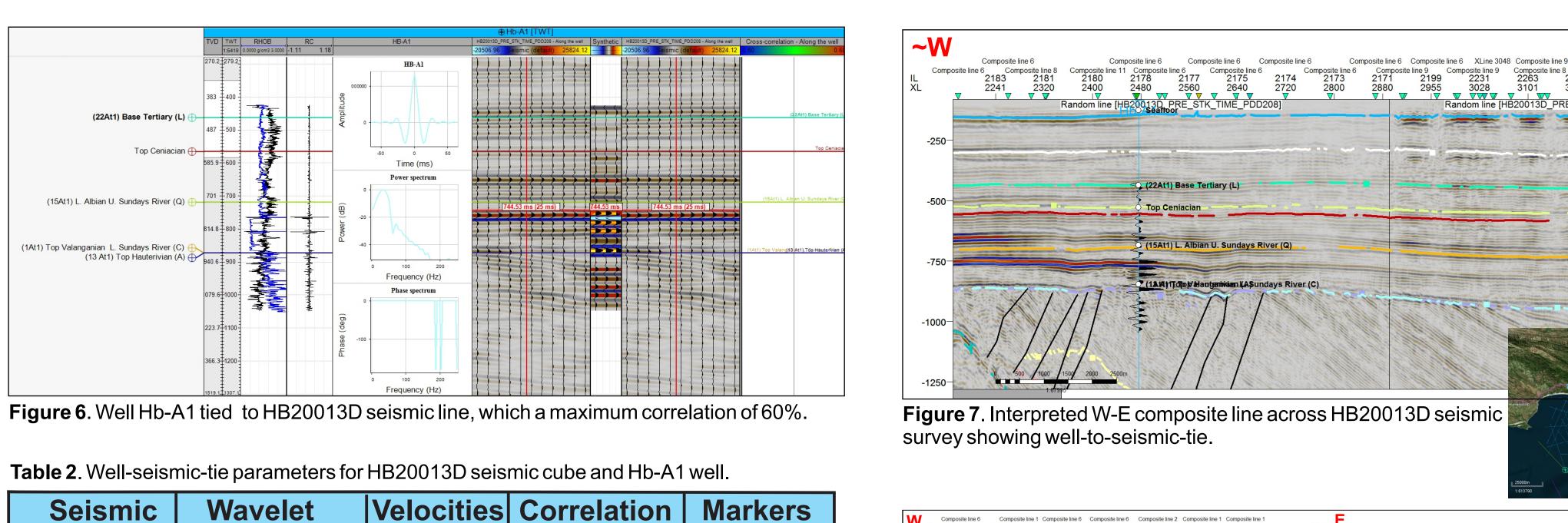
2. Seismic vintages were processed difefrently, some lines had to be phase rotated by 90 degrees.

RC

Water

RESULTS

Well-to-seismic-tie



Pre_stk_time | Phase: Minimum 13At1 and 1At1

Statistical (Full Angle) Checkshot:Yes

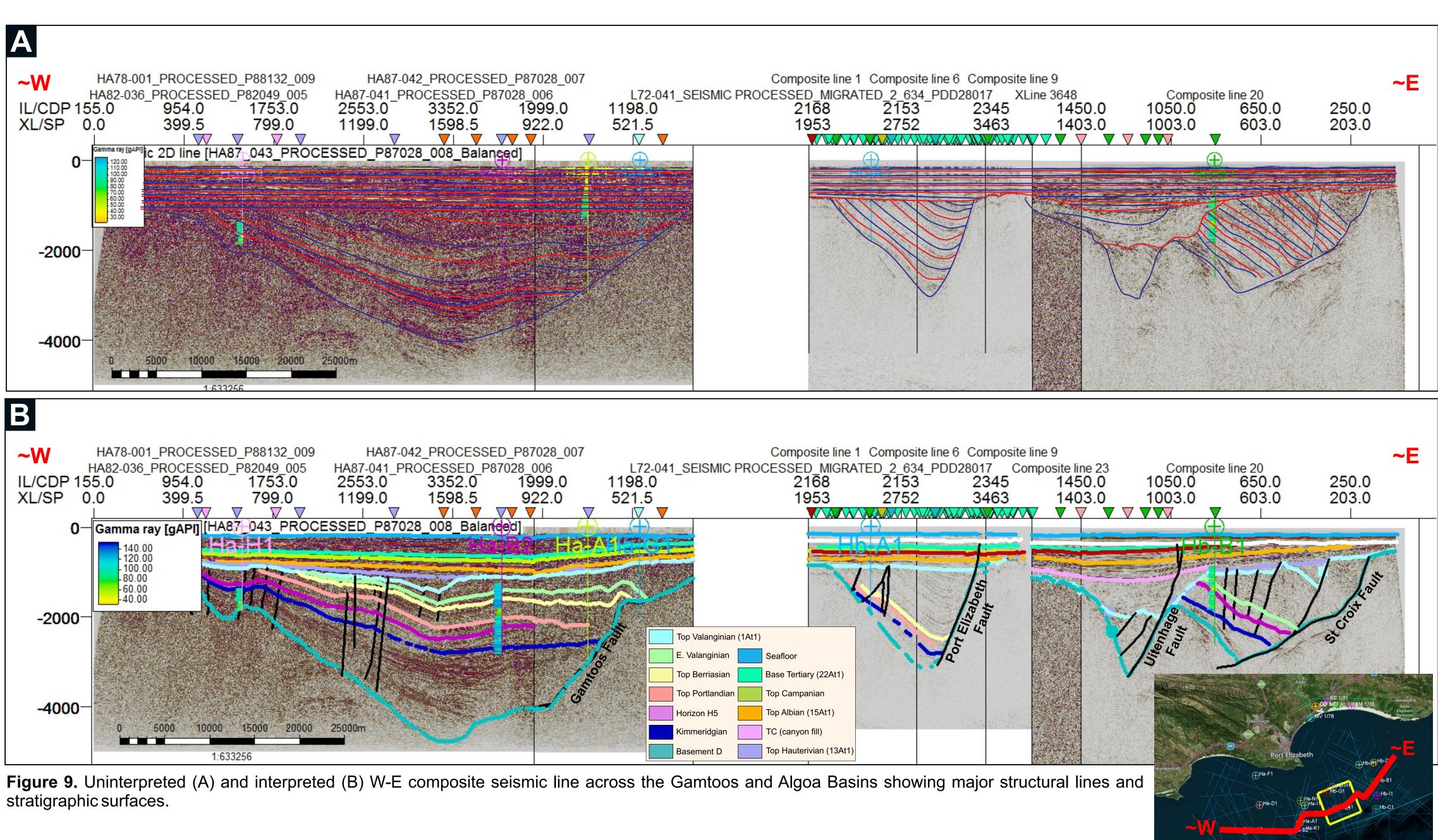
- 1. Maximum correlation of 60% was achieved on the 3D seismic volume, without stretching and squeezing the synthetic (Fig. 6-8, Table 2).
 - Reverse Polarity Figure 8. The 3D seismic dataset is reverse polarity, where an increase in acoustic impedance is represented by a through.

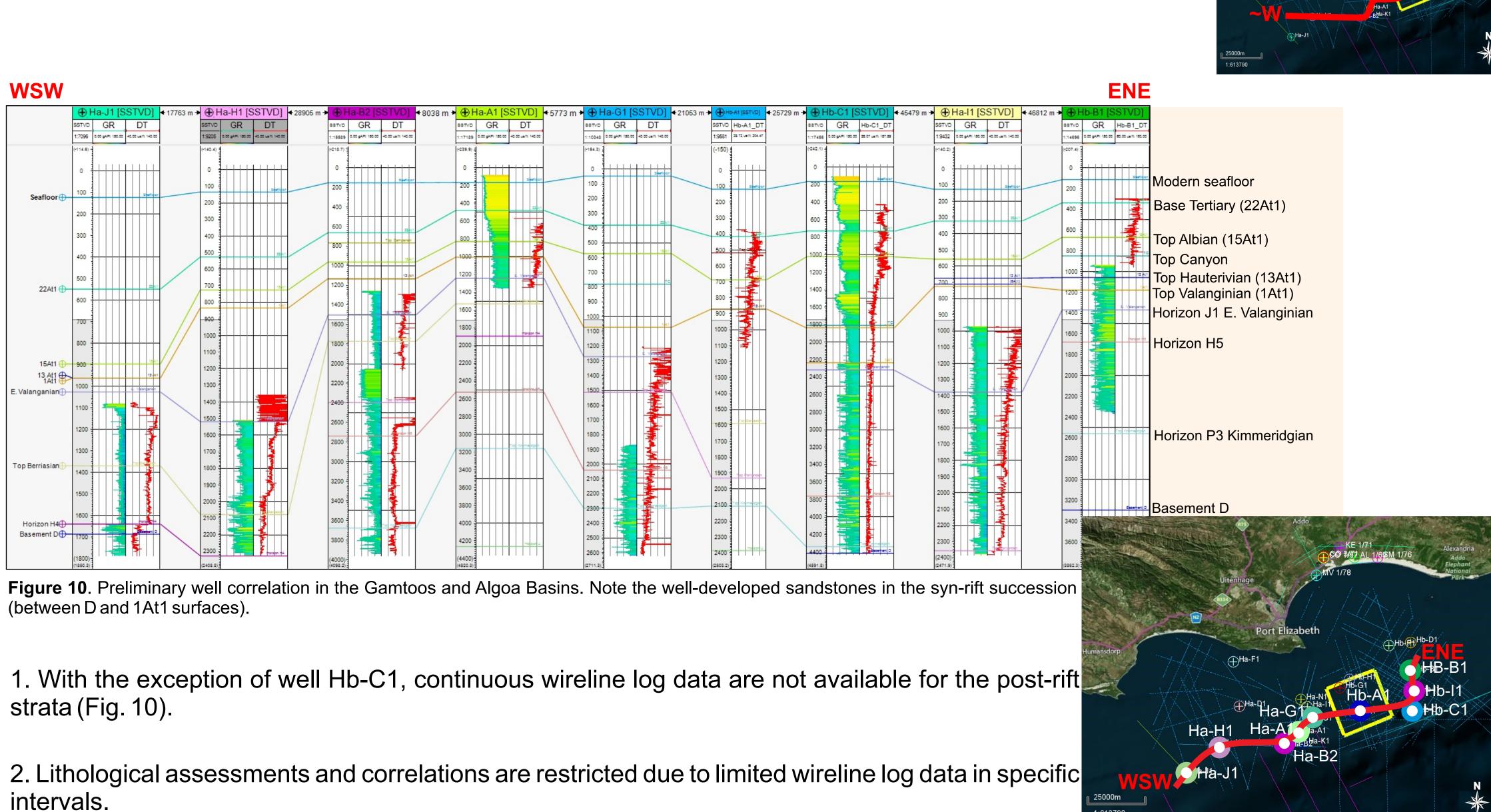
22At1, 15At1,

1. Major sequence boundaries are: Basement D, 1At1, 13At1, 15At1, 22At1 and modern seafloor (Figs. 6-11).

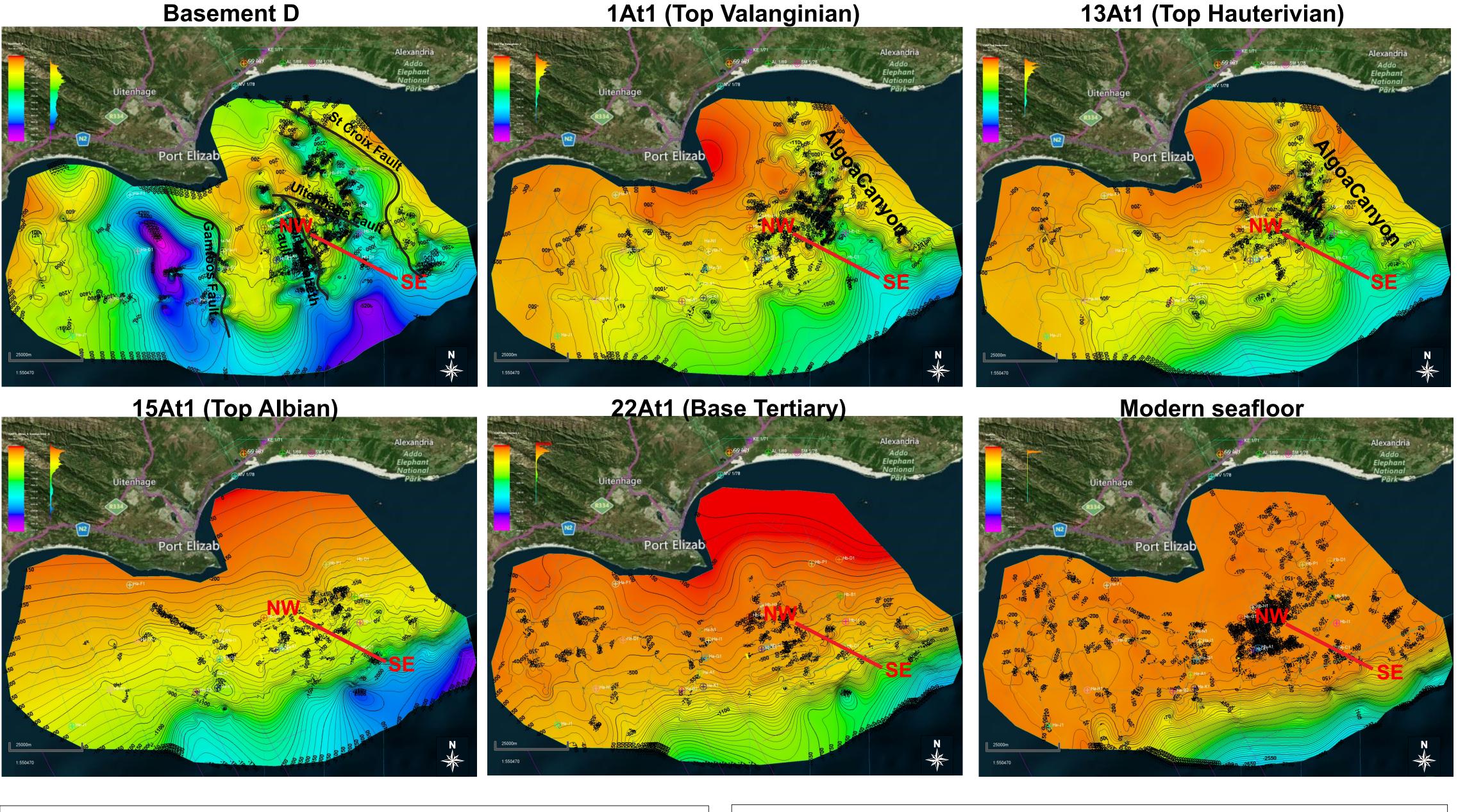
Correlation: 60%

- 2. These represent unconformities observed on wireline and seismic data and inferrence from literature.
- 3. Sediments between the Basement to 1At1 were deposited during syn-rift, whereas the succession between 13At1 to modern seafloor is the drifting phase sediment pile.
- 4. The syn-rift nature of the basins is accompanied by predominately north west/south east trending normal faults.





- 1. TWT (two way time) maps (Fig. 11) show the geomorphological evolution of the Algoa and Gamtoos Basins from the Kimmeridgian to modern day.
- 2. Basement D appears to be affected by movement along the St. Croix, Uitenhage, Port Elizabeth and Gamtoos Faults.
- 3. Valanginian/Hauterivian (1At1/13At1) reflectors mark angular unconformities and are accompanied by a NW-SE orientated canyon feature (Fig. 11).
- 4. Top Albian (15At1) to modern seafloor reflectors appear to be horizontal, and show minimal offset by faults.



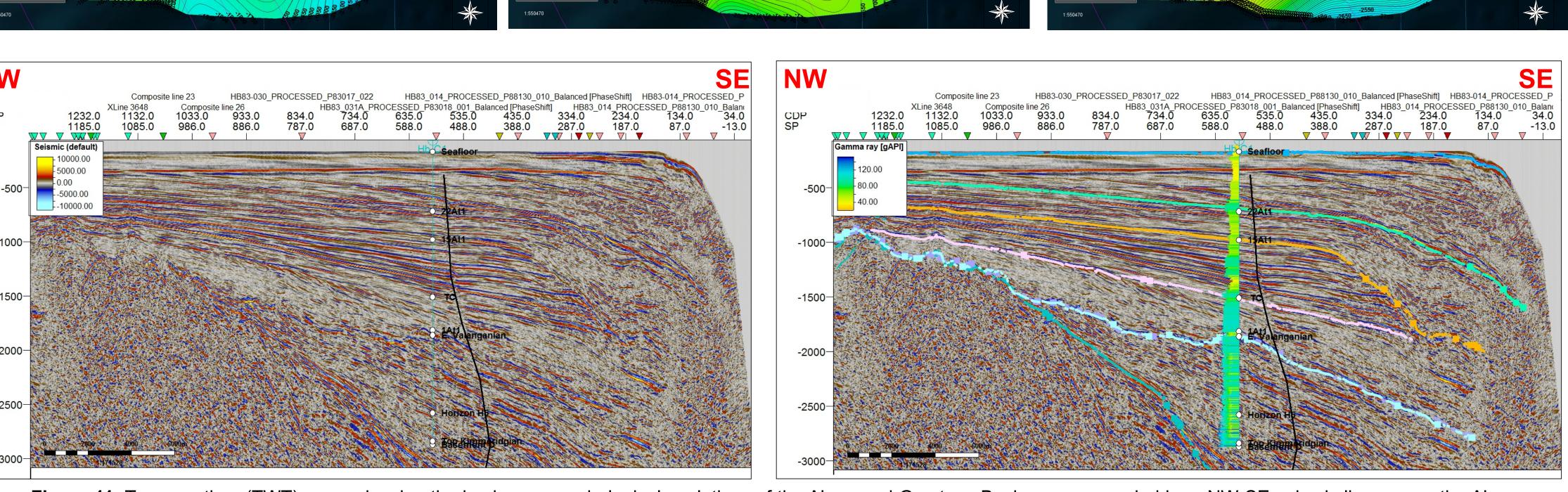


Figure 11. Two way time (TWT) maps showing the basin geomorphological evolution of the Algoa and Gamtoos Basins, accompanied by a NW-SE seismic line across the Algoa

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