CHAPTER 5

SEISMIC RESERVOIR CHARACTERIZATION.

Objectives:

Characterize the sand distribution, using the Marathon and Veritas 3D post-stack seismic volumes, in order to guide the lithofacies distribution for GDE mapping.

Workflow and methodology:

- The acoustic inversion of the two seismic cubes has been performed using InterWell® software to generate denoised synthetic seismic with enhanced frequency bandwidth. The different steps of the inversion are the following:
  - Well-to-seismic calibration of the 5 wells available in the 3D: Annapolis-G-24, Balvenie-B-79, Chebucto-K-94, Crimson-F-81 and Glenelg-J-48;
  - A priori model building using the key interpreted horizons to define the structural grid;
  - Acoustic inversion.

- From well data, acoustic impedance does not allow a clear discrimination of sands from shales and other lithologies (Figure 2). Moreover, the sand beds are quite thin and potentially too thin for seismic resolution (approximately 25m). Therefore, lithologies cannot be directly predicted from the acoustic impedance volume resulting from inversion. It was then decided to perform seismic facies analysis on the H, L and M sand interpreted horizons, using both supervised and non-supervised K-means classification, in order to characterize the lateral variations of these sand intervals. The principle of seismic facies analysis is to analyze the character of the seismic traces – or the reflectivity trace − at the reservoir level and relate its variations to the geological properties of the reservoir:
  - The non-supervised approach consists in a seismic trace classification, here with the k-means technique, without giving any geological a priori information from the wells. It gives a neutral, objective view of the seismic data set;
  - With the supervised approach, a priori geological information is introduced via the selection of typical wells, grouped in *n* classes. Each class is linked to particular characteristics of the wells, for example the porosity range, to define *n* classes. Training traces are extracted in the vicinity of the typical wells, within the thickness under investigation, and are used to build a discriminant function in order to obtain *n* classes seismic facies maps.

- Several seismic attributes (RMS, Similarity) have also been calculated on the 2 seismic volumes at different levels (seabed, K94, K101, K130) in order to highlight potential areas of interest and to identify the lateral variations.

- The maps resulting from the seismic reservoir characterization were then used as a guide for GDE maps construction.

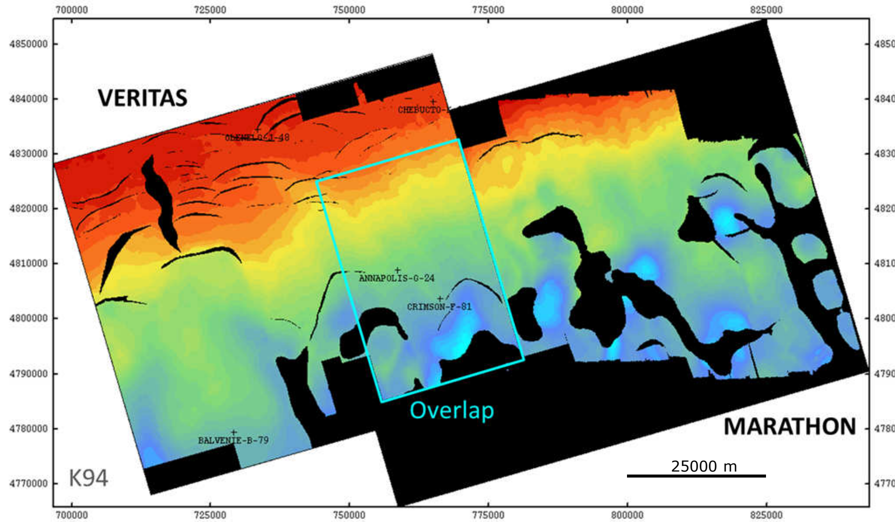


Figure 1: Location map of the Veritas and Marathon 3D cubes with the available wells. The two cubes overlap in the region of Annapolis-G-24 and Crimson-F-81 wells. The Balvenie-B-79, Chebucto-K-90 and Glenelg-J-48 wells are located within the Veritas survey only.

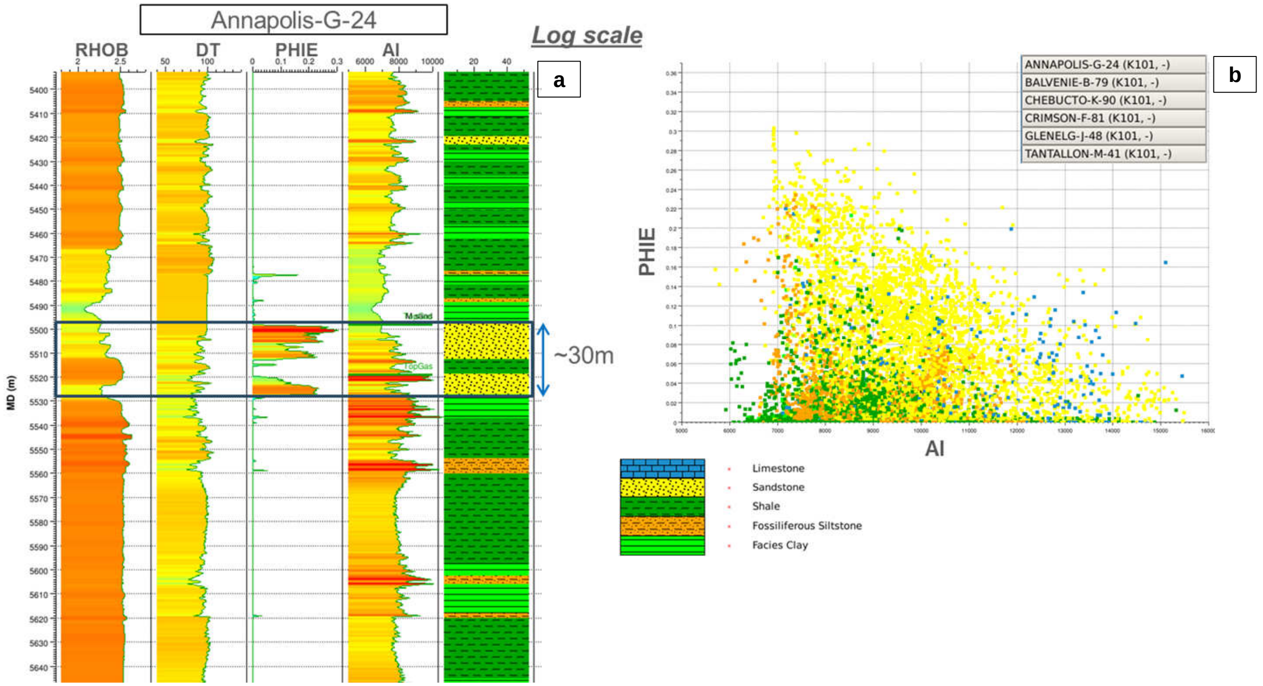


Figure 2: (a) RHOB, DT, PHIE, AI and facies logs at the Annapolis-G-24 well. Sands do not have a clear acoustic impedance signature allowing them to be differentiated from other lithologies. (b) AI vs PHIE cross-plot at the 5 wells available in the 3D, below K101. Sands cannot be discriminated using acoustic impedance only.

Marathon acoustic inversion:

- The well-to-seismic calibration results on the Marathon seismic cube are satisfactory (Figure 3) The estimated phase rotation (0°) and the final results are coherent with those of the previous seismic interpretation;
- The Marathon inversion gives satisfactory results, with a good attenuation of random noise, as illustrated by the noise maps (Figure 4);
- Acoustic impedances resulting from inversion are likely to be impacted by the burial trend; to remove this trend seismic characterization (Seismic Facies Analysis and attribute computation) has been performed on the seismic reflectivity resulting from inversion

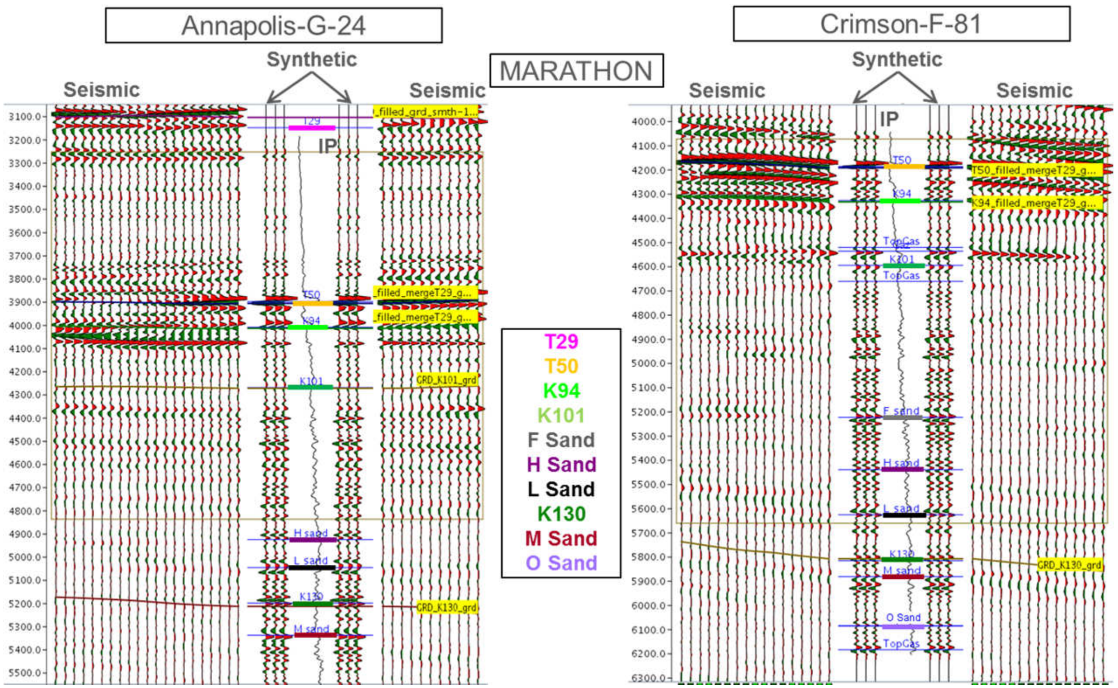


Figure 3: Good well-to-seismic calibration results at the Annapolis-G-24 and Crimson-F-81 wells on the Marathon seismic. Notice the strong attenuation of seismic amplitudes below K94.

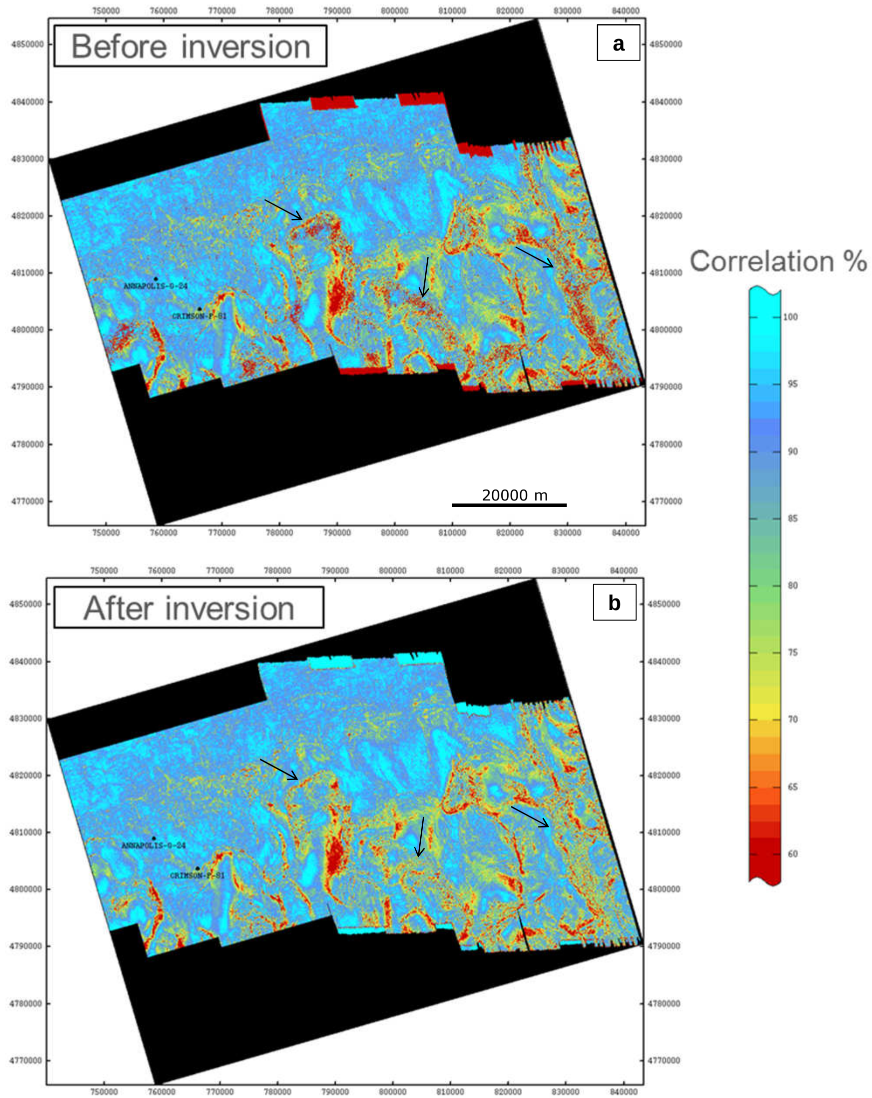


Figure 4: Noise maps calculated on Marathon (200ms below top T50) before (a) and after (b) inversion. The correlation values are higher after inversion: the inversion has attenuated random noise.

Veritas acoustic inversion:

- The well-to-seismic calibration results on the Veritas seismic cube are satisfactory (Figure 5);
- An AGC (Amplitude Gain Control) has been applied to the Veritas cube during seismic processing (Figure 6). Because of this process, seismic amplitudes are not preserved. Acoustic inversion is strongly impacted by this amplitude homogenization and inversion results are therefore not reliable;
- The Veritas seismic cube, which covers both the shelf and slope areas, has however still been useful for direct seismic attribute interpretation. Seismic characterization (Seismic Facies Analysis and attribute computation) has thus been performed on the raw seismic volume.

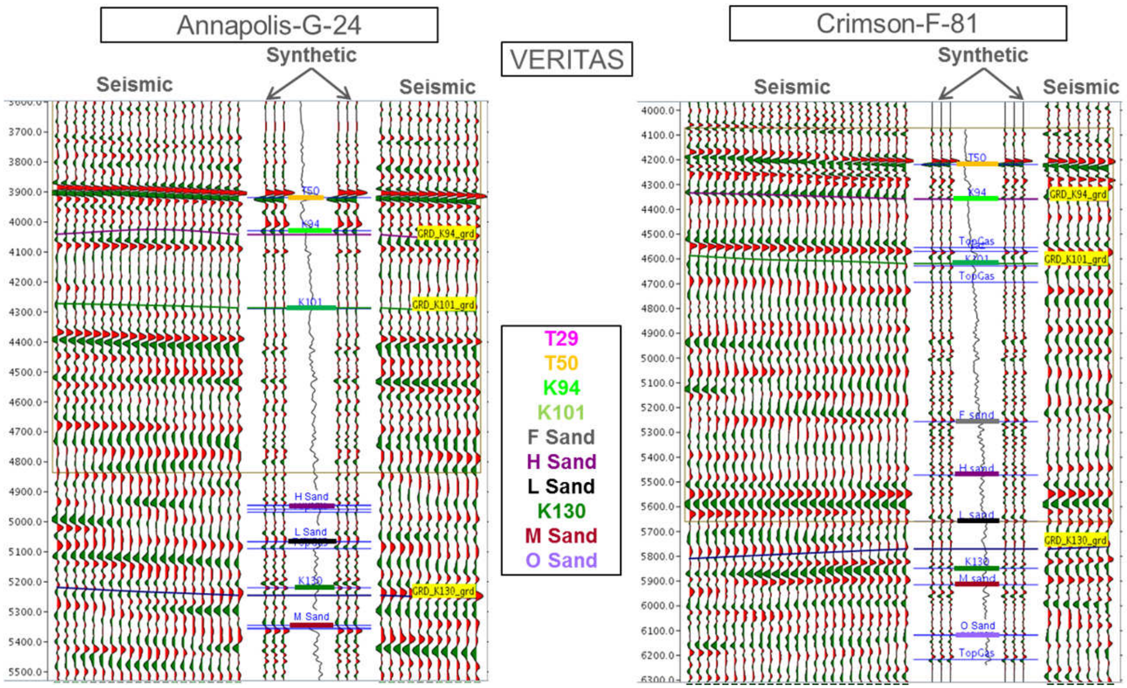


Figure 5: Good well-to-seismic calibration results at the Annapolis-G-24 and Crimson-F-81 wells on Veritas seismic. The effect of the AGC is clearly visible on the calibration tables: amplitudes are boosted in the lower part, below K94, in comparison with Marathon 3D seismic data.

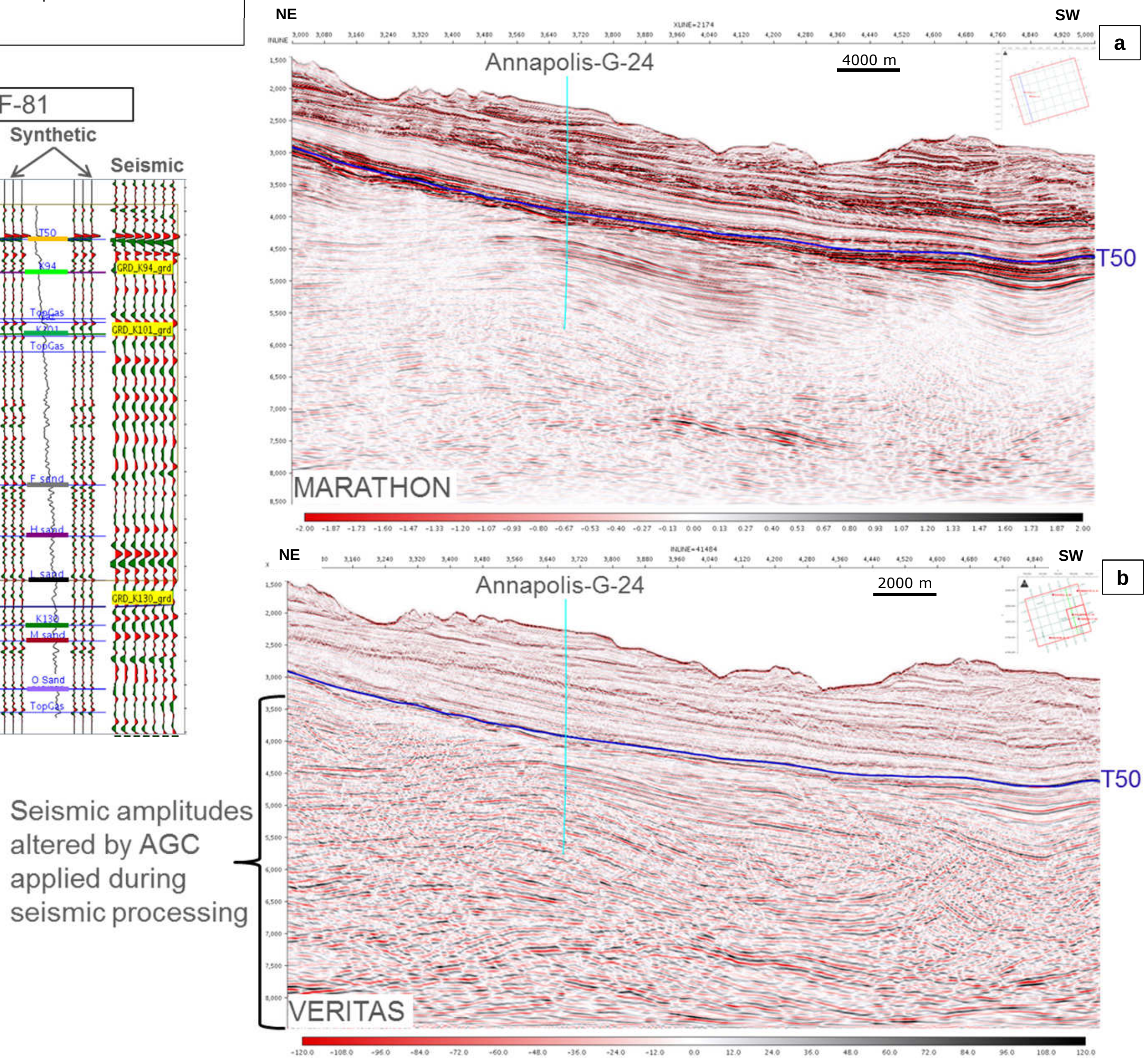


Figure 6: Comparison between a seismic section through the Annapolis-G-24 well from the Marathon (a) and Veritas seismic cubes (b). An AGC has been applied on this cube during processing, seismic amplitudes are not preserved, acoustic inversion cannot provide reliable results.

Seismic characterization at H Sand level on the Marathon seismic data:

Both supervised and unsupervised seismic facies maps were generated at the H Sand level on the Marathon 3D cube (Figure 8).

- The unsupervised seismic facies map was built with three classes (red, blue and green), which present a clear NNW-SSE trend compatible with sand deposit direction. The Annapolis-G-24 well, in which the thickest sand was found, is located in the red class, whereas the Crimson-F-81 well, with lower sand thickness (Figure 11 in **plate 5.5**), is located in the blue class. Robot traces present much larger amplitudes for green and red classes. Analogies with the RMS map presented in Figure 9 are evident, with the red class clearly linked with high RMS amplitudes. A first interpretation is then to define green and red classes as "sand" classes.
- Supervised classification has been guided by traces extracted around the two wells, assigning them to two classes; the first or red class is linked to Annapolis-G-24, the sandier well. The other (blue) class should reflect the characteristics of Crimson-F-81. Observations given for unsupervised classification are confirmed here, with the red class associated with the presence of more sand, and the blue class with lessor amounts of sand.

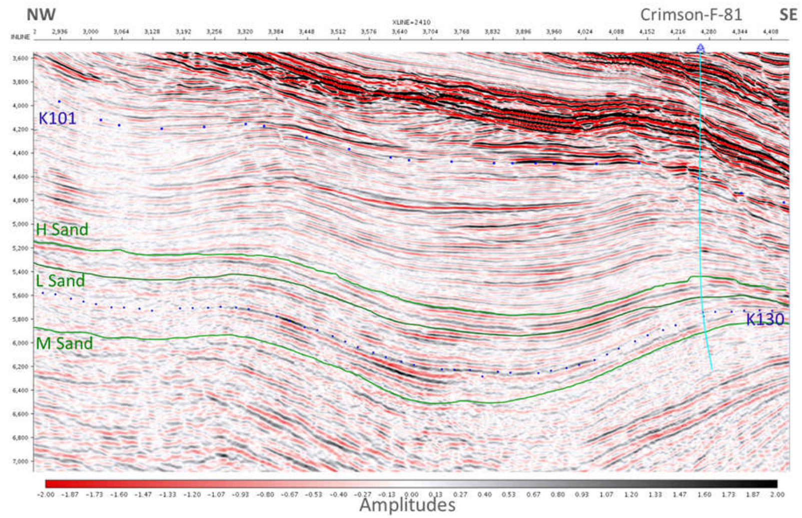


Figure 7: Seismic section in the Marathon cube through Annapolis-G-24, showing the location of the H, L and M Sand interpreted horizons on which seismic characterization was performed.

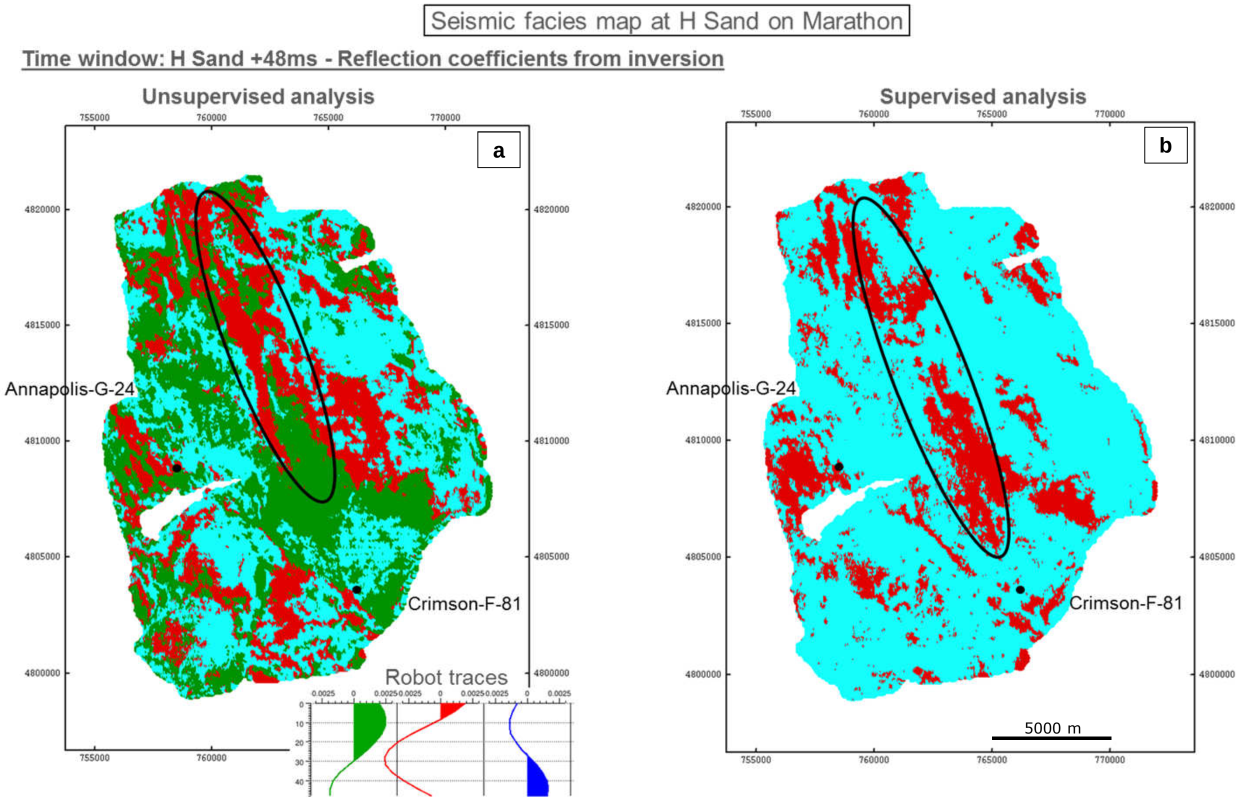


Figure 8: Unsupervised (a) and supervised (b) seismic facies maps calculated at the H Sand level (48ms below top H Sand) on Marathon seismic reflectivity from inversion. The supervised approach is composed of two classes guided respectively by Annapolis-G-24 and Crimson-F-81. The two maps are well correlated; the circled pattern, which is present on both maps, may correspond to sand infilling.

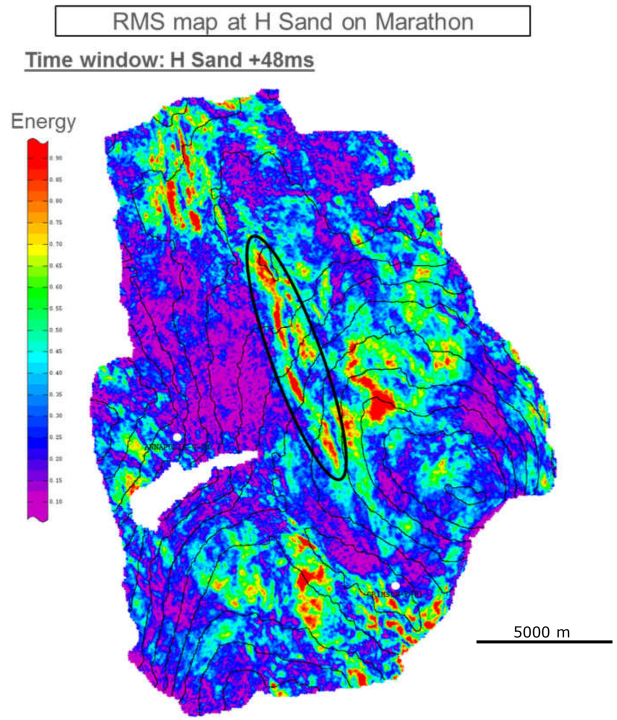


Figure 9 : RMS map calculated at H Sand (48ms below top H Sand). The circled energy anomaly corresponds to a topographic high bounded by a fault. The features of this map are well correlated with those of the seismic facies maps.

Seismic characterization at H Sand level on the Veritas seismic data:

An unsupervised seismic facies map was generated on Veritas seismic at the H sand level (Figure12). Because of the post-processing applied to these data (AGC), the seismic facies analysis was conducted on the raw seismic traces instead of reflectivity traces. In the zone covered by both Veritas and Marathon surveys, the unsupervised seismic facies map appears much noisier than Marathon's (Figure 8), but presents the same global features, with a clear NNW-ESE trend. The robot traces are also very similar to those obtained with Marathon cube. On the platform area where Chebucto and Glenelg wells are located, the supposed red sand follows a more coastal trend; this behavior is consistent with Dionisos modeling **(PL. 6.2)**.

1D seismic modeling test:

A 1D modeling test was performed at Annapolis-G-24: the AI log was modified to mimic a thickening of the sand interval at the H Sand level, from 3 m to 12 m, to evaluate its impact on the seismic response (Figure 10). Synthetic and reflectivity traces (RC) were then generated from the modified AI log. The sand layer thickening leads to a change of the seismic response: the original reflectivity trace in green evolves to the red trace presenting larger negative amplitude. This is what is observed on robot traces, indicating that the red class may correspond to a thickening of the sand layer. Therefore, the red areas evidenced by the seismic facies maps, mostly located around Glenelg-J-48 and Chebucto-K90, which present thicker H Sands (Figure 11), and at the east of Annapolis-G-24 and Crimson-F-81, may correspond to sandier areas.

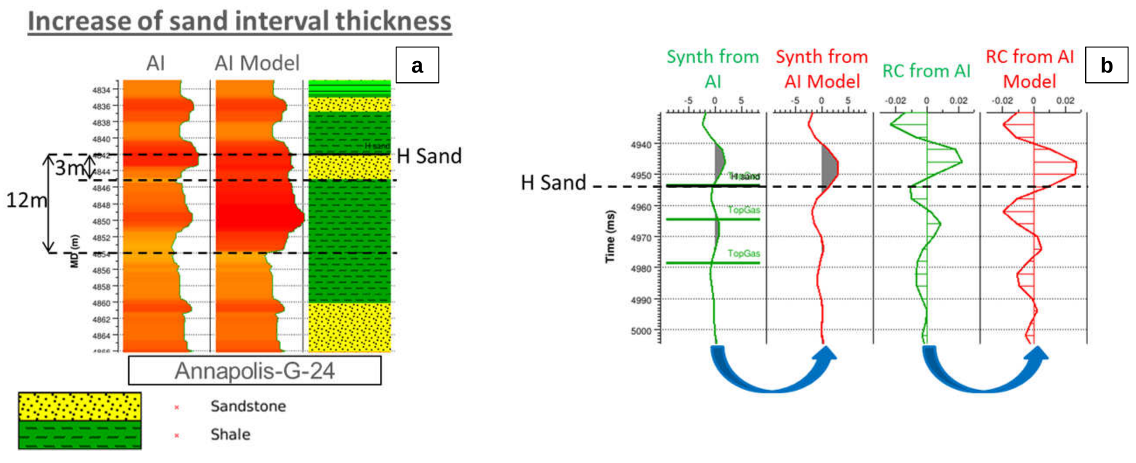


Figure 10: (a) Modeling on the AI log at Annapolis-G-24 of an increase of sand thickness from 3 to 12 m. (b) Synthetic and reflectivity logs generated from the original (green) and modelled (red) AI. A change of the seismic trace can be observed due to the thickening of the sand layer.

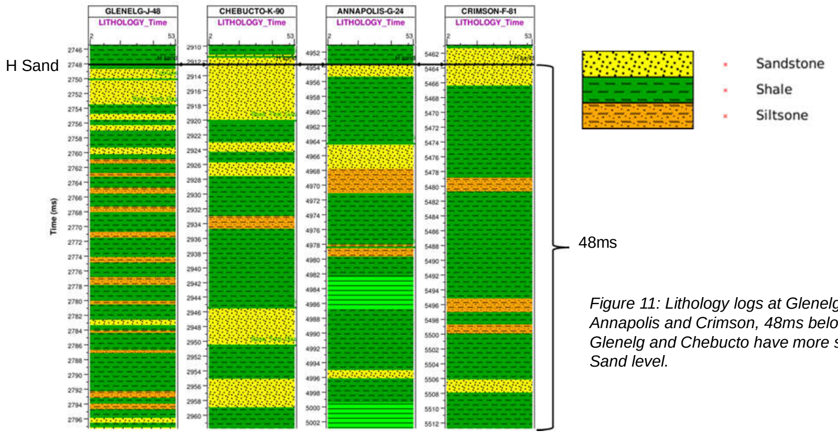


Figure 11: Lithology logs at Glenelg, Chebucto, Annapolis and Crimson, 48ms below H Sand. Glenelg and Chebucto have more sands at the H Sand level.

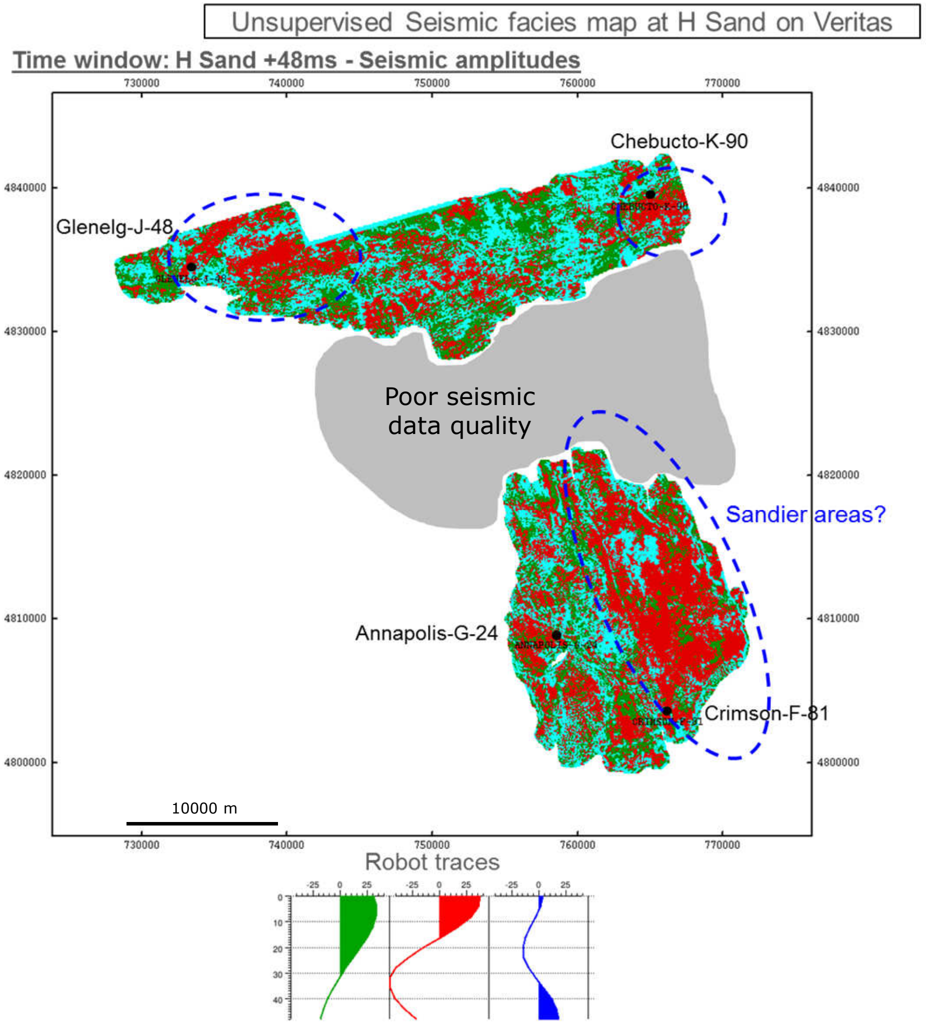
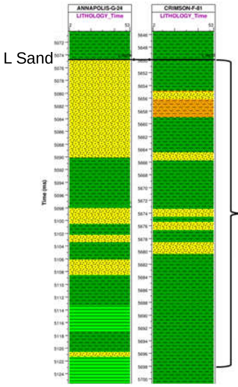


Figure 12: Unsupervised seismic facies map calculated at the H Sand level (48 ms below top H Sand) on Veritas seismic. Based on the 1D modeling results, the red traces may correspond to a sand thickening. The red zones on the map might therefore correspond to sandier areas.

Seismic characterization at the L Sand level :

Both supervised and unsupervised seismic facies maps have been generated at the L Sand level on Marathon and Veritas (Figures 15 and 16), using the same techniques as for the H Sand. The seismic facies are less organized than at the H Sand level; this could be due to the poor seismic data quality and the resulting less accurate horizon picking.



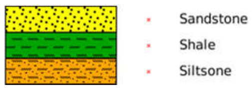


Figure 13: Lithology logs at Annapolis and Crimson, 48ms below L Sand. Annapolis has more sands at the L Sand level.

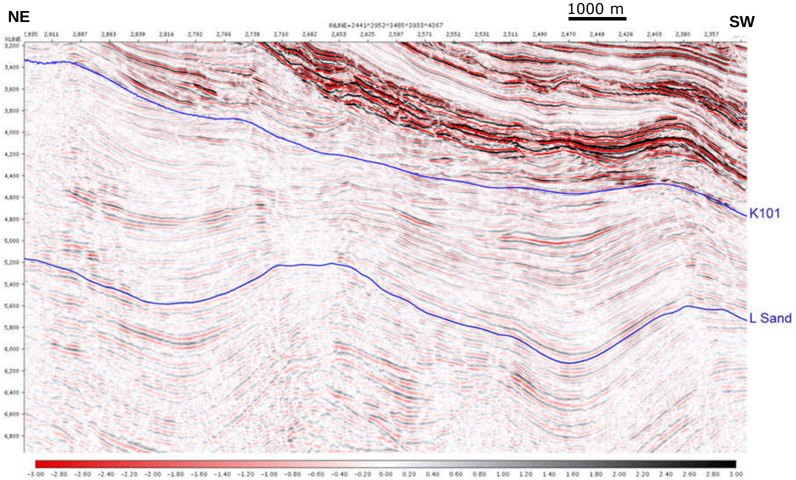


Figure 14: Seismic section in the Marathon cube going through the 2 structures highlighted in Figure 15.

Unsupervised Seismic facies map at L Sand on Veritas

Time window: L Sand +48ms - Seismic amplitudes

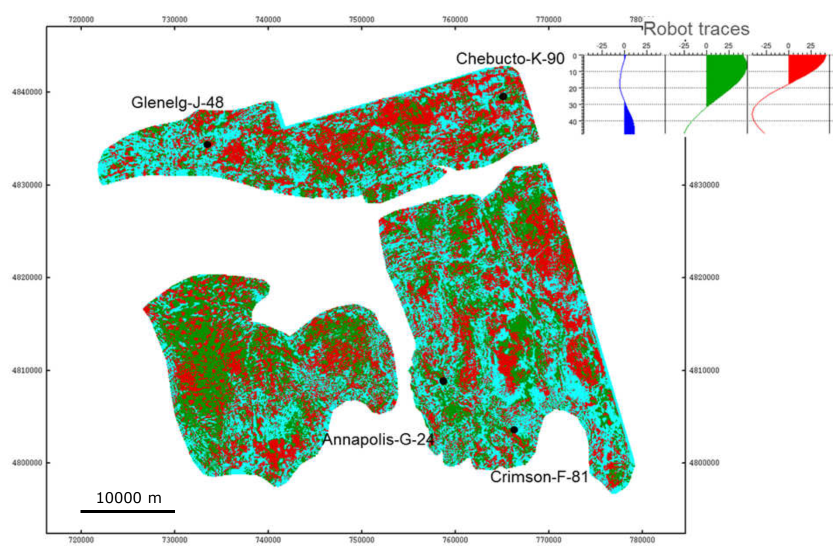
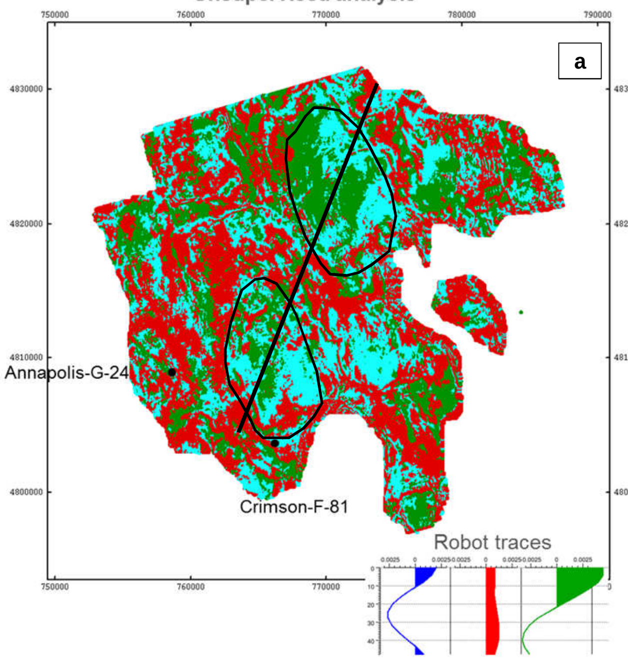


Figure 16: Unsupervised seismic facies map calculated at the L Sand level (48ms below top L Sand) on Veritas seismic. The NNW-SSE trend is still visible in the basin at this level.

Seismic facies map at L Sand on Marathon

Time window: L Sand +48ms - Reflection coefficients from inversion

Unsupervised analysis



Supervised analysis

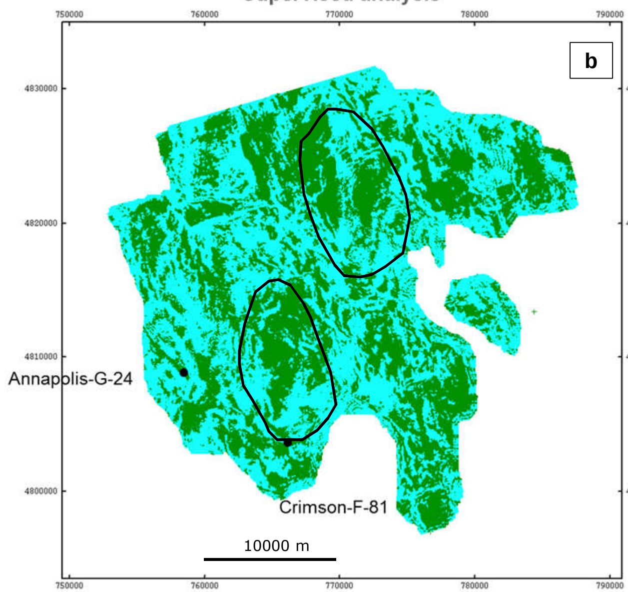


Figure 15: Unsupervised (a) and supervised (b) seismic facies maps calculated at the L Sand level (48ms below top L Sand) on Marathon seismic reflectivity from inversion. The supervised approach uses two classes guided by Annapolis-G-24 and Crimson-F-81 wells. The dark line in Figure (a) indicates the location of the seismic section shown in Figure 14.

Similarity map at L Sand on Marathon

Time window: L Sand +48ms

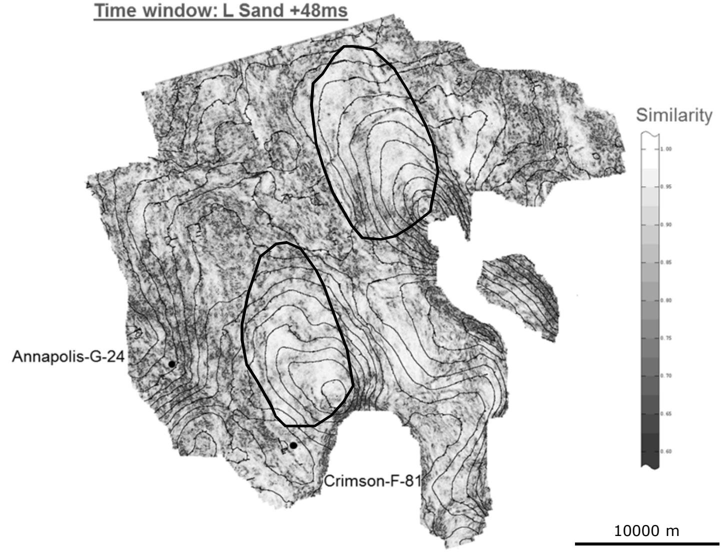


Figure 17: Similarity map at L Sand with isolines.

Seismic characterization at the M Sand level:

Both supervised and unsupervised seismic facies maps were generated at the M Sand level on Marathon and Veritas (Figure 20 and 21). No clear organization of the seismic facies can be observed at this level; this could be due to the poor seismic data quality and the resulting less accurate horizon picking.

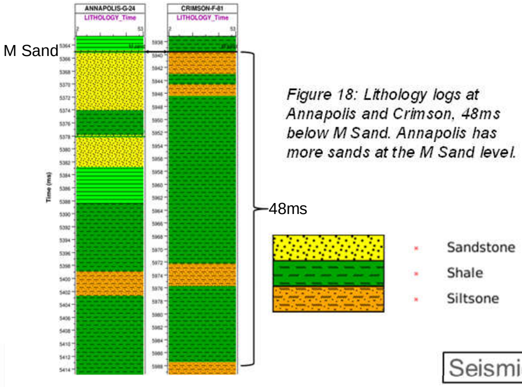


Figure 18: Lithology logs at Annapolis and Crimson, 48ms below M Sand. Annapolis has more sands at the M Sand level.

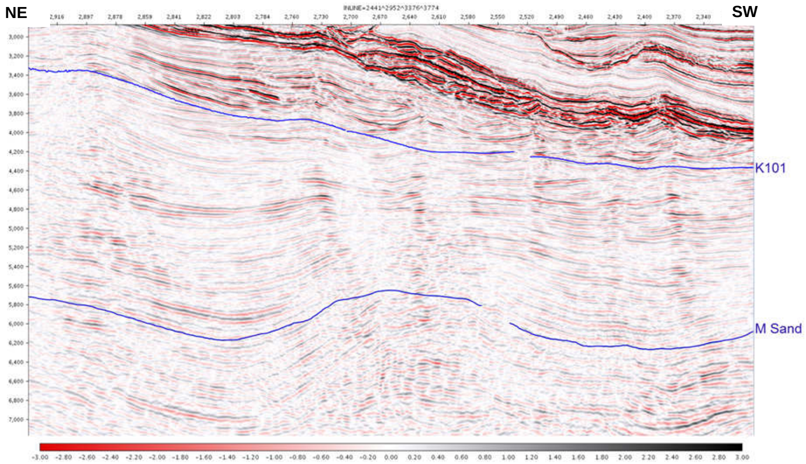


Figure 19: Seismic section in the Marathon cube through the two structures highlighted in Figure 20.

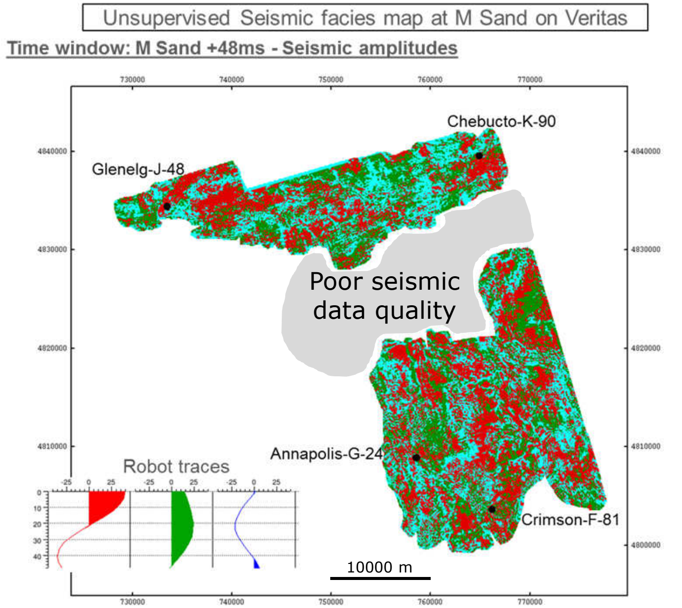


Figure 21: Unsupervised seismic facies map calculated at the M Sand level (48ms below top M Sand) on Veritas 3D seismic data. There is no clear organization of the seismic facies.

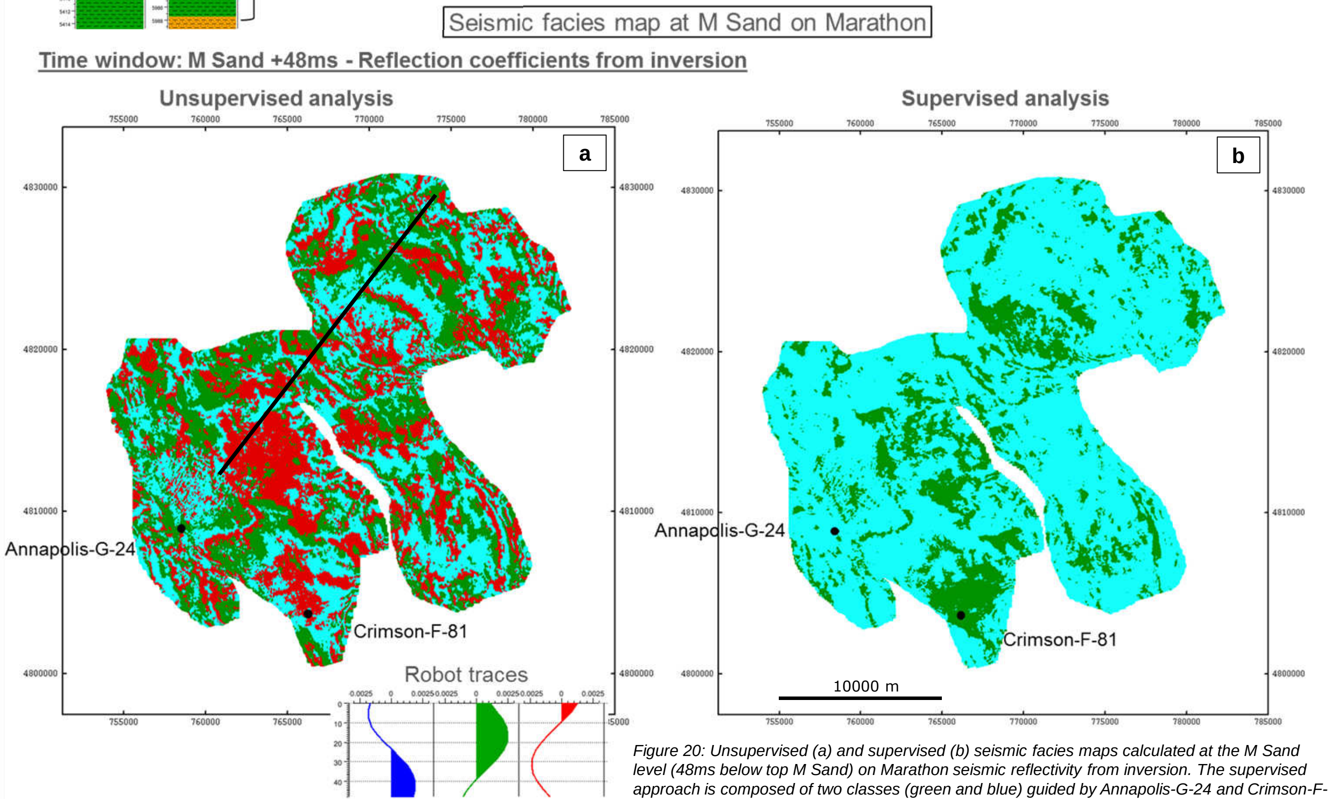


Figure 20: Unsupervised (a) and supervised (b) seismic facies maps calculated at the M Sand level (48ms below top M Sand) on Marathon seismic reflectivity from inversion. The supervised approach is composed of two classes (green and blue) guided by Annapolis-G-24 and Crimson-F-81 wells. The dark line in Figure (a) corresponds to the seismic line shown in Figure 19.

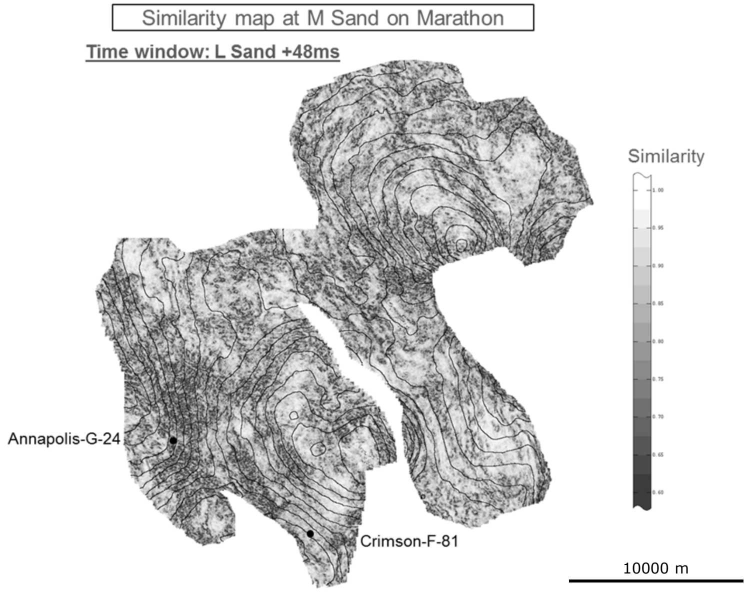
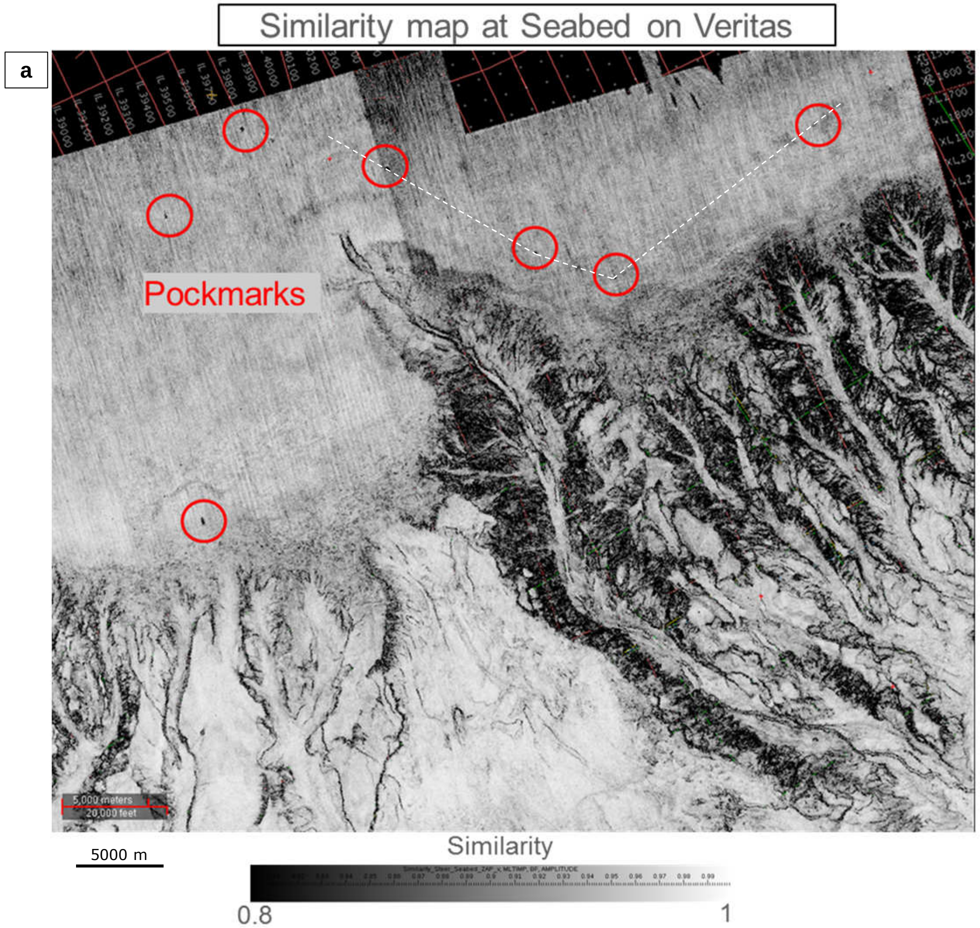


Figure 22: Similarity map at M Sand with isolines.

Attribute generation at seabed:

- The similarity maps calculated on the two seismic cubes at the seabed level show clear evidence of pockmarks which are also clearly visible on seismic sections (Figure 23).
- These pockmarks are more visible on the shelf but can also be identified on the slope.



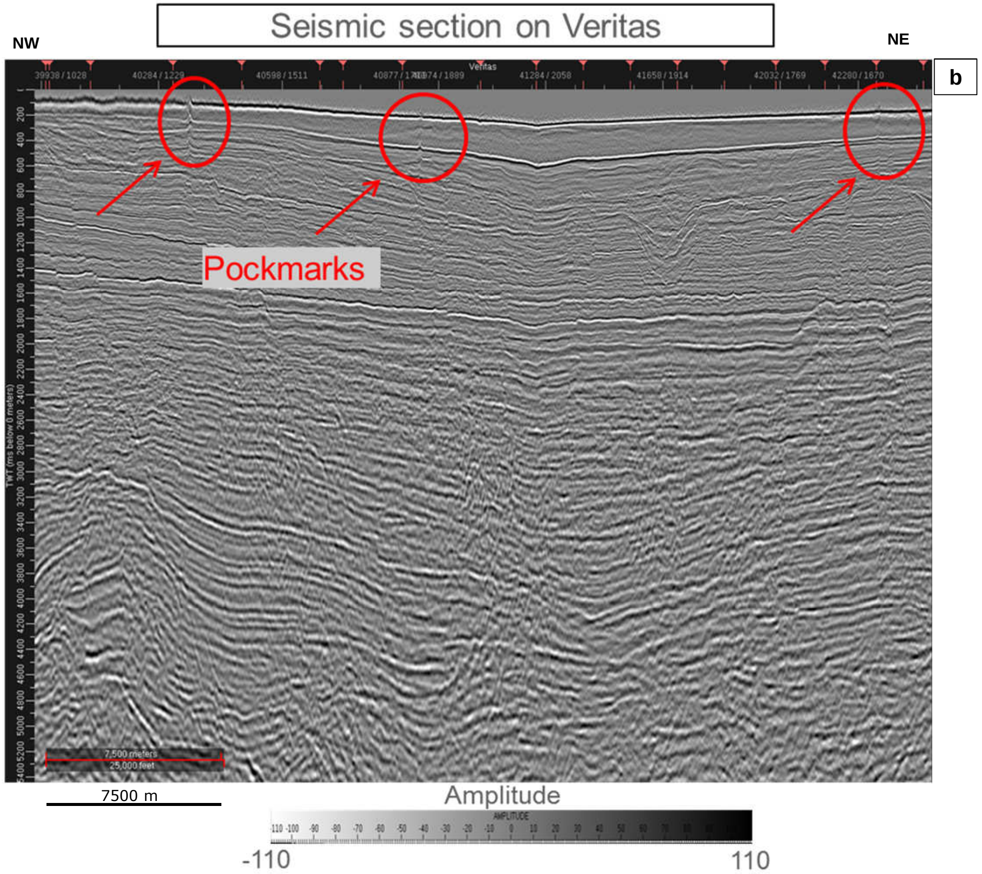
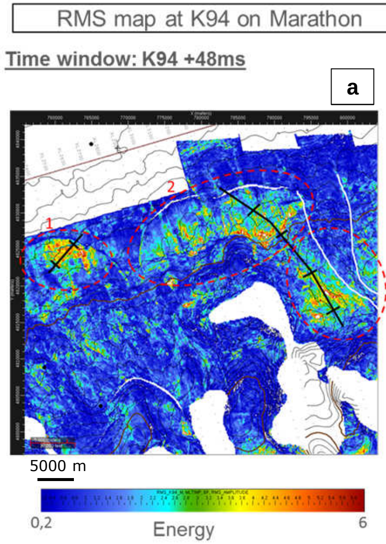


Figure 23: (a) Similarity map calculated at seabed (48ms below seabed) on Veritas seismic. It highlights the presence of pockmarks, which are also observed on the seismic section (b) along the white dotted line of Figure (a). These pockmarks evidence gas rising up to the surface.

Attribute generation at K94:

- The energy anomalies located in the upper part of the RMS maps (zones 1 and 2 on Figures 24 and 25) are bounded by listric faults. They are associated with two small basins located at the base of prograding wedges.
- Zone 3 corresponds to a third small basin located slightly downslope from basin 2. It is limited by roll-over structures (Figure 24). In contrast to basin 1, the energy anomaly is restricted to the south-west part of the basin (Figure 24a). The low energy portion corresponds to a channel with an upslope-downslope orientation. The high energy area is located in the central part of the small basin.
- Note that the K94 closes the small basins (Figure 24b and 25b).



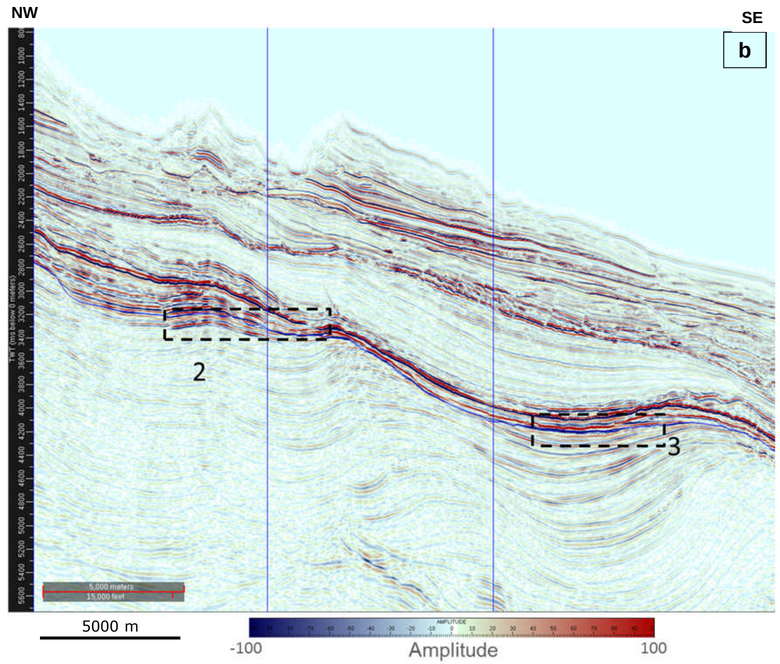


Figure 24: (a) RMS map calculated at K94 on Marathon seismic showing three energy anomaly zones - (b) Seismic section on Marathon through zone 2 and 3.

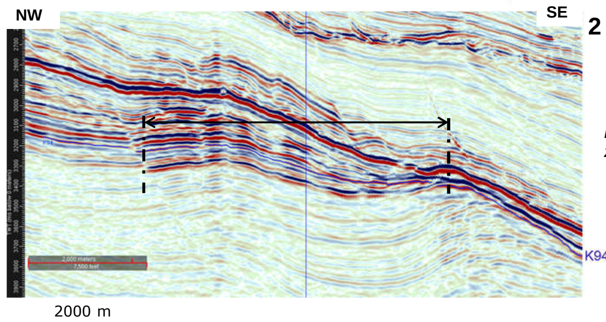


Figure 24-2: Close-up of zone 2 of Figure 21.

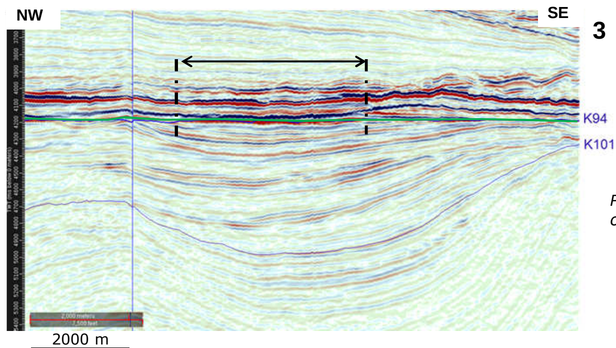


Figure 24-3: Close-up of zone 3 of Figure 21.

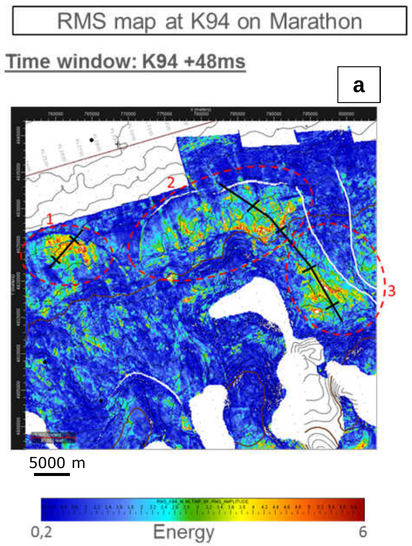
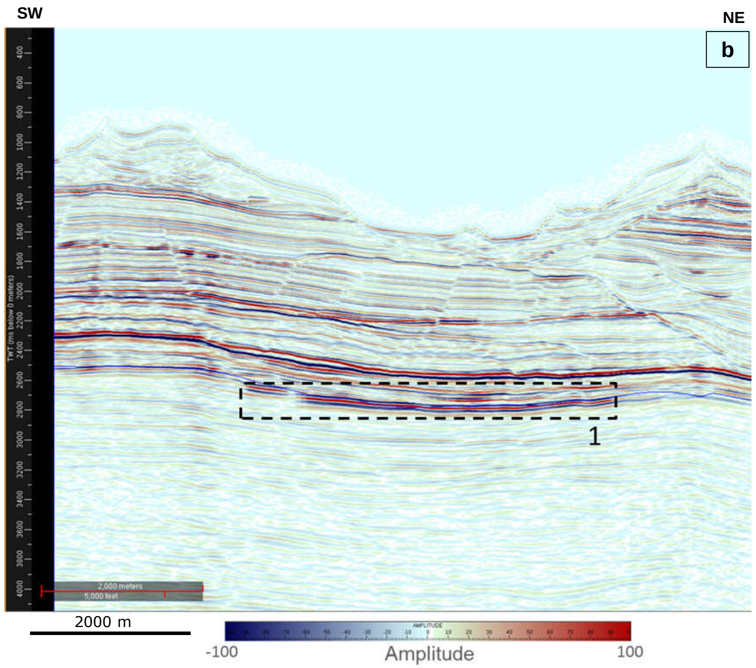
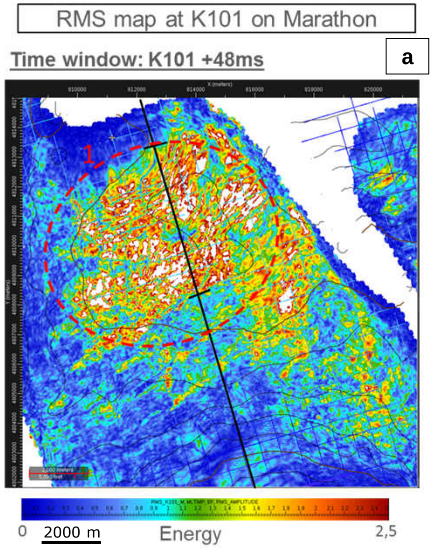


Figure 25: (a) RMS map calculated at K94 on Marathon seismic showing three energy anomaly zones - (b) Seismic section on Marathon through zone 1.



Attribute generation at K101:

- Zone 1 (Figure 26) corresponds to a faulted turtle back. The energy is concentrated at the top of the structure (Figure 26a); high amplitudes are also present inside the structure (Figure 26b).
- Zone 2 (Figure 27 and section 2) also corresponds to a roll-over with high energy at the summit. It is bounded by a listric fault at the southeast.
- An amplitude anomaly is present in the upper part of the onshore-offshore channel defined by zone 3 (Figure 27 and section 3).
- Zone 4 (Figure 27 and section 4) is a slightly inverted. The energy anomaly corresponds to the top of the structure and is bounded by faults.



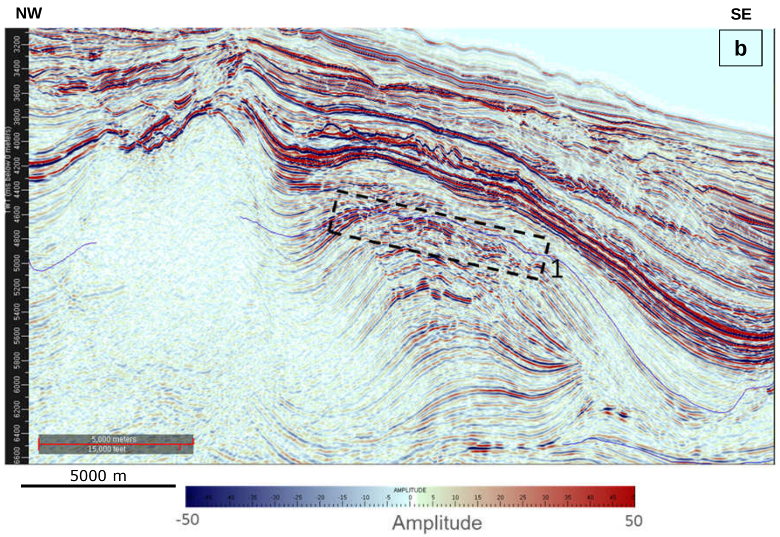
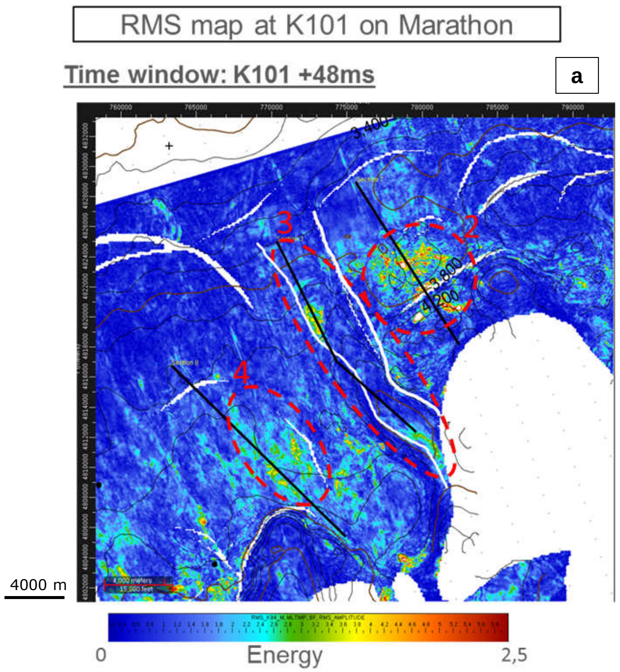
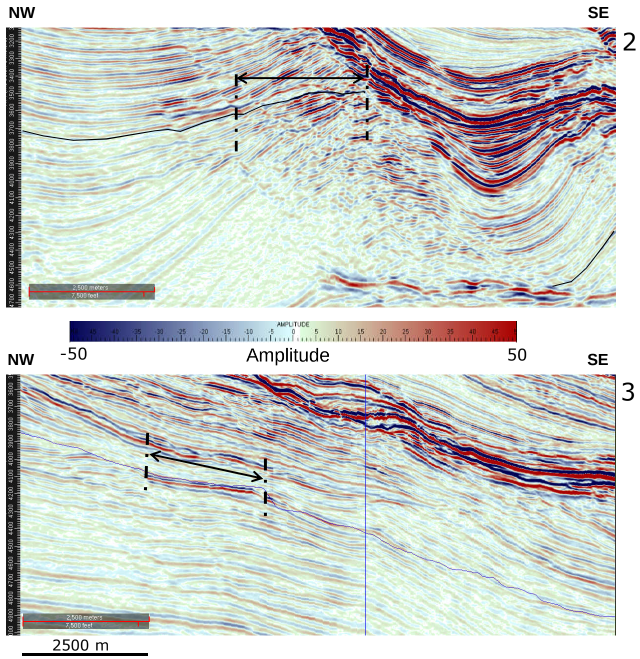


Figure 26: (a) RMS map calculated at K101 on Marathon seismic showing one energy anomaly zone; (b) Seismic section on Marathon through zone 1.





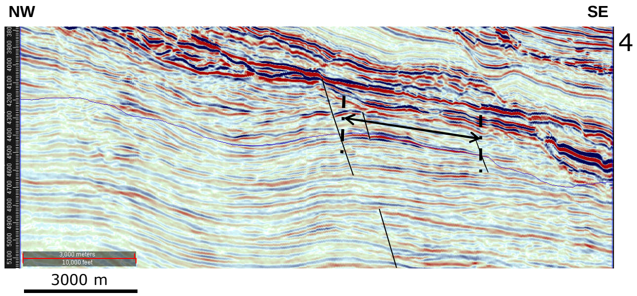
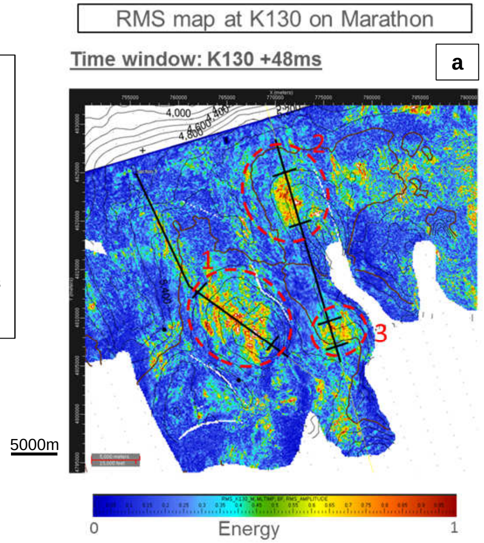


Figure 27: (a) RMS map calculated at K101 on Marathon seismic showing three energy anomaly zones; (2) Seismic section on Marathon through zone 2; (3) Seismic section on Marathon through zone 3; (4) Seismic section on Marathon through zone 4.

Attribute generation at K130:

- Zone 1 (Figure 28a) corresponds to the sediment infill of a small basin probably related to deep seated salt movements. The energy anomaly is located in the axial part of the basin and is limited to the east by a north-south striking fault. This energy anomaly likely corresponds to a sandsheet deposit in this small basin (Figure 28b).
- Zone 2 (Figure 29) corresponds to the sediment infill of a small basin related to deep seated salt movement and growth fault structures. It is located at the base of a prograding wedge; the energy anomaly is concentrated in the southwest part of the basin. This area appears to correspond to a sandsheet deposit (Figure 29A);
- Zone 3 (Figure 29) corresponds to an anomaly on the flank of a turtle back structure. The K130 caps a complex set of inverted channels. The high energies are located at the top or on the flank of this structure (Figure 29B). It is limited to the northeast by a salt diapir.



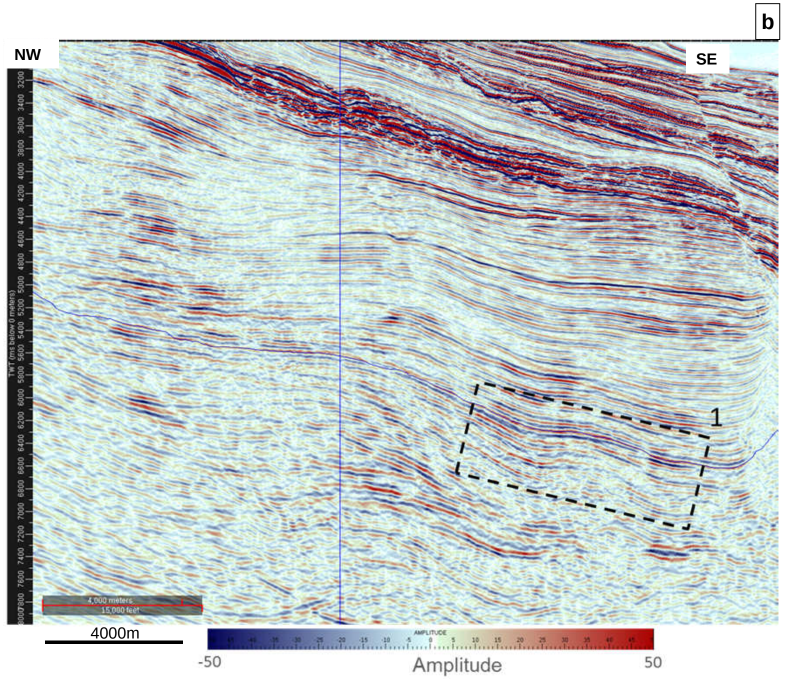


Figure 28: (a) RMS map calculated at K130 on Marathon seismic showing one energy anomaly zone; (b) Seismic section on Marathon through zone 1.

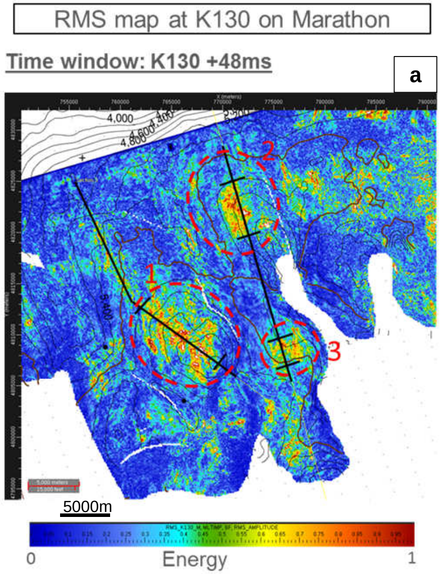
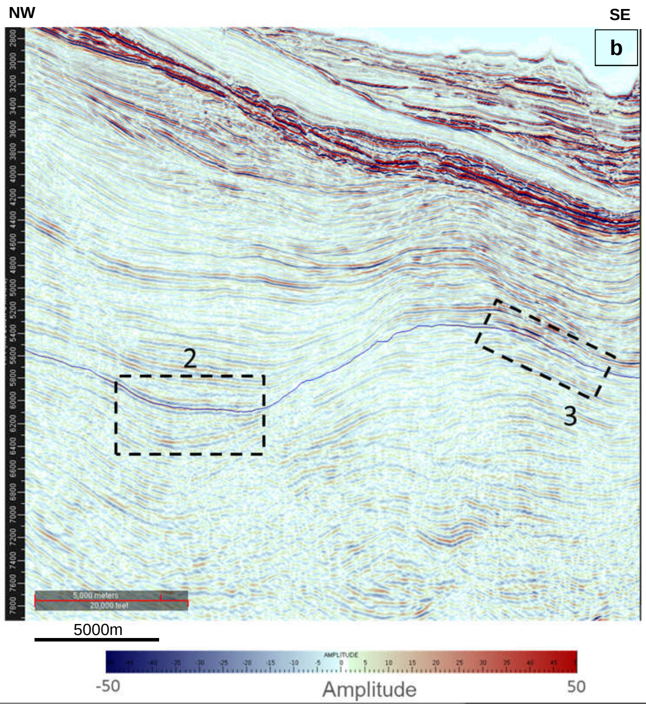


Figure 29: (a) RMS map calculated at K130 on Marathon seismic showing three energy anomaly zones; (b) Seismic section on Marathon through zone 2 and 3.



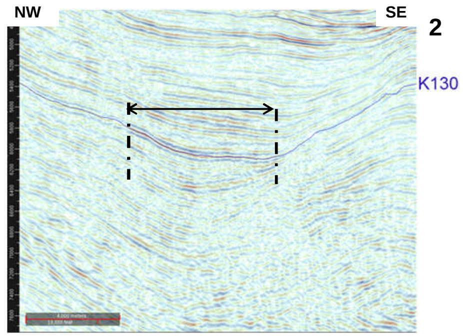


Figure 29-2: Close-up of zone 2 of Figure 26.

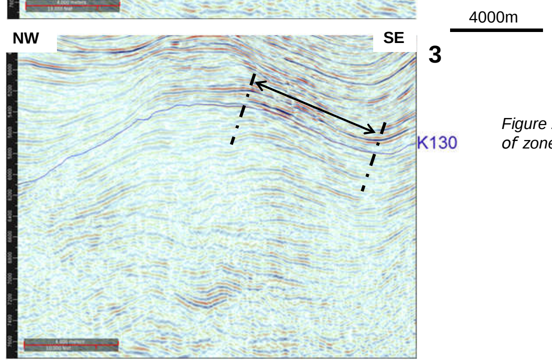


Figure 29-3: Close-up of zone 3 of Figure 26.