University of Alberta

SEISMIC STRATIGRAPHY AND GEOMORPHOLOGY OF THE EXMOUTH PLATEAU, NORTH-WESTERN SHELF, AUSTRALIA

by

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Abstract

The Exmouth Plateau is a part of the Northern Carnarvon Basin, offshore northwest Australia. It evolved from a pre-rift in the late Paleozoic, experiencing many tectonic activities, from syn-rift sub-basins in the Mesozoic to a passive margin in the Cenozoic. The study area, located within the Exmouth Plateau, is a gas exploration target named the Chandon Field. The Chandon-1 well was drilled in 2006 and is the only well from the area that provides the data used in this study. The seismic data penetrate up to 5000 milliseconds, covering an area of 875 km^2. The information regarding basin evolution in the Paleozoic Age is scarce, as the main exploration interest rests with the Mesozoic and Cenozoic.

The objective of this study is to investigate sequence stratigraphy and geomorphology of the area. In order to understand the evolution of the depositional environments and the paleogeography, 3-D seismic data have been interpreted by means of horizon picking. Furthermore, the outcomes of the study, which are 9 seismic units, 11 horizons, and 10 horizon slices, reveal that the provenance of sediments were derived from various sources from the Triassic, Jurassic, Cretaceous and Cenozoic ages. The Pre-breakup seismic units were from terrestrial environments, such as fluvio-deltaic environments. On the other hand, the Post-breakup seismic units were derived from a wide range of marine environments, ranging from shallow to deep water.

In this study, most of the time was dedicated to the generation and analysis of horizon slices. In addition, the interpretation of 10 seismic horizon slices overlaid by different seismic attributes, reveals new information which should be investigated further in the future. This information should also be investigated on time slices.

Acknowledgements

Completion of this research would not be possible without many supports of institutions and individuals.

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I would like to thank dGB Earth Sciences Amsterdam for the software providing. Also, I thank Chevron Australia for the data that were used in this study. I thank Woodside Australia for the introduction of the area. I would like to thank WAPIMS, Government of Western Australia, Department of Mines and Petroleum for the well data.

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Chapter 1

Introduction

Depositional environments and paleogeography are important keys to understanding the interrelationship of the physical, chemical and biological processes involved in the development of stratigraphic sequences in the geological record. For petroleum exploration in particular, understanding of the depositional environment in any area, concession or acreage release is crucial. For example, the occurrence of dry wells and the chance of improperly positioning in a well can be decreased. Furthermore, study of such factors increase our understanding of reservoir distribution, reservoir connectivity and the potential for discovering new reservoirs. In summary, an understanding of the depositional environment and paleogeography of a petroleum exploration area can help reduce exploration budget immensely.

This work builds on earlier studies such as Larson (1977), Powell (1982), Exon (1992), Langhi and Borel (2005), and King et al. (2009). Unlike the earlier studies, the seismic volume of the Chandon Field has never been used or published as an academic research before, since the data is presently an exploration target of Chevron Australia Pty Ltd.

The objective of the study is to investigate and reveal the geologic history of the Chandon Field in the Exmouth Plateau, North Western Shelf, Australia by using 3D seismic interpretation method.

The study area, called the “Chandon Field”, lies oceanward from Northwest Australia into the Indian Ocean. The Chandon Field is located in the Exmouth Plateau of the Northern Carnarvon Basin on the North West Australian Shelf (Figure 1-1). The Exmouth Plateau is a gigantic submerged continental block off the Northwest Shelf of Australia. Its prolongation is in the northeast direction and is bounded by three abyssal plains on three sides. The tectonic frameworks of the Exmouth Plateau were controlled by rifting and transform faulting in the Mesozoic which was accompanied by the breakup of Australia and Greater India; after that, the plateau sank to bathyal depths. The pre-breakup sequence consist of Paleozoic and Mesozoic sediments about 5000 m in thickness and the post-breakup sequences consist of late Mesozoic and Cenozoic sediments about 2000 m in thickness (Exon, 1982).

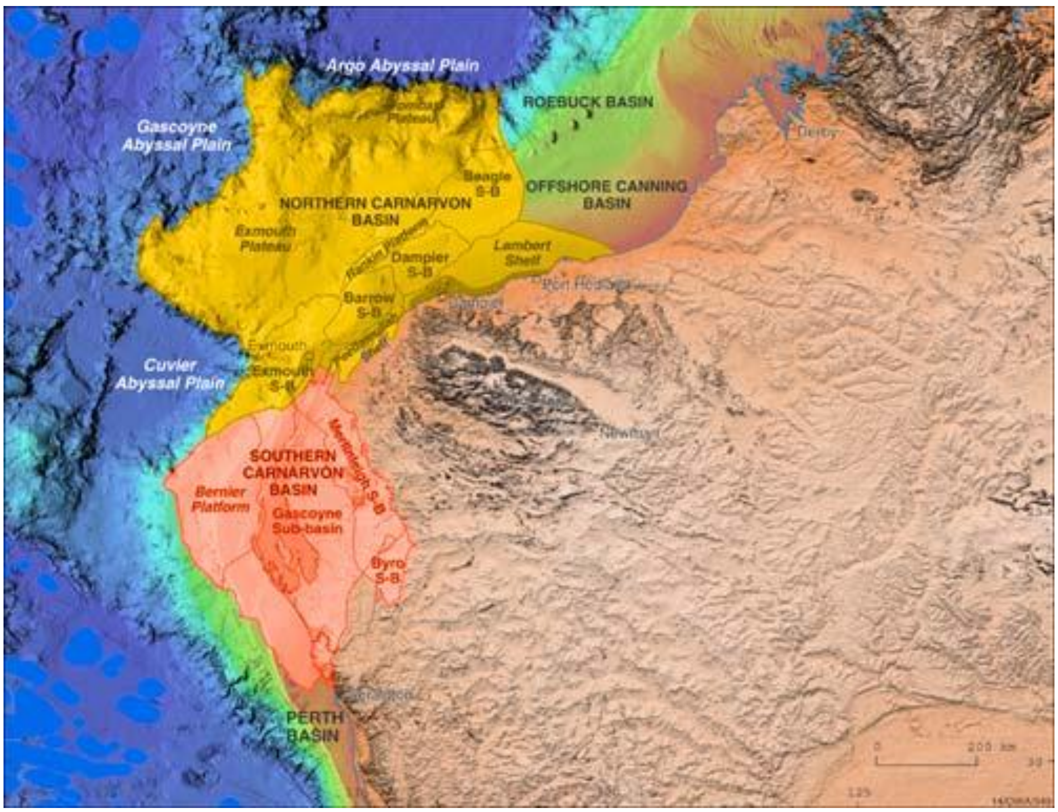


Figure 1-1: The Exmouth Plateau located in the Northern Carnarvon Basin.

The Chandon Field covers an area of 875 km^2. It is situated in the "Greater Gorgon" which refers to a group of several gas fields: Chandon, Gorgon, Geryon, Orthrus, Maenad, Eurytion, Urania, Chysaor, Dinysus, West Tryal Rocks and Janz/Io. As shown in Figure 1-2, the Chandon Field is located about 50 km apart from the Janz/Io Field to the Northwest and 160 km west of the Dampier sub-basin. Optimistic estimation indicates that reserves in the Chandon Field could be as high as 4 Trillion Cubic Feet of gas in place.

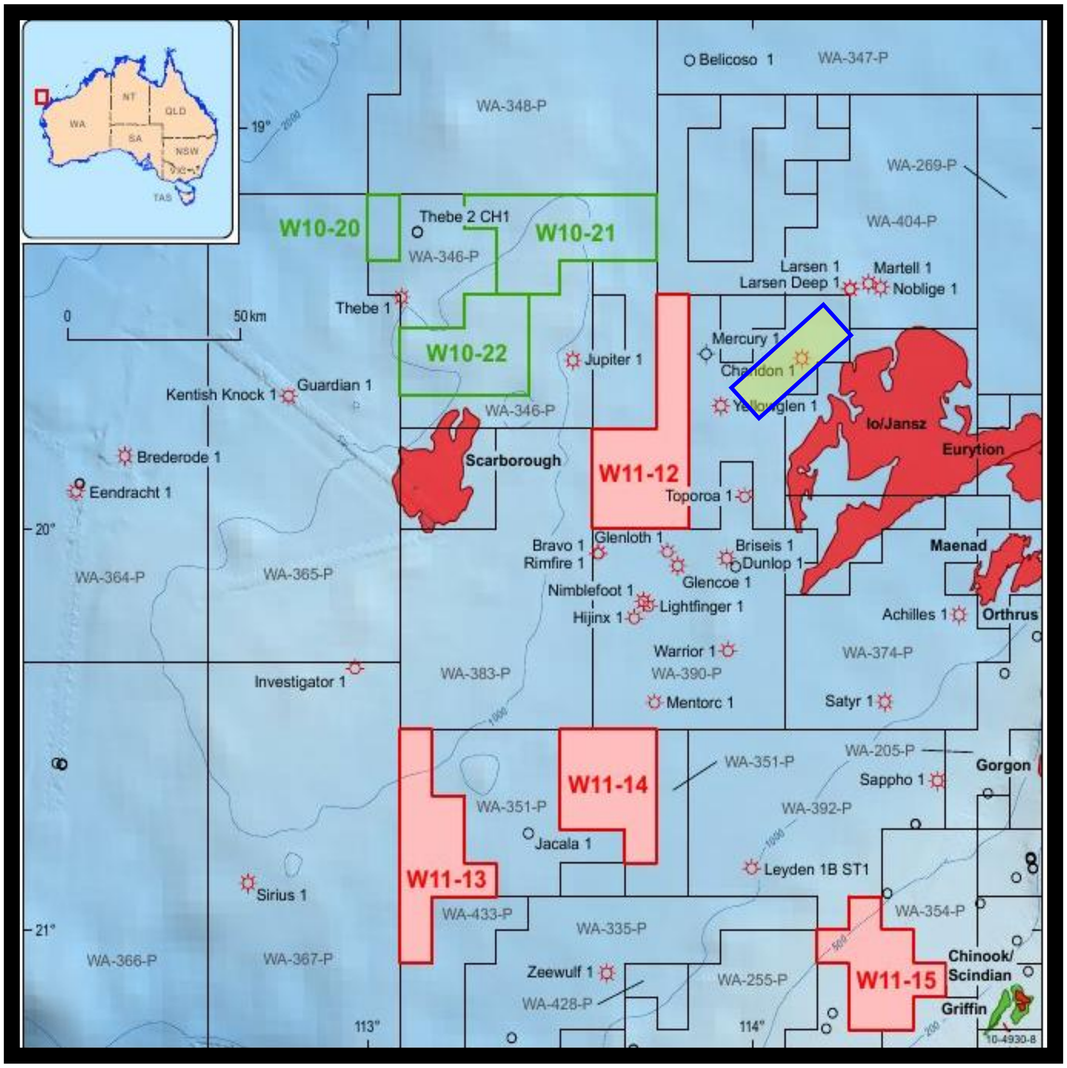


Figure 1-2: Chandon Filed located 50 km away from Janz/Io Field.

The Chandon Field is an active exploration target in WA-268 P, belongs to Chevron Australia Pty Ltd. In 2006, the first well was drilled, it is named the "Chandon-1". Three years later another well was drilled, the Chandon-2. Recently (March 2011), another well was drilled, the Chandon-3. However, this study started in 2009 and the Chandon-1 is the only well that provides information for this study. The Chandon-1 is 185 km from Barrow Island, Northwest Australia

The 3D seismic survey data were provided by Chevron Australia Pty Ltd as well. The software that is used in this study is the Opendtect, which belongs to the dGB Earth Sciences Company. The software versions that have been used are ranged from opendtect-4.0.1 to opendtect-4.2.0. Funding of this project is supported by PTT Exploration and Production Public Company Limited, Thailand (PTTEP).

There are 5 chapters in this thesis. The next chapter will be described regional geology of the Northern Carnarvon Basin and the Exmouth Plateau itself, as well as pinpointing the exact location of the study area. In chapter 3, it will be elucidated about the method using in this study, where the data came from, what kind of data and information used in this study. Chapter 4 will explain about the results of seismic stratigraphic interpretation: which sequences are in what ages and geomorphology of different times of the study area will be revealed. The last chapter, chapter 5 will present discussions and conclusions.

Chapter2
Geological Framework

2.1 Study Area

The study area is called the Chandon Field, which lies 185 km away from northwest of Barrow Island, on the Northwest Shelf of Australia. The Chandon Field is located between two giant gas fields, Scarborough and Io/Jansz (Figure 2-1). The study area is located in the Exmouth Plateau (Figure 2-2), which is one part of the Northern Carnarvon Basin. The Northern Carnarvon Basin combines with three other basins to comprise the "Westralian Superbasin" (Yeates et al., 1987) (Figure 2-3).

The structural styles of the Northern Carnarvon Basin are largely due to rifting associated with breakup of Gondwana and the evolution of the Westralian Superbasin, as described below.

2.2 Westralian Superbasin

The Westralian Superbasin is the combination of four basins along the northwest shelf of Australia. The basin is lying in the northeast-trending, consists of the Northern Carnavon, Offshore Canning or Roebuck, Browse and Bonaparte basins.

Gartrell (2000) gave a brief idea on the occurrence of the Westralian Superbasin that the Neothethys rift system propagated from Australia to the eastern Mediterranean area generate extensive deformation trending north-northeast on the northwestern margin of Australia. That defined the large-scale geometry of the margin and that formed the so-called 'Westralian Superbasin' (Yeates et al., 1987; Langli et al., 2005)

Powell (1982) notes, the Northwest Shelf of Australia is regarded as a good example of a passive ‘Atlantic-type’ margin that evolved as a result of major rifting on a continental scale, starting in the Late Palaeozoic and continuing into the Early Cretaceous. These pull-apart movements resulted in the complete disassociation of eastern Gondwanaland with the separation of a western landmass from the Australian Plate. Geologically the area as a whole comprises a number of Permian and Mesozoic epicontinental basins lying offshore from the Australian craton and developed parallel to the principal rift system. These extend westwards across a series of marginal plateaux to the base of the present continental slope.

2.2.1 Spreading History

Johnson et al. (1976) have divided the history of spreading of the Greater Indian Plate, Antarctic Plate and Australian Plate based on evidence from magnetic survey and deep sea drilling into 4 stages. In Early Cretaceous to Late Cretaceous (130-80 Ma), spreading occurred between India and Antarctica-Australia created a rectangular land-locked sea between them. During Late Cretaceous to Late Paleocene (80-53 Ma), rapid spreading occurred first between India and Antarctica-Australia, then transferring a small part of the Antarctic-Australian Plate. Then in Late Paleocene to Late Eocene (53-32 Ma), spreading occurred between India and Antarctica and Australia. Finally, the final stage occurred in Late Eocene to Present (32-0 Ma), spreading between India-Australia and Antarctica. Spreading stopped between India and Australia then the both plates were going together and were drifting away from Antarctica. In addition, Veevers and McElhinny noted in their summary of the separation of Australia from other continents that “India separated from Antarctica-Australia Early in the Cretaceous (130 Ma) and Antarctica separated from Australia at the end of the Paleocence (53 Ma)”.

Powell (1982) states that open marine conditions, related to the breakup of the Gondwanaland and the opening of the Indian Ocean, became widespread during the Albian in the southern part of the Australian Northwest Shelf. The deposition of a thick prograding wedge of mainly carbonate sedimentation since the mid-Eocene resulted in a northwesterly regional tilt of the shelf.

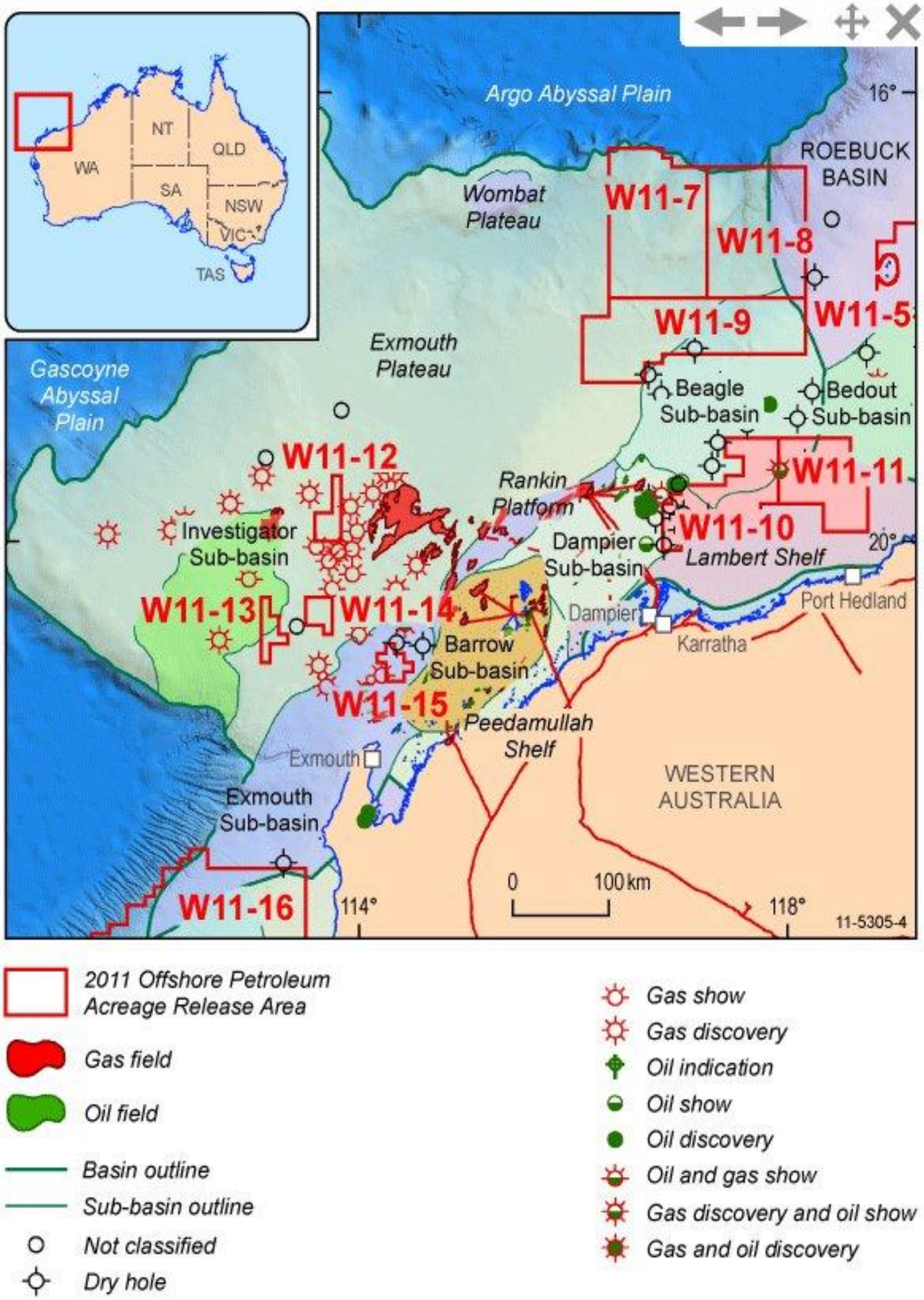


Figure 2-1: The Chandon Field is located in the Exmouth Plateau, shown in the small yellow rectangular. (modified from http://www.pnronline.com.au/images/article/844/5.jpg)

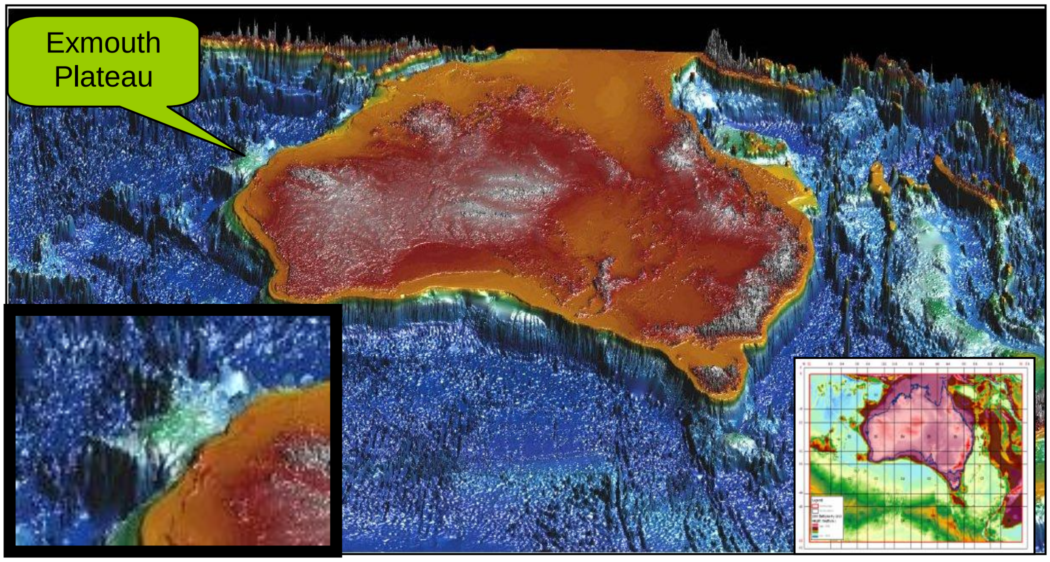


Figure 2-2: Location of the Exmouth Plateau in the Northern Carnarvon Basin, northwest shelf of Australia (modified from Whiteway, 2009; Heap and Harris 2008)

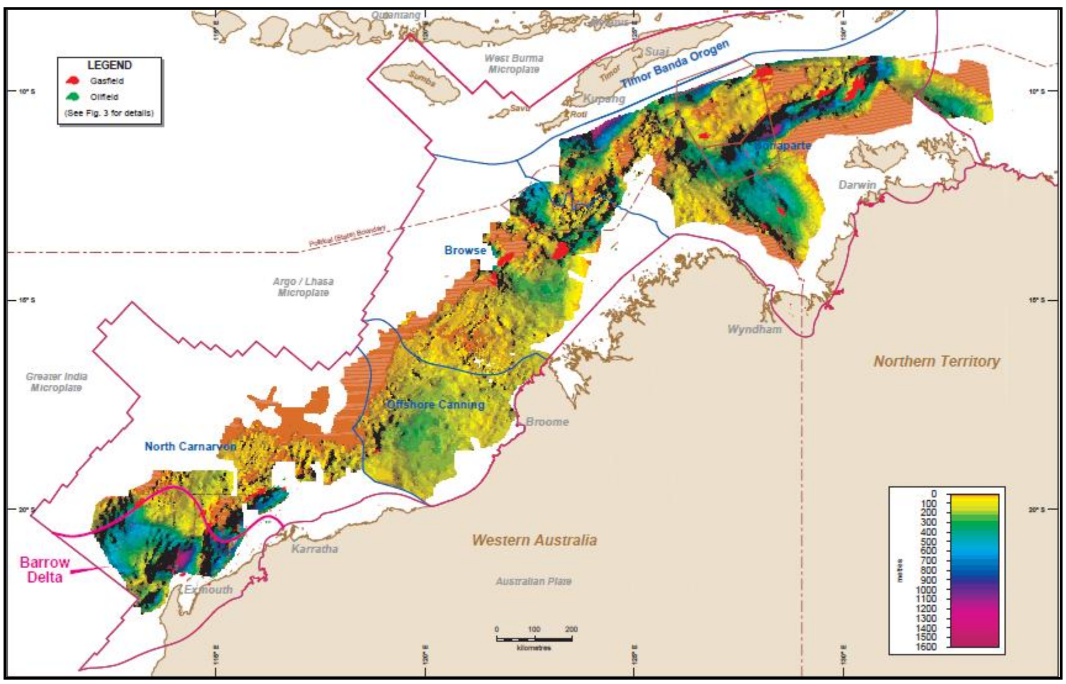


Figure 2-3: Westralian Superbasin is composed of the Northern Carnarvon Basin, Offshore Canning or Roebuck Basin, Browse Basin and Bonaparte Basin (Longley et al., 2003).

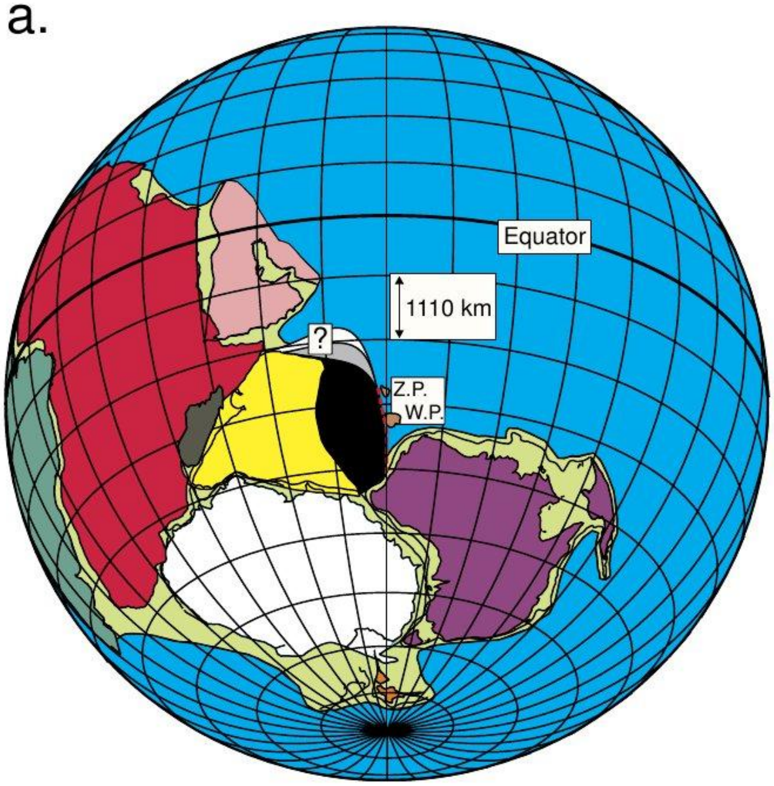
2.2.2 Regional Geology of the Northern Carnarvon Basin

Australian Government (2010) notes “The Northern Carnarvon Basin is the southernmost of the Late Paleozoic to Cenozoic basins comprising the Westralian Superbasin that underlies the northwestern continental margin of Australia (Bradshaw et al, 1988). It is bounded to the northeast by the Roebuck and Offshore Canning basins, to the southeast by cratonic Pilbara Block, to the south by the Southern Carnarvon Basin, and to the northwest by the Argo, Cuvier and Gascoyne abyssal plains. The basin is predominantly offshore, covering an area of approximately 535000 km^2 deep down to 3500 m. The sedimentary fill is up to 15 km thick and dominated by deltaic to marine siliclastics and shelfal carbonates of Mesozoic age.”

The offshore part of the Northern Carnarvon Basin encompasses two plateaus and five sub-basins. The plateaus are the Wombat Plateau and the Exmouth Plateau including the Rankin Platform and Kangaroo Syncline. The sub-basins are the Exmouth sub-basin, Investigator sub-basin, Barrow sub-basin, Dampier sub-basin and Beagle sub-basin. Moreover, the Northern Carnarvon Basin combines the Enderby Terrace, Peedamullah Shelf and Lambert Shelf.

The present structure of the basin is a result of rifting associated with the breakup of Gondwana during the Jurassic to Early Cretaceous (Callovian to Hautervian). Accordingly, there are two major trends of structure created in the Northern Carnarvon Basin. The NE-SW trend, is the first structural trend and the N-S or NNW-SSE trend is the secondary structural trend. The primary structural trends can be seen in the major faults and the positioning of the sub-basins and their depositions. The secondary structural trend is also visible in the separating zones of the sub-basins and acts as the major fault trend in some sub-basin such as in the Beagle Sub-basin (This sub-basin is in transition between the Northern Carnarvon Basin and Offshore Canning and Roebuck Basins).

a.



b.

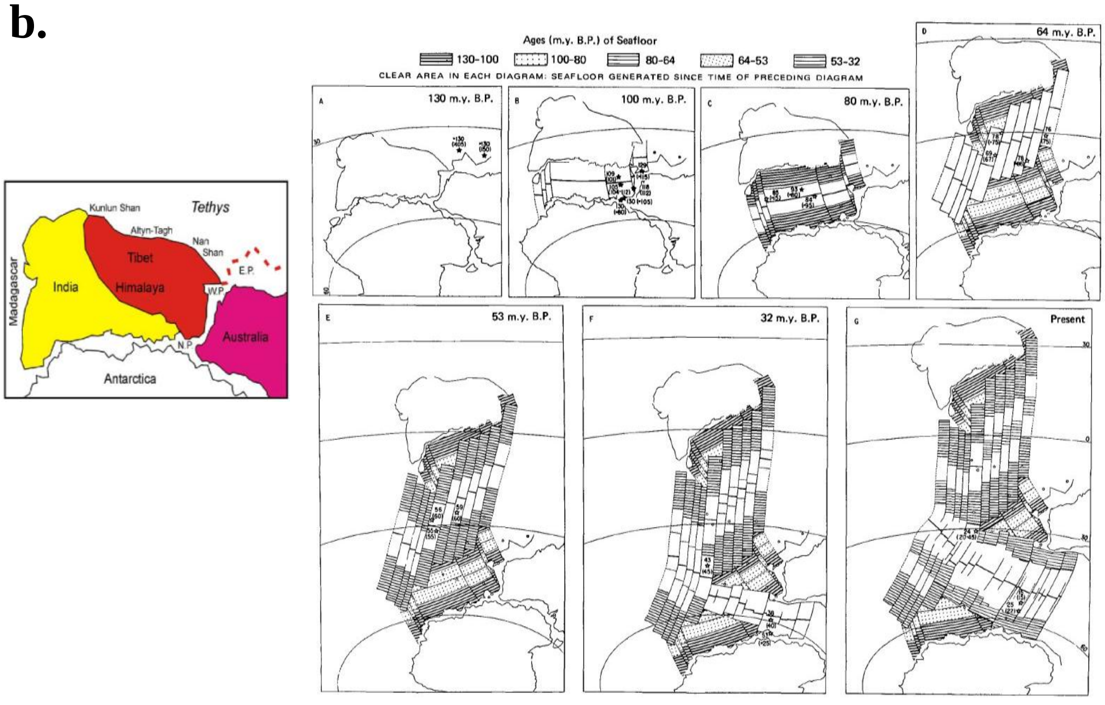


Figure 2-4: Spreading history of Greater Indian Plate, Antarctica Plate and Australian Plate (Jason et al., 2005; Johnson et al., 1976).

Rift tectonism initiated in the Early Jurassic, dominates the tectonic elements of the region by a northeastern trend, continuing until the Late Triassic. Inboard basin-bounding faults are in similar orientation, and subsequent tectonic movement have variably inherited this structural alignment. The last major rift-related tectonism occurred in the Valanginian, preceding the final continental separation of Greater India from Australia. As a result of rift tectonism in the Jurassic and Early Cretaceous, the Barrow and Dampier sub-basins form a northeast-trending graben, bounded on the outboard side by the steep slope of the Rankin Platform and the Exmouth Plateau. The outboard side of the Exmouth Sub-basin and Exmouth Plateau is bounded by oceanic crust.

2.2.3 Basin Evolution and Tectonic Development

Evolution of the Northern Carnarvon Basin, according to Australian Government (2010), can be divided into 6 periods:

1. Silurian to Early Jurassic (Toarcian): Pre-rift intracratonic basins
2. Toarcian to earlieast Callovian: Early syn-rift
3. Earliest Callovian to Berriasian: Main syn-rift
4. Berriasian to Valanginian: Late syn-rift Barrow Delta
5. Valanginian to mid-Santonian: Post-breakup subsidence
6. Mid-Santonian to present: Passive margin

1\. Silurian to Early Jurassic (Toarcian): Pre-rift intracontinental basins

In the initial stage of Gondwana breakup during the Silurian to the Permian, development of the sag-type intracontinental basin resulted in the deposition of non-marine to shallow marine sediments, which are presently deposited in the deep parts of the basin.

Overlying the Permian sediments, a regional marine transgression from the

Triassic was deposited unconformably. Called the “Locker Shale”, it is composed of claystone and siltstone. This unit consequently graded upward during the Middle to Late Triassic into the “Mungaroo Formation”. Its fluvio-deltaic systems, are composed of thick channel fluvial and estuarine sandstones and deltaic sandstone with minor coal. The Mungaroo Formation is the main gas-prone source rock formation in the Exmouth Plateau and the Barrow and Dampier sub-basins.

The abundant volume of sediment within the Mungaroo Delta suggests that the sediments were possibly influxed from central Australia or northern Australia by transcontinental river systems (Norvick, 2002; Jablonski and Saitta, 2004). However, sediment supply during the Triassic were mostly transported from the Pilbara Block/Craton.

In the Late Triassic to the Early Jurassic, rapid subsidence was bringing about deposition of transgressive shelfal Brigadier Formation and Murat Siltstone. Both formations contain siltstone, claystone and marl. In the outer part of the Northern Carnarvon Basin, the Brigadier Formation has been well preserved below the widespread upper Jurassic unconformity. The top part of the Brigadier Formation is the maximum flooding surface of the Early Jurassic marine transgressive.

2. Toarcian to earliest Callovian: Early syn-rift

General northeast-southwest-trending structural framework in the Northern Carnarvon Basin resulted from rifting from the Pliensbachian age. Extensional faulting and associated deformation resulted in the widespread formation of tilted fault blocks, horsts and grabens, and the distribution and the configuration of the fault systems strongly controlled sediment deposition (Barber, 1988).

The echelon arrangement and compartmentalization of the sub-basins were caused by the extension associated with rifting appears to have contained a significant oblique component, which combined with the pre-existing Proterozoic to Paleozoic north-south structural grain (Romine et al., 1997)

The Pliensbachian unconformity or the JP1 seismic horizon represents the onset of rifting. During Toarcian-earliest Callovian, the sediments are of the Atol Formation and the Legendre Formation, which are restricted marine claystone, siltstone and regressive deltaic sandstone, respectively. The Legendre Formation is the prospective source of hydrocarbon in the Dampier Sub-basin, and hosts gas fields such as Reindeer and Rosemary.

3. Earliest Callovian to Berriasian: Main syn-rift

During the Callovian to the Oxfordian, the separation of Argo Land from Australia and the onset of seafloor spreading in the Argo Abyssal Plain created regional uplift and erosion (Jablonski, 1997). The JC seismic horizon represents the boundary between the Early syn-rift (Toarcian to earliest Callovian) and main syn-rift (earliest Callovian to Berriasian) sequences. Over the JC unconformity, the Calypso Formation, which is the transgressive claystones were deposited locally only in the Barrow and Dampier sub-basins.

Norvick (2002) states that major faults related to rifting developed along the northern edge of the Exmouth Plateau in the Callovian, but continuous forming of oceanic crust was not created till the Late Oxfordian. The phase of continental breakup and the beginning of sea-floor spreading to form the Argo Abyssal Plain was represented by the breakup unconformity or the main unconformity or the basal Oxfordian unconformity or the JO seismic horizon.

Uplifting and tilting of the Exmouth Plateau and the Rankin Platform resulted from movement on extensional faults that continued after continental breakup in the Late Jurassic. As a result, sediment was repelled from the uplifted area into adjacent depocenters. After that, the Dingo Claystone, a thick deep-water marine succession, gradually filled the depocenters of the Barrow, Dampier and Exmouth sub-basins (Tindale et al, 1998). Furthermore, the Dingo Claystone is an Oxfordian maximum flooding phase provided a favourable depositional environment for high quality, oil-prone source rocks (Norvick, 2002).

In Late Jurassic, sandy shelfal facies occurred within restricted shallow basins on the eastern part of the Exmouth Plateau. In the southern part of the Exmouth plateau, the Kangaroo syncline formed in response to uplifting of the footwall of tilted Triassic fault block on the Rankin Platform, as well as in the northern part of the Exmouth Sub-basin (Jenkins et al, 2003). In uplifted area, coarse clastic sediments were derived from the erosion of the Mungaroo Formation and transported into the shallow marine environment of the syncline. Before the Berriasian, the subsidence and peneplanation of the sediment source area were gradual. Thus, the clastic inputs were limited to the syncline (Jenkins et al, 2003).

During the Early Berriasian, deposition was terminated by another episode of uplift and erosion, marking the onset of rifting between Greater India and Australia.

4. Berriasian to Valanginian: Late syn-rift Barrow Delta

Up to 2500 m, the thickness of the extensive Barrow Delta system and the deposition of the Barrow Group represent sedimentation during Berriasian to Valanginian. Progradation of two main delta lobes were in two major phases.

The first depositional phase over the Exmouth Sub-basin resulted from a supply of sediment primarily to the south. After that, the delta prograded quickly to the north over a thick pile of turbidites and pro-delta shale to a maximum northward limit roughly west from Barrow Island across the Exmouth Plateau. The Barrow Group on the Exmouth Plateau consists of turbidites, basin-floor fans and fluvio-deltaic sediments of the lower Barrow Delta lobe. Then the sandstone complex was formed by a turbidite fan at the Scarborough gas accumulation to the north of the delta front (Norvick, 2002).

The progradation of the Barrow Delta resume in the Late Berriasian; meanwhile the lower delta lobes in the shoreline part of the Exmouth Sub-basin were eroding, which resulted in the new depocenter of the delta. In the second phase, the depocenter retreated 250 km away to the east and extended beyond the eastern limit of the first phase. Therefore a back-stepped delta (upper Barrow Delta lobe) developed in the Barrow and Dampier sub-basins. The second phase of delta prograded its northern limit to the Gorgon horst.

The sediments of the western or lower lobe of Barrow Delta, consisting of bottom set submarine fan sandstones and pro-delta claystones, were known as the Malouet Formation. On the other hand, sediments of the eastern or upper lobe of the Barrow Delta, called the Flacourt Formation, are comprised of basinal turbidities, foreset claystones and top set sandstones. Baillie and Jacobson (1997) note "The boundary between the lower and the upper lobes is diachronous and can not always be picked as a continuous regional seismic horizon". The lower lobe contains 75% of the sediment deposited by the Barrow Delta system (Ross & Vail, 1994). The Barrow Group sandstones are mostly composed of quartz with minor clay matrix and are loosely cemented by calcite, pyrite or siderite. These sandstones in the outer part of the Northern Carnarvon Basin are excellent in porosity and permeability.

In the top Barrow Group, the sandy units are named differently, for instance, the top sandstone of the Barrow Group, the top sandstone of the Flacourt Formation, the Zeepaard Formation, and the Flag Sandstone. In the Early Valanginian, the Zeepaard Formation was deposited as progradational top set units of the Barrow Delta in front of multiple distributaries across the Barrow and Exmouth sub-basins, Rankin Platform and Exmouth Plateau.

The onset of continental breakup in the Valanginian to the southwest of the Exmouth Plateau resulted in halting of sediment supply for the Barrow Delta system, as it was broken by a major fluvial distributary system (Hocking, 1990). Tectonic inversion occurred during breakup in the Exmouth Sub-basin and Exmouth Plateau. However, subsidence and marine sedimentation continued over the Barrow and Dampier Sub-basins.

5. Valanginian to mid-Santonian: Post-breakup subsidence

During the Valanginian, continental breakup and the onset of seafloor spreading in the Gascoyne and Cuvier abyssal plains occurred. As a result, peneplanation took place extensively in the Northern Carnarvon Basin. Evidence of the breakup can be seen as the “KV” seismic horizon, the Valanginaian unconformity. After that subsidence occurred rapidly, resulting in a widespread transgression and the deposition of a fining-upward marine sequence over the Valanginian unconformity surface.

At first, the Birdrong Sandstone and the glauconitic Mardie Greensand were deposited in coastal plain, delta, and shelf environments. This localized sedimentation cycle was followed by the basin-wide deposition of the transgressive marine Muderong shale, Windalia Radiolarite and Gear Siltstone. The Muderong Shale is not only the regional seal, but also an important reservoir, which is contain petroleum-bearing sandstone, the M. australis Sandstone or Stag Sandstone, and the Windalia Sandstone Member in the Barrow and Dampier sub-basins. These sandstones are diachronous, superimposing the glauconitic intra-Valanginian unconformity.

According to Ellis et al (1999), the Windalia Sandstone of the Muderong

Shale has been a primary exploration target in the Barrow Sub-basin.

6. Mid-Santonian to present: Passive margin

Tectonic stability and the decreasing supply of terrigenous sediment resulted in the cessation of siliclasitic sedimentation. As a result, shelfal carbonate sediments were deposited on the passive continental margin. The region continued to subside after the completion of rifting in the Late Cretaceous and Cenozoic. During this period, on the deep water Exmouth Plateau, the sedimentary succession deposited during this period was relatively thin, as subsidence rates outpace sediment input. Just before the end of the Cretaceous, the major depocenter of the Northern Carnarvon Basin was the Kangaroo Syncline on the Exmouth Plateau.

The formation of the Exmouth Plateau Arch during the Campanian was a result of a phase inversion in the Exmouth Sub-basin and Exmouth Plateau (Tindale et al., 1998). It also marked the onset of the transpressional structural growth of pre-existing rift-related structures within the Barrow and Dampier sub-basins, including the formation of Barrow Island (Longley et al, 2002; Cathro & Karner, 2006).

Affecting the entire Northwestern margin of Australia in the Miocence, a major compressional event associated with the collision of the Australia-India plates, includes the Northern Carnarvon Basin, resulting in tilting, inversion, renewed movement on faults and the creation of new strike-slip faults and form structural traps of Cretaceous and Cenozoic strata (Malcolm et al, 1991; Cathro & Karner, 2006).

2.3 The Exmouth Plateau

In this study, the Study area, which is called "Chandon Field" is located in the Exmouth Plateau. The Exmouth Plateau is a large submerged extension into the Indian Ocean. The plateau is a subsided continental platform characterized by a faulted dominantly Triassic sedimentary succession attaining a thickness of up to 15 km. The Exmouth Plateau encompasses several sub-elements including the Rankin Platform, Kangaroo Syncline, Investigator sub-basin and Wombat Plateau (Tindale et al, 1998; Stagg et al, 2004). The Exmouth Plateau is confined by the Northwest Shelf to the southeast, the Argo Abyssal Plain to the northeast, and the Gascoyne Abyssal Plain and Cuvier Abyssal Plain to the northwest and southwest, respectively. The thickness of the crust of the Exmouth Plateau is about 20 km and consists of 50% Phanerozoic sediments. The plateau is 250 km away from the shore. Its apex lies 800 m below sea level. The plateau, adjacent spurs, and the lower continental margin cover 300,000 km^2 (Exon, 1982). The Exmouth Plateau is dominated by a thick fluvio-deltaic Triassic sequence, it hosts several giant gas accumulations and is an area of active and successful exploration

Falvey (1972) considered the Exmouth Plateau to be a marginal plateau of continental crustal material that foundered during the differential vertical movements after continental break-up. Recent work, however, has shown that the plateau was a depositional presence of the Northern Carnarvon Basin for much of the Early Mesozoic and owes its present position in deep water to the fact that the Tertiary prograding carbonate wedge has not yet covered it. Seismic correlation into the plateau area from well control on the Rankin platform suggests that a thick, faulted Permian to Triassic sequence is overlain by relatively thin Cretaceous to Recent sediment (Branson 1974). The western margin of the plateau is characterized by strong northeast-trending fault blocks downthrowing westwards to the Gascoyne Abyssal Plain. This fault zone represents a rapid thinning of the continental crust down to the 4000 m isobath, located about 600 km offshore, which marks the approximate boundary between continental and oceanic crust.

In the Exmouth Plateau, the deep structure is intricate. The major structure trend is different between north-south and northeast-southwest, reflecting the interplay between the oblique geometry of the eastern part leading to the formation of the continental margin along the plateau, and the pre-existing structural grain of the basement (Stagg et al, 2004). Faulting along the two dominant trends has produced horsts with a triangular platform over the Rankin Platform, the uplifted eastern margin of the Exmouth Plateau. The older sequence can be separated into eastward dipping blocks by numerous normal faults which dip steeply westward (Exon, 1982).

The three outer margins of the plateau are conspicuously different in morphology; the northern margin is steep and cut by large canyons, the western margin is moderately steep, but has relatively few indents, and the southern margin is straight, gently sloping, and has almost no canyons. Authentication from deep-sea magnetic lineations and from deep-sea drillholes (Veevers & Heirtzler et al., 1974), shows that the margins formed by faulting associated with seafloor spreading: Callovian in the northern margin, Neocomian in the southern margin, and at least most of the western margin in the Neocomian. Plate tectonic models such as that of Veevers et al. 1974 obviously indicated that there was rifting of the western margin, rifting and shearing in the northern margin, and shearing in the southern margin (Exon, 1982).

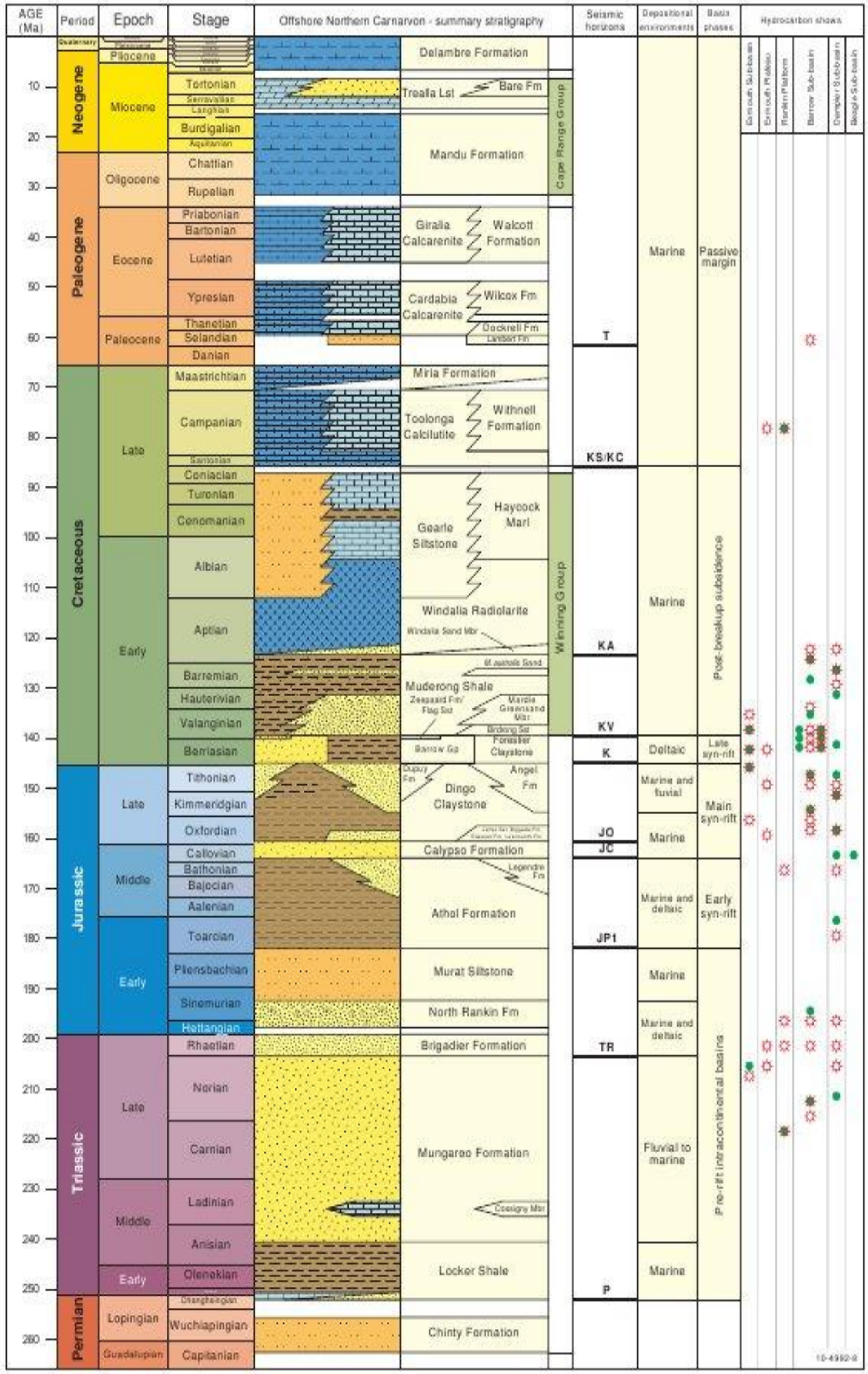


Figure 2-5: Stratigraphic chart of the Northern Carnarvon Basin

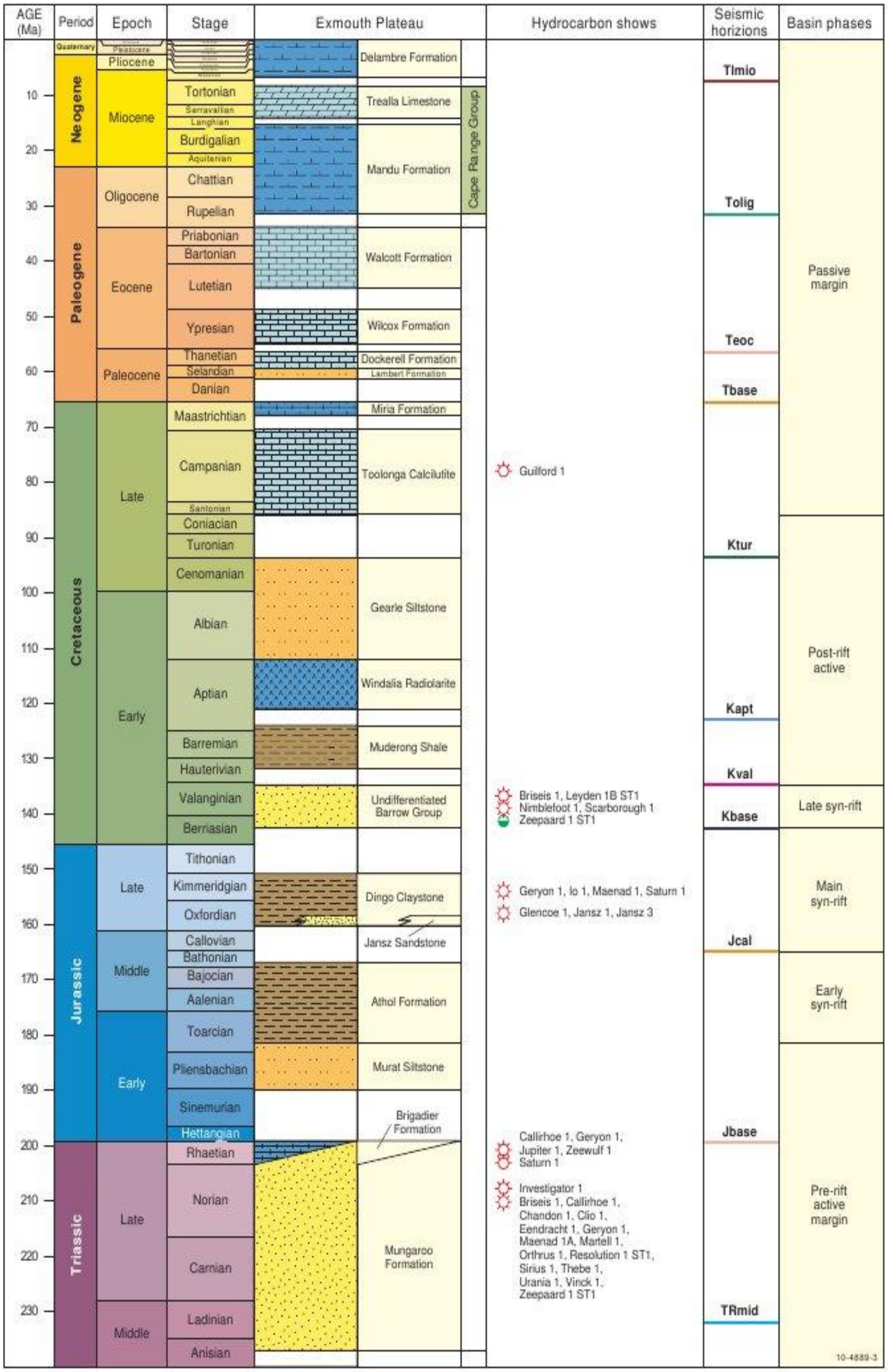


Figure 2-6: Stratigraphic chart of the Exmouth Plateau.

Chapter 3

Methodology

3.1 Data

3.1.1 Seismic Survey Data

The center of Chandon Filed is located approximately 185 km northwest of Barrow Island.

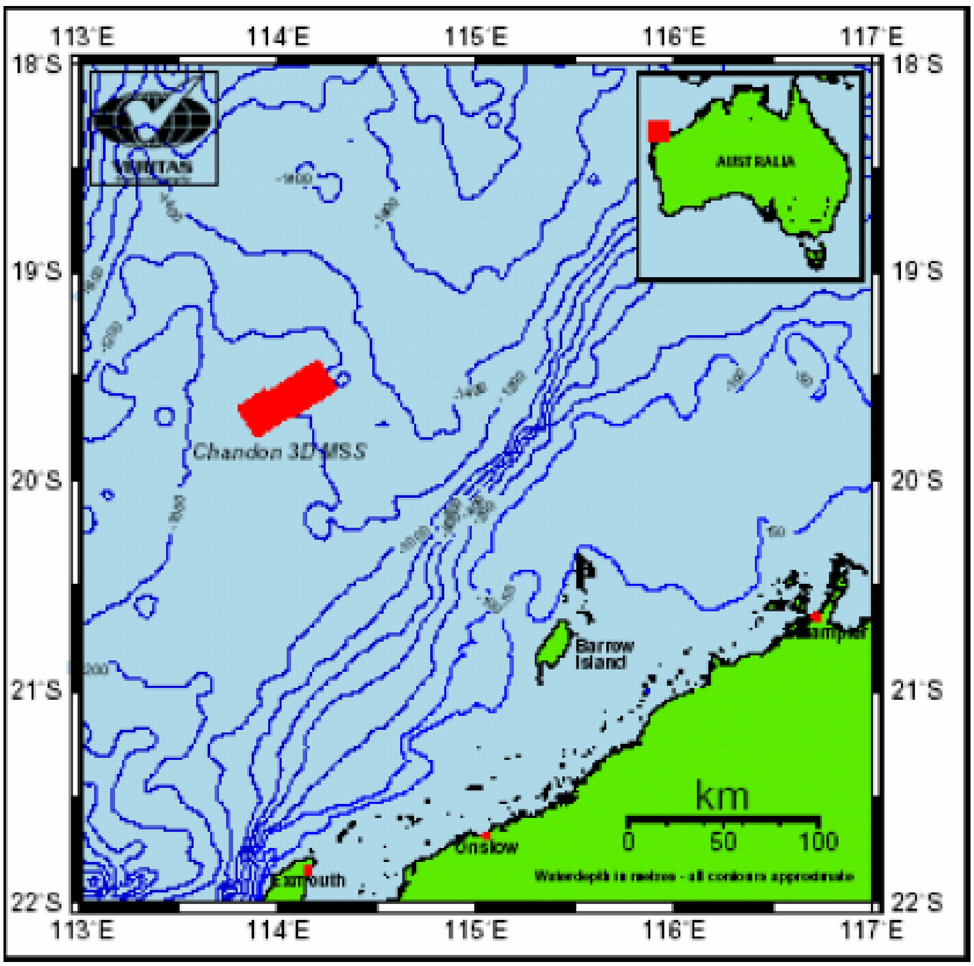


Figure 3-1: Survey location of Chandon Field.

Between January 28th and April 8th, 2004, ChevronTexaco Australia Pyt Ltd. hired Veritas DGC Asia Pacific Ltd. to do the 3-D seismic acquisition of Chandon Field. This seismic survey was processed in Veritas DGC's Singapore processing center later on.

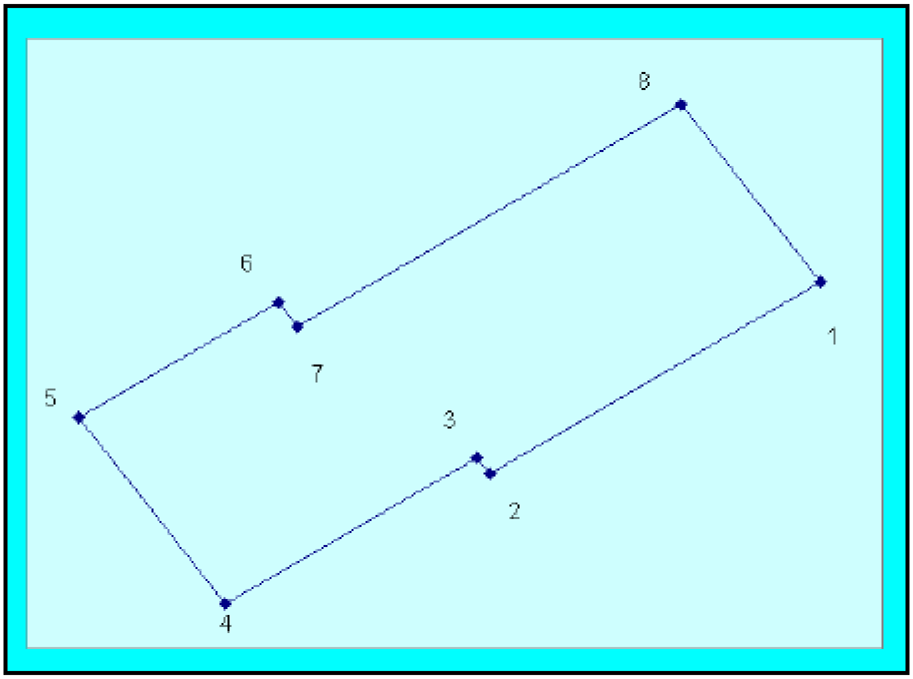


Figure 3-2: Co-ordinate points define the layout of the 3-D seismic data.

POINT #	INLINE	XLINE	EASTING	NORTHING
1	1001	5146	215686	7835008
2	1001	2902	192451	7819294
3	1065	2902	191554	7820620
4	1065	1201	173941	7808708
5	1800	1201	163648	7823929
6	1800	2554	177657	7833404
7	1704	2554	179002	7831416
8	1704	5146	205840	7849566
1	1001	5146	215686	7835008

Table 3-1: Co-ordinate points of Chandon Field.

The total area of Chandon Field is 874,845 km^2. The seismic survey data are shown vertically in two-way-travel time or two-way-time (TWT) between 0-5000 milliseconds. TWT represents the length of time from the source travel through the subsurface and back to the reflector. The horizontal section represents distance in meters.

In general, any 3-D volume contains a regular-spaced orthogonal array of data points that are defined by the acquisition geometry and may be adjusted later during processing (Brown 2003). The three orthogonal arrays or the three primary directions are shown as X, Y and Z in Figure 3-3.

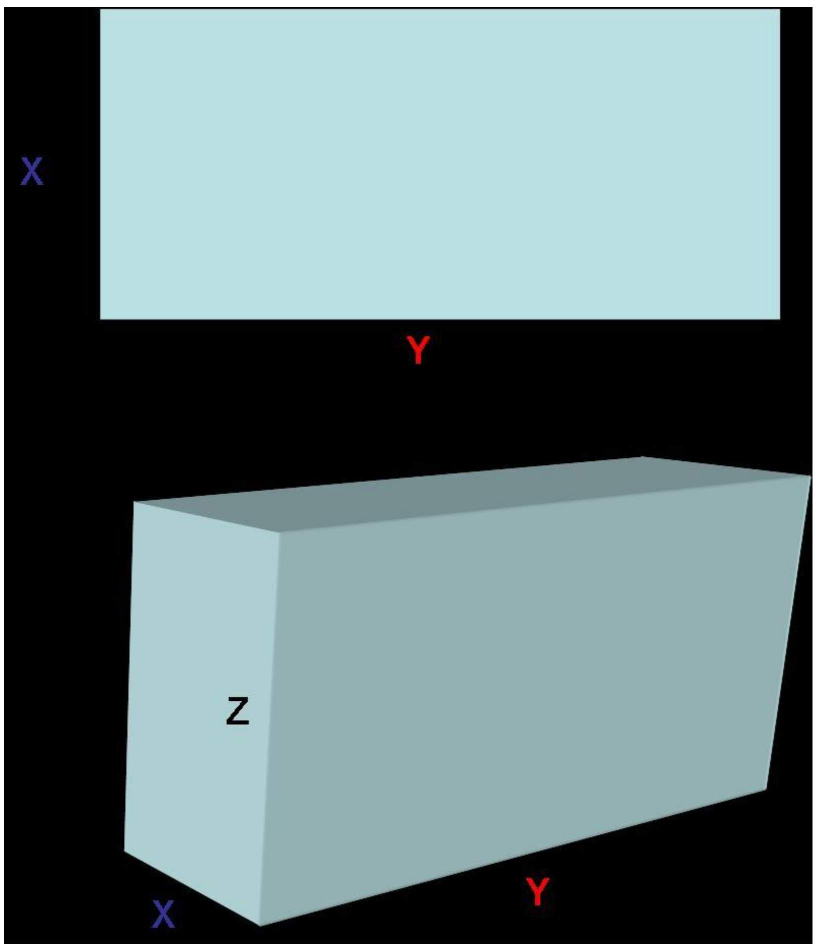


Figure 3-3: The ‘X’ axis represents the width of the area, while the ‘Y’ axis represents the length of the area, approximately 19915 and 54800 m. The ‘Z’ axis represents two-way-travel time between 0-5 milliseconds.

3.1.2 Well Data

There is only one well provided in this study, Chandon-1. It was drilled 1196 meters below mean seal level (MSL) to its total depth (TD) of 3124 meters below the rotary table (mRT) or -3095 meters under true vertical depth sub-sea (mTVDSS). Chandon-1 is located between two giant gas fields, Scarborough and Io/Janz (Figure 3-4, 3-5). It is located 27 km east of Mercury-1 and 31 km northwest of the Jansz-2 wells (Figure 3-6).

The objective of drilling the Chandon-1 was to test a Triassic fault block. A total of 197 m of high quality sandstone of the Mungaroo Formation was encountered, suggesting greater possibility of successful drilling (Jonasson, 2007). An optimistic estimate up to 4 Tcf (trillion cubic feet) of gas has been made (Blevin, 2007).

However, neighboring well data have been combined in this study. They are Mercury-1, Briseis-1, Glencoe-1, Jansz-1, Jansz-2, Jansz-3, and Nimblefoot-1.

3.1.2.1 Wireline log

Wireline logging is a method used for borehole property measurement. An instrument that is used is called a logging tool or a sonde. It is conveyed down hole and up hole. It is powered electrically then transmits its records from the borehole formation into a wireline log or a well log. Measurements include various kinds of properties such as conductivity, acoustic, radioactive, density and fluid properties.

Gamma Ray log

Gamma ray log can be used for lithology identification by measure the radioactivity in the formations. Low gamma ray response such as shale free sandstones and carbonates give left kick in the column. On the other hand, high gamma ray response gives right kick because of high radioactive material in shale. However, sandstone that contain low content of shale can also give high reading of gamma ray as a result of potassium feldspars, micas, glauconite or water containing uranium.

Sonic log

Sonic or acoustic log is a porosity log that measures interval transit time (microsecond per foot) of a compressional sound wave traveling through the formation along the borehole. It consists of one ore more ultrasonic transmitters and at least two receivers (Asquith and Krygowski, 2004). Sonic log is an extremely useful tool for geologists to convey well correlation and help geophysicists to determine the interval velocities of formation and later relate timing of seismic reflectors to actual rocks around a borehole by means of time-depth conversions (Selley, 1998).

Caliper log

Caliper log measure the size and shape of the borehole. It is possible that cave in, shale swelling or rugose occurring when drilling. Caliper log is an important indicator of the reliability of the other well logs (Figure 3-9).

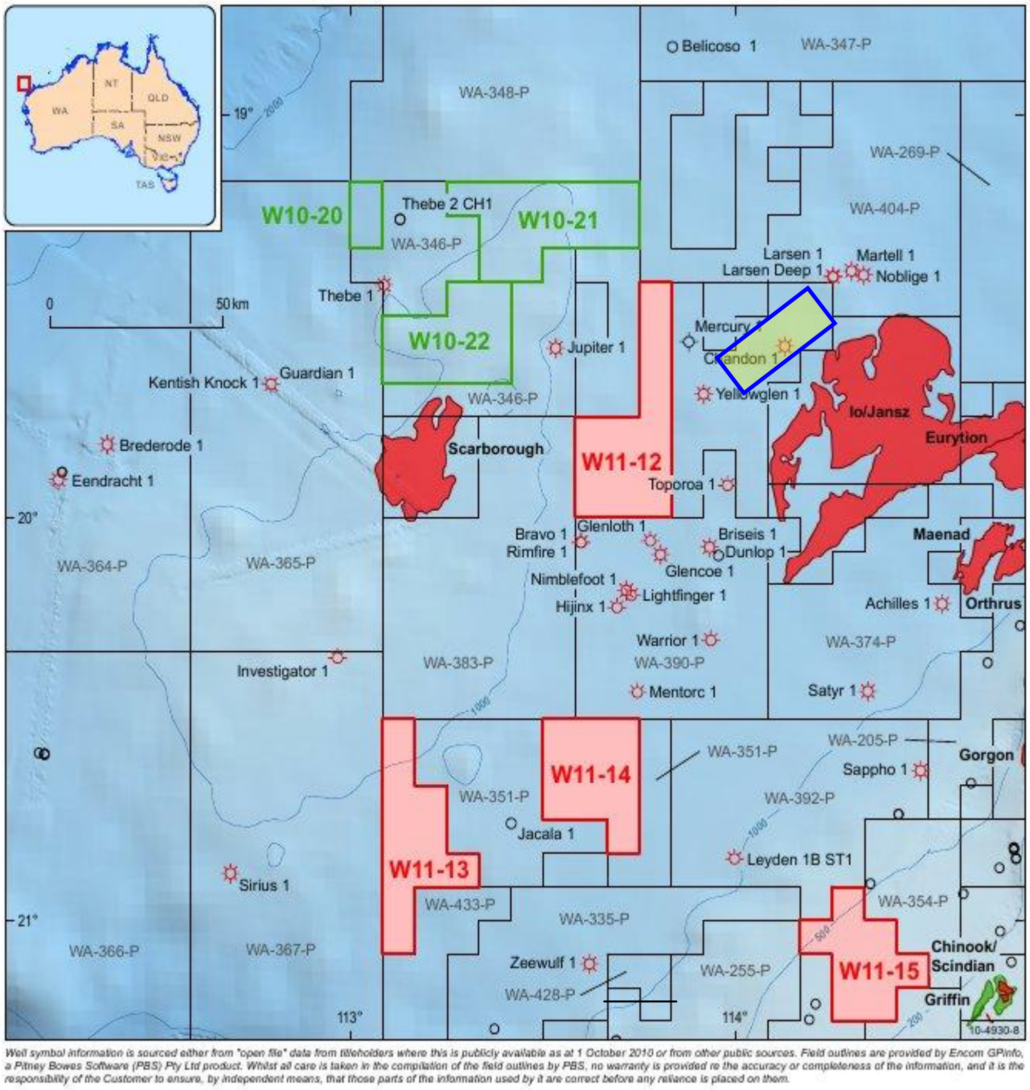
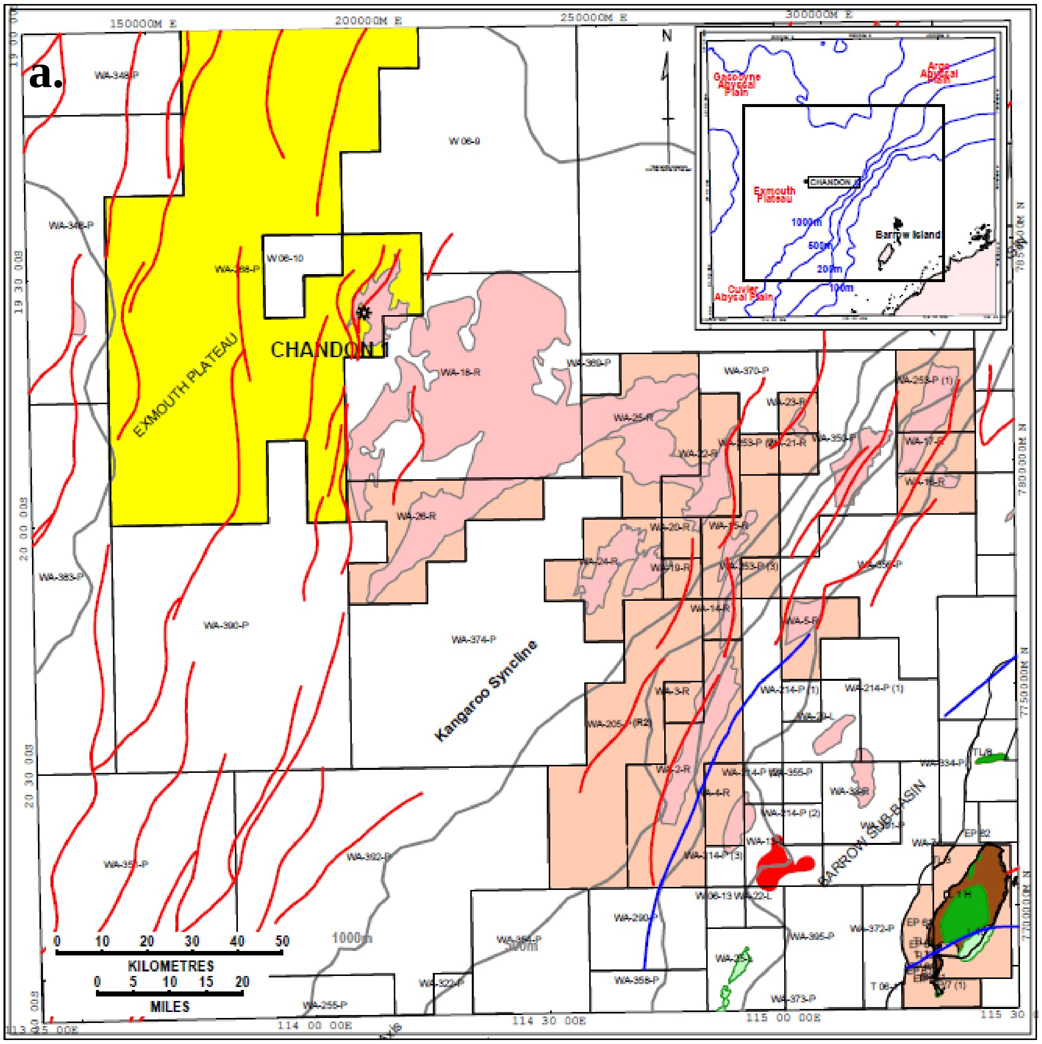


Figure 3-4: Chandon Field is located between two giant gas fields, Scarborough and Io/Janz. Modified from 2011 release, Australian Government webpage.



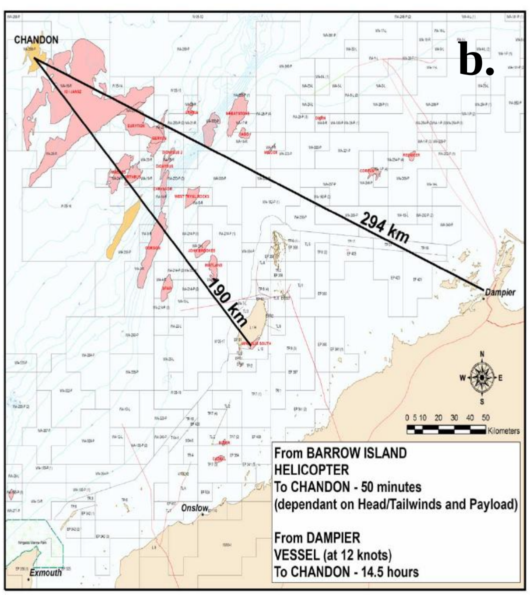


Figure 3-5: Location of Chandon Field is shown:

a. Strucutural map of Chandon Field
b. Chandon Field is away from Barrow Island and Dampier Port 190 and 294 km, respectively.

(modified from End of well report)

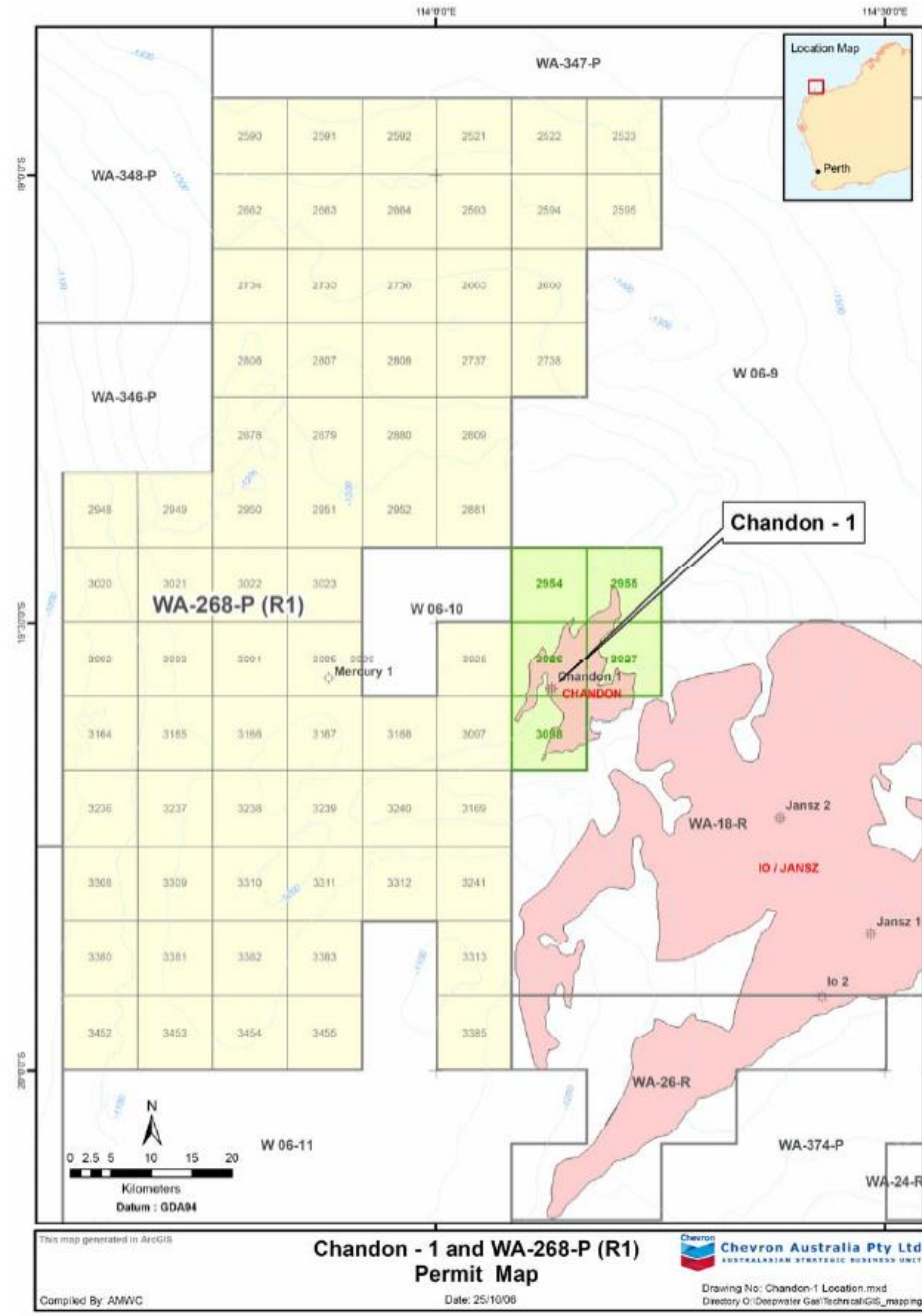


Figure 3-6: Chandon Field is located 27 km east of Mercury-1 and 31 km northwest of the Jansz-2. (modified from End of Well Report)

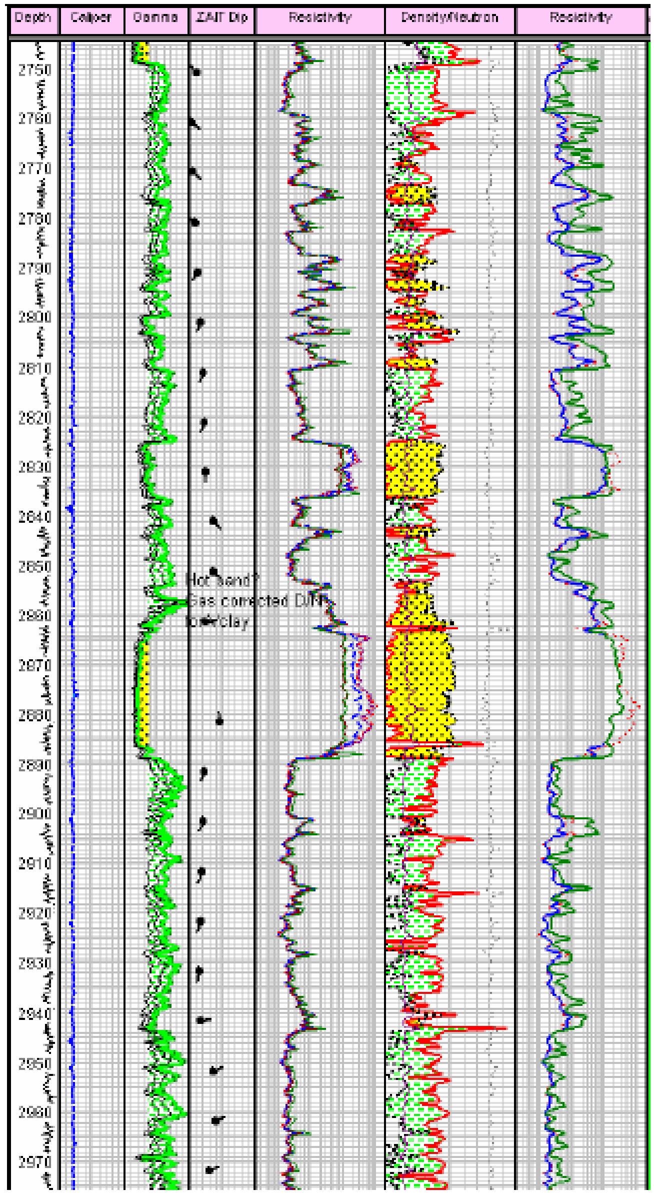


Figure 3-7: Wireline log of Chandon-1 and its different property measurement

3.2 Seismic to Well-Tie

In this study, the primary data that were used are 3-D seismic data. However, the data have not been converted from the time domain into the depth domain (time-depth conversion). Thus seismic data that using in this study remains in two-way-time.

In normal practice, a seismic to well-tie is the first step of data validation. The reason for performing the seismic to well tie is to establish the relationship between seismic and well data, and therefore between seismic reflections and stratigraphy. For structural mapping, it may be adequate to set up an approximate relationship (Bacon et al., 2007). The wavelet must be extracted, followed by the generation of a synthetic seismogram (Figure 3-8). Tying well data to seismic data using the synthetic seismogram method, two important logs are required: the sonic log and the formation density log. Multiplying the sonic log and the density log, an acoustic impedance can be generated.

According to Bacon (2007), sonic and density values are both logged as a function of depth in boreholes. Sonic velocity is determined based on the travel time of a pulse of high frequency (e.g. 20 kHz) between a down hole source and down hole receivers. As a result, the sound travels as a refracted arrival in the borehole wall. Density is interpreted based on the intensity of back-scattered radiation from a down hole gamma-ray source. Hence, the amount of back scatter is proportional to the bulk density.

In this study, the survey data are recently obtained using advanced technology, so the data are quite new and are in good resolution. In addition, data obtained from the sonic log and the density log are in a good shapes as confirmed by the results of the calliper log; the borehole was not washed-out. Otherwise, the borehole would have been invaded with drilling fluid and it would have been measured by logs instead of the formation (Figure 3-9).

According to Tearpock (1991), “As a rule of thumb, a shift of the synthetic more than about one hundred milliseconds should be highly suspect”. Missing tied in the right horizon results in missing the relationship between the seismic response and its correlative log response. Thus the traces of geologic surfaces as seen on seismic lines must intersect at the tie points between lines (Figure 3-10).

a.

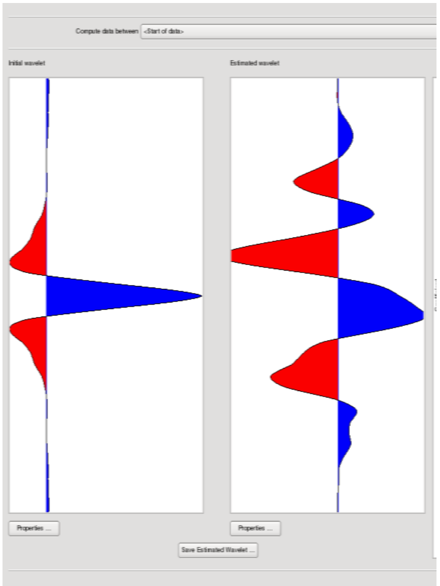
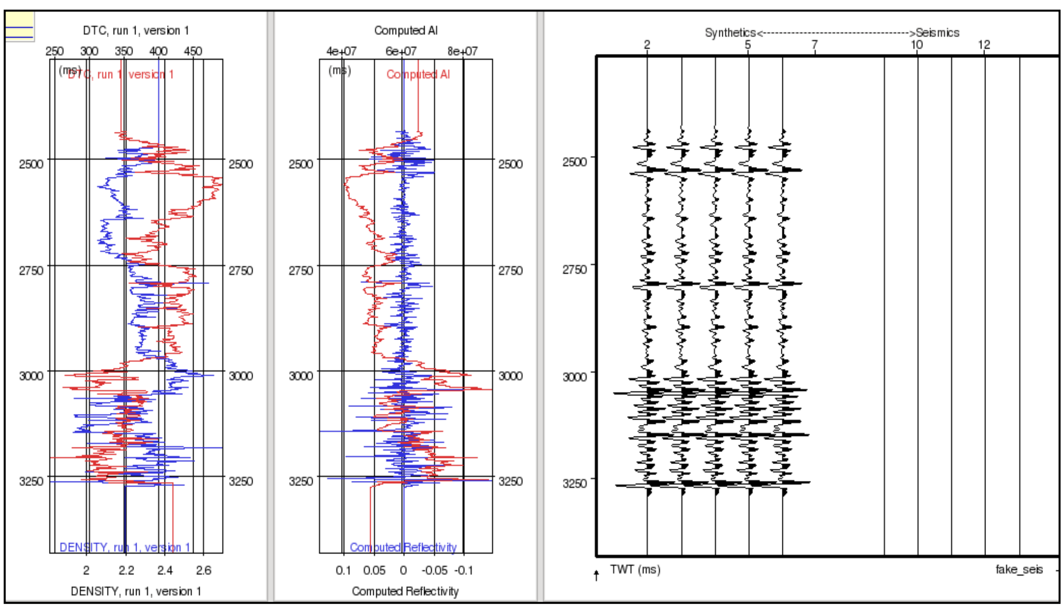


Figure 3-8:
a. Extracted wavelet
b. Synthetic seismogram combines sonic and density logs.

b.



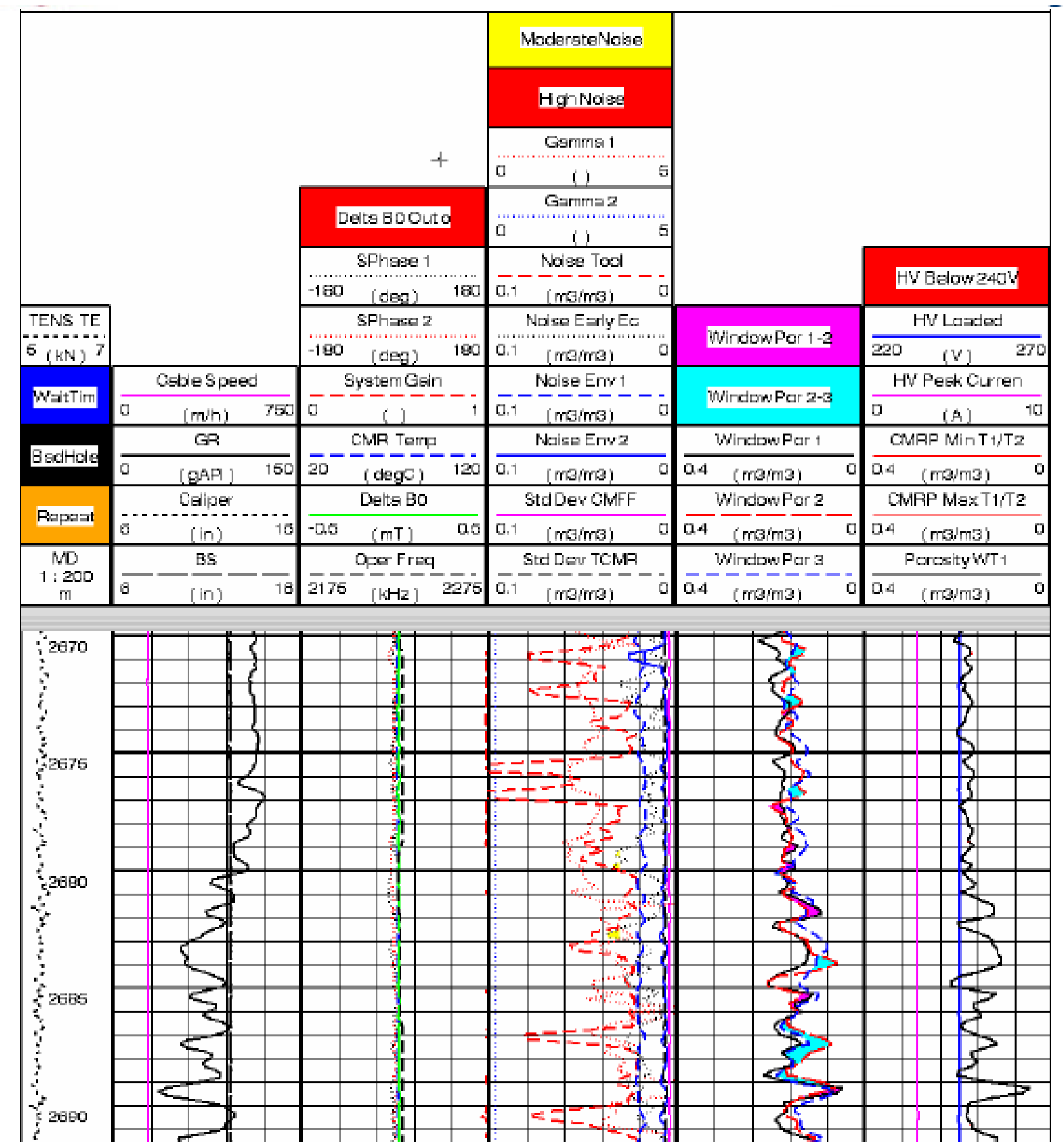


Figure 3-9: Caliper log (dotted line on the left) shows good quality of data. This picture was modified from End of Well Report of Chandon-1 (part: Rt Scanner Processing Report by Shlumberger DCS, 2007).

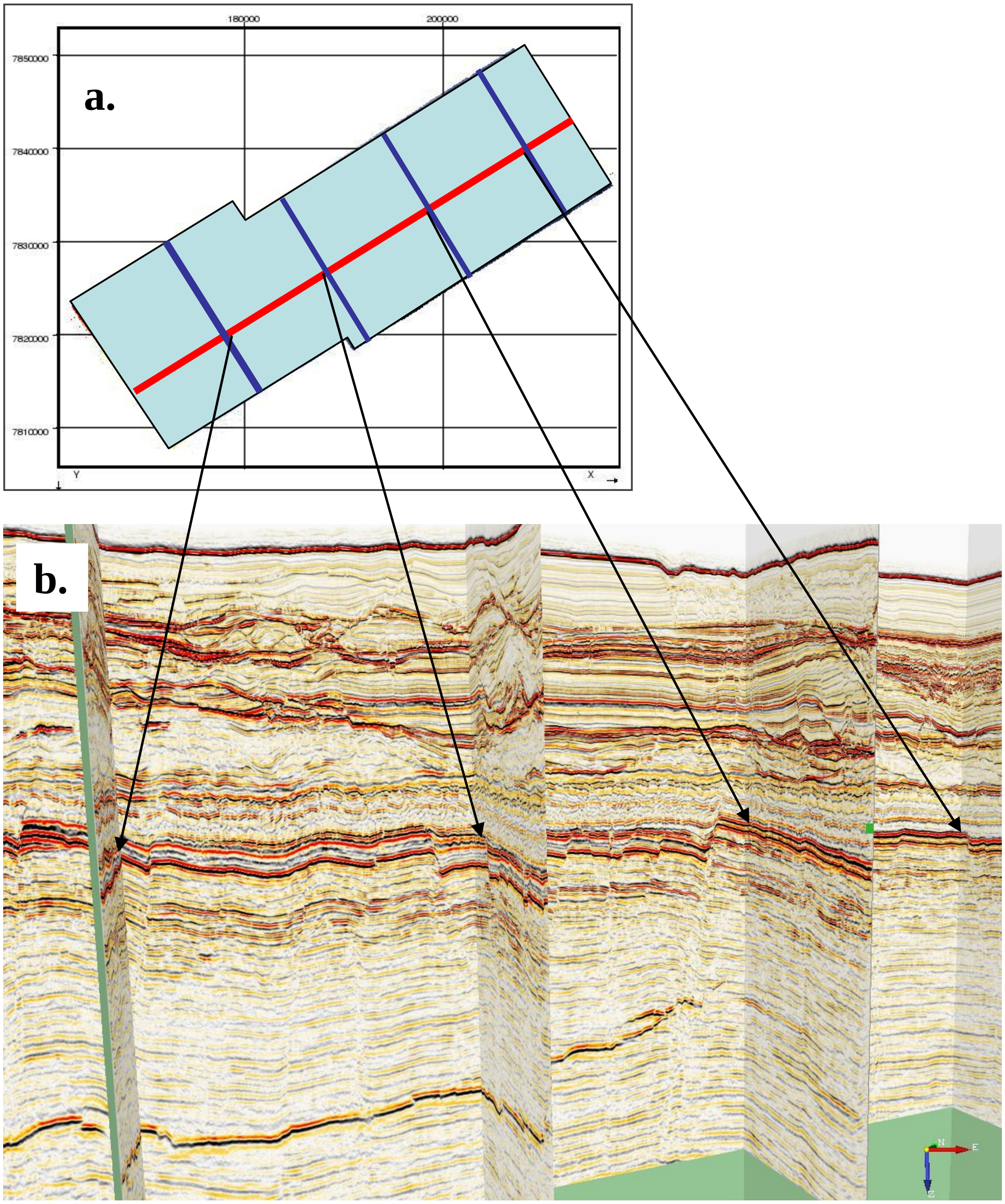


Figure 3-10: Basemap showing position of in-line 1300 (red) intersects with cross-lines (blue) 2000, 3000, 4000 and 5000 (a). Seismic lines are shown in vertical sections with no missing tie on the intersections (b).

3.3 Seismic Analogy

Seismic analogy is an alternative option to pinpoint the ages of the interpreted seismic horizons and stratigraphic units. In the normal practice of an oil company, the time-depth conversion in a seismic survey must be done by a geophysicist before passing to a geologist. Then the geologist can use the seismic data in the depth domain, integrate well data and do markers matching between markers from the wireline log and pick horizon from the seismic data. After that, the converted seismic horizon can be used by the geologist to plan a well target. However, the main objective of this study is to reveal sequence stratigraphy and geomorphology which is acceptable and sufficient to be done in the time domain. Therefore another method which was considered in this study is to analogue from the other existing wells nearby.

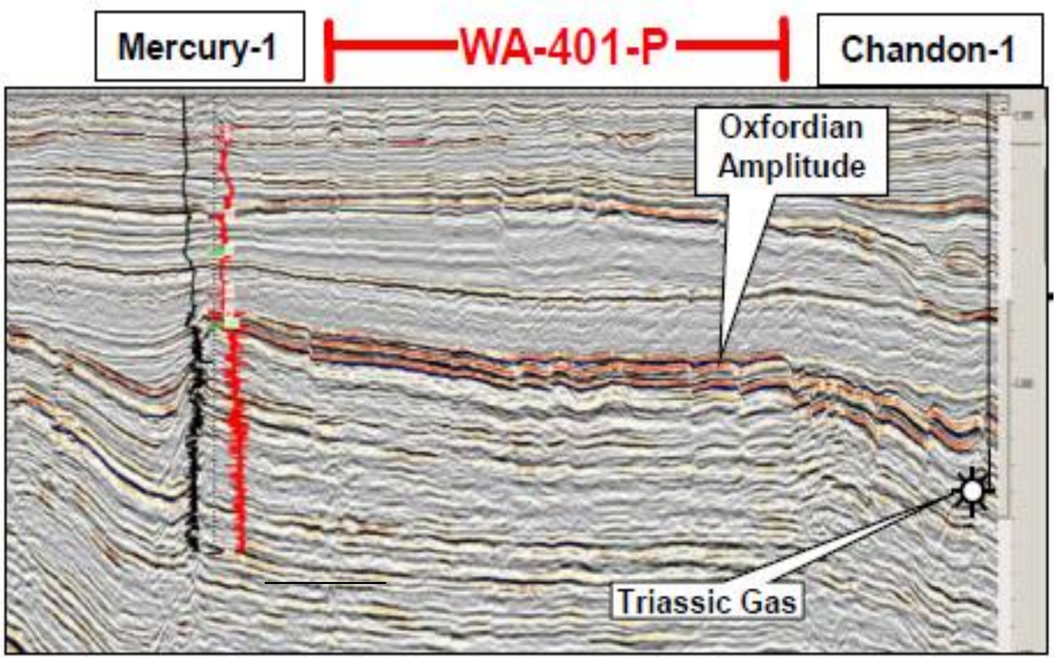


Figure 3-11: A seismic vertical section shows the well Chandon-1 intersects Mercury-1. The Oxfordian period and the Triassic time are revealed.

3.4 Seismic Interpretation

In a seismic volume, three major sections of seismic line can be presented: vertical section, horizontal section and surface tracking. The vertical sections are in-line, cross-line and random or arbitrary line. The horizontal sections are time slice and depth slice. The surface trackings are horizon slice, horizon attribute display and fault slice (Brown 2003).

3.4.1 Seismic Vertical Interpretation

Vertical resolution while interpreting is exaggerated 15 times in order that clear structures can be seen.

3.4.1.1 In-line

It is confusing and controversial defining an in-line or a cross-line in a seismic cube. According to Brown (2003), “the vertical section in the direction of boat movement or cable lay-out is called a 'line' or 'in-line' and the vertical section perpendicular to it is called a cross-line” In this study, the in-lines are represented in the strike or parallel direction to the shelf edge (Figure 3-10, 3-12).

3.4.1.2 Cross-line

By contrast to the in-line, a cross-line is a seismic vertical section which is perpendicular to the inline. The cross-lines are in the dip direction as shown by the blue lines in Figure 3-10.

To gain clearer picture as regards studying in sequence stratigraphy of an area, a long section of cross-lines in any particular area is needed. However, seismic data that are used in this study have the cross-lines in the shorter section and in-lines in the longer section. It was quite a challenge to interpret sequence stratigraphy.

3.4.1.3 Arbitrary line

A random or an arbitrary line is any deviated, diagonal, well-intersected or other user-picked line. A random line helps to guide the correlation between in-lines and cross-lines. An editable random line is a very helpful tool, which not only helps QC the accuracy of picking in-lines and cross-lines but also helps save time while picking a horizon. Unfortunately, it was not possible to pick random lines and to benefit their proficiencies in this study, since this is beyond the ability of the software.

3.4.2 Seismic Horizontal Interpretation

3.4.2.1 Horizon Slicing

In this study, seismic data have been sliced into in-lines, cross-lines, random or arbitrary lines, time slices and horizon slices (the most difficult one), as shown in Figure 3-12.

In this study, countless and innumerable in-lines and cross-lines were picked to construct each horizon slice. Most of the time spent on picking was dedicated to this stage. Greatly detailed work has been carried out by picking surfaces in two-way reflection time from several horizons from all of the traces of the survey; as a result, 10 horizons have been created.

At the beginning of the picking process, it is useful to know the geology of the area (more of rationale detail will be discussed in Chapter 4). After a significant horizon is identified based on an understanding of the geology of the area, it needs to be traced across the survey cube, which is the process of "Horizon picking". Horizon picking is the method of defining the actual geologic history by picking along or parallel to the actual geology. In most cases, geologic surfaces such as unconformities, maximum flooding surfaces, erosion surface.

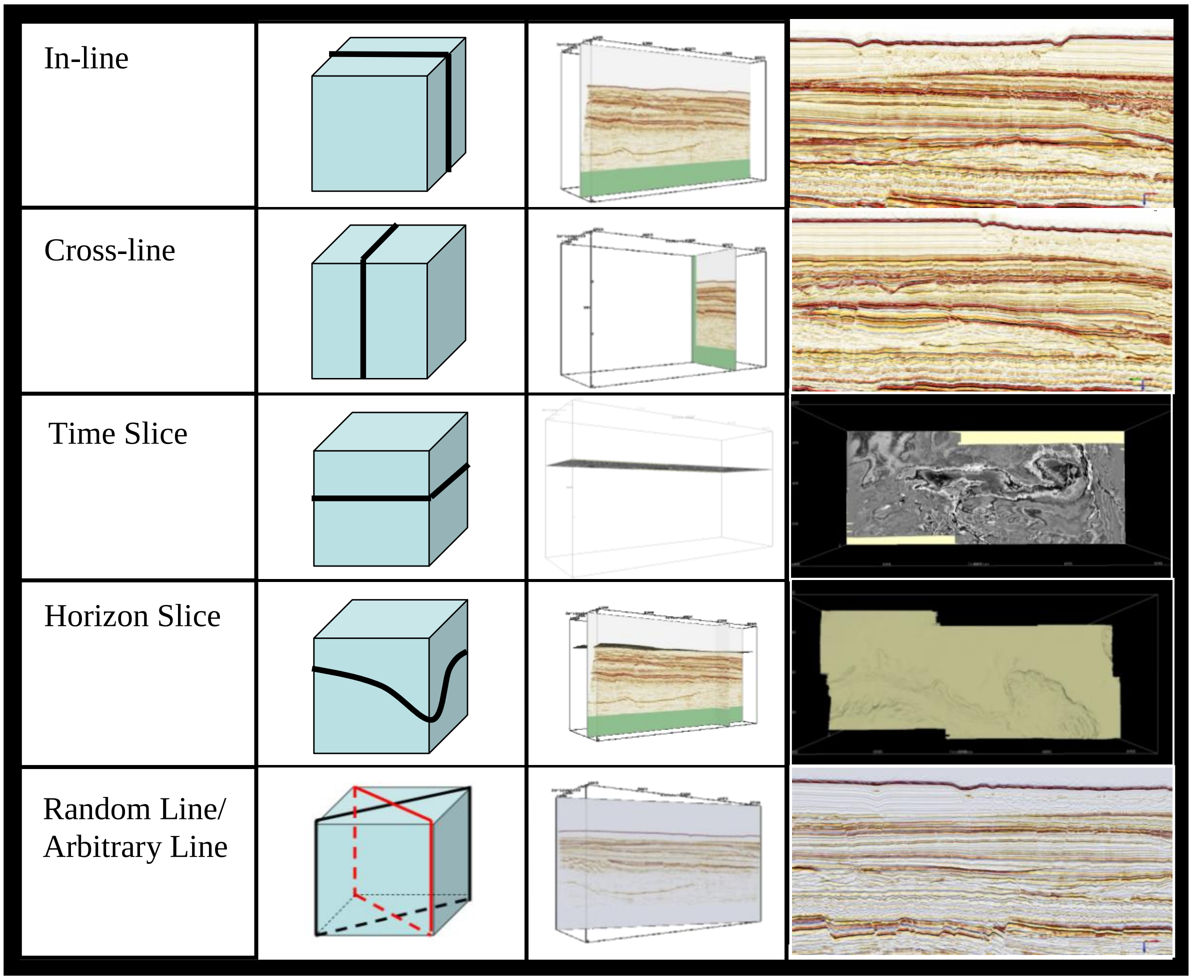


Figure 3-12: Examples of different methods of seismic slicing in this study.

To begin with, a seed or initial point is established as a reference or a datum. After that the rest of the lines can be picked by following the reference points. The seed points can be started where the seismic loop has good lateral connectivity and can be traced nearly all over the area, beginning with the vivid and traceable reflection first.

In the areas in which the seismic loop is bright, clear, unambiguous and has good connectivity, seed points is less frequent (Figure 3-13).

After the seed points are defined, glancing at the continuity through the whole area is unavoidable. Some seismic loops may be very bright and very easy to pick in a section (in-lines and cross-lines) in a particular area, but may impossible to track any further when the researcher moves to other areas or when views on other sections.

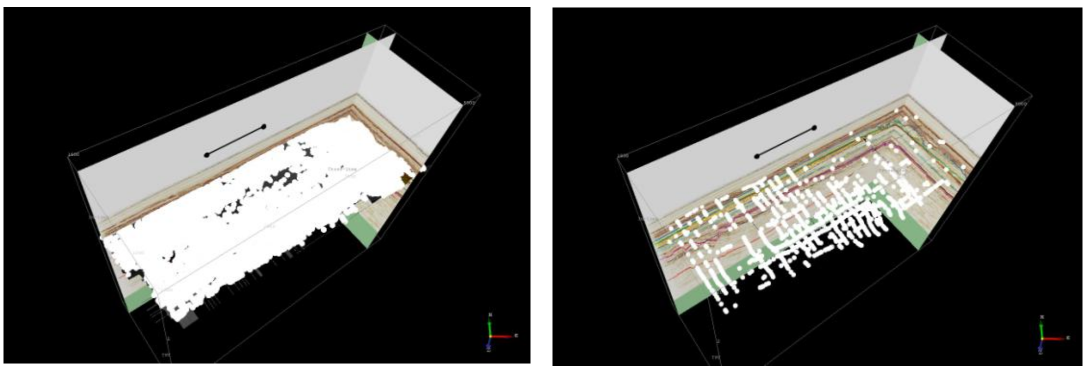


Figure 3-13: The seed points are shown in the little white dots. On the left picture, a number of the seed points are shown; however, on the right picture, quite a few of the seed points are shown. These are because the left horizon is more difficult to be picked due to weak continuity of the reflection, and vice versa to the horizon on the right picture. The black lines show the scale of 10 km in distance.

The Chandon 3-D volume contains 25 m in-line intervals and 12.5 m cross-line intervals. The in-line increment is 1 and the cross-line increment is 2. The in-lines are sliced parallel to the shelf edge, which is along strike. By contrast, the cross-lines are sliced perpendicular to the in-lines in the dip direction.

Before horizon slices are executed, picking horizons from vertical sections in in-lines, cross-lines and random or arbitrary lines must be done. However, given the limitations of the software in picking random lines, only in-lines and cross-lines are used for horizon picking in this study.

To obtain a time structural map, a horizon slice needs to be interpreted. To generate a horizon slice, uncountable vertical sections are picked; in-lines and cross-lines are picked in crisscross patterns (Figure 3-14).

Systematizing in horizon picking is also important. It makes life easier when the wrong horizon is picked, and later it can be corrected easily line by line.

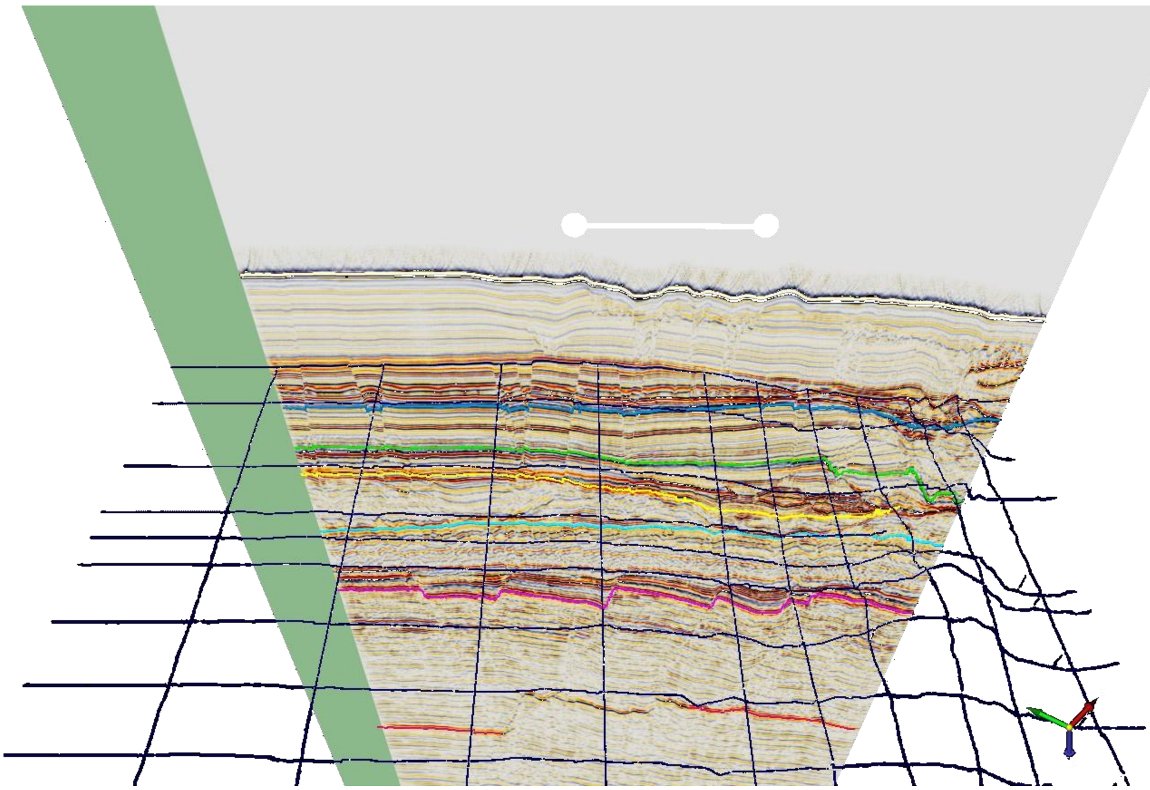


Figure 3-14: Horizon picking can be done crisscrossly. The white line with dot ends shows 4 km in distance.

In this study, many trials and errors have been carried out to compare the advantages and the disadvantages of using the extrapolating tool, also, to find the best and fastest way of generating a horizon slice. In addition, the software provides three options for the auto-tracking or auto-picking: tracking in volume, line tracking, and manual line tracking, and each of theses can be chosen to do extrapolation which is useful dramatically in ideal surfaces. (Generating an ideal horizon slice, the horizon that has bright reflection, is vivid and is continuous throughout, can be done quickly in a short time period less than 30 minutes.) On the contrary, the use of the extrapolating auto-picker can create a drastically messed up a surface (Figure 3-15). Thus, it is very necessary to re-check the picking correlation between the picked lines before generating a 3-D surface to avoid a critical mess, which increase the time required to solve the unpleased 3-D horizon.

Although the solving of an uneven area on a horizon slice, creating by 3-D generator, is torture (figure 3-16), it is crucial, since the next phase of using the horizon slice is mapping as well as geological modeling and well planning. Also, it is a common practice nowadays in planning a well on a horizon slice (after converting it into depth function).

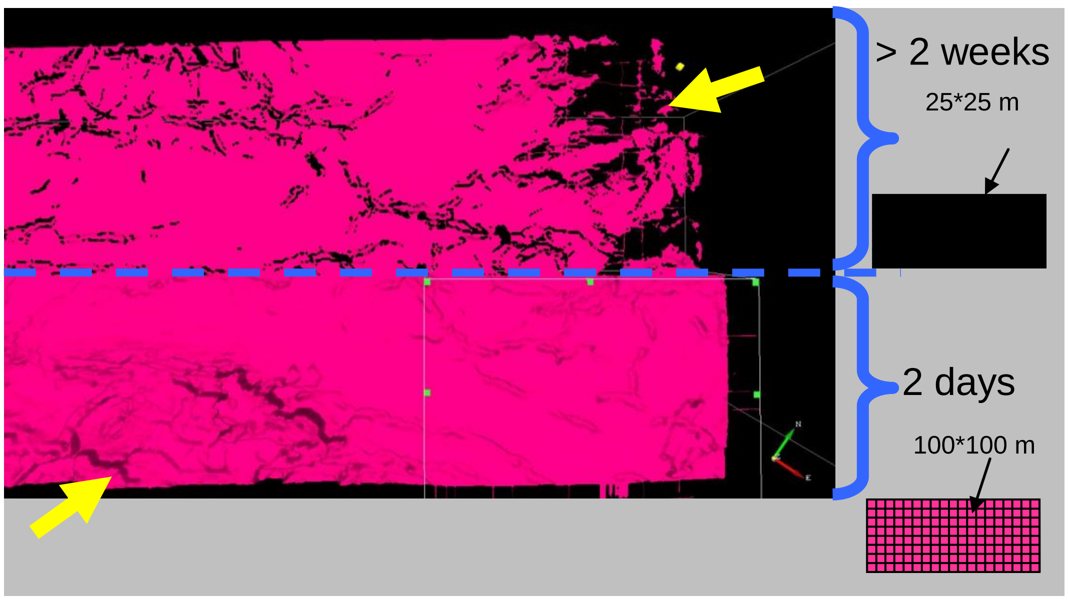


Figure 3-15: Non-extrapolation VS Extrapolation. The upper half of the pink horizon is a result of non-extrapolation approach. The non-extrapolation approach leaves behind the holes and the areas that are not picked properly from in-lines and cross-lines. The software will not push the 3-D auto-tracking to generate the unsure area. The lower half of the pink horizon is conducted by an extrapolation approach. None of the holes can be seen, as the 3-D auto-tracking do a very good job in binding all holes. However, the uneven area is created and required quite a long time to solve the bumpy feature. The areas pointed by the yellow arrows require quite some time to be solved.

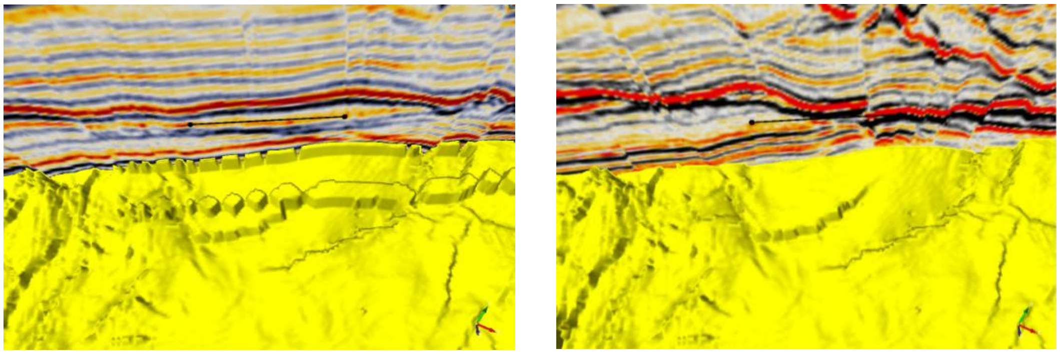


Figure 3-16: Pictures on the left and on the right sides show before and after QC the horizon slice (both pictures showing almost on the same vertical section, plus/minus 5 m). Scale in black is showing 1 km in distance.

3.4.2.2 Time Slicing

A time slice is a display of seismic data in horizontal view. It displays a horizon section on an exact time defined by the interpreter, regardless of structural feature or geological surface. It reveals only map view geometry. Therefore, a time slice does not show data referring to the stratigraphic level or structural dip presented (Figure 3-17).

Figure 3-17: Time slice at 1800 ms shows destroyed levees and splays. The line shown in red is 5700 m in distance. The green arrow points to the North.

3.4.3 Composite Seismic Profile

Composite seismic profile or a composite display is one of the advantages of 3-D seismic data. It is the combination of vertical section(s) and a horizon section. This provides a greater understanding of the relationship of the seismic reflections (Figure 3-18).

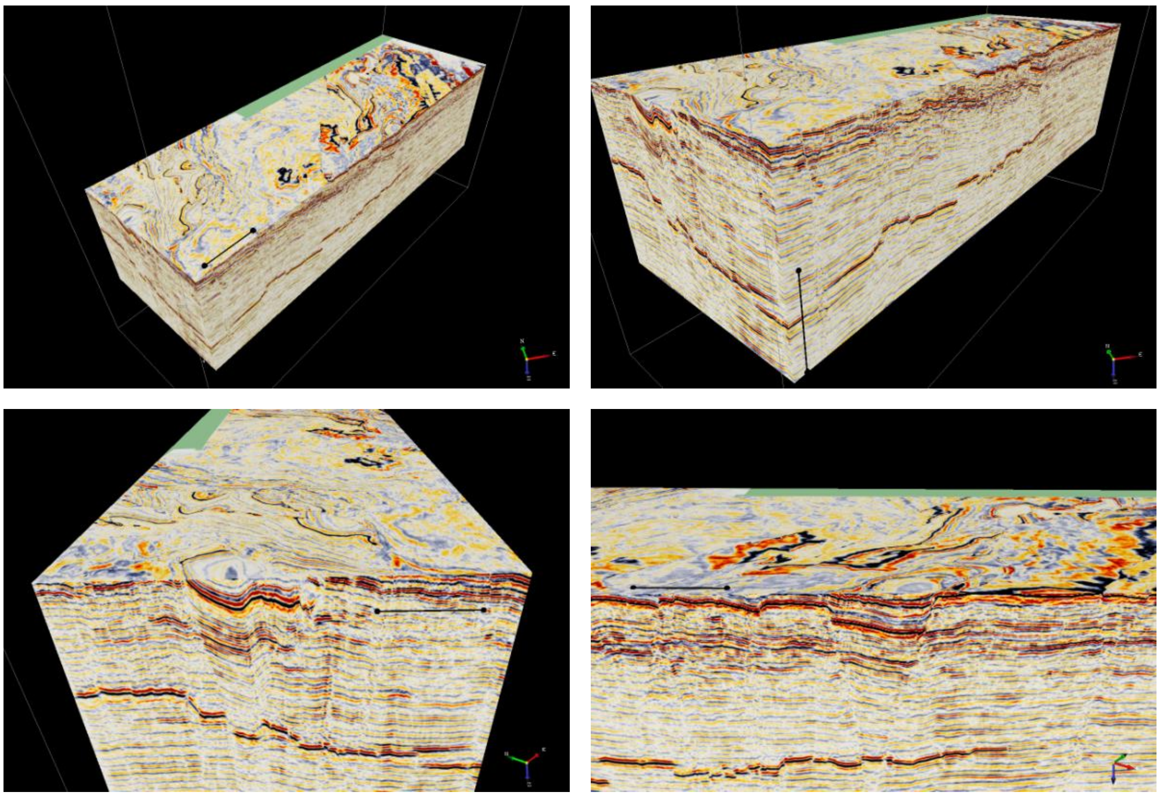


Figure 3-18: A composite seismic profile is shown from different directions. In this case the horizon section shown is a time slice at 3160 TWT, in line 1101 and cross line 1174. Scales shown are: in vertical direction 1000 millisecond; on the time slice 5.5 km in distance.

3.5 Mapping

A subsurface geological map is the most important tool which is used for petroleum exploration. As the seismic data used in this study are in the time domain, time structural map and isopach map are the ultimate outcomes. They will be illustrated in more detail in Chapter 4.

3.5.1 Time Structural Map

After a horizon slice has been created, a subsurface geological map can be generated later on. Subsurface structural mapping, which is geological and geophysical based relates to the availability of the data. In this study, unfortunately, the data are in TWT and the data from only one well are available. Due to the time constraints and the large volume of the area, faults have not been interpreted in the 3-D domain.

3.5.2 Isopach Map

An isopach map is a contour map illustrating variation thickness within a rock unit or stratum. An isopach map represents true stratigraphic vertical thickness between two strata. In this case, the isopach maps represent true vertical thickness in time of the two particular horizons.

3.5.3 Attribute Map

Seismic attributes are any data derived from seismic data. Measuring seismic data by conveying seismic attributes helps in visualization. It can reveal patterns and features that may be difficult to see on general horizon sections.

3.5.3.1 Amplitude

The amplitude attribute using in this study was the energy amplitude. It is a post-stack attribute that generated by the computation of the arithmetic mean of the amplitude of a trace within a defined time gate or window.

The usefulness of the amplitude attribute is that it helps to indicate direct hydrocarbon indicators. Moreover, it reveals other useful information pertaining to reservoir characteristics and field production, tectonic and structural geology, lithology and sedimentology of the area (Enachescu, 1993).

3.5.3.2 Spectral decomposition

Spectral decomposition can help refine geologic interpretation by extracting detailed stratigraphic patterns. It is used for thickness prediction. The thinner bed is captured by the higher frequency. On the contrary, the thicker bed is imaged by the lower frequency (Laughlin et al., 2003). Thus spectral decomposition is a useful tool to interpret sub-seismic resolution. In addition, spectral decomposition can be used for seismic geomorphology prediction and direct hydrocarbon prediction (Marfurt & Kirlin, 2001).

Partyka et al. (1999) explain the following:

Spectral decomposition provides a novel means of utilizing seismic data and the discrete Fourier transform (DFT) for imaging and mapping temporal bed thickness and geological discontinuities over large 3-D seismic surveys (Partyka and Gridley, 1997). By transforming the seismic data into the frequency domain via the DFT, the amplitude spectra delineate temporal bed thickness variability while the phase spectra indicate lateral geologic discontinuities. This signal analysis technology has been used successfully in 3-D seismic surveys to delineate stratigraphic settings such as channel sands and structural settings involving complex fault systems. (Partyka et al., 1999, pp. 353)

3.5.3.3 Coherence

The coherence cube was introduced to the world in 1995 by Amoco production Research (Bahorich & Farmer, 1995).

Coherence can help in mapping minor faults and depicting other stratigraphic anomalies clearly, on time or horizon slices. These images reveal data characteristics. As a result, the coherence cube can extract detailed features from the data cube with good efficiency (Manna et al., 2008).

In 3-D seismic data, coherence portrays the trace-to-trace similarity. Thus the changes of traces can be interpreted. Similar traces have high continuities; they are mapped with high coherence coefficients. On the other hand, different traces have low discontinuities; they are mapped with low coherence coefficients. As a result, sharp discontinuities can be seen along fault planes which are outlined by low coherence (Chopra, 2002).

Niestanak et al. (2007) state the following:

Coherency attribute is one of the proper tools in interpretation of structural discontinuities and stratigraphy features in 3-D seismic data. Coherency measurements in three dimensions discuss trace-to-trace similarity and therefore represent interpretable changes in these cases. The similar traces are mapped with high coherence coefficients while anomalies and discontinuities have low coherence coefficients. Coherency attribute shows evaluation criterion of lateral changes in the seismic response, caused by variation in structure, stratigraphy, lithology, porosity and the presence of hydrocarbon. Output of this attribute is a coherence cube which illustrates structural discontinuities and stratigraphy features with higher resolution (Niestanak et al., 2007, pp. 48).

Nissen (2007) illustrates how to generate a spectral decomposition and a coherence attribute as shown in Figure 3-19 and 3-20.

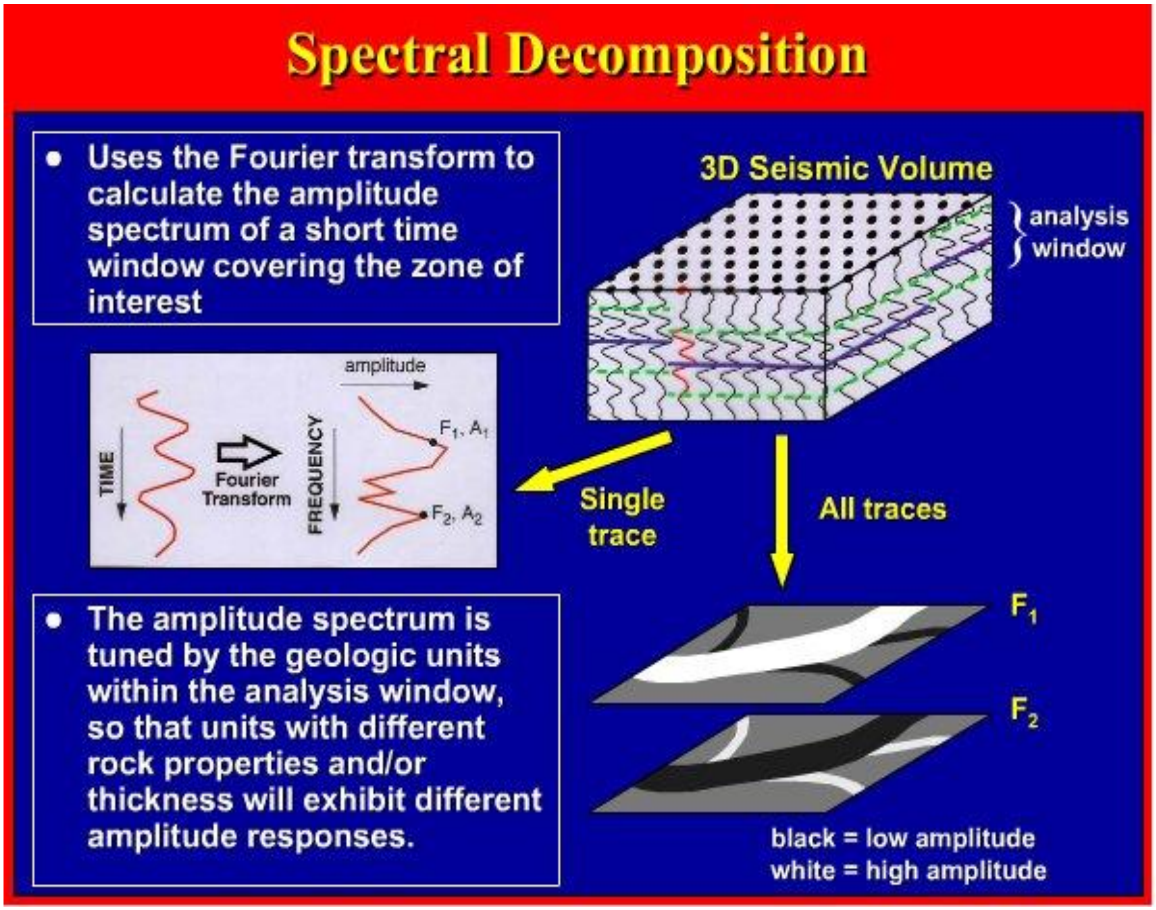


Figure 3-19: The method to generate a spectral decomposition attribute is illustrated by Nissen (2007).

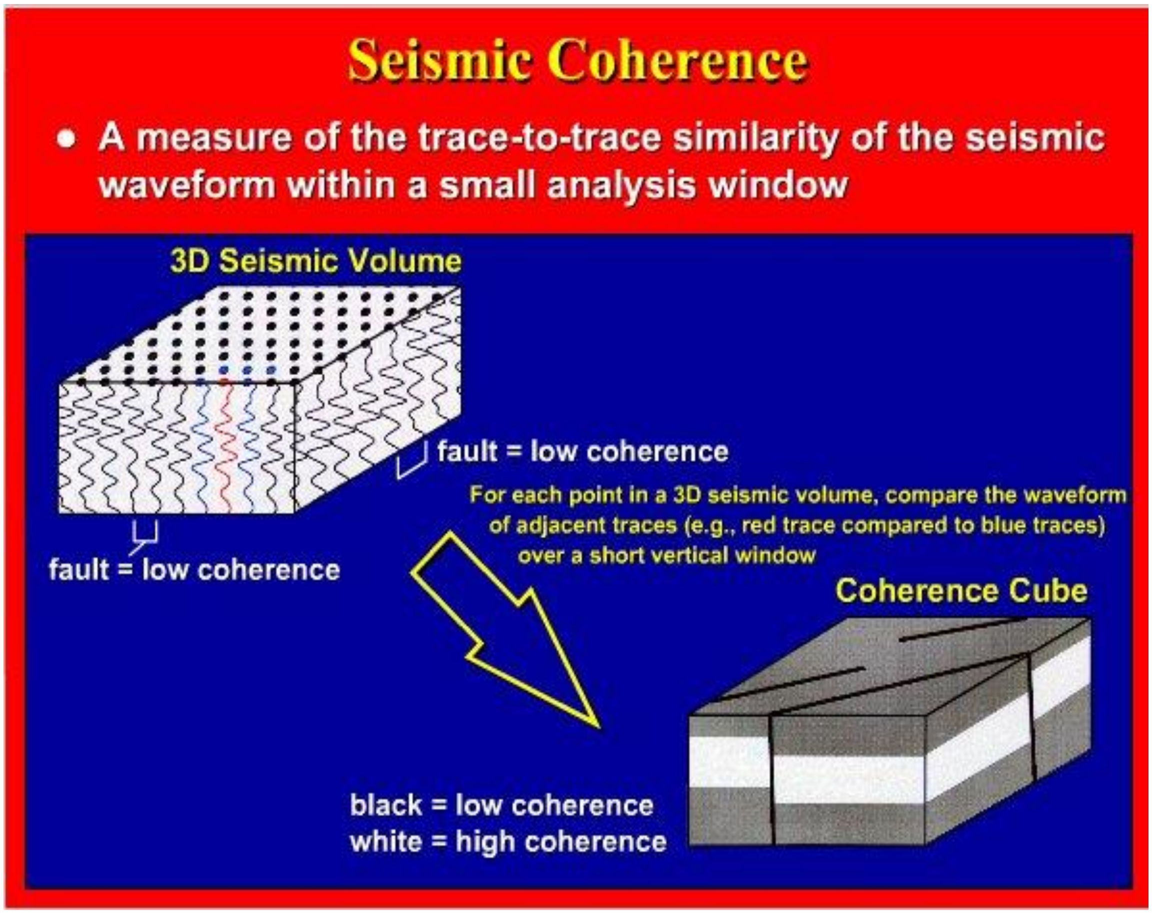


Figure 3-20: The method to generate a coherence attribute is illustrated by Nissen (2007).

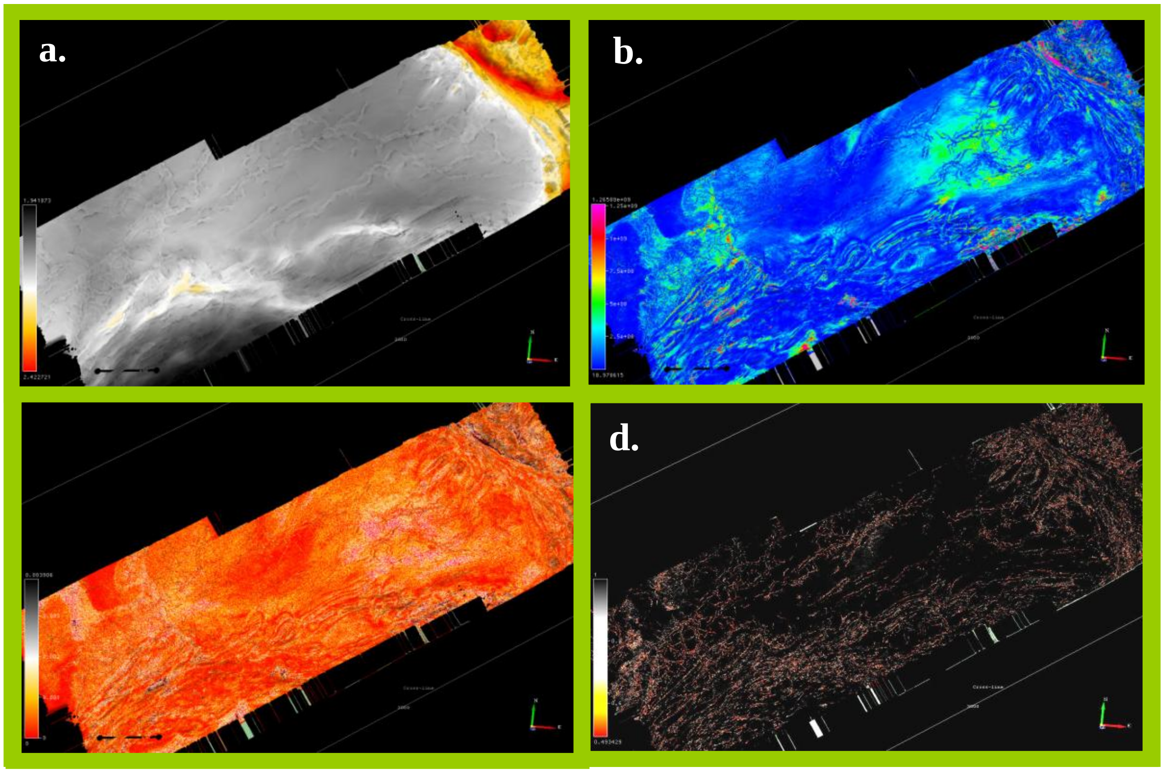


Figure 3-21: Comparison of 4 different attributes: z value (a), amplitude (b), spectral decomposition (c), and coherency (d). Scale bars show 5.2 km in distance.

Chapter 4

Interpretation of Seismic Stratigraphy

This chapter shows the results of seismic sequence stratigraphy on seismic data from Chandon Field in the Exmouth Plateau. Geologic history can be interpreted from seismic reflections. Recognition of seismic reflections is mostly interpreted based on the intervening surfaces between seismic sequences, which may include erosional surface, transgressive surface, and unconformity.

4.1 Interpretation based on seismic reflection

4.1.1 Un-interpreted and Interpreted in-line and cross-line

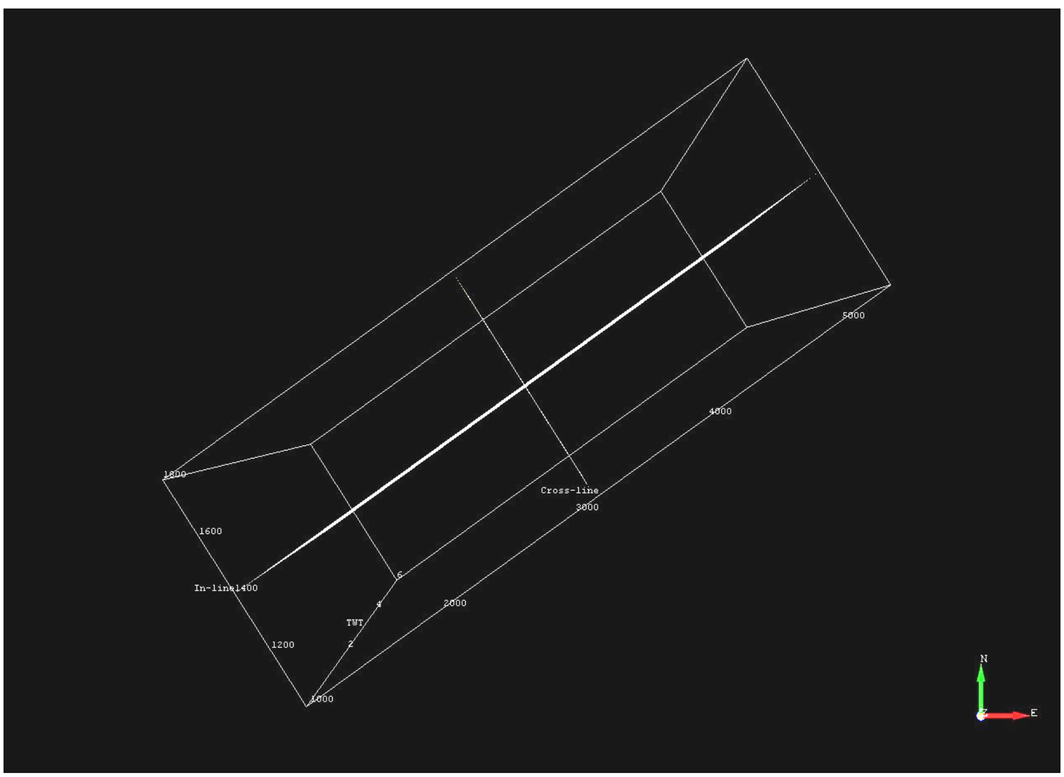


Figure 4-1: Location of seismic vertical sections from a bird’s-eyed view, in-line 1400 and cross-line 3150.

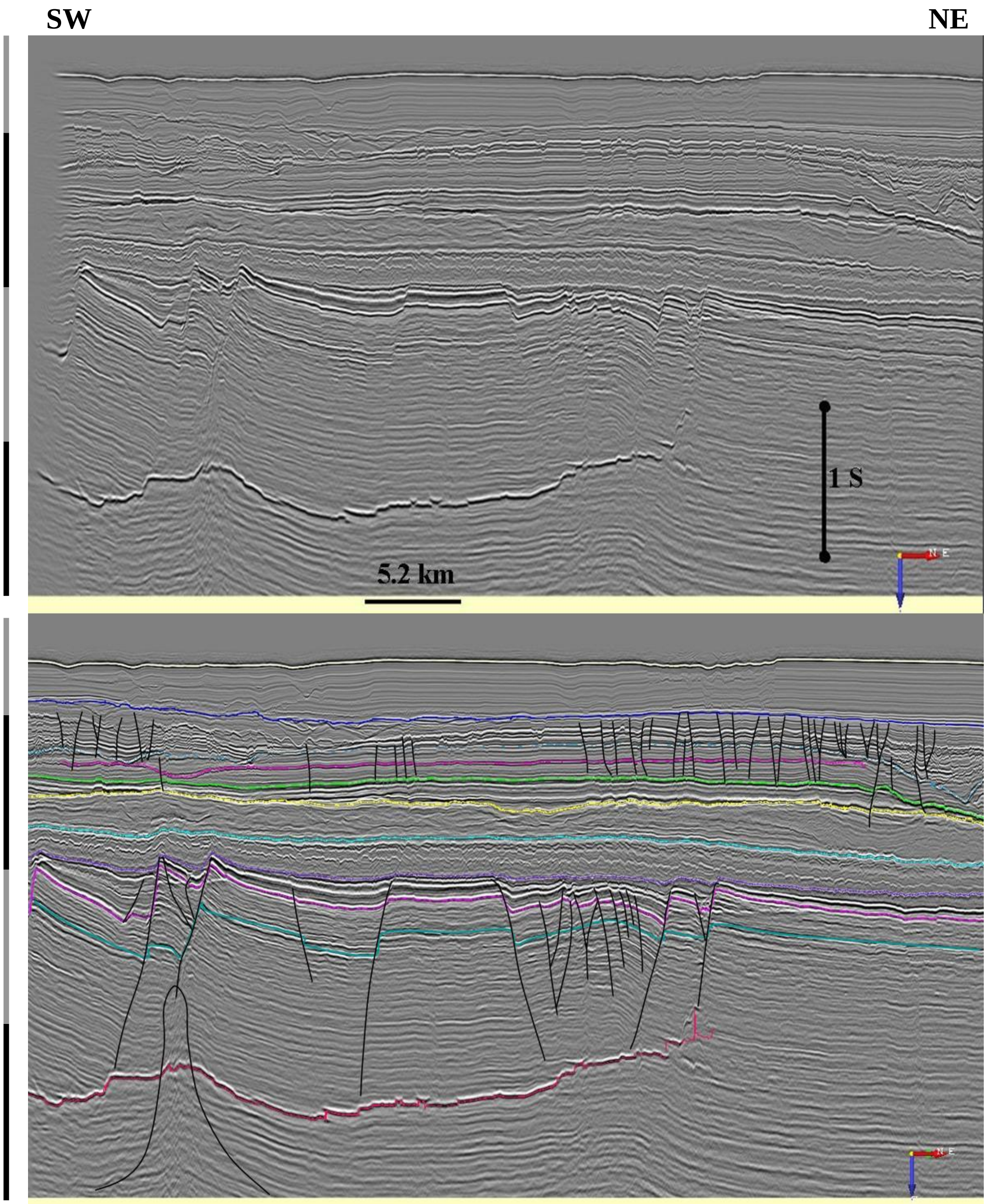


Figure 4-2: Seismic vertical section of in-line 1400. The vertical scale on the left side shows TWT between 1370-5000 milliseconds.

Up: Un-interpreted section

Down: Interpreted section

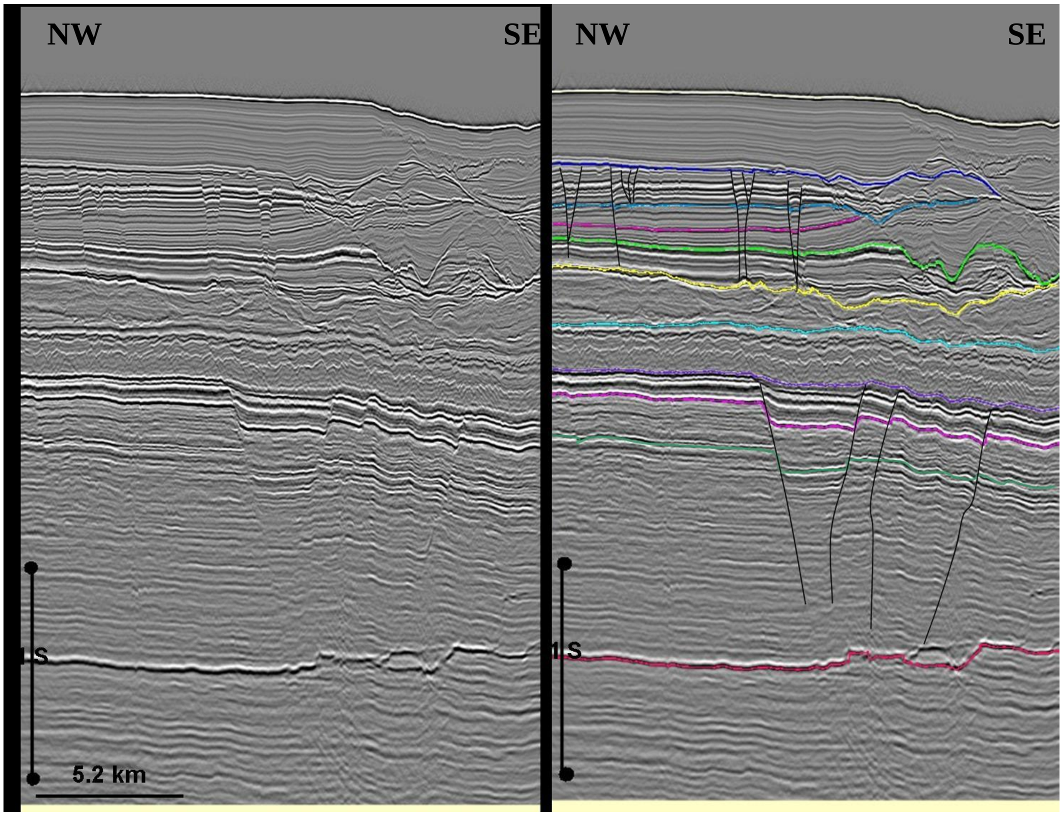


Figure 4-3: Seismic vertical section of cross-line 3150.
Left: Un-interpreted section
Right: Interpreted section

4.1.2 Seismic Reflections and Seismic Units

Seismic reflections or seismic horizons extracted from Chandon Field have been divided into 11 horizons/reflectors (Figure 4-1). The reflectors have been numbered 1 through 11. They will be depicted as horizon slices later in chapter 5. However, due to the impossibility of tracking, Horizon 1* will be shown only in the vertical sections. Seismic horizons are described from bottom to top.

Ten seismic units can be distinguished between the 11 horizons. Due to limited subsurface data, the first seismic unit is identified from the seismic sequence above the first intervening reflector. Horizon slices, which are the outcome of the combination of the horizon picked from numerous in-lines and cross-lines, are displayed on a map view, and different kinds of attributes are introduced by being overlaid on the slices. All 10 horizon slices are named so that they directly relate to what they were called for horizons, except that Horizon slice 1* is not interpreted as a horizon slice.

The time structural map from each of the horizon slices is shown and followed by illustration of different attributes. The attributes are z-value, spectral decomposition, amplitude and coherency. Later, the attribute that occupies interesting geomorphological features is close-up presented. Further more, this chapter also gives some examples of time slices from particular times. It would be interesting to investigate time slices in more detail by using different attributes; however, this is beyond the focus of this study.

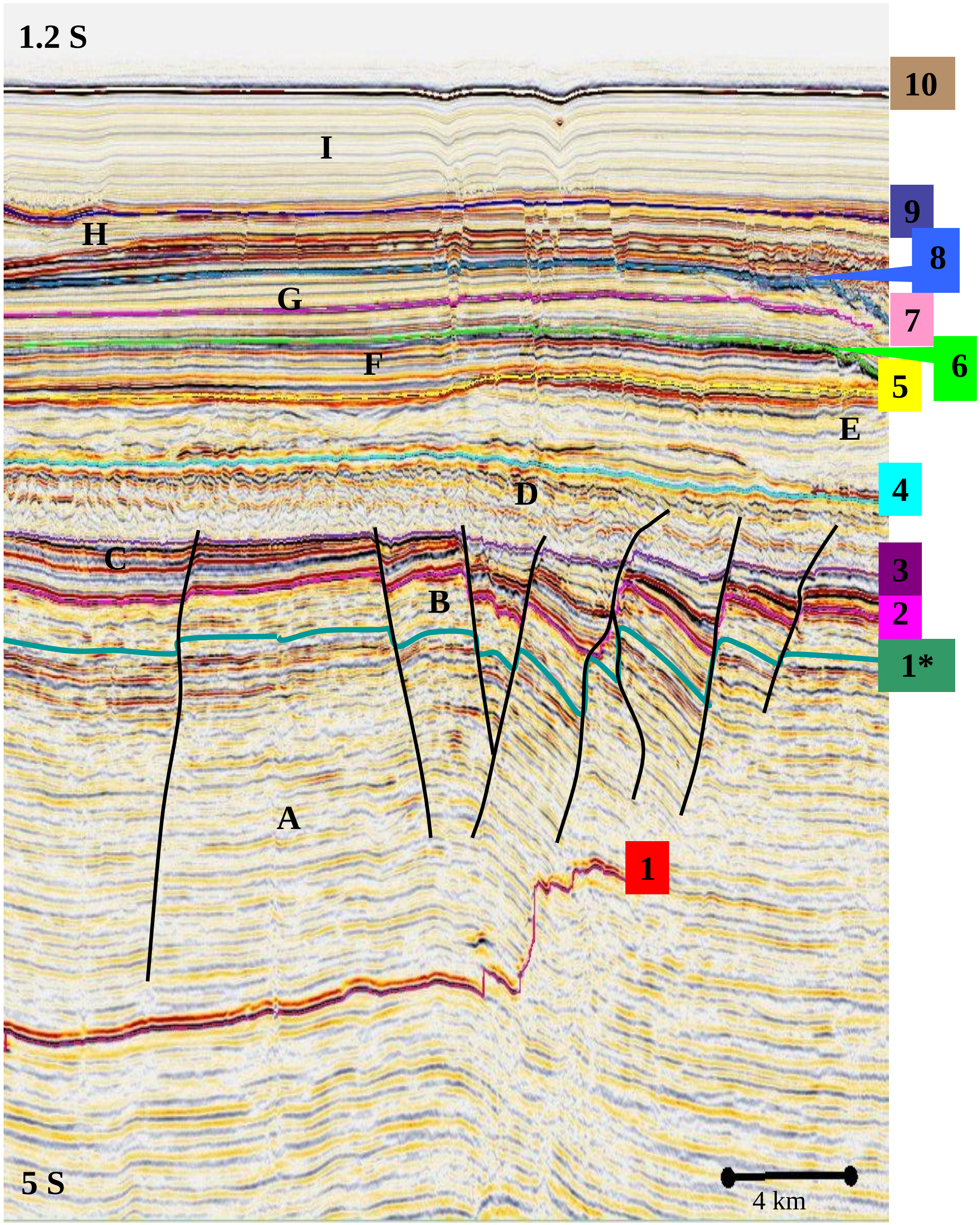


Figure 4-4: Seismic vertical section from part of inline 1490, showing Horizon 1 to Horizon 11.

4.1.2.1 Horizon 1: Intra-Triassic

Horizon 1 is the undermost horizon, which represents a point in time during the Triassic Age. This horizon exists in the range between 4000 ms and 5000 ms. The seismic reflection in this horizon is very bright; however, it lacks lateral continuity and vanishes in about 25% of the area to the northeast. In some areas, the reflections are obscured by faulting and intruding of volcanic activity (Figure 4-5).

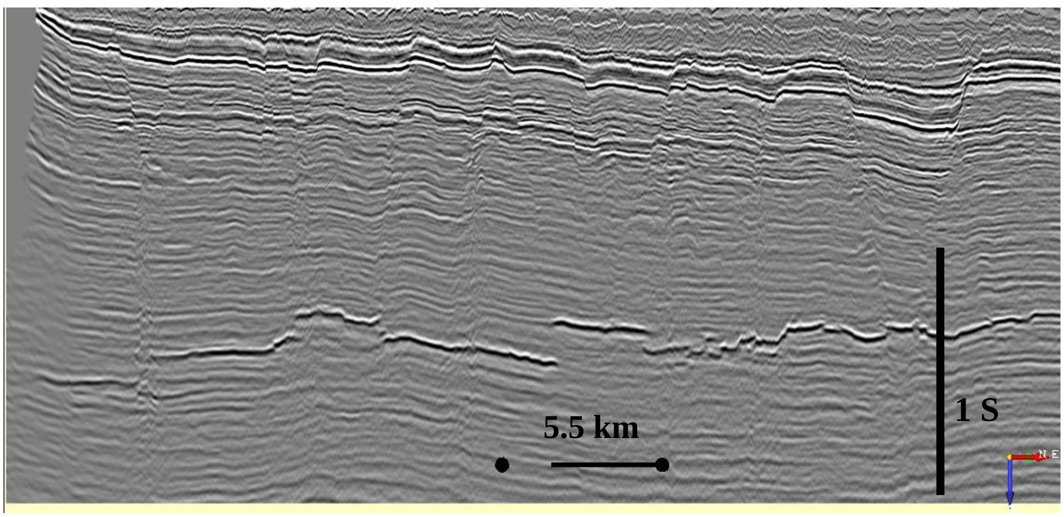


Figure 4-5: The reflection of Horizon 1 is very bright. However, the reflections are obscure in some areas (in-line 1100).

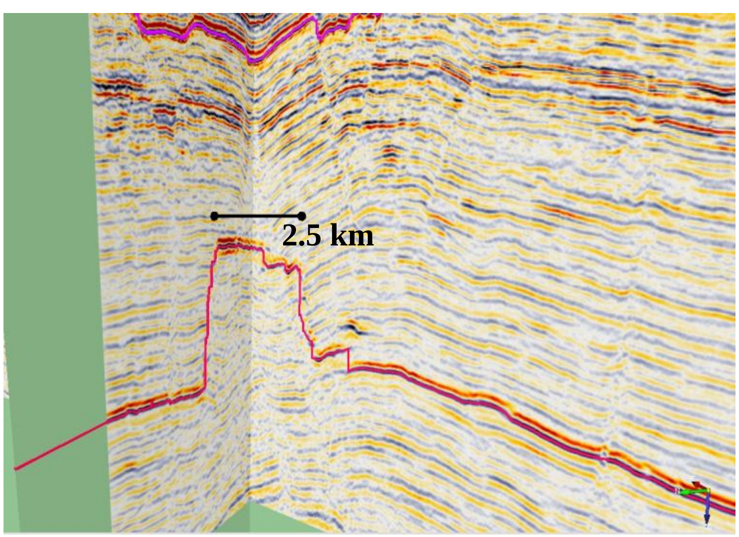


Figure 4-6: The intersection of seismic lines between cross line 3868 and inline 1490 shows intrusion of volcanic rock through Triassic Period.

4.1.2.1.1 Horizon Slice 1

A horizon slice is a seismic horizontal section which reveals the top view of a horizon in vertical sections, so that geomorphology can be investigated. The Horizon Slice 1 is a result of the interpretation of Horizon 1 in the whole area.

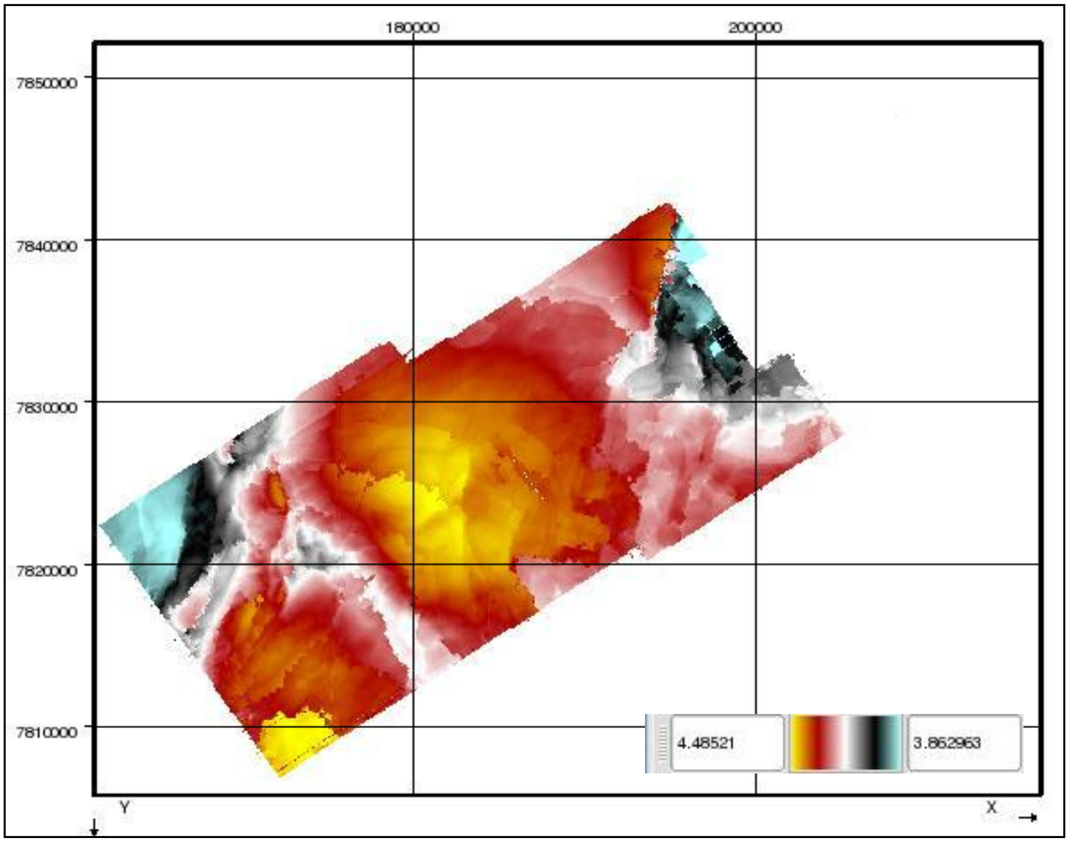


Figure 4-7: Time Structural map of Horizon Slice 1.

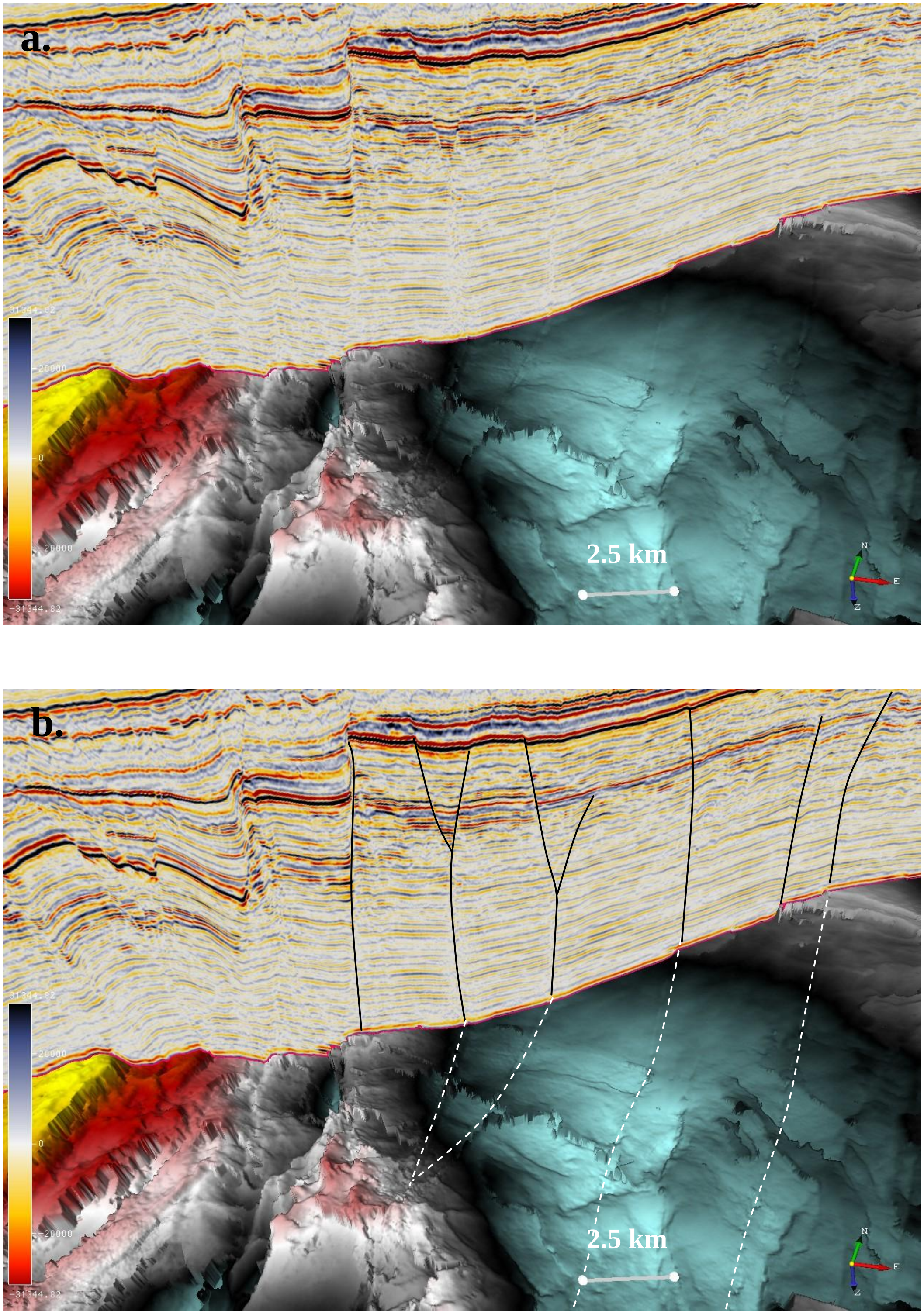


Figure 4-8: Intersection between Horizon 1 and inline 1680 (a), and intersection between Horizon 1 and inline 1680 with interpretation of faults seen on the Horizon Slice (b).

4.1.2.1.2 Unit A

Seismic Unit A is the area between Horizon 1 (red) and 1* (cyan). It grows thicker in a southwest direction. Unit A is located in horst and graben setting. The activity of faults can be clearly seen in this unit. The seismic section suggests the unit was cut later by faults, and is in a post-sedimentary fault setting. In addition, the fault throw seems to be equal on each side of the faults. According to Powell (1982), Unit A is the thick Triassic sequence (up to 3000 m thick), which consists of fluvio-deltaic sediments. This sequence expanded throughout the Northwest shelf area.

In some areas, the Unit A was intruded by gas from the sequences below, causing a feature called gas chimney as shown in Figure 4-9.

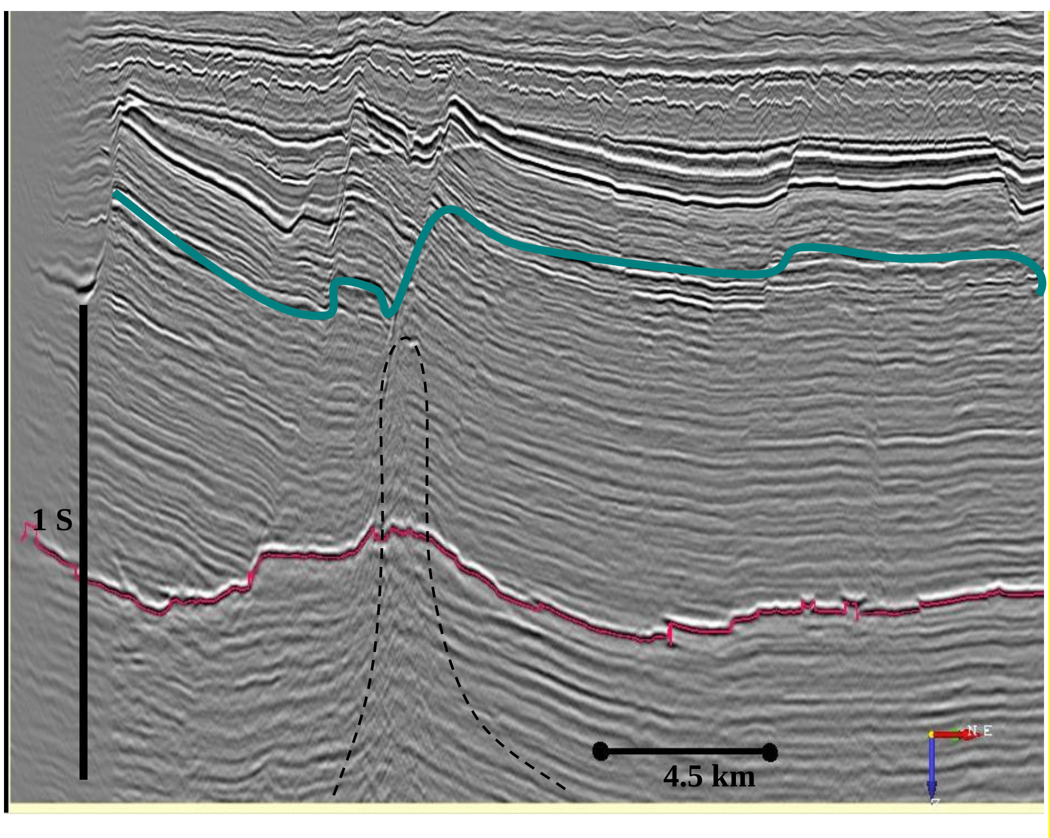


Figure 4-9: A gas chimney is shown in the in-line 1400.

4.1.2.2 Horizon 1*: Late Triassic

Horizon 1*, the cyan horizon, can be seen at 3500 ms on average. The amplitude reflects poor to moderate connectivity. Tracing this horizon in detail was not easy as it was quite difficult to distinguish the horizon apart from the units above and below when zoomed in. However, in a particular vertical section it can be easy to recognise. This horizon marked the top of the first tilting blocks, indicating a pre-rift stage.

4.1.2.2.1 Unit B

Seismic Unit B is the area between Horizon 1* (cyan) and Horizon 2. The seismic features are more or less the same as those in Unit A, except Unit B is clearly seen in horsts and grabens. The thickness of Unit B is between 180 and 250 ms thick, and is thinner to the northeast but thicker to the southwest. This unit was probably pre-rift sediment that was deposited during the Late Triassic Age (Falvey, 1974). This unit was revealed to be composed of fluvio-deltaic sediment in most areas (Exon et al., 1982).

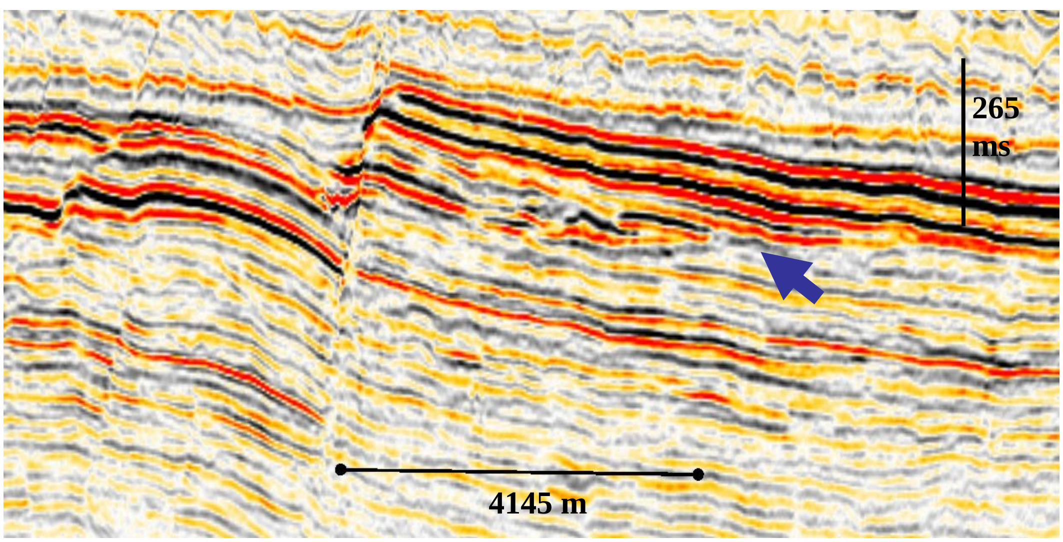


Figure 4-10: Direct Hydrocarbon Indicator (DHI), in this case a “flat spot” from inline 1320 (1320/4110), shows gas-water contact (GWC) in Unit B.

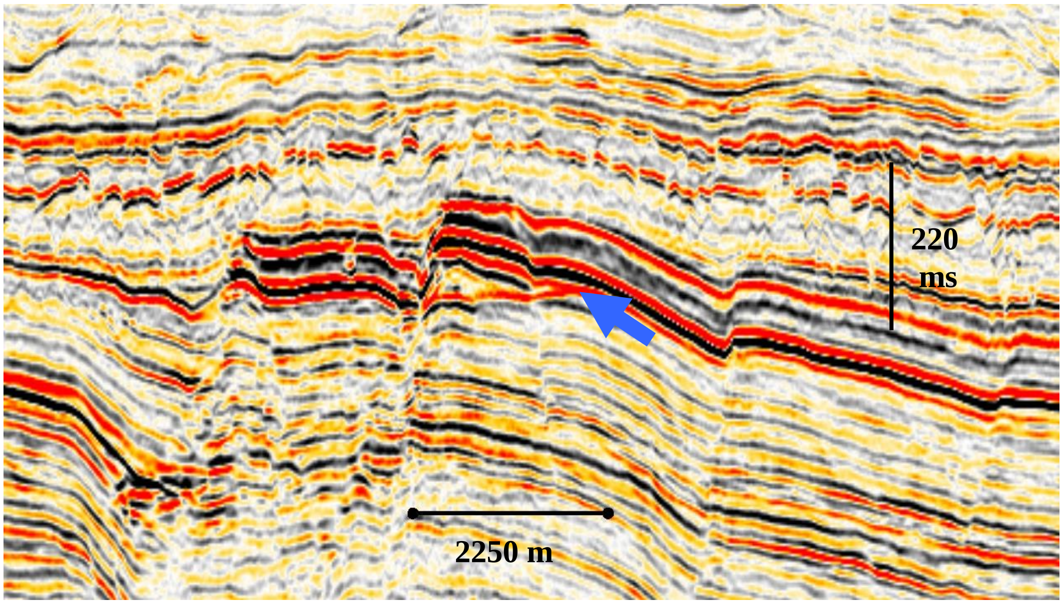


Figure 4-11**:** Direct Hydrocarbon Indicator (DHI), in this case “flat spot” from inline 1320 (1320/1954) shows gas-water contact in Unit B.

4.1.2.3 Horizon 2

In Figure 4-4, Horizon 2 is shown in pink. It appears nearly conformable to the previous horizon, Horizon 1*. Horizon 2 is heavily cut by faults, mostly of which are normal faults. The occurrence of normal faults suggests that the area was stretched. This horizon was interpreted as pre-rift stage.

4.1.2.3.1 Horizon Slice 2

A horizon slice is a seismic horizontal section which reveals the top view of a horizon in vertical sections, so that geomorphology can be investigated. The Horizon Slice 2 is a result of the interpretation of Horizon 2 in the whole area.

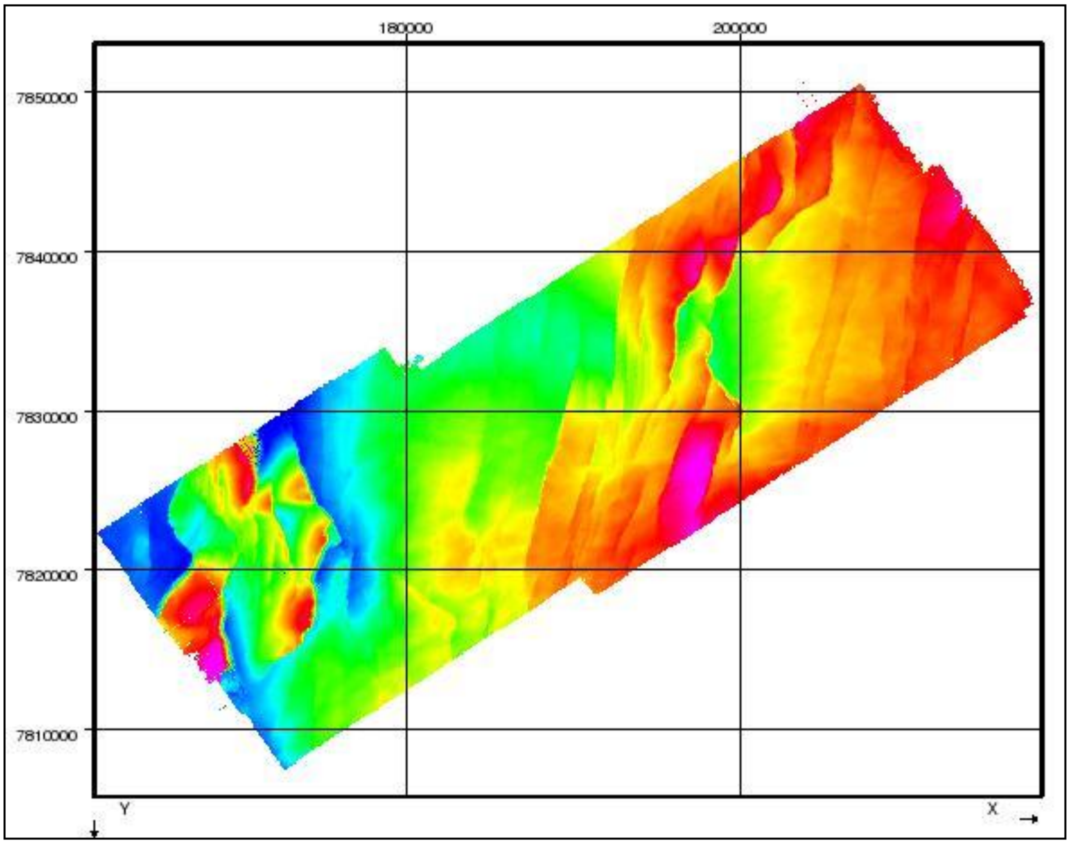


Figure 4-12: Time Structural map of Horizon Slice 2.

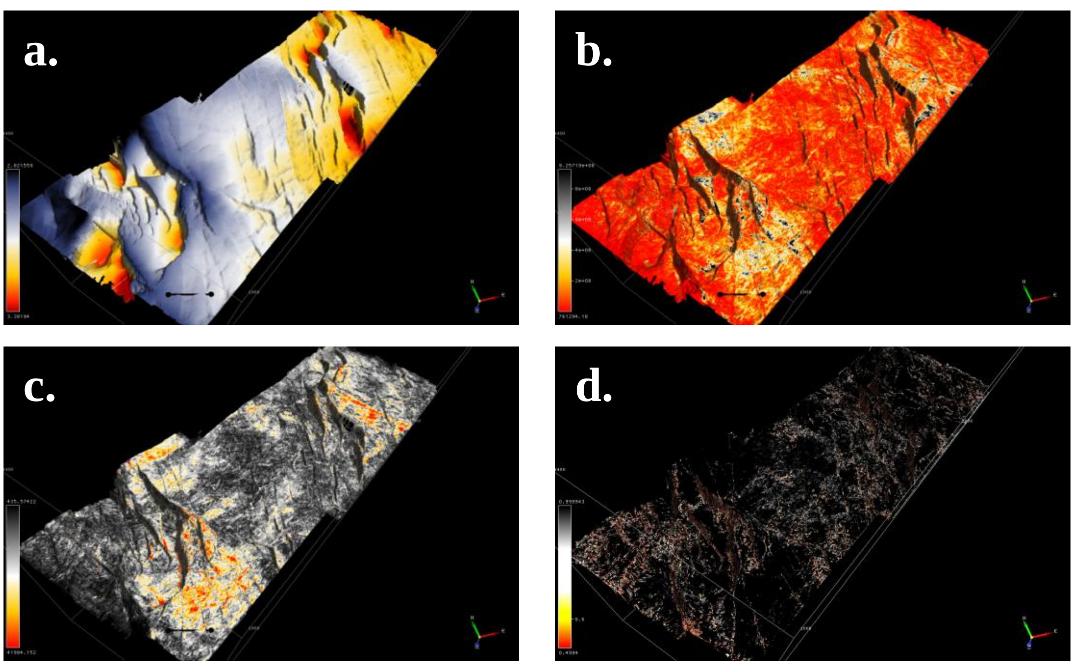


Figure 4-13: Different kinds of attributes of Horizon Slice 2: z value (a), amplitude (b), spectral decomposition (c), and coherency (d). Scale bars show 3.5 km in distance.

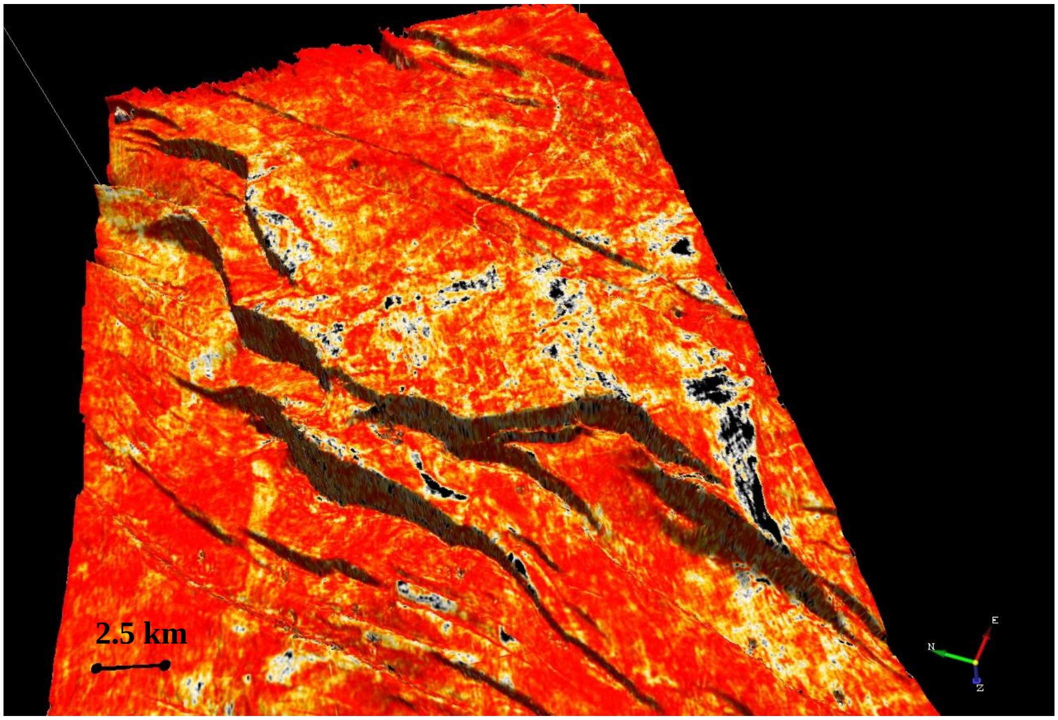


Figure 4-14: Amplitude map of Horizon Slice 2. Anomalies are shown in black.

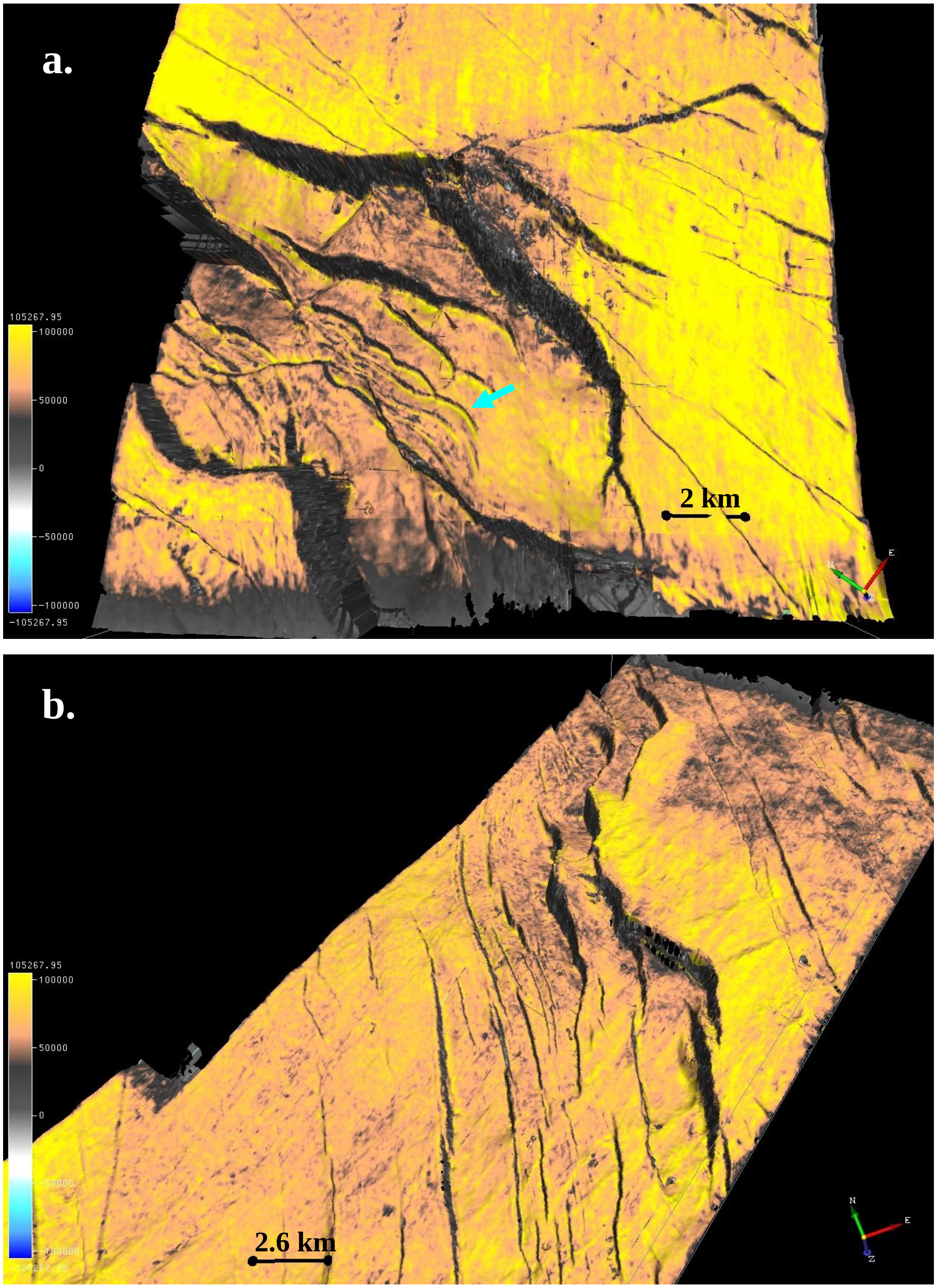


Figure 4-15: Reactivation of faults is shown (a). 3-D seismic interpretation suggest normal faults are curves (b). Fault scarps can be clearly seen on Horizon Slice 2.

Horizon Slice 2 is the top Mungaroo Formation of the Late Triassic. It is the main reservoir of the field. To define a new target, combination of Horizon Slice and seismic vertical sections is recommended. In order to decrease the uncertainties, different kinds of seismic attributes were used to compare the result. As shown in Figure 4-16, picture a. is Horizon Slice 2 with Z-value attributes superimposed on it. The dotted blue circle shows the higher area than the vicinity in yellow, is also represented in different view as Figure 4-16b. Figure 4-16c, shows gas-water contact in the blue-dashed line which confirms the existing of hydrocarbon in the area and it is in line with the high area represent in yellow when using a seismic attribute.

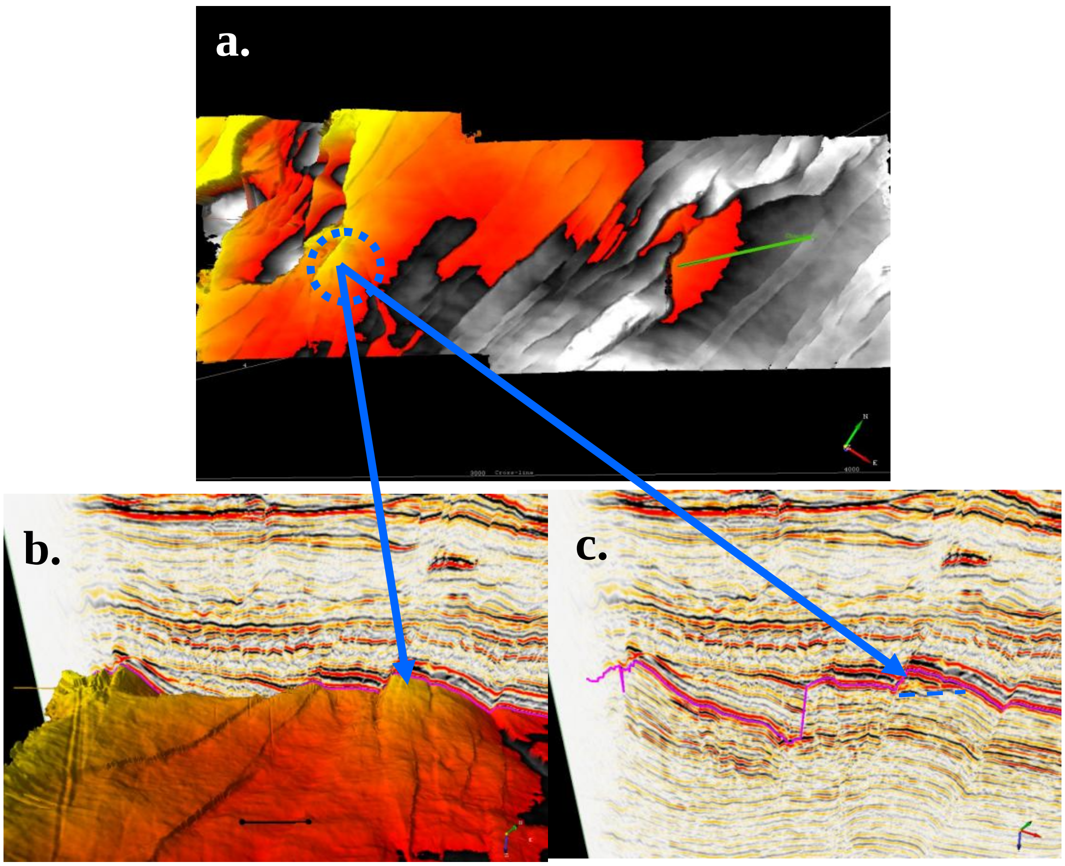


Figure 4-16: a. Over view of Horizon Slice 2, the green line is the location of Chandon-1. The blue-dashed circle hints the area of a new hydrocarbon target. b. The yellow area from the blue-dashed circle is shown with a seismic vertical section. c. The same seismic vertical section represent GWC with the blue-dashed line. Scale is shown 3 km.

4.1.2.3.2 Unit C

Seismic Unit C is the area between Horizon 2 (pink) and Horizon 3 (violet). High amplitude with strong reflection can be seen all over the area except in half-graben areas. The seismic features in Unit C are generally parallel to the horizon below. Unit C is clearly seen in horsts, grabens and half grabens causing variability in the thickness of the sediment. Some growth faults can be seen in Unit C (Figure 4-17). This represents a syn-tectonic deposition or a syn-sedimentary deposition in an extensional structural style regime. This indicates that the sediment was deposited during the same period as the plateau was stretched. According to Exon et al. (1982) Unit C was deposited in the Callovian Period. Consequently, Unit C was planed off by Horizon 3.

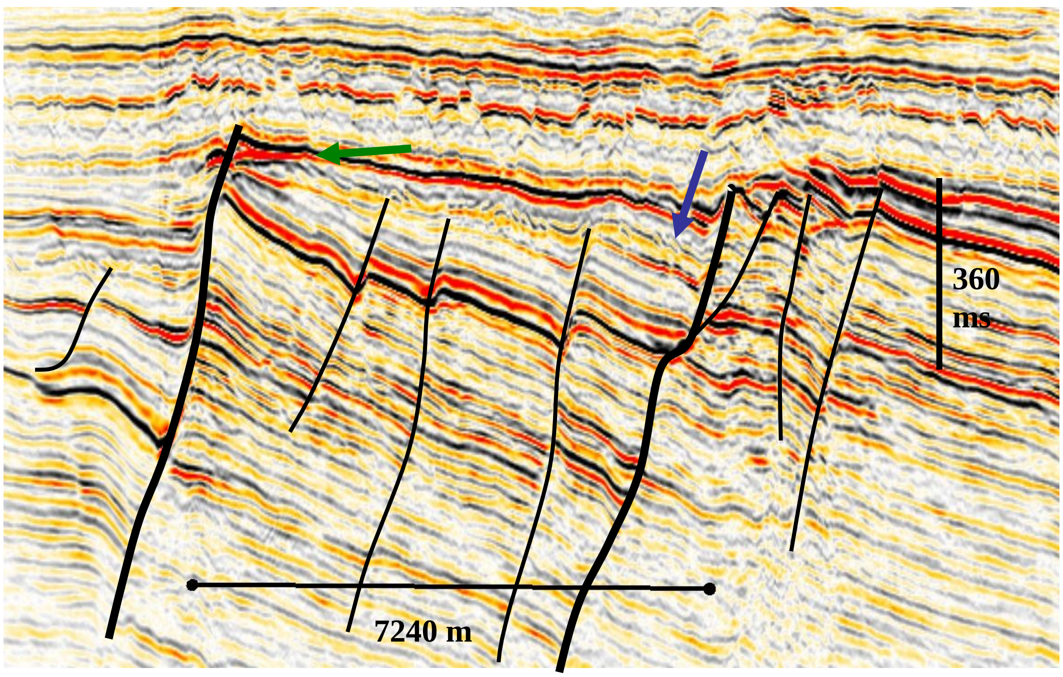


Figure 4-17: In-line 1450, sediment deposited in a half-graben as a result of syn-sedimentary fault or a growth fault in Unit C, indicated by the blue arrow. Hydrocarbon moved up to the crest of the structure GWC, shown by the green arrow.

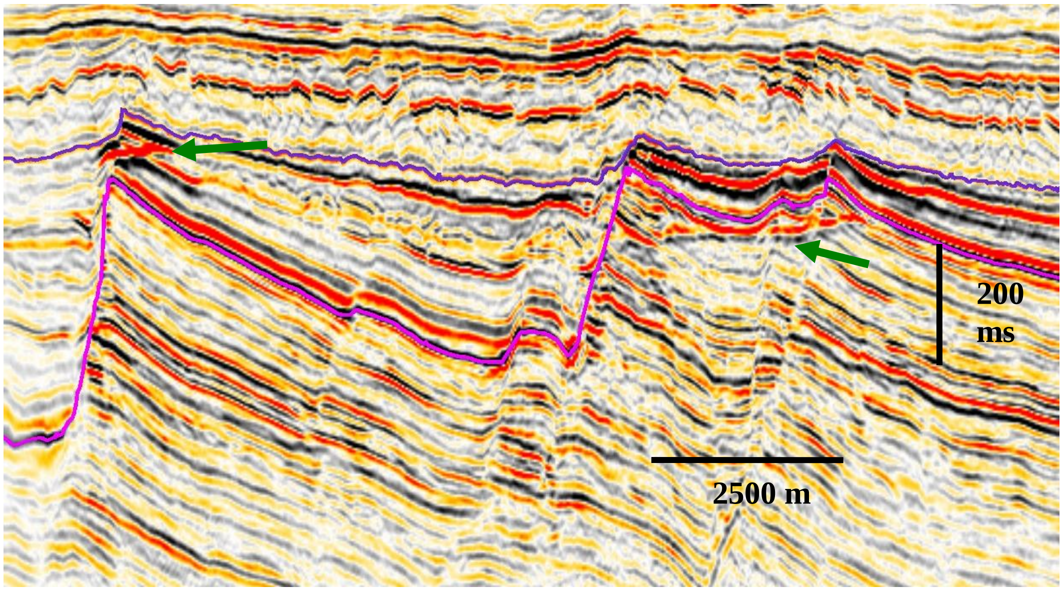


Figure 4-18: In-line 1420, arrows show two flat spots in Unit C (left) and Unit B (right).

4.1.2.4 Horizon 3

In Figure 4-2 to 4-4, Horizon 3 is coloured in violet. The amplitude is no longer conformable to the previous horizons. No fault activity penetrates through this horizon. This horizon planed off the horsts and irregular seismic features beneath it between the Late Jurassic and Early Cretaceous times (Exon et al., 1982). Evidence supports the claim that Horizon 3 is the breakup unconformity in this area. In addition, Horizon 3 was found to have formed in the Late Jurassic, Oxfordian Age.

The basal Oxfordian unconformity has been widely referred to as the Main Unconformity; however, it is diachronous from the basal Jurassic to the Aptian from place to place (Jablonski, 1997). It is also called the 'Intra-Jurassic Unconformity' (Sibley et al, 1999).

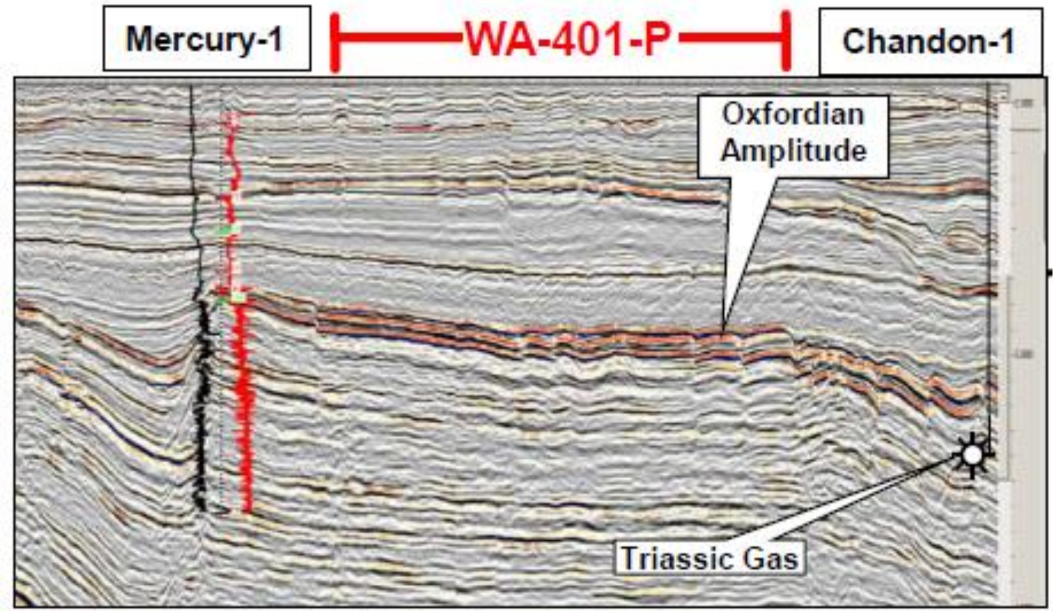


Figure 4-19: Offset well data reveal the age of Horizon 3, which is the breakup unconformity in Oxfordian.

4.1.2.4.1 Horizon Slice 3

A horizon slice is a seismic horizontal section which reveals the top view of a horizon in vertical sections, so that geomorphology can be investigated. The Horizon Slice 3 is a result of the interpretation of Horizon 3 in the whole area.

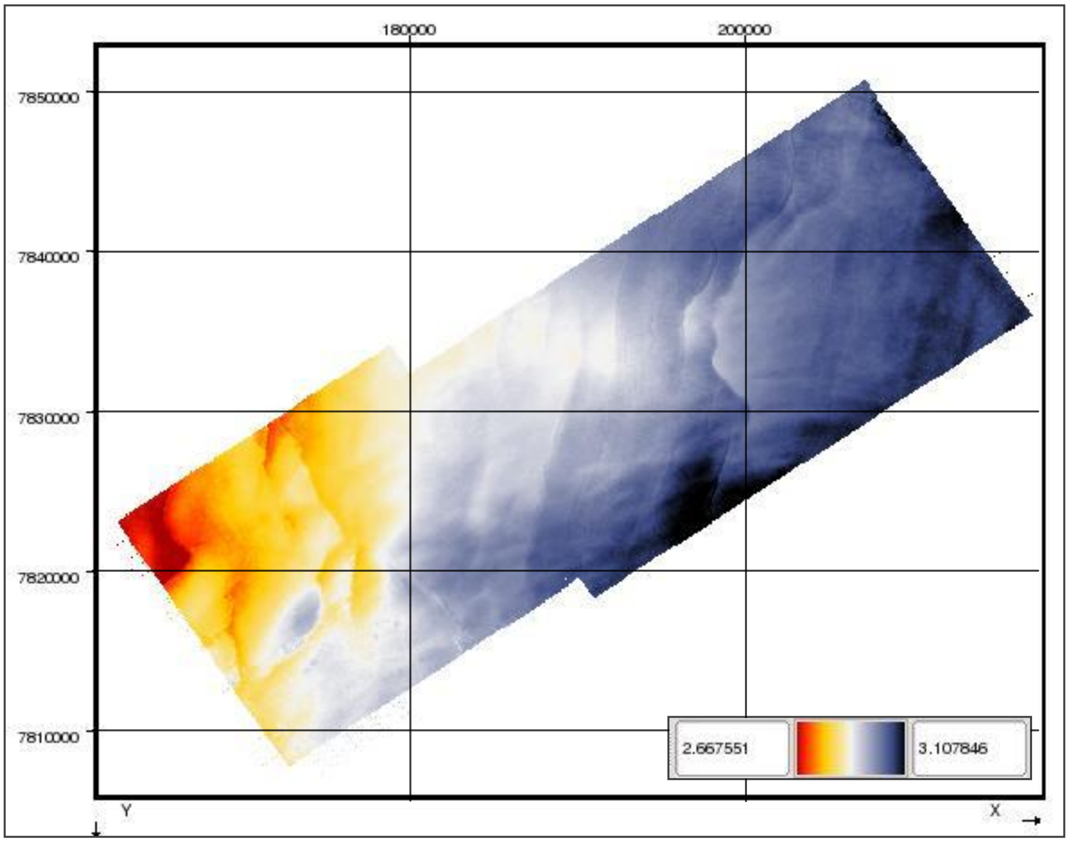


Figure 4-20: Time Structural map of Horizon Slice 3.

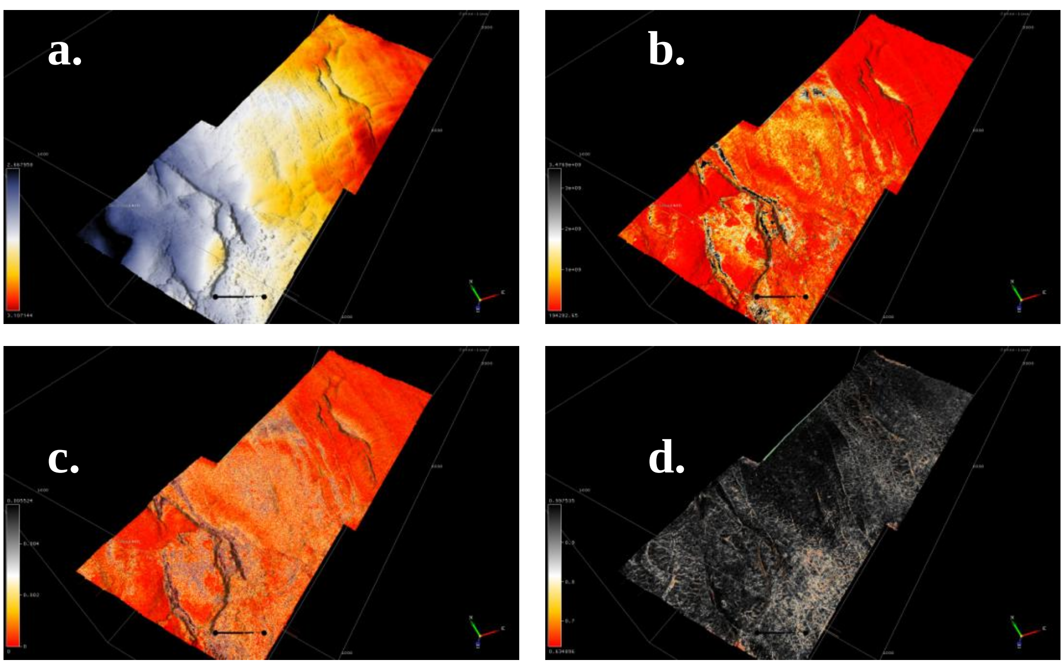


Figure 4-21: Different kinds of attributes of Horizon Slice 3: z value (a), amplitude (b), spectral decomposition (c), and coherency (d). Scale bars show 4.4 km in distance**.**

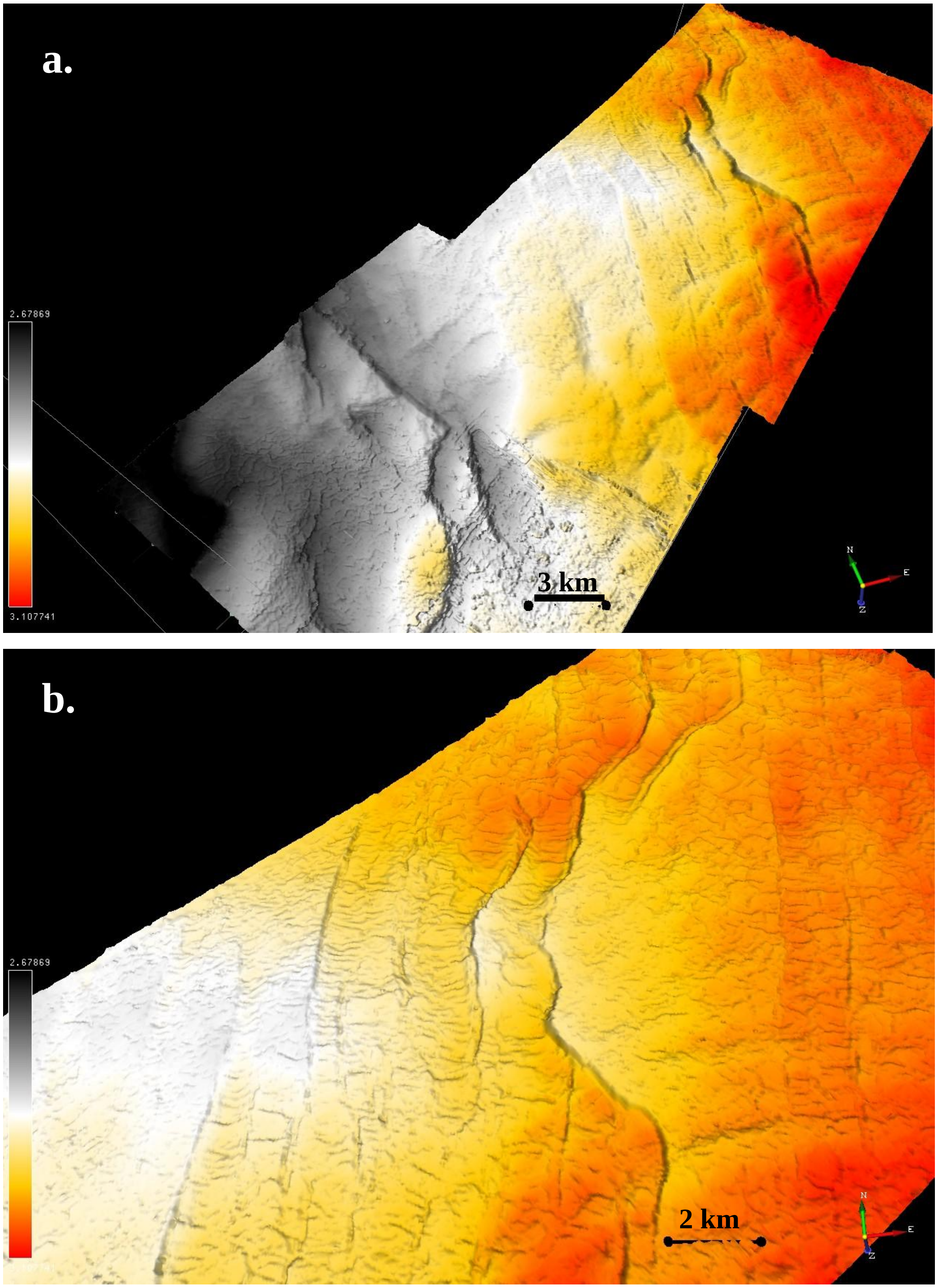


Figure 4-22: Overview of Horizon slice 3 is shown (a), and zoomed in to show soft sediment texture (b).

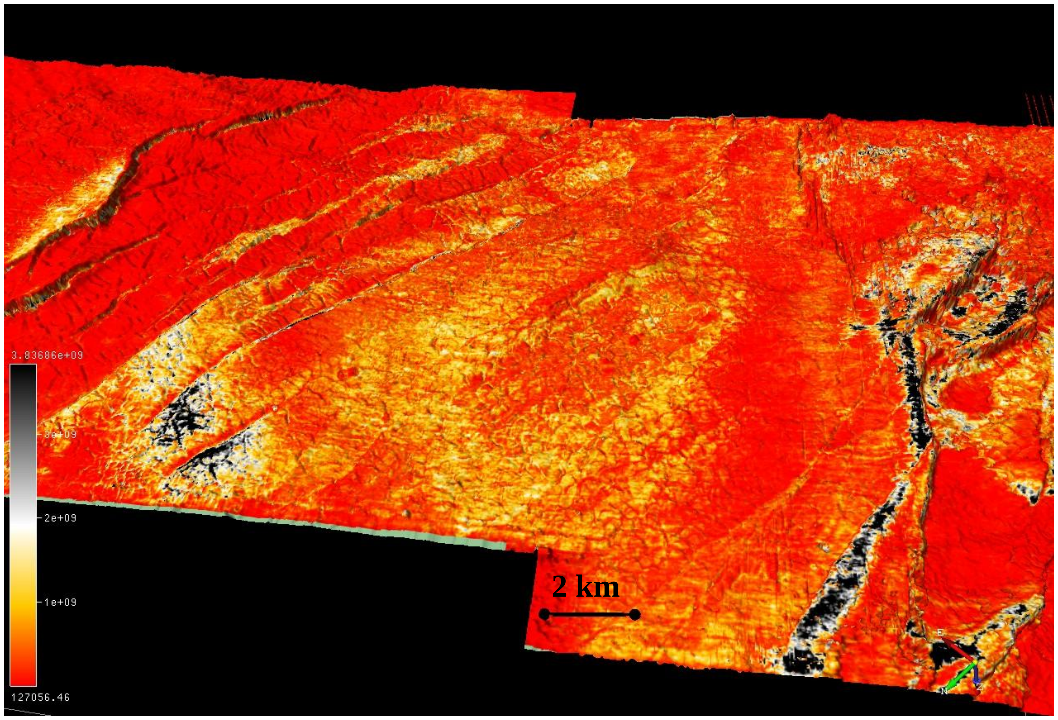


Figure 4-23: Amplitude attribute of Horizon Slice 3, anomalies are shown in black.

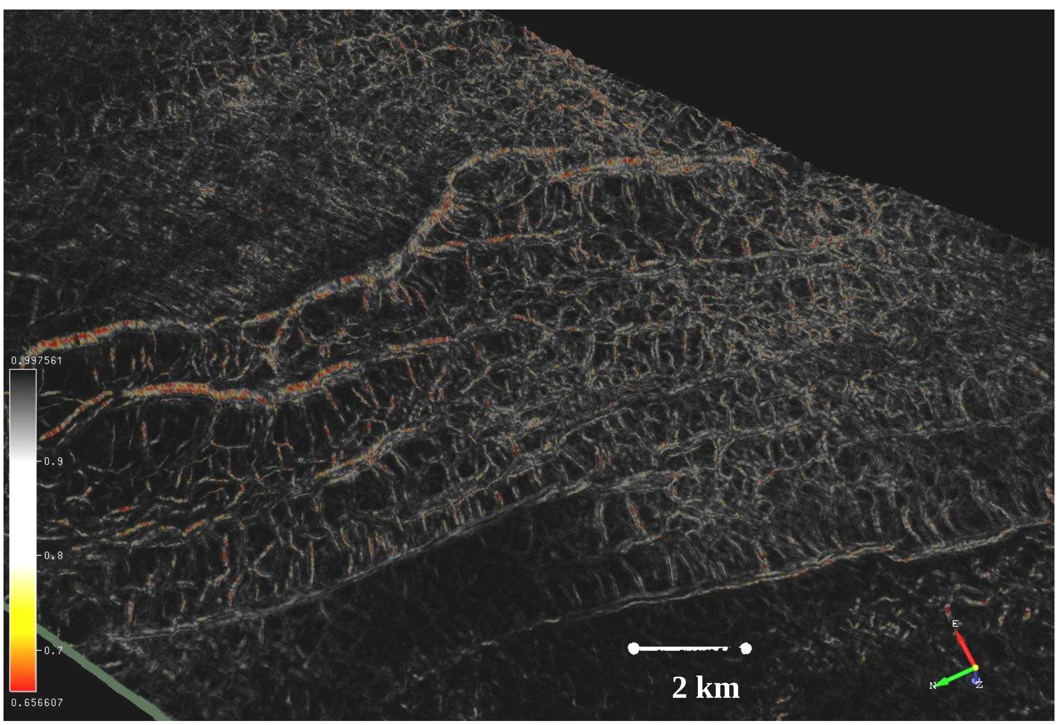


Figure 4-24: Coherency attribute of Horizon Slice 2, cracking features are revealed by the white and the red color. The areas that have good connectivity are shown in black.

4.1.2.4.2 Unit D

Unit D is situated between Horizon 3 (violet) and Horizon 4 (blue as shown in Figure 4-25). Unlike the previous units, Unit D shows the features of fine-grained sediment deposit which were broken in small pieces by small scale faults. Also, it acted like a blanket which is covering the whole area. This unit is probably the transgressive marine shale that covered most parts of the Exmouth plateau during the Early Cretaceous.

4.1.2.5 Horizon 4

Horizon 4 is shown in blue. It clearly separates the lower unit from the upper unit. Although the amplitude is weak to moderately bright with low visibility in some parts, it has excellent continuity all over the area. Most parts of this horizon are in low to moderate contrast to the amplitude above and below; however, there is a high contrast in some regions as shown in Figure 4-25. Picking in high contrast versus low contrast affects the smoothness of the horizon. Greater contrast in amplitude makes a smoother horizon. On the other hand, in the areas with poor amplitude contrast, irregular features were generated.

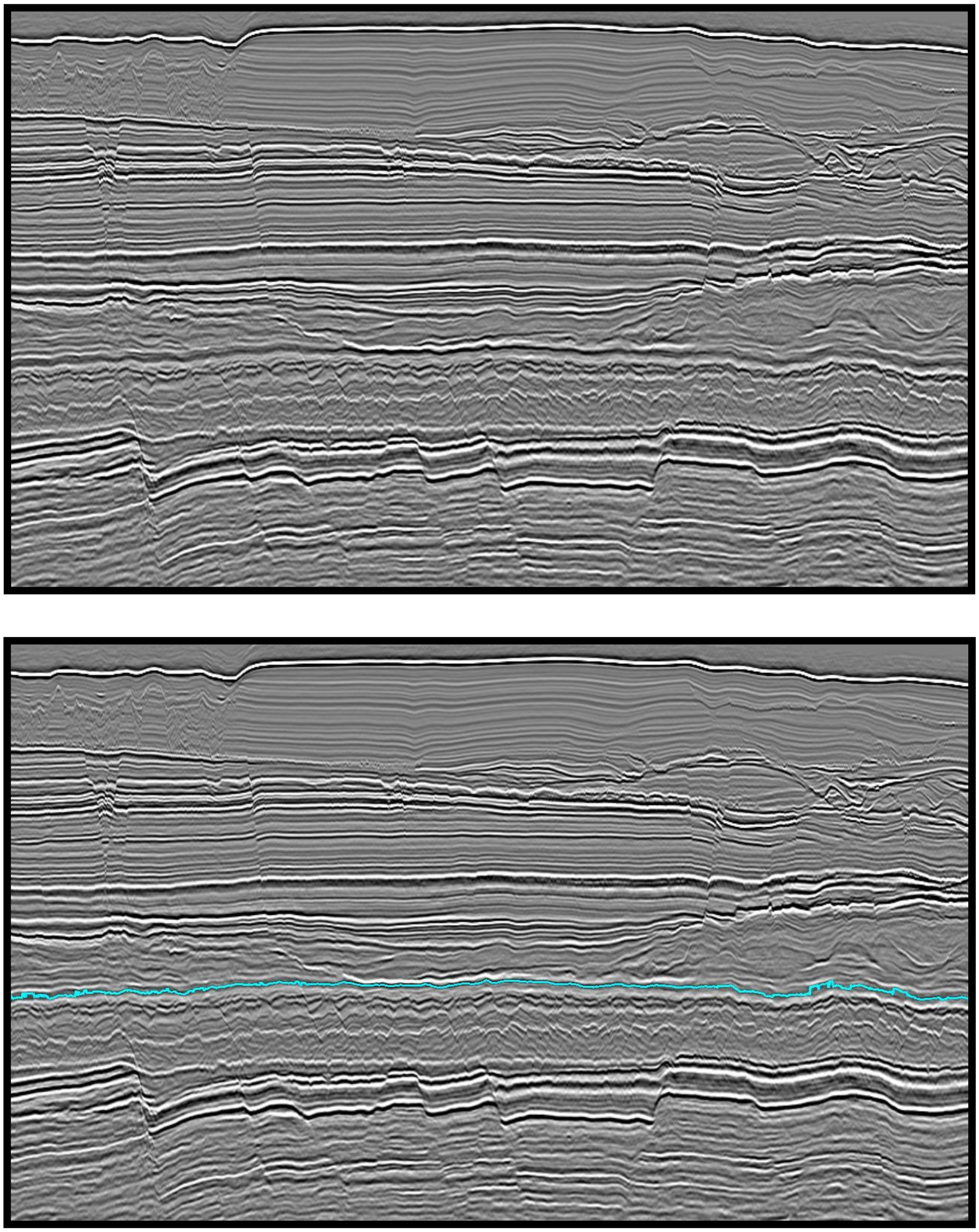


Figure 4-25: Different degrees of smoothness of Horizon 4 caused by picking in high contrast and low contrast area.

a. Un-interpreted data
b. Interpreted data

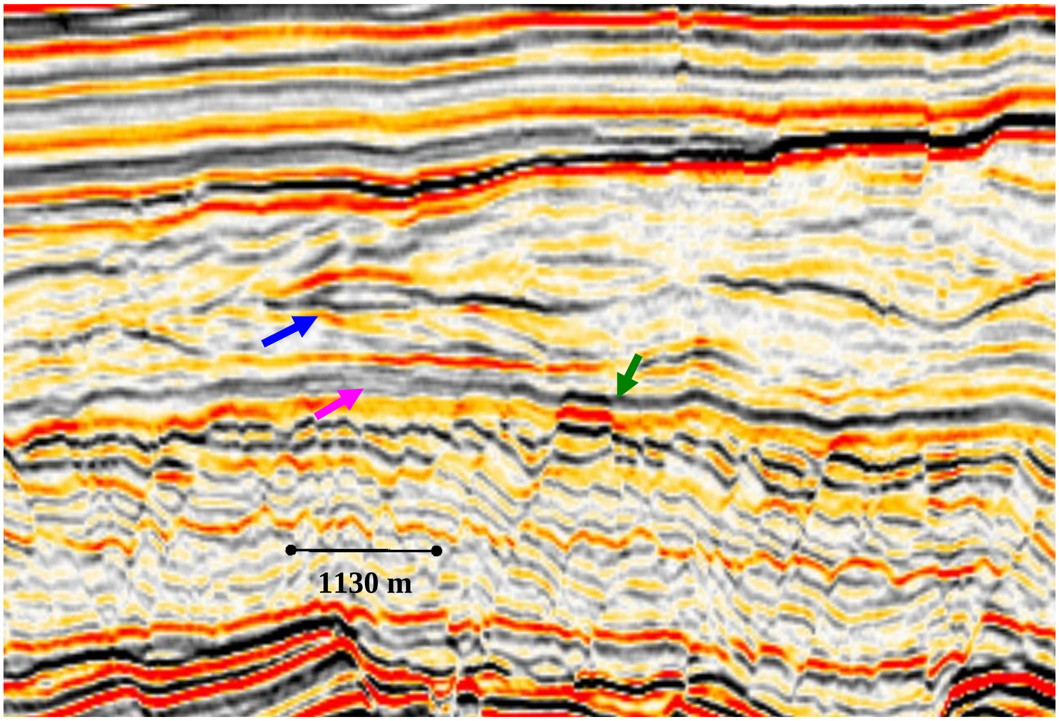


Figure 4-26: A flat spot (blue arrow) in the unit above Horizon 4, Unit E. A bright spot on Horizon 4 is shown by green arrow. Generally the reflection of Horizon 4 is dim with good connectivity (pink arrow).

4.1.2.5.1 Horizon Slice 4

A horizon slice is a seismic horizontal section which reveals the top view of a horizon in vertical sections, so that geomorphology can be investigated. The Horizon Slice 4 is a result of the interpretation of Horizon 4 in the whole area.

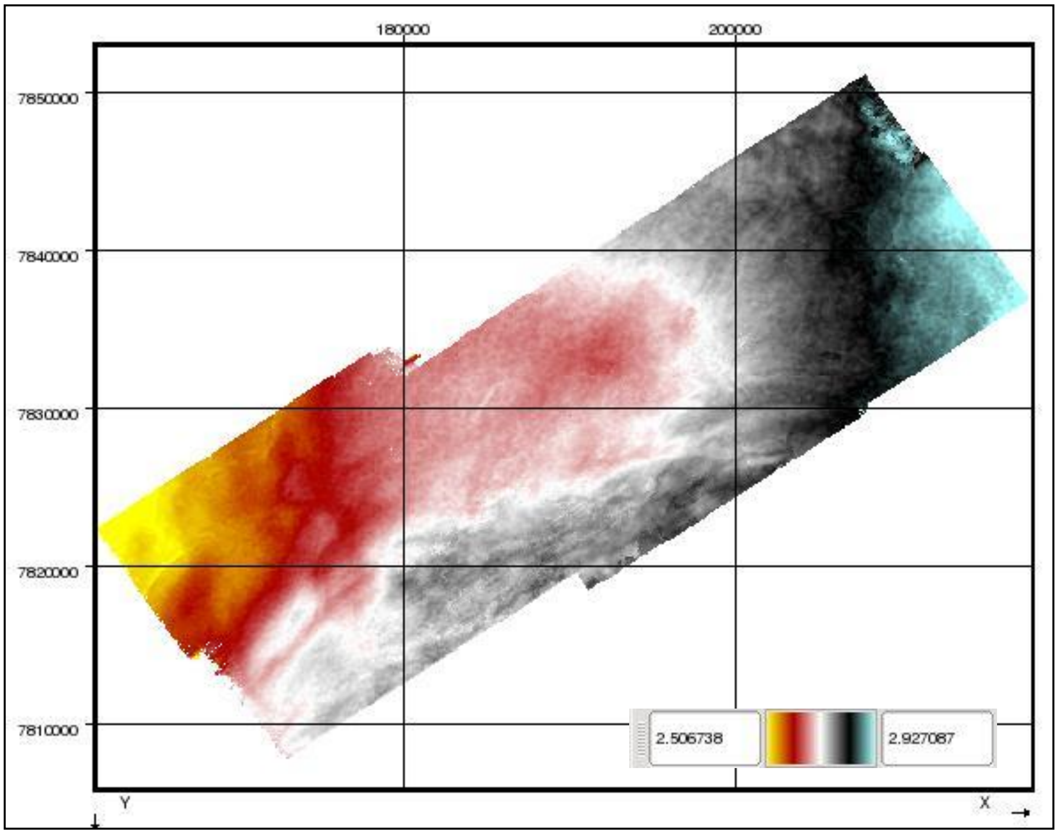


Figure 4-27: Time Structural map of Horizon Slice 4.

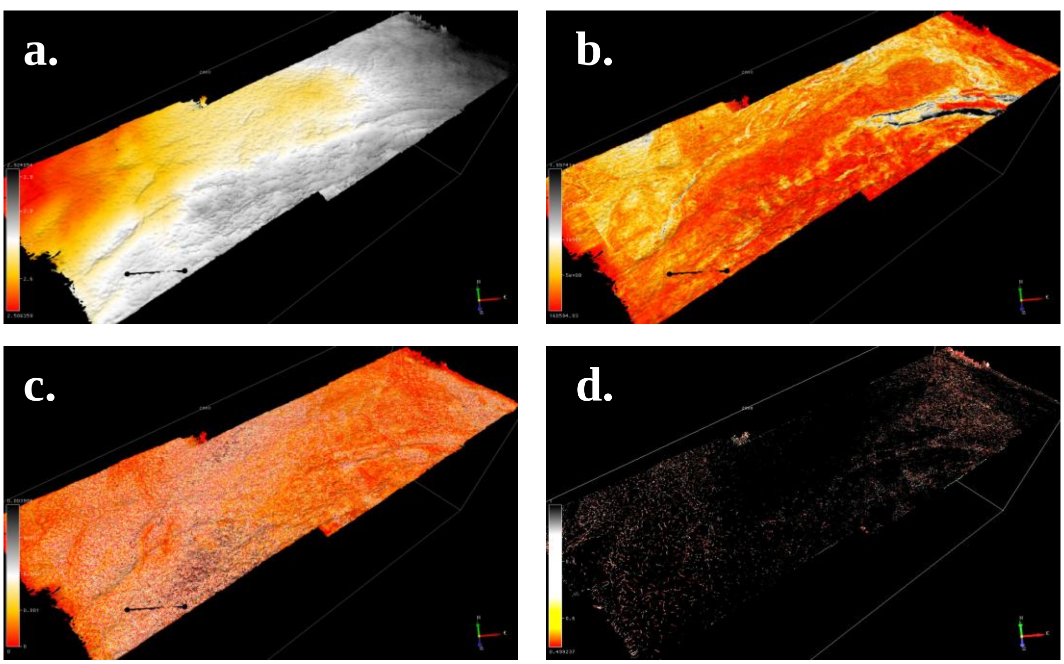


Figure 4-28: Different kinds of attributes: z value (a), amplitude (b), spectral decomposition (c), and coherency (d). Scale bars show 4.4 km in distance.

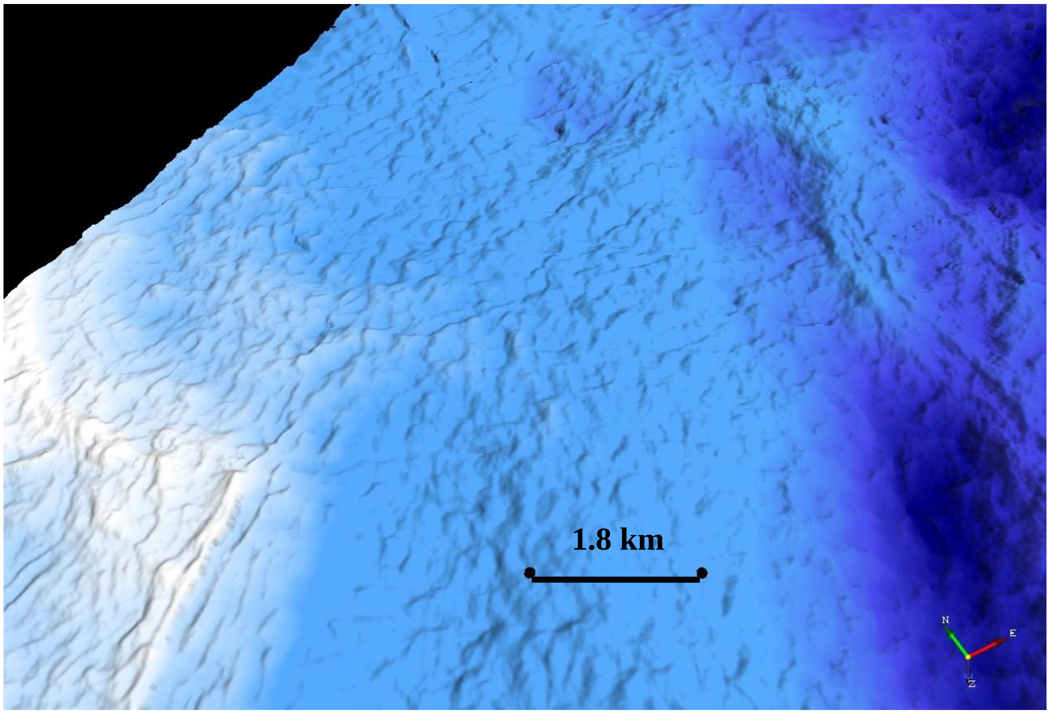


Figure 4-29: Horizon Slice 4 represents deposition of very fine-grained sediment.

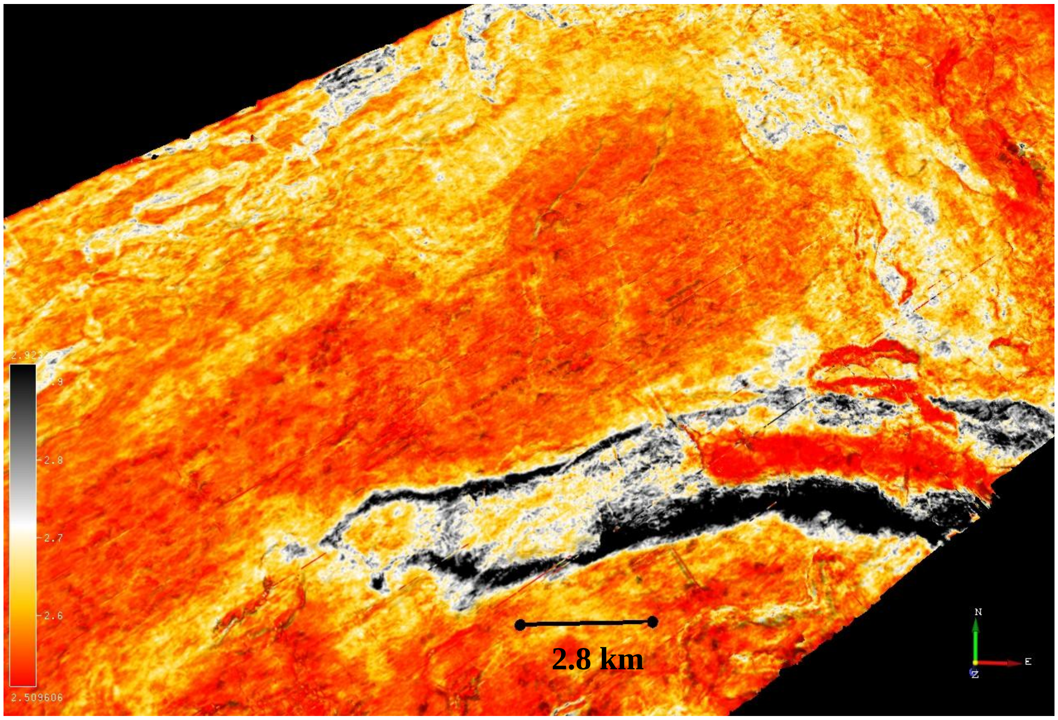


Figure 4-30: Zoom in of amplitude attribute with the channel-like anomaly in black in Horizon Slice 4.

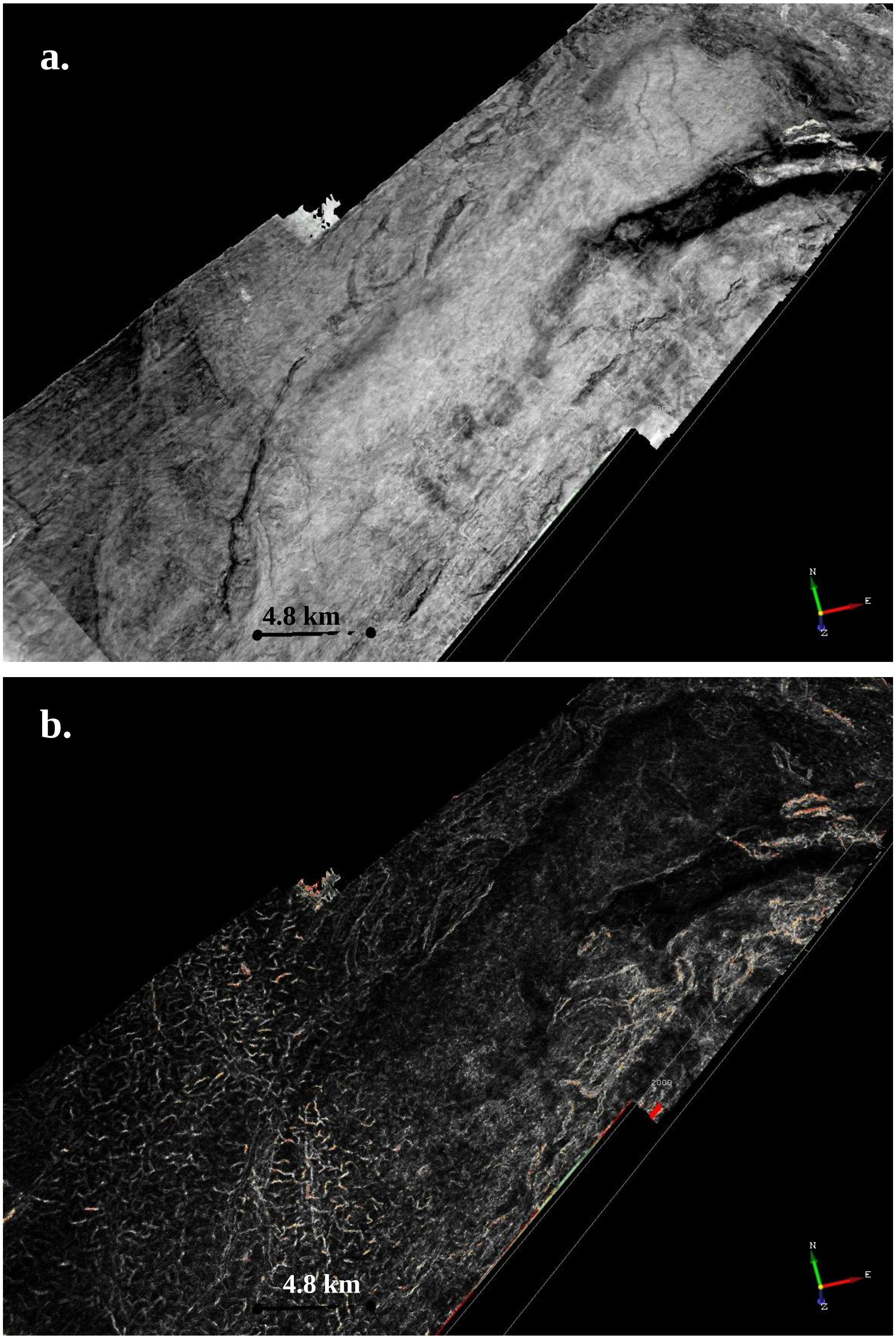


Figure 4-31: Amplitude attribute in gray scale (a) vs. coherency attribute (b) of Horizon Slice 4.

4.1.2.5.2 Unit E

Unit E is located between Horizon 4 (blue) and Horizon 5 (yellow). The seismic features within Unit E are no longer conformable like those in the earlier units. Its seismic reflection is obviously non-parallel in most of the area. It is acoustically semi-transparent and chaotic in some places. Curved and channel-like features can be seen in some areas. In the southwest parts, a moderate bright amplitude is sandwiched by good bright amplitudes (Figure 4-32, 4-33). The thickness of this unit is the most variable. It ranges from 100 ms thick in the center and increases to 460 ms in the northern and southern parts.

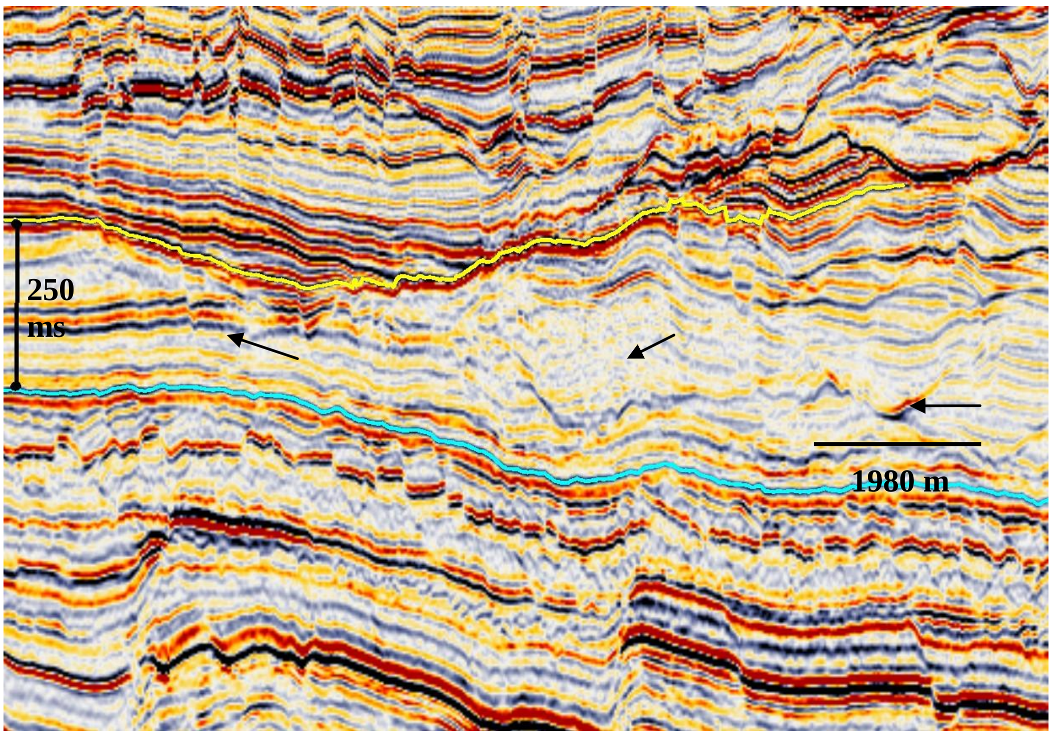


Figure 4-32: Three different amplitude features from left to right: strong and conformable, dim and chaotic, channel-liked amplitude.

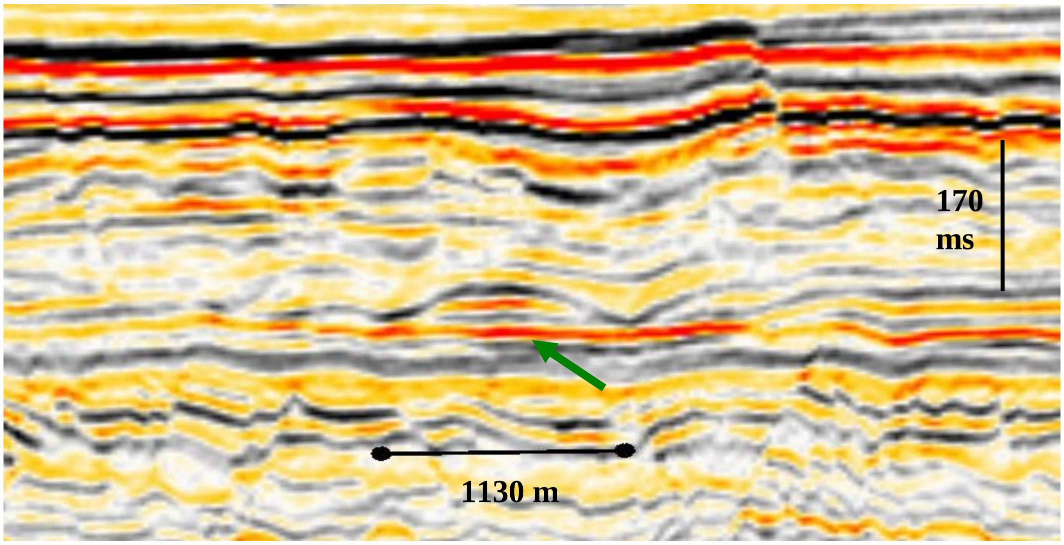


Figure 4-33: A fluid contact reflection shown in in-line 1320. A flat spot is always increase in impedance.

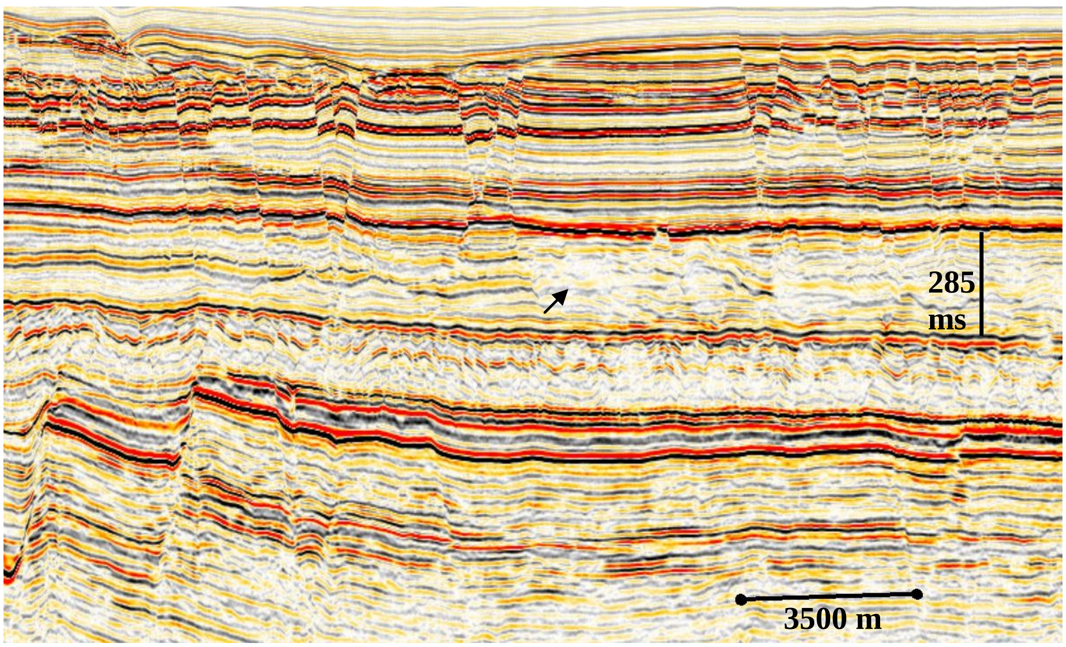


Figure 4-34: Dim features in Unit E.

4.1.2.6 Horizon 5

Horizon 5 is coloured in yellow in Figure 4-4. This horizon was picked in a maximum phase (black) in between bright minimum phases that sandwich it.

This horizon separates the chaotic low amplitude sequence below from the conformable moderate bright amplitudes above.

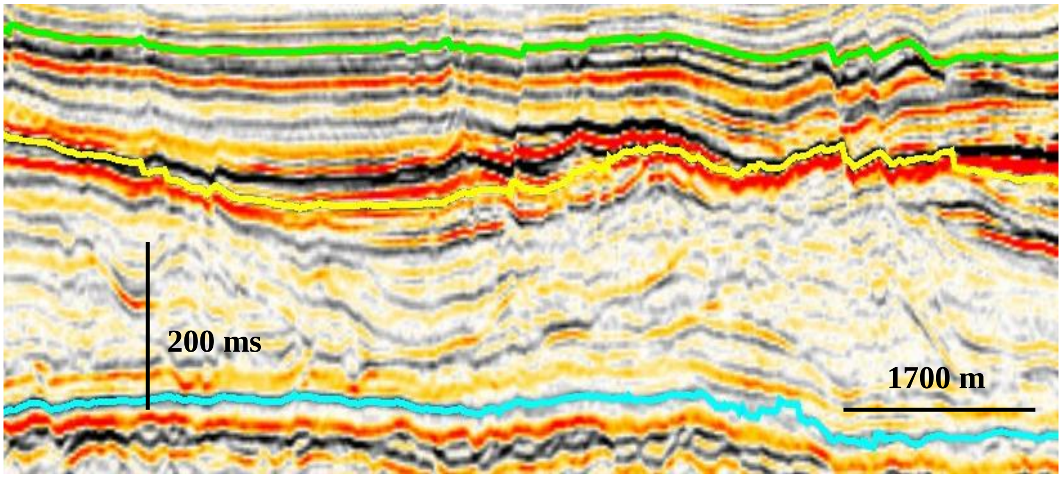


Figure 4-35: Horizon 5 separates the chaotic low amplitude sequence below from the conformable moderate bright amplitudes above.

4.1.2.6.1 Horizon Slice 5

A horizon slice is a seismic horizontal section which reveals the top view of a horizon in vertical sections, so that geomorphology can be investigated. The Horizon Slice 5 is a result of the interpretation of Horizon 5 in the whole area.

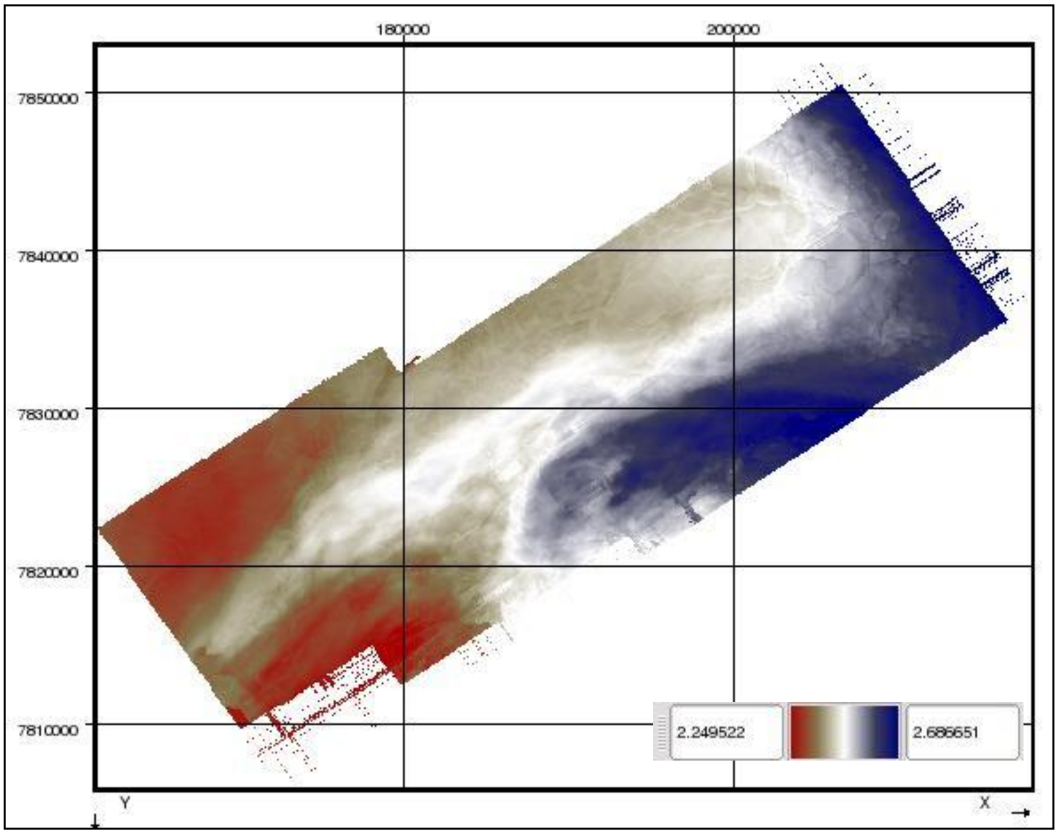


Figure 4-36: Time Structural map of Horizon Slice 5.

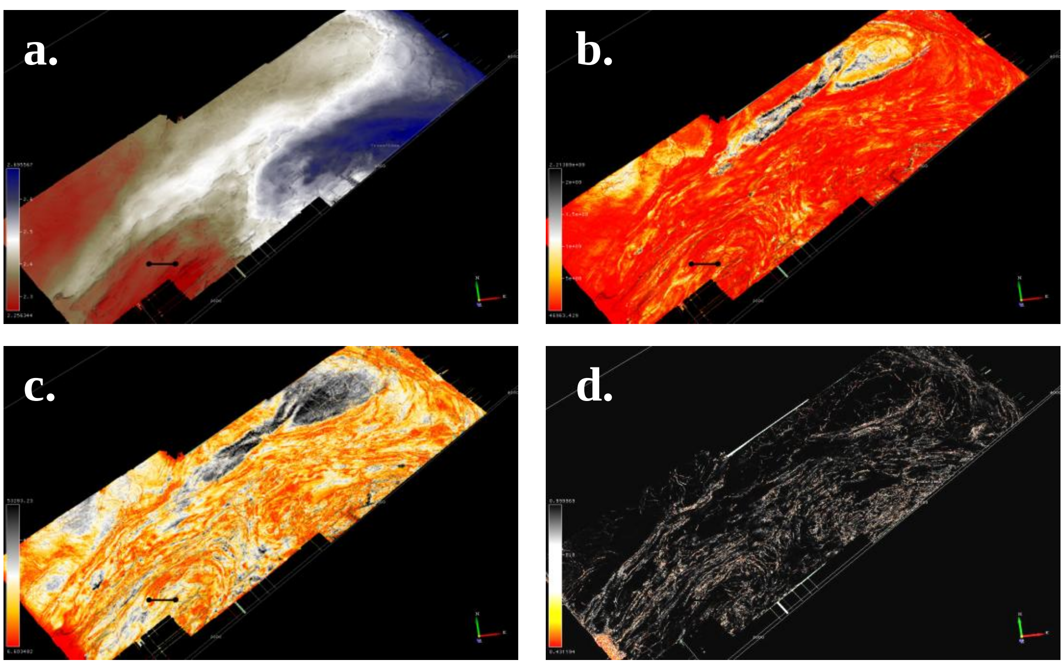


Figure 4-37: Different kinds of attributes of Horizon Slice 5: z value (a), amplitude (b), spectral decomposition (c), and coherency (d). Scale bars show 2.5 km in distance.

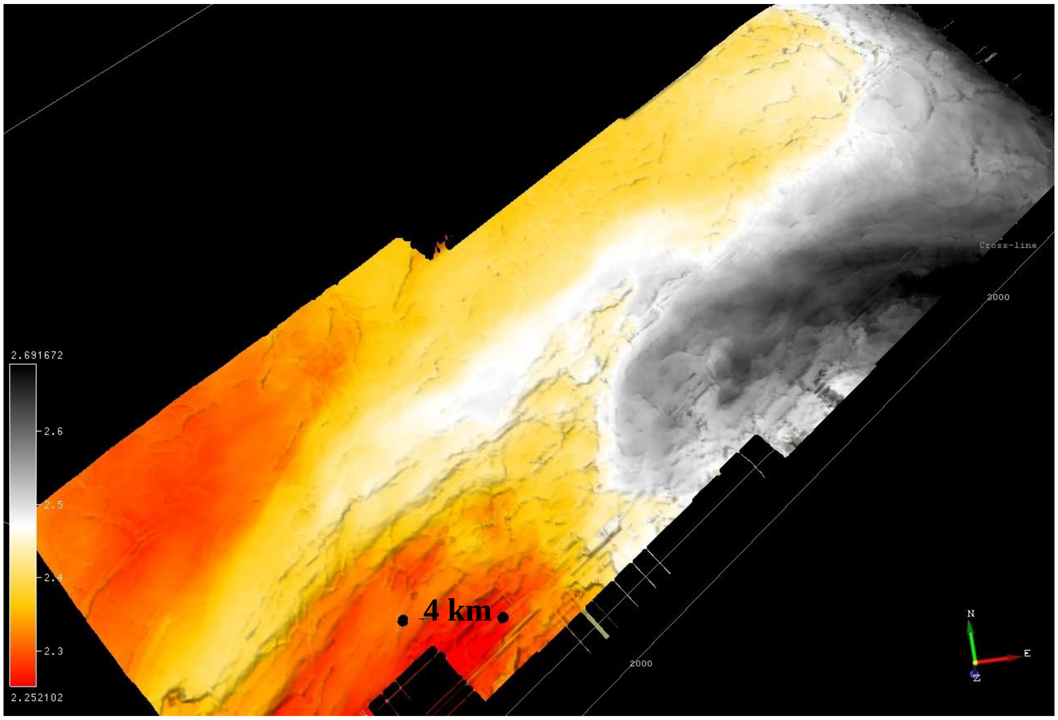


Figure 4-38: Horizon Slice 5, Z-value in “red-white-black” attribute can not capture the anomaly.

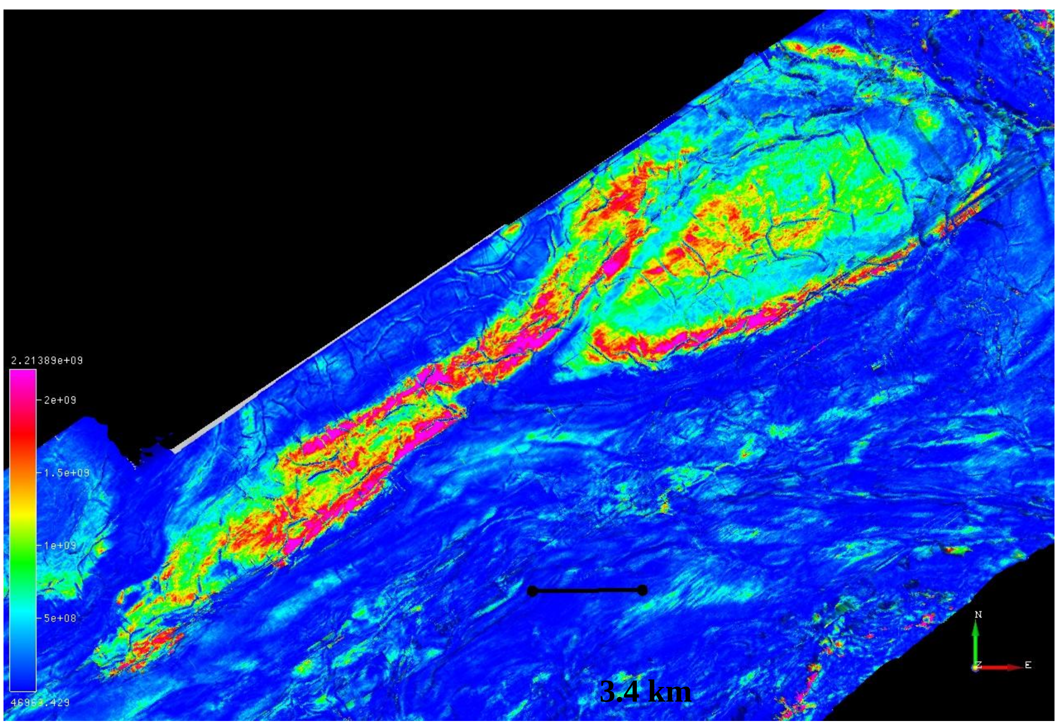


Figure 4-39: Horizon Slice 5, the flipped “question mark-liked” anomaly is revealed in rainbow when using amplitude attributes.

4.1.2.6.2 Unit F

Unit F is located between Horizon 5 (yellow) and Horizon 6 (green) in Figure 4-4. The seismic features are quite conformable either with the horizon above or with the horizon below, except the northeastern part, Carbonate deposition can be found only in the northeastern parts of the area.

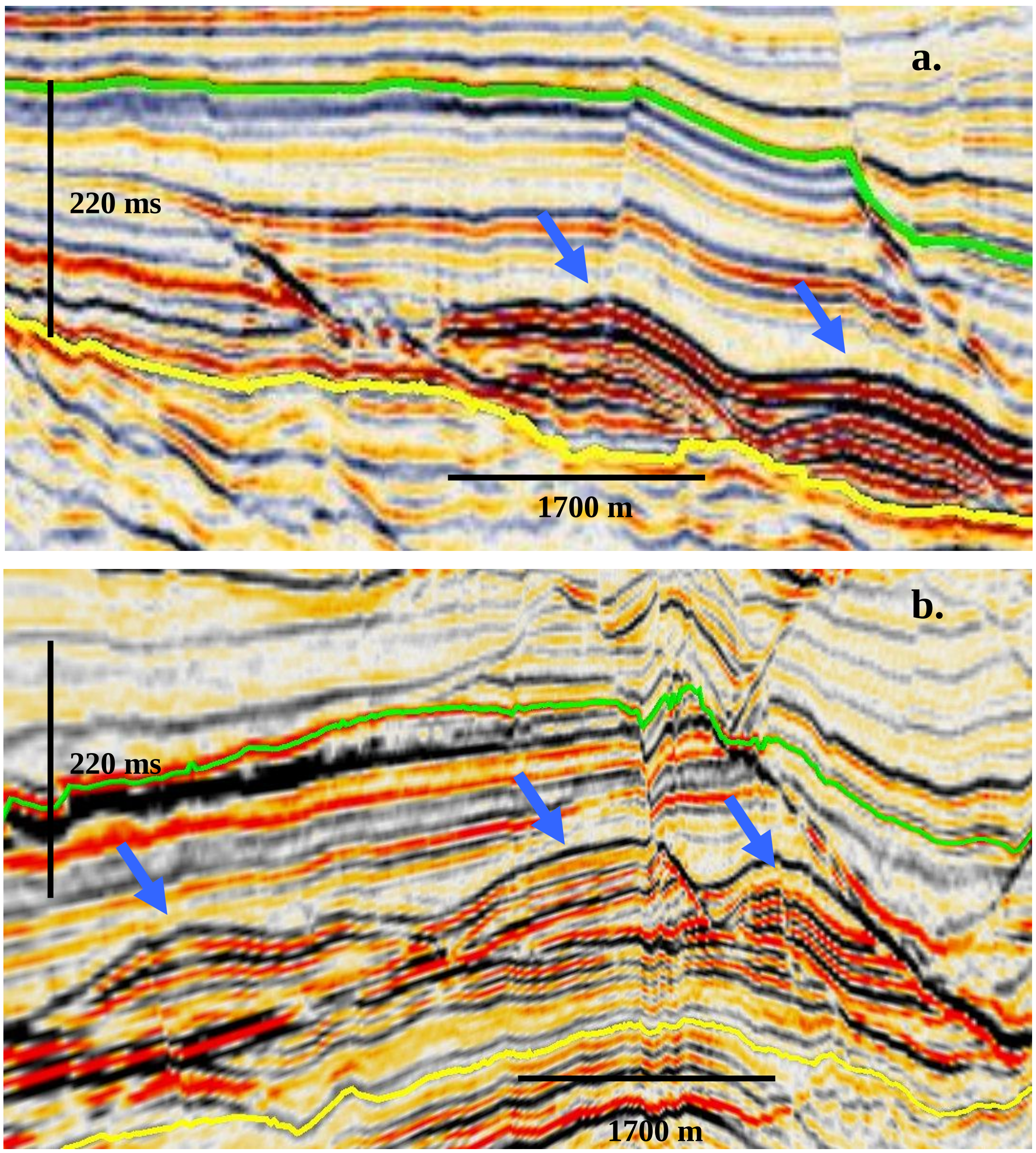


Figure 4-40: In Unit F, carbonate mounds shown in cross-line 4200 (a) and intersection of in-line 1220 and cross-line 3560 (b).

4.1.2.7 Horizon 6

In Figure 4-3, Horizon 6 is shown in green. Its amplitude is very bright in the northeastern part and dims toward the southwest part. Most parts of this horizon are conformable to the units above and below (Figure 4-41). However, some parts in the southeast become an erosion surface as shown in Figure 4-42.

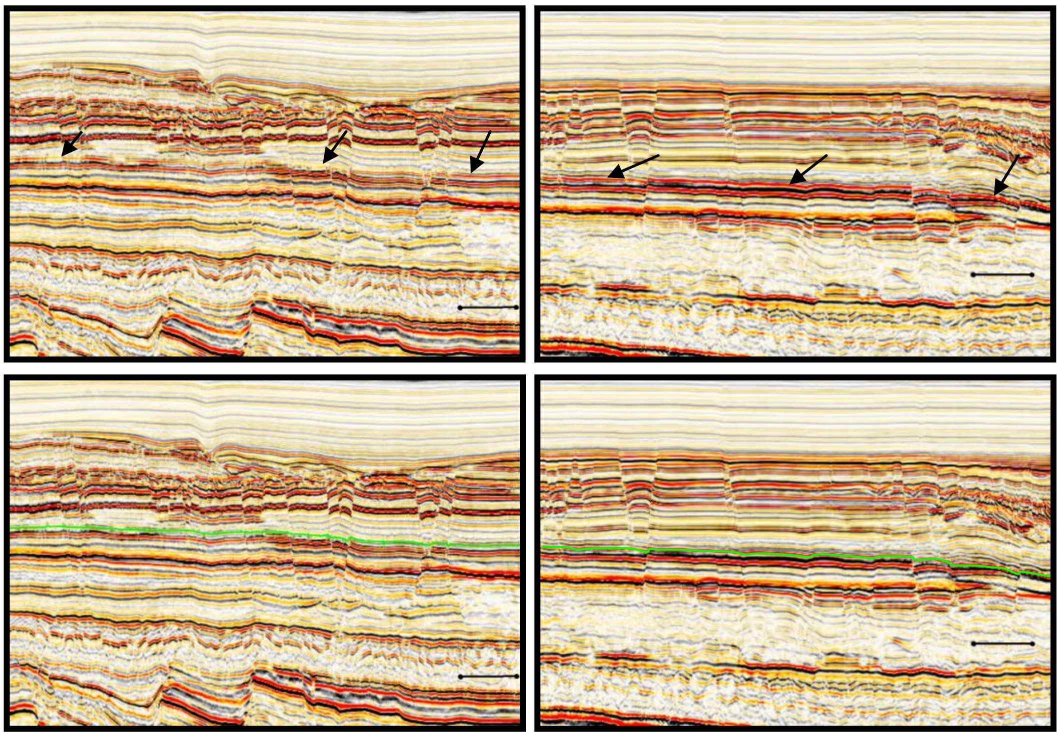


Figure 4-41: Horizon 6 is very bright in amplitude in the northern part and dims toward the southern part (shown by arrows). Scales shown are 1800 m in distance.

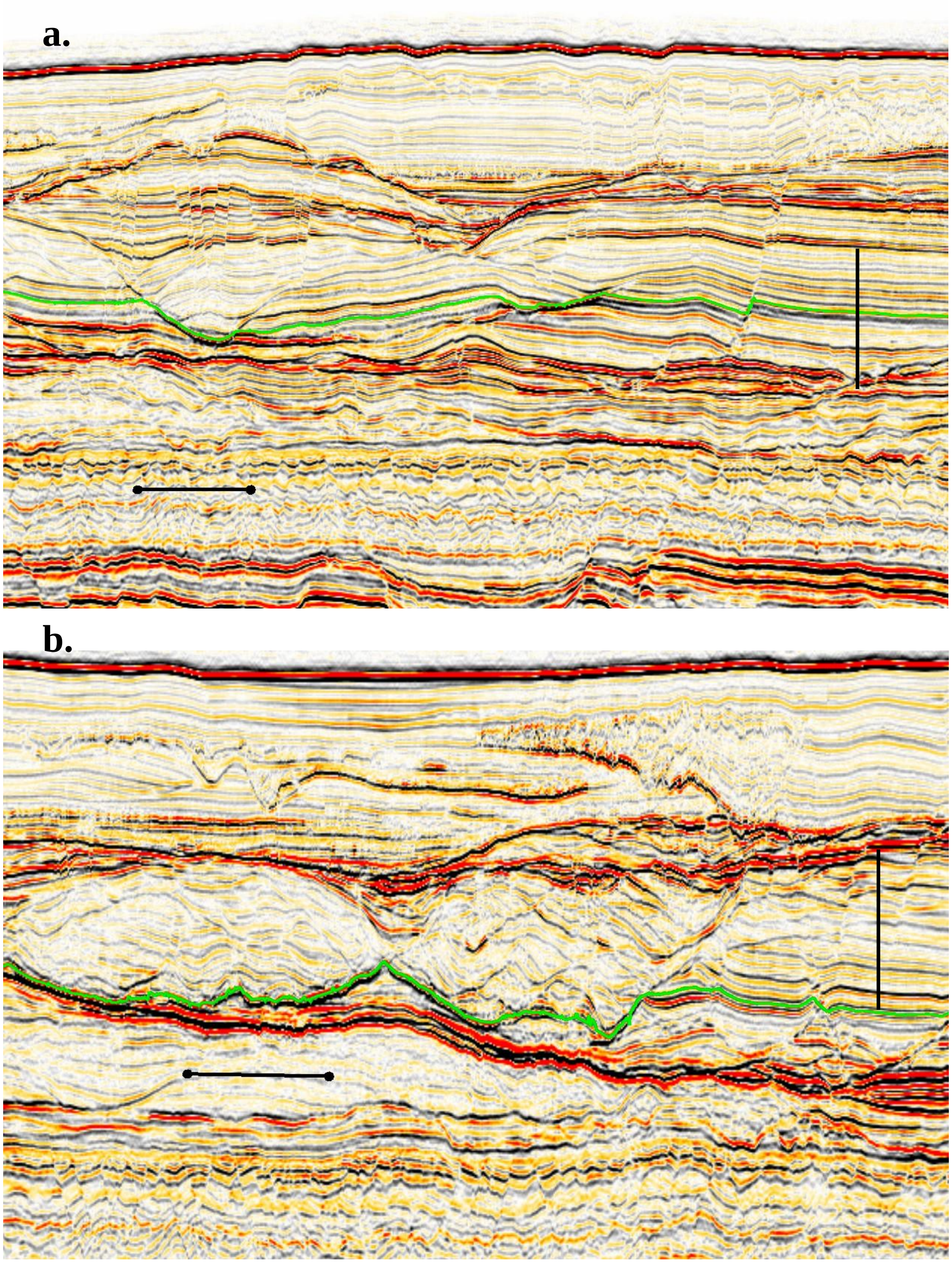


Figure 4-42: Erosion surface from Horizon 6 in different parts. Vertical scales show TWT 360 ms and horizontal scales show 2350 m

a: In-line 1161

b: In-line 1040

4.1.2.7.1 Horizon Slice 6

A horizon slice is a seismic horizontal section which reveals the top view of a horizon in vertical sections, so that geomorphology can be investigated. The Horizon Slice 6 is a result of the interpretation of Horizon 6 in the whole area.

Horizon Slice 6 is the top of Unit F which is the Toolonga Calcilutites. It is composed of shallow marine open shelf carbonates.

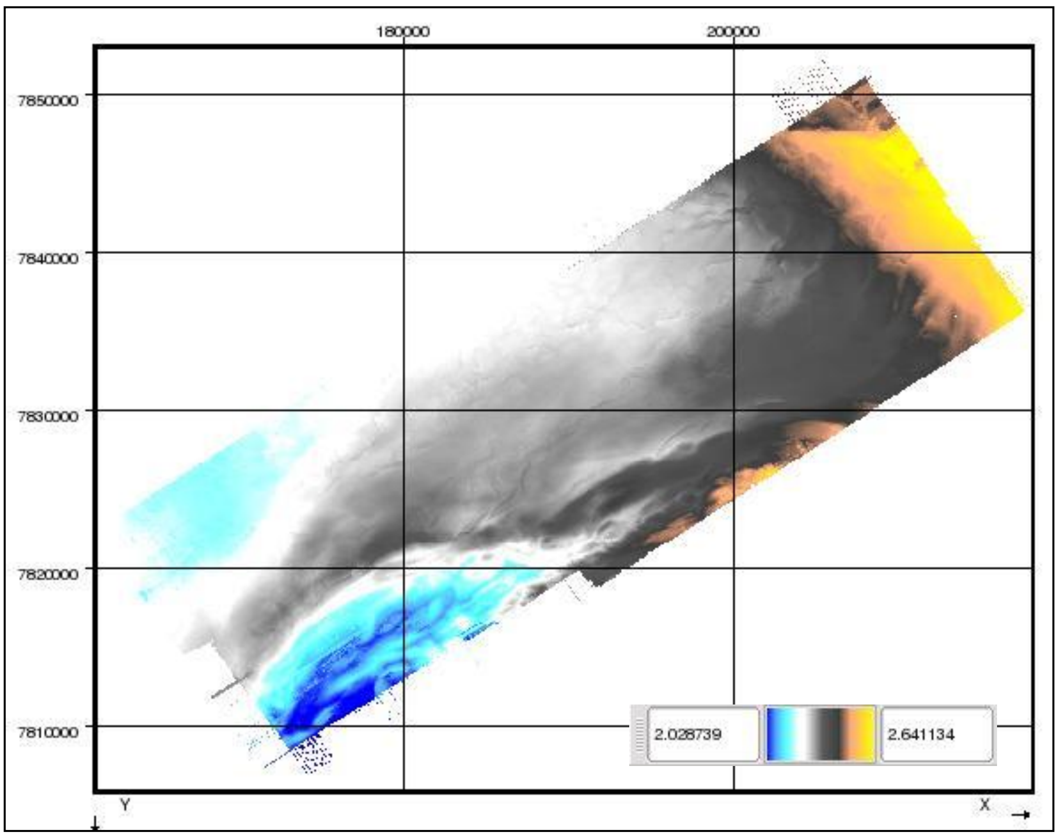


Figure 4-43: Time Structural map of Horizon Slice 6.

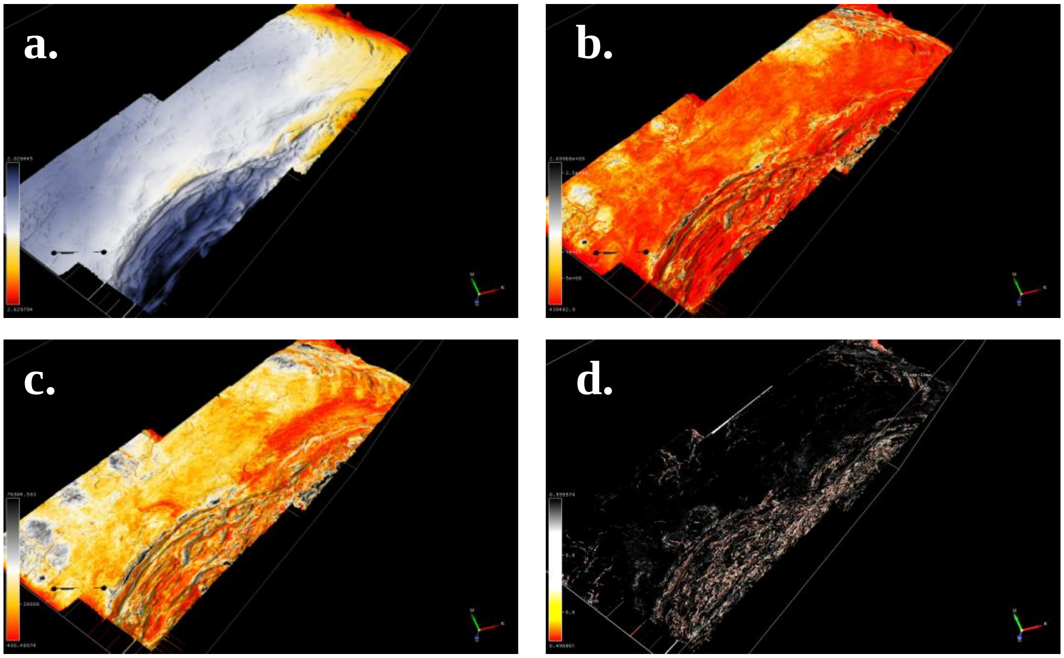


Figure 4-44: Different kinds of attributes of Horizon Slice 6: z value (a), amplitude (b), spectral decomposition (c), and coherency (d). Scale bars show 4 km in distance.

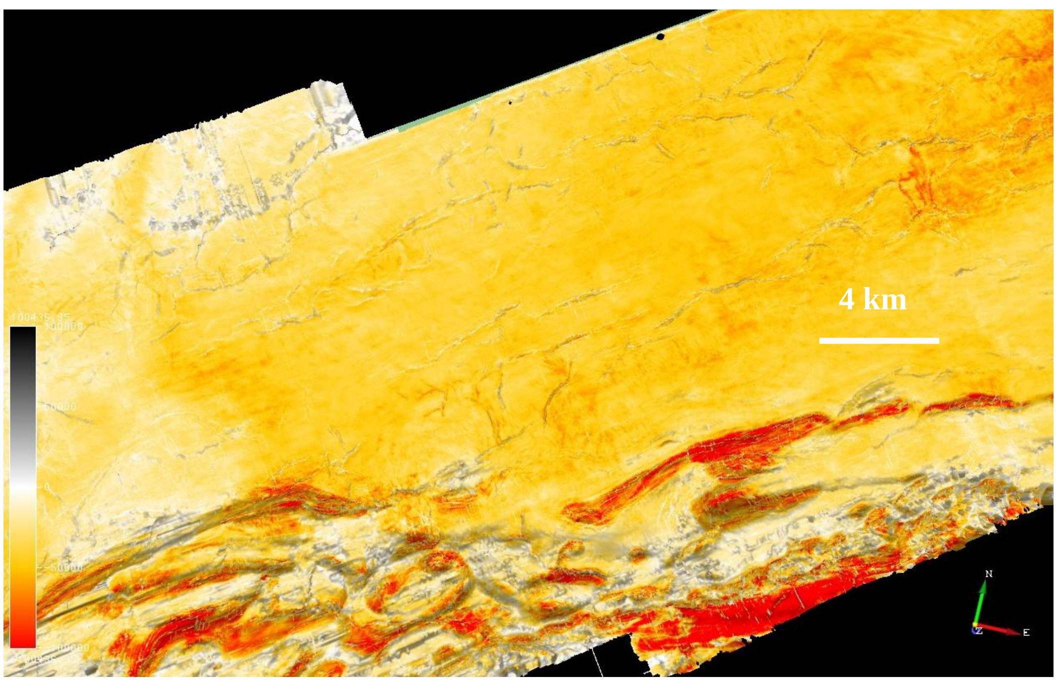


Figure 4-45: The circlet feature shows a carbonate ring of the Toolonga Formation displayed on Horizon Slice 6 with spectral decomposition attributes.

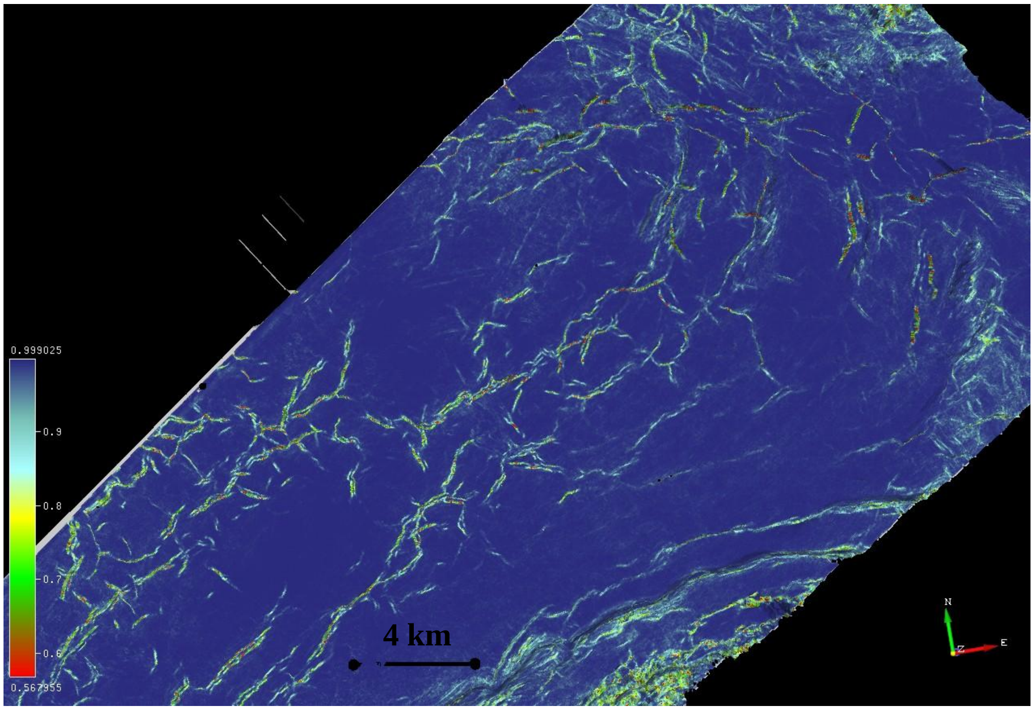


Figure 4-46: Structures similar to drainage systems top of the Toolonga Calcilutite and a set of listric fault are shown as the curve features on Horizon Slice 6 (z value attributes).

4.1.2.7.2 Unit G

Unit G is located in between Horizon 6 (green) and Horizon 8 (dark blue) in Figure 4-4. Overall, the seismic reflections in this unit are planar and conformable in the western and south western parts of the area. The northern part and especially the northeast corner of the field are severely interrupted by the horizon above resulting in unconformable seismic amplitude. Thus, in some parts, Unit G thins out and disappears as a result of the invasion of the unconformity above. Carbonate build up can be found only in the northwestern part (Figure 4-47).

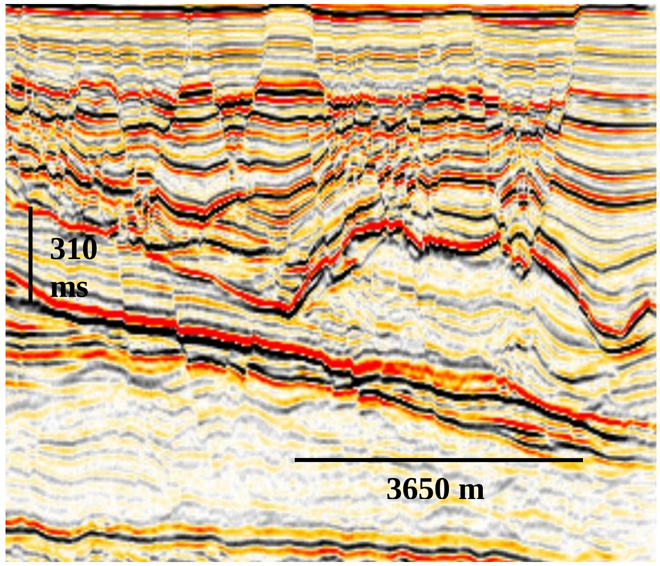


Figure 4-47: In-line 1420 carbonate build up of Unit G.

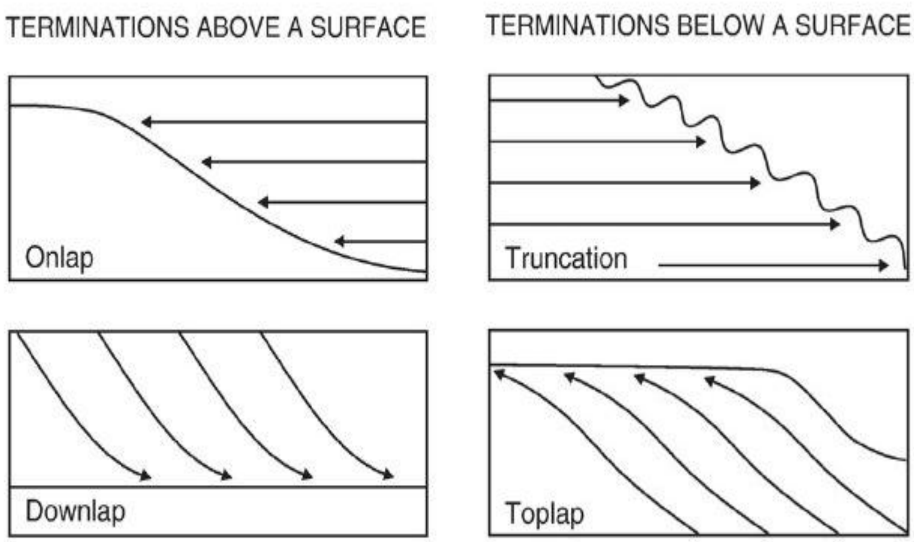


Figure 4-48: Stratal terminations above surface and below surface. Modified from Catuneanu et al., 2009.

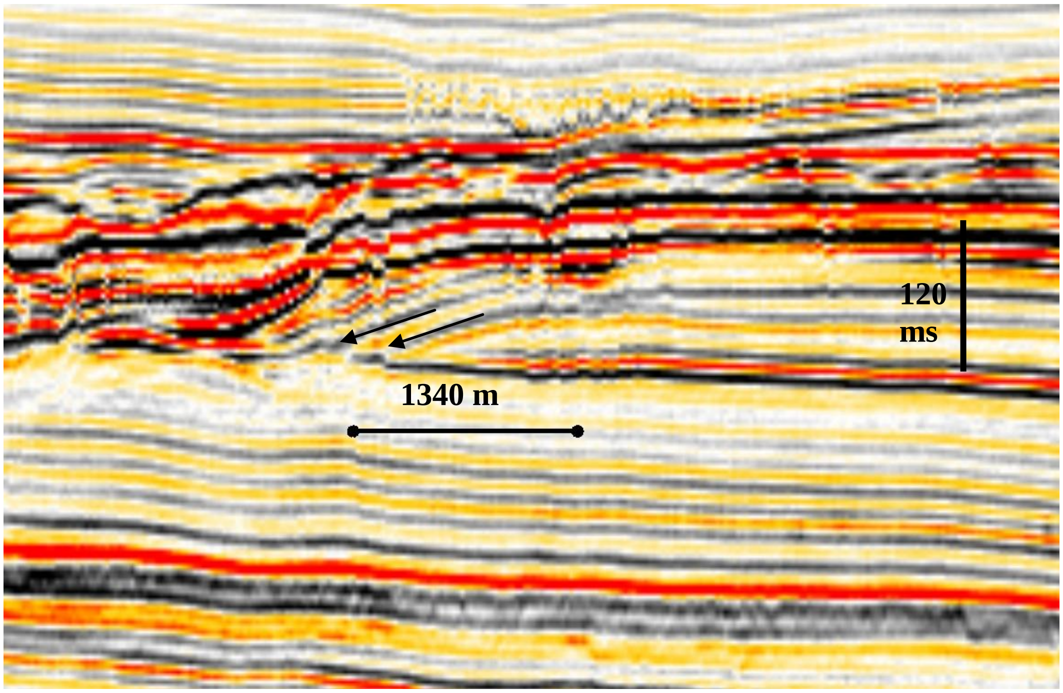


Figure 4-49: A termination above surface is shown in in-line 1271. In this case, downlap shows steeper overlying strata against the low angle surface below (Horizon 7).

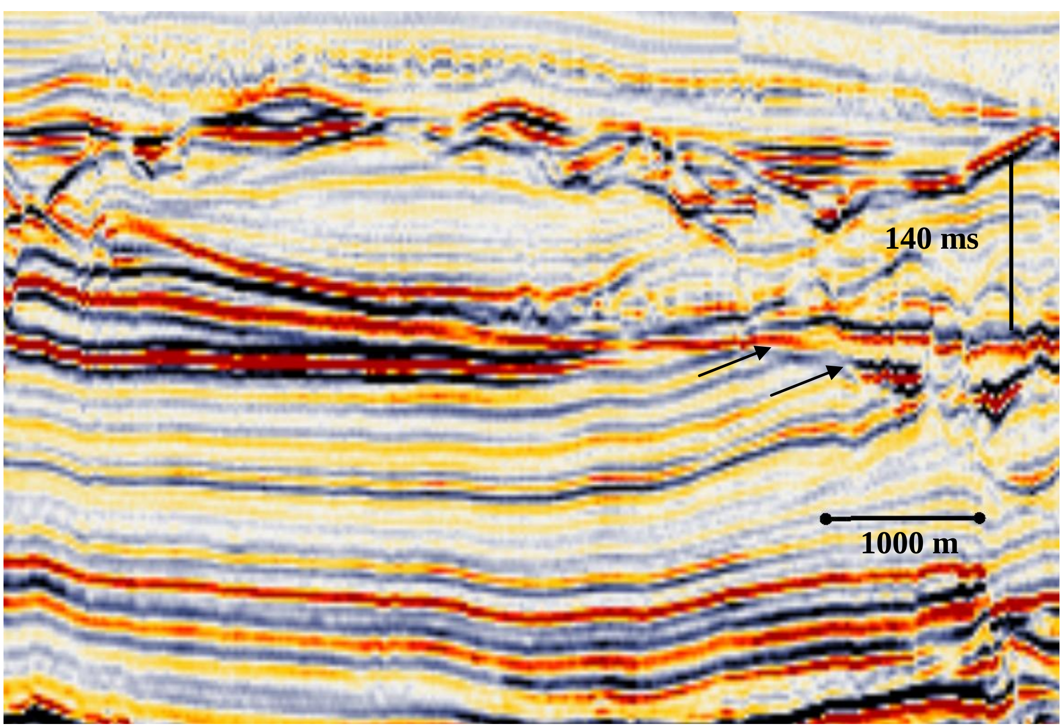


Figure 4-50: Truncation from cross-line 2436 in Unit G.

4.1.2.8 Horizon 7

Horizon 7 is the intervening surface in Unit G. Horizon 7 is the only bright amplitude with moderate to good continuity existing in Unit G. It is located way between Horizon 6 and Horizon 8. It can be traced only 70% out of the total area, as it was truncated by the unconformity/erosional surface above (Horizon 8), which is in the northern, eastern, southern and southeastern parts.

4.1.2.8.1 Horizon Slice 7

A horizon slice is a seismic horizontal section which reveals the top view of a horizon in vertical sections, so that geomorphology can be investigated. The Horizon Slice 7 is a result of the interpretation of Horizon 7 in the whole area.

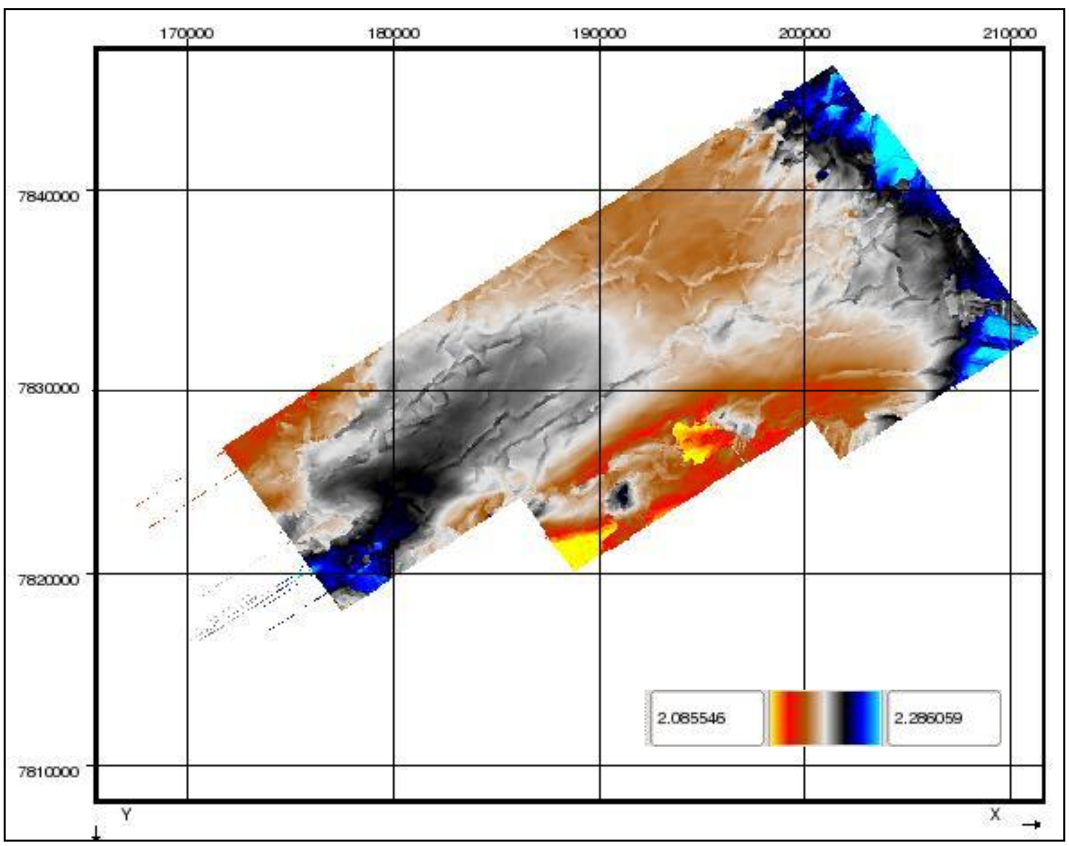


Figure 4-51: Time Structural map of Horizon Slice 7.

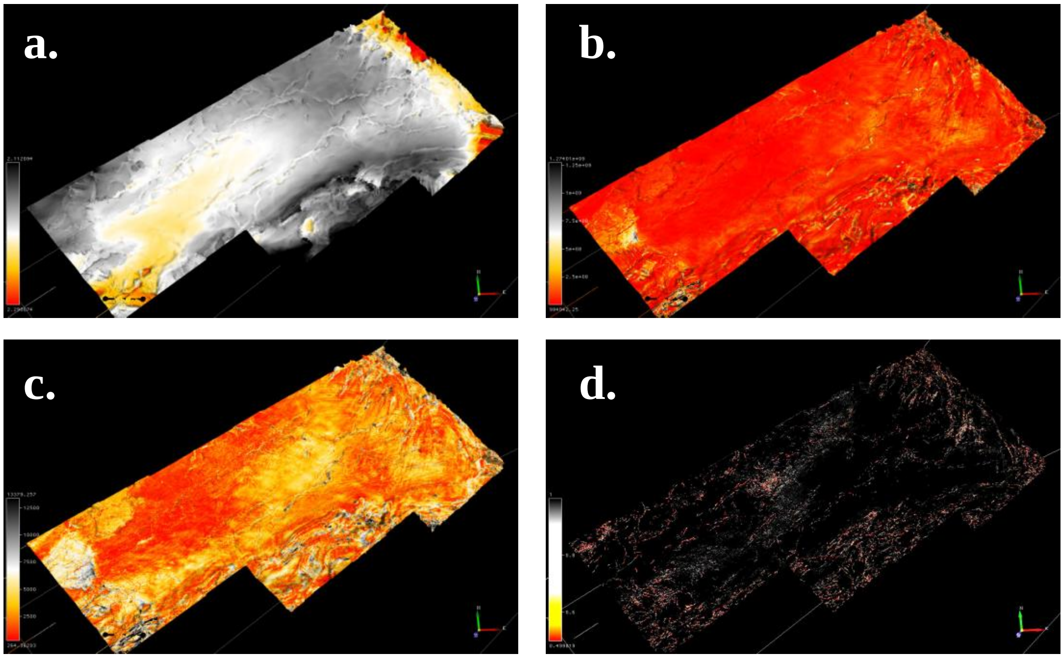


Figure 4-52: Different kinds of attributes of Horizon Slice 7: z value (a), amplitude (b), spectral decomposition (c), and coherency (d). Scale bars show 2.4 km in distance.

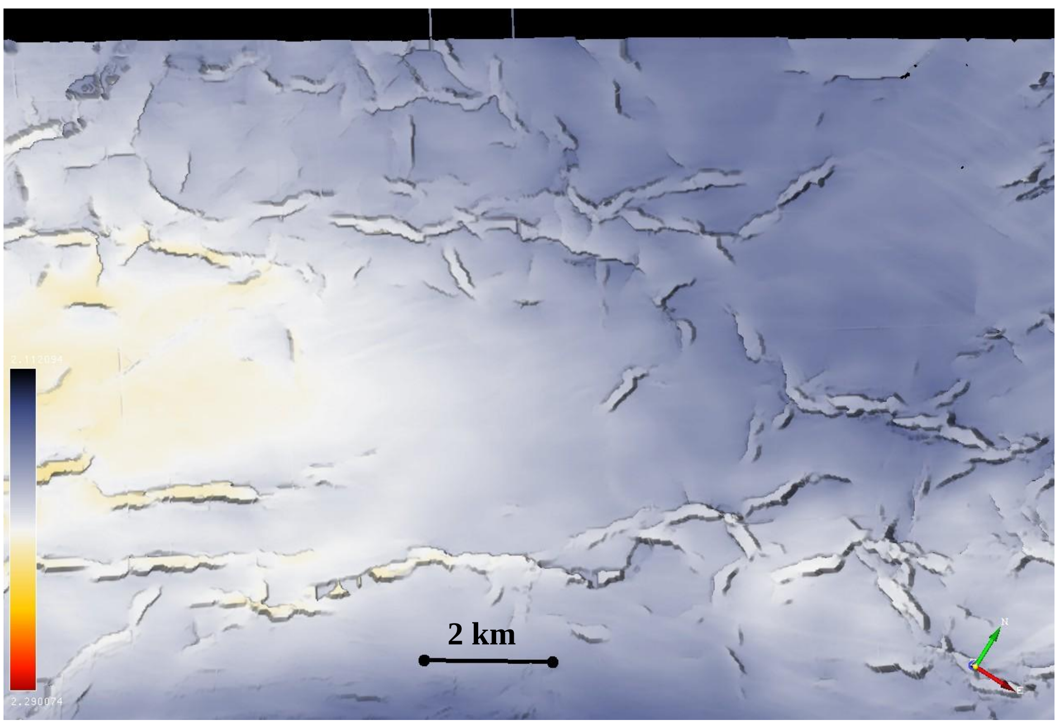


Figure 4-53: Zoom in of Horizon Slice 7, reveals drainage systems.

4.1.2.9 Horizon 8

Horizon 8 is shown in dark blue. The brightness of amplitude is poor to good. The continuity of the amplitude is excellent in the central and south western parts, good in the northern part and poor to moderately poor in the southeastern part. Using an extrapolation tool while picking this horizon is not recommended. In the areas that feature poor amplitude and poor continuity, the horizon can be suggested by the perpendicular seismic sections. This horizon happens to be erosion surface in some parts (Figure 4-54). Moreover, in the northwest corner it reflects channel-like unconformity. Evidence suggests that Horizon 8 represents the base of the Tertiary Period.

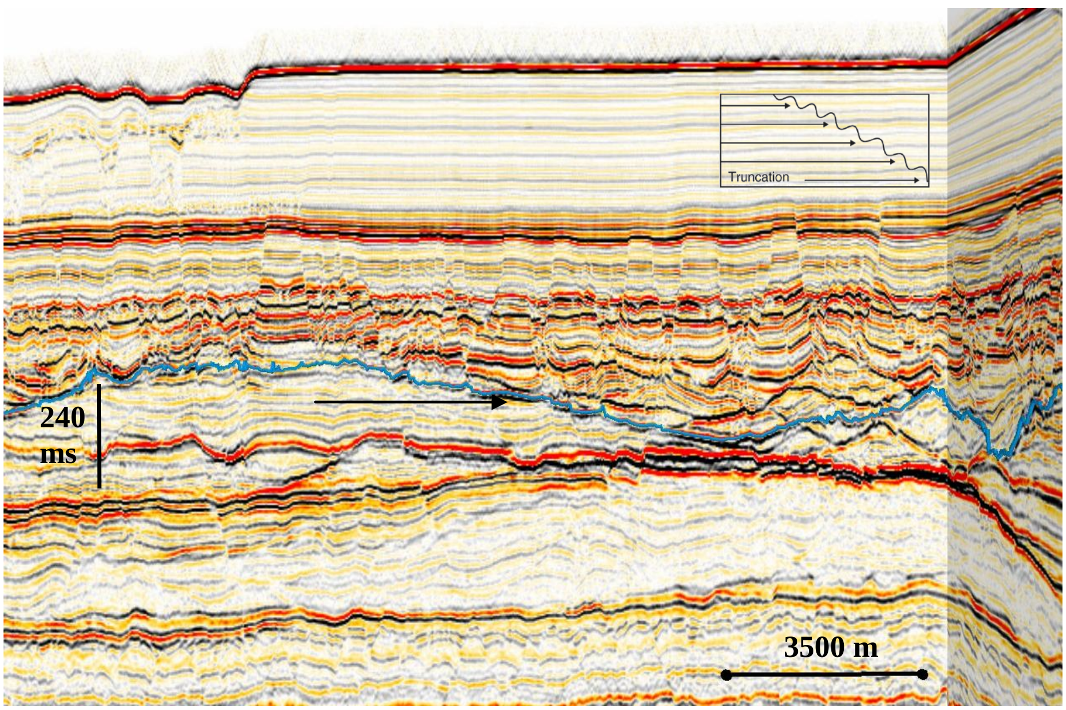


Figure 4-54: Cross-line 4825/1700 shows an erosion surface of Horizon 8 and the truncation of Unit G towards Horizon 8 (arrow).

4.1.2.9.1 Horizon Slice 8

A horizon slice is a seismic horizontal section which reveals the top view of a horizon in vertical sections, so that geomorphology can be investigated. The Horizon Slice 8 is a result of the interpretation of Horizon 8 in the whole area.

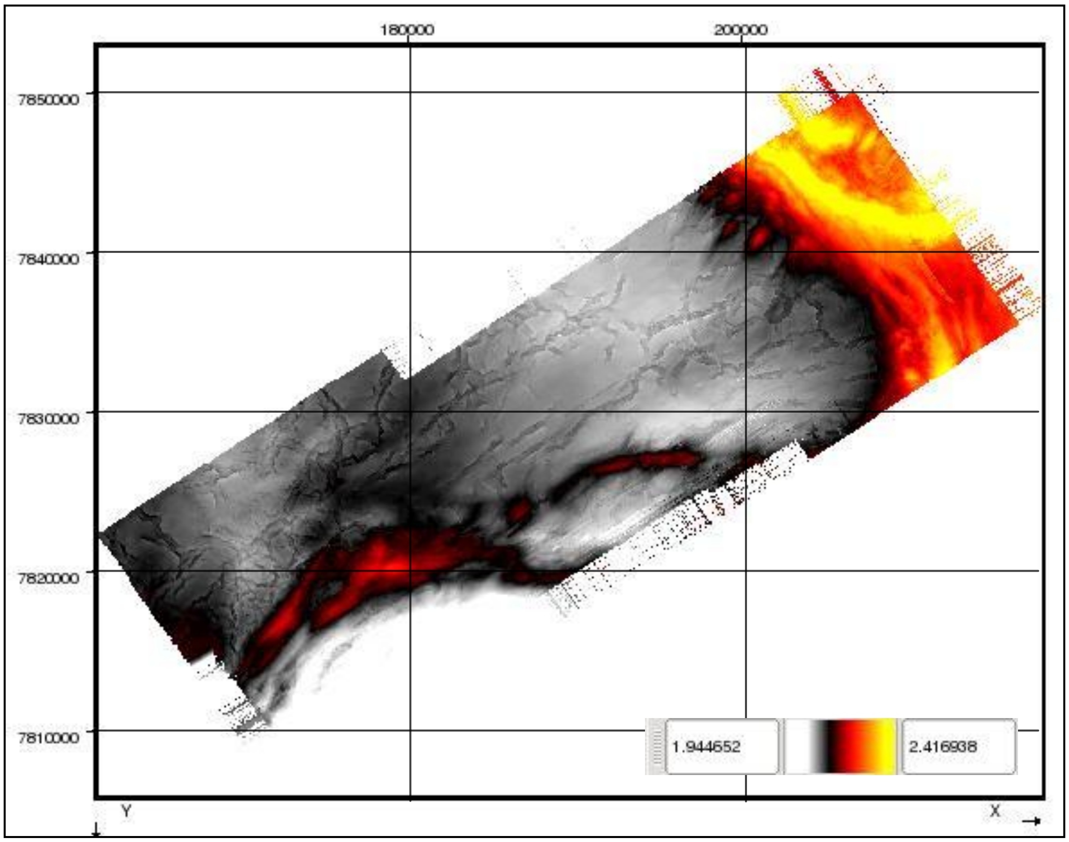


Figure 4-55: Time Structural map of Horizon Slice 8.

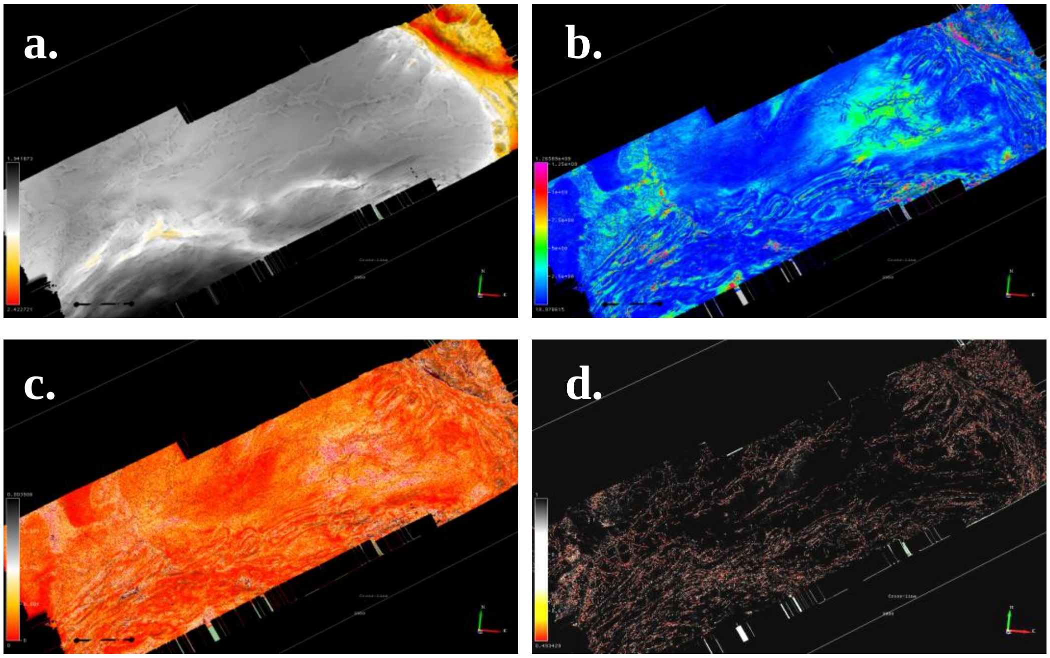


Figure 4-56: Different kinds of attributes of Horizon Slice 8: z value (a), amplitude (b), spectral decomposition (c), and coherency (d). Scale bars show 5.2 km in distance.

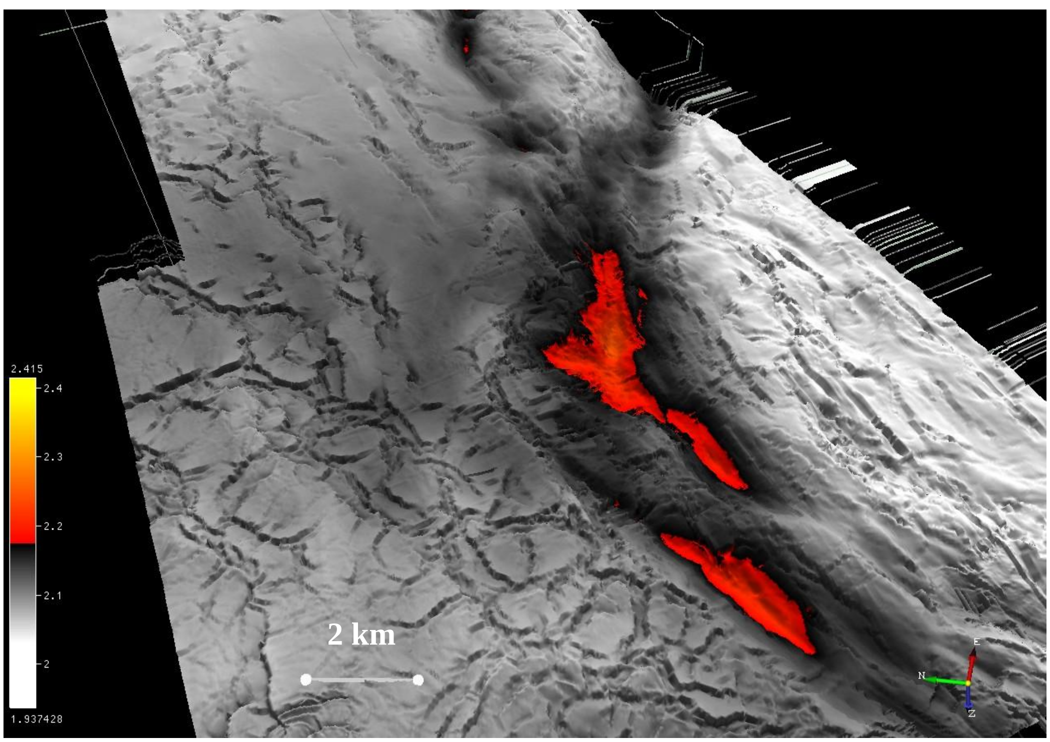


Figure 4-57: A channel with incised deep bed is shown in red on Horizon Slice 8 with z-value attributes.

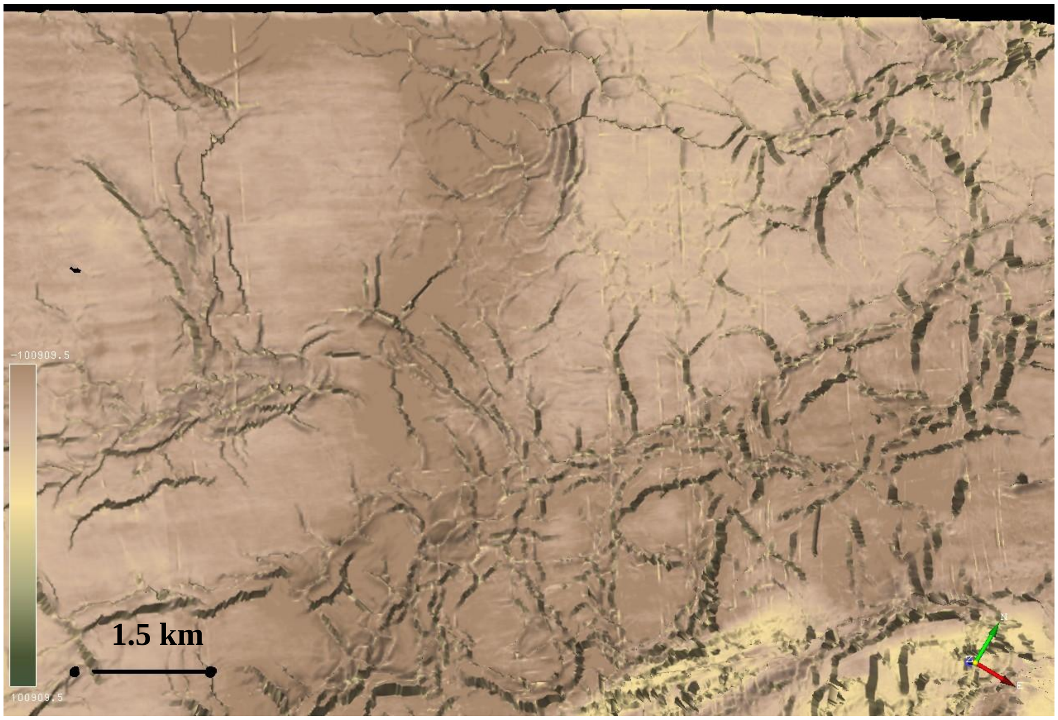


Figure 4-58: Fluid migration faults are revealed by using z-value attributes .

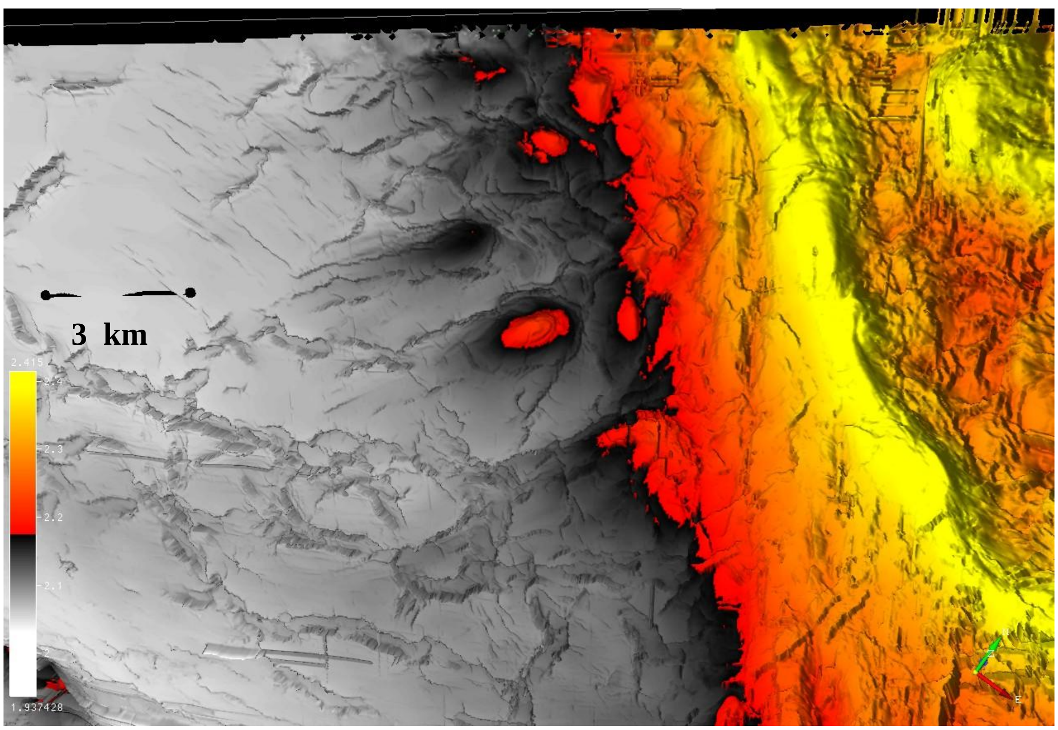


Figure 4-59: The unidentifiable concoidal features are shown in red and the deep feature, the channel-liked erosion surface is shown in yellow.

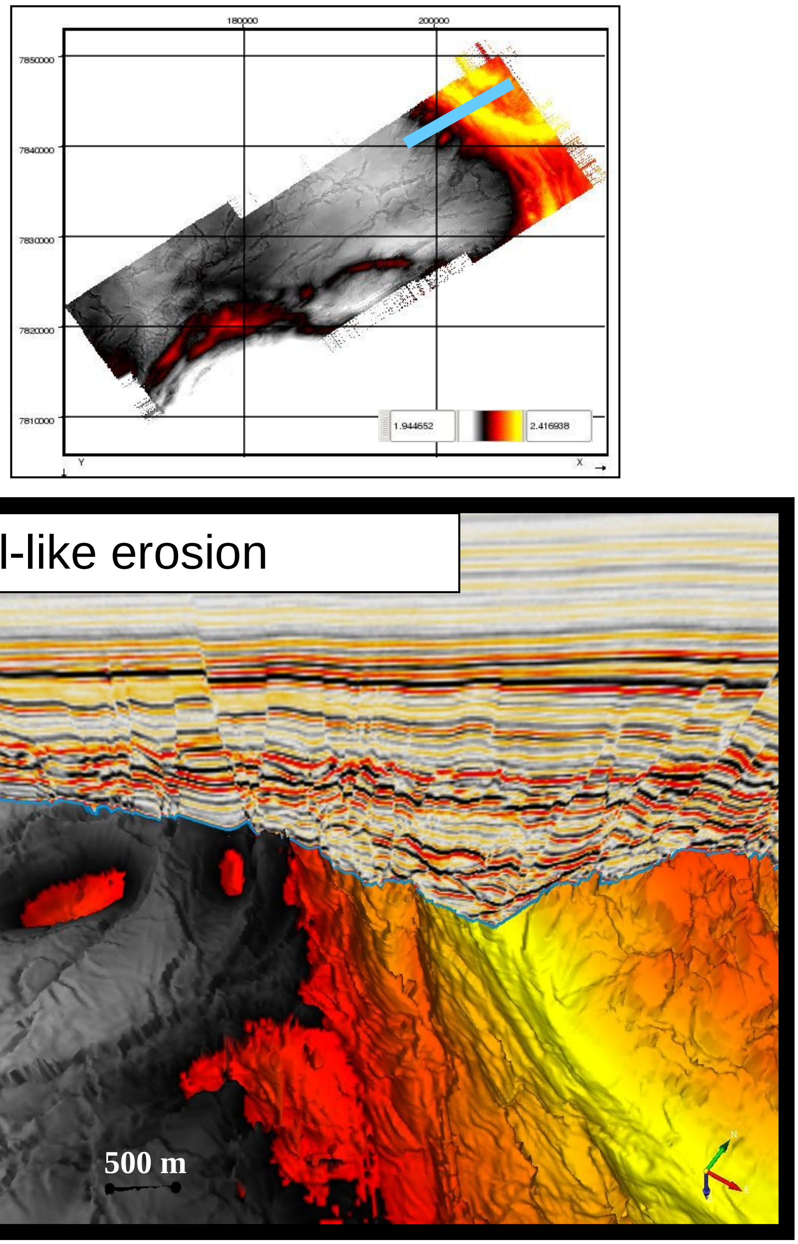


Figure 4-60: Channel-like erosion surface of Horizon Slice 8 revealed by combination of a z-value attributes on seismic horizon slice and a seismic vertical section.

4.1.2.9.2 Unit H

Unit H is situated between Horizon 8 (dark blue) and Horizon 9 (navy). The thickness of this unit varies from 30-500 ms thick in TWT. This unit is thinnest in the central part and swells out toward the northern and southern parts.

Exon et al. (1982) suggest that this unit was deposited during the Eocene Age and that the sediment was pelagic chalk or ooze. Pelagic sediments are an indicator for sedimentary deposition in the abyssal plain, which is the deep part of the ocean.

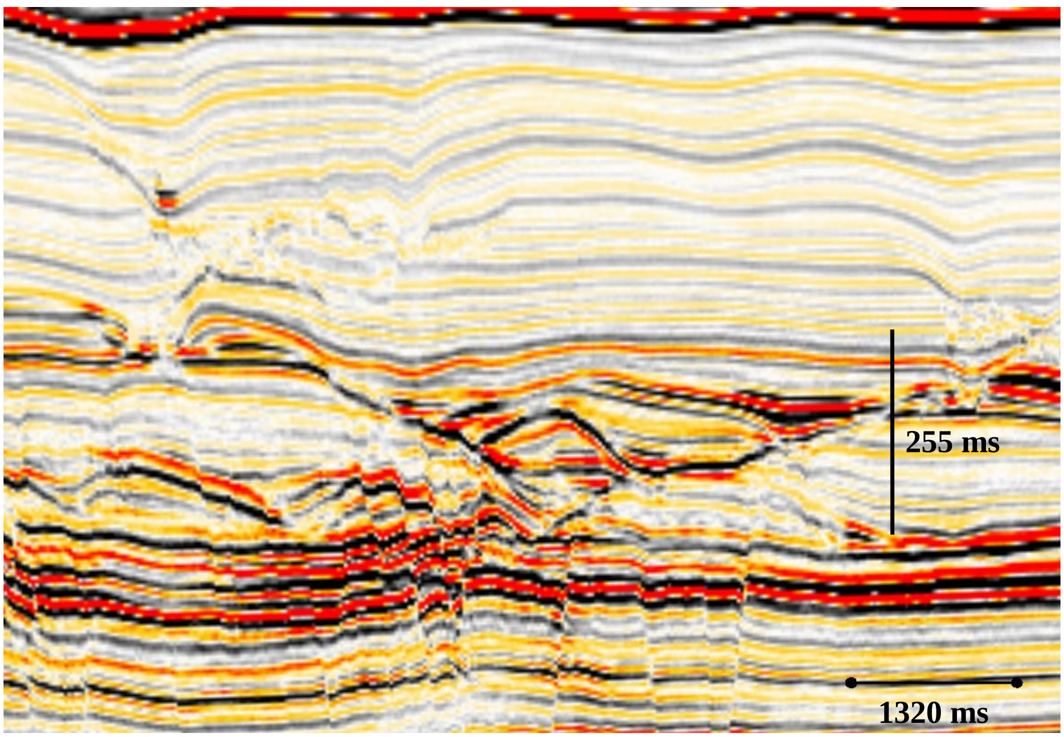


Figure 4-61: A channel-liked feature in Unit H with possibly a pelagic ooze on top.

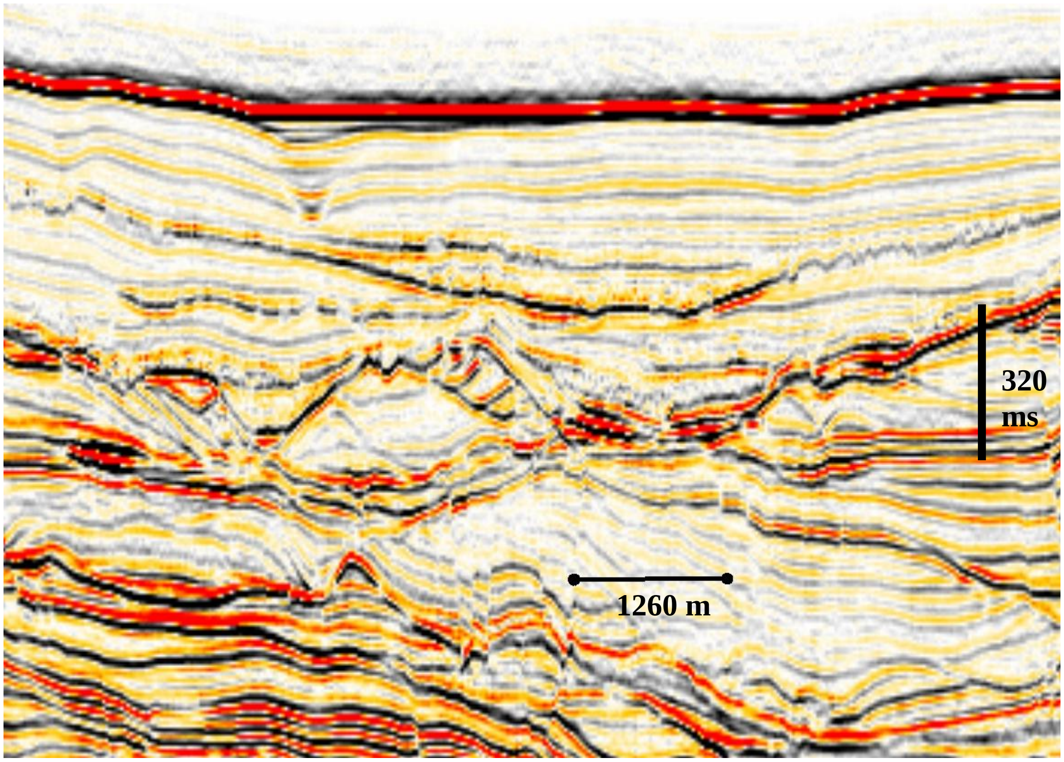


Figure 4-62: An upside down gastropod-liked feature in Unit H.

4.1.2.10 Horizon 9

In Figure 4-4, Horizon 9 is coloured in navy. It has bright amplitude, and high visibility, and is conformable to the underlying unit from the northern part to the center part of the area, but the amplitude from the center part to the south is no longer conformable and not continuous. It is possible that Horizon 9 was disturbed and cut by channels. About one-third of the total area in the south presents problems in picking this horizon. Also, picking this horizon in the eastern and south eastern parts was extremely difficult. Combination of in-line and cross-line intersections did not suggest much clue. Picking this horizon by using an extrapolation tool was absolutely avoided. Although picking this horizon was very challenging, it was an important horizon. The approximate location of this horizon clearly separates the low amplitudes of the unit above and the bright amplitude unit below.

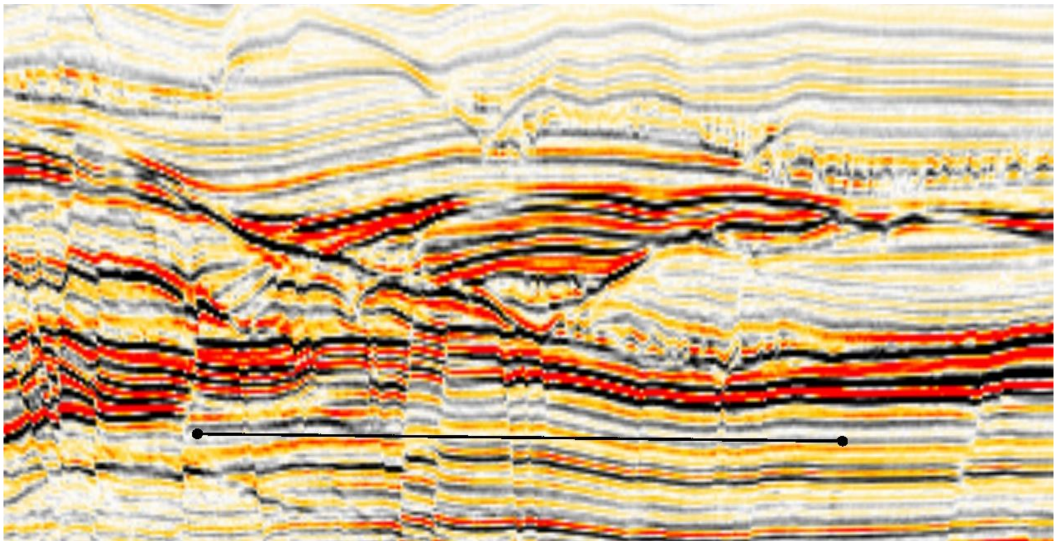


Figure 4-63: A channel is shown in in-line 1450; the scale shows 5355 m**.**

4.1.2.10.1 Horizon Slice 9

A horizon slice is a seismic horizontal section which reveals the top view of a horizon in vertical sections, so that geomorphology can be investigated. The Horizon Slice 9 is a result of the interpretation of Horizon 9 in the whole area.

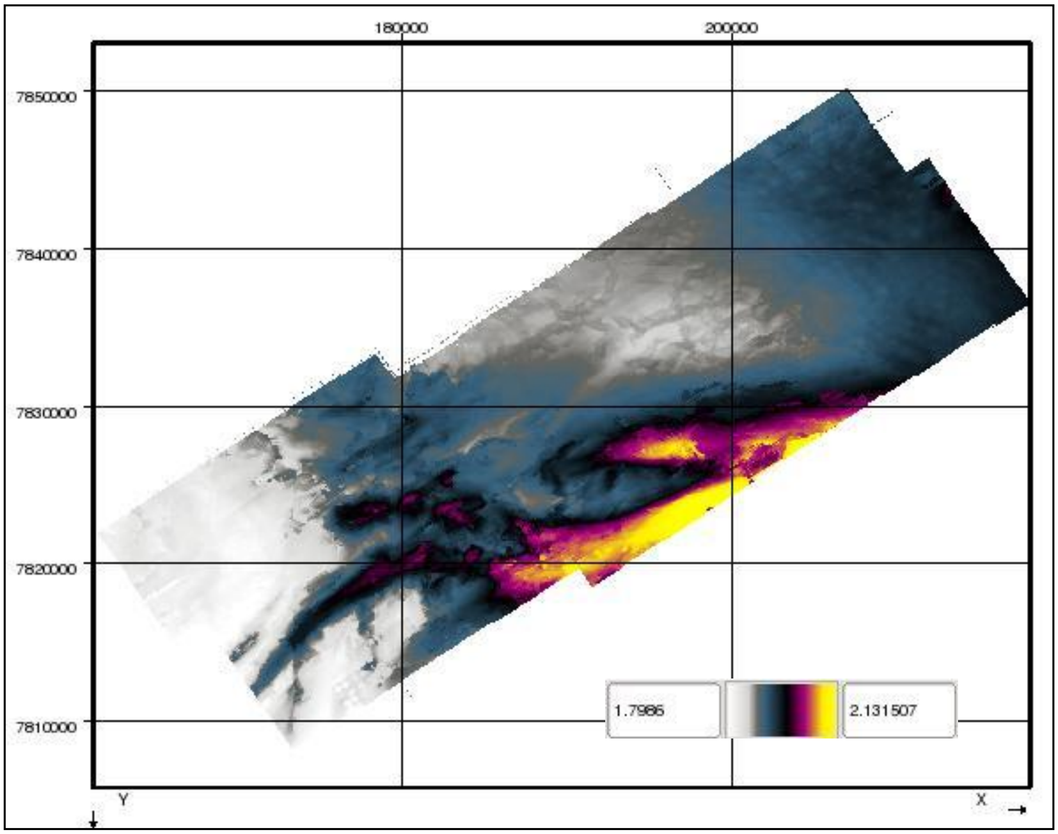


Figure 4-64: Time Structural map of Horizon Slice 9.

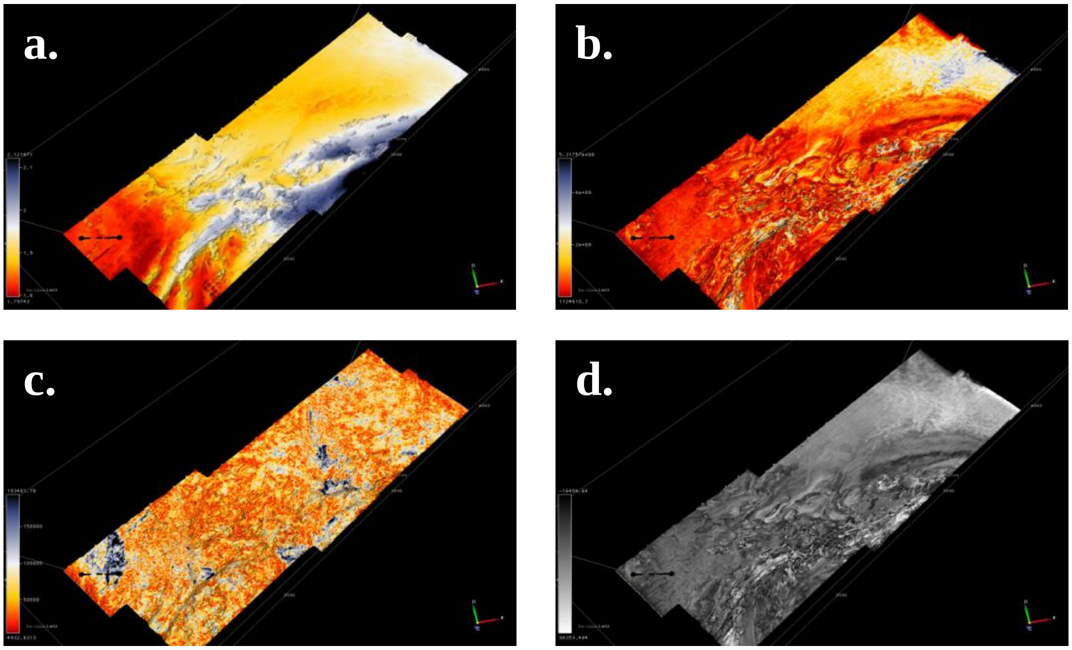


Figure 4-65: Different kinds of attributes of Horizon Slice 9: z value (a), amplitude (b), spectral decomposition (c), and coherency (d). Scale bars show 4.3 km in distance.

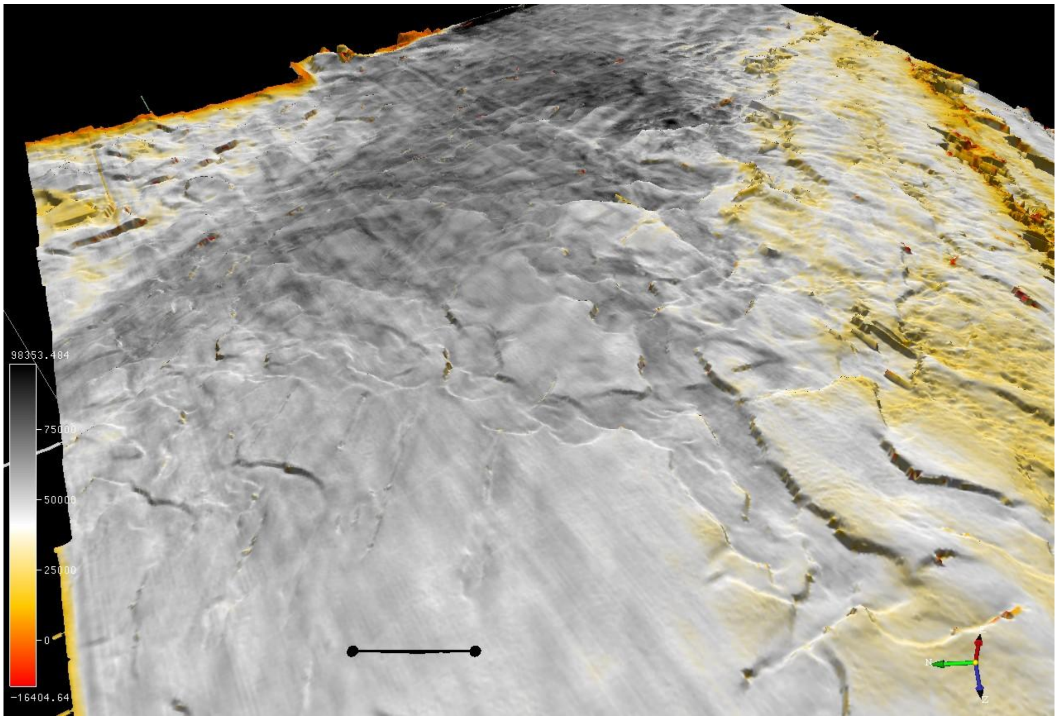


Figure 4-66 Segmented features and lineations from Horizon 9. Scale shows 1 km in distance.

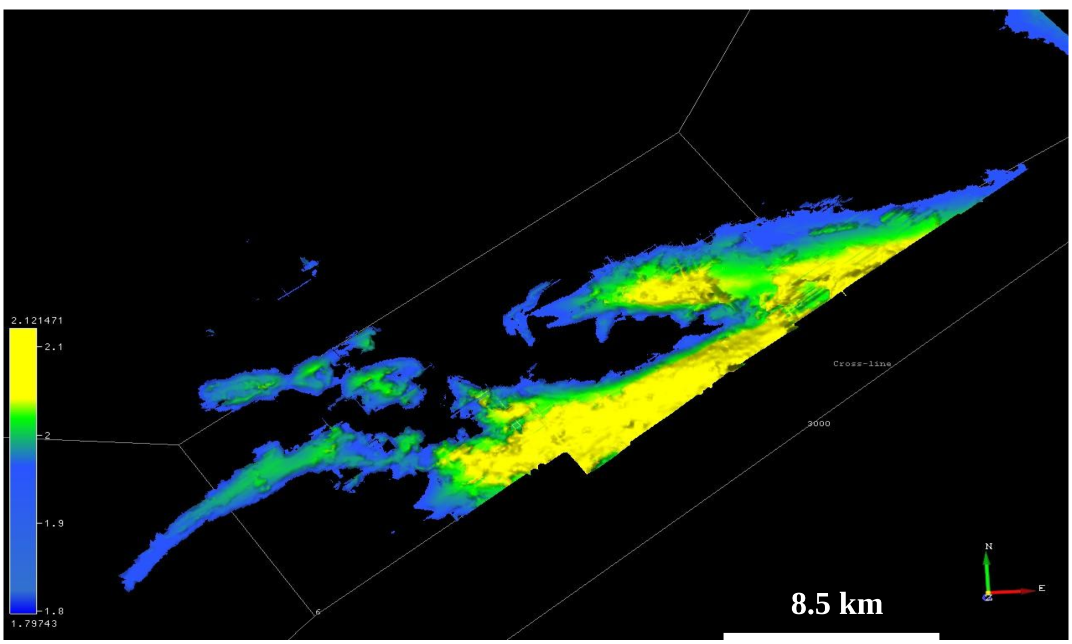


Figure 4-67: Horizon 9, channels, the deepest part shown in yellow and the shallowest part shown in blue.

4.1.2.10.2 Unit I

Unit I is the uppermost seismic unit. Its sequences are composed of weak seismic amplitudes. However, they have good continuity in the western part of the area. In the place that was not disturbed by the horizon above, the seismic reflection of Unit I is conformable to the horizon above and below. On the contrary, amplitude of Unit I was highly disturbed in the area under the disturbed overlying horizon (Figure 4-68).

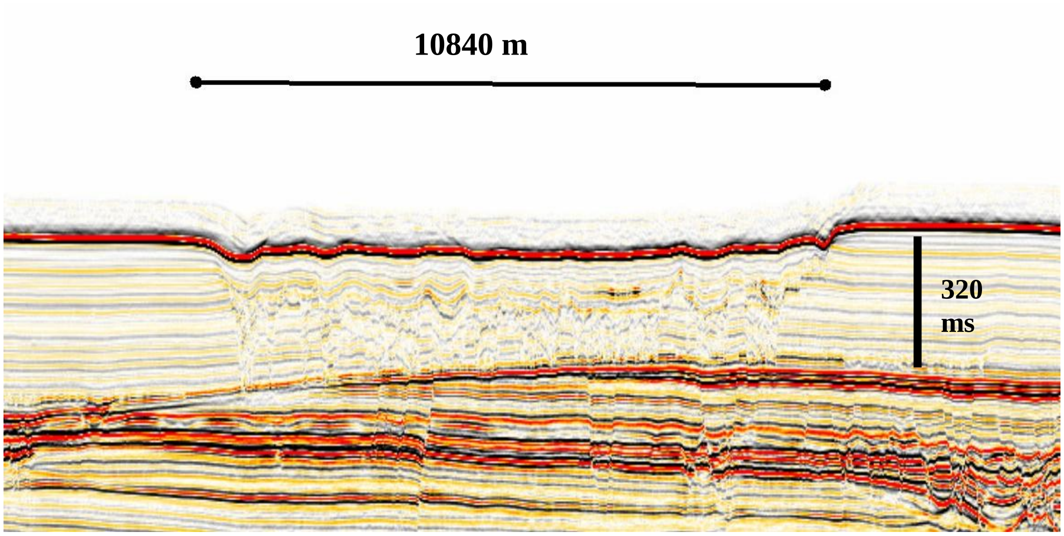


Figure 4- 68: The disturbed area resulted from the disturbed horizon above.

4.1.2.11 Horizon 10

Horizon 10 is the upper most horizon which represents recent sea bottom. It is an example of a very ideal horizon. It has a very vivid, bright, and the most visible amplitude. In addition, the continuity of the amplitude is excellent. The amplitude itself was confined with high amplitudes, above and below.

4.1.2.11.1 Horizon Slice 10

A horizon slice is a seismic horizontal section which reveals the top view of a horizon in vertical sections, so that geomorphology can be investigated. The Horizon Slice 5 is a result of the interpretation of Horizon 5 in the whole area.

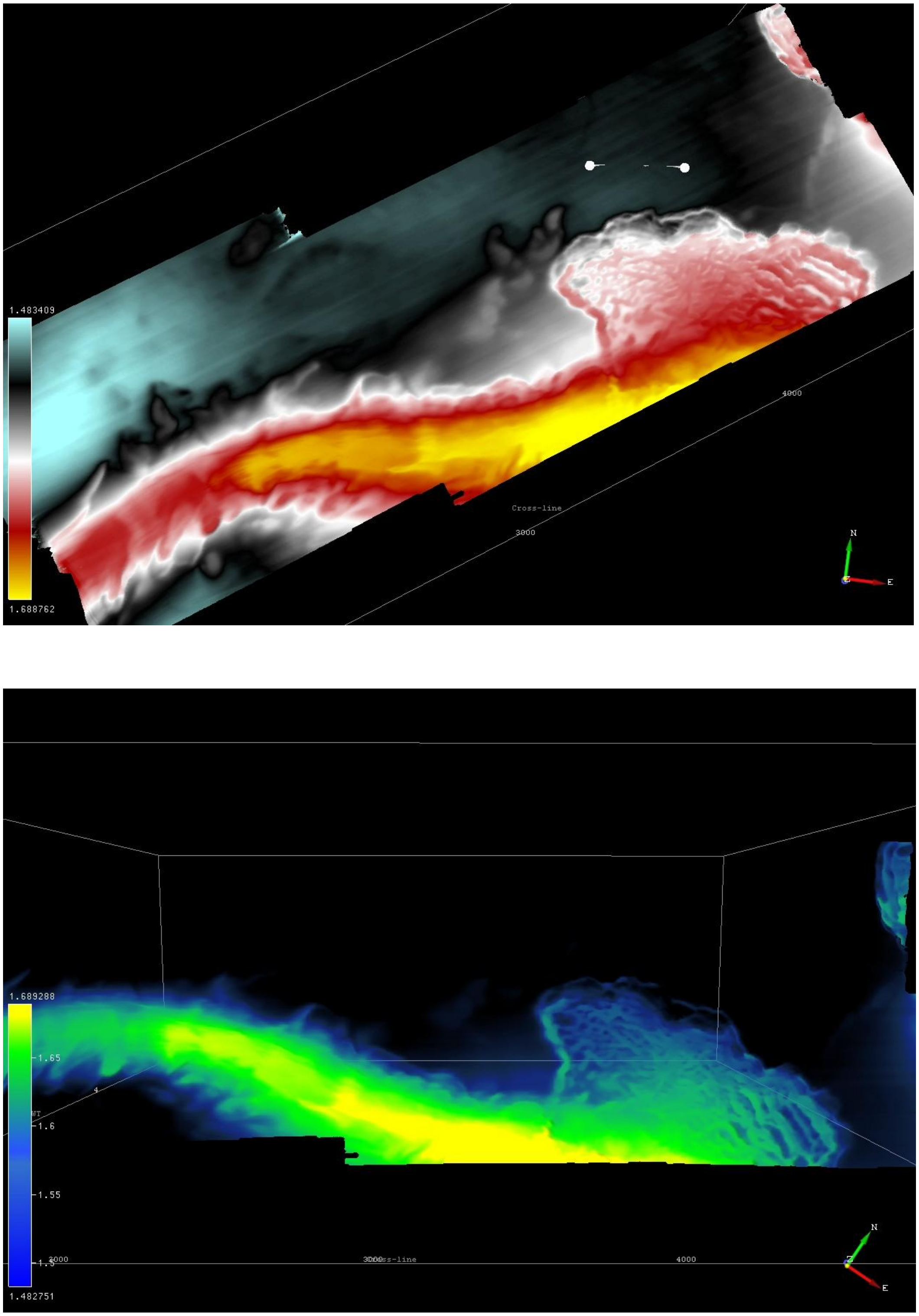


Figure 4- 69: Horizon slice 10 in different defining colors of Z-Value attribute.

4.2 Interpretation based on wire-line well log

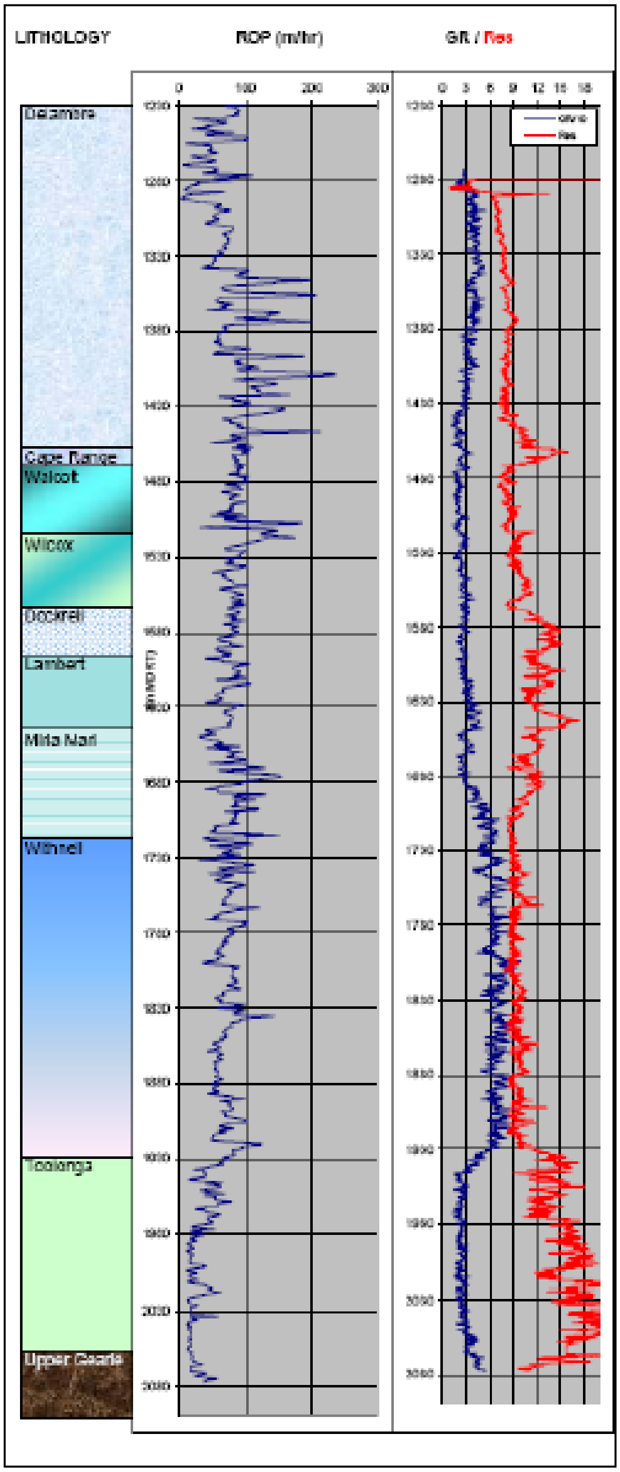


Figure 4-70: Geological sequence, Rate of penetration (ROP) and Gamma Ray log from left to right (modified from End of Well Report of Chandon-1).

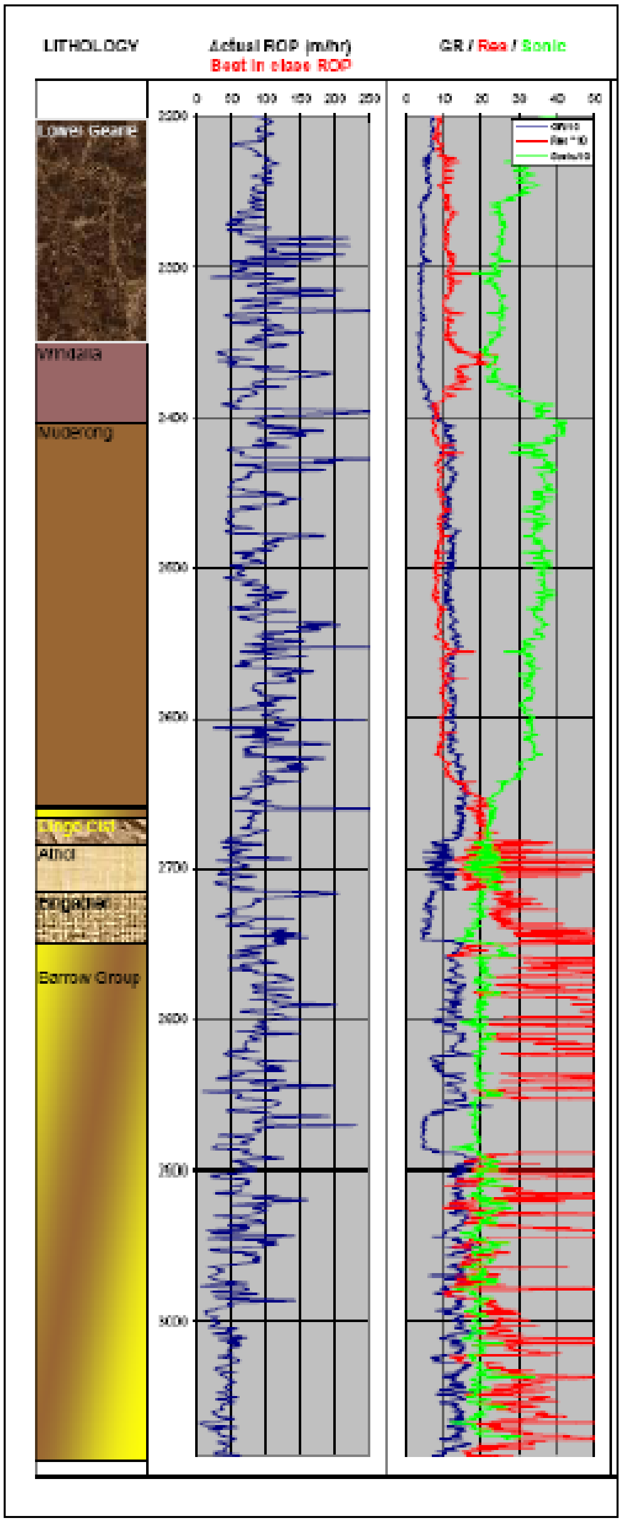


Figure 4-71: Lithology, Rate of penetration (ROP) and Gamma Ray log from left to right (part 2, modified from End of Well Report of Chandon-1).

4.3 Interpretation based on seismic reflections and wire-line well log

Unit B

Gamma ray log of Chandon-1 indicates that Unit B is in shale-prone environment with a single thick package of sandstone-prone environment. Early well log Interpretation which was done by Chevron, defines Unit B as Barrow Group. The Barrow Group according to Australian Government (2011) “The sediments of the lower (or western) Barrow Delta lobe are collectively known as the Malouet Formation, and those of the upper (or eastern) lobe as the Flacourt Formation. The boundary between the two lobes is markedly diachronous (Baillie and Jacobson, 1997). Dominant facies include basin-floor fan sandstone, pro-delta to foreset claystone, and top-set sandstone. The sandstone at the top of Barrow Group is known in parts as the Zeepaard Formation and Flag Sandstone”. Thus typically the Barrow group should represent coarsening upward feature in gamma ray log. However, it is possible that this well was drilled off the main delta lobes and was drilled on a flood plain and encountered a channel instead. The Barrow Group is normally suggests Early Cretaceous time.

However, late interpretation suggested that the Unit B is not belonging to the Barrow Group but it is actually an upper part of the thick Mungaroo Formation, which is the reservoir of the area.

Unit C

Unit C is composed of the Brigadier Formation and the Athol Formation which represent restricted marine with fluvial supply. The gamma ray log show fining upward in this sequence. The top Mungaroo Formation can be shown as Horizon Slice 2.

Unit D

Gamma ray log of Chandon-1 indicates that Unit D is shale. In this case, the coarsening upward response of log shows transgressive marine shale. It also aligns with the interpretation from seismic data. Most hydrocarbon discoveries within the Northern Carnarvon Basin are accommodated by reservoirs beneath the Muderong Shale, which forms an effective regional seal and has contributed to a high exploration success rate (Baillie and Jacobson, 1997). The Muderong Shale suggests Early Cretaceous time.

Unit E

Well data of Chandon-1 reveal that Unit E is composed of Windalia Radiolarite at the base and most of the unit are Gearle Siltstone. Both formations represent deep water environment. Windalia Radiolarite can be divided into the lower and upper units. The environments of the lower unit compose of restricted marine setting with less oceanic circulation, less silica-rich water, resulting in hardly grow of radiolarians. Windalia Radiolarite indicates Early Cretaceous time (Aptian). The base of the Windalia Radiolarite is a Type-1 sequence boundary, known as the `KA' Unconformity, which generates a strong continuous trough on seismic sections (Gardner, 1991).

Unit F

Gamma ray log of Chandon-1 indicates that Unit F composed of low gamma ray rocks which could be sandstone or limestone. In this case, it is Toolonga Calcilutite based on markers from Chevron. Seismic interpretation shows carbonate build up as in Figure 4-45. Toolonga Calcilutite is foraminifera limestone with mud-sized grains. It can be found in a shallow marine open shelf environment.

Unit G

Unit G based on well data is Withnell Formation. It can be interpreted as sandy shale or high radioactivity carbonate, as a result of high radioactivity. The top part of Unit G is Miria Formation which represents the latest Cretaceous, Maastrichtian. The Miria Formation is composed of calcarenite which is limestone or dolomite rock with a sandy texture, including silica sand fragments and sand-sized coral or shell fragments and possibly other sand sized particles derived from the weathering of older limestones; commonly deposited on or near coastlines. Thus the depositional environment of Unit G is shallow marine.

Unit H

Gammy ray log shows carbonate response in Unit H. This unit based on well data composed of Lambert, Dockerell, Wilcox and Walcott formations and Cape Range Group. All of them present Tertiary Age. Exon et al. (1982) suggest that this unit was deposited during the Eocene Age and that the sediment was pelagic chalk or ooze. Pelagic sediments are an indicator for sedimentary deposition in the abyssal plain, which is the deep part of the ocean.

Unit I

Well log reveals that Unit I is composed of Delambre Formation. It is consisted of fine-grained calcareous sequence with foraminifera assemblages which is an indicator for deep sea environment (below carbonate compensation depth or CCD).

Period	Seismic units	Formation of each unit	Depositional Environment
Q	I	Delambre	**Deep marine**
Te	H	Cape Range, Walcott, Willcox, Dockerell, Lambert	**Marine, Pelagic Chalk**
K	G	Miria Marl Withnell	**Shallow marine, LST deltaic system (log shows prodelta)**
	F	Toolonga Calcilutite	**Shallow marine open shelf**
	E	Gearle Siltstone, Windalia Radiolarite	**Deep marine**
	D	Muderong Shale, Barrow Gp, Dingo Clyst	**TS marine shale**
J	C	Brigadier	**Restricted marine with fluvial Supply (estuarine, mouthbar)**
Tr	B	Mungaroo Sandstone	**"Rift-valley" fluvio-deltaic**
	A	Mungaroo Sandstone	**Fluvio-deltaic**

Terrestrial

Marine Shale

Deep marine

Mesozoic Era

Cenozoic Era

Shallow marine

Tr = Triassic
J = Jurassic
K = Cretaceous
Te = Tertiary
Q = Quaternary

Table 4-1: Summary of depositional environments in each seismic units. Seismic Unit A, B and C were deposited during early to middle Mesozoic Era, were classified to be terrestrial sediments. The top of seismic unit C is the Oxfordian breakup unconformity followed by transgressive marine shale in Cretaceous (Unit D). Unit E represented deep marine environments and gradually became shallow marine environments until Tertiary Period (Unit H). Late Tertiary to Present, the area became deep water environment again (Unit H and Unit I).

The data that are used in this study are in time domain (TWT). However, the well log is in depth domain (m). To establish the relationship between seismic data and well log, the checkshot data need to be combined. The checkshot data is one of borehole seismic data used to determine seismic velocity of rock layers by measure the TWT from the source on the surface to the receiver at known depths in the well. In this study, since there is only one well, Chandon-1 provided, the well was converted into time domain. The wire-line well log superimposes on seismic line is shown in Figure 4-72.

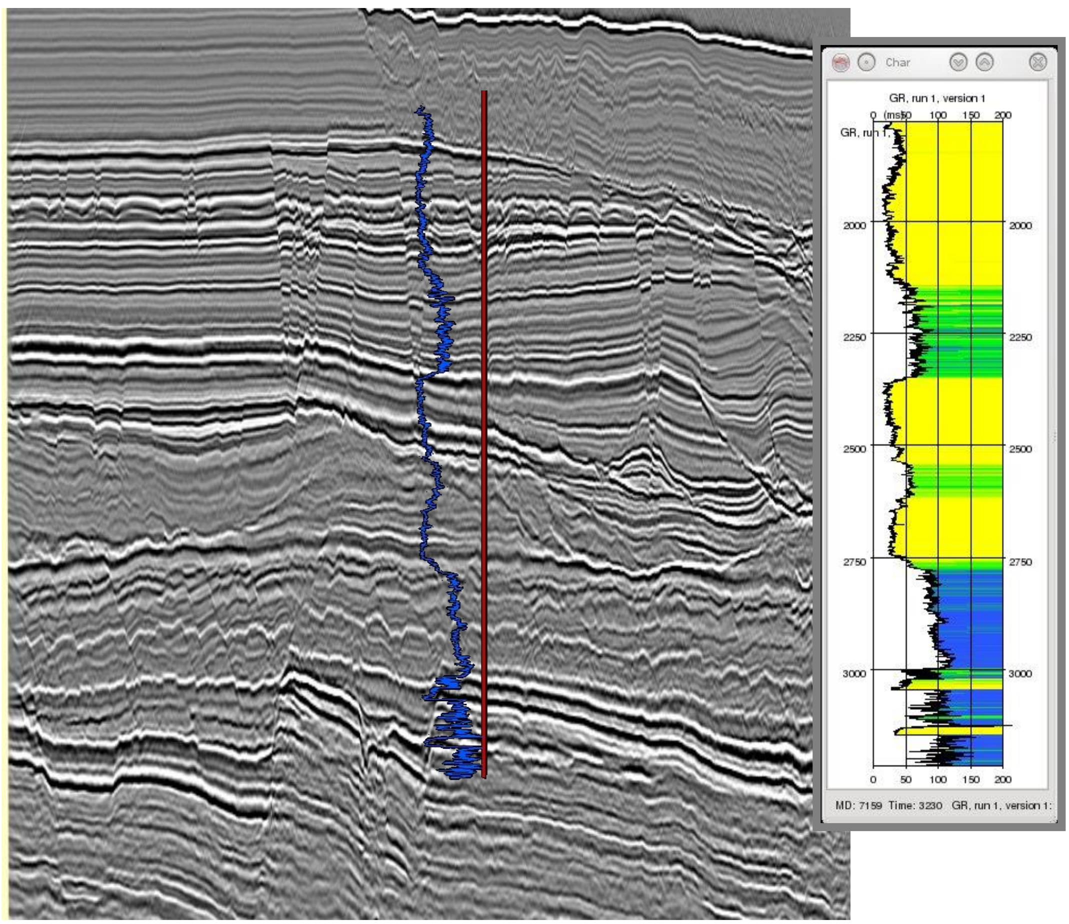


Figure 4-72: Wire-line well log of Chandon-1 in time domain: superimpose on cross-line 3930 (left) and show total depth of 3230 TWT (right). In the right picture, response from gamma ray log shows low radioactive rocks in yellow and high radioactive rocks in blue. The low radioactive rocks are potentially reservoirs such as sandstone and limestone. The high radioactive rocks are larger in clay content.

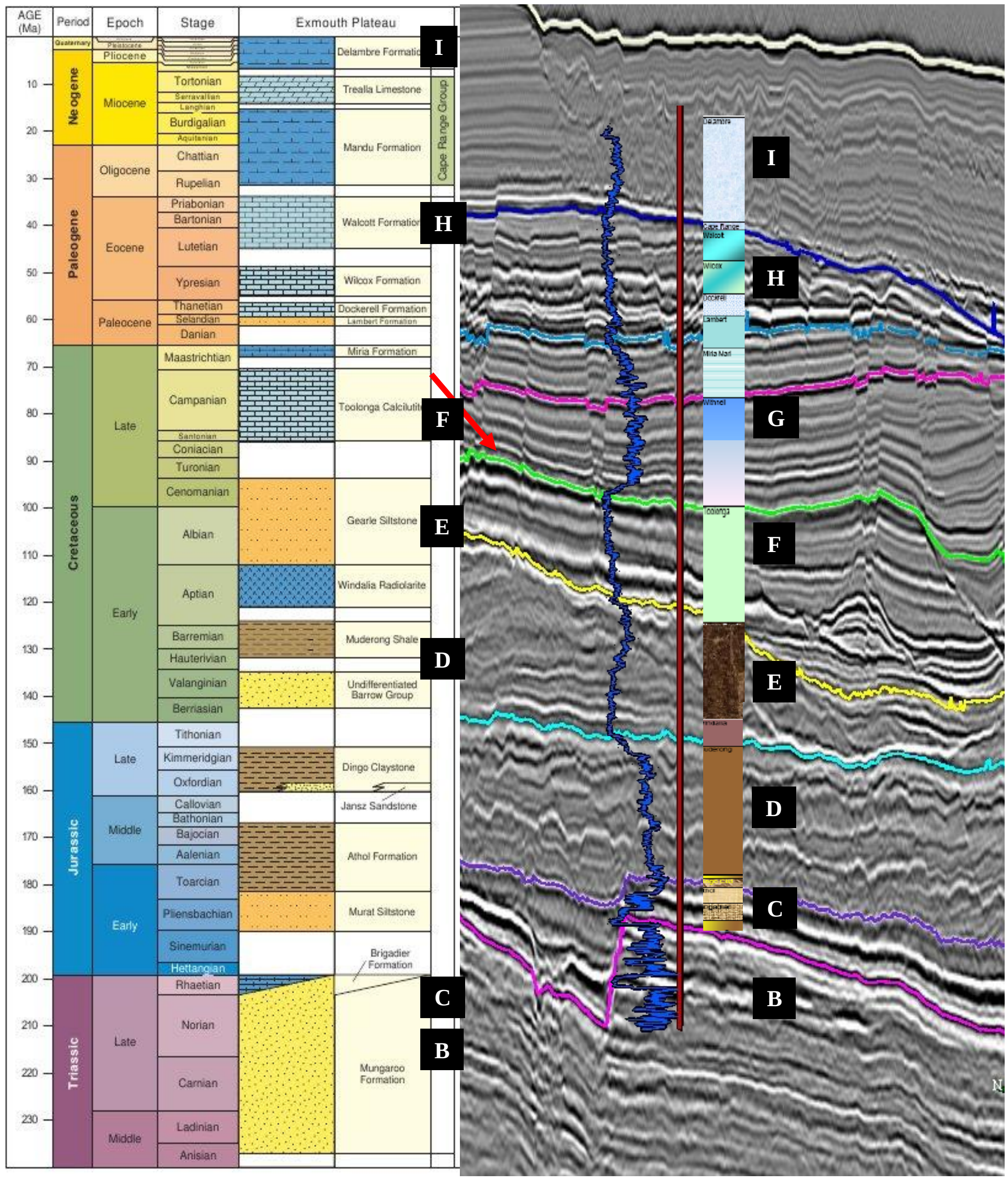


Figure 4-73: Combination of seismic and well log interpretation (modified from Australian Government and End of Well Report of Chandon-1).

Conclusion

A major rifting event during the Permian in the Northwest Australia translated in a westward direction to generate the Exmouth Plateau (Williamson and Falvey, 1988). Later, along the western Australian margin, a thick depositional wedge of Triassic sediment accumulated and was involved in subsidence and progadation (Boote & Kirk, 1989). Rifting between the Late Triassic and the Late Jurassic caused block-faulting. In the Late Jurassic, the Exmouth Plateau was covered by transgressive marine sediment from the Early Cretaceous. After the breakup, three abyssal plains confined the Exmouth Plateau on three sides, decreasing the influx of terrigenous sediment. Then the plateau sank, and the deposition of deep water sediment increased. In the Miocene, the plateau was uplifted, resulting in basin inversion, and this reactivated some pre-existing structures. During the same period, the carbonate wedge was built and prograded off the shelf.

Chapter 5

Conclusion and Discussion

5.1 Conclusion

This study was focused on seismic stratigraphy and seismic geomorphology. The seismic stratigraphy of the area was revealed by interpretating seismic reflections and the intervening horizons between them from different 2-D seismic vertical sections. 11 horizons were interpreted: Horizon1, 1*, 2, 3, 4, 5, 6, 7, 8, 9, and 10. Nine seismic units were interpreted: Unit A, B, C, D, E, F, G, H, and I. The geomorphology of the area was revealed through the interpretation of seismic horizon slices, and later the slices were displayed with the seismic attributes overlaid on them. The interpretation shows that different kinds of attributes divulge different geomorphological features. 10 horizon slices were interpreted: Horizon Slices 1, 2, 3, 4, 5, 6, 7, 8, 9, and 10.

The result of this study suggests that these seismic horizons and seismic units range from the Triassic period to recent times. Unit A, Unit B and Horizon 1, 1* and 2 were deposited during Triassic. Unit C and Horizon /Horizon Slice 3, which is obviously the breakup unconformity of the area and can be correlated to one of its offset wells, Mercury-1, revealed that its age was the Late Jurassic, Oxfordian. Evidence from the well log suggests that Unit D, E, F, and G, and also Horizon/ Horizon Slice 4, 5, 6, and 7, were deposited during the Cretaceous Period. Units H and I, Horizons/ Horizon Slices 9 and 10 were indicated as Tertiary successions.

5.2 Discussion

Seismic interpretation is multi-disciplinary work. It normally requires both geologists and geophysicists to collaborate. For the purpose of this study, however, the process of time-depth conversion, which is normally done by geophysicists, was skipped, and another method was used. A wire-line well log was instead converted into the time domain. After tying seismic and well data in the same domain, all of the seismic sequences were more reliable. In addition, markers revealed by Chevron helped to link and identify seismic units with the real formations. By integrating all data together, the interpretation was made more trustworthy.

Furthermore, in normal practice in an oil company, horizons and faults are picked by geophysicists, and they are next converted from the time domain to the depth domain. Then geologists can take over and continue the work by combining those horizons and faults. Geologists can use these to create maps, plan wells and finally construct a structural model by including sedimentology, stratigraphy, structurual geology and paleoclimatology data. Meanwhile, geophysicists can investigate more about the attributes of horizon sections. Later, reservoir engineers can apply the geological model to reservoir simulation, which can be used to predict the fluid flow, help to identify the number of wells required, predict expected production of gas oil and water, and monitor a reservoir in the petroleum development phase of a field. Reservoir simulation suggests the most economic and the safest approach to developing petroleum in the field.

Generating horizon slices is challenging and time-consuming work. Most researchers show their horizon sections with time slices because they are much more easily and more conveniently to generated; they can be produced merely by defining a particular time or the depth interest, after which the software will calculate and generate them automatically. However, investigating the paleoenvironment from horizon slices can reveal what happened in a particular time period, which is an important key in studying sequence stratigraphy. In addition, horizon slices can be used for a better understanding of geomorphology. Studying geomorphology by investigating different kinds of attributes can offer more clues and point out some features that have never been revealed.

Unfortunately, the seismic survey data were acquired in a direction perpendicular to what it was supposed to be. The layout of the data was an obstacle to further investigate in system tracts, since the dip direction of the data was too short. To accomplish this kind of work, a full-time IT support and a software support should be promptly whenever a problem occurs.

For future work, on the horizon slices, minor irregular and unsmooth area still need to be done away with more time, as it seems to be a never ending work. The process of time-depth conversion is recommended as well as fault picking. After that, faults should be interpreted in 3-D and modelled. Then a geological model can be constructed later on. More kinds of attributes can be investigated in more detail, both on horizon slices and on time slices.

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