SEISMIC SEQUENCE STRATIGRAPHY OF THE INTRA-BARROW GROUP, BARROW SUB-BASIN, NORTHWEST SHELF, AUSTRALIA

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ABSTRACT

Regional exploration in the Barrow Sub-basin has dominantly focused on structural traps in the Top Barrow Group. A lack of recent discoveries has focused attention more towards the economic potential of the Early Cretaceous intra-Barrow Group plays. The aim of this study was to interpret the seismic sequence stratigraphy and depositional history of the intra-Barrow Group within the Barrow Sub-basin, with emphasis on the identification of stratigraphic traps and potential locations of economic seal/reservoir couplets within the study area.

The study area lies south of Barrow Island, and contains the topsets, foresets and toesets of the ‘Barrow delta’, which are an amalgamation of Mesozoic sand-prone fluvial, coastal deltaic and deepwater successions. The final stages of the break-up of Gondwana impacted on the structural development of the Barrow Sub-basin, when a large shelf-margin fluvial/deltaic system built out toward the north to northeast, contributing to northerly shelf margin accretion, with large-scale clinoform features and associated depositional environments.

The dataset comprises the Flinders 3D seismic survey 1267 km^2 and 35 well logs. Eleven seismic sequences are identified and a seismic sequence stratigraphic framework tied to the wells has been developed, via detailed sequence stratigraphic mapping, integrated with 3D visualisation techniques with the use of Petrel. These eleven second-order sequences are further subdivided into lowstand, transgressive and highstand systems tracts. The movement of the palaeo-shelf break, slope and base of slope can be traced throughout each sequence, displaying an overall trend of building out in a north to northeast direction. A series of palaeo-geographic maps for each sequence has been developed to illustrate the basin’s evolution. The seismic sequences identified display progradation, followed by aggradation, then downstepping, concluding with progradation and aggradation.

A high-resolution sequence stratigraphic study of Seismic Sequence 1 showed that several higher-order sequences can be identified, including numerous lowstand systems wedges, along with associated channel features, which could be targeted as new plays. The sequence stratigraphic framework developed, palaeo-geographic reconstructions and all other interpretations made for this project have been integrated to assess the prospectivity of the intra-Barrow Group over the study area, resulting in the identification of a number of leads and prospectivity summaries for each of the 11 Seismic Sequences identified within the intra-Barrow Group.

1.0 INTRODUCTION

1.1 RATIONALE

The Barrow Sub-basin has been a key area for exploration since 1962 and includes the largest onshore oilfield discovery in Australia namely Barrow Island discovered in 1964. The Barrow Sub-basin covers an area both onshore and offshore and spans some 15,000 km^2 (Figure 1.1) (Baillie and Jacobson, 1997). The Barrow Sub-basin is a major hydrocarbon province in Australia and has produced oil, condensate and natural gas from a large number of discoveries since the early 1960s. The bulk of discoveries have been in structural traps at the top Barrow Group level. These discoveries are now either nearing the end of their producing life or have been entirely exhausted.

This project looks in detail at the intra-Barrow Group succession. Minor and major oil and gas shows have previously been identified throughout this succession, such as at South Pepper-1. However, due to the smaller field sizes discovered within the Barrow Sub-basin recently, few discoveries have been made commercial. Consequently, the rationale for this project is to examine the hydrocarbon prospectivity that may be present in the intra-Barrow Group. An improved understanding of this succession may contribute to future exploration programs within the Barrow Sub-basin. Extensive work has been carried out in the past to identify obvious structural traps within the study area. This project will

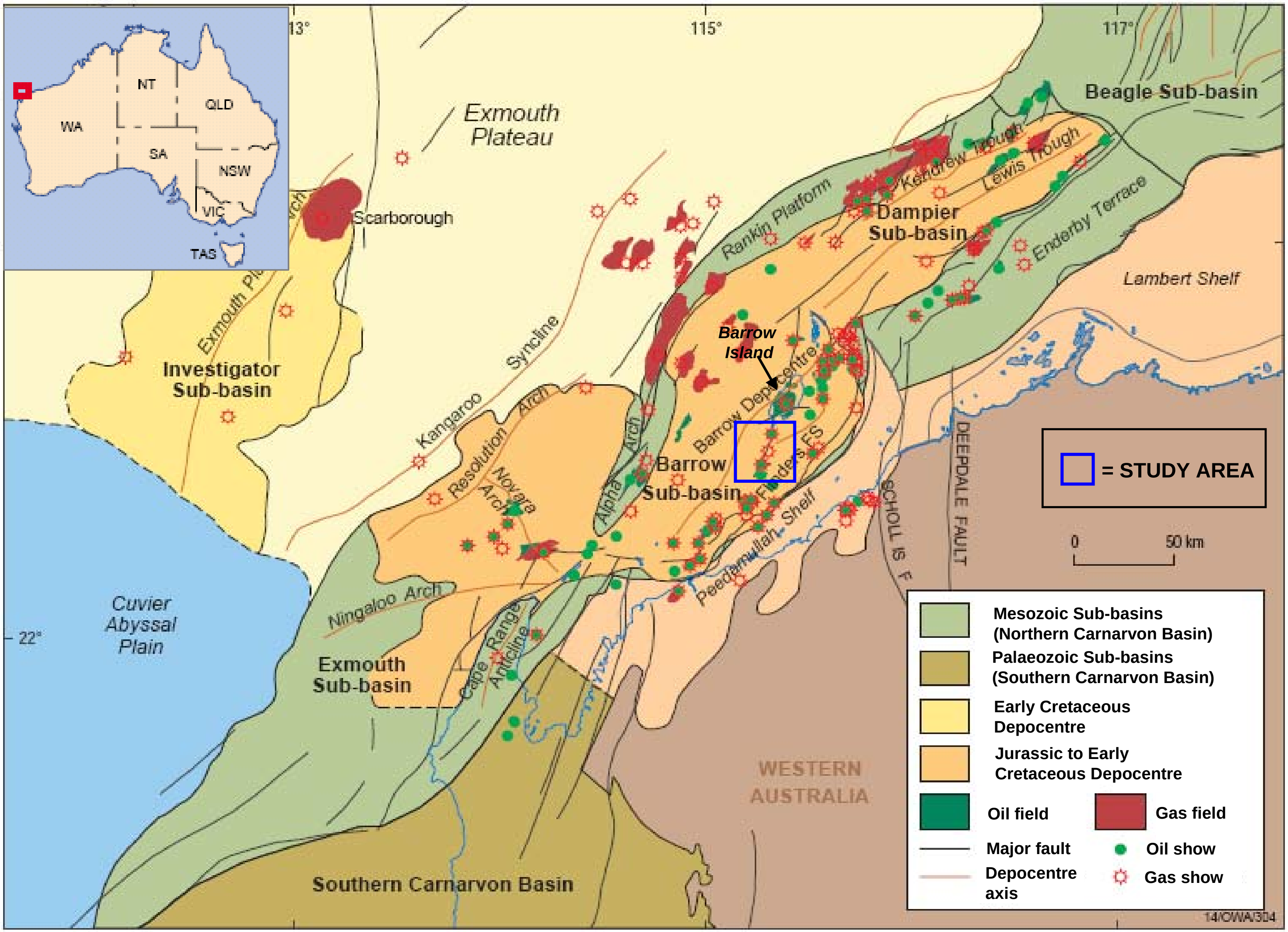


Figure 1.1 Northern Carnarvon Basin Regional Structural Elements Map (modified from GA Website, 2006)

discuss the identification of new play types in the study area through the use of sequence stratigraphy, especially in the form of stratigraphic traps.

1.2 AIMS AND OBJECTIVES

The aim of this project is to locate potential stratigraphic plays within the intra-Barrow Group succession, based on 3D seismic stratigraphic analysis. The integration of all available data, including the 3D seismic dataset, well logs, palynology data, core and cuttings descriptions, will aid the objective of creating a seismic sequence stratigraphic framework over the study area. Additional steps in this process include outlining a depositional model for the intra-Barrow Group, thus creating a predictive tool for hydrocarbon prospectivity within the study area. A subsequent deliberate search through the 3D seismic survey may result in the location of new hydrocarbon prospects (both stratigraphic and structural).

The main objectives of this study, within the interval of interest over the study area, are to:

- Review all available data and previous interpretations.
- Identify significant seismic-based sequence boundaries within the intra-Barrow Group succession.

- Develop a seismic sequence stratigraphic framework for the intra-Barrow Group succession.
- Develop a depositional model illustrated in schematic palaeogeographic reconstructions for each interval.
- Provide a quick-look high resolution sequence stratigraphy study for Seismic Sequence 1.
- Integrate the seismic sequence stratigraphic framework developed into the hydrocarbon prospectivity evaluation and explanation.
- Evaluate the hydrocarbon prospectivity of the interval of interest (intra-Barrow Group) in the study area.

1.3 STUDY AREA

The study area is located in the Barrow Sub-basin and focuses on the area covered by the Flinders 3D survey area (Figure 1.2). It is located entirely offshore, just south of Barrow Island (Figure 1.2). The study area covers approximately 1,267 km^2 and extends over the petroleum production and exploration licenses; TP/7 (Parts 1-4), TL/2 and parts of EP 364 and EP 409. Apache Energy Australia, Santos, Tap Oil and Pan Pacific Petroleum presently have equity within some or all of these permits (June 2007).

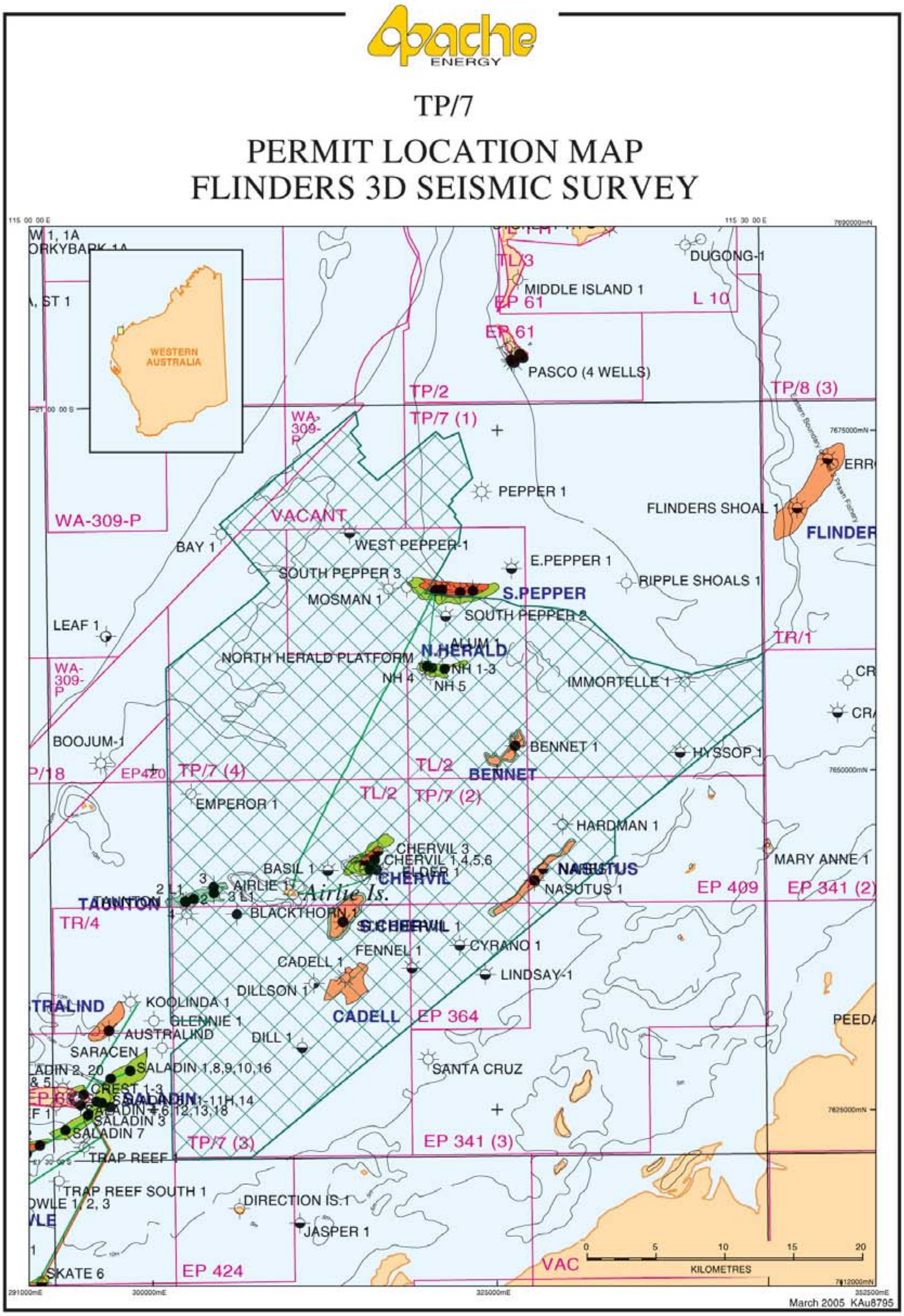


Figure 1.2 Location and outline of the 1267 sq km Flinders 3D seismic survey (hashed area), Barrow Sub-basin.

2.0 GEOLOGIC SETTING

2.1 INTRODUCTION

The Northwest Shelf of Australia encompasses the offshore and marginal coastal areas of the northwest part of Australia, including four basins: the Northern Carnarvon, Offshore Canning, Browse and Bonaparte basins (Figure 2.1) (Hocking, 1990). The Northwest Shelf has been involved in a number of continental rifting periods. This has been characterized by shifts in the location of rifts, failure of rifts, and changes in the direction of stress. These rifts are associated with Cambrian age separation of Australia from Chinese continental blocks forming the paleo-Tethys Ocean (Baillie and others, 1994), and Carboniferous to Permian age separation of China-Burma-Malay-Sumatra continental blocks forming the neo-Tethys Ocean (Veevers, 1974).

The Northern Carnarvon Basin is located at the southern extreme of the Northwest Shelf and was developed by rifting during the Jurassic to earliest Cretaceous times (Etheridge & O’Brien, 1994). The Northern Carnarvon Basin is 375,000 km^2 and contains up to 15 km of Mesozoic sedimentary rocks. The main structural subdivisions of the Northern Carnarvon Basin are dominated by a southwest-trending set of troughs and include the Exmouth, Barrow, Dampier and Beagle Sub-basins, and the Rankin Platform and Exmouth Plateau (Figure 1.1) (Hocking, 1988). Water depths are generally less than 200 m, with a gentle

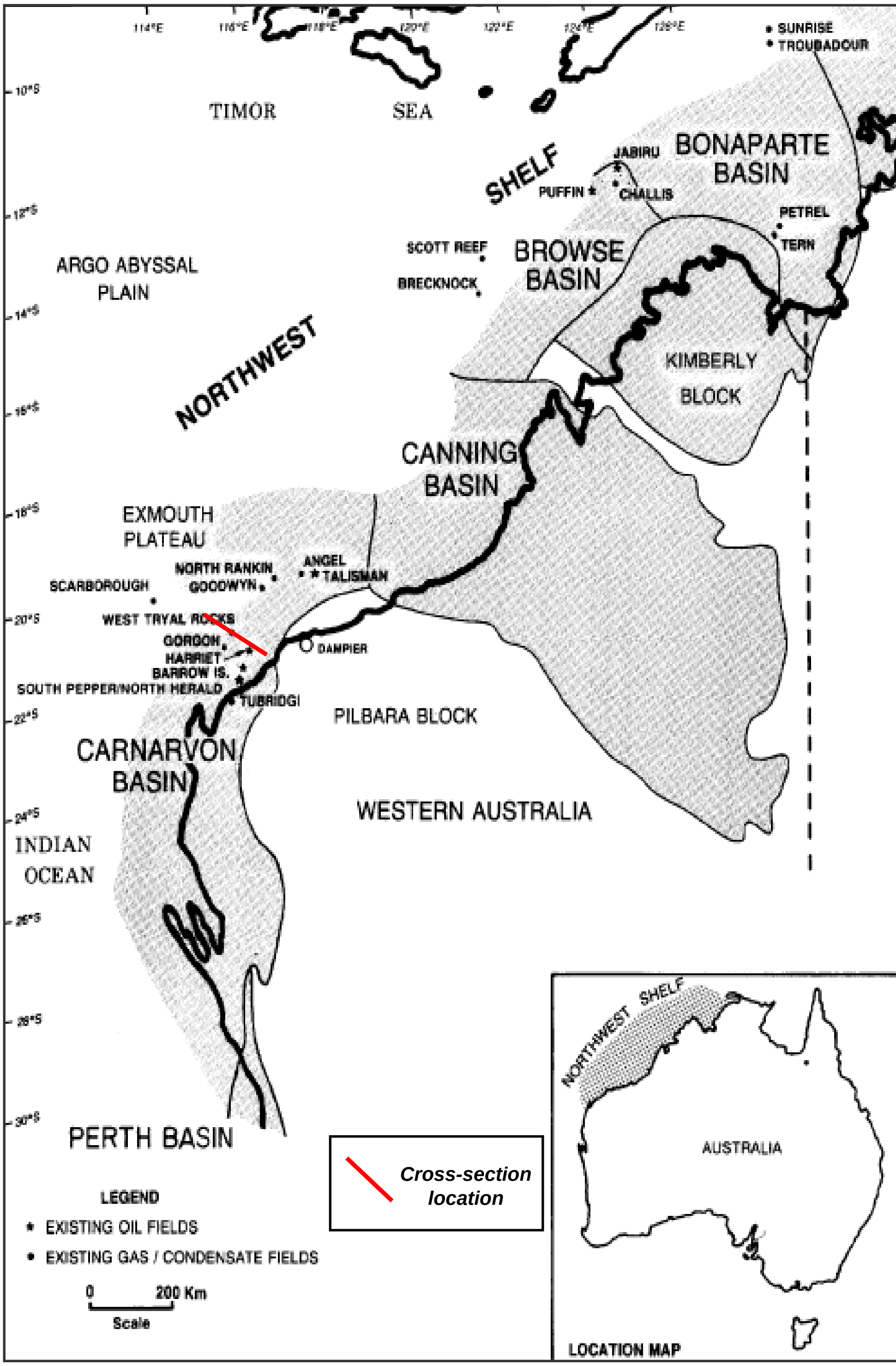


Figure 2.1 Main basin subdivisions and existing fields on the Northwest Shelf of Australia (Butcher, 1988).

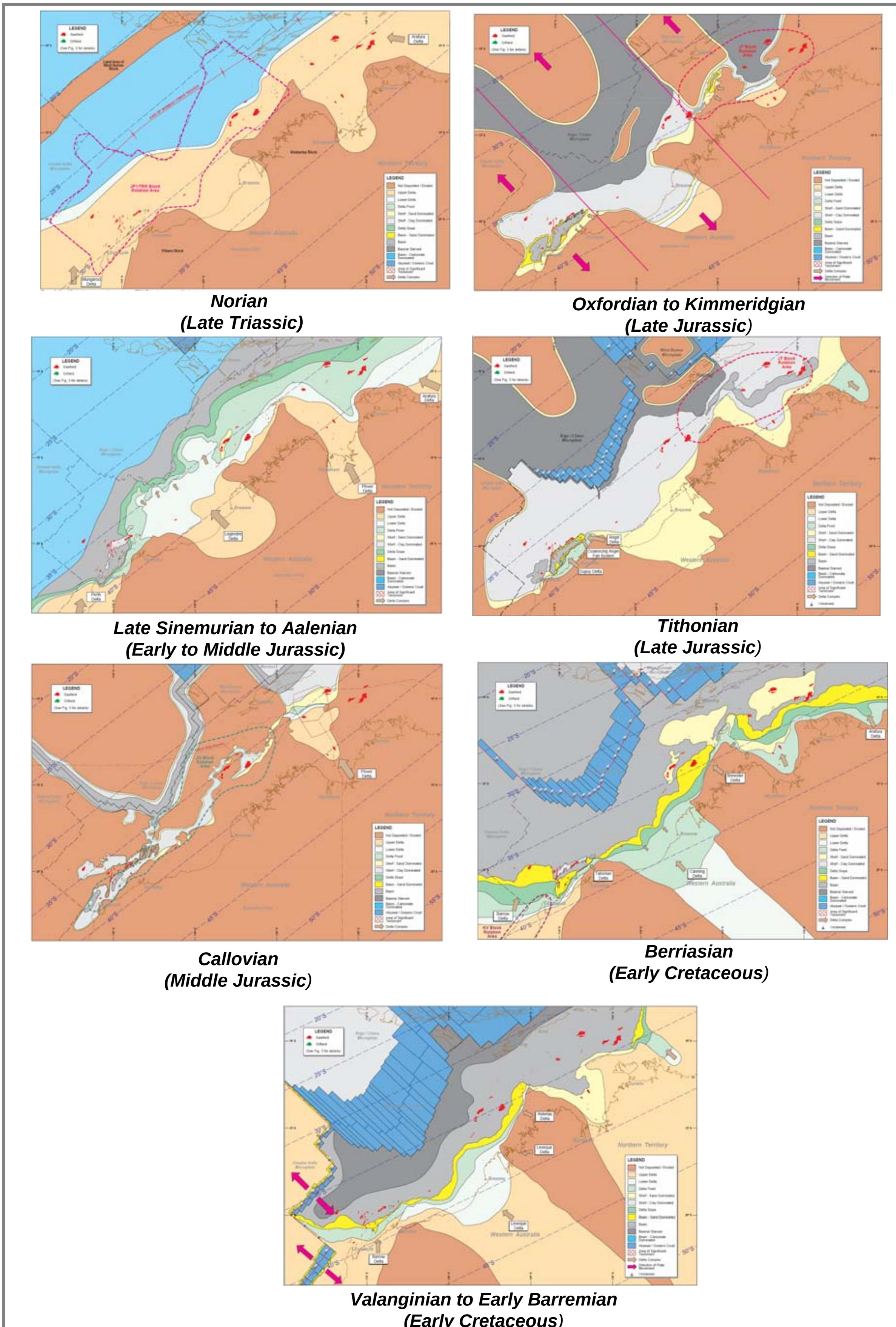
seabed that slopes to the NW. Numerous islands in the area provide excellent locations for production facilities such as those found at Barrow and Varanus Islands (Ferdinando, 2004).

2.2 TECTONIC EVOLUTION

The evolution of the Northern Carnarvon Basin commenced in the Late Palaeozoic (Figure 2.2). Key phases in its evolution include extension, which terminated in the late Permian, and three main post-Permian phases (Veevers et al., 1991) (Figure 2.2). The evolution during post-Permian time can be divided into a Triassic pre-rift phase, a syn-rift continental break-up phase and a post-rift (thermal sag) phase (Westphal & Aigner, 1997) (Figure 2.2). The major structural elements of the Northern Carnarvon Basin include major basin faults trending north or northeast which define a series of structural highs (Hocking, 1988).

The key stages identified in the tectonic evolution of the Northern Carnarvon Basin have been divided into four parts:

1. The first phase occurred from the Silurian to Permian and developed as a series of intracratonic basins during the break-up of Gondwana along the western margin of Australia (Hocking, 1988).



Norian (Late Triassic)

Oxfordian to Kimmeridgian (Late Jurassic)

Late Sinemurian to Aalenian (Early to Middle Jurassic)

Tithonian (Late Jurassic)

Callovian (Middle Jurassic)

Berriasian (Early Cretaceous)

Valanginian to Early Barremian (Early Cretaceous)

Figure 2.2 Simplified palaeogeographic maps for the NWS from the Late Triassic through to Early Cretaceous (Longley et al., 2001).

2. The second phase occurred during Early Jurassic extension, which initiated four main depocentres; the Exmouth, Barrow, Dampier and Beagle sub-basins (Hocking, 1988).

3. A third extensional phase in the Middle Jurassic resulted in seafloor spreading in the Argo Abyssal Plain to the north (Hocking, 1988).

4. The fourth (Tithonian to Valanginian) rifting phase culminated in the creation of the Gascoyne-Cuvier abyssal plains to the west and south. This was followed by the formation of the Exmouth Plateau in response to thermal sag after the Valanginian break-up (Hocking, 1988).

2.3 BARROW SUB-BASIN EVOLUTION

The Barrow Sub-basin is an elongate trough situated on the northwestern margin of the Australian continent, within the Northern Carnarvon Basin, and is classified as a rift basin (Figure 2.2 & 2.3) (Ehrhard et al., 1992). The sub-basin covers an area of approximately 15,000 km^2 and is bounded on the west by the Triassic horsts of the southern Rankin Platform and on the east and south by the faulted edge of the Peedamullah Shelf (Bradshaw et al., 1994). Sediments range in age from Permian to recent and are up to 15,000 m thick in some sections of the sub-basin (Figure 2.3) (Thomas & Smith, 1976). The sub-basin is located entirely

BARROW SUB-BASIN

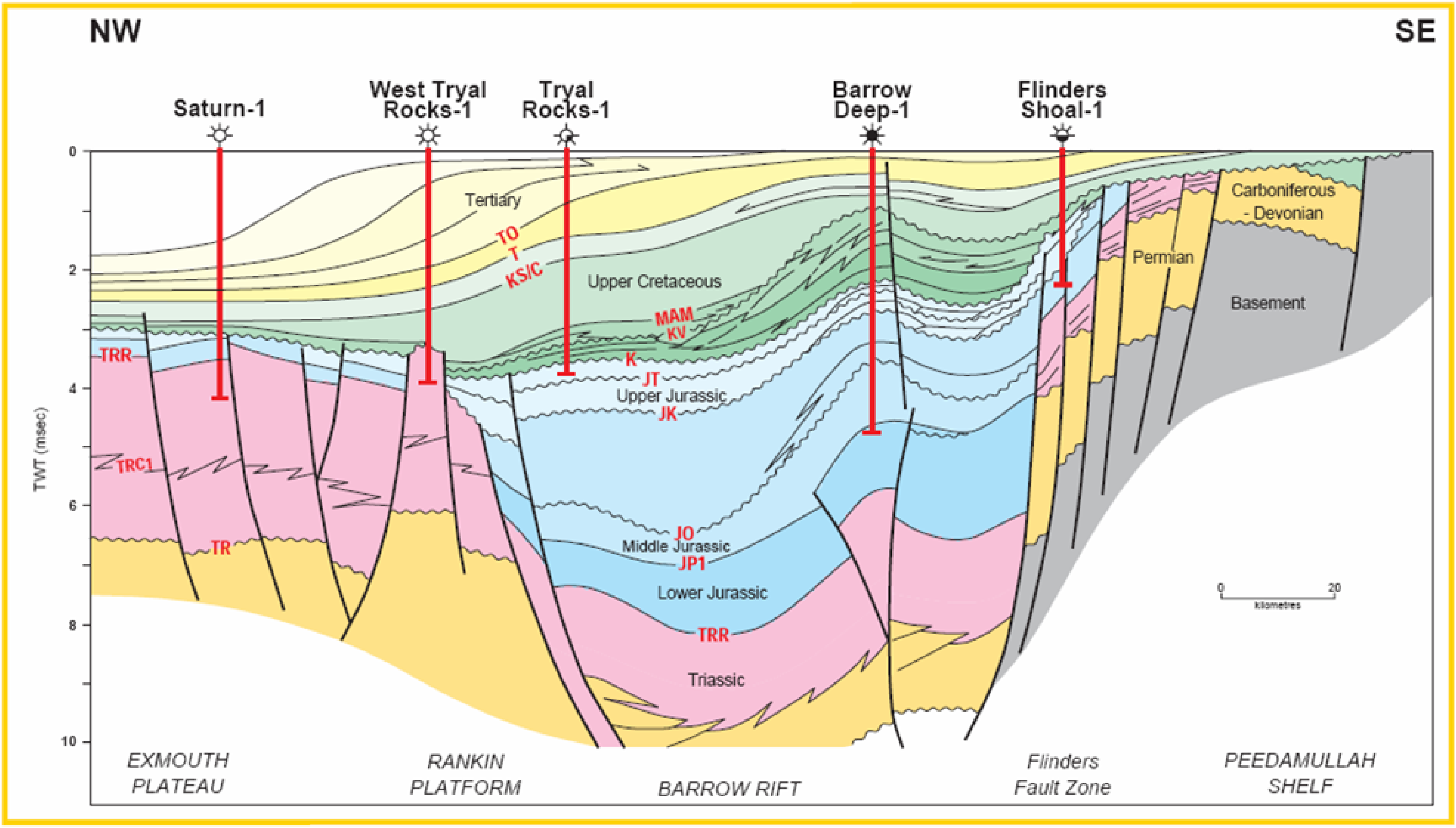


Figure 2.3 Simplified regional geological cross-section from northwest to southeast. Section location is shown on Figure 2.1.

offshore, although some Tertiary sediments crop out on a number of islands, including Barrow Island.

2.3.1 TECTONIC EVOLUTION OF THE BARROW SUB-BASIN

The development of the Barrow Sub-basin commenced in the Palaeozoic and is largely a result of Late Triassic to Early Jurassic rifting between Australia and the Greater India/Western Burma Block break-up of eastern Gondwanaland (Baillie and Jacobson, 1997) (Figure 2.2). In the Middle Jurassic, continental break-up occurred west of the Exmouth Plateau and rifting ceased in the Barrow Sub-basin (Boote & Kirk, 1989). The structural traps present in the Barrow Sub-basin are due to extensional events in the Middle to Late Jurassic and Early Cretaceous, Late Cretaceous inversion and Miocene compression (Ehrhard et al., 1992).

2.3.2 MAIN STRUCTURAL ELEMENTS OF THE BARROW SUB-BASIN

The Barrow Sub-basin is an elongate, north-northeast to south-southwest trending offshore basin which is bound to the west by horst blocks, to the south by the Rankin Platform and to the east by the faulted edge of the Peedamullah Shelf (Tait, 1985). The major structural elements include the Flinders Fault System which defines the eastern limits of the basin and the east-west trending

Long Island Fault System which delineates the southern margin of the basin (Figure 2.4).

Normal faults, representing the dominant fault style, occur in the eastern part of the Barrow Sub-basin. In areas such as the South Pepper discovery and Barrow Island, faulting is oblique or sub-parallel to the regional trend (Figure 2.4). These en-echelon faults are normal faults with minor reverse components. Other regional structural styles present in the Barrow Sub-basin include anticlinal and synclinal structures that trend northeast to southwest. These trends, such as the Barrow Island anticlinal trend, form prominent, elongate, arched anticlines in the north and south of the sub-basin and are partially fault-bounded (Kospen & McGann, 1985). These anticlinal features form the predominant structural trapping style in the basin.

2.3.3 STRATIGRAPHY OF THE BARROW SUB-BASIN

The Palaeozoic to Cainozoic Barrow Sub-basin is a deep, synclinal graben that formed a depocentre during the Mesozoic to Cainozoic (Polomka & Lemon, 1996). Strata at the deepest part of the basin are over 10 km thick, while on the shallower faulted terraces, the stratigraphy is up to 5 km thick (Parry & Smith, 1988) (Figure 2.5).

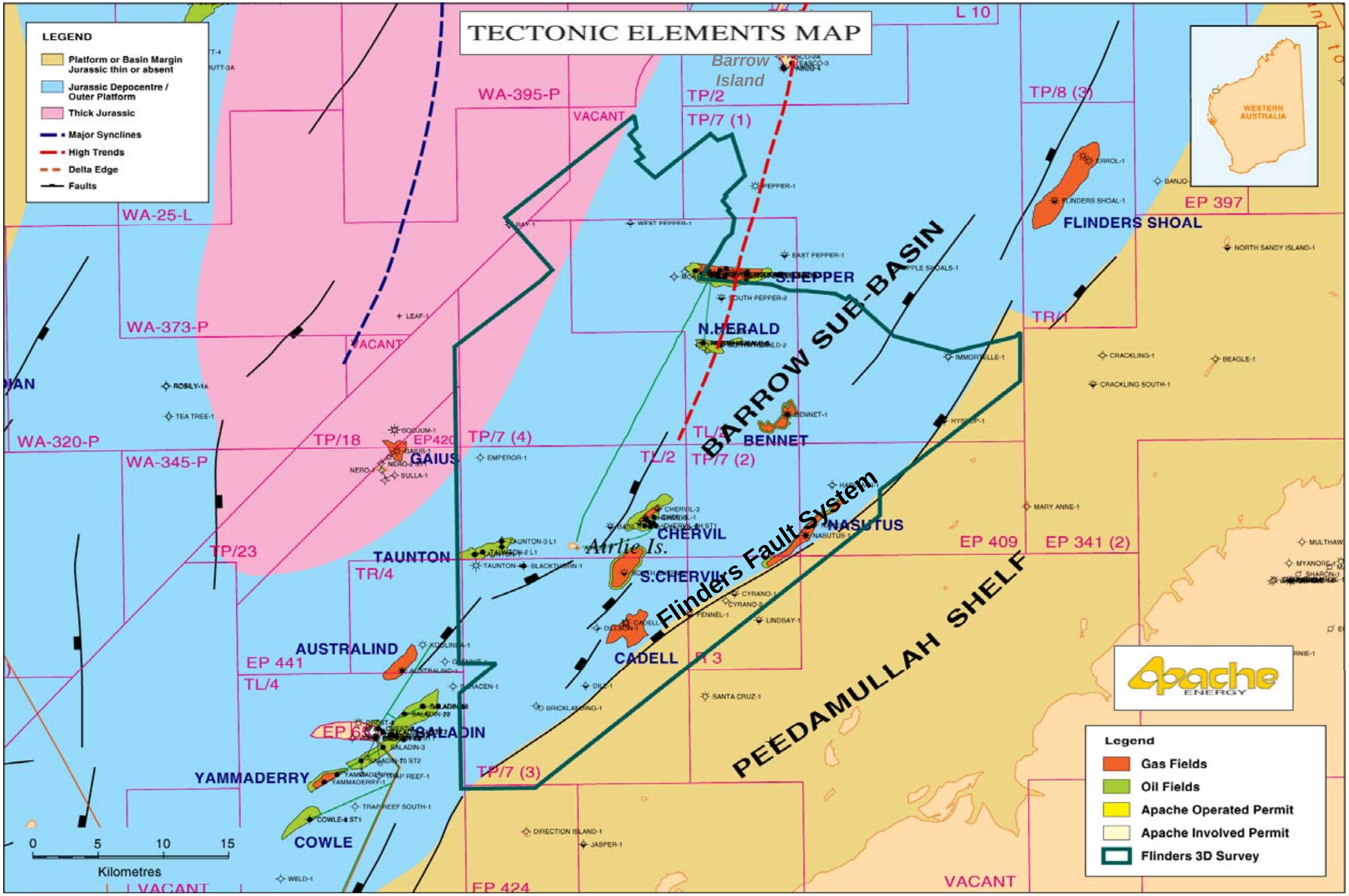


Figure 2.4 Tectonic elements map over Flinders 3D study area (dark green outline), Barrow Sub-basin, Northern Carnarvon Basin, NW Australia.

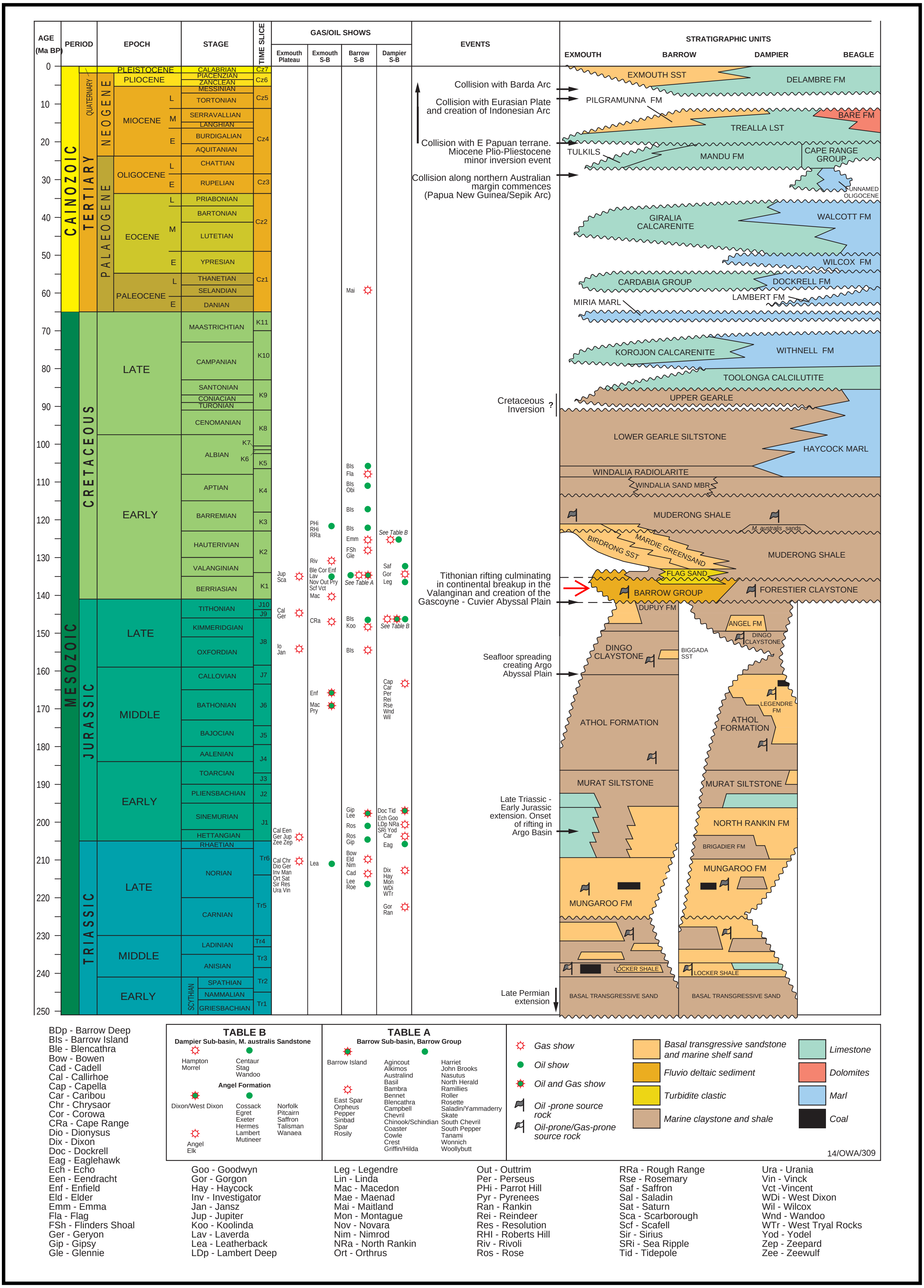


Figure 2.5 Northern Carnarvon Basin Stratigraphic Column (GA, 2007). Early Cretaceous Barrow Group highlighted (red arrow).

2.3.3.1 Pre-Mesozoic

The Palaeozoic succession present in the Northern Carnarvon Basin is poorly understood due to the sparse number of wells drilled through this succession. Thick, rhythmic, parallel-bedded seismic reflectors have been identified and correspond to this era. These beds typically comprise marine shelfal sediments and are therefore possible source rocks (Kospen & McGann, 1985).

2.3.3.2 Triassic

The Triassic succession was initially deposited during a transgression, followed by a regression (Jablonski, 1997). The lower Locker Shale interval was deposited mid-transgression and resulted in widespread deposition of thick claystone (Figure 2.5). The upper Triassic consists of regressive fluvio-deltaic sediments and coal of the Mungaroo Formation (Longley et al., 2002) (Figure 2.5).

2.3.3.3 Jurassic

Key formations forming the Jurassic succession include the Brigadier Formation, Murat Siltstone, North Ranking Formation, Athol Formation, Legendre Formation, Dingo Claystone, Angel Formation and Dupuy Formation (Figure 2.5). During the Hettangian, the North Rankin Formation, a widespread sandstone, was deposited as a succession of nearshore/shoreline facies (Jablonski, 1997) (Figure 2.5). A widespread transgression during the Sinemurian time led to the deposition of the think marine Dingo Claystone (Bradshaw et al., 1988) (Figure 2.4). Marine claystone deposition continued until the Tithonian with marine sandstone units such as the Dupuy Sandstone being deposited locally (Longley et al., 2002) (Figure 2.5).

2.3.3.4 Cretaceous

The Cretaceous succession overlies the Dupuy Formation and Dingo Claystone (Figure 2.5). The deposition of the thick clastic sequence of the Barrow Group occurred in the Early Cretaceous (Figure 2.5) (Wiseman, 1979). Followed by a major transgression during the late Valanginian that led to the widespread deposition of a marine claystone unit called the Muderong Shale (Bradshaw et al., 1988) (Figure 2.5). The Birdrong Sandstone and Mardie Greensand units are found at the base of the Muderong Shale (Figure 2.5) and are thought to have been deposited in a littoral to sublittoral environment (Arditto, 1993). At the top of the Muderong Shale, the Windalia Sandstone Member was deposited and possibly represents a minor regressive phase (Longley et al., 2002) (Figure 2.5). During the middle to late Cretaceous, the deposition of the Gearle Siltstone and Haycock Marl occurred, followed by the deepening of seas and eventual deposition of fine-grained carbonates and argillaceous calcilutite, calcarenite and marl (Longley et al., 2002) (Figure 2.5).

2.3.3.5 Tertiary

During the Tertiary, carbonate sedimentation in shallow seas was dominant (Mollan et al., 1969). Members include the Walcott Formation, Giralia Calcarenite and Mandu Calcarenite, as well as several others (Longley et al., 2002) (Figure 2.5).

2.3.4 BARROW GROUP STRATIGRAPHY

The Barrow Group is the main formation of interest for this study, in particular the intra-Barrow Group (Figure 2.6 & 2.7). The Barrow Group was deposited over the entire Barrow Sub-basin and across a large part of the Exmouth Plateau during the Early Cretaceous (Barber, 1994). The Barrow Group is interpreted as a prograding shelf complex, which built north from the Cape Range area into the Exmouth and Barrow Sub-basins (Tait, 1985). Its provenance was the northern Gascoyne Sub-basin and, to a lesser extent, the Pilbara Block and Hammersley Basin (Hocking, 1988). The subaerial part of the Barrow Group covered at least 50,000 km^2 (Tait, 1985). The approximate time span for the Barrow Group is 8

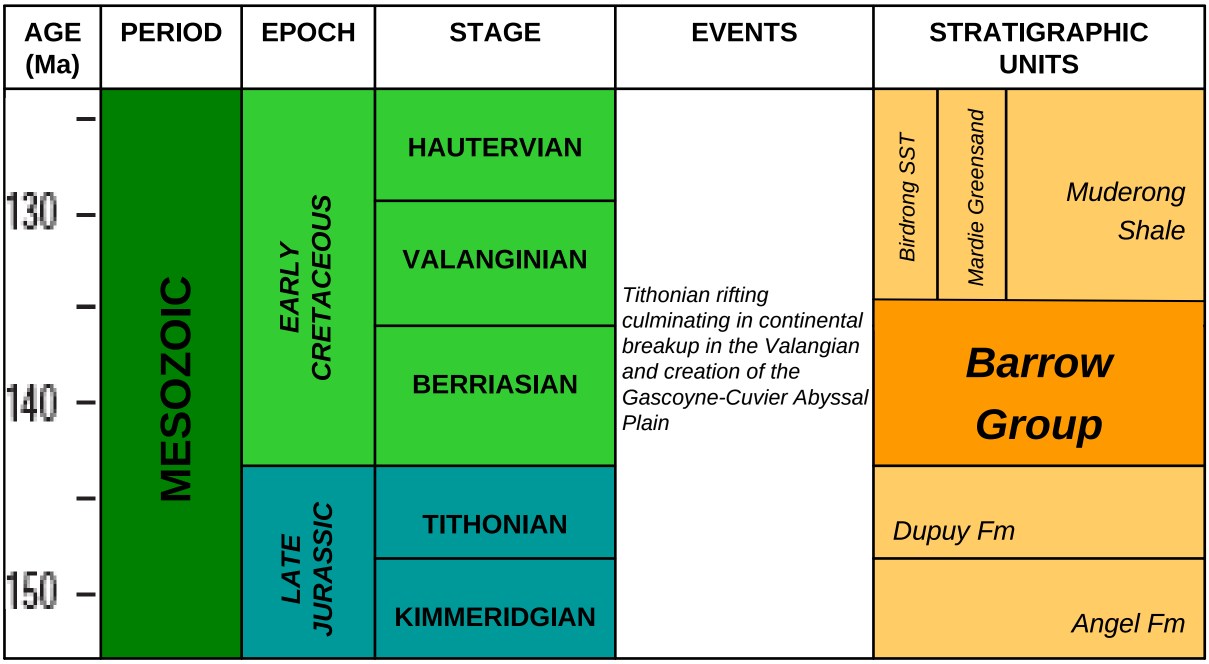


Figure 2.6 Zoom in over stratigraphic interval of interest, the Early Cretaceous Barrow Group.

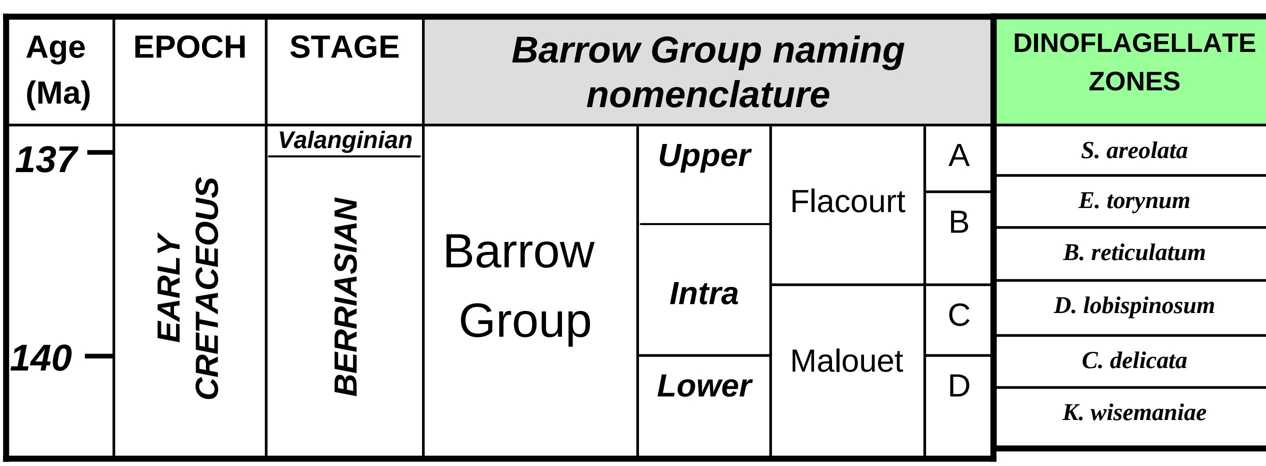


Figure 2.7 Numerous naming conventions used for the Barrow Group in publications over time (grey column). Biostratigraphic differentiation for the Barrow Group via dinoflagellate information (green column).

million years (Tait, 1985). Seismic displays continental slope dips between 2 and 5 degrees once structural dips are removed (Tait, 1985).

Through time, the Barrow Group has been sub-divided and given numerous names (Figure 2.7). The most accepted is the division of the Barrow Group into two seismically evident lithostratigraphic units comprising the Flacourt Formation (topset and foreset facies) and the Malouet Formation (bottomset facies) (Figure 2.7) (Tait, 1985). Western Mining Co. Ltd. adopted an informal four-fold division of the Barrow Group (Units A, B, C and D) based on lithology and interpreted depositional environment (Figure 2.7) (Williams & Poyton, 1985).

The Barrow Group is a coarsening-upward sequence, from interbedded siltstone and sandstone, in the Malouet Formation, to sandstone with minor siltstone, in the Flacourt Formation (Eriyagama et al., 1988). The two formations are distinguished by different seismic reflection signatures: the Malouet Formation consists of horizontal reflections (bottomsets), and the Flacourt Formation consists of inclined, progradational reflections (topsets and foresets) (Eriyagama et al., 1988). For this study, reference is made to the intra- and lower-Barrow Group, which encompasses part of/or entirely, the bottomsets, foresets and topsets of the Barrrow Group succession (Figure 2.7). It is thought using this nomenclature will lead to less confusion, due to the numerous naming conventions previously used.

The Barrow Group is Early Cretaceous or Berriasian in age (Figure 2.4). The corresponding palynological zonations defined for the Berrasian in the Northern Carnarvon Basin include the dinoflagellate zones: P. iehiense, K. wisemaniae, C. delicata, D. lobispinosum, B. reticulatum and E. torynum (Figure 2.7) (from Helby et al., 1987). Hooker (2005) recently re-evaluated the palynological data for a number of wells in and nearby the study area in conjunction with this project. From the available data, Hooker (2005) interprets the B. reticulatum dinoflagellate zone as constituting the majority of the intra-Barrow Group (interval of interest). Hence the majority of the intra-Barrow Group succession discussed for this study lies within this one palynological zone.

2.4 EXPLORATION HISTORY

Oil was discovered in the first well drilled in the Carnarvon Basin (Rough Range 1), at the eastern edge of the Exmouth Sub-basin in 1953, but this field was too small for commercial development. Follow-up discoveries of oil at Barrow Island (1964) and of gas in North Tryal Rocks 1 (1971) established the Northern Carnarvon Basin as a major hydrocarbon province (Campbell et al., 1984). After a decline in exploration during the 1990's, in 2001 and 2002 the level of exploration activity in the region began to increase. As of March 2005, there were 39 producing fields, several new fields in extension or development drilling, and numerous undeveloped hydrocarbon accumulations (Geologic Survey of

WA, 2005). In 2005, some 78 million barrels of oil, 38 million barrels of condensate and 930 BCF of gas were produced from the Northern Carnarvon Basin (Geologic Survey of WA, 2005).

The offshore part of the Northern Carnarvon Basin (Figure 1.1) is covered by a regional and in parts detailed seismic grid. Overall three-dimensional surveying has become a common tool in both exploration and development scenarios (Geologic Survey of WA, 2005). The numerous oil and gas fields of the Northern Carnarvon Basin demonstrate the petroleum potential of the region, particularly offshore (McClure et al., 1988) (Figures 1.1 and 1.2).

Oil is produced primarily from within the Early Cretaceous Barrow Group and Windalia Sandstone. The Barrow Group has excellent reservoir characteristics, and Middle Miocene faulted anticlines provide structural trapping. The main source rock for these post-break-up accumulations is considered to be the Upper Jurassic Dingo Claystone (Zaunbrecher, 1994). The source rocks are estimated to have the capacity to expel eight billion barrels of oil, of which just over 10 % has been discovered within the Barrow Sub-basin to date (Geologic Survey of WA, 2005). The sub-basin margins such as the Peedamullah Shelf, Rankin Trend, Exmouth Gulf, and the sub-basin axes may hold the key to a major portion of the undiscovered reserves (Geologic Survey of WA, 2005).

During 2004, 19 exploration and 38 appraisal/development wells were drilled in the Northern Carnarvon Basin, and a number of oil and gas discoveries were made. The most significant of these are Harrison, Monet, Wheatstone and Stickle. Development and appraisal drilling was undertaken on a number of fields in the Carnarvon Basin in 2006 as numerous hydrocarbon projects in the region commenced development. These included wells for the Exeter-Mutineer development, in-fill drilling in the Bambra, Stag, Wanaea and Lambert fields, and appraisal drilling on the Stybarrow, Ravansworth, Woolybutt and Scarborough fields (Geologic Survey of WA, 2005). Overall, the Northern Carnarvon Basin is the most prolific oil- and gas-producing basin in Australia today and dominates Western Australia production (Geologic Survey of WA, 2005).

2.5 DATABASE

The database for the study includes the Flinders 3D seismic survey, wire-line logs, well completion reports, palynological data, conventional core and cuttings descriptions.

The Flinders 3D survey covers an area of approximately 1267 square kilometres and was provided by TGS (Geophysical Company). The survey lies just south of Barrow Island and is located entirely offshore. Some restrictions on this survey include water depth (hence shape of survey) and islands which disrupted the survey (holes in data). The survey was sufficient to develop a seismic sequence stratigraphic framework for the intra-Barrow Group and was adequate to perform detailed high-resolution sequence stratigraphy on specific sequences.

Digital wire-line logs from 35 wells in the Barrow Sub-basin were available for this study along with well completion reports for all 35 wells, which provided composite logs, thin section descriptions and conventional core and cuttings descriptions. Also, the majority of palynological data used in this thesis was extracted from well completion reports. New palynological reviews for some six wells within the study area were provided by Apache Energy Australia (Hooker, 2005).

3.0 METHODOLOGY

SUMMARY OF PROJECT WORKFLOW

The methodology used for this master's project involves first gathering all necessary and available data applicable to the undertaking the project (Figure 3.1). This included all seismic, well and biostratigraphic data. The next step comprised gaining a good understanding of the regional geology and previous studies carried out for the study area (literature review). This was followed by numerous phases of interpretation of the seismic data (Flinders 3D seismic survey). First regional picks were interpreted (Base Cretaceous, Top Barrow Group, Top Muderong Shale etc.). Then internal erosional truncation, downlap and onlapping events were identified and interpreted. The result was the interpretation of 12 seismic sequence boundaries and associated systems tracts, leading to the development of a sequence stratigraphic framework. The incorporation of well data, the new seismic interpretation, and sequence stratigraphic framework for the intra-Barrow Group then led to the construction of a number of palaeogeographic maps. This step was followed by an analysis of the prospectivity associated within the interval of interest and included the identification of geological analogues.

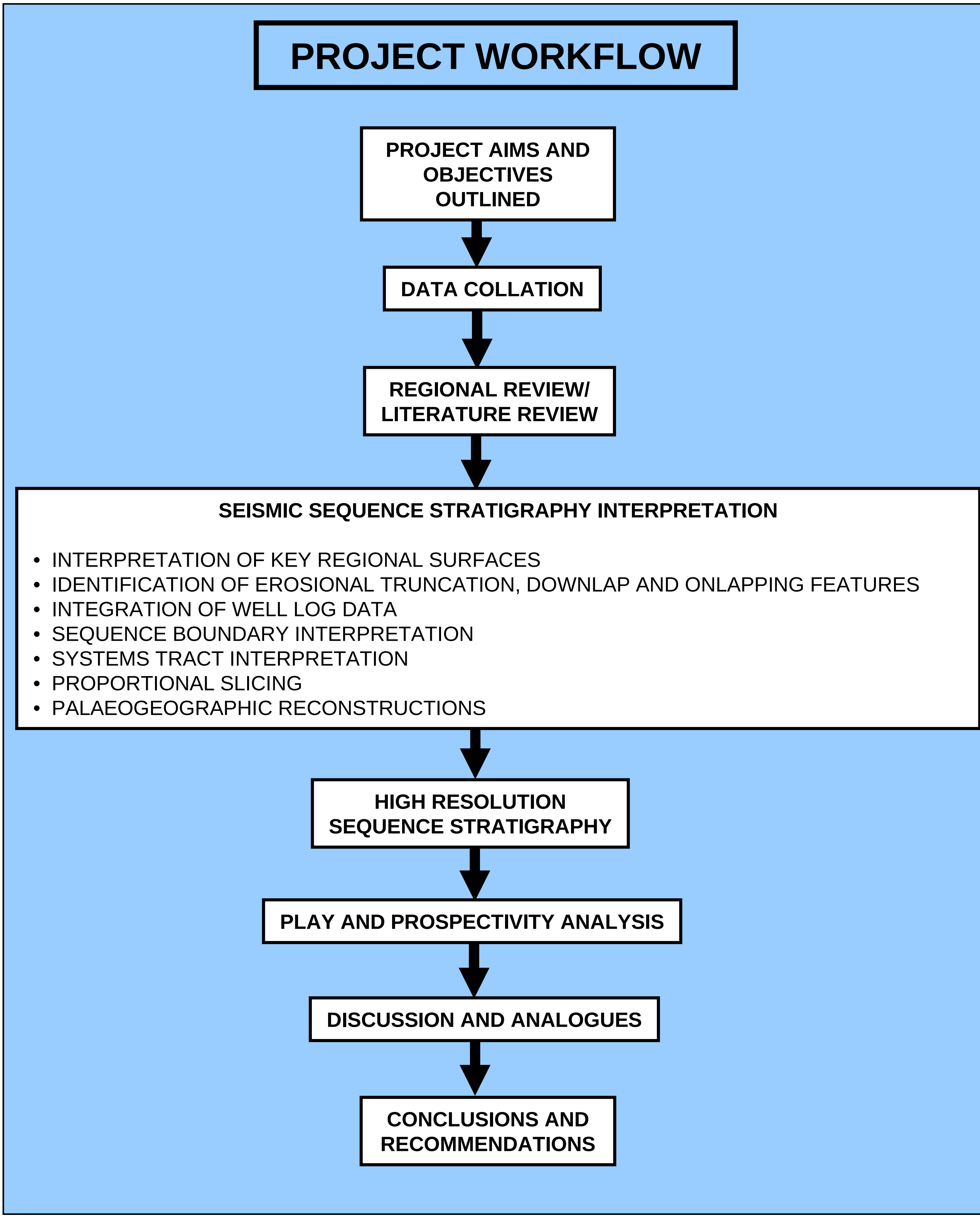


Figure 3.1 Summary of project workflow.

3.1 WELL DATA

There are currently 35 wells located within or nearby the Flinders 3D survey area (Figure 1.2 & Table 3.1). For this study, key wells intersect the specific interval of interest (the intra- and lower-Barrow Group sediments) and aid in the understanding the clinoform features viewed on seismic. For all wells, well completion reports and wireline logs were available. Gamma ray and sonic logs were used for this study due to their sensitivity to lithology changes (Figure 3.2).

Table 3.1 Well list

AIRLIE-1	CYRANO-1	IMMORTELLE-1	PEPPER-1
ALUM-1	DILL-1	JASPER-1	RIPPLE SHOALS-1
BAY-1	DILLSON-1	LEAF-1	SALADIN-1
BASIL-1	EAST PEPPER-1	LINDSAY-1	SANTA CRUZ-1
BENNET-1	ELDER-1	MARYANNE-1	SOUTH CHERVIL-1
BLACKTHORN-1	EMPEROR-1	MOSMAN-1	SOUTH PEPPER-1
CADELL-1	FENNEL-1	NARES-1	TAUNTON-1
CHERVIL-1	HARDMAN-1	NASUTUS-1	WEST PEPPER-1
CRACKLING-1	HYSSOP-1	NORTH HERALD-1	

Additional wells have been drilled within the vicinity of the study area since commencement of this study and include Boojum-1 (intra-Barrow Group discovery). However, the results of these wells are currently confidential to this study.

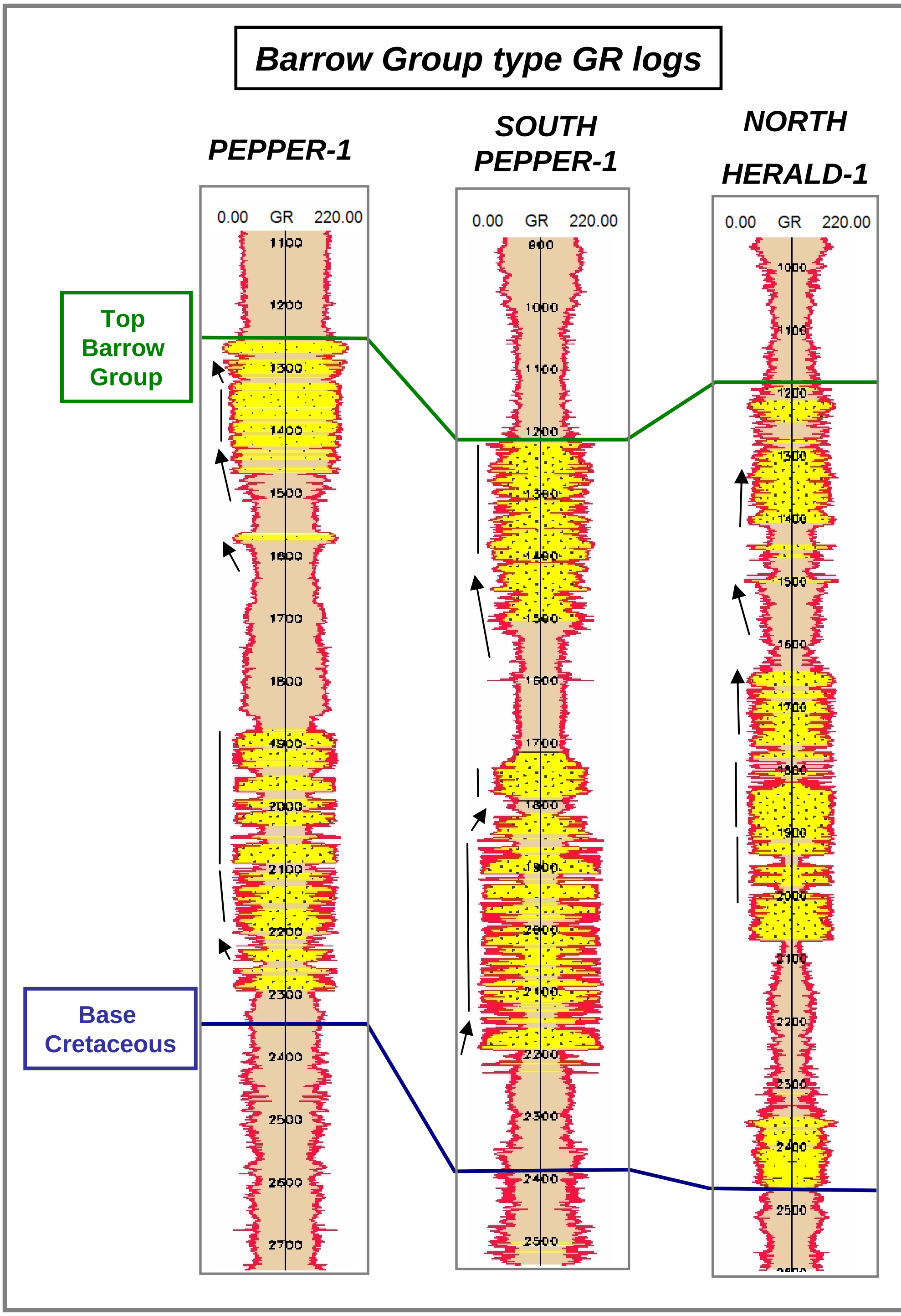


Figure 3.2 Gamma ray type logs for intra-Barrow Group succession in study area. Note, thick blocky sands ranging in thickness from 10 to 90m, interbedded with thick shaley sections.

3.2 BIOSTRATIGRAPHY

Biostratigraphic data is available for all wells and was sourced from well completion reports. The palynology has recently been updated by Hooker (2005) for seven wells in the study area, including Pepper-1, South Pepper-1, Alum-1, Chervil-1, Basil-1, South Chervil-1 and Ripple Shoals-1. The biostratigraphic data used were dinoflagellate information for the Early Cretaceous (Figure 2.7). The presence of dinoflagellates coincides with a siliciclastic-dominated restricted marine to marginal-deltaic environments (Powell, 1982). The use of biostratigraphic data, along with the 3D seismic dataset, has allowed approximations of age and time range of deposition for each of the sequences.

3.3 SEISMIC DATA

The Flinders 3D seismic survey used in the seismic sequence stratigraphic study was acquired by Veritas DGC Asia Pacific Ltd. using the M/V Pacific Sword from the 6th January 2001 to the 9th September 2001. The survey covers an area of approximately 1267 km^2, offshore Western Australia and extends over offshore licence areas TP/7 (Parts 1-4), TL/2 and parts of EP 364 and EP 409 (Figure 1.2).

The seismic data was processed by Veritas DGC Asia Pacific Ltd and produced a medium to high quality dataset that was initially interpreted during the second half of 2002 and 2003 by TGS. The data is relatively high frequency and has high signal to noise ratio. However, data quality deteriorates significantly along the southeastern edge of the survey, in the footwall of the Flinders Fault. Additionally, other poor quality data areas can be attributed to the presence of islands and shallow water depths at the edges of the survey area.

Using Hampson Russell software, a zero phase operator was applied to the migrated dataset by TGS Nopec. After processing by TGS of the raw Flinders 3D data, a 'zero phase' dataset was obtained which was utilised for all the interpretation in this study. The polarity of the data is SEG negative (i.e. a hard is a trough and a soft event is a peak).

3.4 SEISMIC INTERPRETATION

The program used for seismic interpretation was the PC-based Schlumberger program called Petrel (Version 2004). The package used included all available tools for seismic interpretation. Petrel is noted for it's strong visualisation capabilities and ability to QC all data in 3D.

The seismic interpretation of the dataset (occurred in time) included the initial identification of major surfaces within the interval of interest. These surfaces include sequence boundaries, transgressive surfaces and maximum flooding surfaces. The latter two types of surfaces tended to be harder to identify confidently. Sequence recognition numbering was based on sequence boundaries. Identification of sequence boundaries throughout the succession was chiefly seismic-based via the presence of onlapping, downlapping and erosional truncations features viewed on seismic (Figure 3.3). Wireline log responses were incorporated where appropriate and linked to seismic reflectors. This method led to the identification of eleven seismic sequences within the interval of interest.

Isochron, and time-structure maps for each interpreted sequence were then created in Petrel. Amplitude maps were created for some sequences as well.

3.5 PROPORTIONAL SLICING

Proportional slicing was used to assit in paleogeographic reconstructions. Proportional slicing for each interpreted seismic sequence was performed via the use of Petrel. Individual depositional models were interpreted for each seismic sequence. The process involved flattening on both the top and base sequence boundaries, which defined each seismic sequence, followed by the generation of time slices. Geologic features, such as meander channel belts, which would help describe the depositional history of the intra-Barrow Group, were identified by

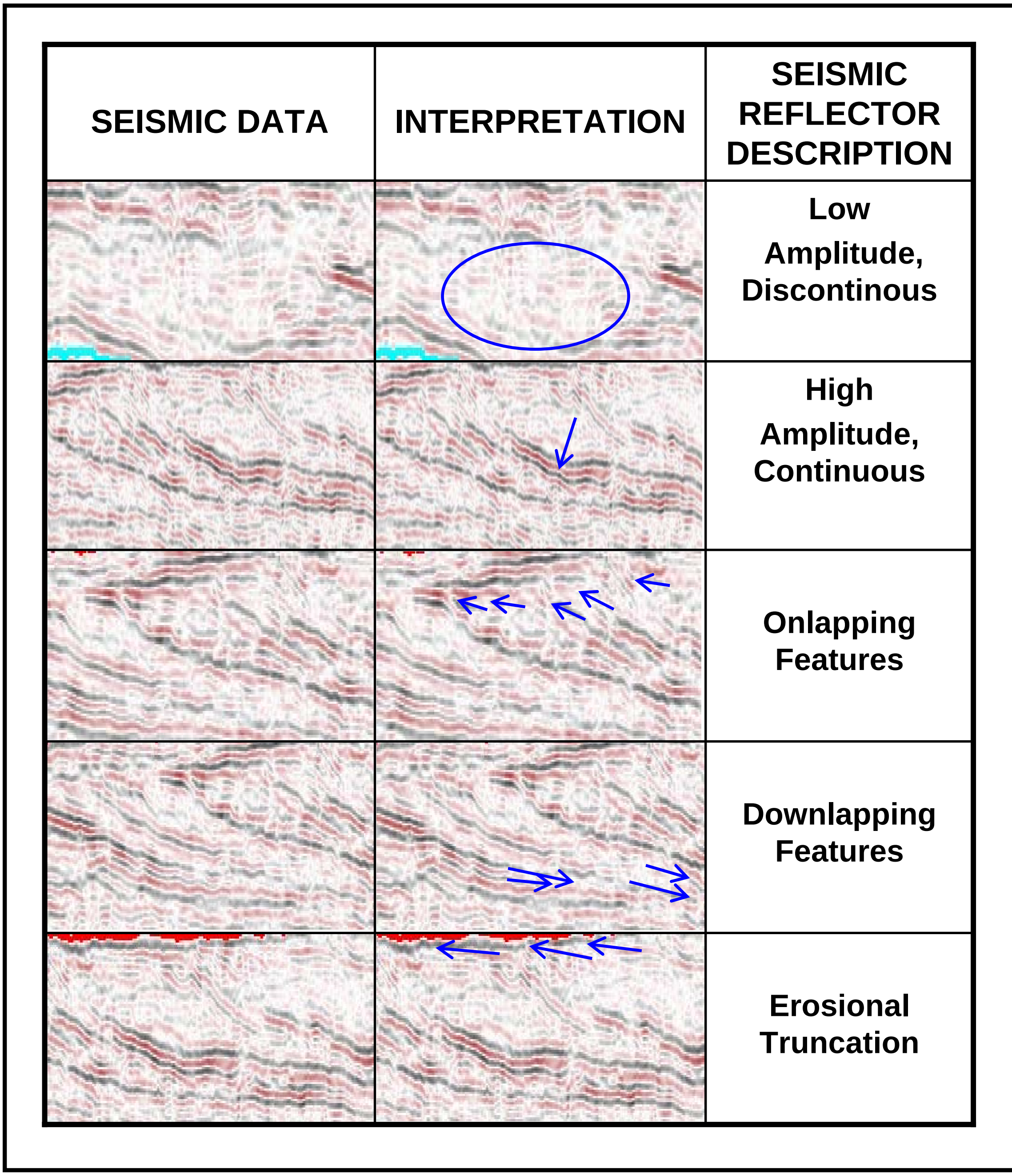


Figure 3.3 Key seismic characteristics and reflection examples (erosional truncation, downlapping and onlapping events) interpreted from Flinders 3D seismic survey.

scrolling up and down through each sequence. Comparisons were then made to decide which time slices displayed higher clarity geologic features.

3.6 PALAEOGEOGRAPHIC RECONSTRUCTIONS

One to two schematic palaeogeographic reconstruction diagrams were constructed for each seismic sequence identified within the interval of interest. The basis for these maps consists of the current seismic interpretation, including the identification of all seismic-based sequence boundaries and the mapping out of the shelf break and base of slope over the study area during the time of deposition. The time slices and isochron maps generated for each seismic sequence were incorporated along with the overall sequence stratigraphic configuration. Additionally, all key well data were integrated into the construction of these maps, including log response and interpretation, cuttings and core results and previous depositional environment interpretations.

3.7 HIGH RESOLUTION SEISMIC SEQUENCE STRATIGRAPHY

This study has identified eleven new seismic sequences and developed a sequence stratigraphic framework tied to the wells. These eleven sequences have been further subdivided into systems tracts. A number of the seismic sequences identified display seismically resolvable, higher frequency depositional packages. High-resolution sequence stratigraphy has been attempted for Seismic Sequence 1 and it has been further broken down into numerous higher-order sequences. The quality of the seismic characteristics has allowed for the identification and detailed mapping of the higher resolution key surfaces and packages linked to seismic reflectors (e.g. onlapping and erosional truncation features for Seismic Sequence 1 (as described previously in section 3.4)).

3.8 PLAY AND PROSPECTIVITY ANALYSIS

The identification of leads in the study area followed a methodology involving the sequence stratigraphic framework and depositional history developed for the interval of interest. The combined use of both of these aspects was applied in the search for prospective areas, so that they could be clearly highlighted and then rated. The search for leads in the study area was based on depositional environments, including shelf, slope and basin-floor. Specific lowstand systems tracts, high-resolution sequence stratigraphic and purely structural leads have been identified.

4.0 SEISMIC SEQUENCE STRATIGRAPHY

4.1 INTRODUCTION

Sequence stratigraphy is 'the subdivision of sedimentary basin fills into genetic packages bounded by unconformities and their correlative conformities' (Emery & Myers, 1996). It is used to provide a chronostratigraphic framework for the correlation and mapping of sedimentary facies and for stratigraphic prediction. Several geological disciplines contribute to the sequence stratigraphic approach, including seismic stratigraphy, biostratigraphy, chronostratigraphy and sedimentology (Posamentier & James, 1993). Many different concepts and definitions exist for what constitutes sequence stratigraphy, including genetic stratigraphic sequences (Galloway, 1989) (Figure 4.1), depositional episodes (Frazier, 1974) and transgressive-regressive cycles (Embry, 1990). For this project the sequence stratigraphic concepts will be used in the sense of Posamentier & Vail (1988) (Figure 4.1a), who advocate the use of regional unconformities and their correlative conformities as sequence boundaries.

4.2 HISTORY OF SEQUENCE STRATIGRAPHY

In the late 1970s, Peter R. Vail and his colleagues at Exxon Production Research Company developed stratigraphic techniques and principles, based on time stratigraphic rather than rock stratigraphic (lithostratigraphic) relationships, using

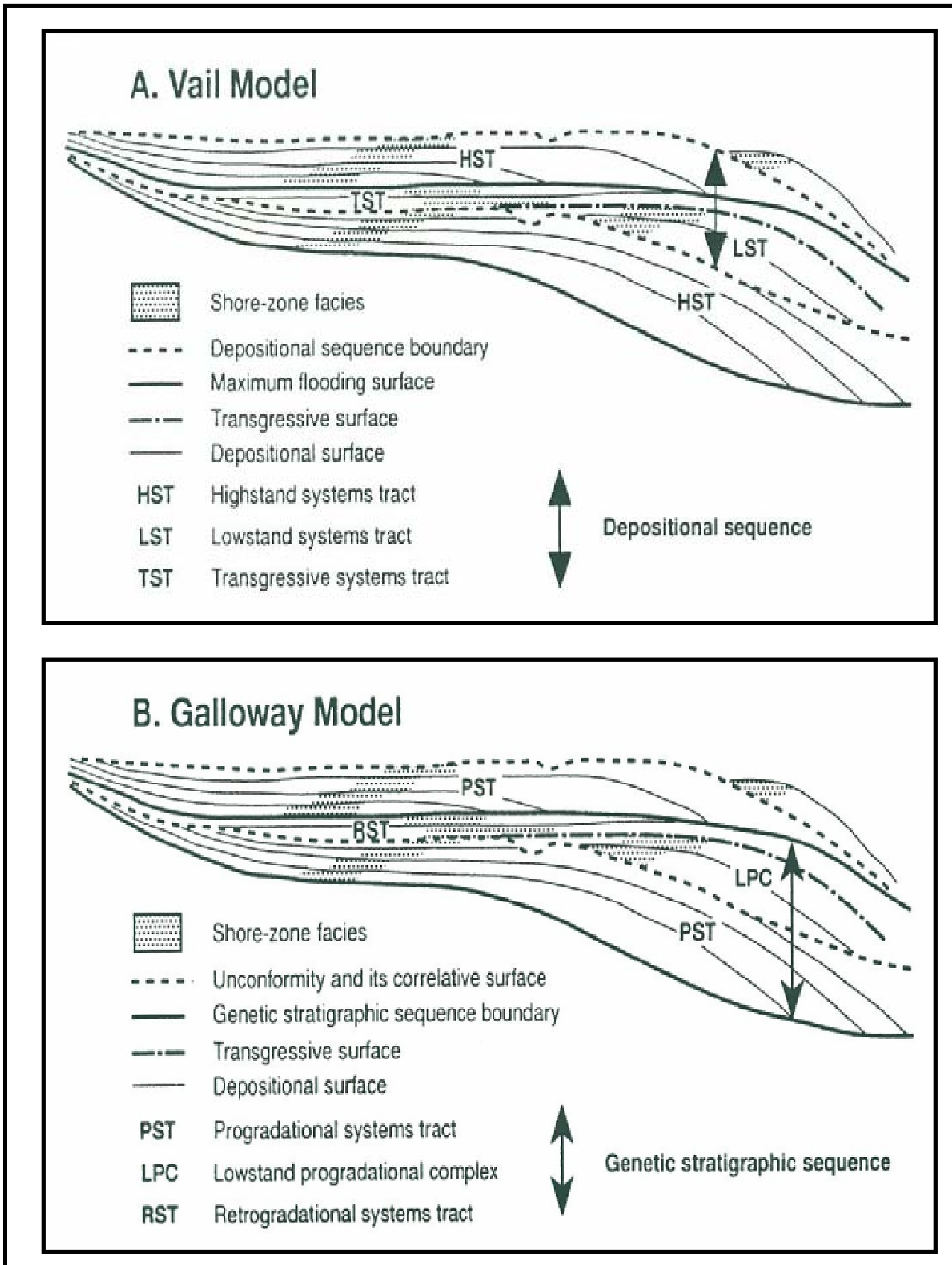


Figure 4.1 Comparison of the Vail/Exxon (A) depositional sequence model with the Frazier/Galloway stratigraphic sequence model (B) (Xue & Galloway, 1993).

multifold seismic reflection data (Vail et al., 1977). Seismic stratigraphic units were called depositional sequences by Mitchum (1977), where the strata within the units seemed conformable and free of any internal stratal discontinuities, except at the maximum flooding surface which is downlapped, as illustrated in Figure 4.1. Sequence boundaries of the units could be mapped by erosional truncation below and onlap above. Sequences were defined as unconformity-bounded successions, implying that a maximum marine flooding surface occurs within the sequence. In places, this may appear to be inconsistent, where some sequences contain multiple maximum flooding surfaces; however this is due to the scale of sequence responses to various controls on long-term and short-term variations in accommodation and sediment supply (i.e. 1^{st}, 2^{nd}, 3^{rd} etc. order sequences) (Posamentier and Vail, 1988).

Although Haq et al. 1987, advanced the idea that global (eustatic) sea-level change was the major control on sequences, and produced a global sea-level chart; on this basis it was clear that local tectonics and sediment supply could be significant factors, especially in active tectonic basins. During the late 1980s and early 1990s, sequence stratigraphy continued to evolve, and new concepts such as accommodation and parasequences were introduced (Posamentier and Vail, 1988). An alternative model for the development of depositional or 'genetic stratigraphic units', bounded by major flooding surfaces, rather than unconformities was proposed by Galloway in 1989. However this was mainly applicable in high subsidence basins, like the Gulf of Mexico, where accommodation on the shelf was mainly increasing, resulting in few mappable sequence boundaries marked by erosion on the shelf.

The major controls on accommodation are changes in relative sea level (i.e. the combined product of eustasy and tectonic movement) (Jervey, 1998). Coe et al., 2002 and Catuneanu, 2002, among many others, put an emphasis on rates of sedimentation as at least a co-equal control of accommodation. "Physical" accommodation comprises the space between sea floor and the "shelf equilibrium profile", as described by Swift and Thorne (1991). Overall eustasy and total sea-floor subsidence, as well as changes in hydrodynamic conditions, govern many of the changes of accommodation space.

Recent advances in sequence stratigraphy have been in the area of high-resolution sub seismic-scale sequence stratigraphy and computer modelling of sedimentary fill, based on outcrops, logs and core (Emery & Myers, 1996).

For this study, 11 seismic sequences have been identified to comprise the intra-Barrow Group within the defined study area. Detailed descriptions and subsequent interpretations for each of the 11 seismic sequences follow in sections 4.3 to 4.12.

4.3 SEISMIC SEQUENCE 1

DESCRIPTION

4.3.1 KEY SURFACES

Seismic Sequence 1 is defined by sequence boundary 1 (SB1) at the base and sequence boundary 2 (SB2) at the top (Figure 4.2, 4.3, 4.4 and 4.5). SB1 is identified at the abrupt base of a blocky sandstone at Emperor-1 and corresponds to downlapping features onto this surface in seismic section (Figure 4.2 and 4.6). SB2 is also defined by erosional truncation, viewed in seismic section (Figure 4.2), and also, from the Emperor-1 log response, which displays an abrupt change in facies (Figure 4.6). Overall, the log response for Seismic Sequence 1 displays constant high gamma ray, indicative of the shaley character of the facies (Figure 4.2).

4.3.2 SEISMIC CHARACTER/SEISMIC FACIES

Seismic character of Seismic Sequence 1 is progradational and is characterised by both high and low amplitude continuous and semi-continuous reflectors (Figure 4.2). There is a continuous set of moderate amplitude reflectors that downlap onto SB1. These are then overlain by semi-continuous moderate to high-amplitude reflectors of variable amplitude facies.

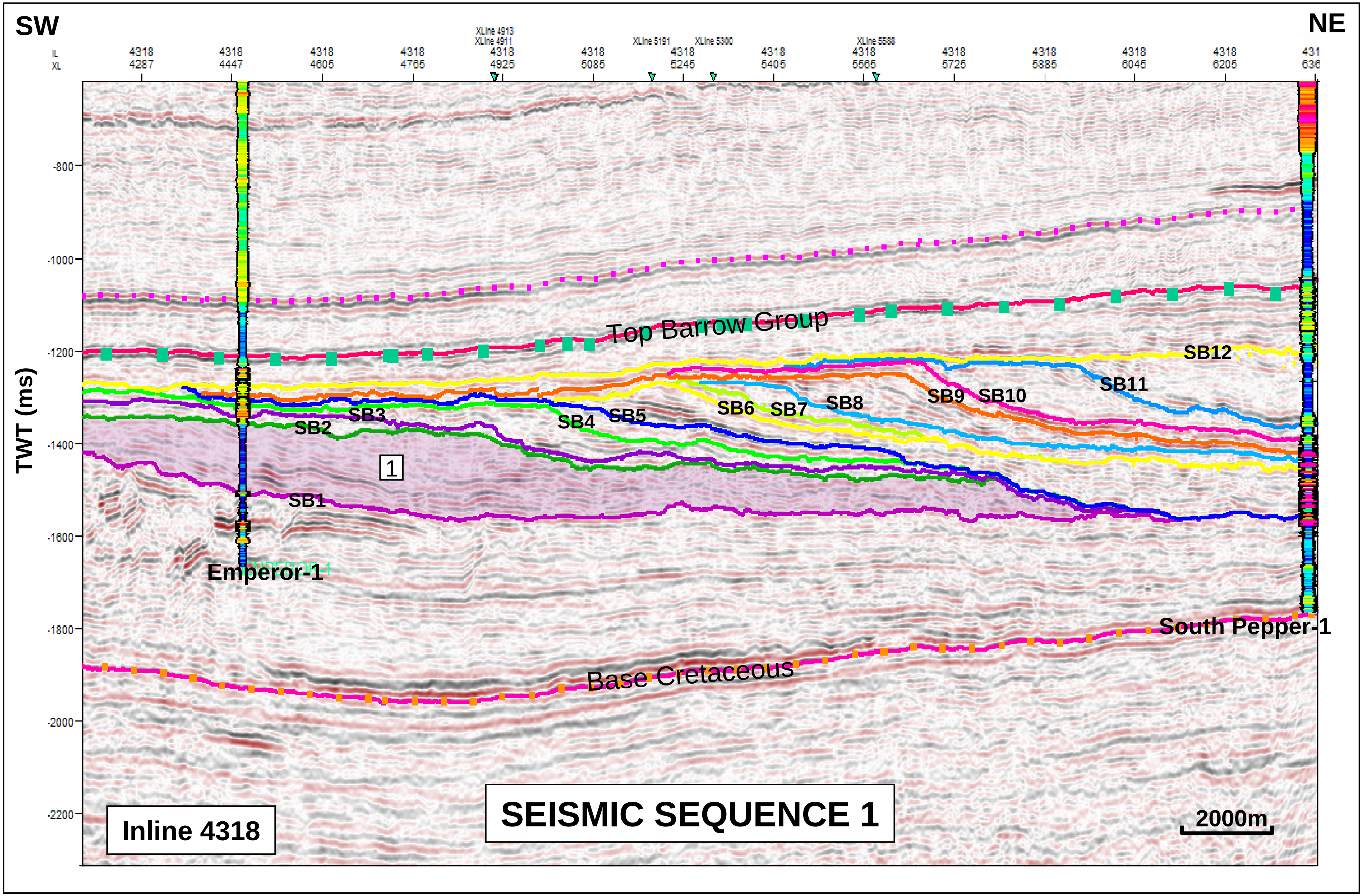


Figure 4.2 Seismic section displaying Seismic Sequence 1, bound by SB1 and SB2. Note the abrupt base to a blocky sandstone in Emperor-1 GR log at the inferred SB1 and similarly for SB2. Location of seismic line indicated in Figure 4.3.

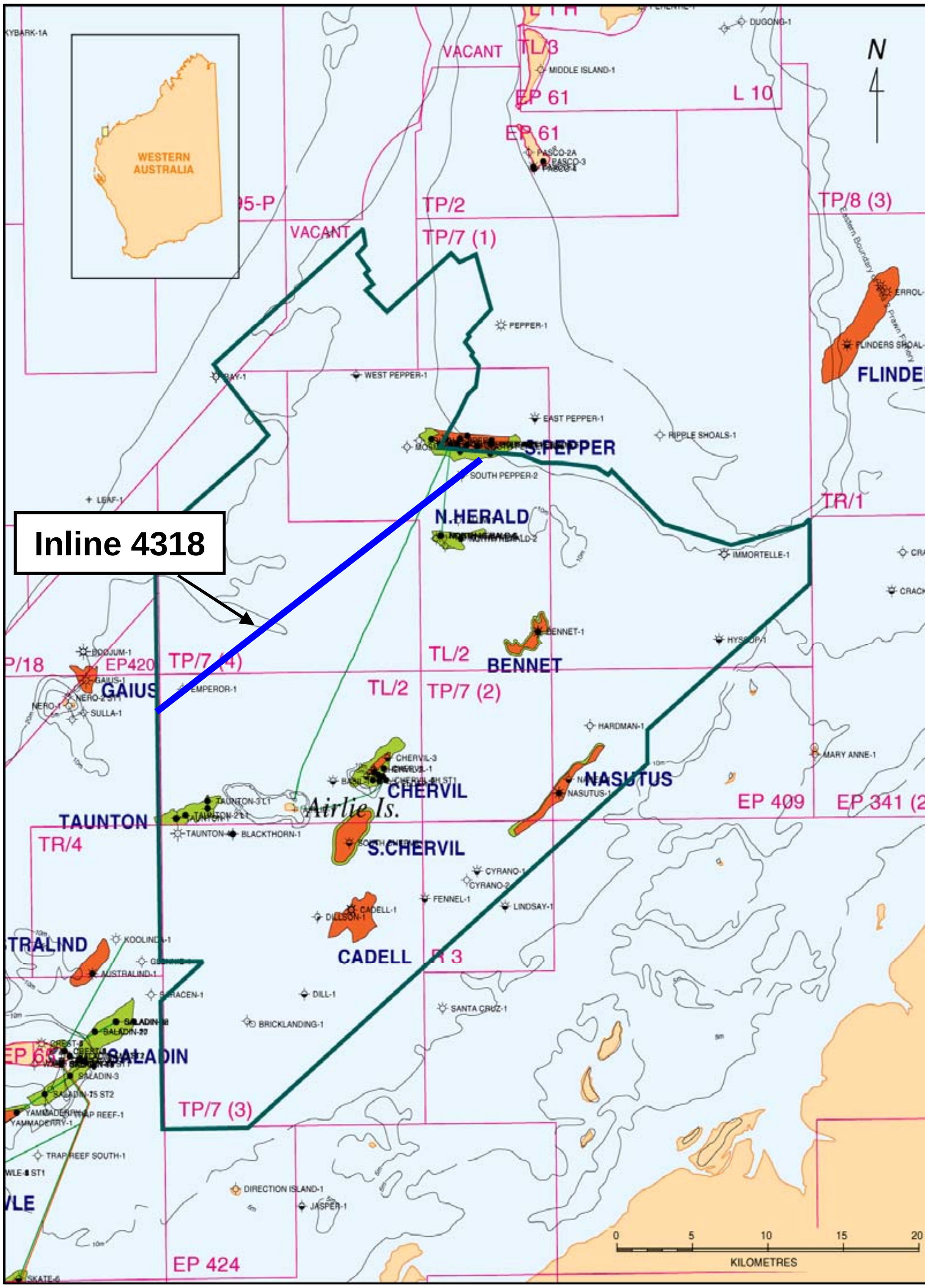


Figure 4.3 Location map of key seismic line 4318 (blue line) within the Flinders 3D survey (green outline).

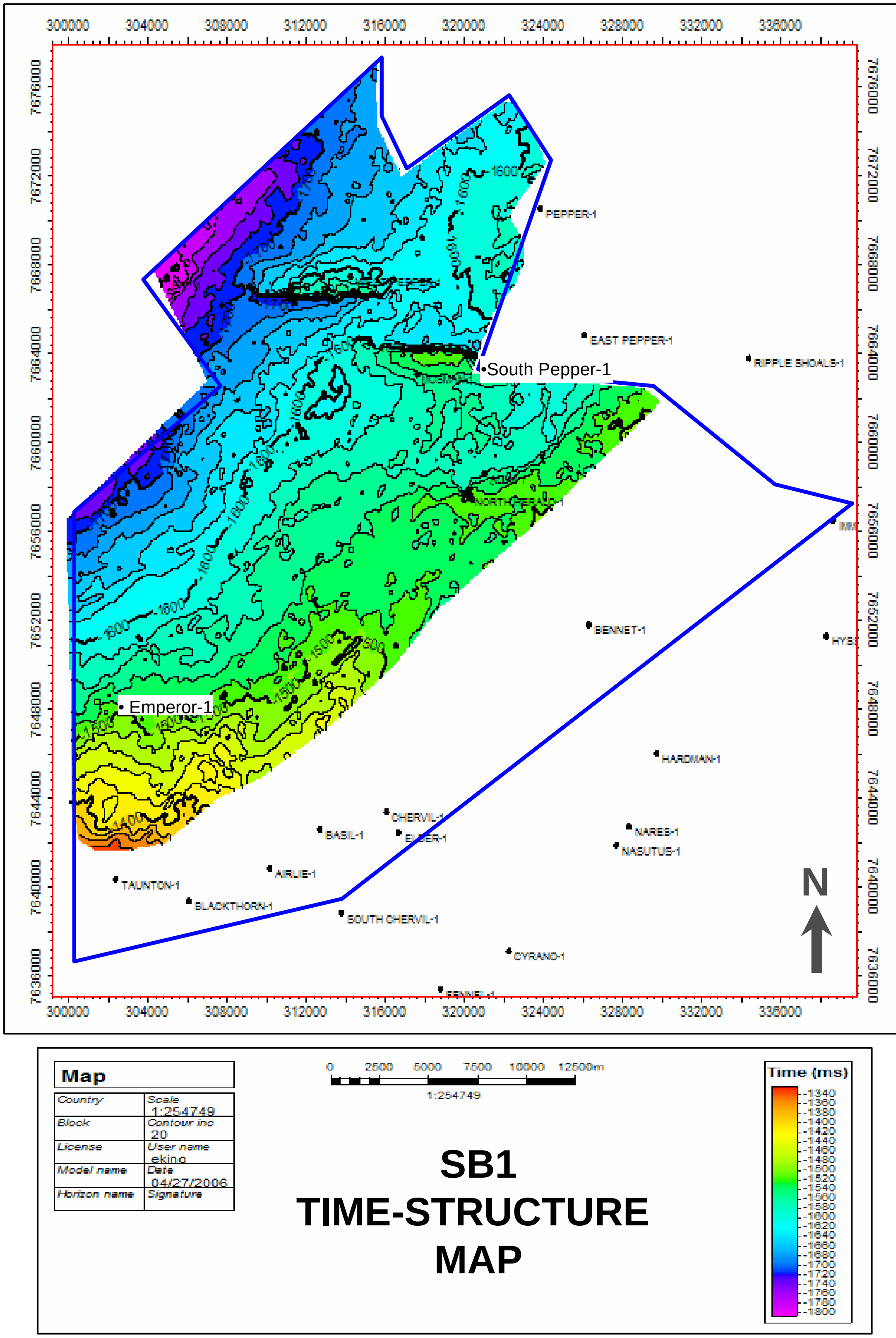


Figure 4.4 Sequence Boundary 1 Time-Structure Map.

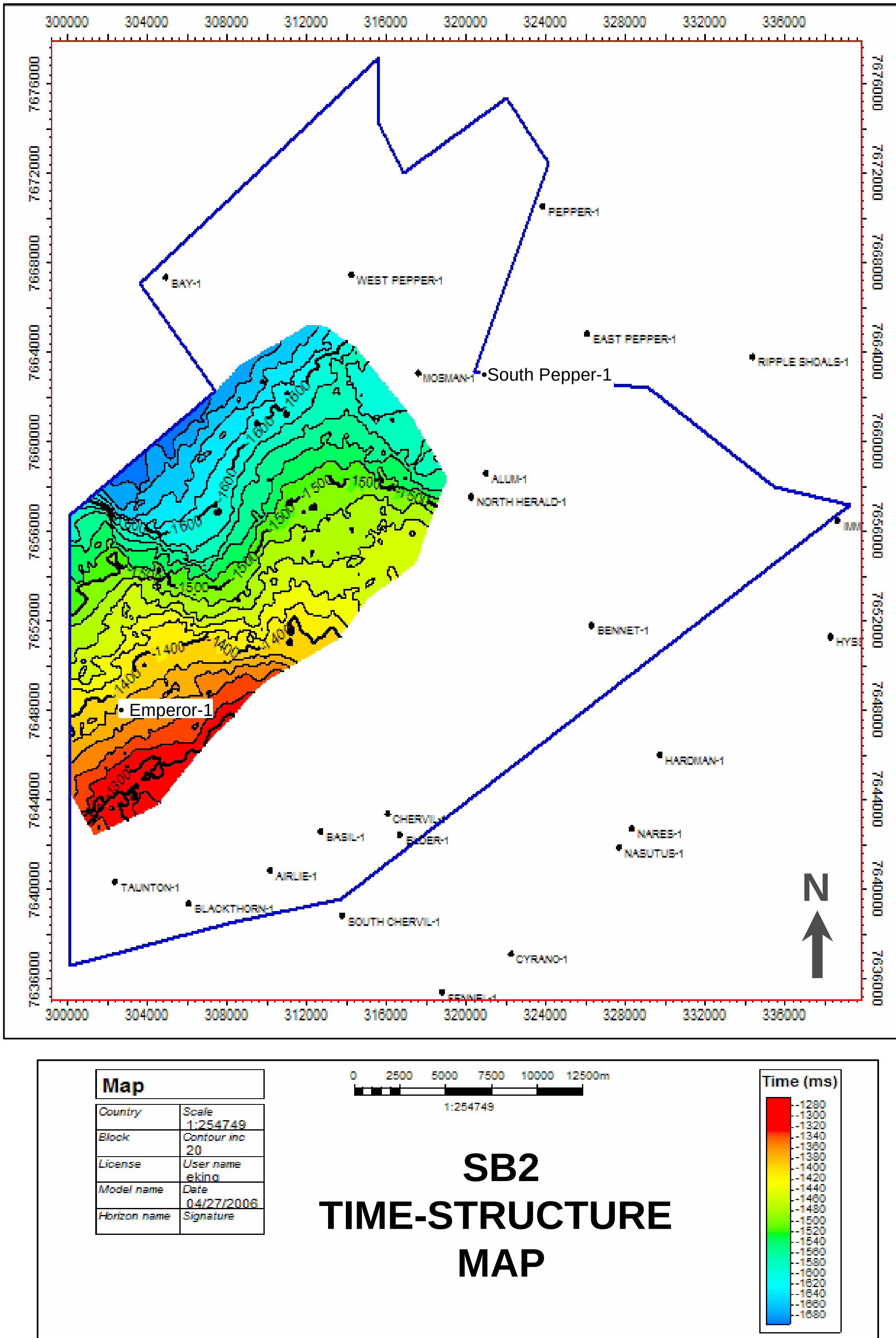


Figure 4.5 Sequence Boundary 2 Time-Structure Map.

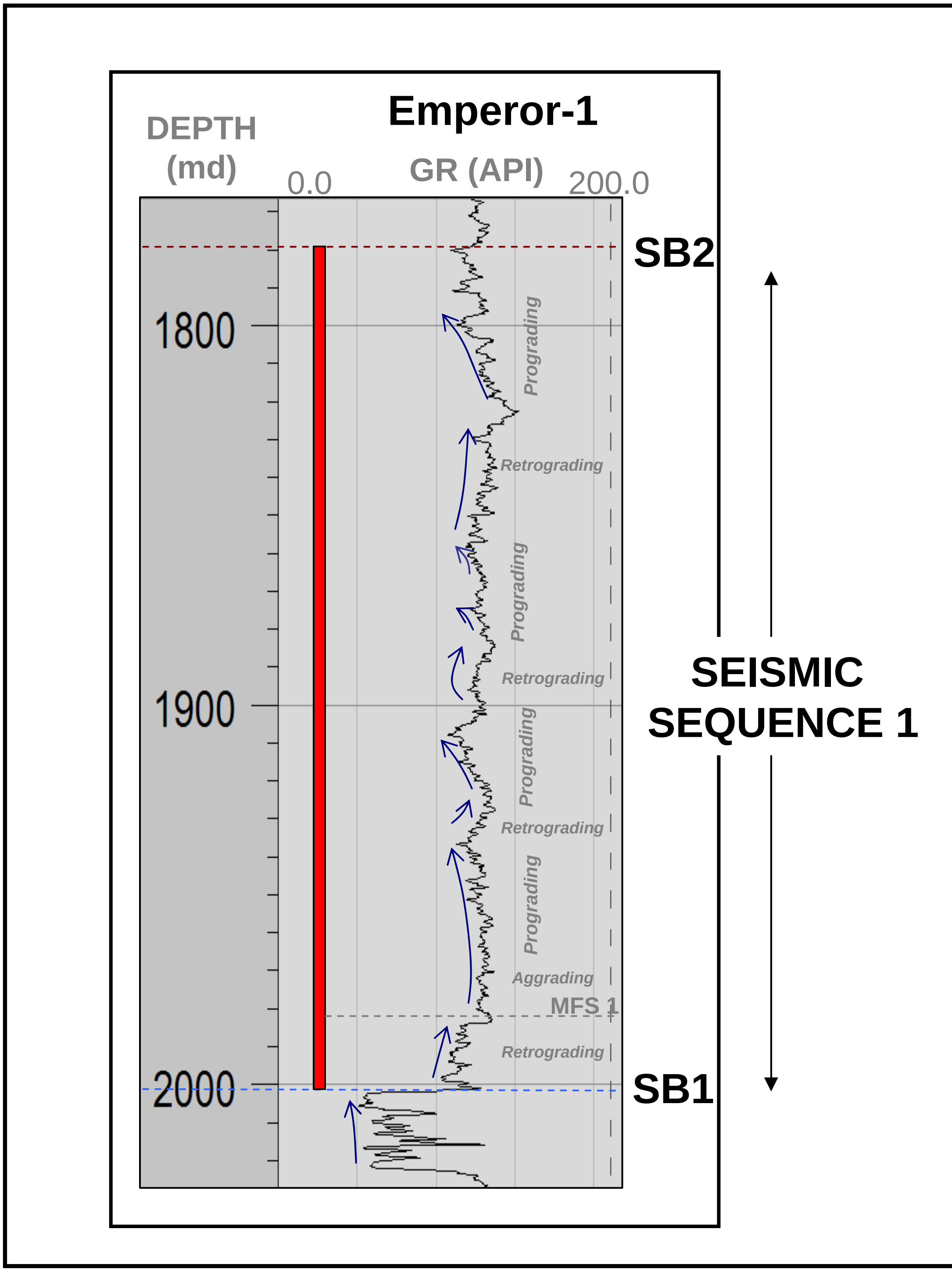


Figure 4.6 **Gamma ray response at Emperor-1 for Seismic Sequence 1. Note overall high gamma ray response for majority of sequence, representing low net-to-gross shelf margin deltas stacking in retrogradational, aggradational and then progradational nature, ranging in thickness from 25-45m thick.**

4.3.3 DISTRIBUTION AND EXTENT

Seismic Sequence 1 was mapped across the Flinders 3D survey, covering approximately 246 km^2 of the study area (Figure 4.7) ranging in thickness from 0 to 180 ms. This time package is thickest near Emperor-1 and thins to the northeast.

4.3.4 DEPOCENTRE POSITION

Isochron maps of Seismic Sequence 1 indicate the main centre for deposition lying in a NW-SE tending direction between Emperor-1 and Basil-1 (Figure 4.7), indicated by the thickening of deposition toward the southeast.

4.3.5 STACKING PATTERNS (seismic and well)

Seismic stacking patterns for Seismic Sequence 1 include initial retrogradation at the base of the sequence and then progradation to the northeast across the study area (Figure 4.2).

The log motif of Emperor-1 displays a basal retrogradational stacking pattern followed by aggradational stacking patterns for the majority of the package with

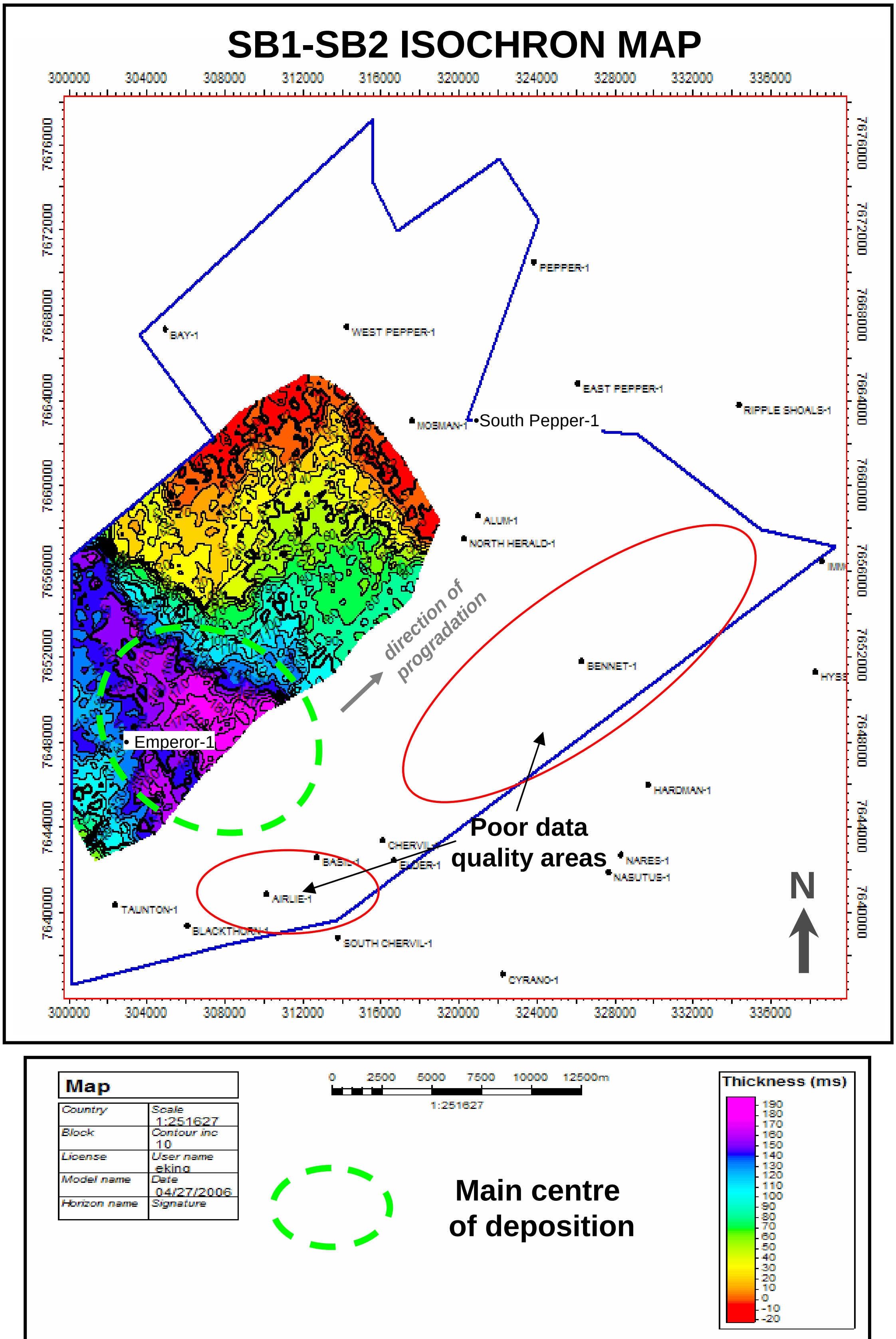


Figure 4.7 **SB1 – SB2 Isochron Map, displaying one main centre of deposition. Additionally, areas of poor seismic data quality are displayed via red circles.**

maximum flooding surfaces represented by high gamma ray readings (Figure 4.6).

4.3.6 SLOPE ANGLE

The structurally restored slope angle calculation for the sigmoidal clinoforms of Seismic Sequence 1 was approximated at 5° (Figure 4.2). This average for the entire sequence agrees with Poreski and Steel's (2003) estimate that shelf-margin clinoform slope gradients should be between 3 and 6°.

4.3.7 AGE

Seismic Sequence 1 is Berriasian in age and was deposited during the late synrift mega-sequence during the Early Cretaceous. Seismic Sequence 1 spans the *B.reticulatum* dinocyst zone. The age of this sequence is estimated at *135-137 Ma*.

INTERPRETATION

4.3.8 SYSTEMS TRACT

A transgressive systems tract (TST) overlain by a highstand systems tract (HST) is recognised for Seismic Sequence 1 (Figure 4.8). Maximum flooding surface 1

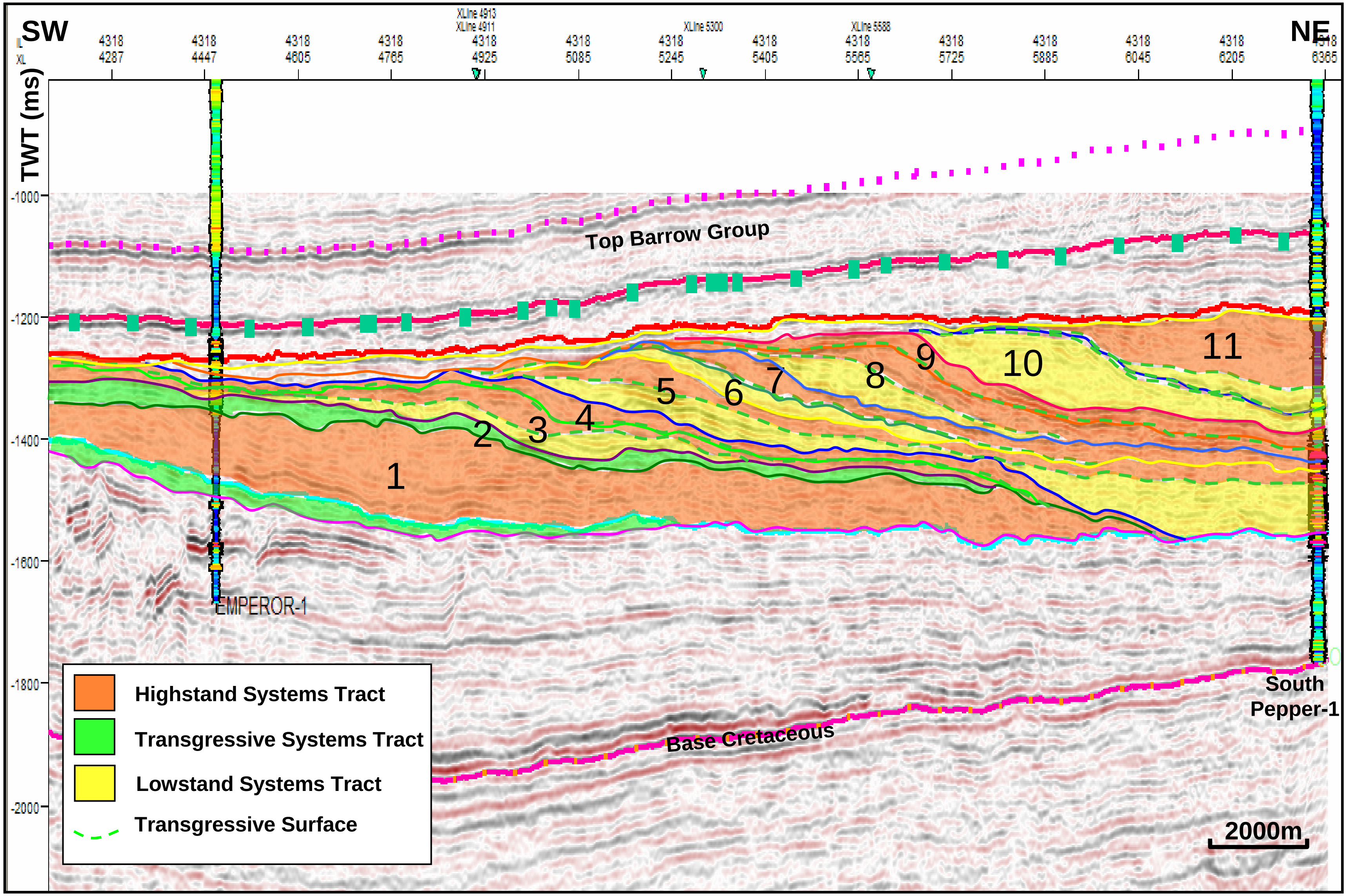


Figure 4.8 Seismic sequence stratigraphic framework developed for intra-Barrow Group Seismic Sequences 1 through 11. Location of line indicated in Figure 4.3.

(MFS 1) interpreted at Emperor-1 (Figure 4.6) separates the lower TST from the upper HST and is regionally extensive over the study area. The lower TST is also regionally extensive over the study area as it tends to build back over the lower sediments (retrogradational nature displayed on seismic) with a minor amount of erosion and slumping present (Figure 4.8). The upper prograding HST is relatively thick and extensive, composed of mainly shaley sediments, with a high degree of erosion post-deposition occurring due to the presence of a significant unconformity representing the top of Seismic Sequence 1.

4.3.9 RESERVOIR/SEAL POTENTIAL

Emperor-1 well logs indicate that Seismic Sequence 1 is comprised mainly of shaley/silty sediments with occasional thin sands and is described overall as a mud-prone package (Figure 4.6). Both log (constant high gamma ray response) and seismic response (low amplitude continuous reflectors) indicate that Seismic Sequence 1 is mainly comprised of massive shale/siltstone with minor sand interbeds. Therefore Seismic Sequence 1 is more likely to consist of potentially sealing facies.

4.3.10 PALAEOGEOGRAPHIC RECONSTRUCTIONS

Seismic Sequence 1 was deposited initially during a minor transgression followed by a major regressive phase. The bulk of sediment was supplied via the large fluvial/deltaic system building out towards the north-north-east, hence the relatively thick preserved succession (>180 ms) (Figure 4.9). Multiple shelf-edge deltas have been interpreted from seismic and well logs to have been building out onto the shelf and contributing to the overall shelf margin accretion. Positions of the palaeo-shelf break, slope and base of slope have also been inferred from the seismic data (Figure 4.9 and Figure 4.9a).

For a complete summary of Seismic Sequence 1, please refer to *Appendix 1.0*, Seismic Sequence 1 A3 summary sheet.

4.4 SEISMIC SEQUENCE 2

DESCRIPTION

4.4.1 KEY SURFACES

Seismic Sequence 2 is defined by key surfaces SB2 and sequence boundary 3 (SB3) (Figure 4.10). SB2 extends across part of the study area and is defined by apparent erosional truncation (Figure 4.5). The upper bounding SB3 is onlapped by overlying Seismic Sequence 3 sediments and has been mapped over the seismic survey area (Figure 4.11).

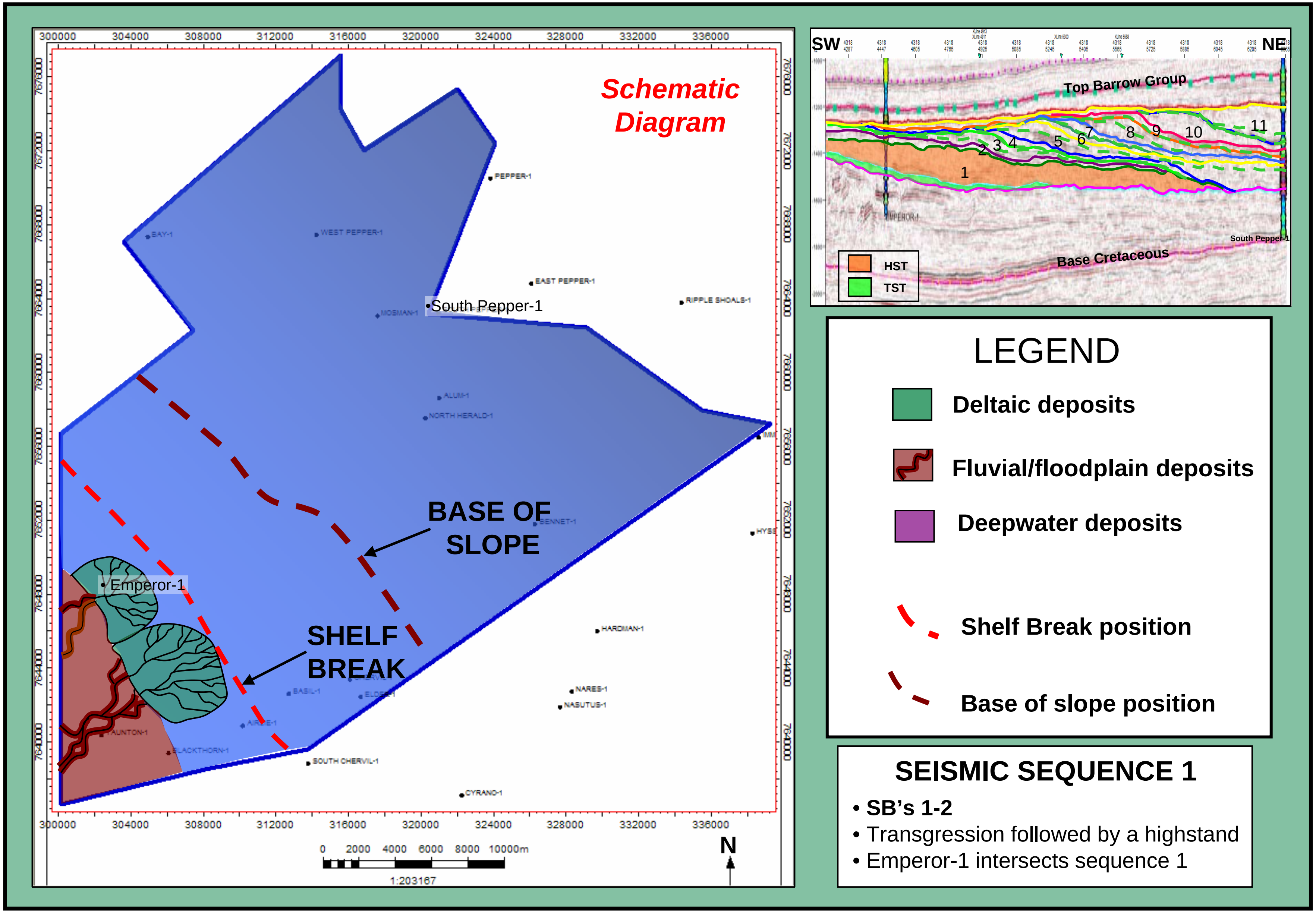
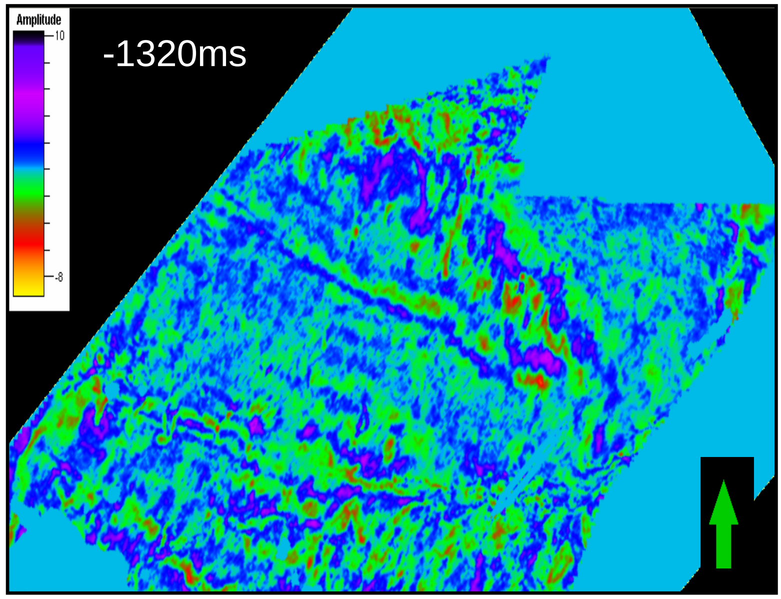
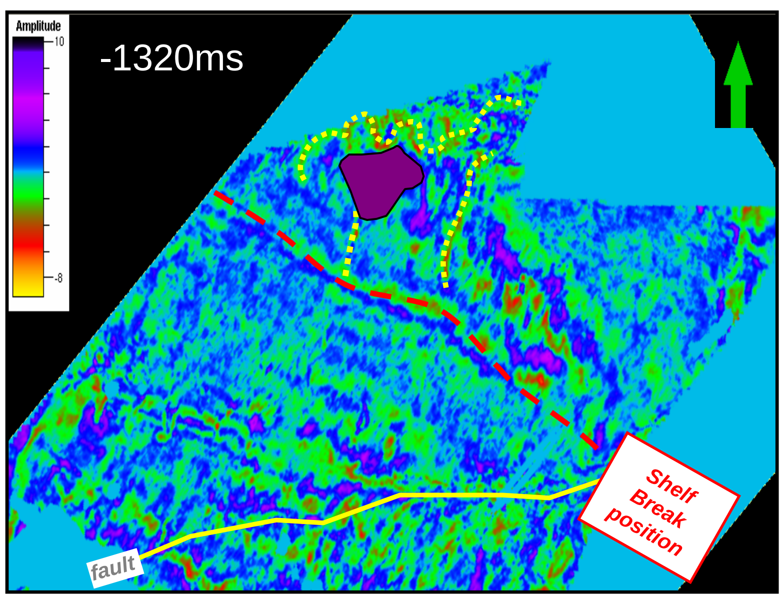


Figure 4.9 Seismic Sequence 1 schematic palaeo-geography map.



Un-interpreted flattened timeslice



Interpreted flattened timeslice

Figure 4.9a Un-interpreted and interpreted timeslice, flattened at -1320ms. Palaeo-shelf break (red), incised valleys (orange) and delta lobe (purple) are interpreted for Seismic Sequence 1.

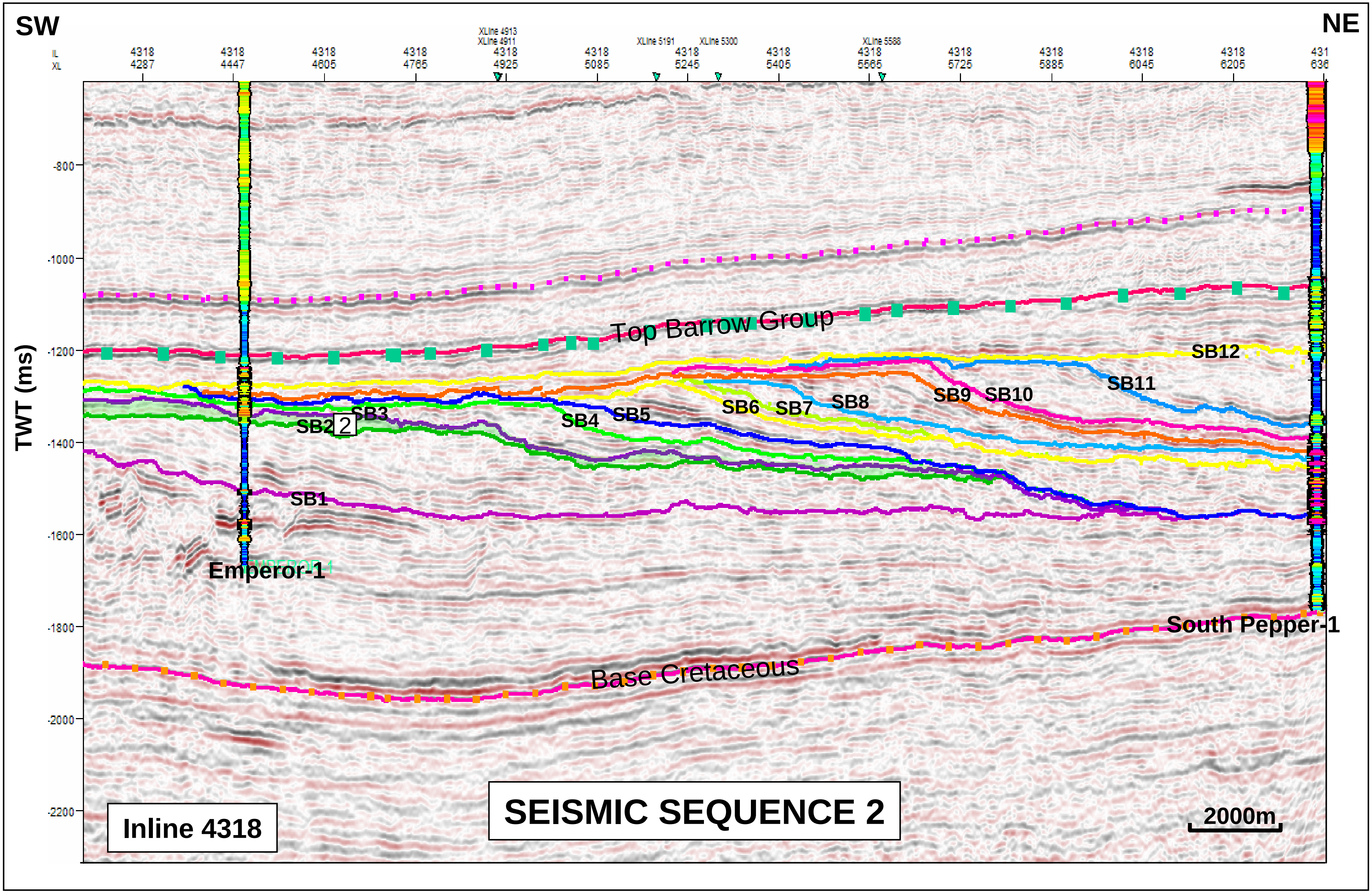


Figure 4.10 Seismic section displaying Seismic Sequence 2, bound by SB2 and SB3. Location of line indicated in Figure 4.3.

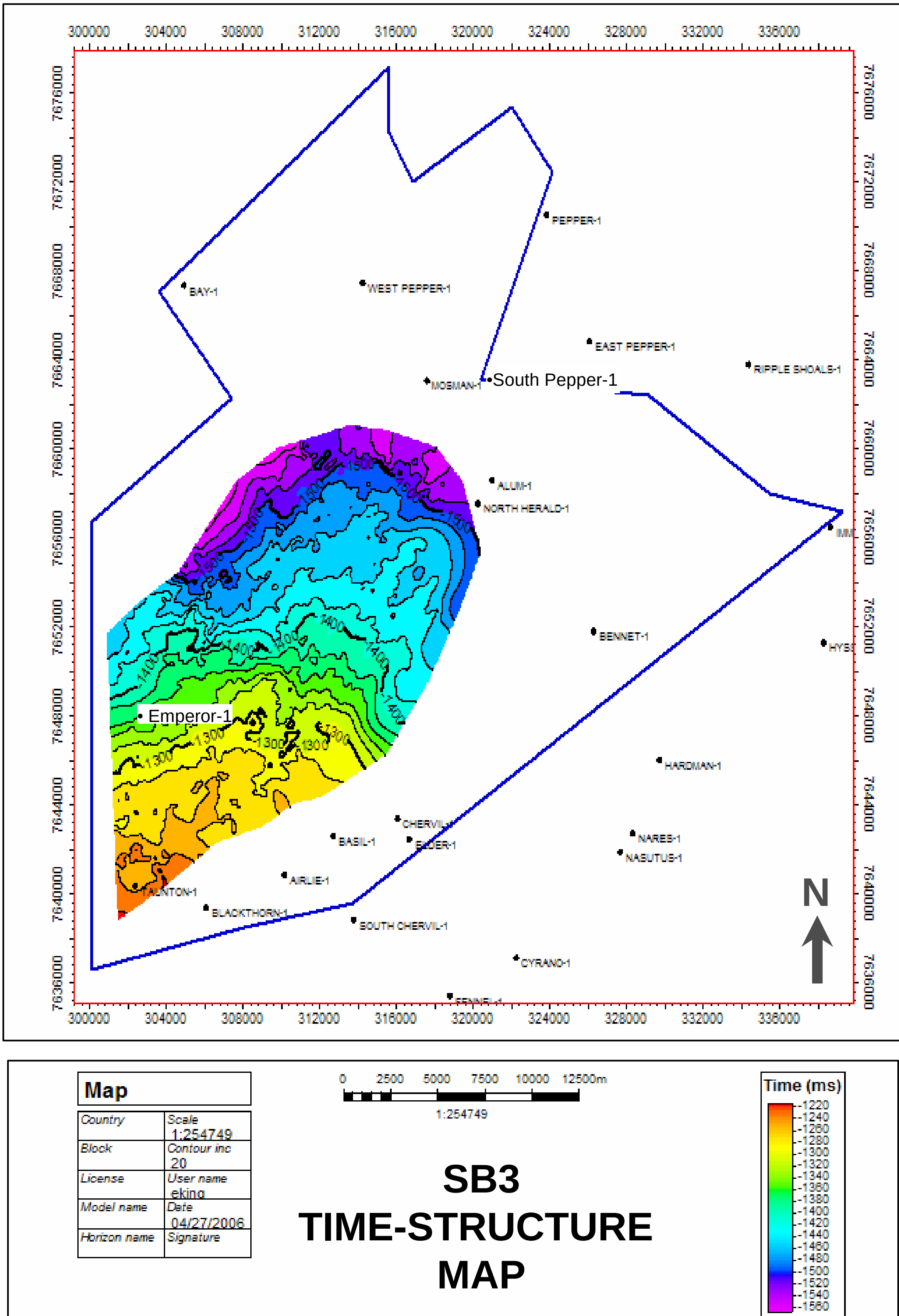


Figure 4.11 Sequence Boundary 3 Time-Structure Map.

4.4.2 SEISMIC CHARACTER/SEISMIC FACIES

The seismic character of Seismic Sequence 2 is generally low-amplitude continuous reflectors (Figure 4.10).

4.4.3 DISTRIBUTION AND EXTENT

Seismic Sequence 2 has a regional extent of approximately 166 km^2 and ranges in thickness from 0 to 70 ms (Figure 4.12). The isochron map suggests that the inferred depositional trend filled up the accommodation space left by Seismic Sequence 1. The thickest part of Seismic Sequence 2 lies ~10km west of North Herald-1 and Alum-1 and is generally lobate in shape (Figure 4.12).

4.4.4 DEPOCENTRE POSITION

The position of Seismic Sequence 2 depocentre displays that sedimentation has shifted further north and slightly more towards the east, towards the vicinity of North Herald-1 and Alum-1 (Figure 4.12), indicating the progradational nature for the intra-Barrow Group.

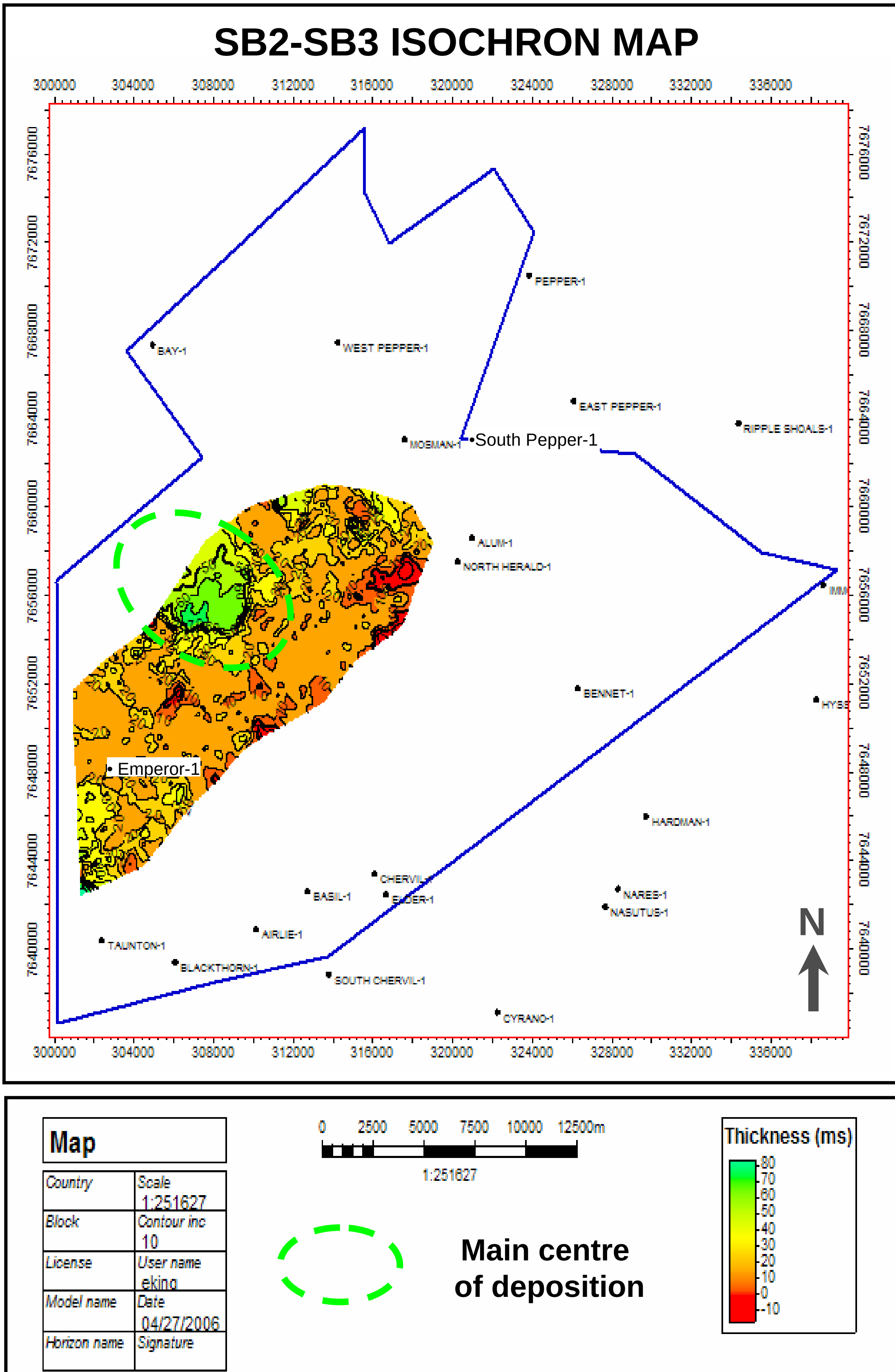


Figure 4.12 SB2 – SB3 Isochron Map, displaying one main centre of deposition during Seismic Sequence 2 deposition.

4.4.5 STACKING PATTERNS (seismic and well)

The seismic stacking patterns of Seismic Sequence 2 are retrogradational and aggradational across the study area. The log motif for Seismic Sequence 2 at Emperor-1 displays three retrograding and prograding stacked packages, followed by serrated aggradational stacked patterns (Figure 4.13).

4.4.6 SLOPE ANGLE

Seismic Sequence 2 is not laterally extensive and does not have a substantial enough thickness to calculate the paleo-slope angle.

4.4.7 AGE

Seismic Sequence 2 is Early Cretaceous (Berriasian) in age, spanning the *B.reticulatum* dinocyst zone. The age of this sequence is estimated at *135-137 Ma*.

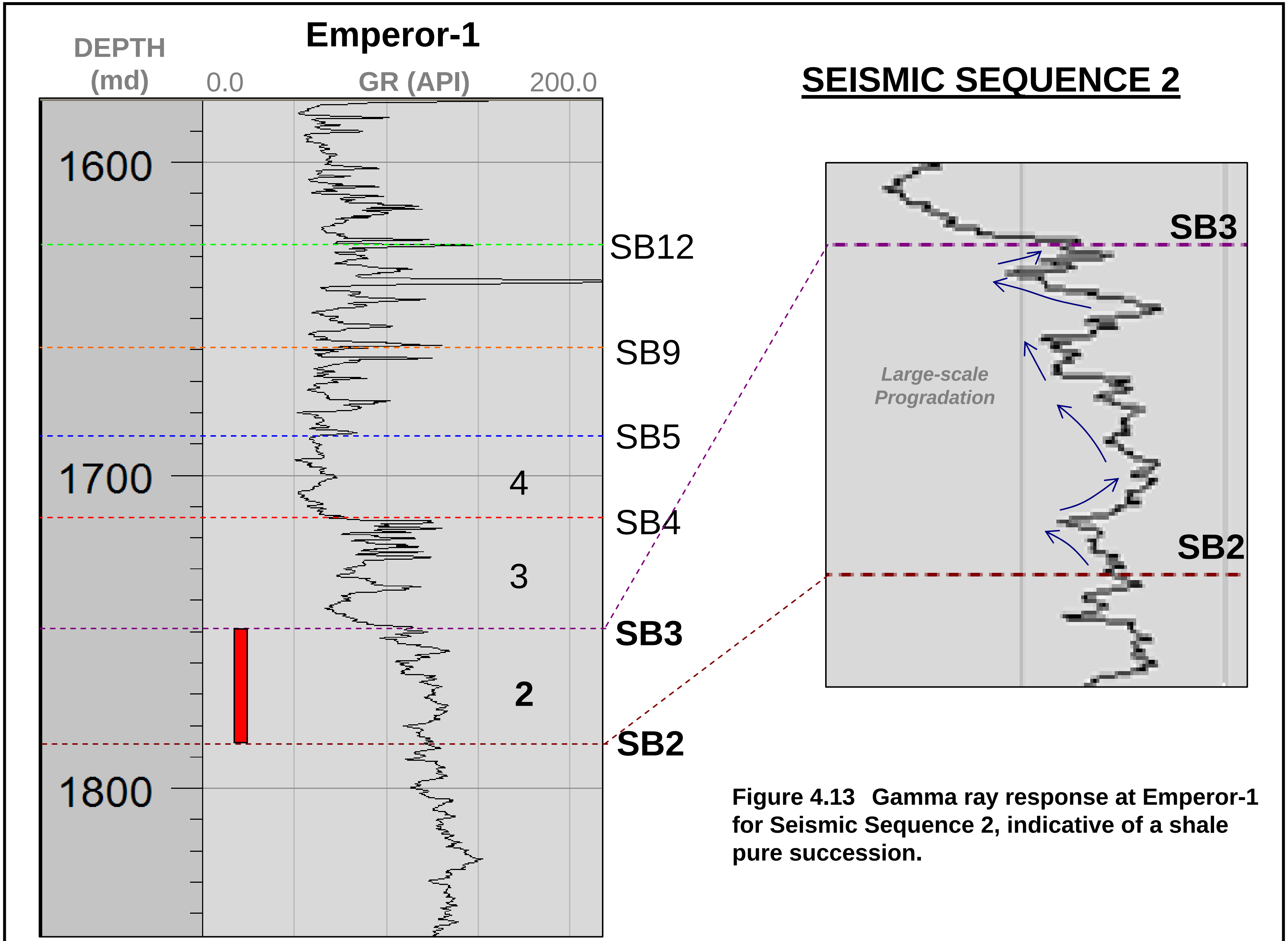


Figure 4.13 Gamma ray response at Emperor-1 for Seismic Sequence 2, indicative of a shale pure succession.

INTERPRETATION

4.4.8 SYSTEMS TRACTS

Seismic Sequence 2 is interpreted as a TST bound by sequence boundaries 2 and 3 (Figure 4.8). The transgressive sediments consist of blocky sands and interbedded shales. In seismic section backstepping trends building back over the highstand sediments of Seismic Sequence 1.

4.4.9 RESERVOIR/SEAL POTENTIAL

Seismic Sequence 2 is mud-prone based on the log response in Emperor-1 (Figure 4.13). The sequence is predicted to be mostly interbedded, shaley and silty sediments, with some minor sandstone intervals and therefore potentially consisting of non-reservoir facies.

4.4.10 PALAEOGEOGRAPHIC RECONSTRUCTIONS

Seismic Sequence 2 is interpreted to be within an overall transgression with an associated rise in relative sea-level (Figure 4.14). Slight backstepping of deltas may have occurred and deepwater sediments accumulated on the slope and basin floor.

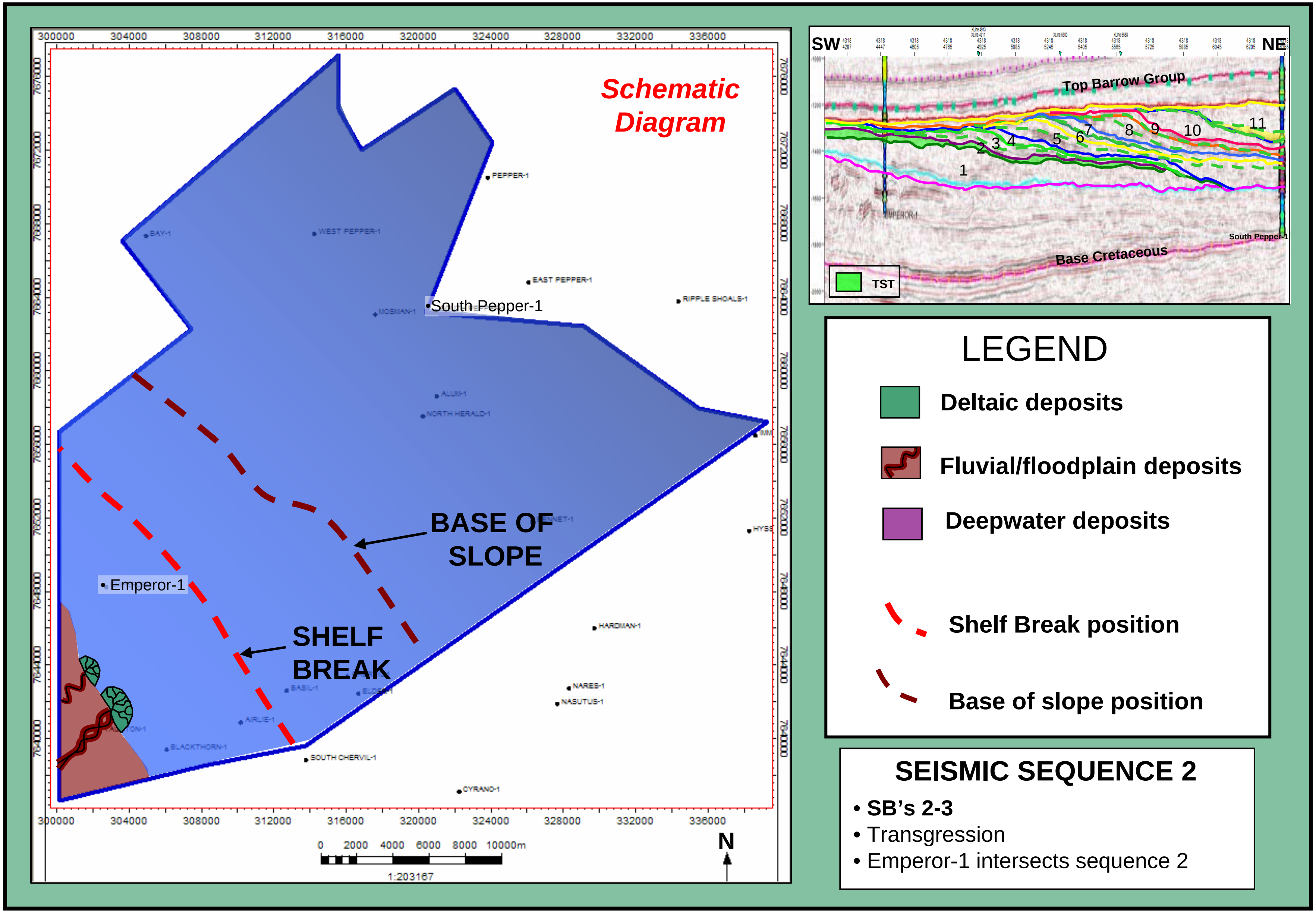


Figure 4.14 Seismic Sequence 2 schematic palaeo-geography map.

For a complete summary of Seismic Sequence 2, please refer to *Appendix 1.0*, Seismic Sequence 2 A3 summary sheet.

4.5 SEISMIC SEQUENCE 3

DESCRIPTION

4.5.1 KEY SURFACES

Seismic Sequence 3 is defined by key surfaces SB3 and sequence boundary 4 (SB4) (Figure 4.15). Seismic Sequence 3 is present mainly in the southwest part of the study area. The basal SB3 is identified by onlapping and downlapping sediments above the boundary, which corresponds to an erosive boundary at Emperor-1 (Figure 4.11). SB3 marks an abrupt facies change seaward. The upper SB4 is onlapped by overlying Seismic Sequence 4 sediments (Figure 4.16).

4.5.2 SEISMIC CHARACTER/SEISMIC FACIES

The seismic character of Seismic Sequence 3 displays reflectors that are moderately continuous to discontinuous and sub-parallel (Figure 4.15). The reflectors near the base consist of high amplitudes (and onlap and downlap onto SB3), and are fairly continuous. A decrease in reflection amplitude (low to

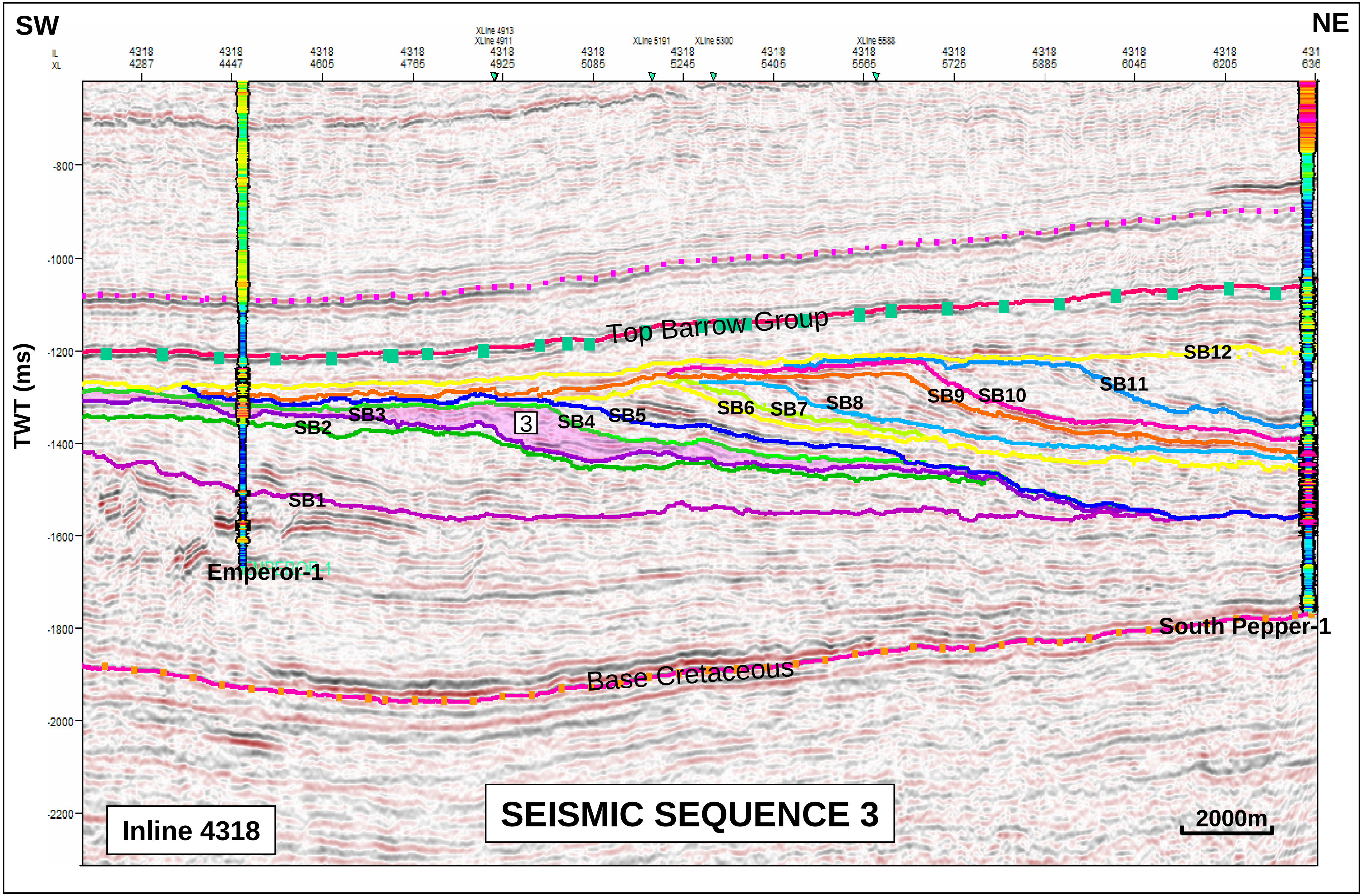


Figure 4.15 Seismic section displaying Seismic Sequence 3, bound by SB3 and SB4. Location of line indicated in Figure 4.3.

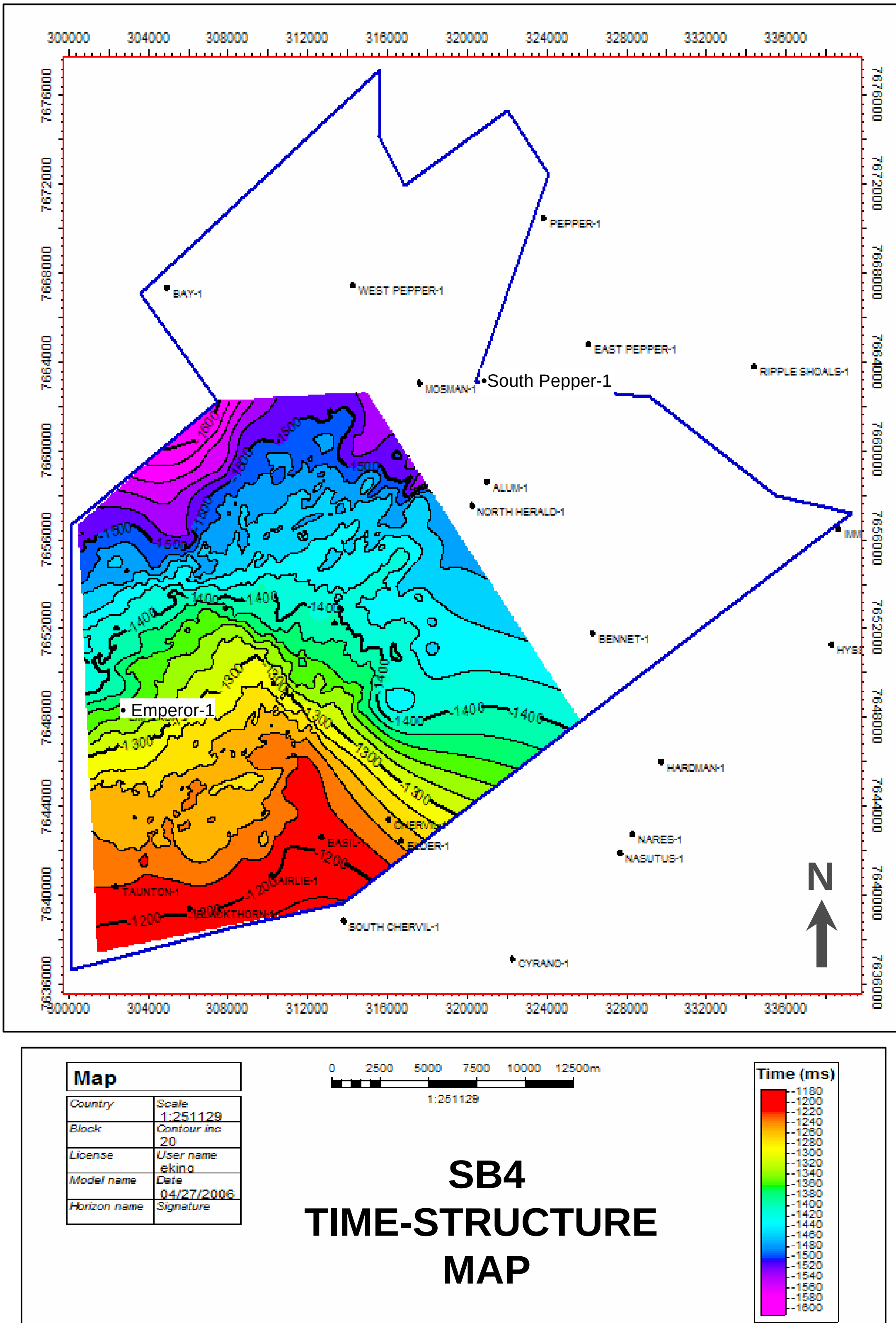


Figure 4.16 Sequence Boundary 4 Time-Structure Map.

moderate) is seen toward the top of the sequence, and reflectors range from continuous to discontinuous.

4.5.3 DISTRIBUTION AND EXTENT

Seismic Sequence 3 has a regional extent of approximately 255 km^2 within the study area (Figure 4.17), ranging in thickness from 0 to 95 ms. The sequence is thickest in the southwest region of the study area, thinning to the southwest and northeast.

4.5.4 DEPOCENTRE POSITION

The depocentre position of Seismic Sequence 3 tends to step back south of the position of Seismic Sequence 2, to the northeast of Emperor-1 (Figure 4.17).

4.5.5 STACKING PATTERNS (seismic and well)

The log motif for Seismic Sequence 3 at Emperor-1 displays an overall retrogradational stacking pattern with intermittent prograding packages and aggrading packages (Figure 4.18). A maximum flooding surface is identified from the high gamma ray reading at the top of the sequence (Figure 4.18).

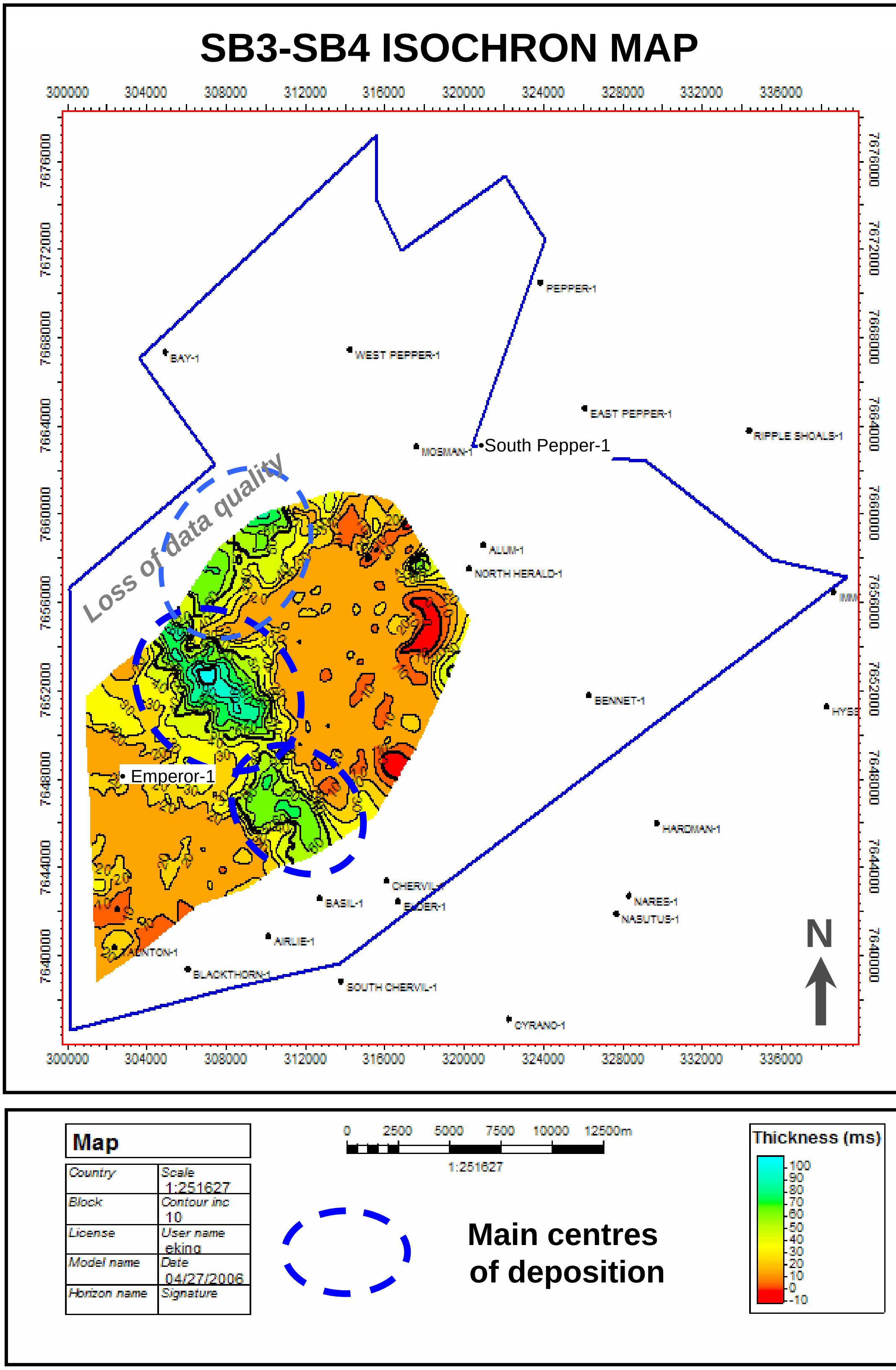


Figure 4.17 SB3 – SB4 Isochron Map, displaying two main centres of deposition (dark blue) and a third potential depocentre (light blue).

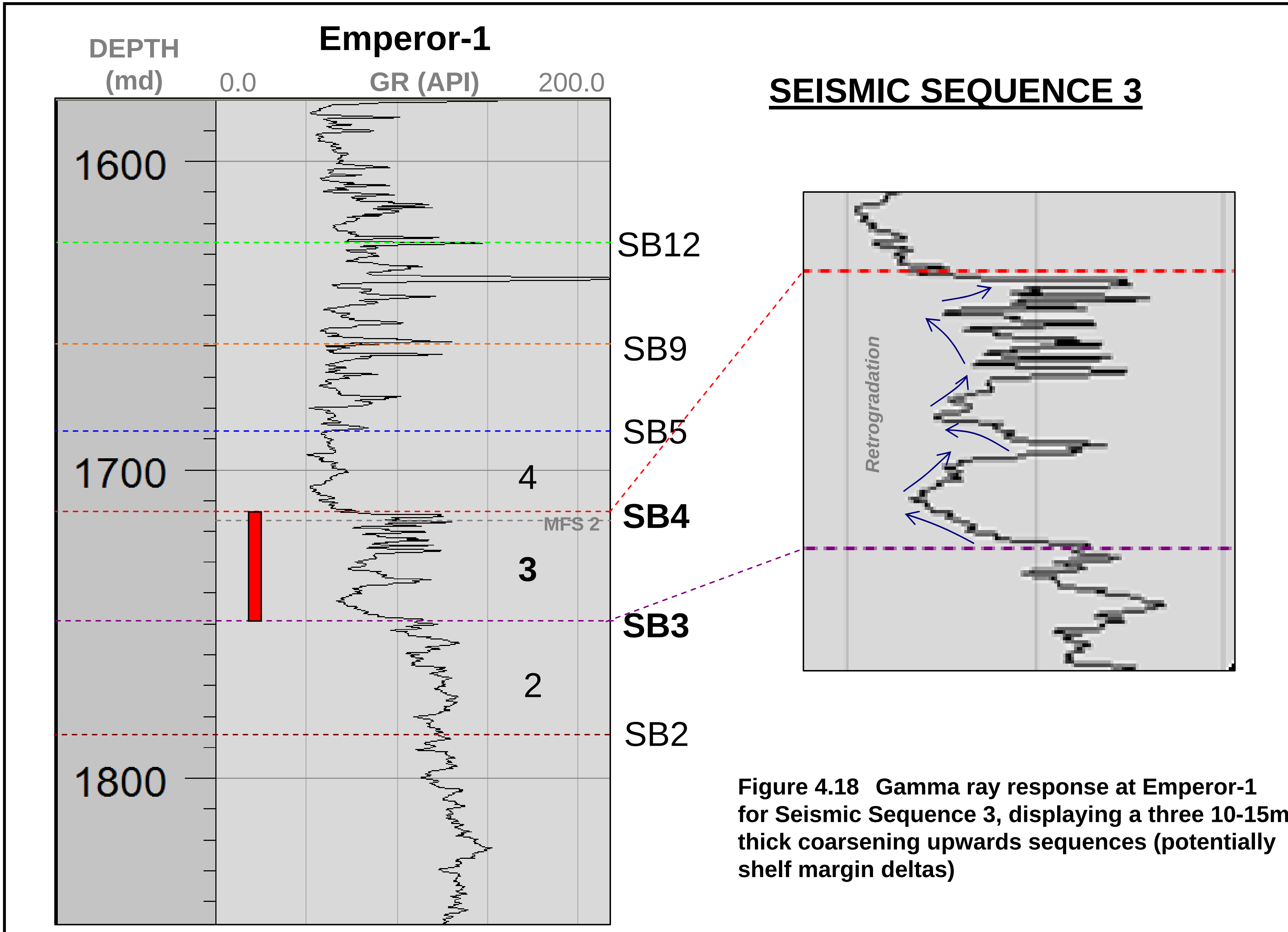


Figure 4.18 Gamma ray response at Emperor-1 for Seismic Sequence 3, displaying a three 10-15m thick coarsening upwards sequences (potentially shelf margin deltas)

Seismic stacking patterns for Seismic Sequence 3 are mainly aggradational with slight progradation towards the top of the sequence.

4.5.6 SLOPE ANGLE

The internal seismic character of Seismic Sequence 3 is too discontinuous to enable accurate slope angle calculations to be performed.

4.5.7 AGE

Based on the intersection at Emperor-1 Seismic Sequence 3, spans the *B. reticulatum* dinocyst zone. The age of this sequence is estimated at *135-137 Ma*.

INTERPRETATION

4.5.8 SYSTEMS TRACTS

From the integration of the seismic data available and well logs intersecting Seismic Sequence 3 a lowstand systems tract (LST) overlain by a TST, followed by a HST have been identified (Figure 4.8). Prograding lowstand wedge sediments dominate the basal section of the package (with corresponding onlapping and downlapping features viewed on seismic), although they are not extensive in nature. The bulk of the remaining sediments lie within the HST (which seismically displays progradation and aggradation) and is separated by a thin TST/transgressive surface (TS) (Figure 4.8).

4.5.9 RESERVOIR/SEAL POTENTIAL

Seismic Sequence 3 is mud-prone, but has some sand present in the Emperor-1 well (Figure 4.18). Seismic Sequence 3 is predicted to be interbedded with alternating layers of shale and silty/sandy sediments, thus consist of more sealing facies.

4.5.10 PALAEOGEOGRAPHIC RECONSTRUCTIONS

Seismic Sequence 3 is interpreted to be an initial lowstand wedge (Figure 4.19) followed by a thin TST, then HST (Figure 4.20). The deposition of the basal prograding lowstand wedge may be localised and confined to areas near the mouths of the incised rivers and in the distal parts of the incised valley (Figure 4.19). Seismic interpretation (time slices) and well log response provide the basis for the interpretation of incised valleys and the associated fall in relative sea-level. The upper part of the succession (late) represents the TST followed by a HST, resulting from a rise in sea-level producing subsequent aggradation due to high sediment supply and accommodation (Figure 4.20).

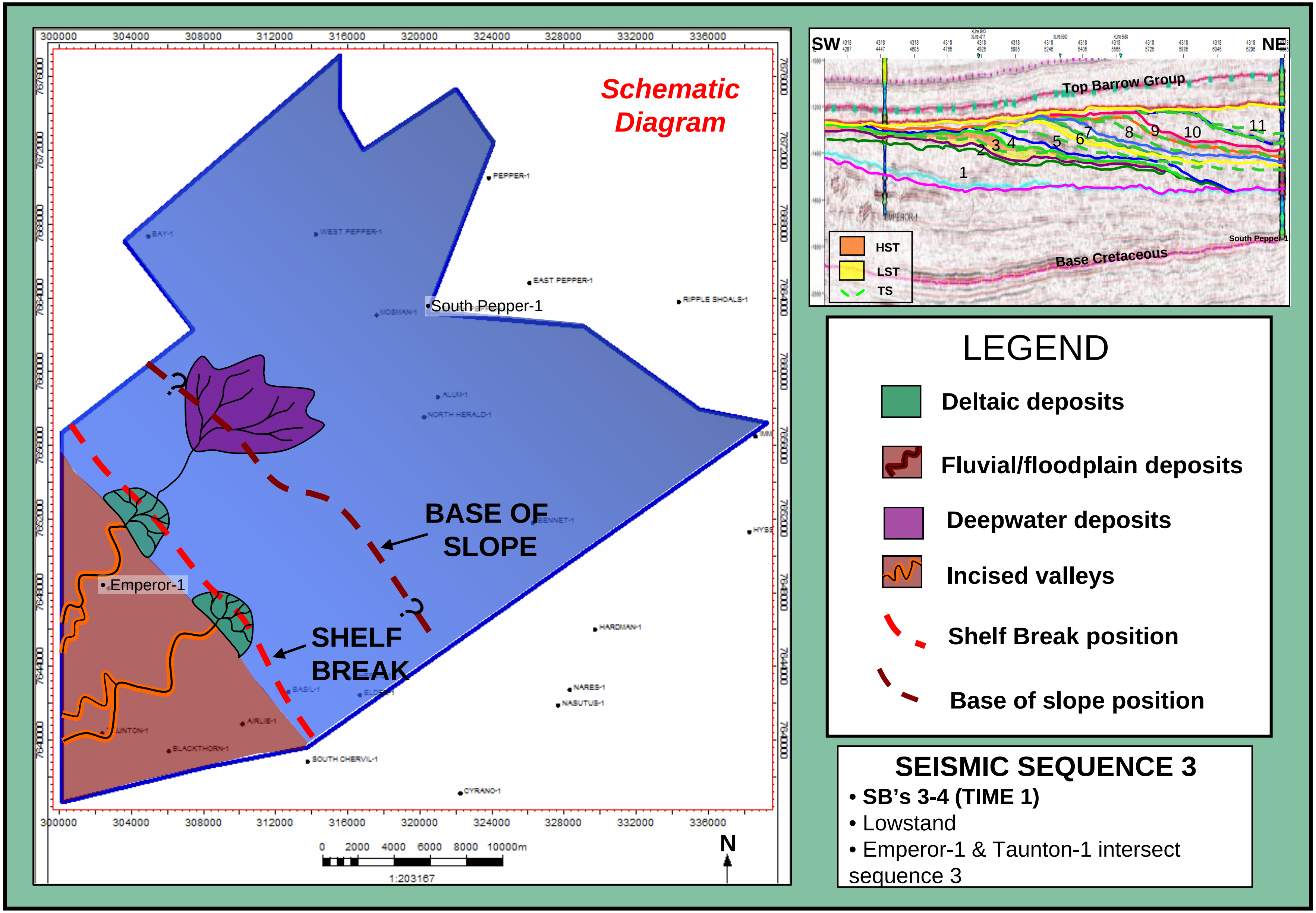


Figure 4.19 Seismic Sequence 3 schematic (early) palaeo-geography map.

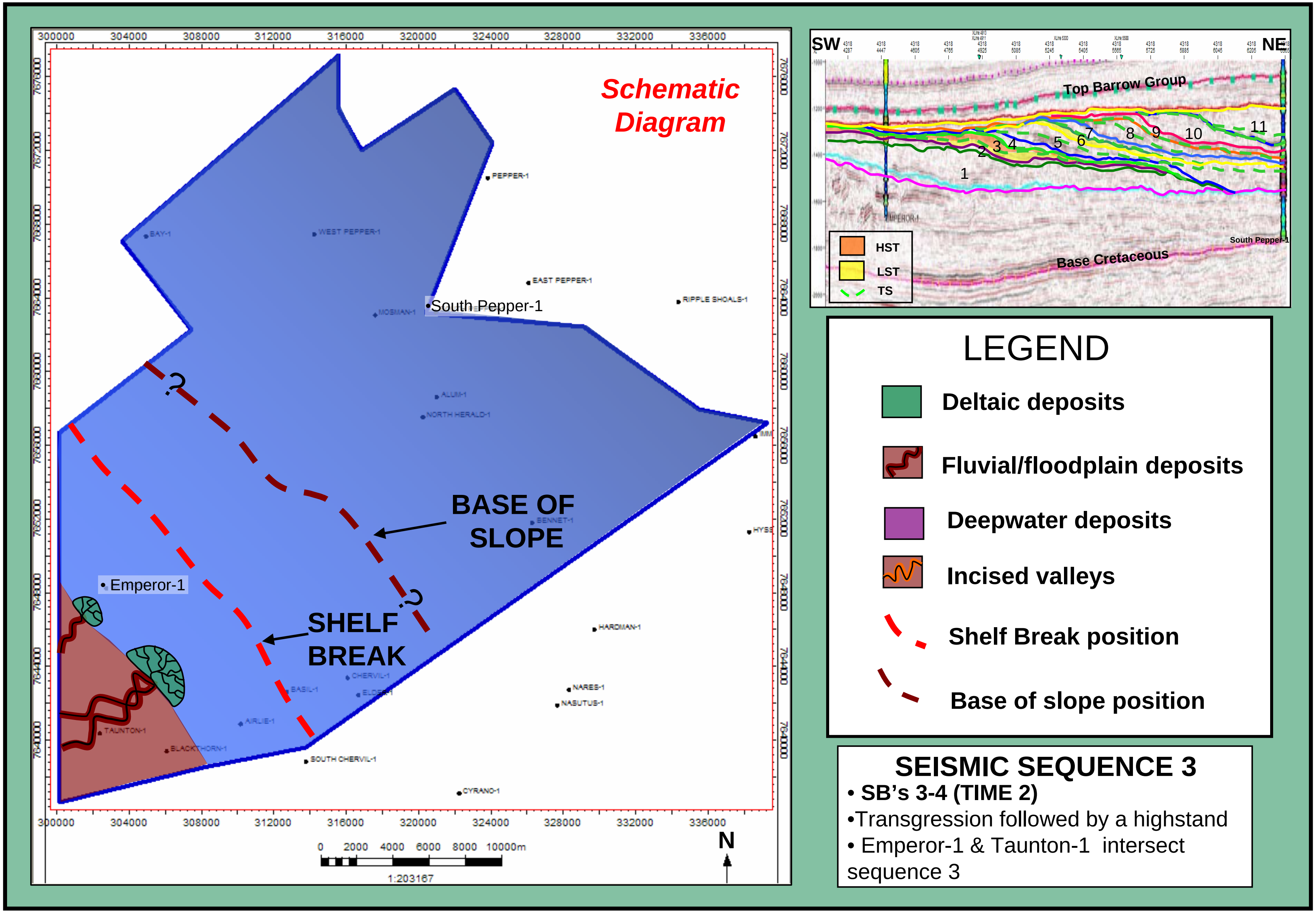


Figure 4.20 Seismic Sequence 3 schematic (late) palaeo-geography map.

For a complete summary of Seismic Sequence 3, please refer to *Appendix 1.0*, Seismic Sequence 3 A3 summary sheet.

4.6 SEISMIC SEQUENCE 4

DESCRIPTION

4.6.1 KEY SURFACES

Seismic Sequence 4 is bounded below by SB4 and above by sequence boundary 5 (SB5) (Figure 4.21). SB4 is defined by an onlap surface (Figure 4.16). The upper SB5 corresponds to the onlapping and downlapping of the overlying Seismic Sequence 5 sediments (Figure 4.22). Log responses at Emperor-1 display relatively constant low gamma ray readings for the bulk of the sequence (Figure 4.23).

4.6.2 SEISMIC CHARACTER/SEISMIC FACIES

The seismic character of Seismic Sequence 4 displays sub-parallel, moderately continuous to discontinuous reflectors (Figure 4.21). The bulk of the package consists of relatively low to moderate amplitude. The reflectors within Seismic Sequence 4 onlap onto the lower SB4 and consist of continuous to semi-continuous reflectors.

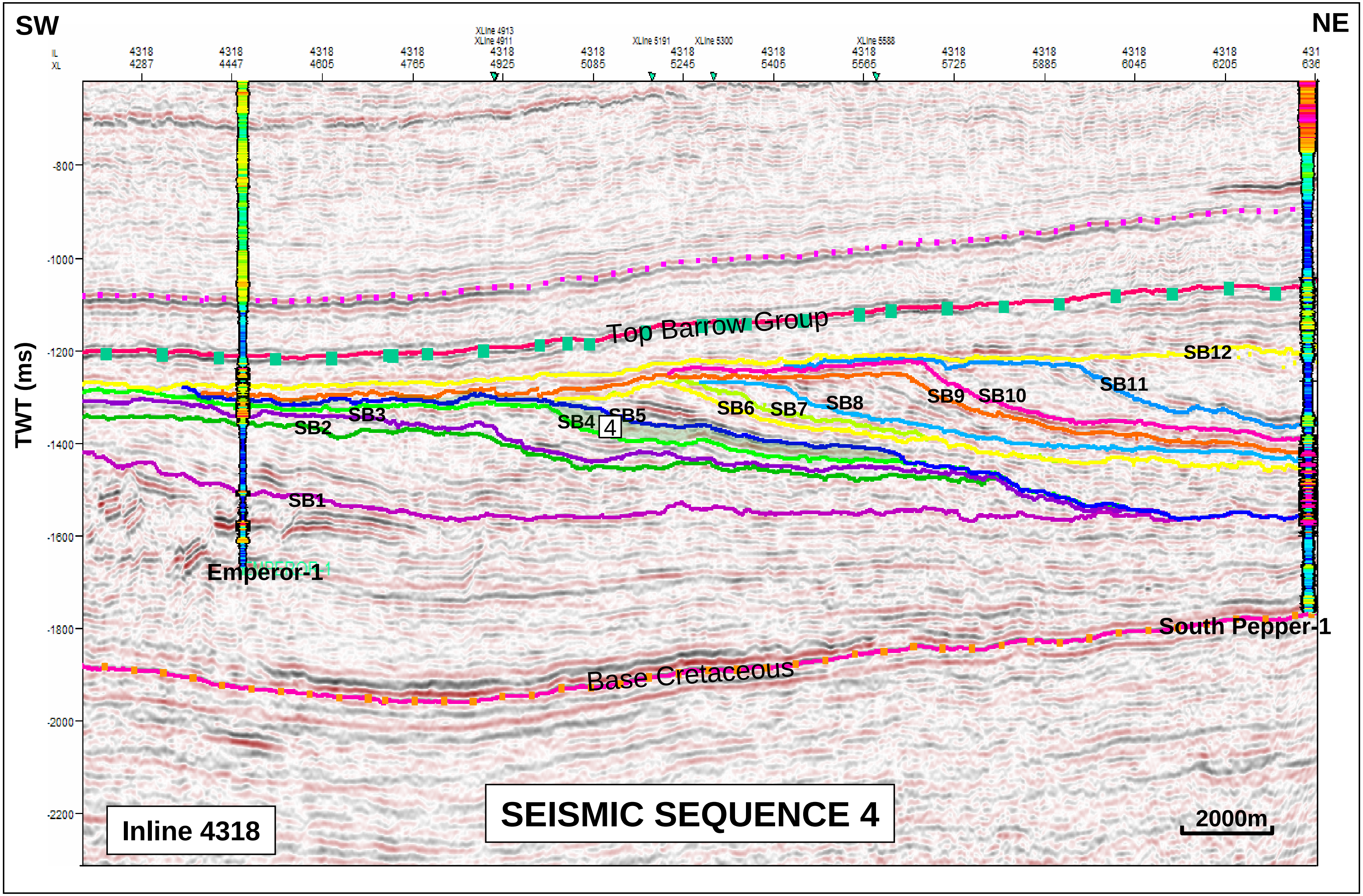


Figure 4.21 Seismic section displaying Seismic Sequence 4, bound by SB4 and SB5. Location of line indicated in Figure 4.3.

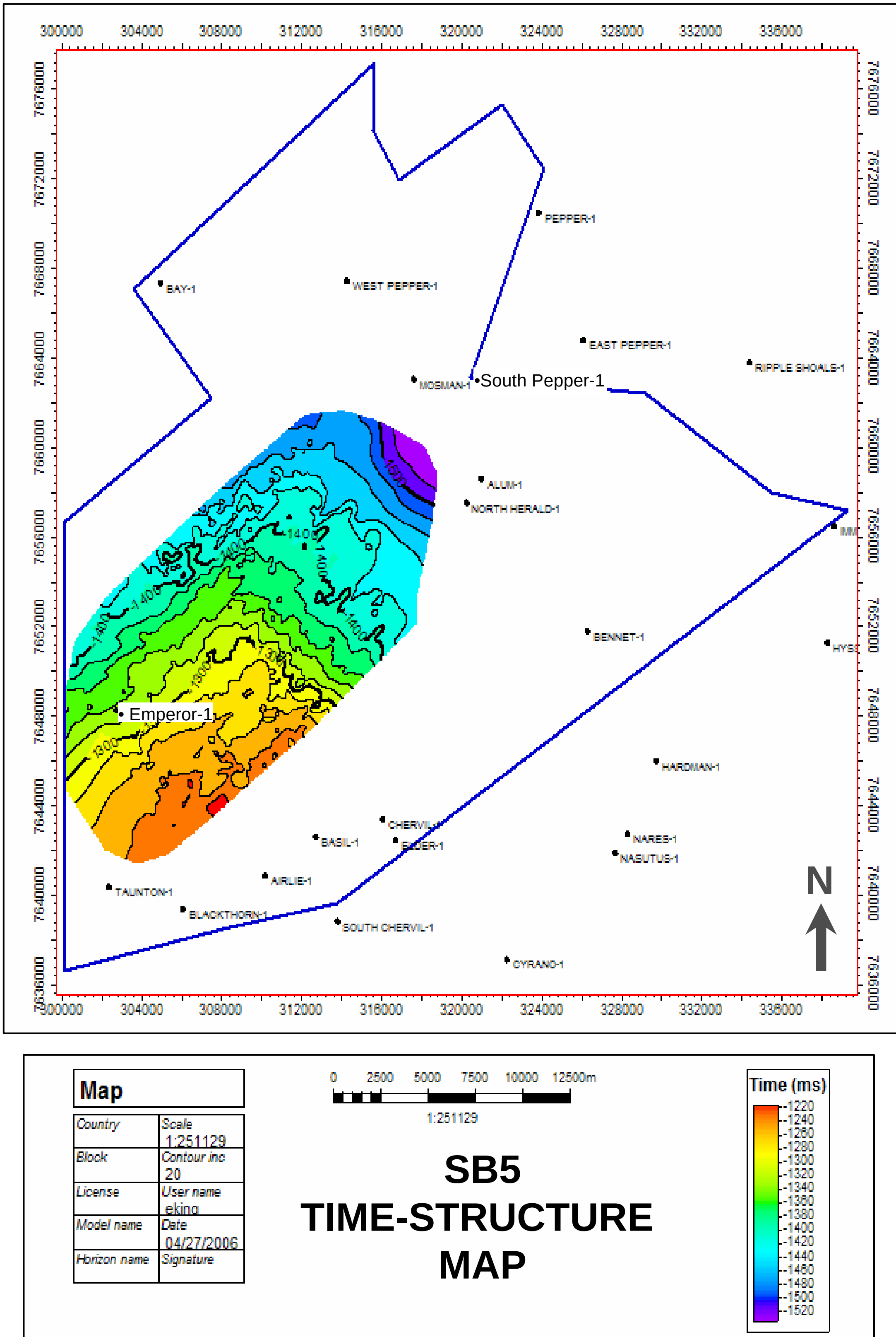


Figure 4.22 Sequence Boundary 5 Time-Structure Map.

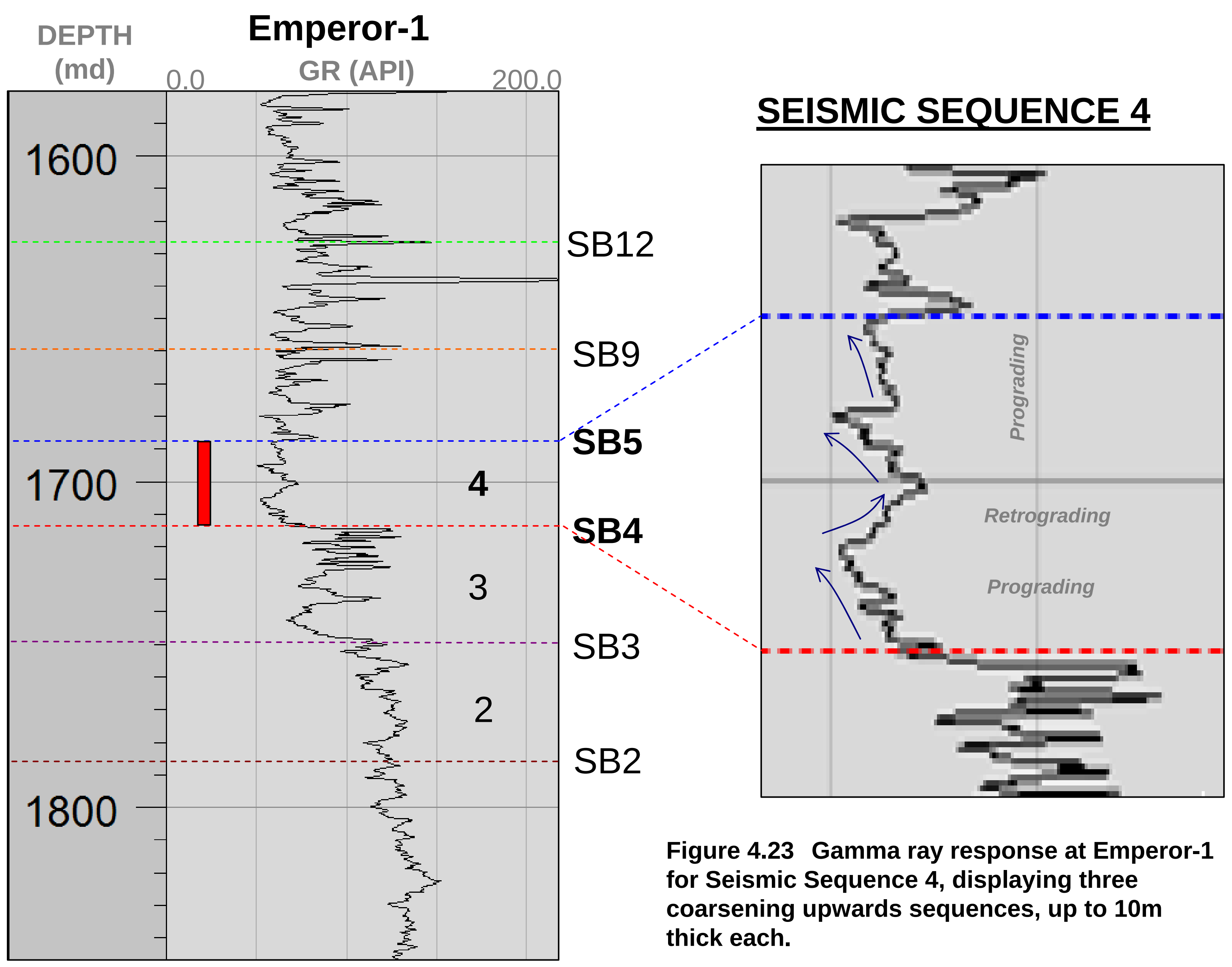


Figure 4.23 Gamma ray response at Emperor-1 for Seismic Sequence 4, displaying three coarsening upwards sequences, up to 10m thick each.

4.6.3 DISTRIBUTION AND EXTENT

Seismic Sequence 4 was mapped out across the study area, but it is confined due to poor seismic data and island locations (holes in survey). The sequence covers an area of approximately 216 km^2 (Figure 4.24), ranging in thickness from 0 to 55 ms. The sequence thins to the southeast, and is thickest to the northwest of North Herald-1 and Alum-1.

4.6.4 DEPOCENTRE POSITION

The shelf depocentre position of Seismic Sequence 4 is located west of North Herald-1 and NNW of Emperor-1, similar to the position of Seismic Sequence 2 (Figure 4.24). In comparison to the depocentre position Seismic Sequence 3, Seismic Sequence 4 has shifted towards the north.

4.6.5 STACKING PATTERNS (seismic and well)

The well log character of Emperor-1 in Seismic Sequence 4 displays one retrogradational and three progradational stacked packages, with an overall high net-to-gross. Low gamma ray readings are interpreted as higher-order maximum flooding surfaces (Figure 4.23).

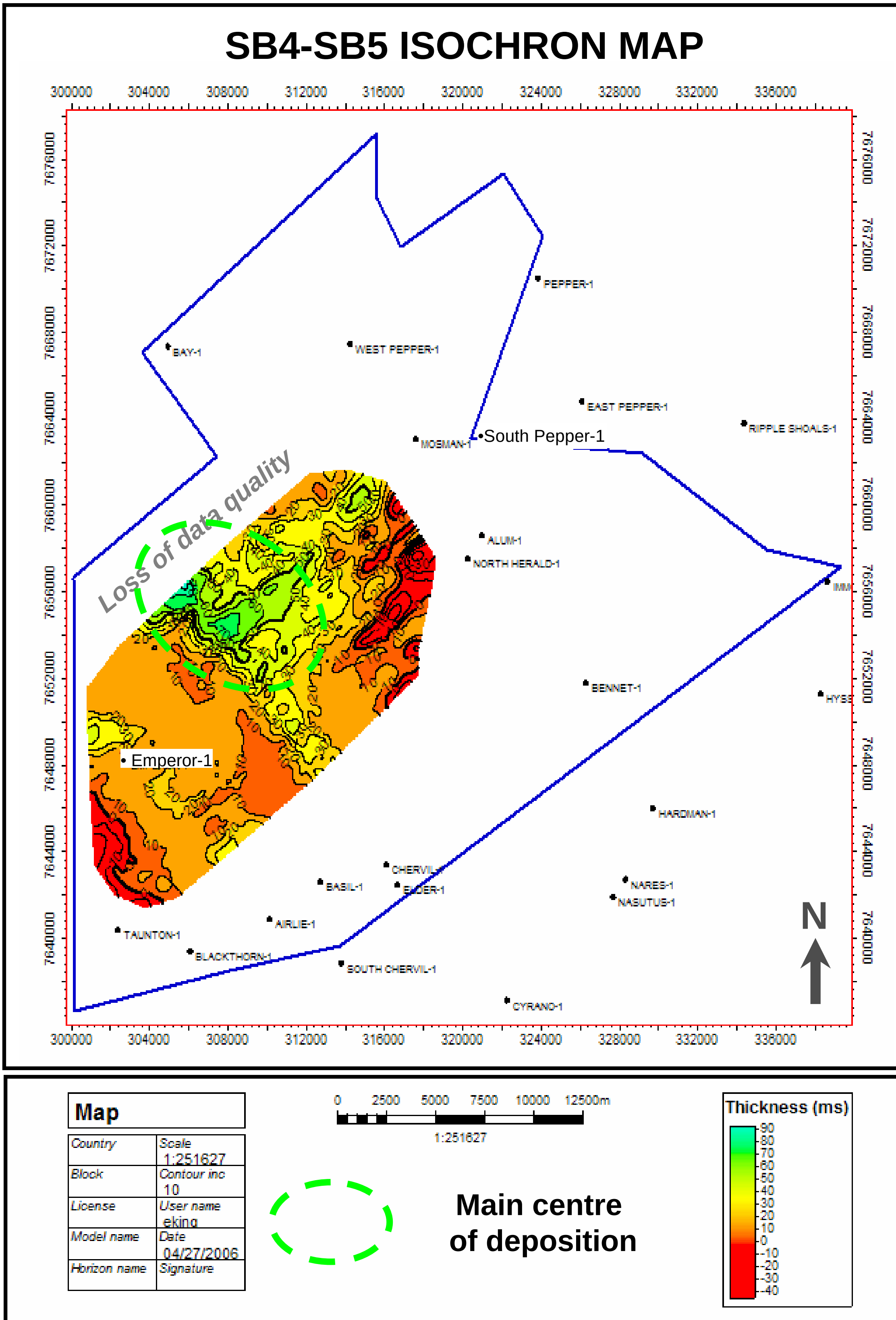


Figure 4.24 SB4 – SB5 Isochron Map, displaying one main centre of deposition during Seismic Sequence 4 deposition.

The seismic character of Seismic Sequence 4 is aggradational and slightly progradational towards the top of the sequence. A reduction in the progradational nature of the sequence is seen toward the northeast.

4.6.6 SLOPE ANGLE

Seismic Sequence 4 is not laterally extensive or of substantial thickness to perform slope angle calculations.

4.6.7 AGE

The *B. reticulatum* dinocyst zone approximately *135–137Ma* spans Seismic Sequence 4.

INTERPRETATION

4.6.8 SYSTEMS TRACTS

Seismic Sequence 4 is interpreted as mainly a HST that is bounded by a lower TST/TS and an upper sequence boundary (SB5) (Figure 4.8). The regressive package is regionally extensive, displays some progradation seismically, and is composed of interbedded sands and shales at Emperor-1.

4.6.9 RESERVOIR/SEAL POTENTIAL

The log response at Emperor-1 indicates that Seismic Sequence 4 is more sand-prone (Figure 4.23). Seismic Sequence 4 is likely to consist of thick sands with shale layers in between.

4.6.10 PALAEOGEOGRAPHIC RECONSTRUCTIONS

Seismic Sequence 4 is interpreted to have been deposited within a transgression followed by a highstand (Figure 4.25). The sequence displays an overall relative sea-level rise during deposition, with slight backstepping of the shoreline toward the sediment source direction (based on seismic character). Subsequently, the building out of deltas onto the shelf and transport of sediment to the slope and base of slope (deep water) is predicted to have occurred (Figure 4.25).

For a complete summary of Seismic Sequence 4, please refer to *Appendix 1.0*, Seismic Sequence 4 A3 summary sheet.

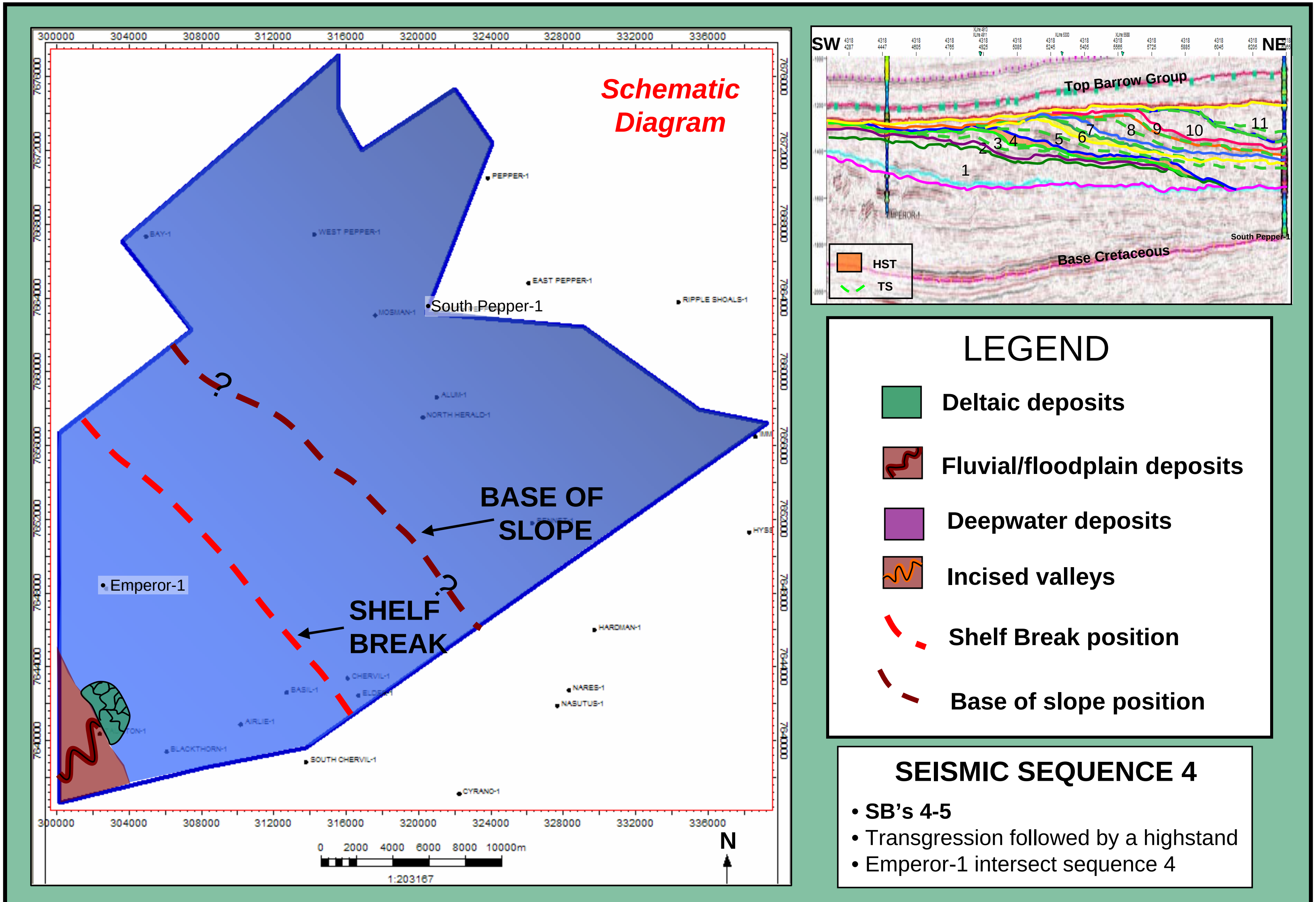


Figure 4.25 Seismic Sequence 4 schematic palaeo-geography map.

4.7 SEISMIC SEQUENCE 5

DESCRIPTION

4.7.1 KEY SURFACES

Seismic Sequence 5 is defined by key surfaces SB5 and sequence boundary 6 (SB6) (Figure 4.26). SB5 can be tracked under both onlapping and downlaping seismic reflectors of Seismic Sequence 5 sediments (Figure 4.22). The upper SB6 displays onlapping features via the overlying Seismic Sequence 6 sediments (Figure 4.27).

4.7.2 SEISMIC CHARACTER/SEISMIC FACIES

The seismic character of Seismic Sequence 5 consists of reflectors that are moderately continuous to discontinuous (Figure 4.26). Towards the base of the sequence the reflectors are moderately continuous, sub-parallel and mounded and of moderate to high amplitude. Towards the top of the sequence the reflectors are slightly discontinuous and of low to moderate amplitude. Overall the seismic facies of Seismic Sequence 5 can be divided into two reflection expressions; the basal high amplitude continuous facies and the lower amplitude continuous to discontinuous mounded facies.

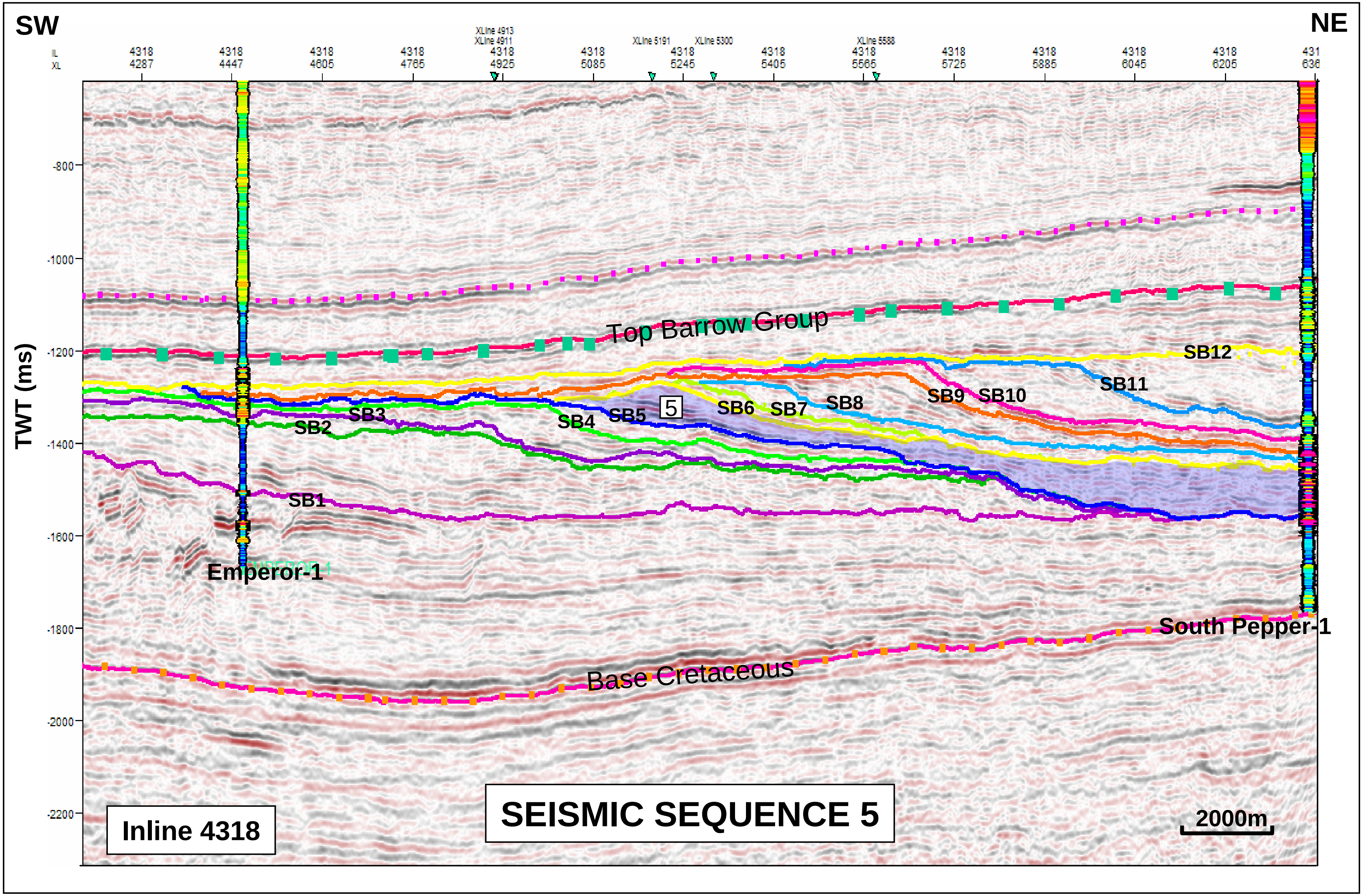


Figure 4.26 Seismic section displaying Seismic Sequence 5, bound by SB5 and SB6. Location of line indicated in Figure 4.3.

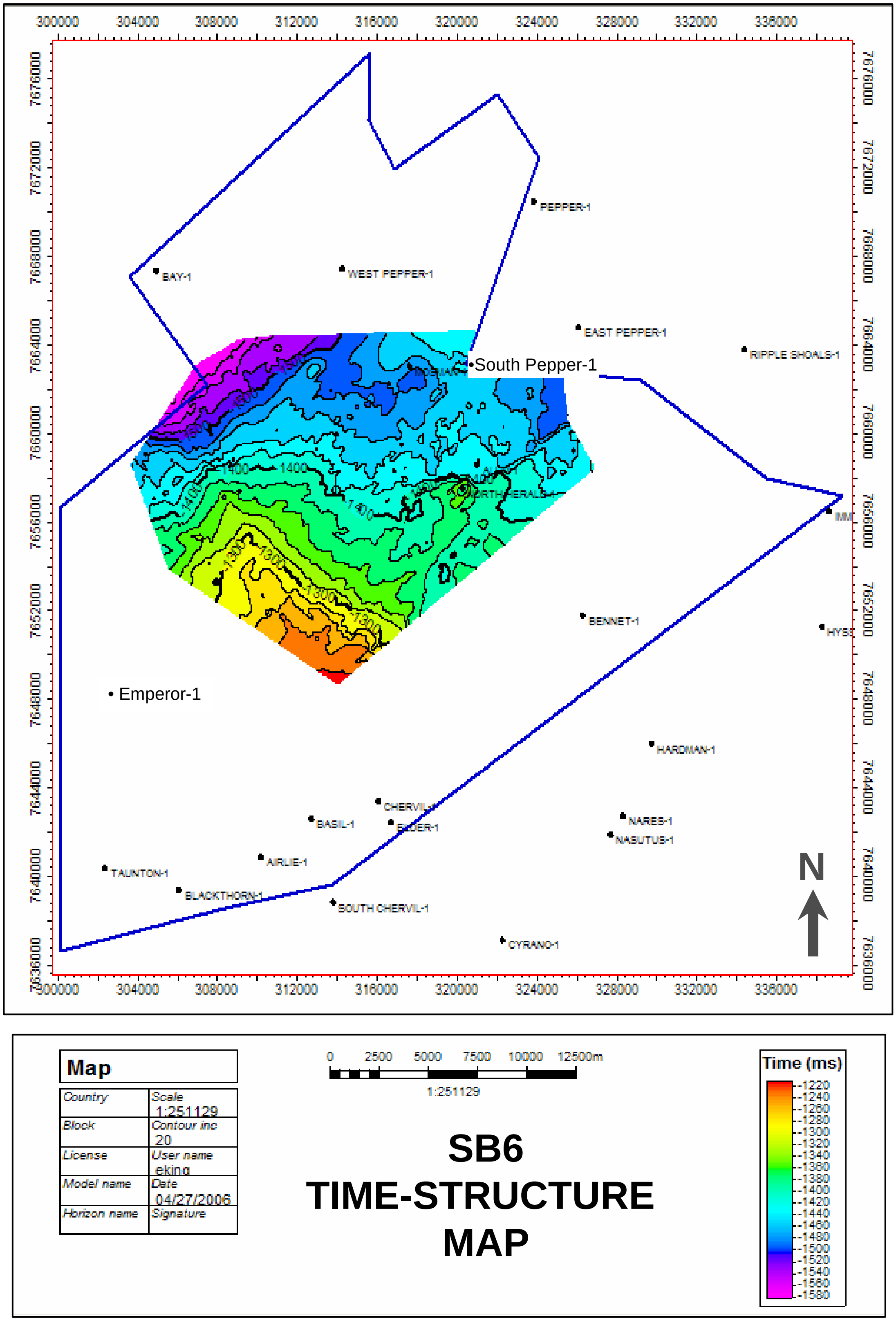


Figure 4.27 Sequence Boundary 6 Time-Structure Map.

4.7.3 DISTRIBUTION AND EXTENT

Seismic Sequence 5 was mapped out across the Flinders 3D survey, covering approximately 114 km^2 of the study area (Figure 4.28). The sequence ranges in thickness from 0 to 100 ms. The sequence is missing in the vicinity of Emperor-1 but thickens to the southeast and thins to both the northeast and southwest.

4.7.4 DEPOCENTRE POSITION

The shelf depocentre position for Seismic Sequence 5 is located west of Bennet-1 and south of North Herald-1 (Figure 4.28). This depocentre has switched towards the east and only moved towards the north slightly in comparison to the previous depocentre for Seismic Sequence 4.

4.7.5 STACKING PATTERNS (seismic and well)

Seismic Sequence 5 displays dominantly aggradational, with some weak progradational stacking patterns across the study area. The log motifs at North Herald-1, South Pepper-1 and Alum-1 display blocky sands with sharp tops and bases interbedded by thick intermittent siltstone and claystone layers (Figure 4.29 and 4.30).

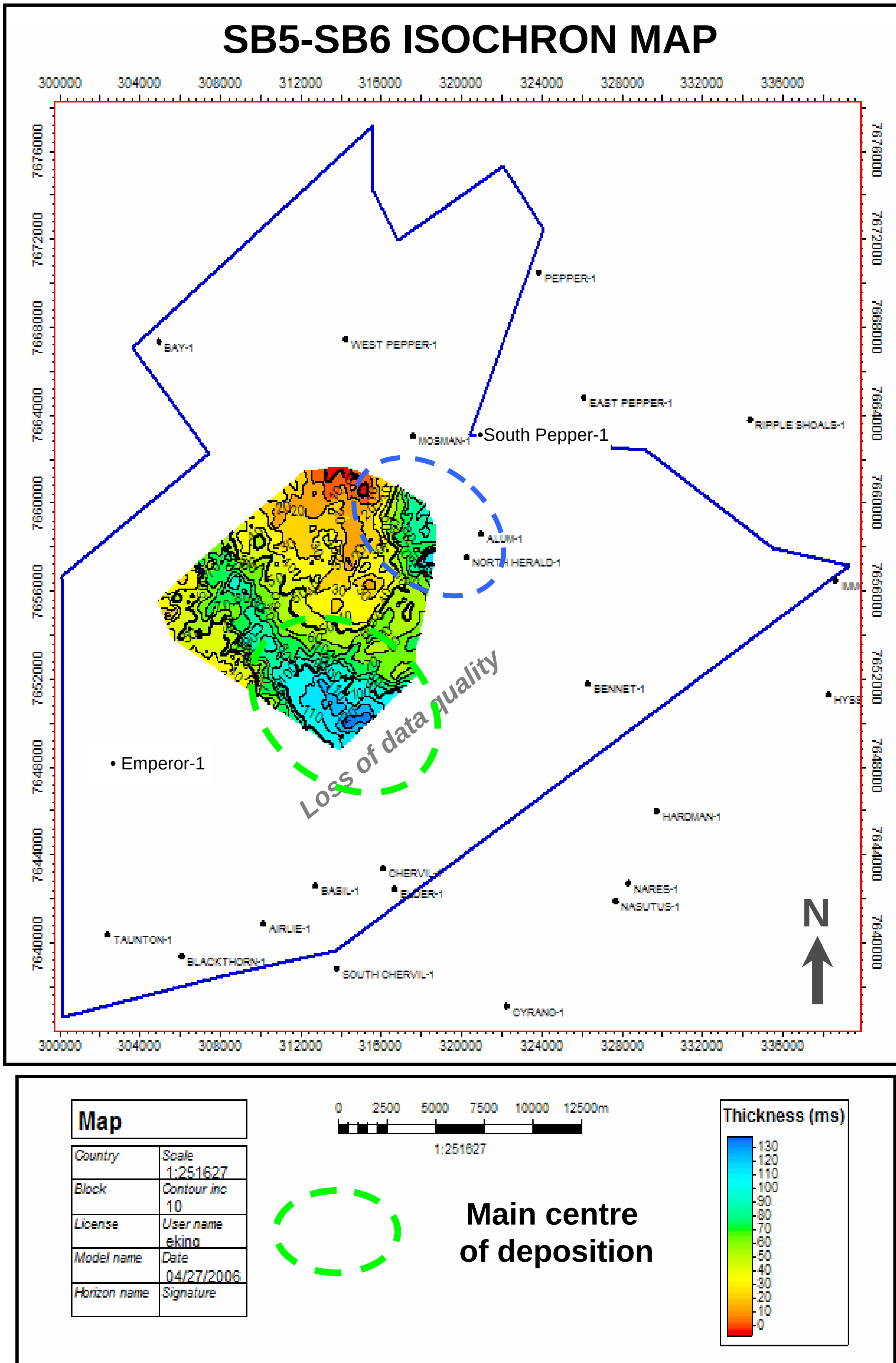


Figure 4.28 SB5 – SB6 Isochron Map, displaying one main centre of deposition during Seismic Sequence 5 deposition (green circle). Additionally a potential second depocentre is highlighted via light blue circle.

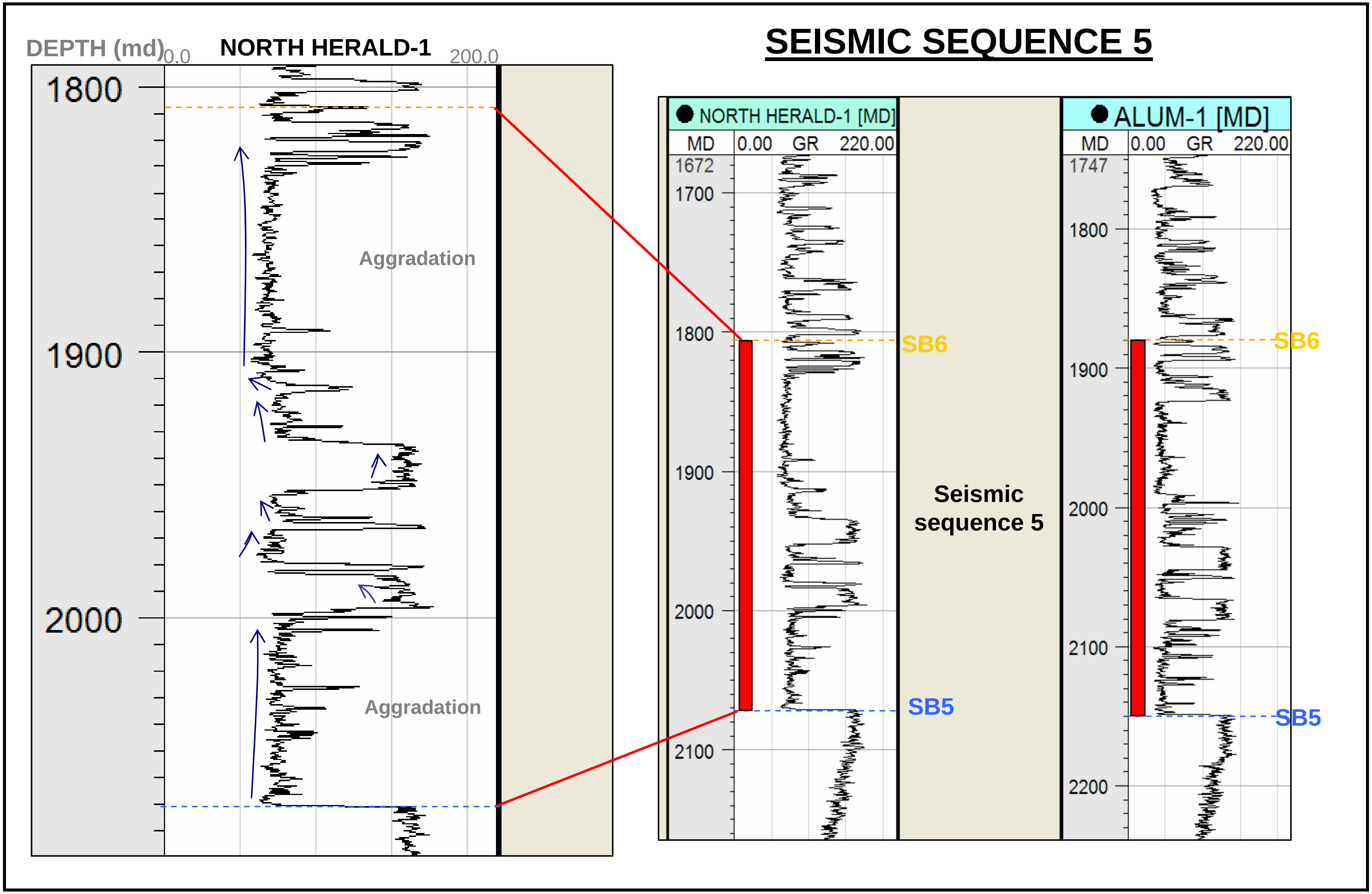


Figure 4.29 Gamma ray response at North Herald-1 and Alum-1 for Seismic Sequence 5, displaying a thick section of predominantly low gamma ray, sharp base and top sandstones (up to 100m thick).

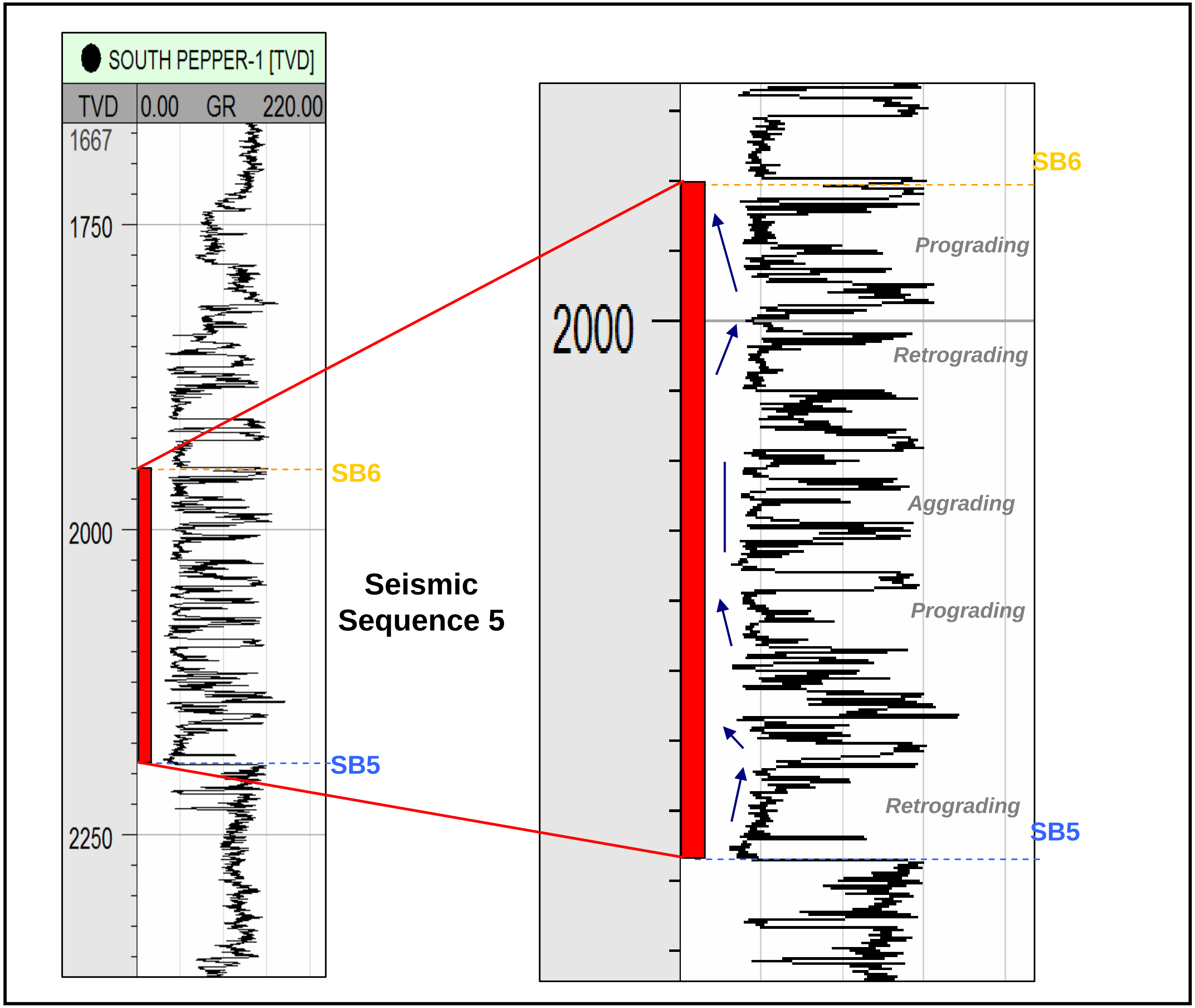


Figure 4.30 Gamma ray response at South Pepper-1 for Seismic Sequence 5.

4.7.7 SLOPE ANGLE

The sigmoid-oblique clinoforms viewed on seismic for Seismic Sequence 5 comprised of slope angles calculated at 4.2° (Figure 4.26). This average for the entire seismic package agrees with Poreski and Steel's (2003) estimate that are shelf-margin clinoform slope gradients between 3 and 6°.

4.7.8 AGE

Seismic Sequence 5 spans the *B. reticulatum* dinocyst zone and is Berriasian in age. The age of this package is interpreted as ~*135-137Ma*.

INTERPRETATION

4.7.9 SYSTEMS TRACTS

The systems tracts interpreted for Seismic Sequence 5 are a LST overlain by a HST, which is separated by a thin TST/TS (Figure 4.8). The prograding wedge of sediments that dominate the basal part of the sequence are composed mainly of thick blocky sands, (e.g. South Pepper-1) and display onlapping and downlapping features seismically, and are interpreted as comprising a LST. The overlying TST is relatively thin and mainly shale prone. The upper HST section displays both prograding and aggrading characteristics and is predominantly sand prone.

4.7.10 RESERVOIR/SEAL POTENTIAL

From numerous well log responses, Seismic Sequence 5 is predicted to be more sand-prone (Figure 4.29 & 4.30). Seismic Sequence 5 is interpreted to consist of thick sands interbedded with shaley intervals.

4.7.11 PALAEOGEOGRAPHIC RECONSTRUCTIONS

During the initial fall in sea-level, the fluvial and deltaic sediments built out almost to the shelf break and deposited a large quantity of sediment on the shelf and slope and in deep water (Figure 4.31). Depositional environments present include fluvial, shallow floodplain, deltaic, shallow marine, slope and deepwater deposits. Evidence for this includes the well log responses at South Pepper-1 representing the deposition of deep water sands (basin floor fans) during this time (Figure 4.30). Seismic Sequence 5 is interpreted to be deposited during a major forced regression followed by a smaller scale transgression and highstand, as similar interpretation made by Posamentier et al., 1992 (Figure 4.31 and 4.32). The later transgression represents a rise in relative sea-level and backstepping of the coastline (Figure 4.32). Palaeo-shelf break, slope and base

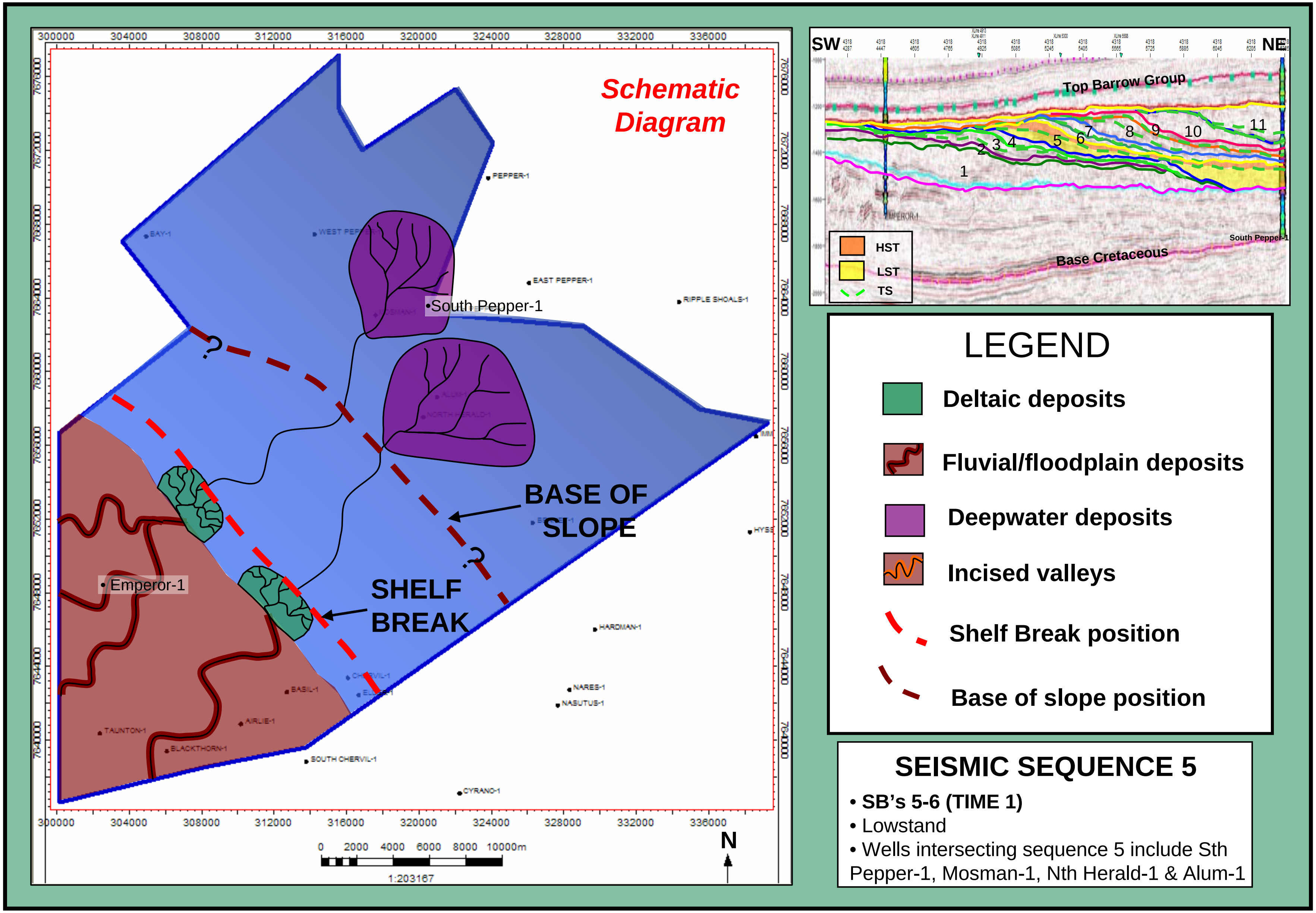


Figure 4.31 Seismic Sequence 5 schematic (early) palaeo-geography map.

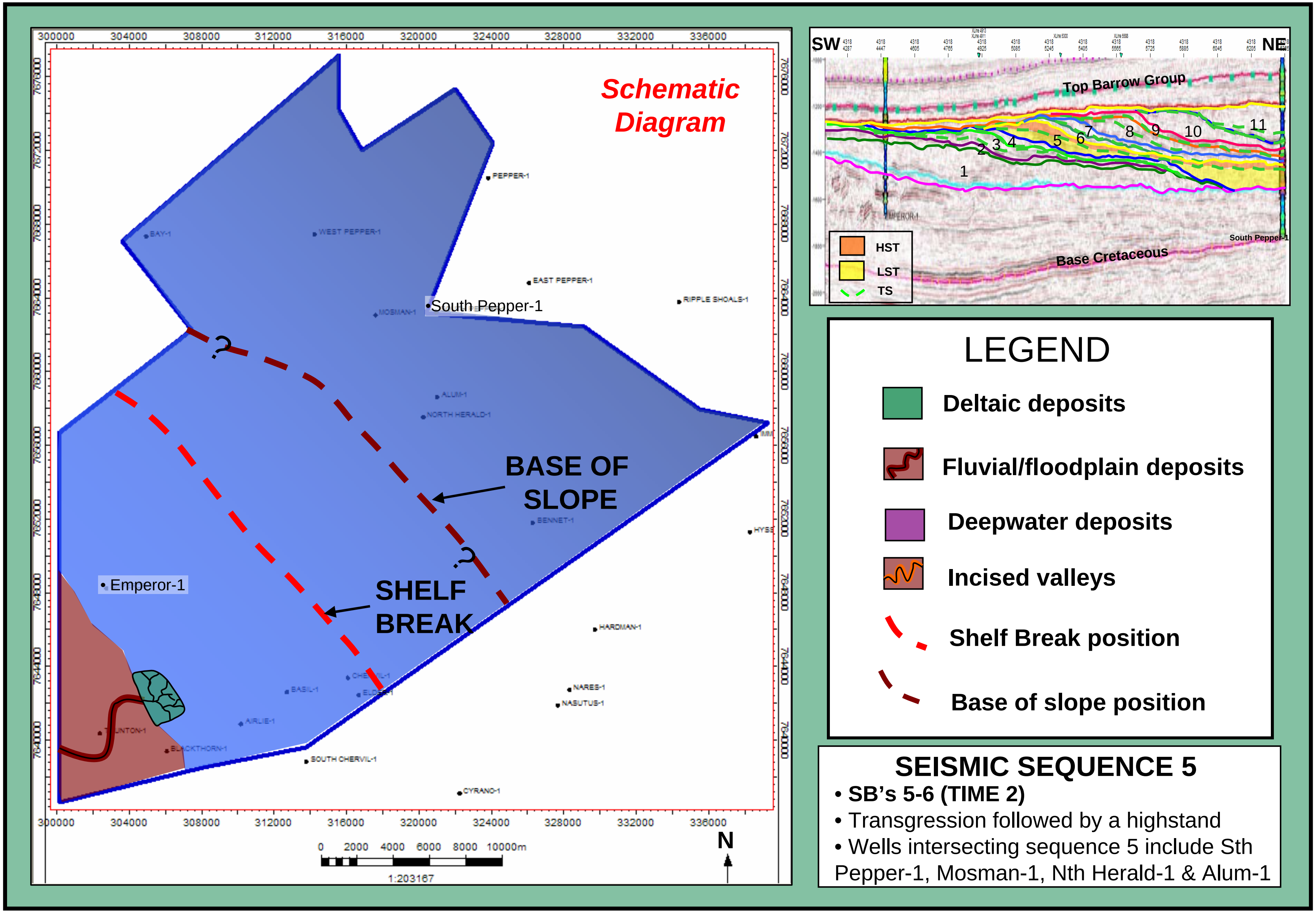


Figure 4.32 Seismic Sequence 5 schematic (late) palaeo-geography map.

of slope interpretations for this sequence also contribute to depositional environment interpretations.

For a complete summary of Seismic Sequence 5, please refer to *Appendix 1.0*, Seismic Sequence 5 A3 summary sheet.

4.8 SEISMIC SEQUENCE 6

DESCRIPTION

4.8.1 KEY SURFACES

Seismic Sequence 6 is defined by key surfaces SB6 and sequence boundary 7 (SB7) (Figure 4.33). The lower SB6 is a well-defined onlapped surface (Figure 4.27). The upper SB7 is recognisable due to its erosional nature and can only be mapped over a small region in the centre of the Flinders 3D survey area (Figure 4.34). Both these surfaces are only recognisable seismically, as there are no well intersections present in this area.

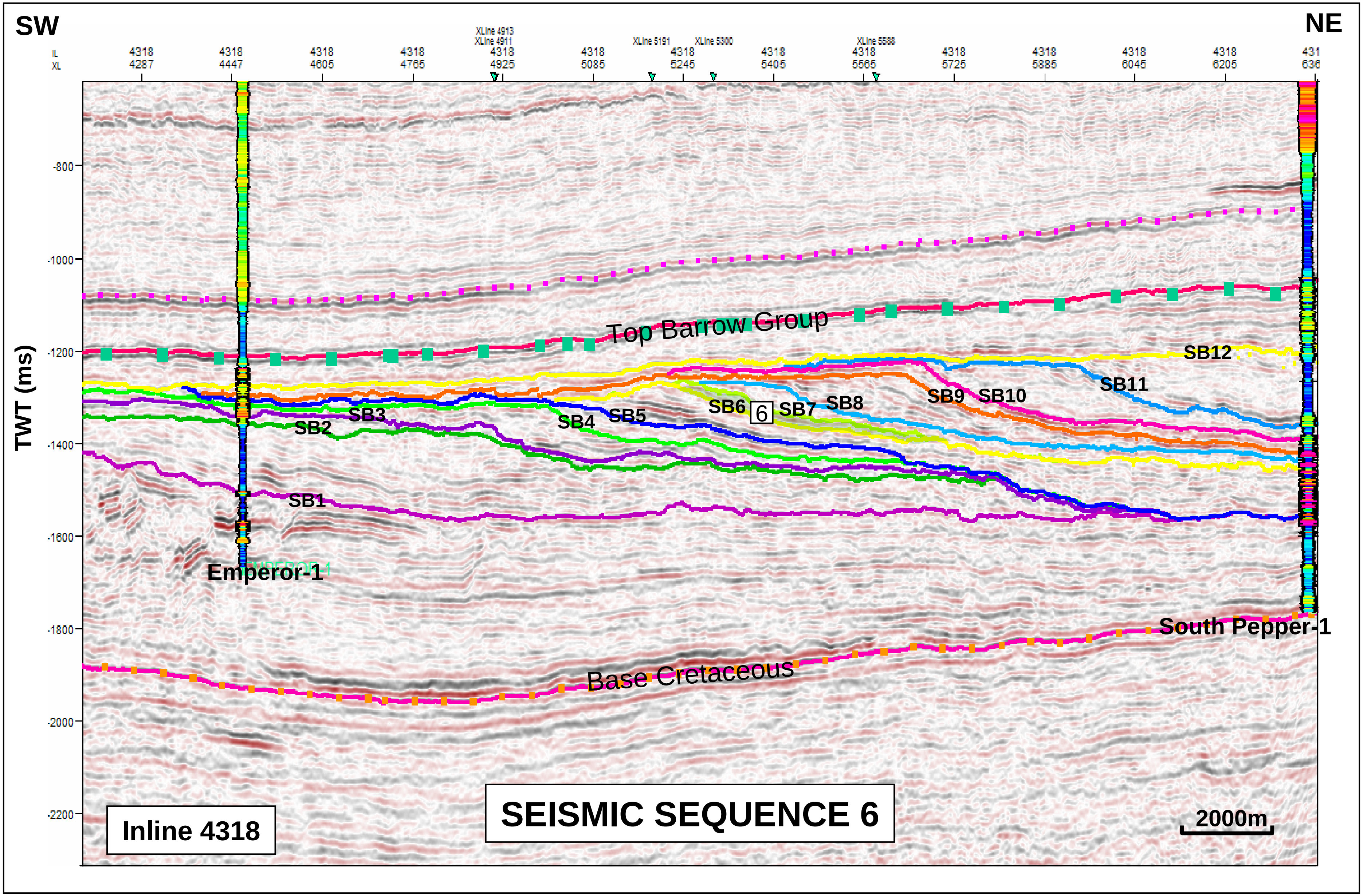


Figure 4.33 Seismic section displaying Seismic Sequence 6, bound by SB6 and SB 7. Location of line indicated in Figure 4.3.

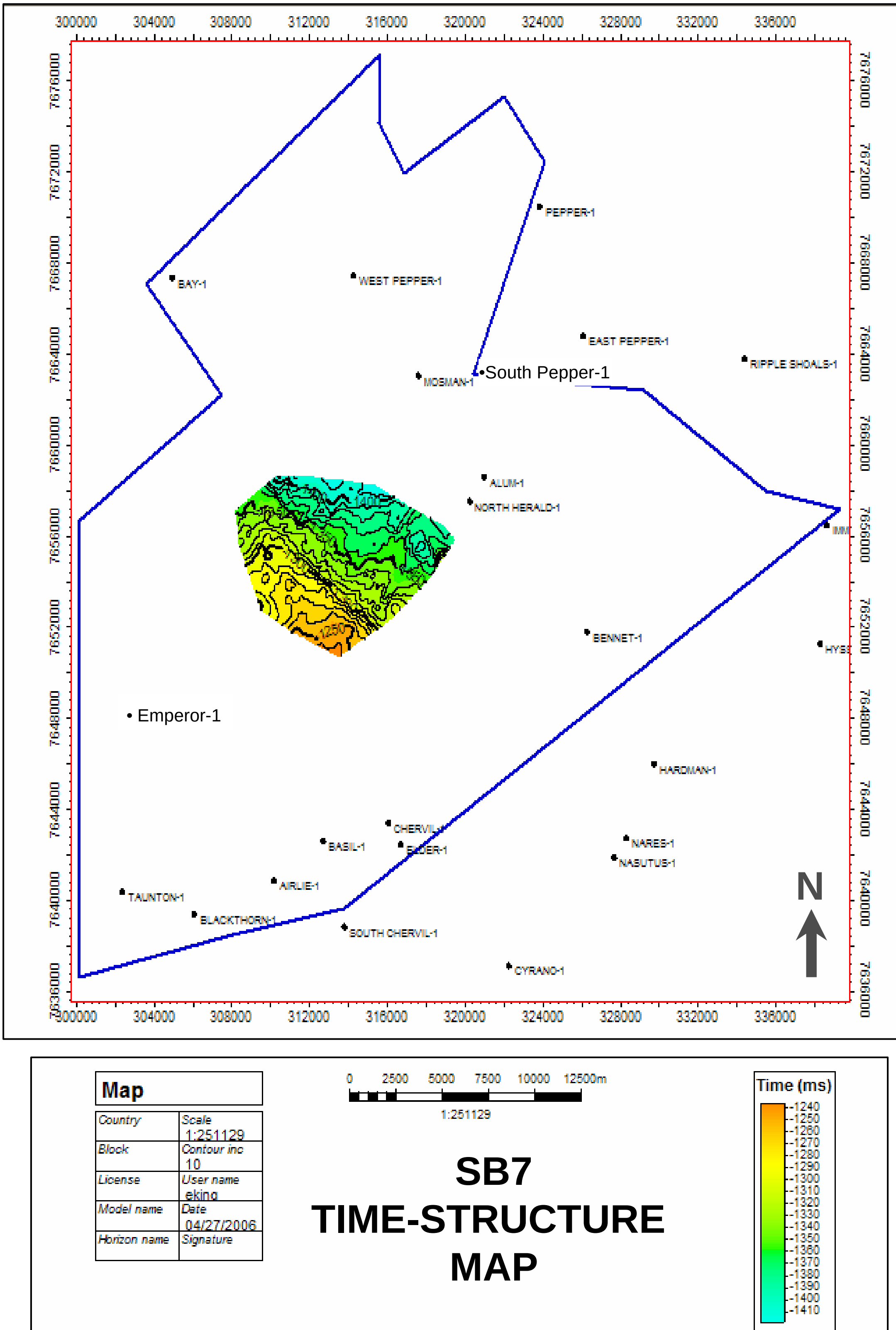


Figure 4.34 Sequence Boundary 7 Time-Structure Map.

4.8.2 SEISMIC CHARACTER/SEISMIC FACIES

The seismic character and facies of Seismic Sequence 6 consists of reflectors that are moderately continuous and parallel, typically of low to moderate amplitude (Figure 4.33).

4.8.3 DISTRIBUTION AND EXTENT

Seismic Sequence 6 has a regional extent of approximately 59 km^2 based on existing seismic resolution (Figure 4.35), ranging in thickness from 0 to 40 ms, thickening slightly to the southeast. Additionally, an isochron from SB6 to SB8 has been created, to better display the extent of Seismic Sequence 6 (Figure 4.36).

4.8.4 DEPOCENTRE POSITION

The shelf depocentre for Seismic Sequence 6 is located just south of North Herald-1. In comparison to the previous depocentre location (Seismic Sequence 5), Seismic Sequence 6 has shifted slightly towards the north (Figure 4.35 and 4.36).

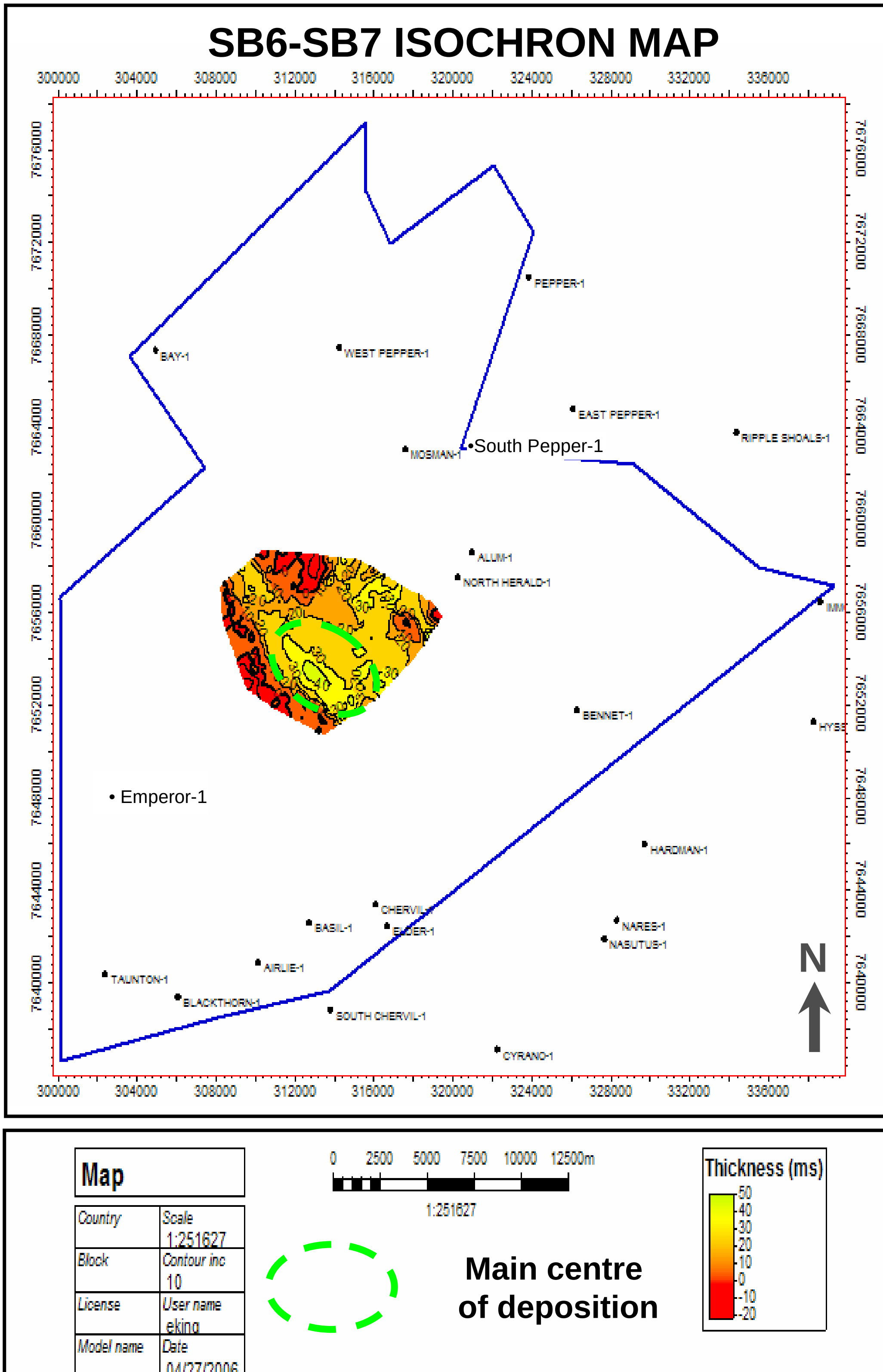


Figure 4.35 SB6 – SB7 Isochron Map, displaying one main centre of deposition during Seismic Sequence 6 deposition.

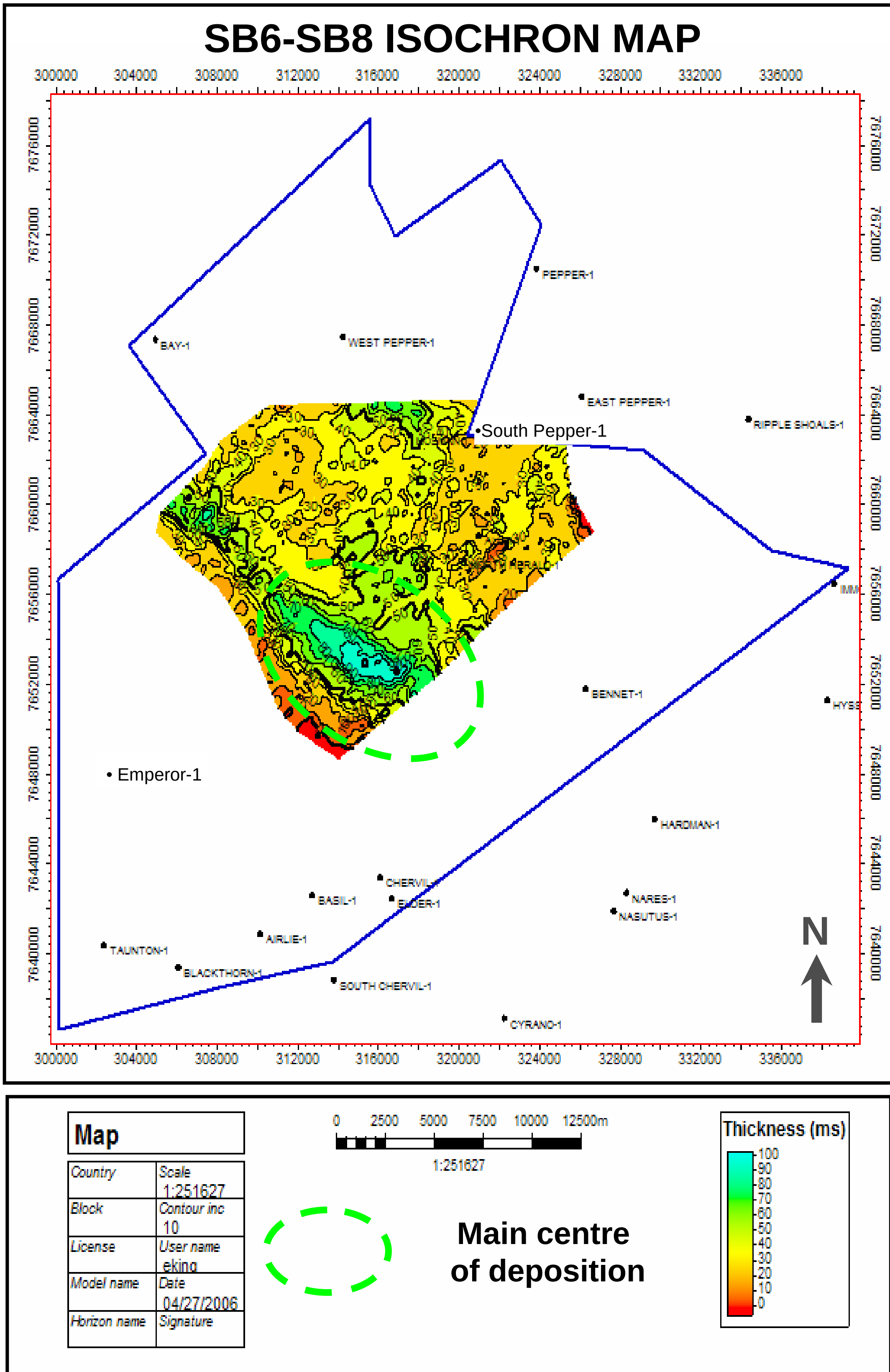


Figure 4.36 SB6 – SB8 Isochron Map, displaying one main centre of deposition during Seismic Sequence 7 deposition.

4.8.5 STACKING PATTERNS (seismic and well)

The seismic interpretation of Seismic Sequence 6 indicates progradation toward the northwest, which has subsequently undergone some erosion. No wells intersect Seismic Sequence 6 in the study area.

4.8.7 SLOPE ANGLE

Seismic Sequence 6 is not laterally extensive or of substantial thickness to calculate slope angle estimates.

4.8.8 AGE

Although Seismic Sequence 6 has not been penetrated by wells, based on stratigraphic position it should be within the *B. reticulatum* (?) dinocyst zone (Berriasian) approximately 135-137Ma.

INTERPRETATION

4.8.9 SYSTEMS TRACTS

Seismic Sequence 6 displays onlap and downlapping features on seismic and is interpreted predominantly to comprise of a LST (Figure 4.8). The lowstand wedge is relatively thin and not extensive over the study area.

4.8.10 RESERVOIR/SEAL POTENTIAL

Seismic Sequence 6 is predicted to be a succession of interbedded sand and shales, due to its position in the seismic sequence stratigraphic framework.

4.8.11 PALAEOGEOGRAPHIC RECONSTRUCTIONS

Seismic Sequence 6 is interpreted as a lowstand wedge. This wedge is localised and may have directly been fed by one river over a small area. A slight fall in sea-level is interpreted, with fluvial and deltaic conditions dominating during the time of deposition (Figure 4.37). It is possible the main centre for deposition during this period may have been outside the study area.

For a complete summary of Seismic Sequence 6, please refer to *Appendix 1.0*, Seismic Sequence 6 A3 summary sheet.

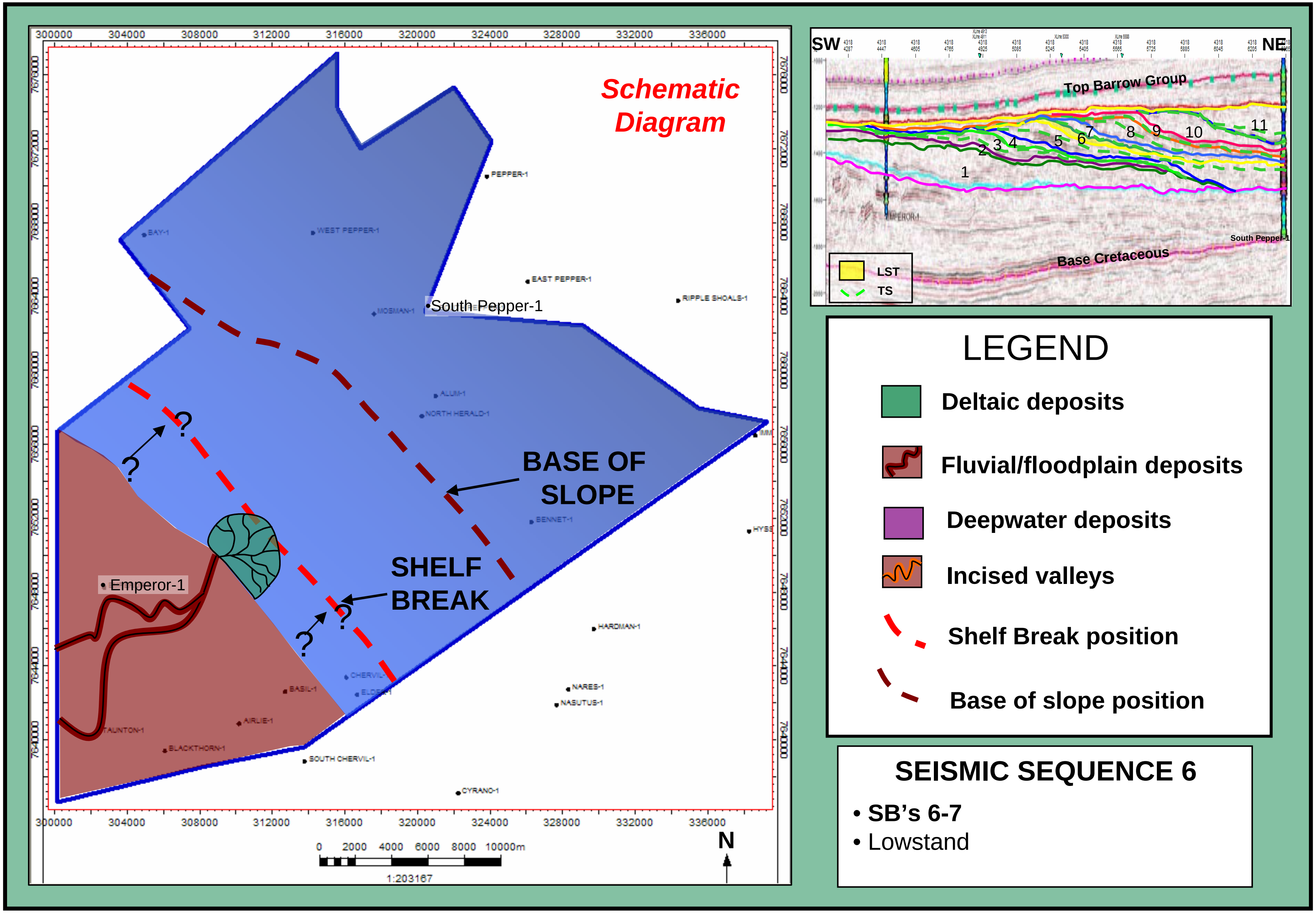


Figure 4.37 Seismic Sequence 6 schematic palaeo-geography map.

4.9 SEISMIC SEQUENCE 7

DESCRIPTION

4.9.1 KEY SURFACES

Seismic Sequence 7 is defined by key surfaces SB6 and sequence boundary 8 (SB8) (Figure 4.38). Both extend across most of the northeastern part of the study area, with a loss in seismic resolution due to faulting in the northeastern corner. The lower SB6 is onlapped by Seismic Sequence 6 and 7 sediments (SB6 is merged into SB7) (Figure 4.27). The upper SB8 is both onlapped and downlapped by overlying Seismic Sequence 8 sediments (Figure 4.39).

4.9.2 SEISMIC CHARACTER/SEISMIC FACIES

The seismic character of Seismic Sequence 7 consists of fair to moderately continuous parallel reflectors of moderate amplitude (Figure 4.38).

4.9.3 DISTRIBUTION AND EXTENT

Seismic Sequence 7 has a regional extent of approximately 58 km^2 within the study area (Figure 4.36 and 4.40), ranging in thickness from 0 to 110ms. This package displays thinning to the northeast and northwest. The second isochron

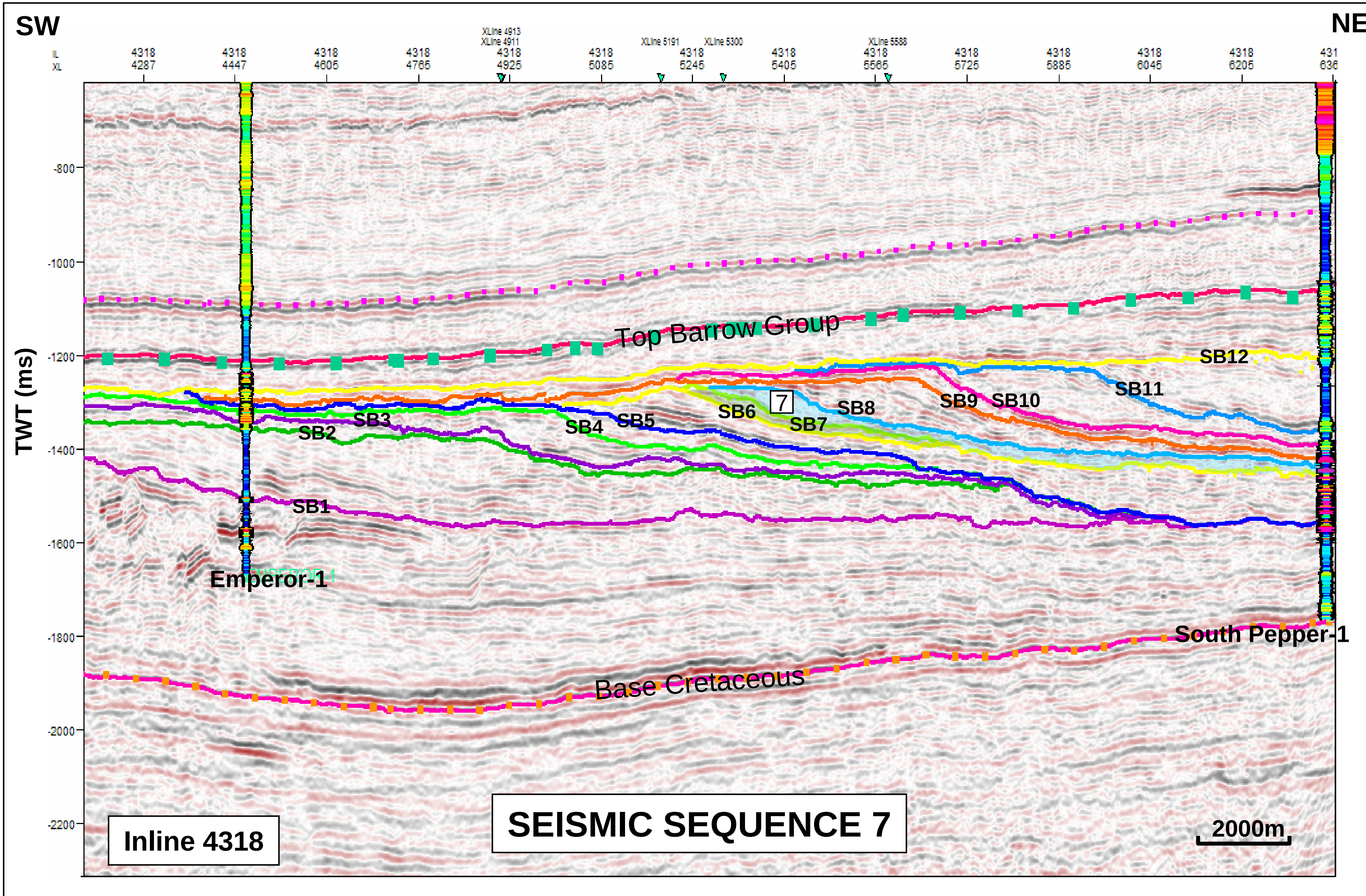
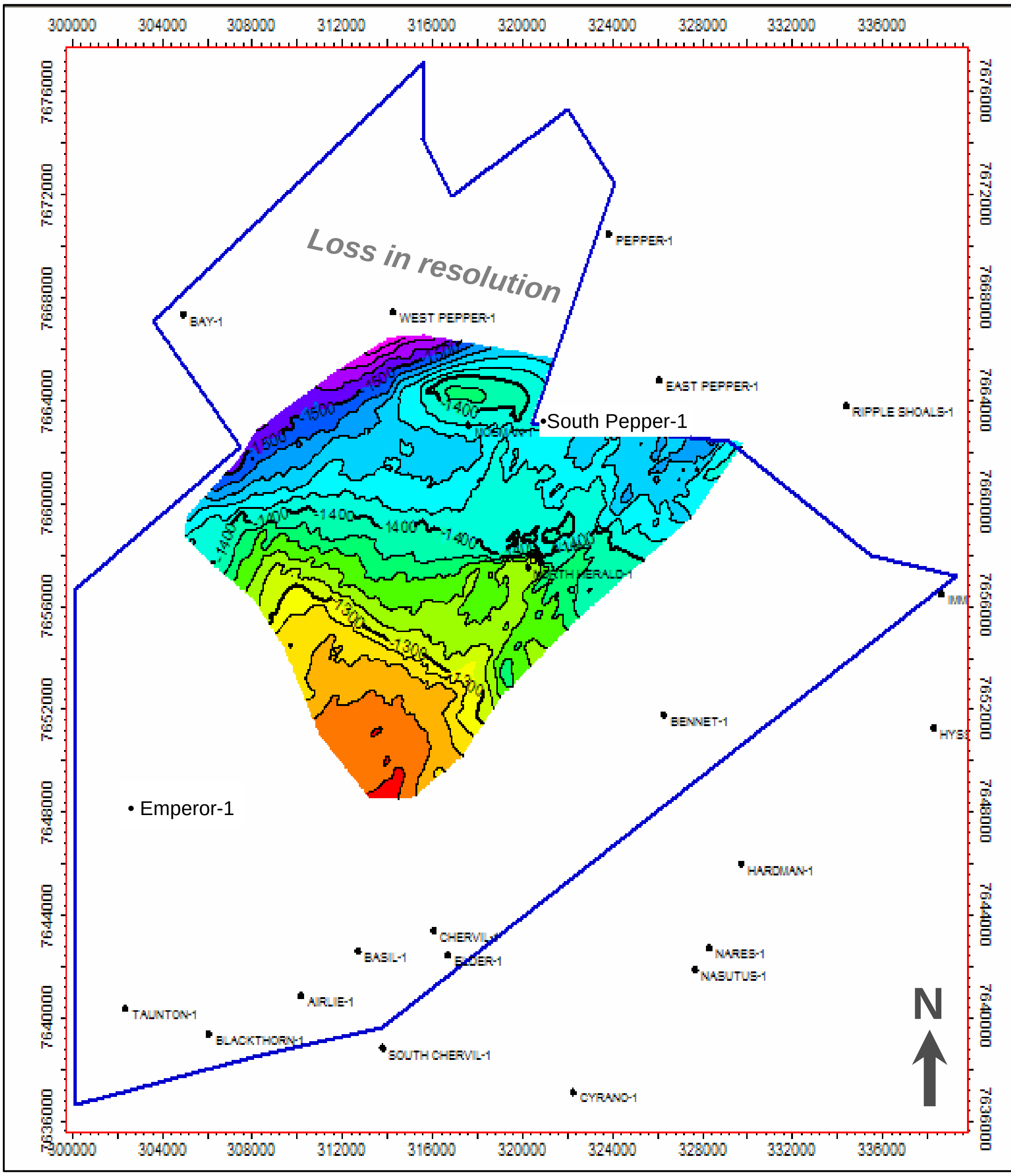


Figure 4.38 Seismic section displaying Seismic Sequence 7, bound by SB6 and SB8. Location of line indicated in Figure 4.3.



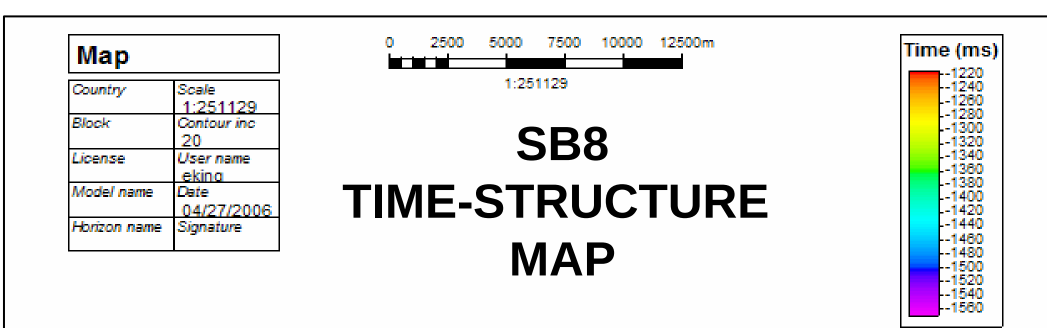


Figure 4.39 Sequence Boundary 8 Time-Structure Map.

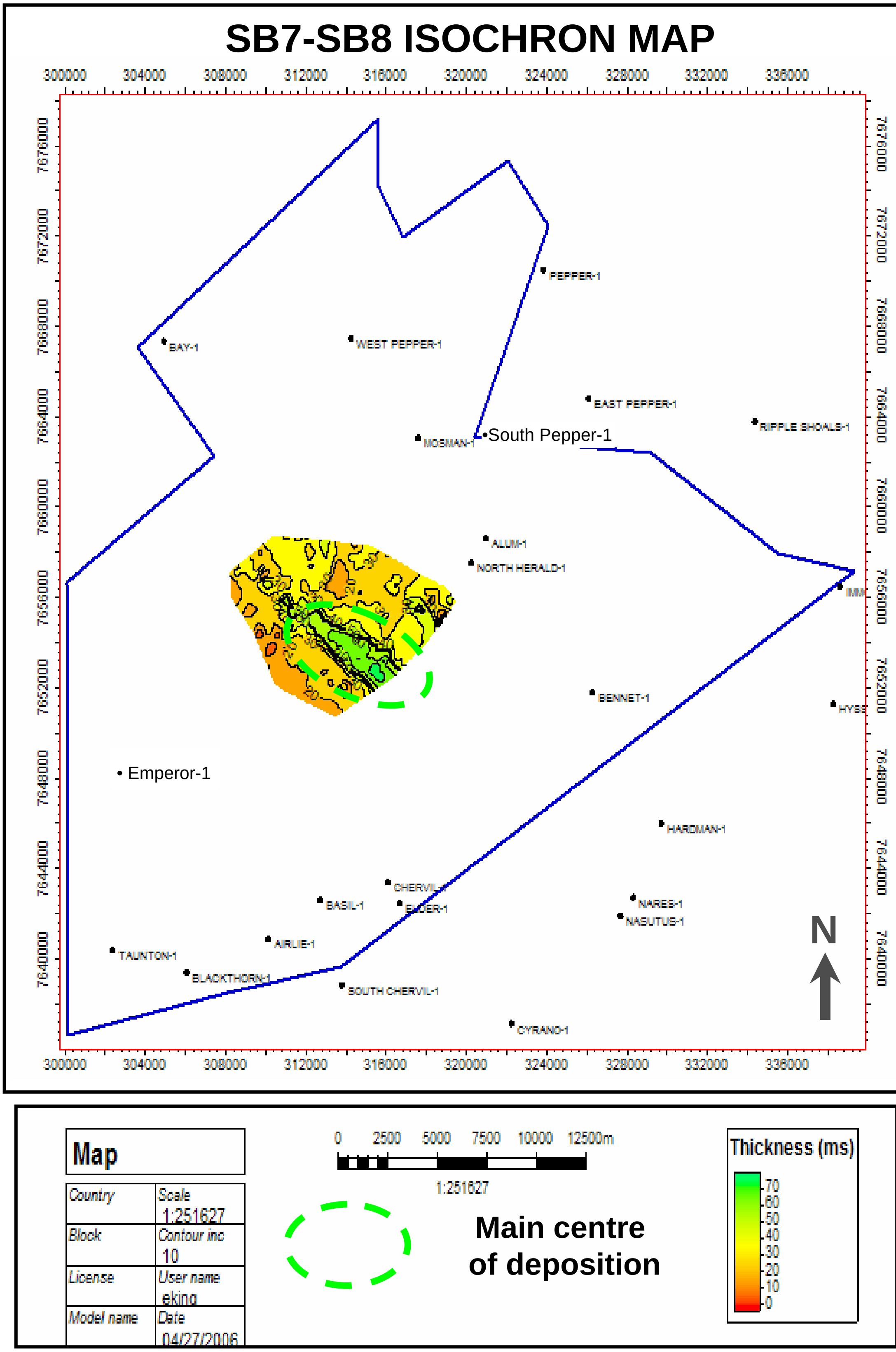


Figure 4.40 SB7 – SB8 Isochron Map, displaying one main centre of deposition during Seismic Sequence 7 deposition.

map displayed, includes both Seismic Sequence 6 and Seismic Sequence 7 sediments, due to both small areal extent and the combination of both better displaying their overall distribution (Figure 4.36).

4.9.4 DEPOCENTRE POSITION

The shelf depocentre of Seismic Sequence 7 is located just south of North Herald-1 (Figure 4.36). In comparison to the depocentre location of Seismic Sequence 6, this sequence has shifted slightly towards the north.

4.9.5 STACKING PATTERNS (seismic and well)

Seismic stacking patterns are mainly progradational at the base of the sequence and slightly aggradational towards the top of the package.

The log motif at South Pepper-1 displays two blocky aggrading stacked packages, separated by thick intermittent high gamma ray packages (Figure 4.41 and 4.42).

4.9.6 SLOPE ANGLE

Seismic Sequence 7 is not laterally extensive or of substantial thickness to calculate slope angle estimates.

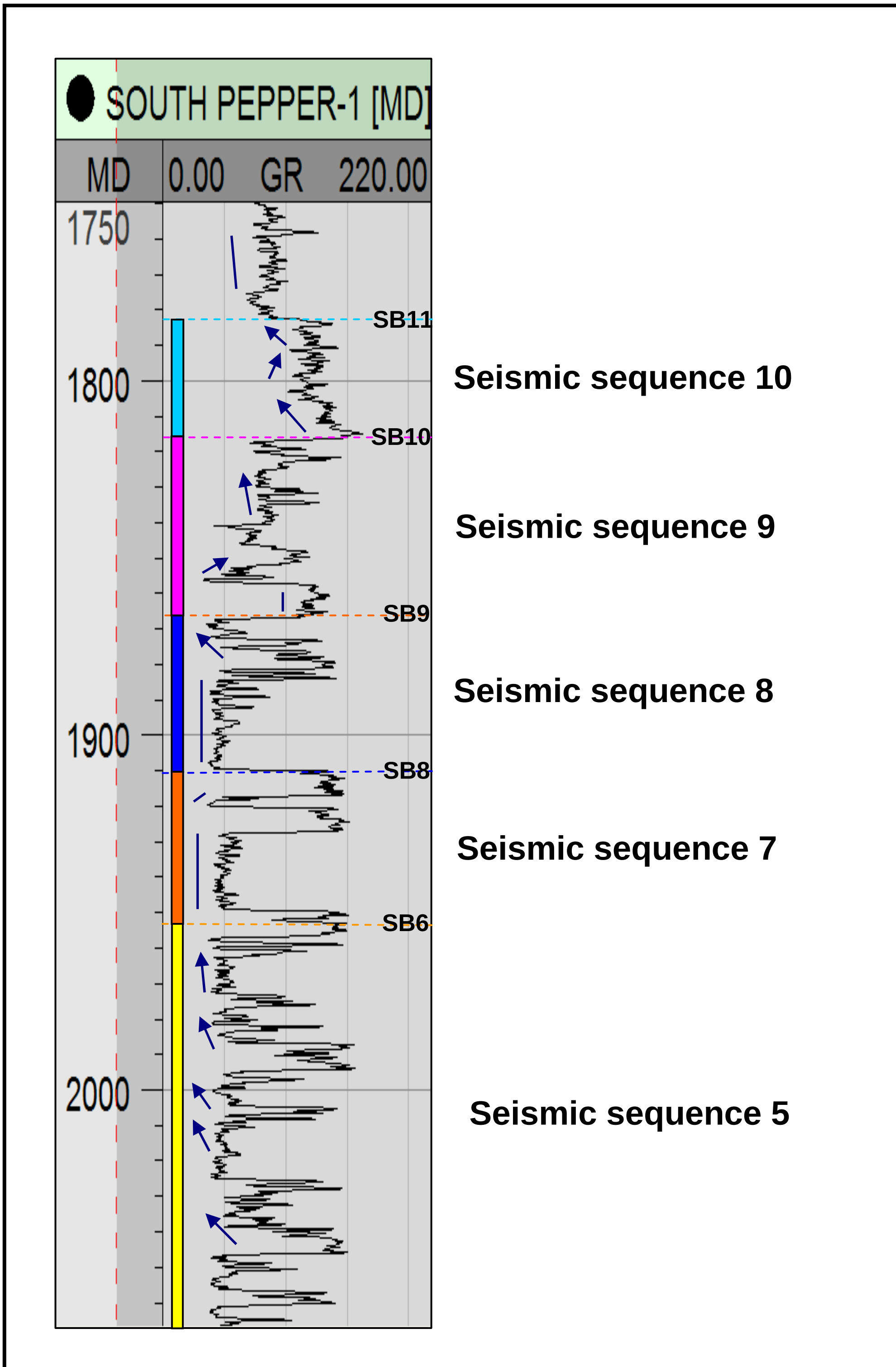


Figure 4.41 Gamma ray response at South Pepper-1 for seismic sequences 5, 7, 8, 9 and 10.

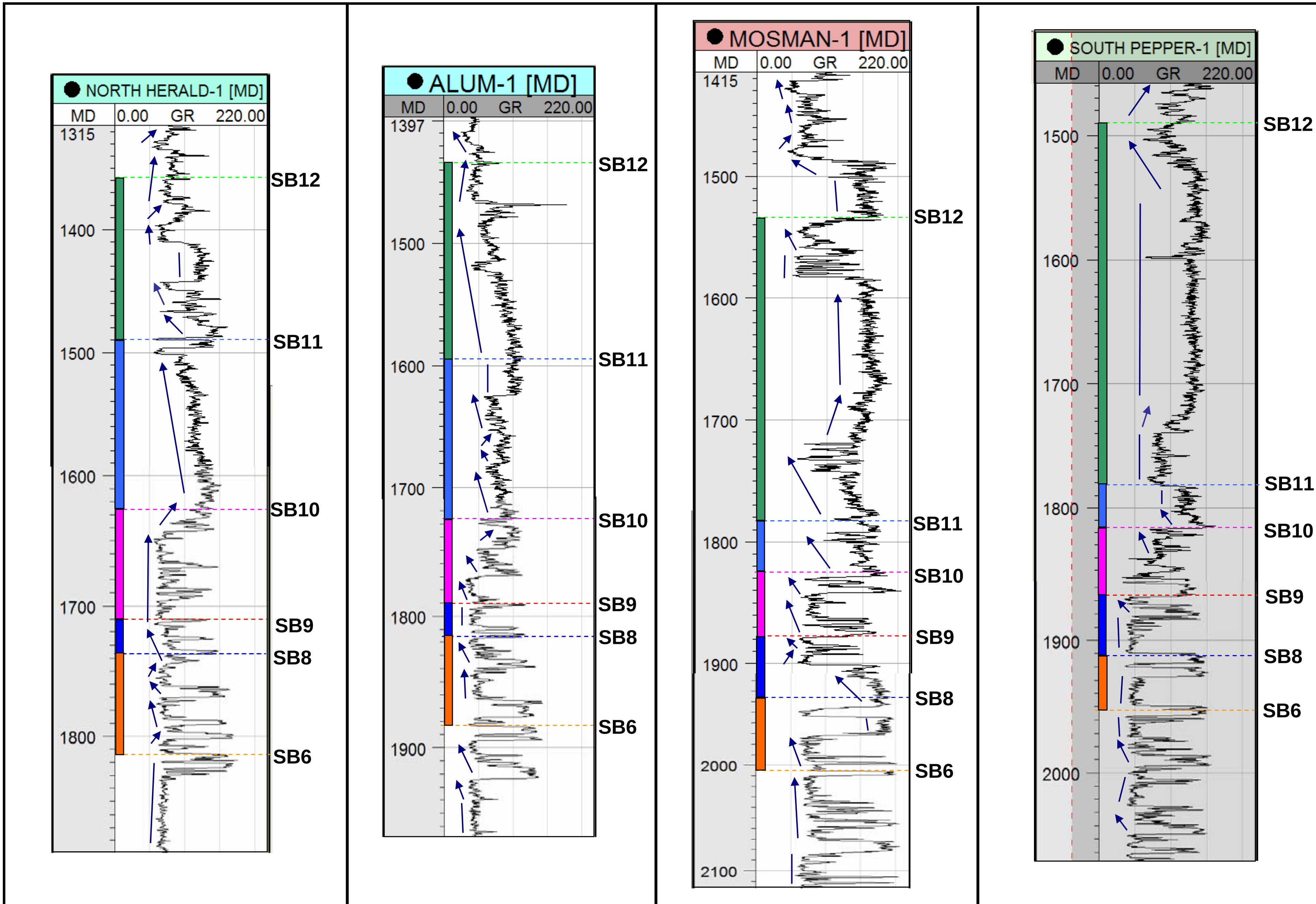


Figure 4.42 Gamma ray response at North Herald-1, Alum-1, Mosman-1 and South Pepper-1 for Seismic Sequence 6 through 11.

4.9.7 AGE

Based on the intersection in South Pepper-1, Seismic Sequence 7 spans the middle *B. reticulatum* dinocyst zone (Berriasian). The age of this package is approximated between 135–137Ma.

INTERPRETATION

4.9.8 SYSTEMS TRACTS

The systems tracts recognised for Seismic Sequence 7 are a TST overlain by a HST (Figure 4.8). This interpretation is made due to the initial back-stepping nature of the seismic reflectors viewed within the seismic sequence, (as is similar interpretations made by Walker, 1992), followed by apparent progradation. The TST is thin and the bulk of the sequence is dominated by prograding HST sediments that are bound by an upper sequence boundary (SB7).

4.9.9 RESERVOIR/SEAL POTENTIAL

Based on multiple well log responses, Seismic Sequence 7 is predicted to be more sand-prone (Figure 4.41 and 4.42). Seismic Sequence 7 is likely to have thick sandstones interbedded by shale layers comprising the package.

4.9.10 PALAEOGEOGRAPHIC RECONSTRUCTIONS

The seismic response for Seismic Sequence 7 displays of apparent backstepping of seismic reflectors onto the shelf, followed by progradation. Additionally, well log responses for Seismic Sequence 7 display thick blocky sandstones and occasional coarsening upwards successions. Seismic Sequence 7 is interpreted to have been deposited initially during a regression, where the backstepping of the shoreline and deposition of sediments occurred landwards. This was then followed by a sea-level rise and subsequent progragation and deposition of sediments in a dominantly fluvial and deltaic depositional environment (Walker, 1992) (Figure 4.43).

For a complete summary of Seismic Sequence 7, please refer to *Appendix 1.0*, Seismic Sequence 7 A3 summary sheet.

4.10 SEISMIC SEQUENCE 8

DESCRIPTION

4.10.1 KEY SURFACES

Seismic Sequence 8 is defined by key surfaces SB8 and sequence boundary 9 (SB9) (Figure 4.44). Both have been mapped across the northeastern part of the

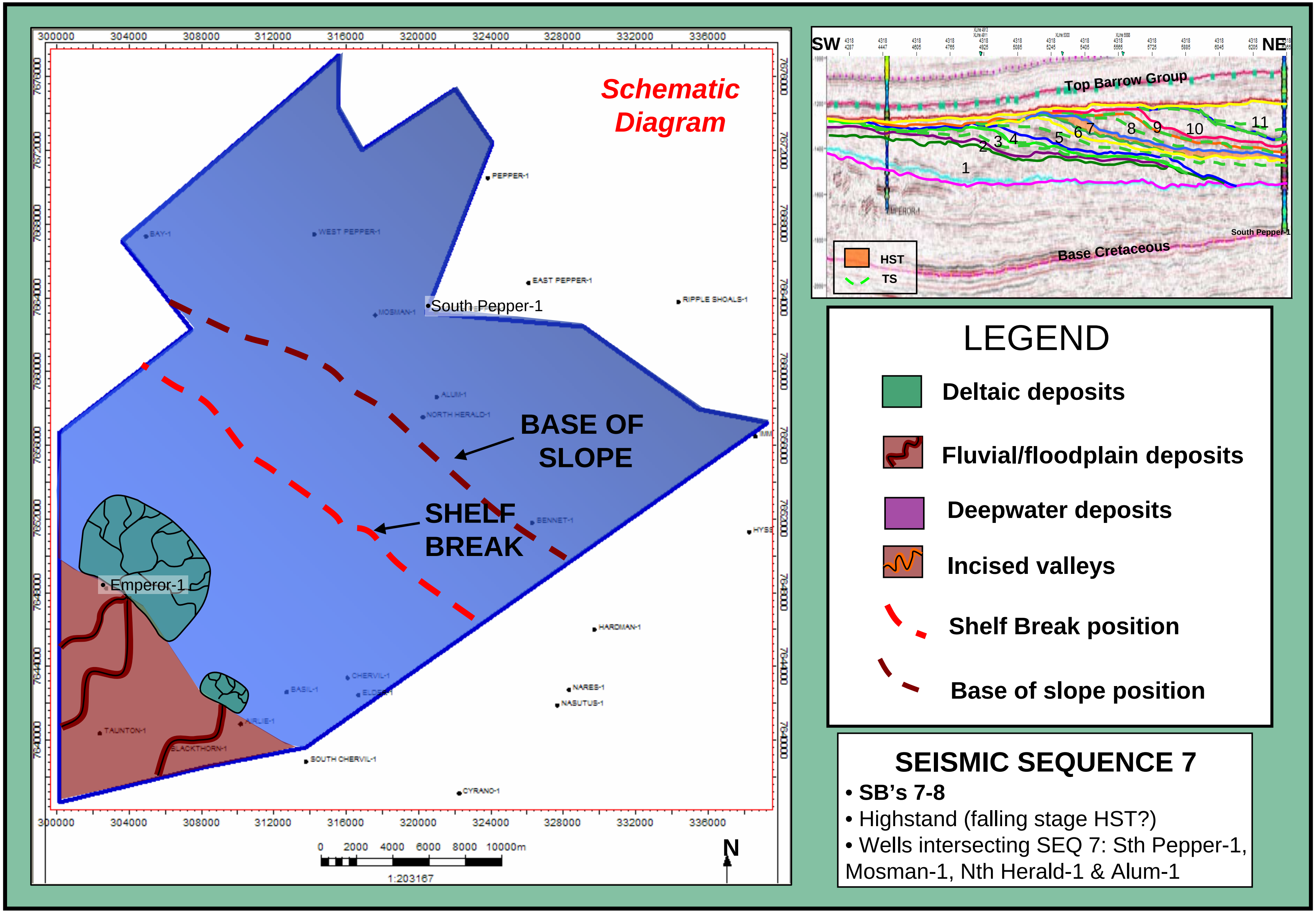


Figure 4.43 Seismic Sequence 7 schematic palaeo-geography map.

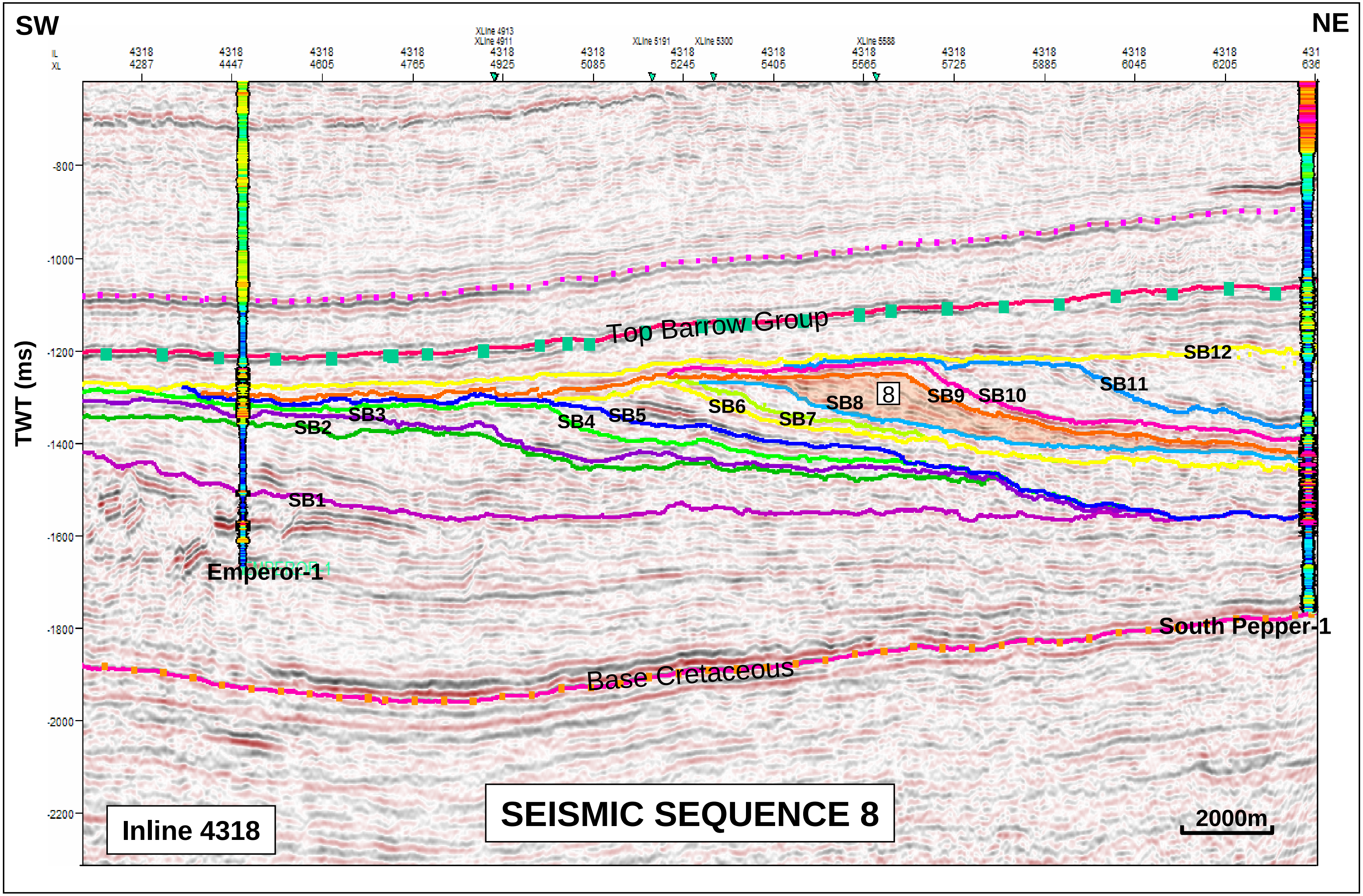


Figure 4.44 Seismic section displaying Seismic Sequence 8, bound by SB8 and SB9. Location of line indicated in Figure 4.3.

seismic survey area. The lower SB8 is both onlapped and downlapped by Seismic Sequence 8 sediments (Figure 4.39). The upper SB9 is onlapped by overlying Seismic Sequence 9 sediments (Figure 4.45). Other key surfaces present within this package include a TS and MFS, separating the lower LST and the upper HST, although is below seismic resolution.

4.10.2 SEISMIC CHARACTER/SEISMIC FACIES

The seismic character of Seismic Sequence 8 displays sigmoid to oblique layered reflections (Figure 4.44). Continuous reflections of moderate to high amplitude are characteristic of this sequence.

4.10.3 DISTRIBUTION AND EXTENT

Seismic Sequence 8 has a regional extent of 225 km^2 within the study area (Figure 4.46), ranging in thickness from 0 to 80 ms. The thickest part of this package is represented by an ‘oval-shaped’ wedge of sediment, thinning to the southwest, northeast and northwest (Figure 4.46).

4.10.4 DEPOCENTRE POSITION

The shelf depocentre position for Seismic Sequence 8 is located just west of North Herald-1 and Alum-1 (Figure 4.46). In comparison to the depocentre

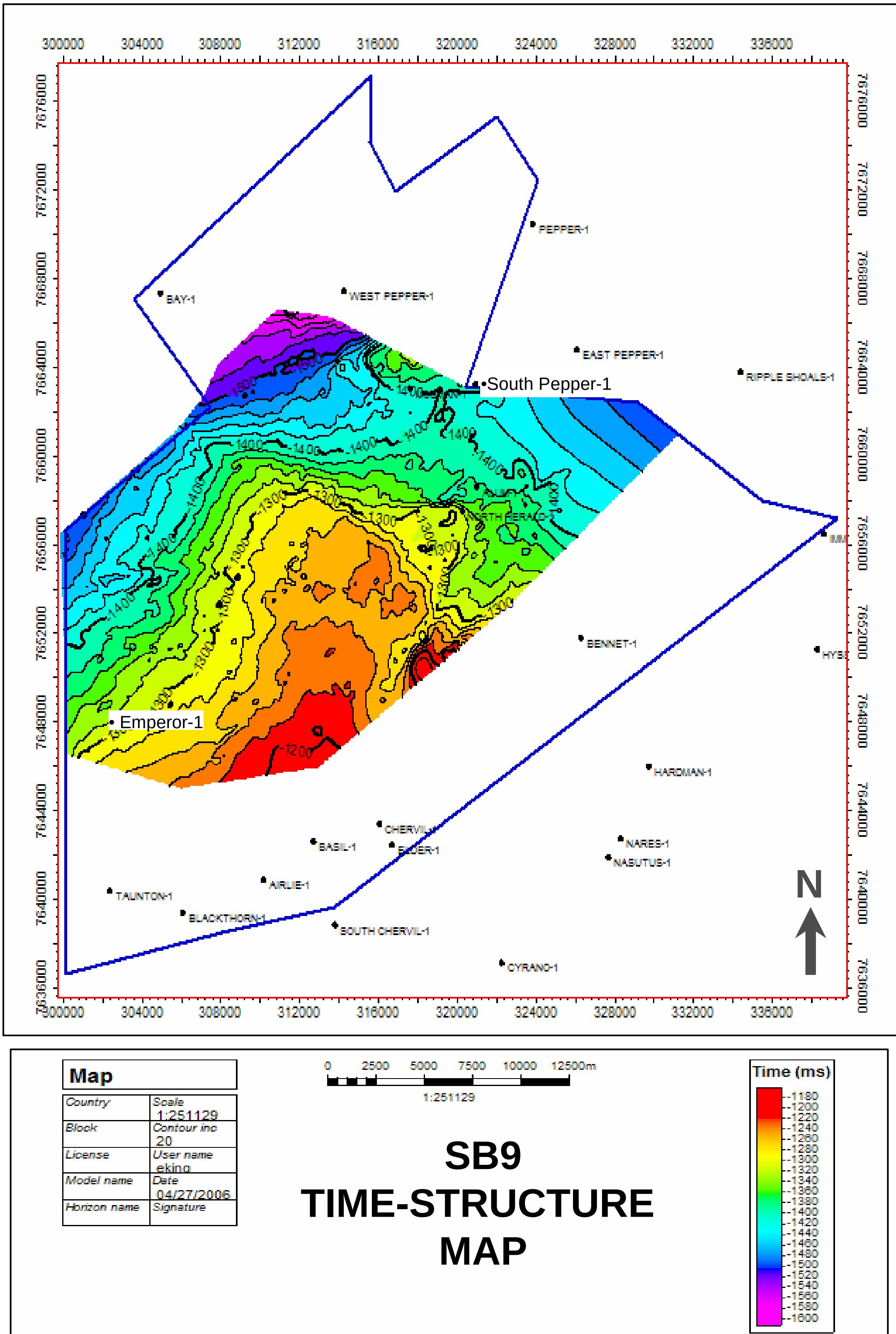


Figure 4.45 Sequence Boundary 9 Time-Structure Map.

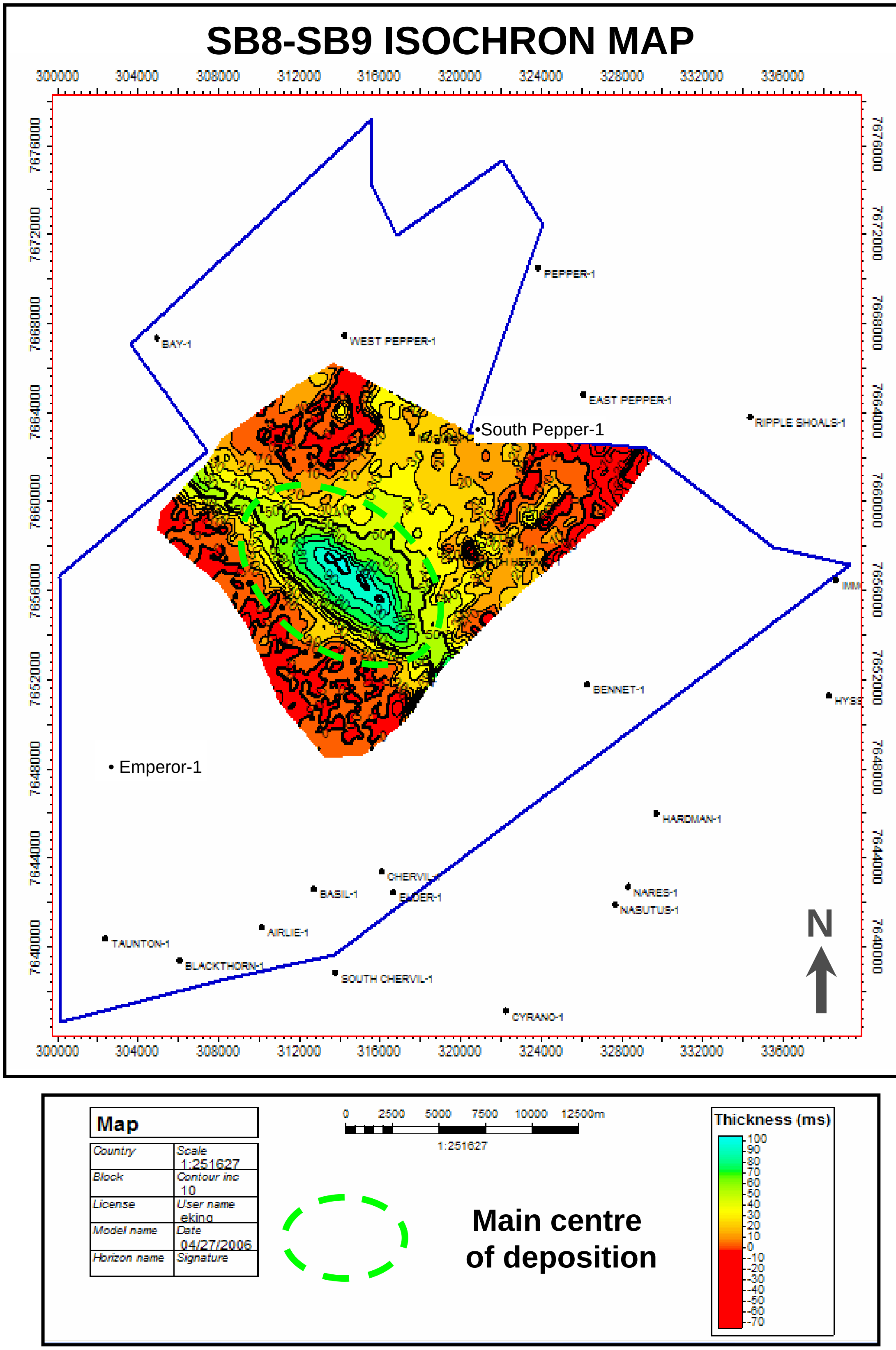


Figure 4.46 SB8 – SB9 Isochron Map, displaying one main centre of deposition during Seismic Sequence 8 deposition.

position for the previous seismic sequences, Seismic Sequence 8 has shifted both northward and eastwards.

4.10.5 STACKING PATTERNS (seismic and well)

The seismic stacking patterns for Seismic Sequence 8 display initially prograding clinoforms, followed by aggradation and slight retrogradation, lastly followed by progradation towards the top of the sequence.

The log motif of South Pepper-1 displays blocky aggradational sandstones towards the base of the sequence and a number of stacked prograding packages towards the top of the sequence (Figure 4.41 and 4.42).

4.10.6 SLOPE ANGLE

Seismic Sequence 8 comprises of sigmoid-oblique clinoforms (viewed on seismic) (Figure 4.44). The slope angle calculated for Seismic Sequence 8 was approximated at 3.8°. This average for the entire seismic package agrees with Poreski and Steel's (2003) estimate that shelf-margin clinoform slope gradients are between 3 and 6°.

4.10.7 AGE

Based on the intersection in South Pepper-1, Seismic Sequence 8 spans the middle *B. reticulatum* dinocyst zone (Berriasian ~*135-137Ma*).

INTERPRETATION

4.10.8 SYSTEMS TRACTS

The systems tracts recognised are a LST overlain by a TS/TST followed by a HST (Figure 4.8). The systems tracts are bounded by the lower SB8 and the upper SB9. The lower part of Seismic Sequence 8 displays excellent downlapping and onlapping features throughout the survey and is interpreted as a lowstand wedge which is relatively thick and extensive over the study area (similar methods of interpretation indicated by Labutis, 1994). While the overlying TST/TS is relatively thin. The bulk of the upper part of Seismic Sequence 8 is dominated by highstand sediments (with progradational features interpreted over the study area) (similar method to Porebski & Steel, 2003). Seismic Sequence 8 sediments are sand-prone as viewed in the South Pepper-1 gamma ray log response (Figure 4.41).

4.10.9 RESERVOIR/SEAL POTENTIAL

Based on numerous log responses, Seismic Sequence 8 is predicted to be more sand-prone (Figure 4.41 and 4.42). Seismic Sequence 8 is likely to have thick sandstones interbedded by shale layers comprising the package.

4.10.10 PALAEOGEOGRAPHIC RECONSTRUCTIONS

Seismic Sequence 8 is interpreted to be within an initially regressive phase followed by a transgressive phase (Figure 4.47 and 4.48). The major depositional environment present early in the sequence includes fluvial and deltaic environments, displaying the seaward movement of the shoreline toward the shelf break position (Figure 4.47). Deep water deposition is indicated by well log interpretations (Figure 4.41 and 4.42). The later part of the sequence infers a sea-level rise and progradation and aggradation of sediments along with backstepping of the shoreline landward (similar method seen to Porebski & Steel, 2003) (Figure 4.48). Fluvial, deltaic and shallow marine are the dominant depositional environments for Seismic Sequence 8.

For a complete summary of Seismic Sequence 8, please refer to *Appendix 1.0*, Seismic Sequence 8 A3 summary sheet.

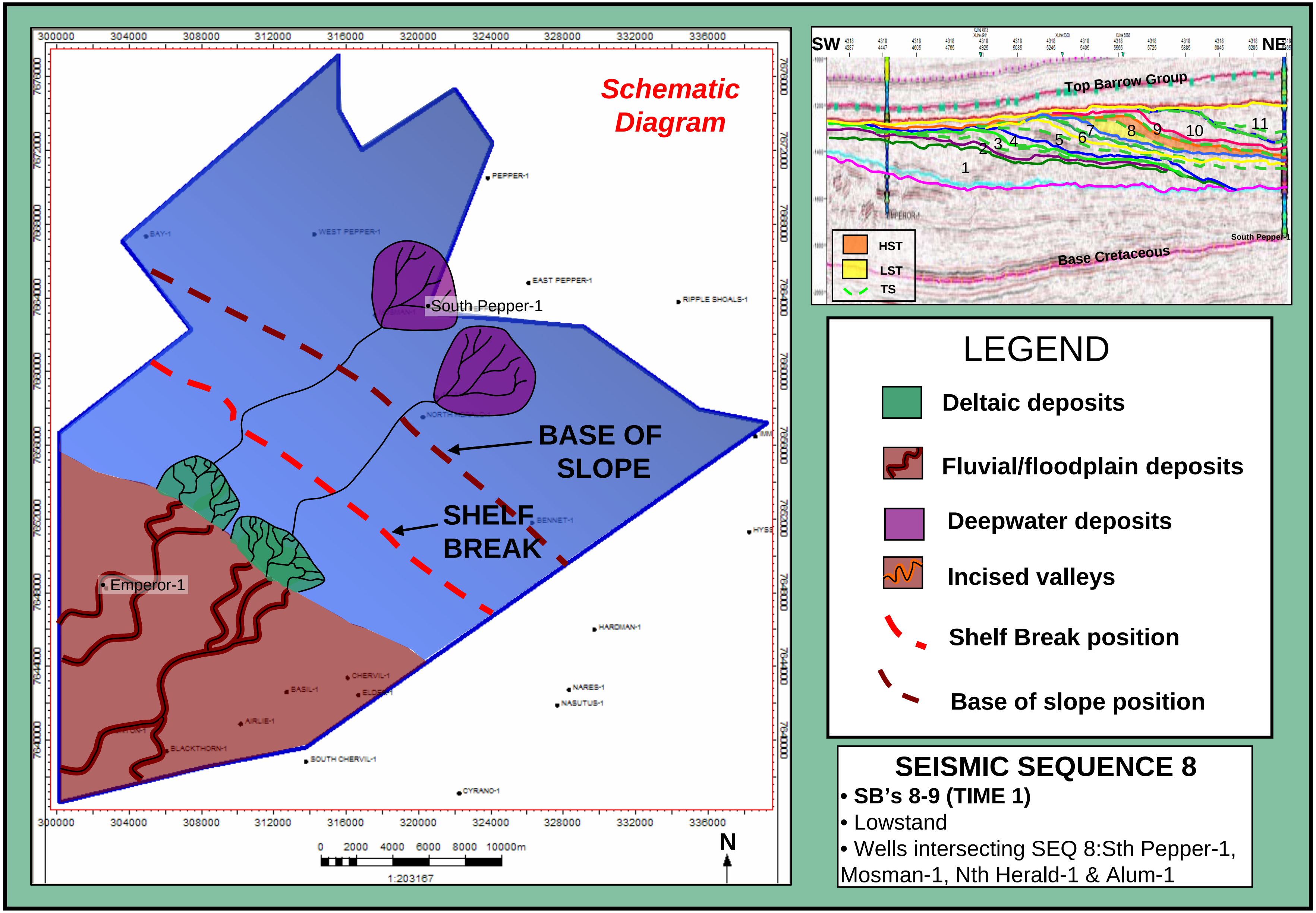


Figure 4.47 Seismic Sequence 8 schematic (early) palaeo-geography map.

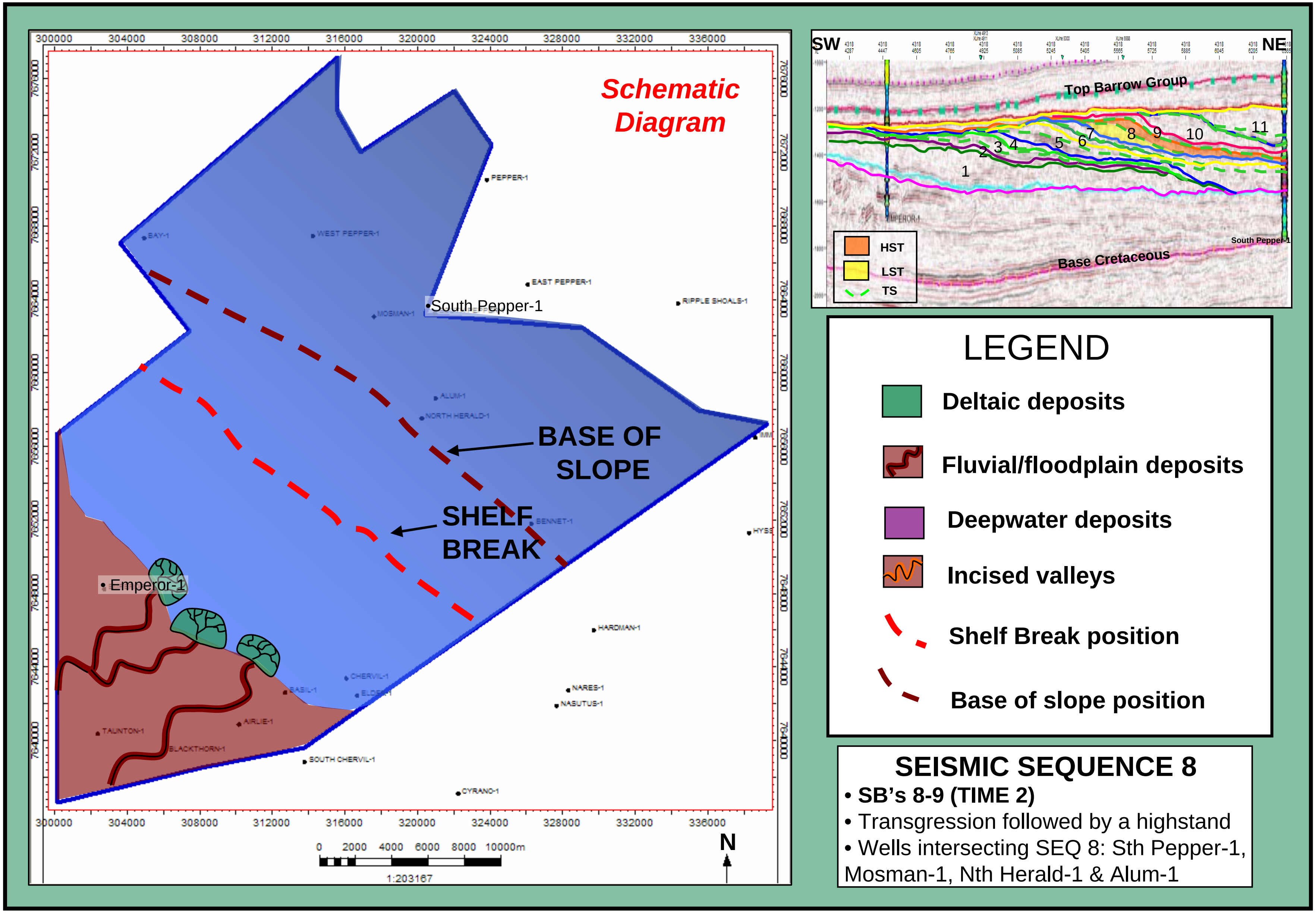


Figure 4.48 Seismic Sequence 8 schematic (late) palaeo-geography map.

4.11 SEISMIC SEQUENCE 9

DESCRIPTION

4.11.1 KEY SURFACES

Seismic Sequence 9 is defined by the lower SB9 and the upper sequence boundary 10 (SB10) (Figure 4.49). SB9 is identified by sediment from Seismic Sequence 9 onlapping onto the surface (Figure 4.45). The upper SB10 has both onlapping and downlapping of the overlying Sequence 10 sediments (Figure 4.50). The gamma ray response for this succession is generally high with intermittent blocky low gamma ray intervals (Figure 4.41 and 4.42).

4.11.2 SEISMIC CHARACTER/SEISMIC FACIES

The seismic character of Seismic Sequence 9 displays parallel to sub-parallel continuous reflectors with overall moderate amplitude (Figure 4.49).

4.11.3 DISTRIBUTION AND EXTENT

Seismic Sequence 9 has a regional extent of approximately 230 km^2 within the study area (Figure 4.51), ranging in thickness from 0 to 60 ms and thins substantially to the southwest and also to the northeast.

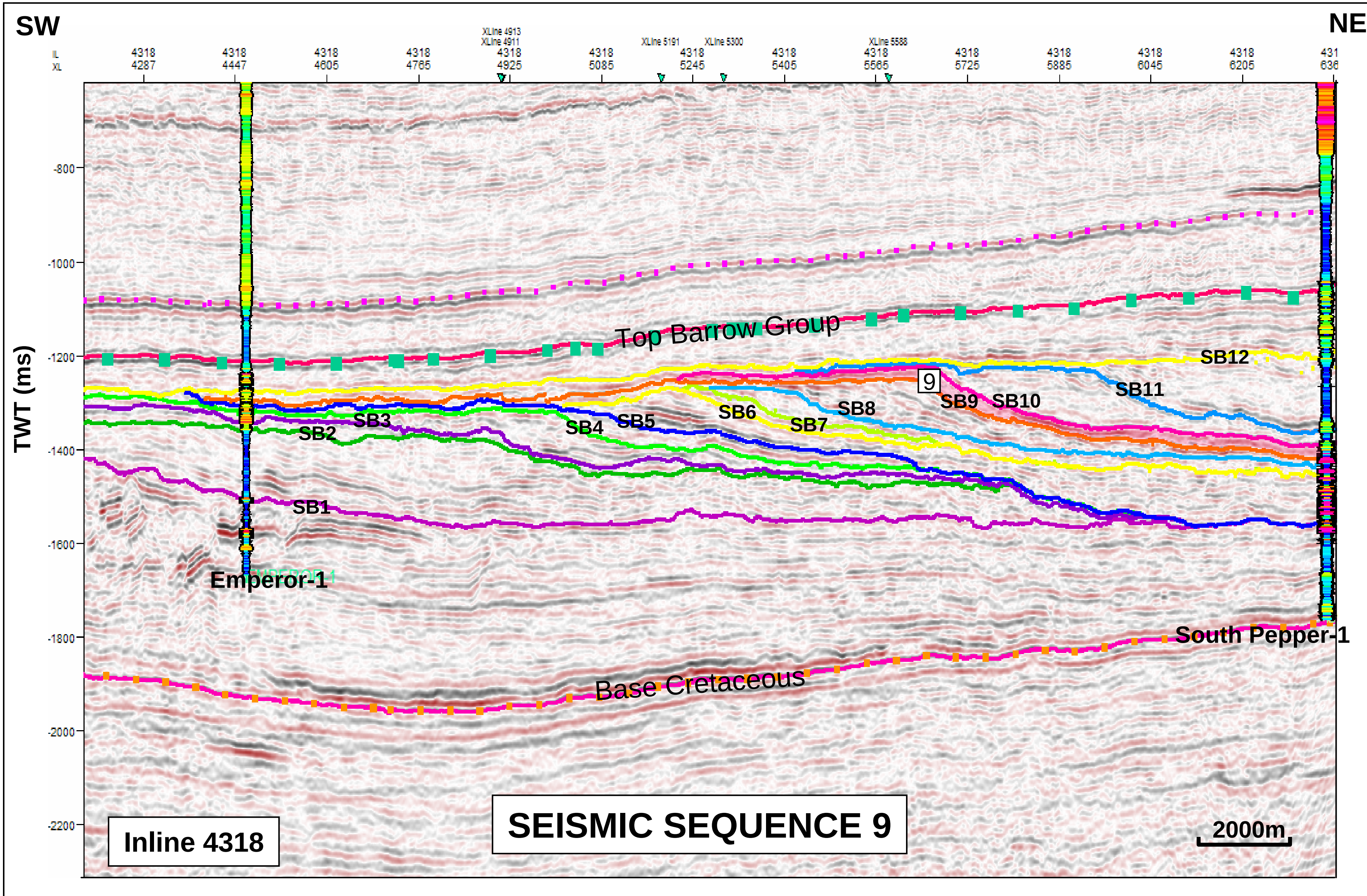


Figure 4.49 Seismic section displaying Seismic Sequence 9, bound by SB9 and SB10. Location of line indicated in Figure 4.3.

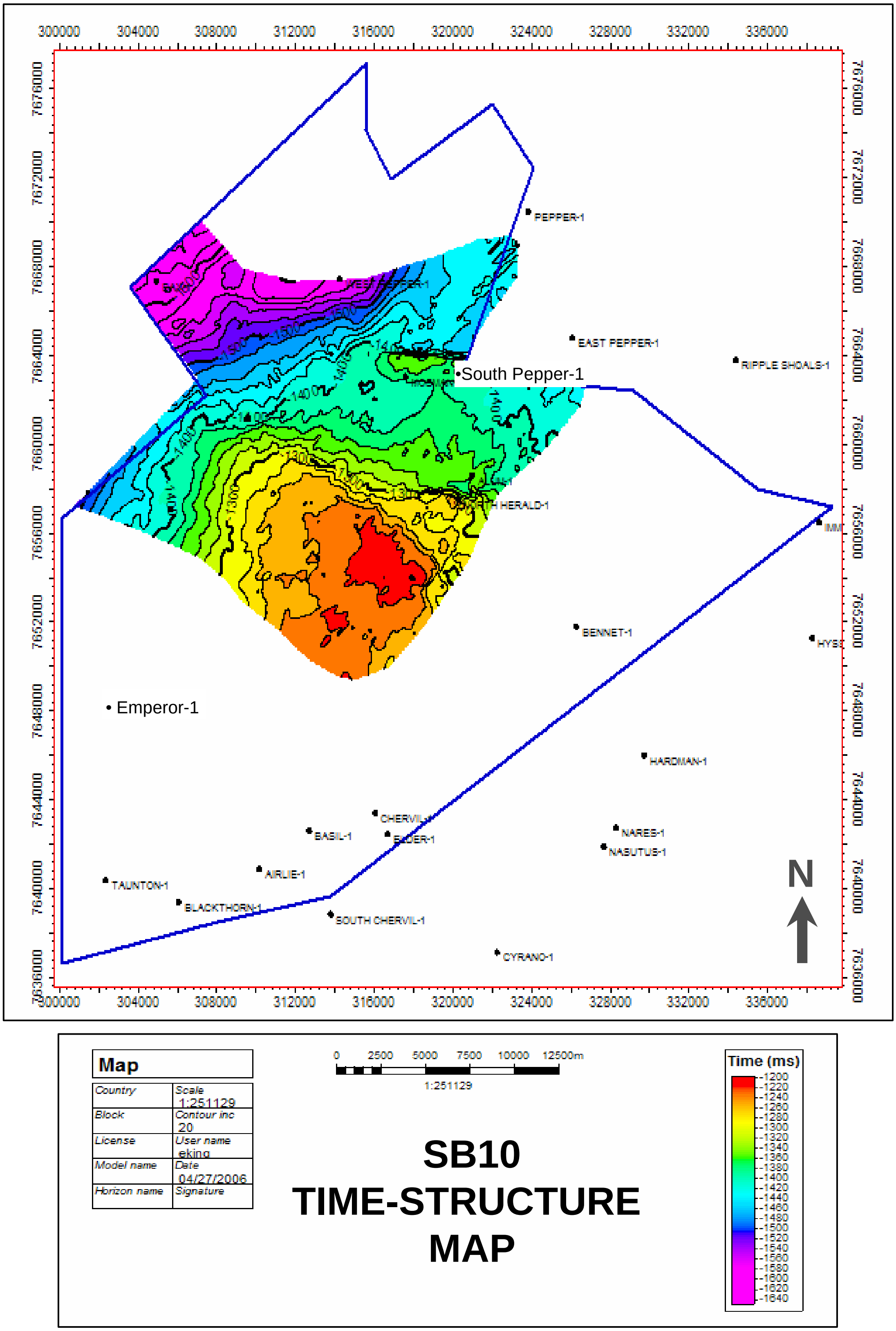


Figure 4.50 Sequence Boundary 10 Time-Structure Map.

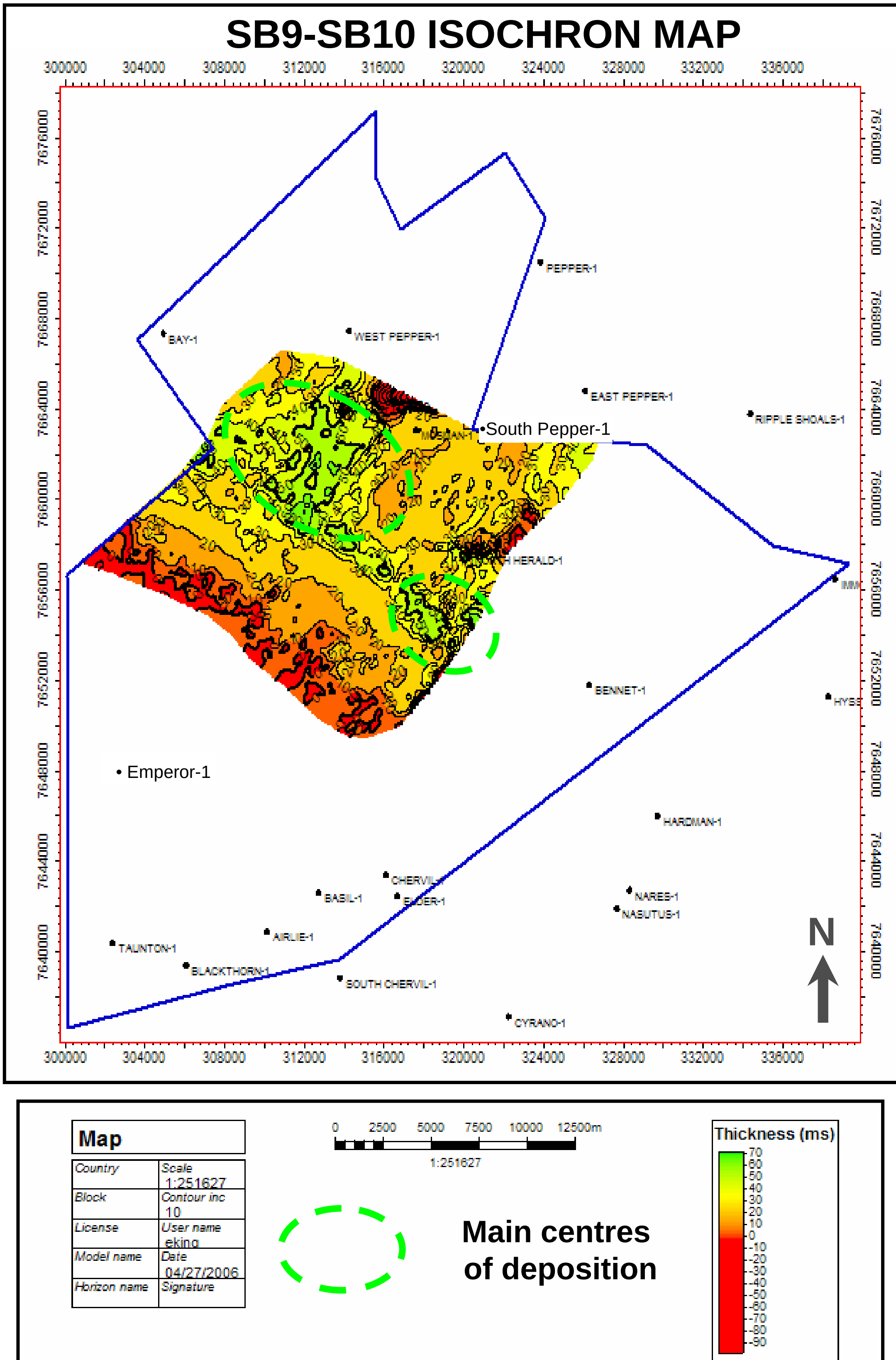


Figure 4.51 SB9 – SB10 Isochron Map, displaying two main centres of deposition during Seismic Sequence 9 deposition.

4.11.4 DEPOCENTRE POSITION

The shelf depocentre position of Seismic Sequence 9 is spilt into two (Figure 4.51). One depocentre is just south of Mosman-1 and other just south of North Herald-1 and Alum-1. These depocentres have both moved northwards and created two main depocentres, one to the northeast and the other northwest in comparison to the previous depocentre for Seismic Sequence 8.

4.11.5 STACKING PATTERNS (seismic and well)

The seismic stacking patterns of Seismic Sequence 9 across the study area are aggradational and progradational.

The log motif of South Pepper-1 displays prograding and retrograding stacking patterns followed by aggradational stacking patterns with maximum flooding surfaces occurring within the high gamma ray intervals (Figure 4.41 and 4.42).

4.11.6 SLOPE ANGLE

Seismic Sequence 9 comprises of sigmoid clinoforms (viewed on seismic) (Figure 4.49). The slope angle calculated for Seismic Sequence 9 was approximated at 3.8°. This average for the entire seismic package agrees with

Poreski and Steel's (2003) estimate that shelf-margin clinoform slope gradients are between 3 and 6°.

4.11.7 AGE

Based on the intersection in South Pepper-1 Seismic Sequence 9 spans the middle *B. reticulatum* dinocyst zone (Berriasian ~*135-137Ma*).

INTERPRETATION

4.11.8 SYSTEMS TRACTS

Seismic Sequence 9 seismically displays progradational and aggradational features throughout the bulk of the it's mapped extent and has an overall high net to gross (as viewed at South Pepper-1, Alum-1, Mosman-1 and North Herald-1) (Figure 4.42). Seismic Sequence 9 is thus interpreted to consist of a mainly regressive HST that is bounded by a lower TS (SB9) and an upper sequence boundary (SB10) (Figure 4.8).

4.11.9 RESERVOIR/SEAL POTENTIAL

Based on numerous log responses, the Seismic Sequence 9 package is predicted to be more sand-prone (Figure 4.41 and 4.42). Seismic Sequence 9 is likely to have thick sandstones interbedded with shale layers (Jennette et al., 2000).

4.11.10 PALAEOGEOGRAPHIC RECONSTRUCTIONS

Seismic Sequence 9 is interpreted to have been deposited during a transgression and highstand, with continued progradation and aggradation of sediments (Figure 4.52). Isochron maps infer the influence of two main sediment sources as there are two areas displaying thick Seismic Sequence 9 successions (potentially two separate river systems).

For a complete summary of Seismic Sequence 9, please refer to *Appendix 1.0*, Seismic Sequence 9 A3 summary sheet.

4.12 SEISMIC SEQUENCE 10

DESCRIPTION

4.12.1 KEY SURFACES

Seismic Sequence 10 is defined by key surfaces SB10 and sequence boundary 11 (SB11) (Figure 4.53). The lower SB10 corresponds to both onlapping and

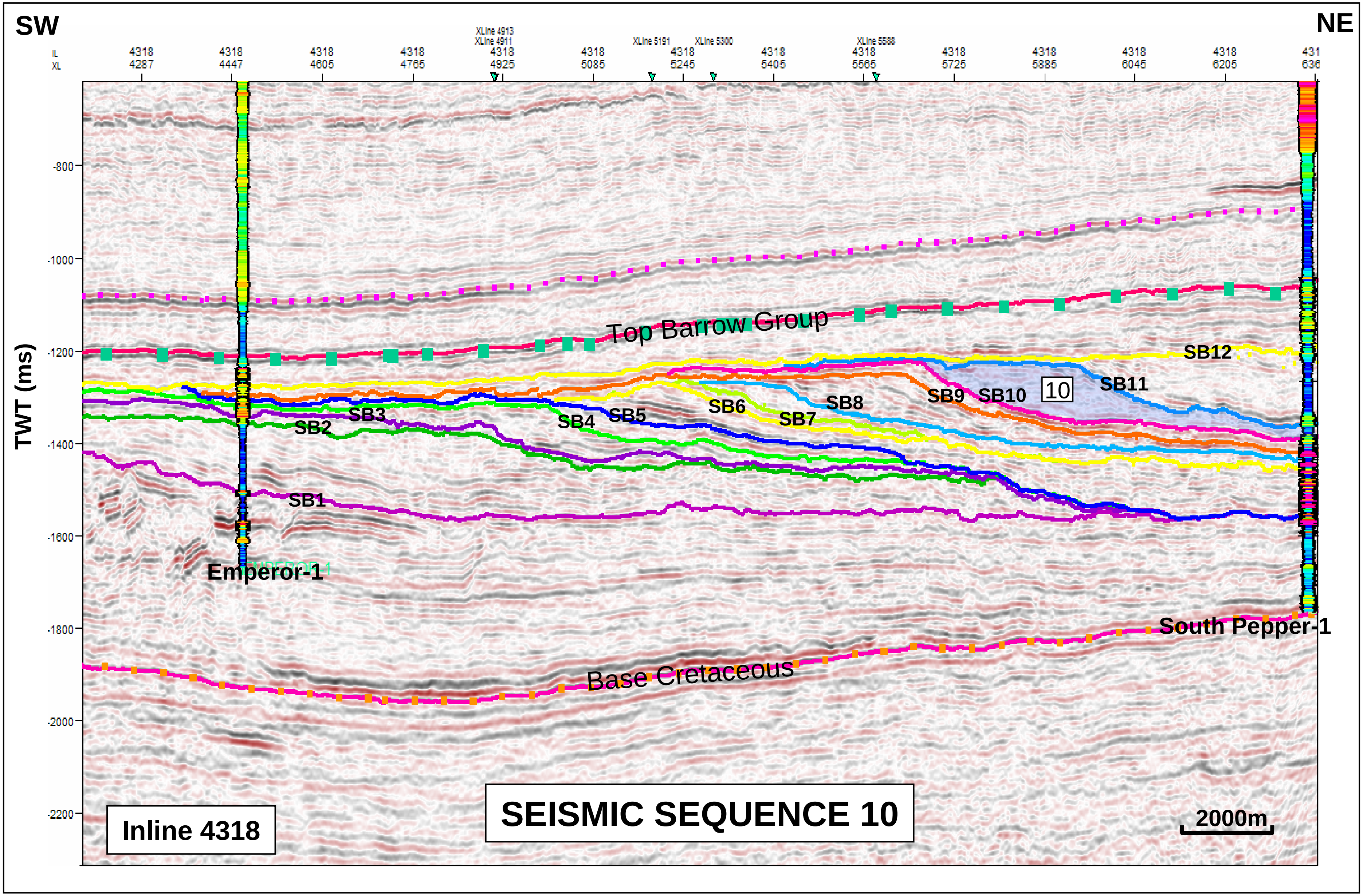


Figure 4.53 Seismic section displaying Seismic Sequence 10, bound by SB10 and SB11. Location of line indicated in Figure 4.3.

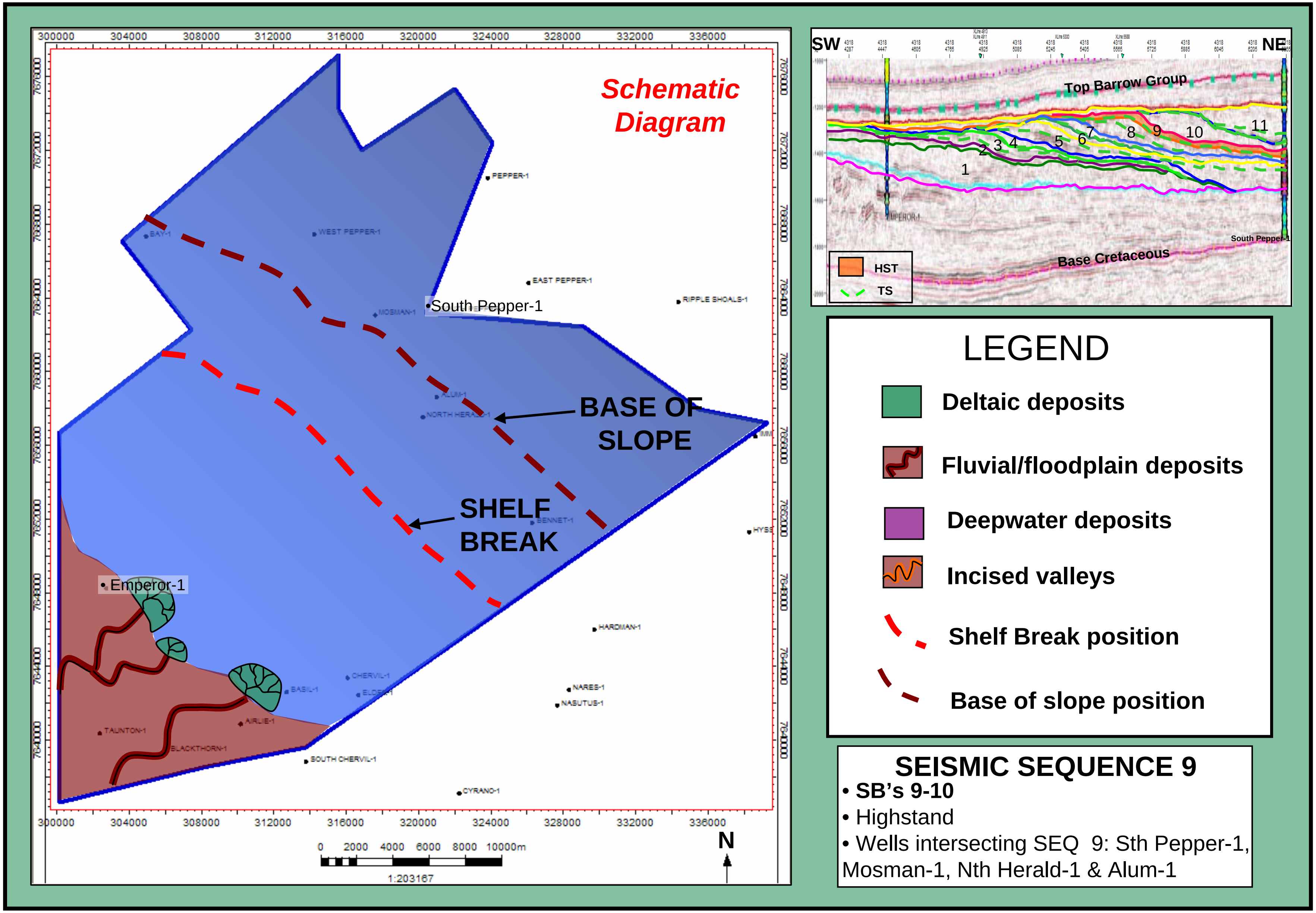


Figure 4.52 Seismic Sequence 9 schematic palaeo-geography map.

downlapping of sediments from within Sequence 10 (Figure 4.50). The upper SB11 is onlapped by overlying Sequence 11 sediments (Figure 4.54).

4.12.2 SEISMIC CHARACTER/SEISMIC FACIES

The seismic facies of Seismic Sequence 10 is represented by both sigmoid-oblique layered reflections and continuous to discontinuous reflections. The reflectors range from low to moderate amplitude (Figure 4.53).

4.12.3 DISTRIBUTION AND EXTENT

Seismic Sequence 10 has a regional extent of 143 km^2 within the study area (Figure 4.55), ranging in thickness from 0 to 110ms. The package shows a consistent thickening to the northeast, which may imply some structural (shelf collapse) influenced deposition.

4.12.4 DEPOCENTRE POSITION

The shelf depocentre of Seismic Sequence 10 is located near North Herald-1, Alum-1 and Mosman-1 well locations and displays one large, thick elongate depocentre (Figure 4.55). This depocentre represents a consistent thickness of Seismic Sequence 10 sediments over a large area. The depocentre has shifted further towards the northeast in comparison to the previous sequence and is

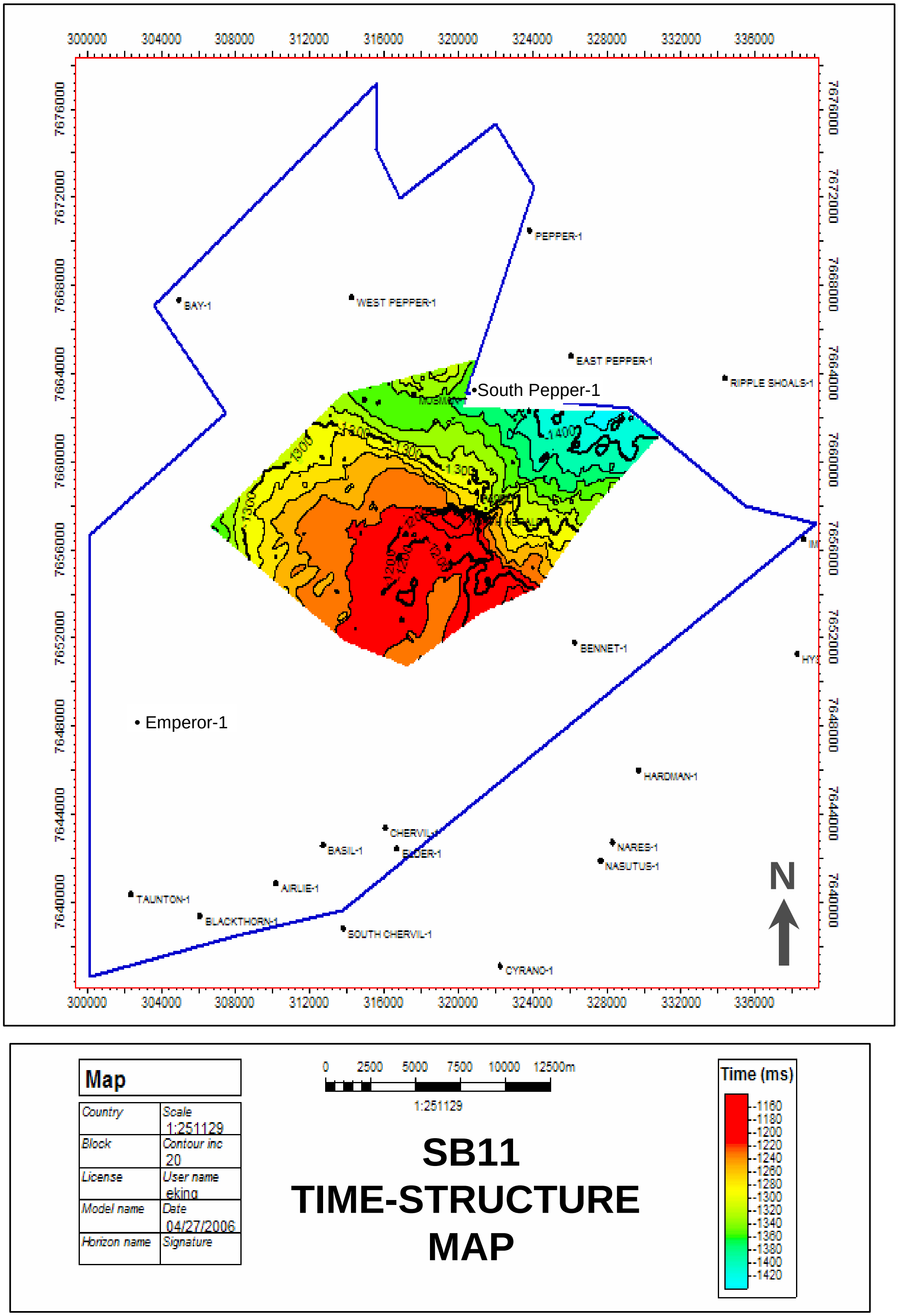


Figure 4.54 Sequence Boundary 11 Time-Structure Map.

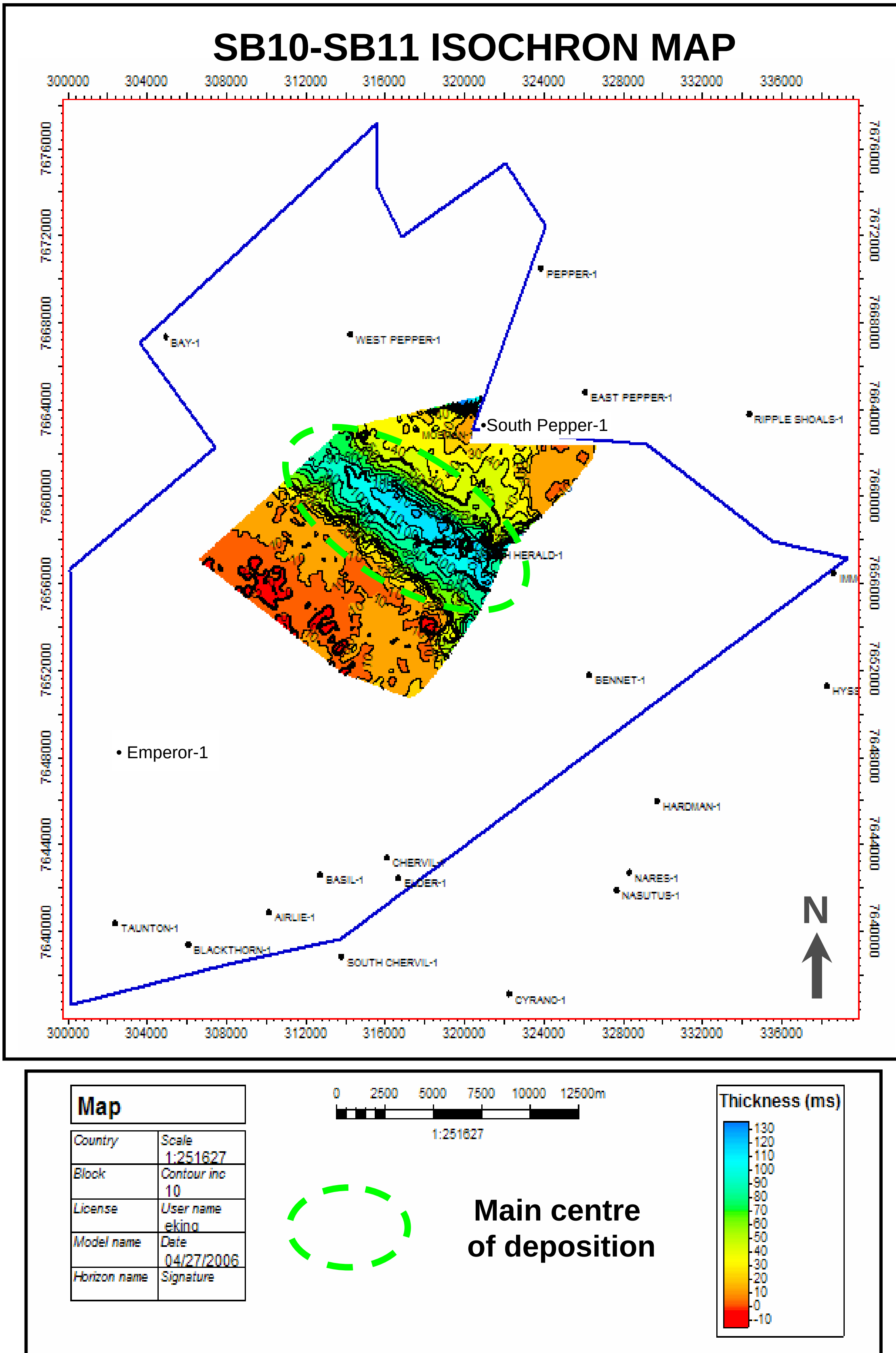


Figure 4.55 SB10 – SB11 Isochron Map, displaying one main centre of deposition during Seismic Sequence 10 deposition, formed potentially via shelf collapse.

likely to have been influenced by some structural processes such as shelf collapse.

4.12.5 STACKING PATTERNS (seismic and well)

The seismic stacking patterns for Seismic Sequence 10 are mainly progradational across the study area.

The log motifs of South Pepper-1, Alum-1, North Herald-1 and Mosman-1 display a number of prograding and retrograding packages with intermittent aggradational packages, and minor progradation at the top of the sequence (Figure 4.41 and 4.42). Maximum flooding surfaces are represented by zones of high gamma ray readings (Figure 4.41 and 4.42).

4.12.6 SLOPE ANGLE

Seismic Sequence 10 comprises of sigmoid-oblique clinoforms (viewed on seismic) (Figure 4.53). The slope angle calculated for Seismic Sequence 10 was approximated at 4.2°. This average for the entire seismic package agrees with Poreski and Steel's (2003) estimate that shelf-margin clinoform slope gradients are between 3 and 6°.

4.12.7 AGE

Based on the intersection in South Pepper-1 Seismic Sequence 10 spans the middle *B. reticulatum* dinocyst zone (Berriasian ~*135-137Ma*).

INTERPRETATION

4.12.8 SYSTEMS TRACTS

Seismic Sequence 10 seismically displays onlapping and downlapping features (interpreted extensively throughout the study area), indicative of a prograding lowstand wedge (Labutis, 1994). Seismic Sequence 10 is interpreted as a LST bounded by the lower SB10 and an upper TS/SB11 (Figure 4.8). The lowstand wedge is relatively thick and consistently interpreted and present over the bulk of the study area. Seismic Sequence 10 sediments display either a slope collapse due to large sediment supply and following instability or shelf collapse at a larger scale due to tectonics in the region at the time of deposition, due to the consistent thickness across the study area for the entire sequence.

4.12.9 RESERVOIR/SEAL POTENTIAL

Based on numerous log responses, Seismic Sequence 10 is predicted to be more mud-prone (Figure 4.41 and 4.42). Seismic Sequence 10 is likely to have thick shale intervals interbedded by sandstone layers comprising the package.

4.12.10 PALAEOGEOGRAPHIC RECONSTRUCTIONS

Seismic Sequence 10 is interpreted as a lowstand wedge within a major regressive phase (Figure 4.56). The palaeo-shoreline is interpreted to be near or at the shelf-break edge with incised valleys feeding to the shelf edge and depositing large amounts of sediment via the growth of deltas on to the slope/base of slope (Porebski & Steel, 2003). Associated deeper water systems are interpreted to have also been present during the time of deposition as indicated by palaeo shelf-break, slope and base of slope interpretations (Walker, 1992).

For a complete summary of Seismic Sequence 10, please refer to *Appendix 1.0*, Seismic Sequence 10 A3 summary sheet.

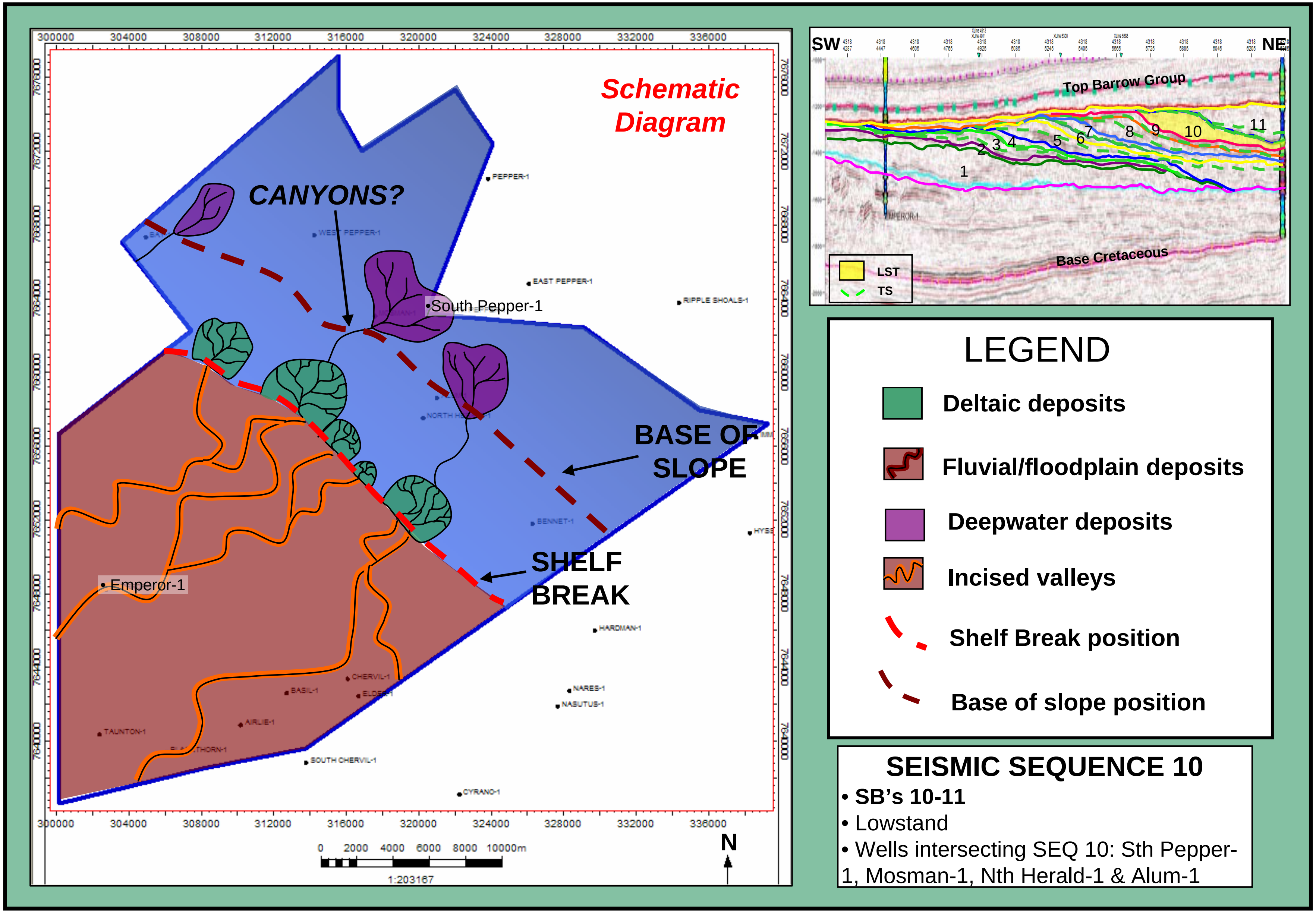


Figure 4.56 Seismic Sequence 10 schematic palaeo-geography map.

4.13 SEISMIC SEQUENCE 11

DESCRIPTION

4.13.1 KEY SURFACES

Seismic Sequence 11 is defined by SB11 and the regionally extensive sequence boundary 12 (SB12) (Figure 4.57). The lower SB11 is onlapped by Seismic Sequence 11 sediments and corresponds to a sharp base of blocky sand, indicated by the gamma ray log response at South Pepper-1 (Figure 4.58). The upper SB12 displays sediments toplapping this surface and has been mapped extensively over the study area (Figure 4.59). Also present within this sequence is a MFS, TS, which are identifiable on the South Pepper-1 wireline log responses, and which displays the transition from LST deposition to HST deposition (Figure 4.58).

4.13.2 SEISMIC CHARACTER/SEISMIC FACIES

The seismic character of Sequence 11 is represented by continuous to discontinuous, parallel to sub-parallel reflectors (Figure 4.57). The reflectors range from low to high amplitude, with the basal part of the sequence represented by higher amplitudes, in comparison to the low to moderate more transparent facies towards the upper part of the sequence (Figure 4.57).

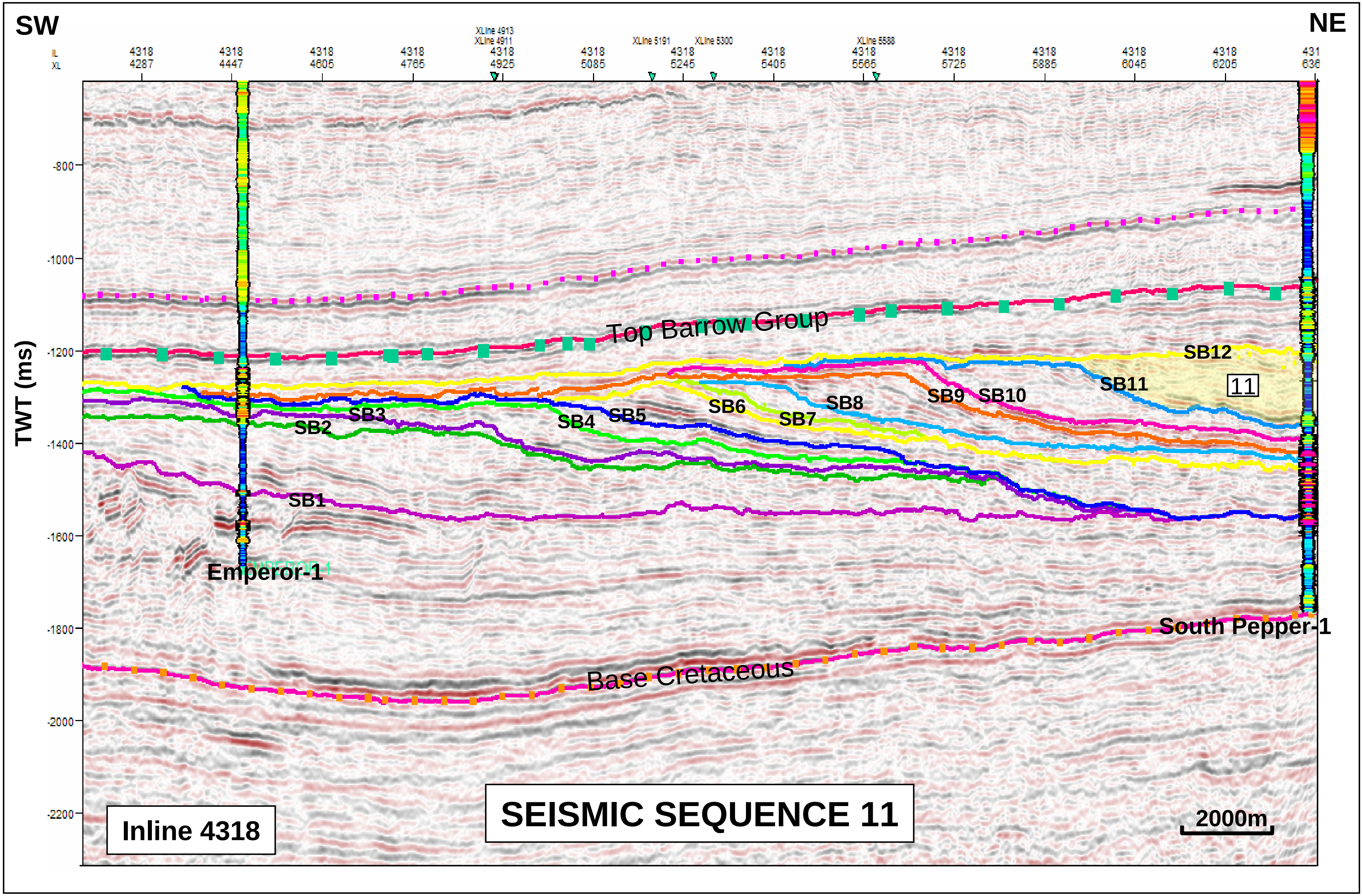


Figure 4.57 Seismic section displaying Seismic Sequence 11, bound by SB11 and SB12. Location of line indicated in Figure 4.3.

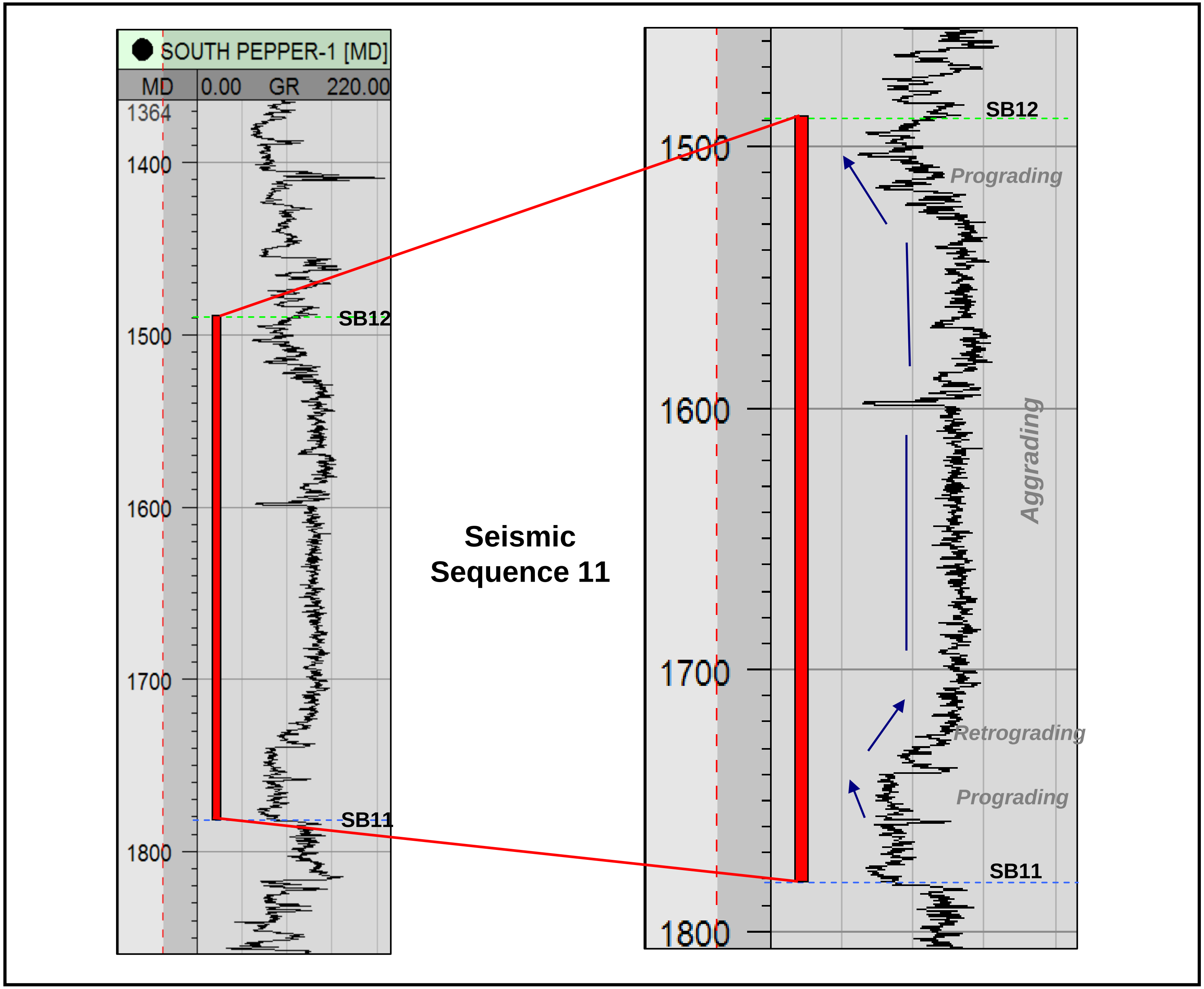


Figure 4.58 Gamma ray response at South Pepper-1 for Seismic Sequence 11.

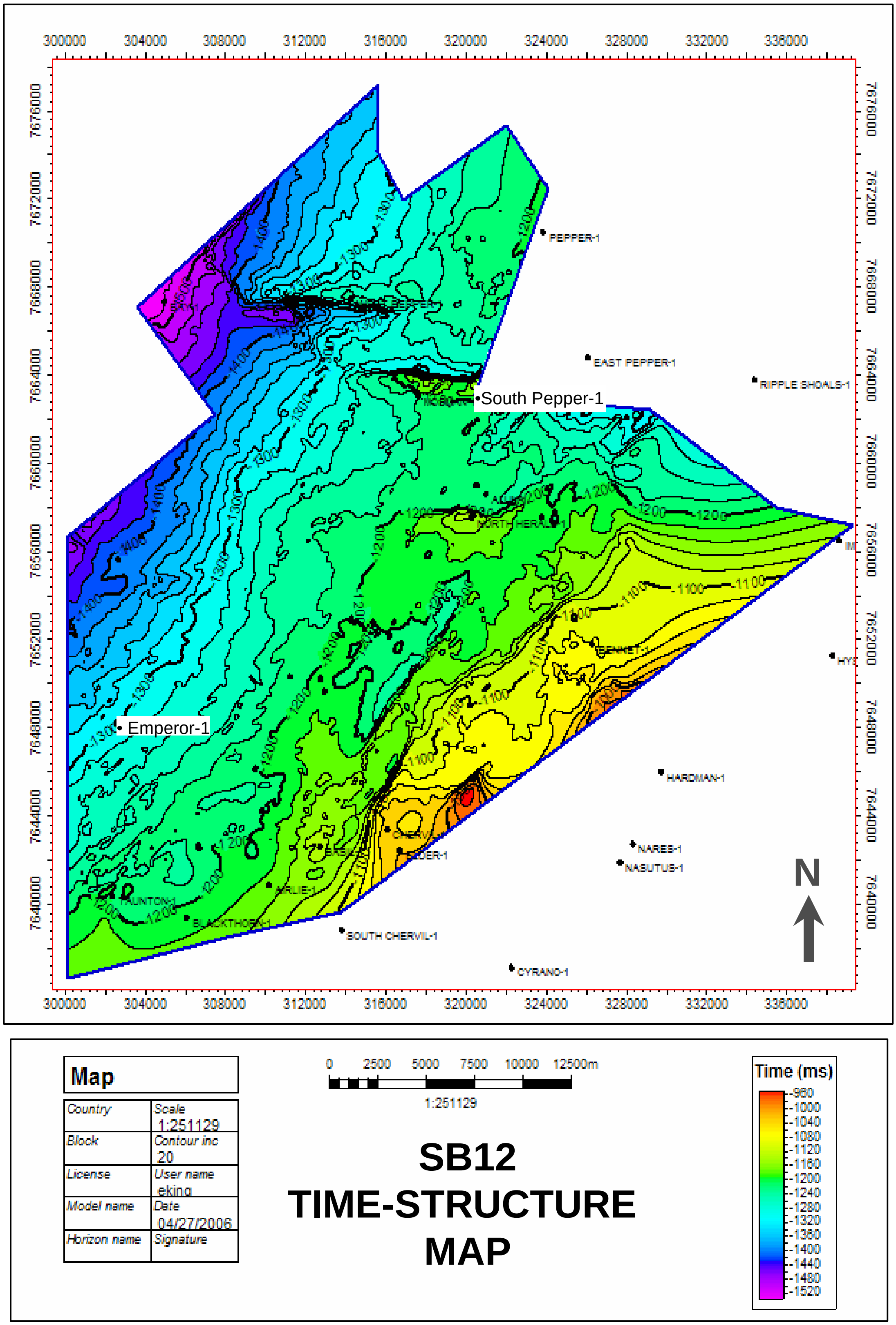


Figure 4.59 Sequence Boundary 12 Time-Structure Map.

4.13.3 DISTRIBUTION AND EXTENT

Seismic Sequence 11 has a regional extent of 184 km^2 within the study area (Figure 4.60), ranging in thickness from 0 to 160 ms. The package increases in thickness to the northeast and two main depocentres can be identified. Seismic Sequence 11 displays a trend of thickening characteristics to Seismic Sequence 10.

4.13.4 DEPOCENTRE POSITION

Two depocentres can be identified from isochron mapping (Figure 4.60). The first shelf depocentre position is northeast of Alum-1 and the other is in close proximity to the location of South Pepper-1. In comparison to the previous seismic sequence depocentre for Seismic Sequence 11 has shifted more to the northeast.

4.13.5 STACKING PATTERNS (seismic and well)

The seismic stacking patterns for Seismic Sequence 11 are mainly progradational across the study area with slight aggradation (Figure 4.57).

The log motif of South Pepper-1 displays basal prograding and aggrading blocky sand stacking patterns, followed by a thick serrated (aggrading) high gamma ray

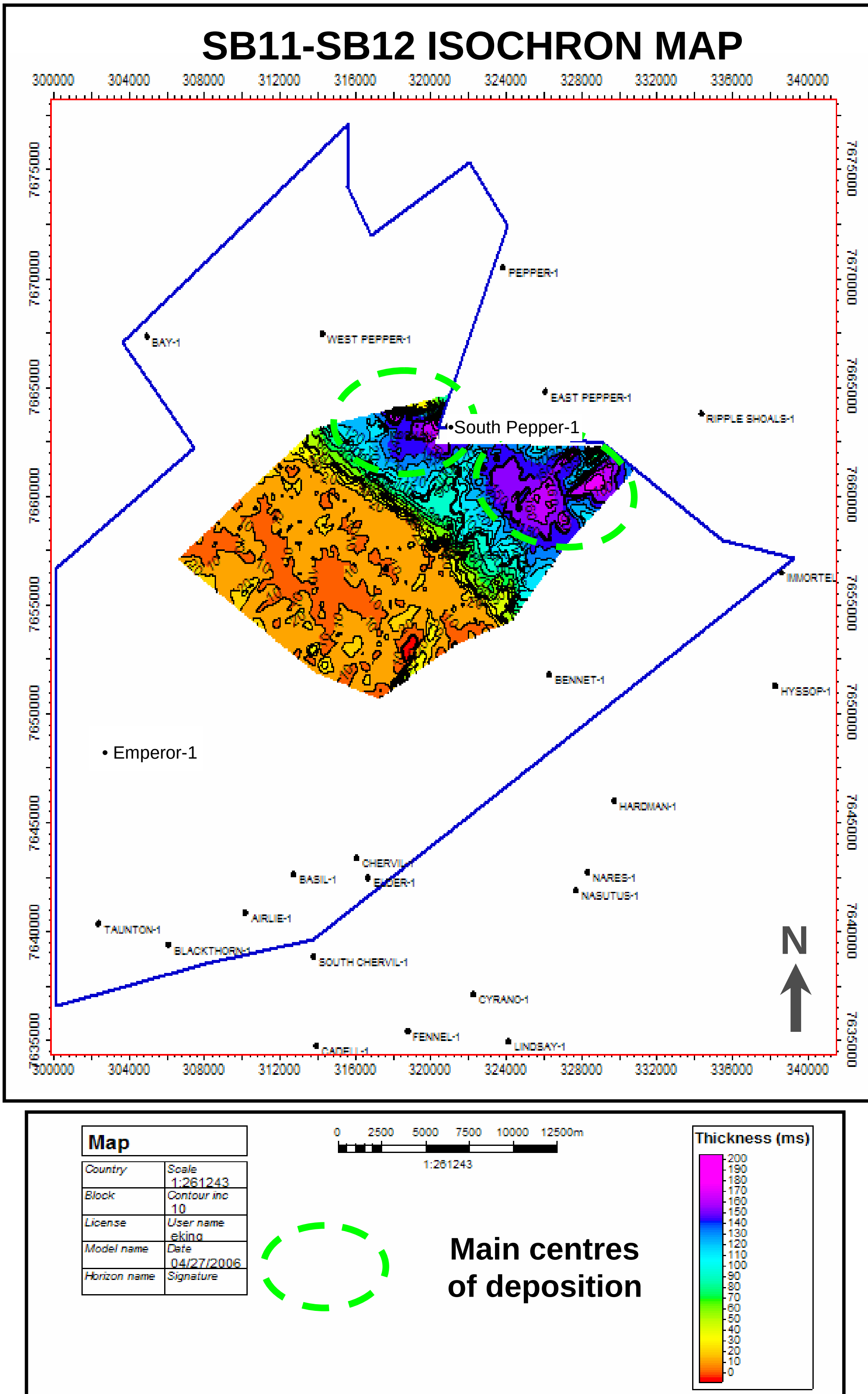


Figure 4.60 SB11 – SB12 Isochron Map, displaying two main centres of deposition during Seismic Sequence 11 deposition.

SB11/TS and upper SB12 (Figure 4.8). The TST is relatively thin, but extensive over the study area.

4.13.9 RESERVOIR/SEAL POTENTIAL

Based on the South Pepper-1 well log response and cuttings descriptions, the bulk of Seismic Sequence 11 is comprised of shale/silt sediments with occasional thin sands, and is overall a more mud-prone package (Figure 4.42 and 4.58). Based on both log and seismic response, Seismic Sequence 11 is largely massive shale/siltstone with minor sand interbeds (Figure 4.42 and 4.58).

4.13.10 PALAEOGEOGRAPHIC RECONSTRUCTIONS

Seismic Sequence 11 is interpreted to have been deposited during a regression followed by a retrogradation, (Figure 4.61, 4.62 and 4.63). Depositional environments present during the basal part of the succession may have included fluvial, deltaic and deepwater environments (Figure 4.61). Well data displays these typical log responses for specified depositional environments. The palaeo-shoreline is interpreted to be near the shelf break with rivers feeding deltas and building out and transporting sediment to deep water systems. The later part of the succession displays a transgression and retrogradation of sediments, with the sea-level rise and backstepping of the shoreline (Figure 4.62 and 4.63).

package comprising the majority of the remaining sequence (Figure 4.42 and 4.58).

4.13.6 SLOPE ANGLE

The internal seismic character of Seismic Sequence 11 is too discontinuous to enable slope angle calculations to be estimated.

4.13.7 AGE

Based on the intersection in South Pepper-1, Seismic Sequence 11 is Berriasian in age, spanning the middle to upper *B. reticulatum* dinocyst zones. The age of this package is between *~135-137Ma*.

INTERPRETATION

4.13.8 SYSTEMS TRACTS

The lower most 45m of Seismic Sequence 11 is represented by thick sandy intervals and the upper 180m of the sequence is dominated by thick, mostly shaley sediments (as seen at South Pepper-1). The systems tracts recognised within Seismic Sequence 11 include a LST (representing the lower part) followed by a TST, overlain by a HST (representing the upper part), bounded by the lower

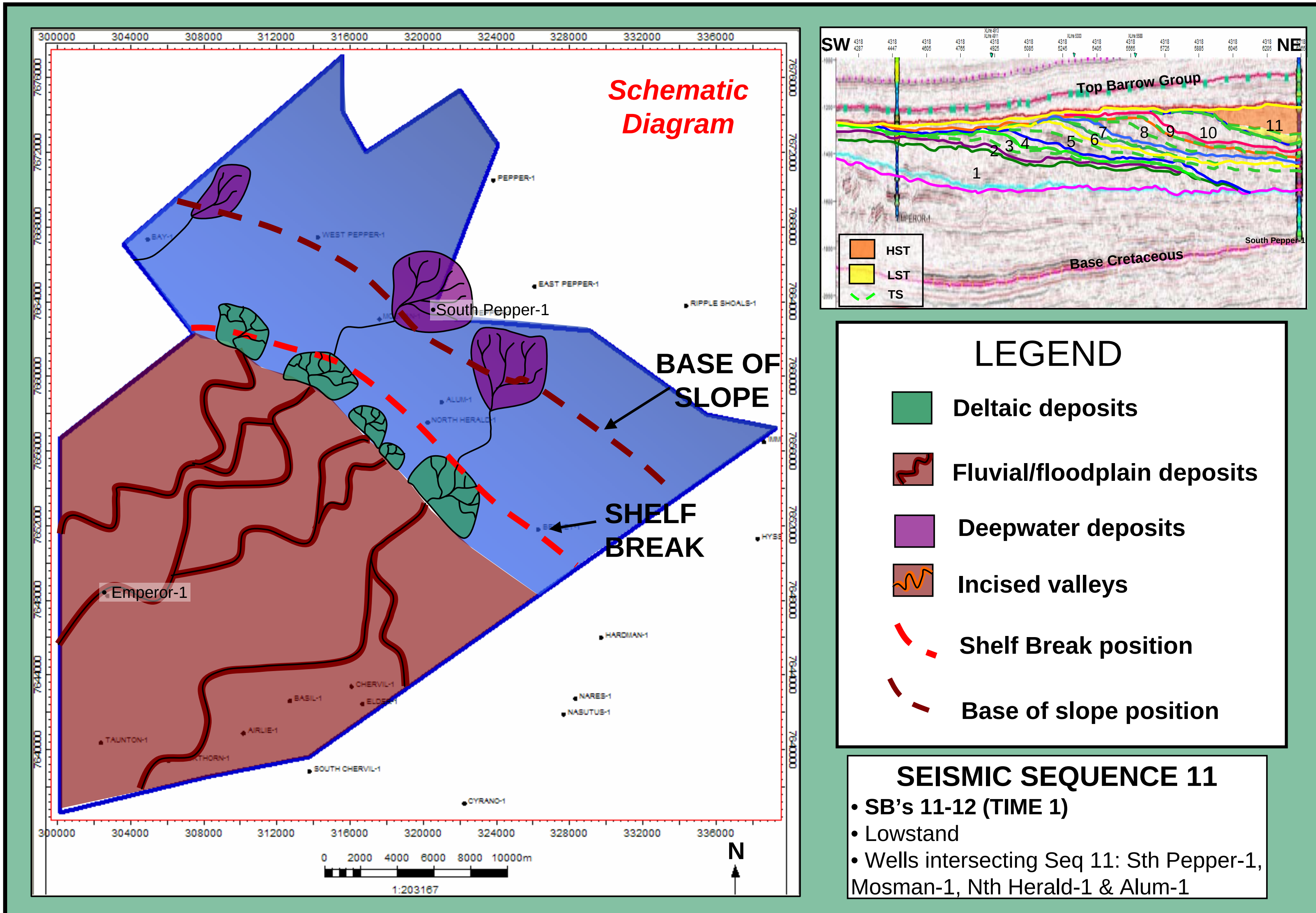


Figure 4.61 Seismic Sequence 11 schematic (early) palaeo-geography map.

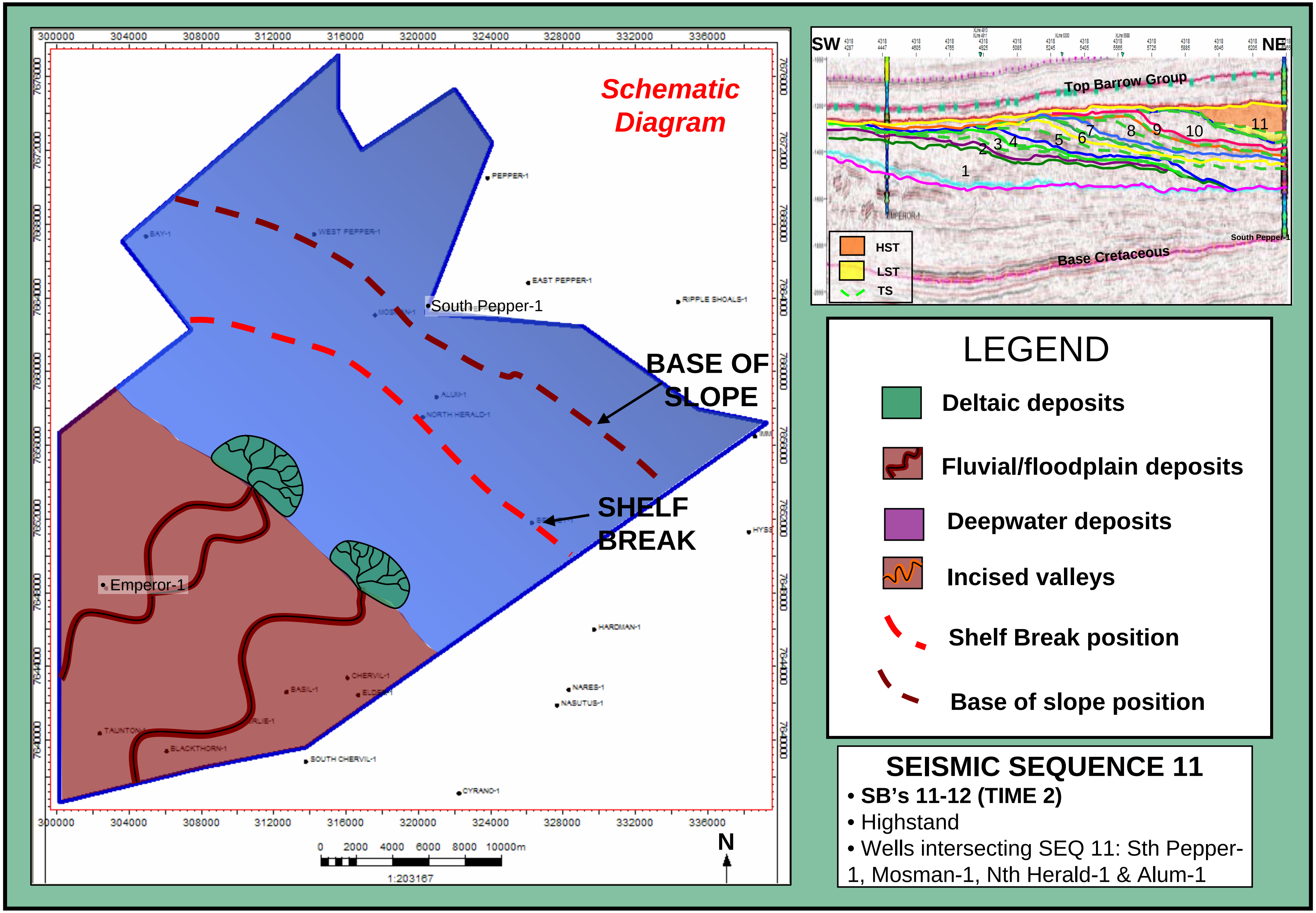


Figure 4.62 Seismic Sequence 11 schematic (mid) palaeo-geography map.

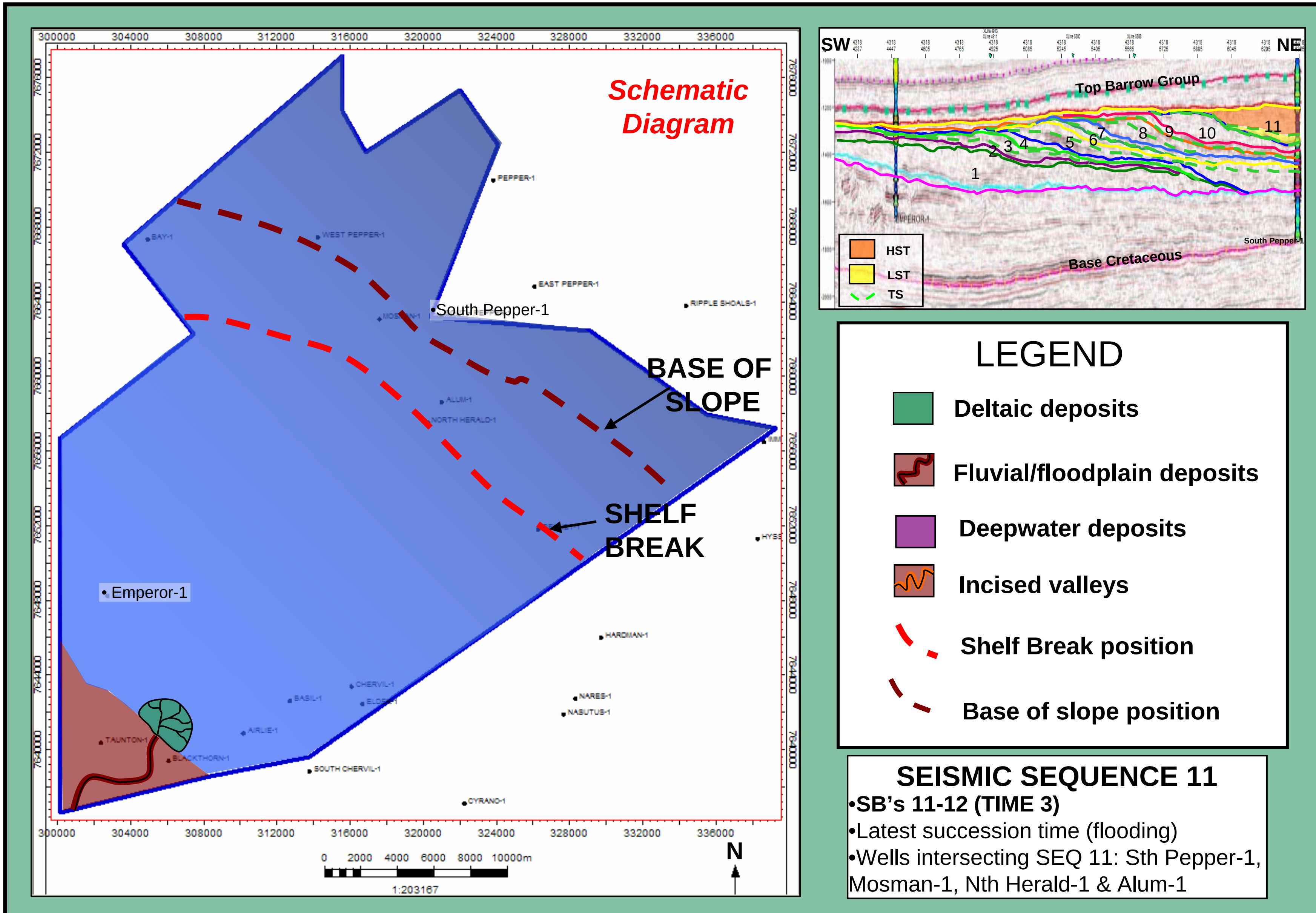


Figure 4.63 Seismic Sequence 11 schematic (late) palaeo-geography map.

For a complete summary of Seismic Sequence 11, please refer to *Appendix 1.0*, Seismic Sequence 11 A3 summary sheet.

5.0 HIGH RESOLUTION SEQUENCE STRATIGRAPHIC ANALYSIS

5.1 INTRODUCTION

High-resolution sequence stratigraphy is emerging as a powerful tool in the analysis and prediction of all sedimentary successions. It has clear applications in deciphering fundamental stratigraphic controls (namely sediment supply and relative sea-level change) and delineating genetic units both in the subsurface and at outcrop (Van Wagoner et al., 1990). In the petroleum industry it provides a rigorous framework for subsurface correlation, and can help in the delineation of reservoir flow units. In addition, it can provide a means for classifying analogue data, and highlighting stratigraphic traps (Emery & Myers, 1996).

This study has identified eleven new seismic sequences and developed a sequence stratigraphic framework tied to key wells. These eleven sequences have been subdivided into systems tracts. A number of these seismic sequences display seismically resolvable, higher frequency depositional packages. High-resolution sequence stratigraphy has been attempted for Seismic Sequence 1, which has been further broken into a number of higher-order sequences. The quality of seismic data within Seismic Sequence 1 has enabled the identification and detailed mapping of reflection geometries at boundaries such as onlapping and truncation features to define the higher-order sequences.

The purpose for performing a high-resolution sequence stratigraphic study for Seismic Sequence 1 is to use it as a tool in hydrocarbon reservoir delineation to enable better predictions in relation to the reservoir-seal couplets that may be present and prospective.

5.2 HIGH-RESOLUTION DESCRIPTION OF SEISMIC SEQUENCE 1

5.2.1 KEY SURFACES

Seismic Sequence 1 is defined by sequence boundary 1 (SB1) and sequence boundary 2 (SB 2) (Figure 4.2). Numerous higher-order surfaces have been interpreted within Seismic Sequence 1. These include sequence boundaries (SB) 1.1 and 1.2, maximum flooding surfaces (MFS) 1.1, 1.2, and 1.3 and transgressive surfaces (TS) 1.2 and 1.3 (Figure 5.1). Reflection terminations used to identify these key surfaces include erosional truncation, downlapping and onlapping features (Figure 5.2). Each new higher-order surface identified differentiates higher frequency depositional packages from those previously described.

5.2.2 SYSTEMS TRACTS

The sequence stratigraphic framework outlined in chapter 4 interprets Seismic Sequence 1 as comprising of a transgressive systems tract (TST) and a thick

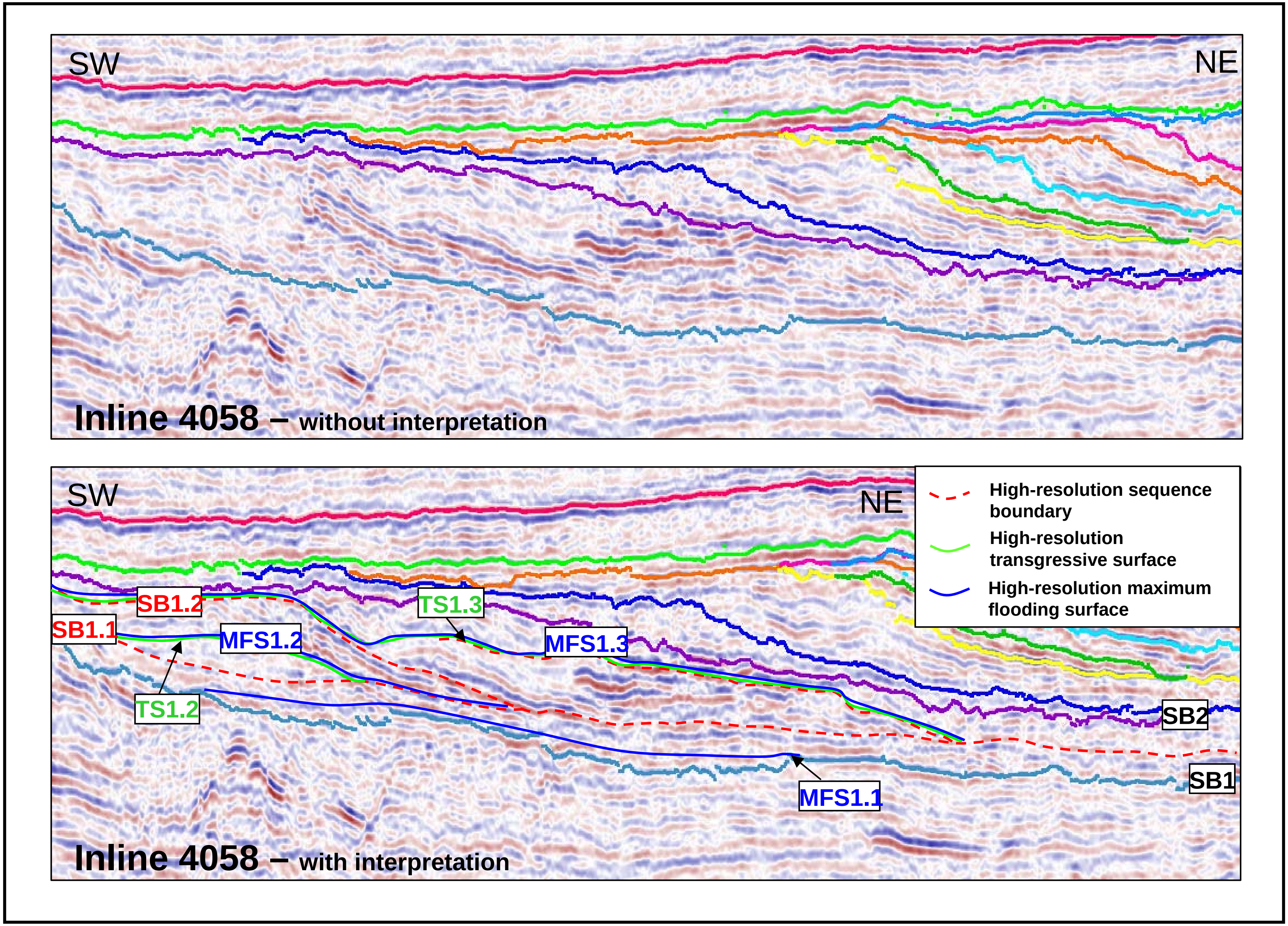


Figure 5.1 Key high-resolution surfaces (includes SB, MFS and TS) for Seismic Sequence 1 on inline 4058 (with and without interpretation).

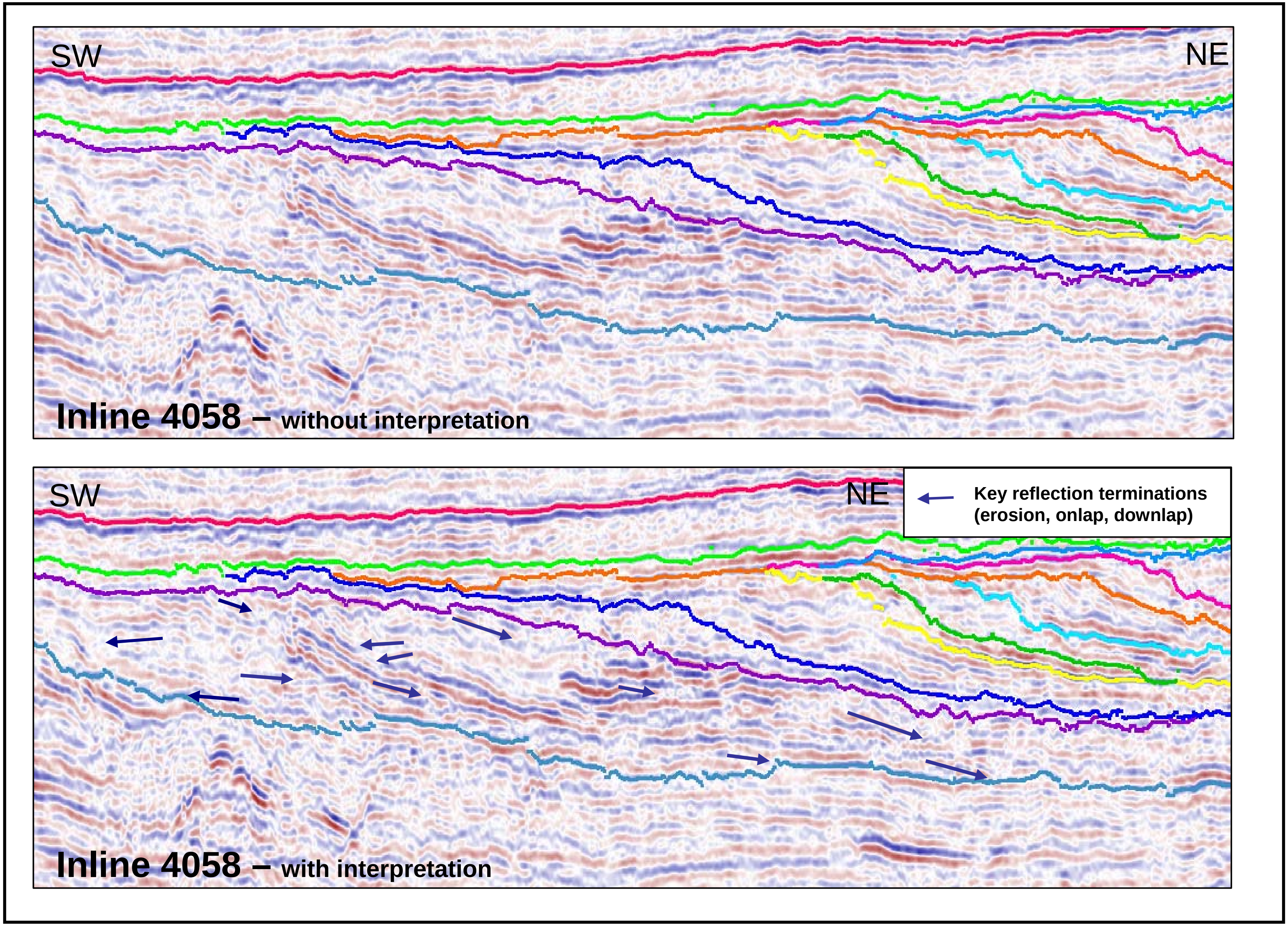


Figure 5.2 Key high resolution reflection terminations (including erosional truncation, onlap and downlap) (blue arrows) for Seismic Sequence 1 on inline 4058 (with and without interpretation).

prograding highstand systems tract (HST). The high-resolution study focuses mainly on the middle and upper parts of Seismic Sequence 1. From the high-resolution sequence stratigraphy study undertaken for Seismic Sequence 1, six higher resolution systems tracts have been interpreted to be present. These include TST 1.1, HST 1.1, LST 1.2, HST 1.2, LST 1.3 and HST 1.3 (Figure 5.3). These higher-order systems tracts are defined by the higher-order key surfaces interpreted, associated reflection terminations viewed on seismic, as well as the overall seismic character and mounding features present (Figure's 5.1, 5.2 and 5.3).

TST 1.1 has been interpreted due to the nature of the succession building back on to the shelf, followed by the deposition of the prograding sediments of HST 1.1 over the top (Figure 5.3). A slight fall in relative sea-level and/or increase in sediment input has seen the deposition of LST 1.2 distributed locally (with onlapping and downlapping features viewed on seismic) (Figure 5.3). This was then followed by a gradual rise in sea-level and deposition of HST 1.2, with prograding features viewed on seismic (Figure 5.3). LST 1.3 is then interpreted to have formed in response to an associated fall in relative sea-level forced regression (Figure 5.3). This interpretation has been made via the progradational nature of the lowstand wedges viewed on seismic, subaerial exposure and fluvial influence (Emperor-1 channel sand) (Posamentier et al., 1992). Lastly, a gradual rise in sea-level and HST 1.3 has been interpreted to comprise the remaining Seismic Sequence 1 (Figure 5.3). This is due to the overall seismic character

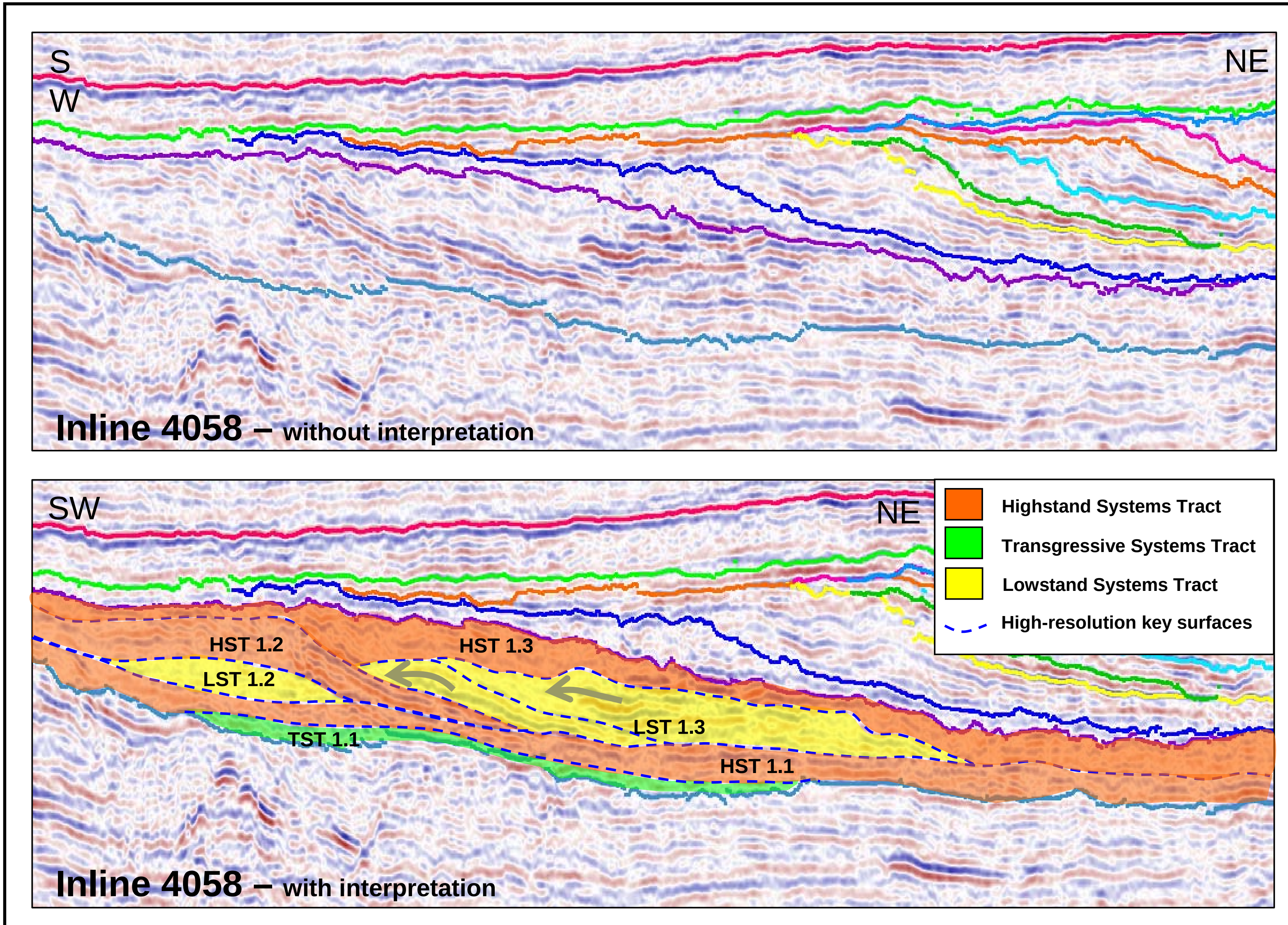


Figure 5.3 High-resolution sequence stratigraphy interpretation for Seismic Sequence 1 on inline 4058 (with and without interpretation). Note LST 1.2 interpretation of formation in response to a forced regression.

displaying prograding sediments building out over the top of the previous lowstand wedge. Additionally the low amplitude character of the seismic for this interval also adds to the HST interpretation.

5.3 ISOCHRON MAPPING AND TIMESLICE INTERPRETATION

Localised mapping of high-resolution sequence boundaries was slightly hampered due to the quality of the seismic data. However, accurate mapping was attempted and the resultant maps analysed. Two depocentres can be recognised from the isochron maps produced (Figure 5.4). During lowstand deposition, up to three different depocentres or lobes can be mapped out, due to the greater thicknesses visible on the isochron maps. Thus, lobe switching may have occurred. Alternatively, numerous feeder systems may have been present at the time of deposition (Figure 5.4). Therefore, the development of these main centres for deposition and progradation of lowstand wedges during this period is consistent with the forced regression interpretation (relative SL fall) and subsequent movement of the shoreline in a seaward direction.

Time-slices of Seismic Sequence 1 show potential channelised features, deposited during the higher-order LST's within Seismic Sequence 1 (Figure 5.5). These features strengthen the interpretation of the higher-order LST's (associated with prograding lowstand wedges viewed on seismic) within Seismic

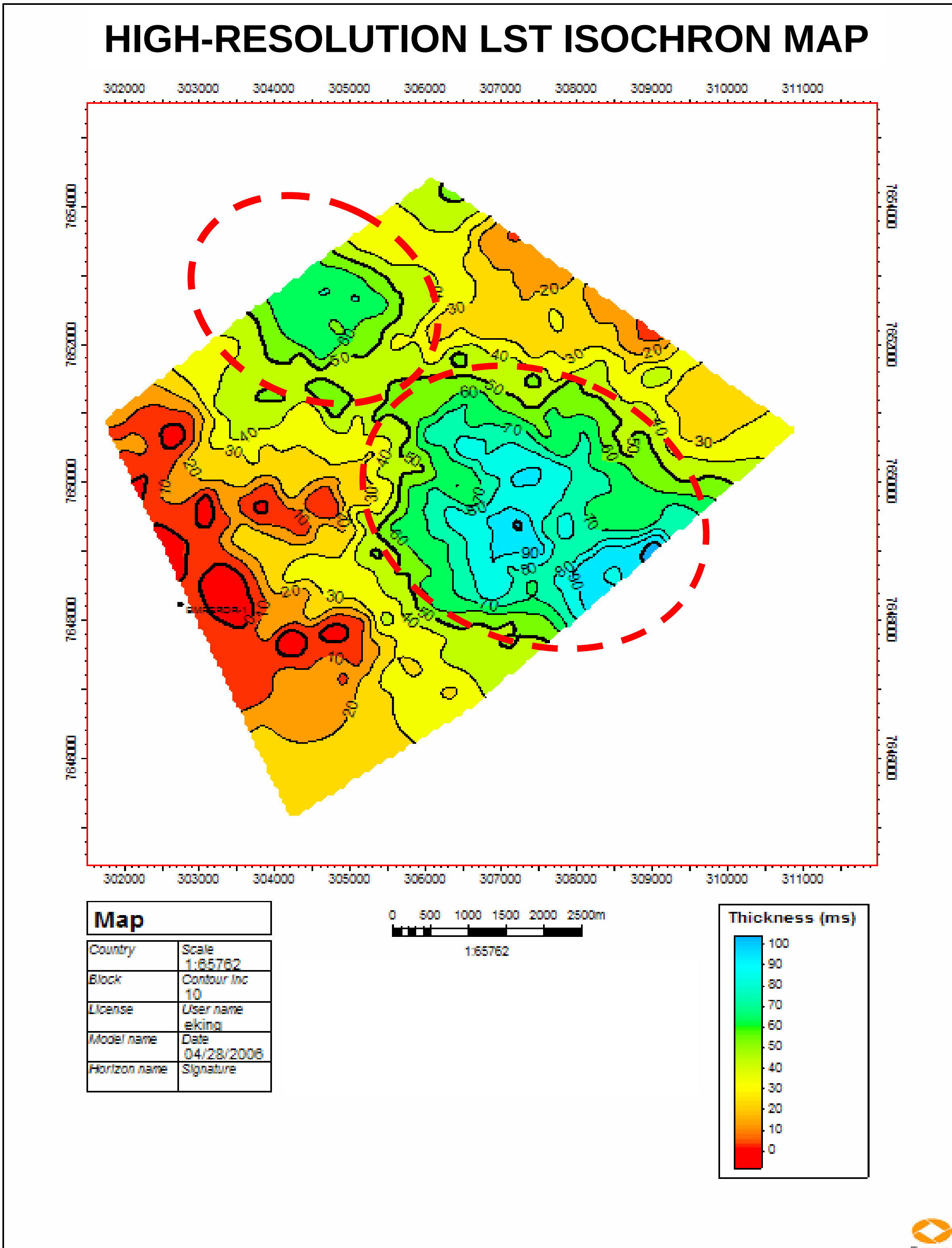


Figure 5.4 Isochron map of high-resolution LST (LST 1.2) identified. Two main centres of deposition can be interpreted from LST 1.2 isochron map (red dashed circles).

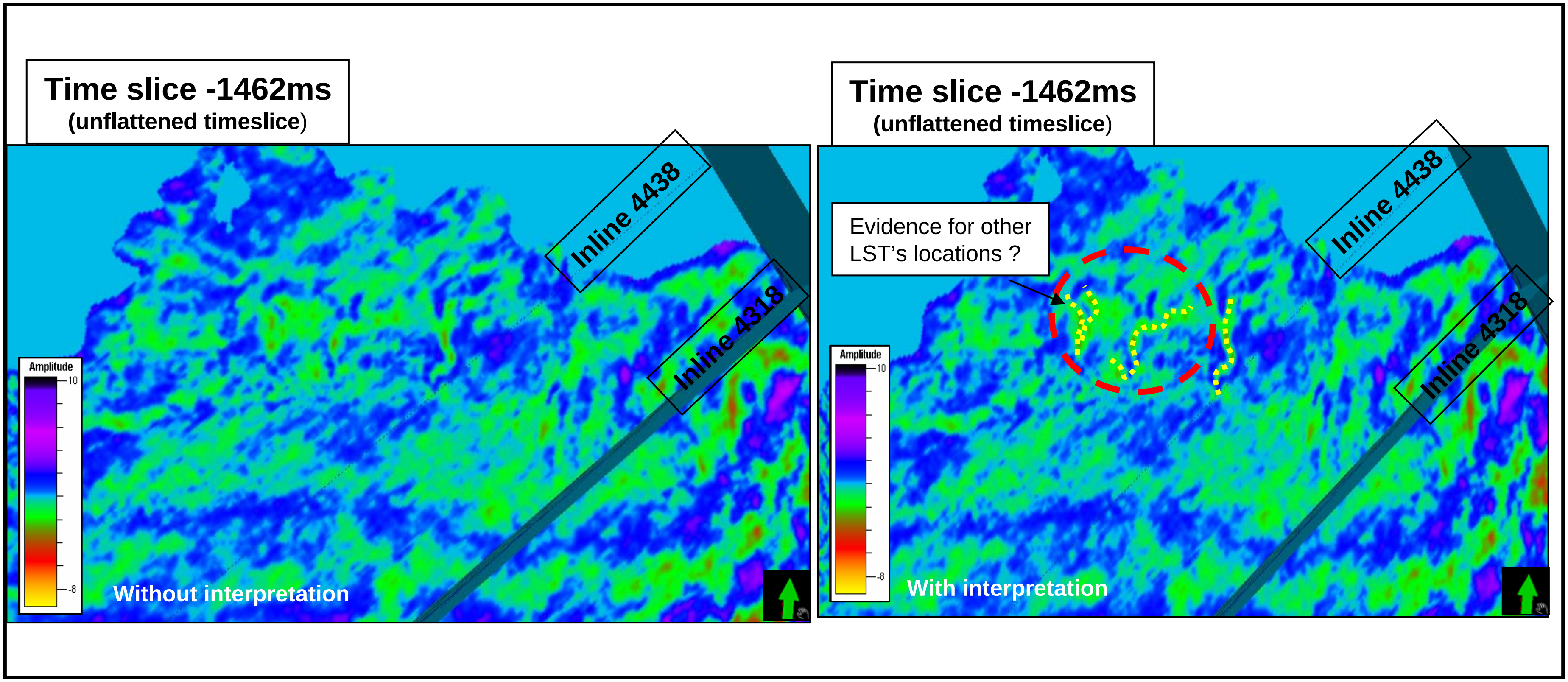


Figure 5.5 **Time-slices through high-resolution packages identified, note channelised features corresponding to the lowstand systems tracts mapped out from high-resolution sequence stratigraphy study undertaken for Seismic Sequence 1.**

Sequence 1 and suggest potential locations of the associated sandy lobes (if sand dominated) at their termination**.**

5.4 RELATION TO HYDROCARBON PROSPECTIVITY

The high-resolution sequence stratigraphic interpretation of Seismic Sequence 1 can assist in assessing hydrocarbon prospectivity. The differentiation of numerous high-resolution LST's enhances the accuracy of identifying prospective areas within the sequence and can also enable more detailed descriptions of depositional history. The presence of LST's also corresponds to more sand-prone intervals, because sub-aerial erosion associated with the relative sea-level fall causes deposition of sandier intervals further offshore rather than shaley deposits (Walker, 1992). In turn this provides a means of shifting seaward a package of reservoir-prone clastics where they will be sealed during subsequent transgression; thus identifying a potential reservoir-seal couplet of high prospectivity.

The high-resolution sequence stratigraphic study directly promotes the increased knowledge of the prospectivity and depositional environment for Seismic Sequence 1. Undertaking such detailed high-resolution sequence stratigraphic studies for each seismic sequence identified is recommended, where thickness and resolution of seismic sequence is adequate, in conjunction with detailed petroleum system analysis.

6.0 PLAY AND PROSPECTIVITY ANALYSIS

There are key elements that make up any given play type: reservoir, seal, source and timing (explusion, migration, preservation). The different combinations of each of the elements give rise to different play types. The following discussion outlines the key elements of the each potential play type, in respect to the prospectivity of the interval of interest over the study area (Table 6.1).

6.1 SOURCE ROCK

The Barrow Sub-basin contains several intervals in the Mesozoic that are recognised as major source rocks. The middle to late Triassic Mungaroo sequence is mainly coaly and humic and is thus gas prone (Smith et al, 2002) (Table 6.1). The early Triassic Locker Shale contains sapropel-enriched zones and is therefore oil generating (Table 6.1). The current view is that the Triassic rocks are the source for most gas and condensates found on part of the Rankin Trend (van Aarssen et al., 1996). The Early to Late Jurassic Dingo Claystone is recognised to be a marine and partly terrestrial source rock (Baillie & Jacobson, 1997) (Table 6.1). The Dingo Claystone was mainly deposited in a deepwater, low-energy, anoxic environment and is the principal source for oil for much of the Carnarvon Basin. The Dingo Claystone retains high total organic carbon contents with mixed sapropelic and humic type II/III to type III kerogens (Kopsen & McGann, 1985). It became thermally mature in the deeper parts of the basin during the Cretaceous (Smith et al, 2002). The Dingo Claystone is up to 3000 m thick in the depocentres of the Exmouth, Barrow and Dampier Sub-basins and is regarded as the most important source rock in the Barrow Sub-basin, generating mainly oils, but also gas (van Aarssen et al., 1996).

6.2 EXPULSION AND MIGRATION

Several episodes of oil generation and migration have occurred within the Barrow Sub-basin (Baillie & Jacobson, 1997). The Triassic Locker Shale is currently in the gas window, due to depth of burial, whereas the younger late Jurassic Dingo Claystone is in or just below the oil window within the Barrow Sub-basin (van Aarssen et al., 1996) (Table 6.1). The main pulse of hydrocarbon generation in the sub-basin occurred from the Dingo Claystone (Table 6.1). Hydrocarbons were expelled during the Early Cretaceous, a process which continued throughout the Late Cretaceous to Cainozoic (Kopsen & McGann, 1985). In the Tertiary, the upper and shallower part of the Dingo Formation generated and expelled oil into interbedded sandstones and the overlying Barrow Group (Kopsen & McGann, 1985).

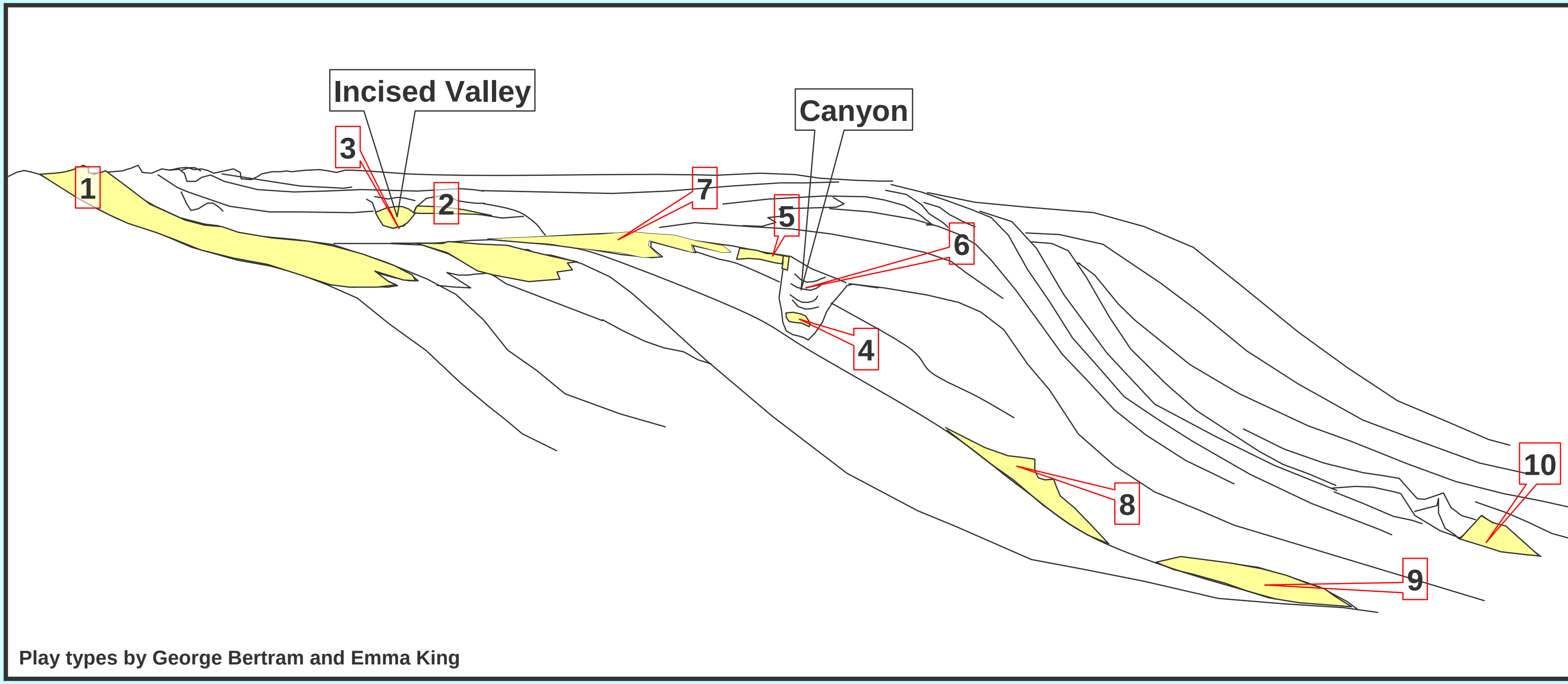
Table 6.1 Barrow Sub-basin Petroleum Play Elements Summary

Barrow Sub-basin Petroleum Play Elements	
Source	Locker-Mungaroo (Triassic) Gas Dingo Claystone (Late Jurassic) Oil
Reservoir	Paleocene sandstone, Windalia Sandstone (Early Cretaceous), Mardie Greensand (Early Cretaceous), Angel Formation (Late Jurassic), Dupuy Formation (Late Jurassic), Early Jurassic reservoirs and the Mungaroo Formation (Late Triassic).
Seal	Muderong Shale (Early Cretaceous), Windalia Radiolarite (Early Cretaceous), Dingo Claystone (Late Jurassic), and intra-formational seals.
Trap	Drape anticlines, horsts blocks, fault roll-over structures and stratigraphic pinch-outs.
Infrastructure and Markets	The study area is in close proximity to existing infrastructure associated with gas and oil developments around Barrow Island. Established gas and oil market.

6.3 PLAY TYPES IN STUDY AREA

Potential play types that can be targeted in the study area include combination structural/stratigraphic (fault-bound) and purely stratigraphic plays. The sequence stratigraphic understanding for the interval of interest has led to the identification of numerous potential play types. Specific plays include shelfal (incised valley fill, lowstand and highstand shoreface sands), slope (channels, lowstand wedges) and basin-floor fan plays (Figure 6.1). Understanding the locations of potential maximum flooding surfaces and other potential sealing facies increases the prospectivity of each play type. Also new structural and combination structural/stratigraphic (fault-bound) plays are potential targets in the study area.

INTRA-BARROW GROUP POTENTIAL PLAY TYPES



1	Erosional Truncation	6	Levee/edge traps
2	Levee Traps	7	Slope channel systems / lowstand / midstand downstepping
3	Valley Fill	8	Slope channel systems
4	Canyon Fill	9	Fan systems
5	Slope/slumped sands in Canyon	10	Slump blocks

Figure 6.1 **Summary of the intra-Barrow Group potential play types within the Flinders 3D (project study area).**

6.4 SEISMIC SEQUENCE PROSPECTIVITY

6.4.1 SEISMIC SEQUENCE 1

The sequence stratigraphic framework developed for Seismic Sequence 1 identifies a transgressive systems tract (TST), overlain by a maximum flooding surface (MFS), followed by a prograding highstand systems tract (HST) package. The high-resolution sequence stratigraphic analysis undertaken for Seismic Sequence 1 (Chapter 5), has increased the detail known about Seismic Sequence 1 and hence the prospective areas within the sequence.

Potential plays that can be targeted within Seismic Sequence 1 include lowstand plays (incised valleys, channels, deep-water deposits, shelf-edge deltas), stratigraphic plays (onlapping reservoir beds overlain by impermeable materials – prodelta material, updip pinchouts), and highstand plays (including deltas, fluvial, shallow marine) (Figure 6.1).

The overall prospectivity of Seismic Sequence 1 can be rated as medium after examining the results of the high-resolution sequence stratigraphic analysis and the subsequent identification of higher-order LST's. If a sandy system was dominant at time of deposition, then potential exists for these lowstand wedges to be sand-rich and thus prospective. Additionally, the identification of numerous MFS's indicate the probability that sealing material may be present and could hold back hydrocarbons which contributes further to the medium rating. A potential incised valley fill has also been identified from the Emperor-1 log, suggesting that further exploration for incised valleys during times of lowstand deposition in the study area would be worthwhile.

6.4.2 SEISMIC SEQUENCE 2

Seismic Sequence 2 has been interpreted mainly as a TST according to the sequence stratigraphic analysis. Based on Seismic Sequence 2's intersection at Emperor-1, silty/shaley intervals are dominant and thus Seismic Sequence 2 displays potentially sealing lithologies. Overall the hydrocarbon prospectivity of Seismic Sequence 2 is low due to its thin interval and limited areal extent.

Potential plays that could be targeted within Seismic Sequence 2 could be stratigraphic with potential reservoir facies deposited in an alluvial, coastal plain and/or shelfal environment, with sealing facies potentially also deposited via these environments as well (Figure 6.1). Hydrocarbons would most likely have to travel via long-distance migration, due to the overall thinning and limited extent of the seismic sequence and also the likelihood of the lack of deposited source rock intervals. Overall this sequence is most likely to have a lower sandstone percentage (Emperor-1 intersection) and is most likely to host non-reservoir claystone lithologies.

6.4.3 SEISMIC SEQUENCE 3

The sequence stratigraphic framework developed for Seismic Sequence 3 includes a LST, TS, MFS and HST. The hydrocarbon prospectivity rating for Seismic Sequence 3 is medium to high. This can be attributed to the sequence's thickness, lithology combination (reservoir/seal), areal extent and sequence stratigraphic interpretation allowing for a number of potential stratigraphic plays that could be targeted in Seismic Sequence 3. These include onlap, incised valley, downlap pinchouts and truncation. Potential reservoir facies include beach, deltaic estuarine, basin floor fans and distributary channels (Figure 6.1). Potential sealing facies include shelf mudstones and/or coastal/delta plain mudstones.

6.4.4 SEISMIC SEQUENCE 4

Seismic Sequence 4 has been interpreted as a HST. Overall, the hydrocarbon prospectivity of Seismic Sequence 4 displays some potential, although the sequence is not regionally extensive or of great thickness. Potential plays that could be targeted within Seismic Sequence 4 include downdip and updip pinchout and truncation plays (Figure 6.1). Associated potential reservoir facies involved in these play types could include fluvial, coastal plain and/or shallow marine. Sealing facies including coastal plain and/or shelfal mudstones. A stratigraphic component is also included in the majority of the Seismic Sequence 4's plays, with structural features also highlighted.

6.4.5 SEISMIC SEQUENCE 5

The sequence stratigraphic framework for Seismic Sequence 5 includes a LST, TS, MFS and HST. Seismic Sequence 5 can be categorised as having high hydrocarbon prospectivity. This rating can be attributed to the thick and regionally extensive nature of the sequence, the sequence stratigraphic interpretation and also intersections of thick blocky sands at South Pepper-1. Potential plays that could be targeted with Seismic Sequence 5 include onlap, downdip pinchout, mounding features and/or truncation (Figure 6.1). Potential reservoir facies include lowstand incised valley sands, shallow marine, slope, deltaic, deep water and channels. Potential sealing facies could include shelf and slope mudstones and also deep water shales, e.g. basin floor fan stratigraphic play or onlapping lowstand wedge sands stratigraphically sealed by overlying shelfal/slope mudstones (or MFS).

6.4.6 SEISMIC SEQUENCE 6

Seismic Sequence 6 is interpreted as comprising of a thin LST. Overall, the hydrocarbon prospectivity for Seismic Sequence 6 can be classed as low to medium. This is due to the seismic sequence's small areal extent and overall thinness and also lack of internal character. Some potential plays that could be targeted within Seismic Sequence 6 include lowstand wedge sands onlapping and being sealed via shelfal mudstones stratigraphically or incised valley fill sealed by shelfal mudstones.

6.4.7 SEISMIC SEQUENCE 7

The sequence stratigraphic framework developed for Seismic Sequence 7 identifies a TS followed by a prograding to aggrading HST. The hydrocarbon prospectivity for Seismic Sequence 7 is overall low to medium. Potential plays within Seismic Sequence 7 include stratigraphic traps such as downdip pinchouts of deltaic or beach sands, sealed by shelfal mudstones, isolated channels with distributary channel sand reservoir facies and coastal or delta plain mudstones as potential sealing facies and/or truncation of beach or deltaic sands that have been sealed stratigraphically by shelfal mudstones (Figure 6.1).

6.4.8 SEISMIC SEQUENCE 8

The sequence stratigraphic framework developed for this sequence identifies a LST, TS, MFS and HST. The internal character, thickness and areal extent of this sequence is excellent for a thorough investigation into the prospectivity of the seismic sequence. Overall, the hydrocarbon prospectivity for Seismic Sequence 8 can be rated as high. Potential plays that could be targeted with Seismic

Sequence 8 include onlap, downdip pinchout, mounding features and/or truncation (Figure 6.1). Potential reservoir facies include lowstand incised valley sands, shallow marine, slope, deltaic, deep water and channels. Potential sealing facies could include shelf and slope mudstones and also deep water shales, e.g. basin floor fan stratigraphic play or onlapping lowstand wedge sands stratigraphically sealed by overlying shelfal/slope mudstones (or MFS). Additionally, South Pepper-1 displays good quality reservoir sandstones within Seismic Sequence 8, which further reinforces the high rating of the prospectivity of this sequence.

6.4.9 SEISMIC SEQUENCE 9

The sequence stratigraphic framework developed for Seismic Sequence 9 includes a TS, MFS and an aggrading HST. The overall hydrocarbon prospectivity for Seismic Sequence 9 can be rated as low to medium. Potential plays that could be targeted within Seismic Sequence 9 include downdip and updip pinchout and truncation (Figure 6.1). Associated potential reservoir facies involved in these play types could include fluvial, coastal plain and/or shallow marine and sealing facies including coastal plain and/or shelfal mudstones. A stratigraphic component is also included in the majority of Seismic Sequence 9's plays, with prospective structural features highlighted.

6.4.10 SEISMIC SEQUENCE 10

Seismic Sequence 10 has been interpreted as a lower-order LST from the regional sequence stratigraphic framework developed in Chapter 4. This seismic sequence displays coherent internal seismic character, thickness and areal extent, with the potential for the ability to attempt detailed mapping of higher-order sequences. The overall hydrocarbon prospectivity for Seismic Sequence 10 is rated as high. Potential plays that could be targeted within Seismic Sequence 10 include basin floor fans and incised valleys with fluvial reservoir facies, sealed by shelfal mudstones (Figure 6.1). Also onlapping lowstand wedge of beach, deltaic or estuarine sandstones sealed stratigraphically by shelf mudstones could be a targeted play type. The development of adequate sealing facies is highlighted as the greatest risk for Seismic Sequence 10, this is due to thick reservoir quality sandstones intersected by nearby wells such as South Pepper-1 within Seismic Sequence 10.

6.4.11 SEISMIC SEQUENCE 11

Based on the sequence stratigraphic framework developed for this study a LST, two TS's and a HST has been identified within Seismic Sequence 11. Overall, the hydrocarbon prospectivity for Seismic Sequence 11 can be rated as high. The basal part of the sequence includes potential plays such as onlapping lowstand wedge, beach, deltaic and/or estuarine reservoir sands stratigraphically sealed by shelfal mudstones and/or MFS with potential for the development of basin floor fans could be targeted for future exploration (Figure 6.1). Additionally the intersection of reservoir quality sandstones with interbedded shaley/silty sealing facies at nearby wells further encourages targeting such potential play types. The upper part of Seismic Sequence 11 displays potential for play types such as downdip pinchout of shore face sands sealed by shelfal mudstones and truncation of shore face sands sealed by overlying shelfal mudstones to be targeted.

6.5 LEADS

Five leads have been identified related to the depositional setting relative to the play type and are discussed as follows (Figure 6.2).

6.5.1 SHELF LEADS

Numerous shelfal leads have been identified based on the currently available data and the technique of using seismic sequence stratigraphy in this study. The shelfal leads identified are mainly incised valleys (Figure 6.1). Incised valleys are associated with a fall in relative sea-level when river profiles adjust to lowered base level. The river creates an incision into the deposits of the previous sequence (Posamentier & Allen, 1999). A grid of wells or outcrop data is usually needed to prove the existence of an incised valley and although neither of these

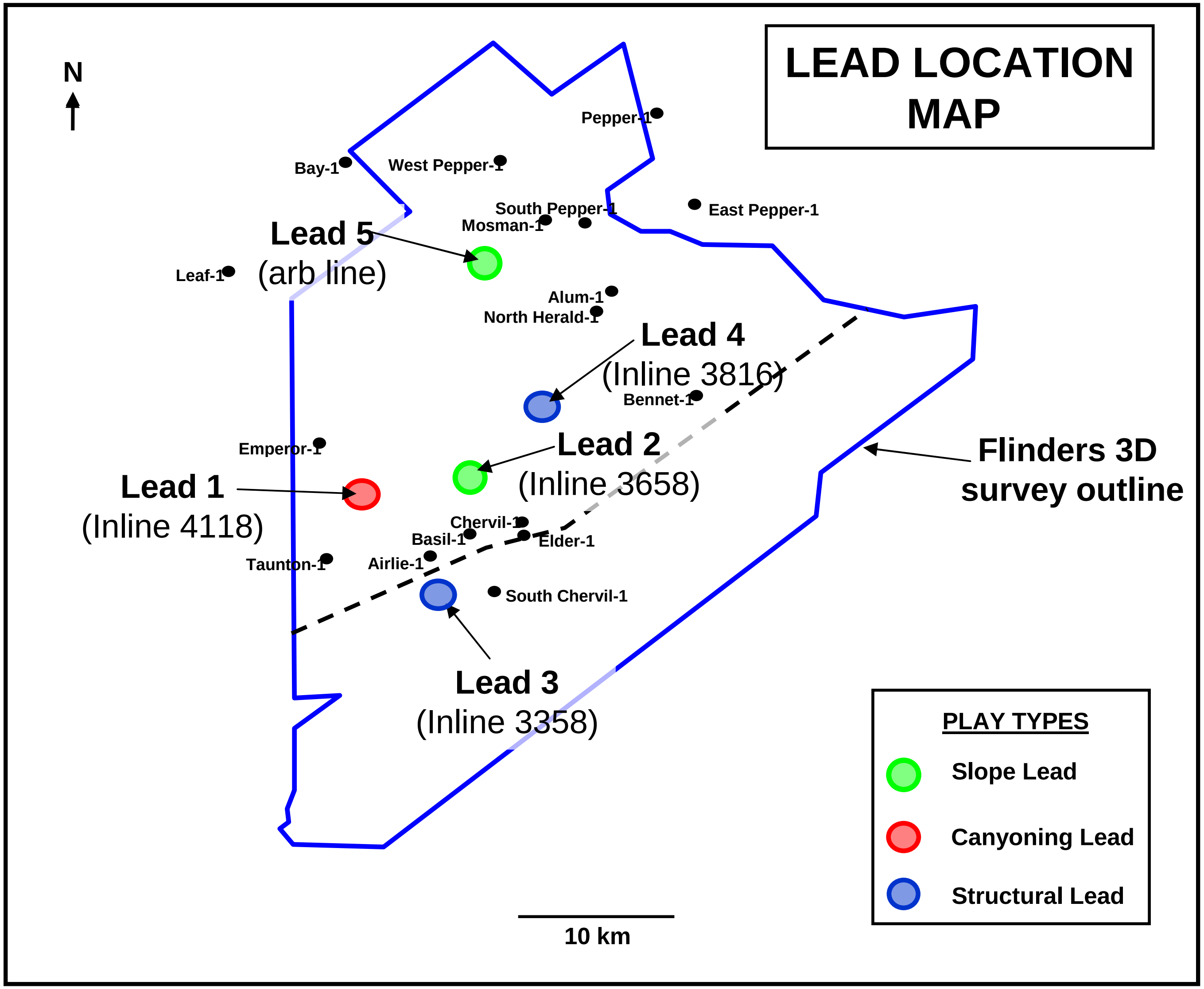


Figure 6.2 Lead location map, note different colours representing different play types.

are available for this study area, Emperor-1 gives some evidence for the existence of an incised valley, displaying a sharp-based sandstone representing an abrupt shallowing from marine shelfal facies to sandy fluvial valley-fill (Figure 4.13). A valley-fill deposit can also be shaley when, as part of a TST, estuarine conditions dominate.

6.5.2 SLOPE LEADS

Two slope leads have been identified via the combined search through the currently available data and the seismic sequence stratigraphic interpretation completed for this study. The first comprises a toe-of-slope play, with potential reservoir sandstones onlapping and pinching out against the older sequence below (Figure 6.3). According to the seismic sequence stratigraphic framework developed, the lead lies within a HST. This lead displays good potential for the presence of a stratigraphic trapping mechanism via the onlapping nature of the sediments highlighted. Although a HST lowers the chance for the presence of reservoir quality sands, it does increase the probability that sealing facies exist.

The second slope lead identified in the study area, is also a toe-of-slope play (Figure 6.4). Potential reservoir sands may be present and display onlapping characteristics (thus potentially trapping hydrocarbons). This lead also displays the presence of an anticlinal structure above the onlapping sediments. Despite the quality of the 3D data being of good quality available, the lack of direct well

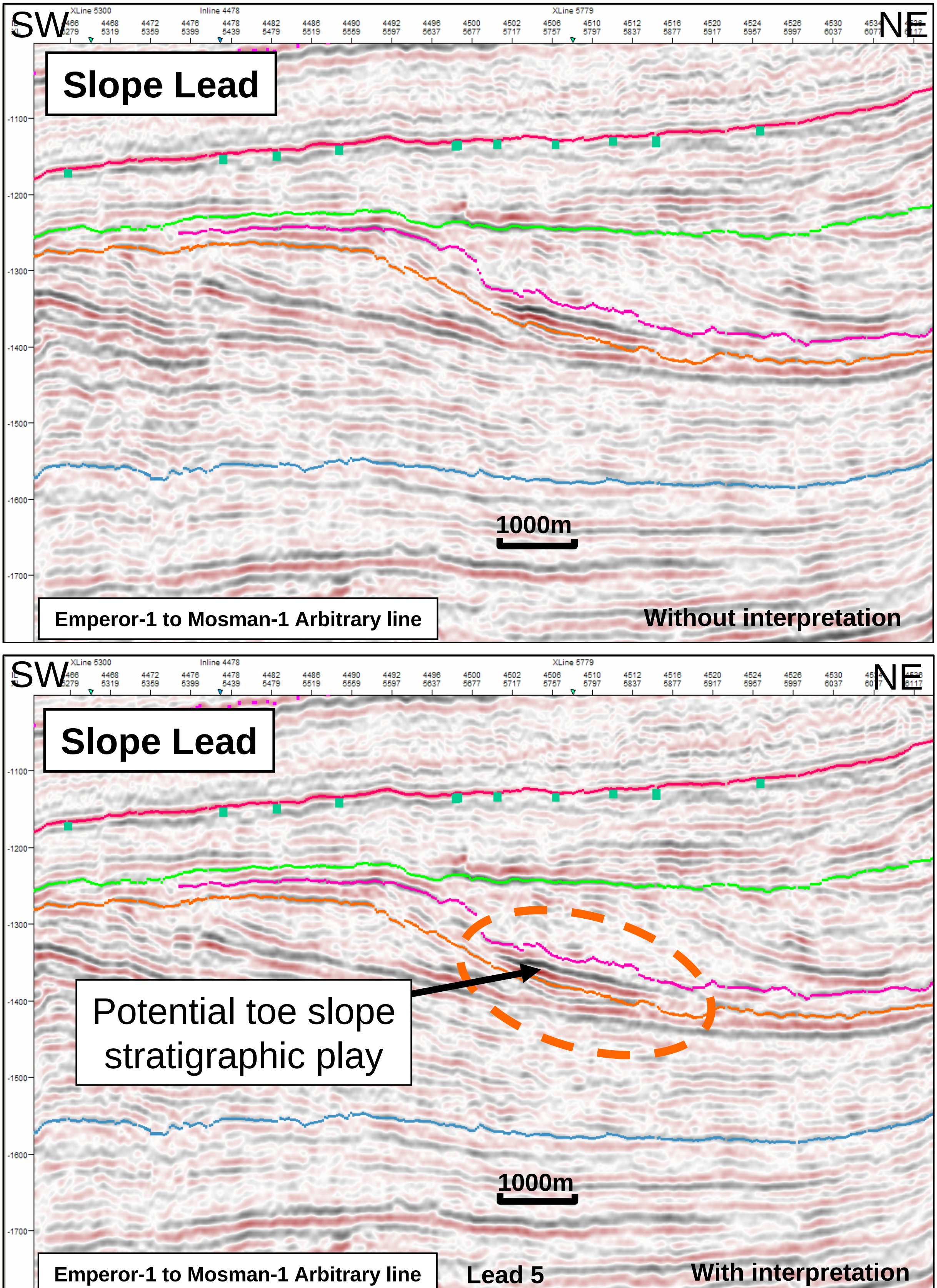


Figure 6.3 Potential intra-Barrow Group slope lead, key risk is presence of top seal.

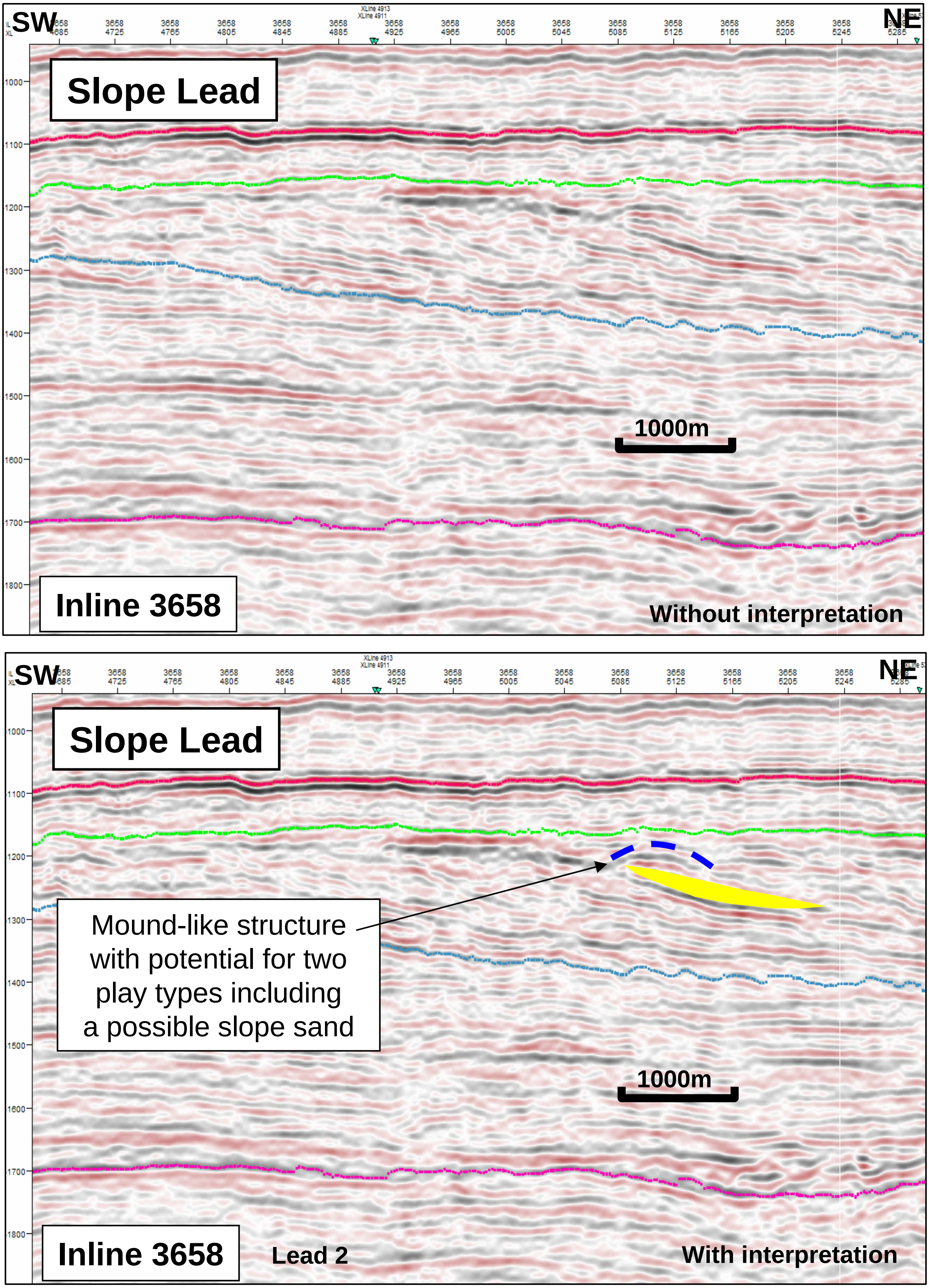


Figure 6.4 Potential intra-Barrow Group slope lead, key risk is top seal.

penetrations makes it difficult to distinguish whether or not there is a sealing facies overlaying the potential reservoir sands for the anticlinal structure that has been interpreted. The issues dealing with timing and migration make it also difficult to ascertain whether or not hydrocarbons have leaked and is beyond the scope of this study.

6.5.3 BASIN-FLOOR LEADS

The palaeo-depositional environments interpreted for the intra-Barrow Group displays the potential for the identification of basin-floor fans. Submarine fan creation is associated with erosion and incised valleys. Siliciclastic sediment bypasses the shelf and slope through the valleys and canyons to feed the basin-floor fan. Further investigations into regions similar to that of the palaeo-depositional schematic interpretations may result in the identification of new basin-floor fans. These prospective areas are in the northeastern part of the study area proximal to Mosman-1, Bay-1 and South Pepper-1. All these wells have intersected distal and proximal portions of submarine fans.

6.5.4 LOWSTAND SYSTEMS TRACTS LEADS

The regional sequence stratigraphic framework developed for the intra-Barrow Group for this study has identified a number of lower-order LST's. A LST is deposited during an interval of relative sea-level fall, and subsequent relative sea-level rise. A LST can be divided into two parts: a unit of submarine fans deposited during falling relative sea-level, and a topset/clinoform system, initially progradational but becoming aggradational, deposited during a relative sea-level rise.

Overall the LST's identified in the study area correspond to well developed, 'blocky' thick sandstones in wells. Potential sealing facies for this LST include overlying TST's and MFS's which have been identified throughout the study area. The thickness, extent and capacity of potential sealing facies, however, need further understanding. The presence of well developed and excellent quality reservoir and sealing intervals coupled with known hydrocarbon charge in the Barrow Sub-basin may lead to the discovery of stacked reservoir/seal objectives within a stratigraphic play.

6.5.5 HIGH-RESOLUTION SEQUENCE STRATIGRAPHY LEADS (SEISMIC SEQUENCE 1)

The high-resolution sequence stratigraphic study undertaken for Seismic Sequence 1 has identified numerous leads. The features identified have been interpreted as lowstand prograding wedges and display onlapping features. Sandy lowstand wedges can be sealed against underlying shales of a HST and overlying shales of a TST, thus forming stratigraphic traps. The presence of sealing lithologies is high, as indicated by the mainly shaley interval displayed by the Emperor-1 intersection for Seismic Sequence 1. Minor reservoir quality sandstones were intersected at Emperor-1 for Seismic Sequence 1, therefore the chance of the presence of reservoir quality sands across the area is low. The presence of associated incised valleys is also possible and has been discussed in Chapter 5 and section 6.5.1.

6.5.6 STRUCTURAL/OTHER LEADS

Two purely structural leads have been identified within the study area and consist of anticlinal structures (Figure 6.5). The first structural lead is on the Barrow Island anticline trend and displays associated roll-over into a fault (Figure 6.5). Previous discoveries in the study area have comprised of such attributes, such as South Pepper-1 and North Herald-1 (Baillie & Jacobson, 1997).

Other potential leads identified in the study area include canyon features (Figure 6.6). These features are present below the interval of interest, but still display potential for hydrocarbon prospectivity. The features associated with the canyon include remnant erosional features and slope/slumped sands within the canyon (Figure 6.6).

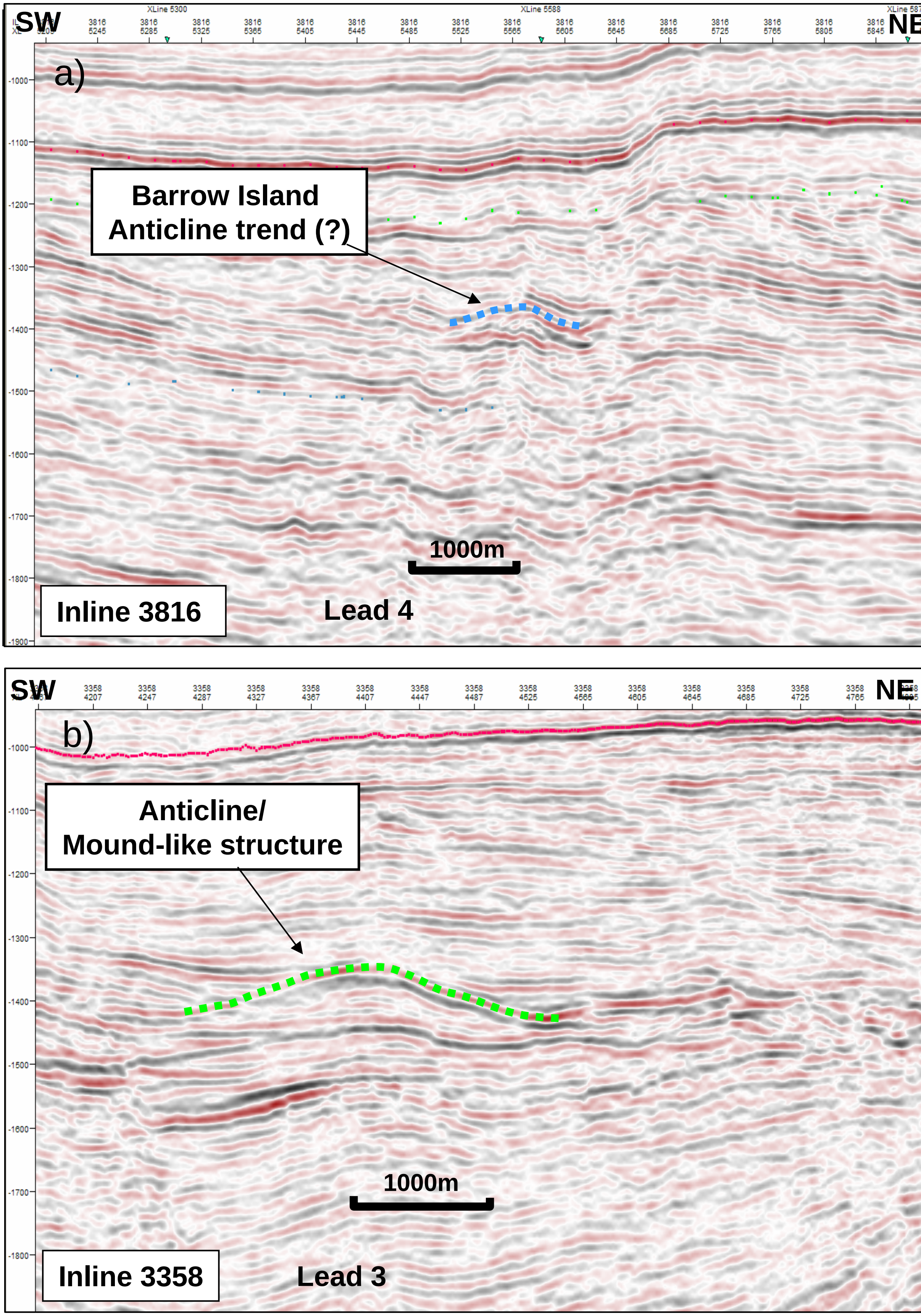


Figure 6.5 Structural leads identified in the study area, a) identified on inline 3816 and b) identified on inline 3358.

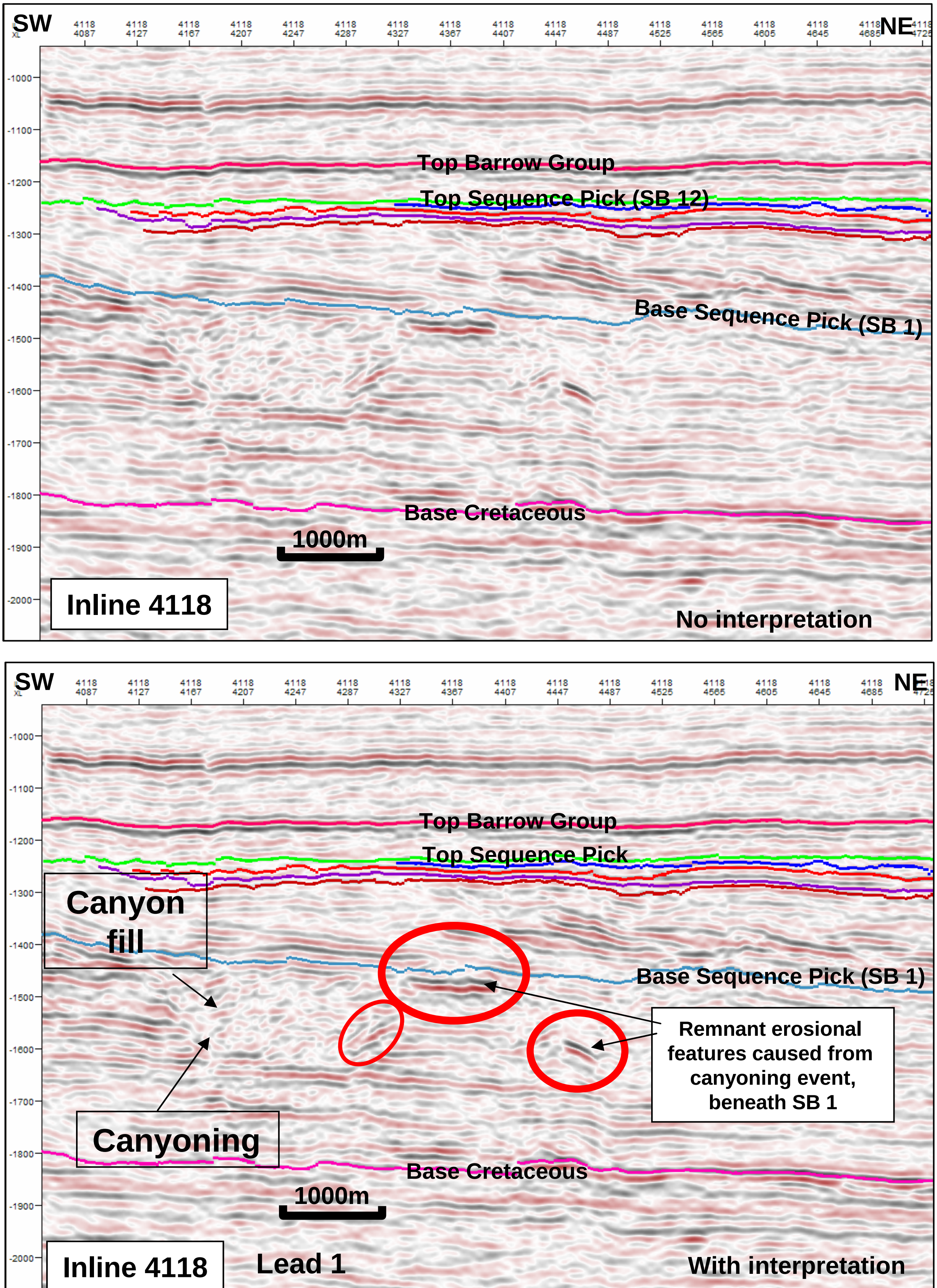


Figure 6.6 Potentially prospective canyoning feature identified in study area, potential play types that could be targeted include canyon fill, sloped/slumped sands in canyon and/or level/edge traps.

7.0 DISCUSSION

7.1 SHELF DEPOCENTRE EVOLUTION

The evolution of the main depositional centre for the interval of interest can be approximated as part of this study. The position of depocentres has been interpreted for each seismic sequence using isochron mapping (Figure 7.1). The purpose of analysing the position of multiple depocentres is to help in predicting the deposition of reservoir units, for example in the form of basin floor fans. These main areas of deposition during each time period (or seismic sequence) range from broad and elongate in shape to almost restricted in distribution.

The migration of the main depocentre for each sequence was interpreted based on the identification of numerous areas of greater thickness, with thinning of the sediments in between. The presence of multiple depositional centres for some seismic sequences may be due to the input of sediment from more than one source direction. The intra-Barrow Group's development can be clearly understood visually from the progression of each seismic sequence's interpreted depocentre. From oldest to youngest the depocentres build out in an overall northeasterly direction over time (Figure 7.1). Overall this technique is a good integrative method and is also discussed in relation to shelf-margin deltas by Porebski and Steel, 2003.

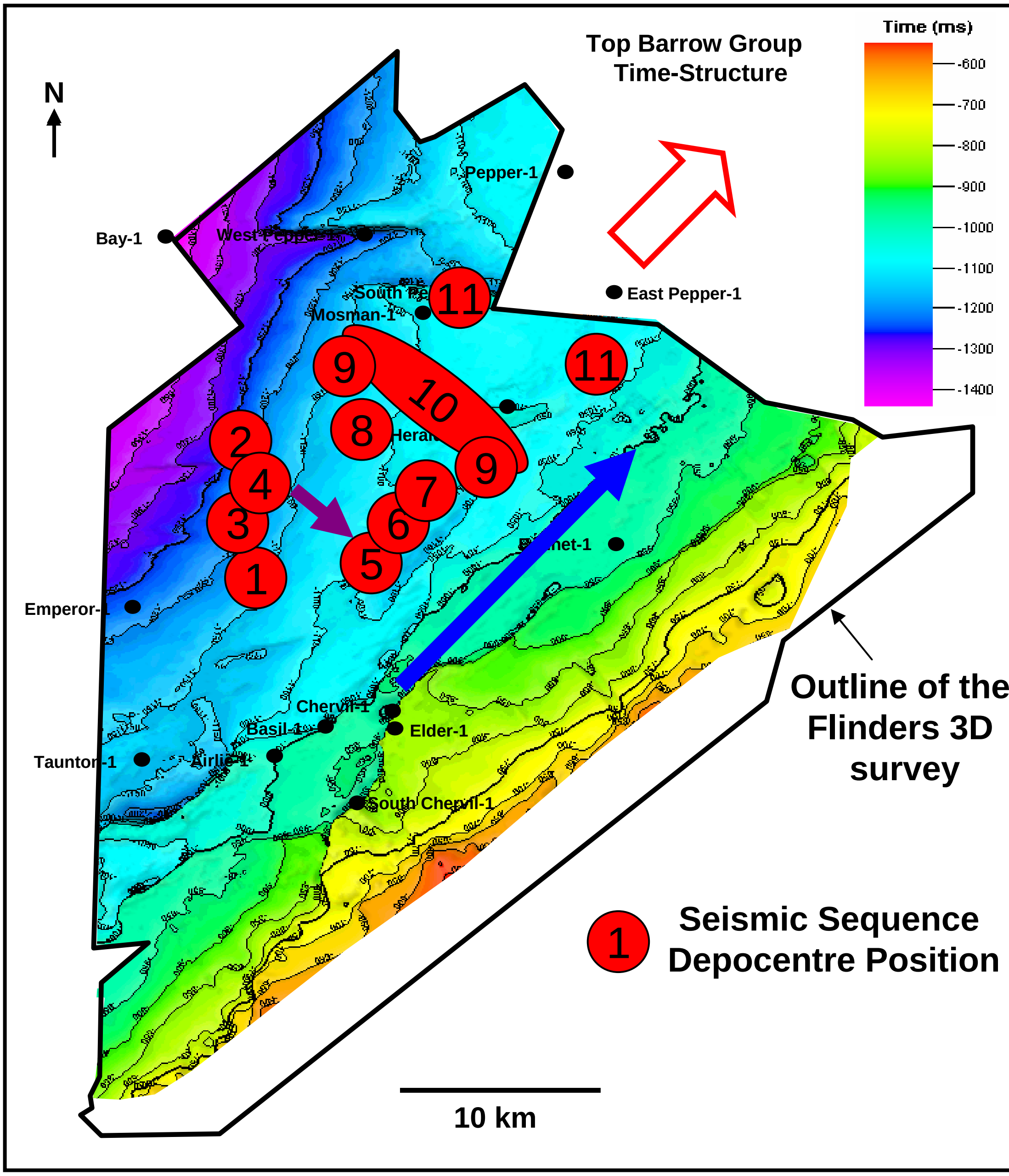


Figure 7.1 Shelf depocentre evolution of the intra-Barrow Group. Note overall progradation of sequences in a northeasterly direction (blue arrow) and apparent lobe switching direction (purple arrow).

7.2 N-NE SHELF PROGRADATION AND ROTATION

The palaeo-shelf break position for each seismic sequence has been mapped out over the Flinders 3D seismic survey study area. The movement of the shelf break position for the interval of interest displays the progradation of the shelf in a northeasterly direction (Figure 7.2). During the evolution of the shelf break, a slight rotation in its direction of movement has been interpreted (Figure 7.2). This rotation alters from a north-easterly stepping direction in the older parts of the succession, to a more northerly direction for the younger part of the succession (Figure 7.2).

Gawthorpe & Colella (1990) discuss tectonic controls on coarse-grained delta depositional systems in rift basins, such as East Greenland, the Dead Sea and the Gulf of Suez, that provide potential analogues applicable to the intra-Barrow Group seismic stratigraphic interval of interest. The analogues suggest that the creation of depocentres and sediment sources due to tectonic movement are caused by rifting, Gawthorpe & Colella (1990) also note the rotation of shelf-break positions in these analogues.

It has been noted that the tectonic activity and associated subsidence with half-graben developments has a marked effect on the basin-fill architecture (Gawthorpe & Colella, 1990). Thus, the tectonic activity occurring during the Early Cretaceous for the study area may have involved development of half-

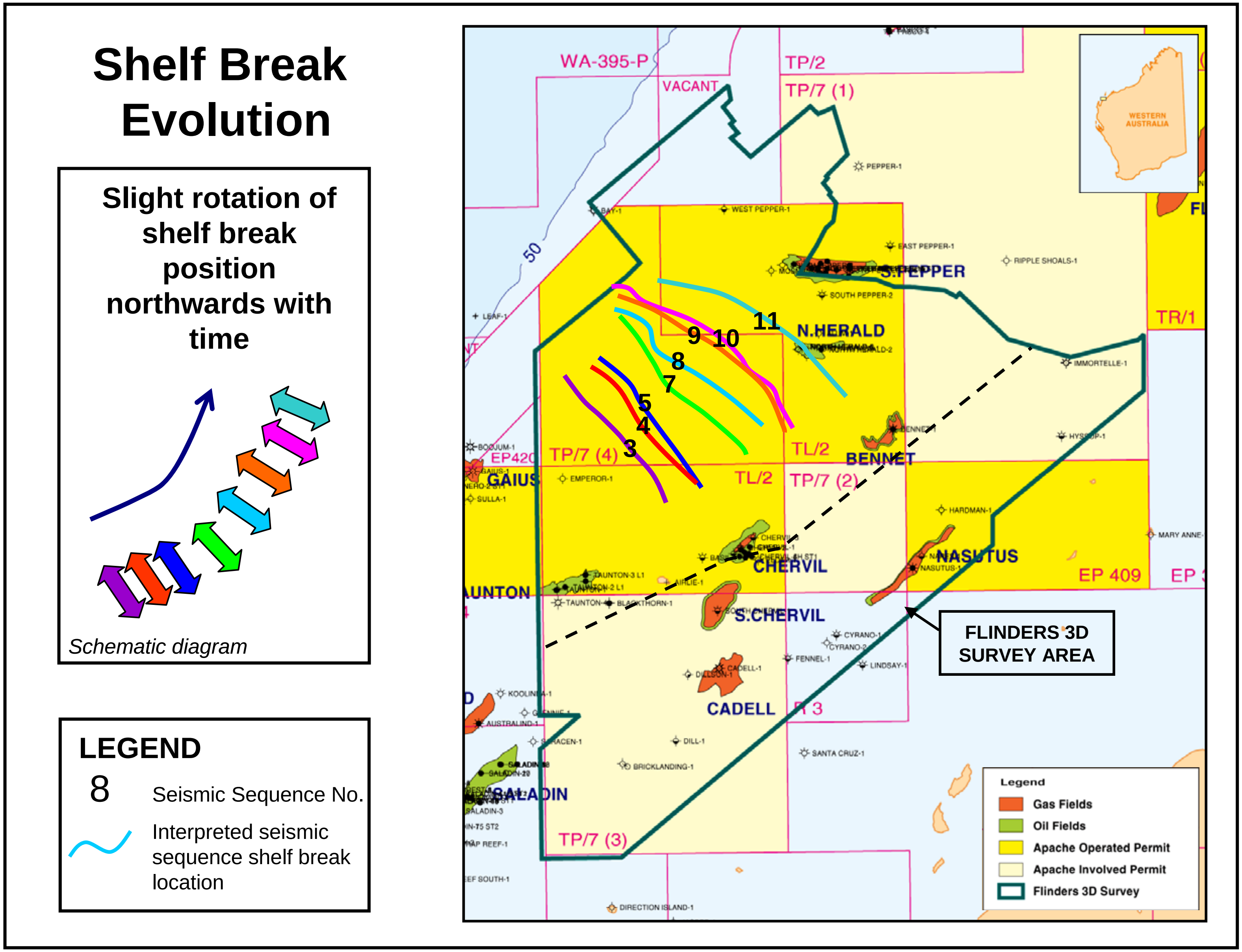


Figure 7.2 Overall N-NE shelf progradation and rotation during intra-Barrow Group deposition.

grabens with rifting and subsequent rotation and further movement of these fault blocks (Eriyagama et al., 1988). This suggests that the continued extension in the Argo-Abyssal Plain and the creation of accommodation space to the west of the study area contributed to the movement of the depocentre during intra-Barrow Group sedimentation (Eriyagama et al., 1988). This provides a possible explanation for the northeast to more northwards change in shelf-break evolution as seen in the study area (Figure 7.2).

7.3 ALASKAN ANALOGUE: NANUSHUK AND TOROK FM

Similar investigations to this project have been undertaken in the Beaufort Sea area in the northeast corner of the National Petroleum Reserve of Alaska (Figure 7.3). The Lower Cretaceous fill in this area includes the coeval clinoform and topset couplet of the Nanushuk Group and Torok Formation (Houseknecht & Schenk, 2002) (Figure 7.3). These deposits include fluvial, deltaic and marine sediments and have a well established regional sequence stratigraphic framework (Johnsson & Sokol, 1998). Studies performed for the Nanushuk Group and Torok Formation include the geometric relationship of sequences, delta migration and local and regional tectonics via the application of seismic sequence stratigraphy (Houseknecht & Schenk, 2002).

The presence of very clear prograding clinoforms in this part of Alaska is comparable to those of the Barrow Group in the Northern Carnarvon Basin,

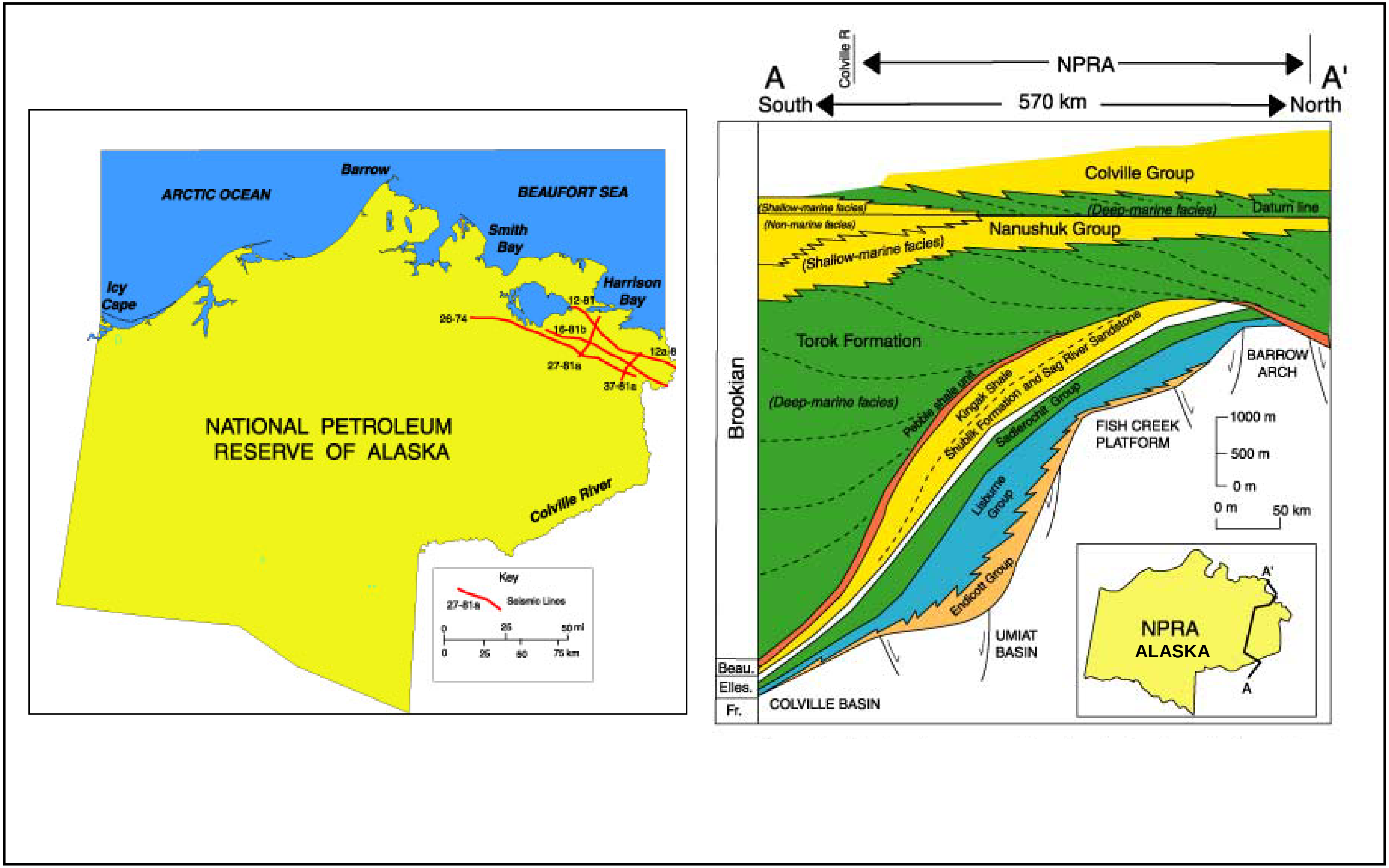


Figure 7.3 Alaskan Analogue: Nanushuk and Torok Formations location map and cross-section of stratigraphy (modified from Johnsson & Sokol, 1998).

Australia (Figure 7.4). The discussions involving these Alaskan sediments again mirror those of the intra-Barrow Group, particularly in regard to the explanation for rotations in progradation direction and reasons why this is seen in the study area. Similarly, the mapping of the crests of the clinoforms can be compared to the mapping of the shelf-break for the intra-Barrow Group over time (Figure 7.4). Both locations display shelf boundary/break progradation and rotation or change of progradation direction over time.

7.4 WEST SPITSBERGEN AND TRINIDAD ANALOGUES

Additional large shelf-margin deltas from West Spitsbergen and Trinidad can be discussed as analogues in respect to the Barrow Group. The shelf-edge successions and shelf-slope-basin floor clinoforms are exposed in outcrop along mountainsides in the Central Basin of Spitsbergen, Norway (Porebski & Steel, 2003) (Figure 7.5). These shelf-edge deltas provide excellent examples from the outer shelf to basin plain facies distributions (Steel et al., 2000). Furthermore canyons, shelf collapse, formation of incised valleys and prograding shelf-edge systems are viewed at Spitsbergen (Porebski & Steel, 2003), can be directly related to and are comparable in scale to the Barrow Group.

The Pliocene aged palaeo-Orinoco Delta, Trinidad can also be used a direct analogue to the Barrow Group. This shelf-edge deltaic system displays prograding sigmoid oblique clinoforms (Steel, 2005) (Figure 7.6), similar to those viewed on seismic at the intra-Barrow Group level. The Orinoco Delta thus

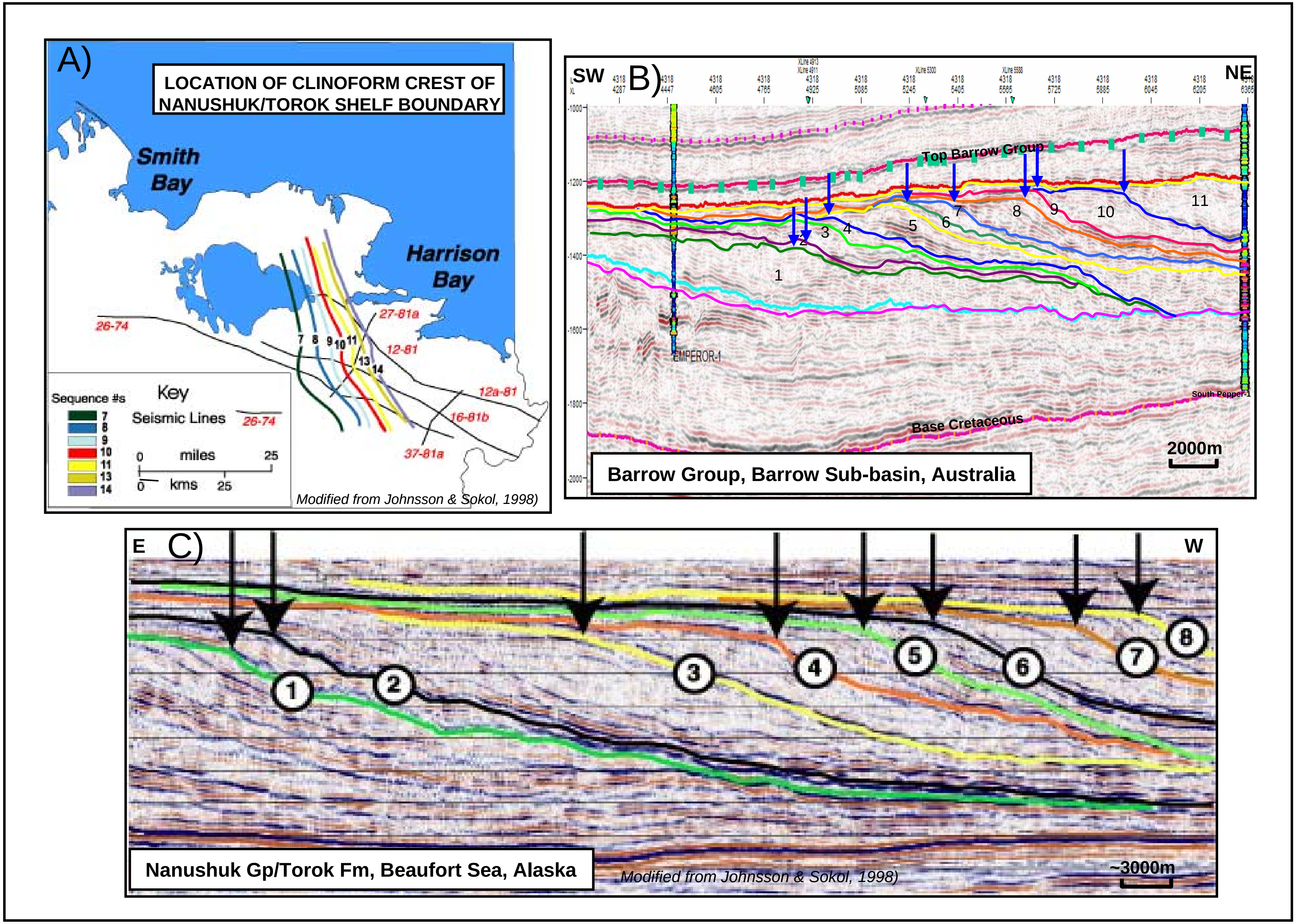


Figure 7.4 Alaskan Analogue comparison to intra-Barrow Group, Australia. A) Location map of clinoform crests of analogue, B) Intra-Barrow Group sequence stratigraphy framework, with clinoform crest locations (highlighted by blue arrows) and C) Alaskan analogue clinoform crest locations, (highlighted by black arrows).

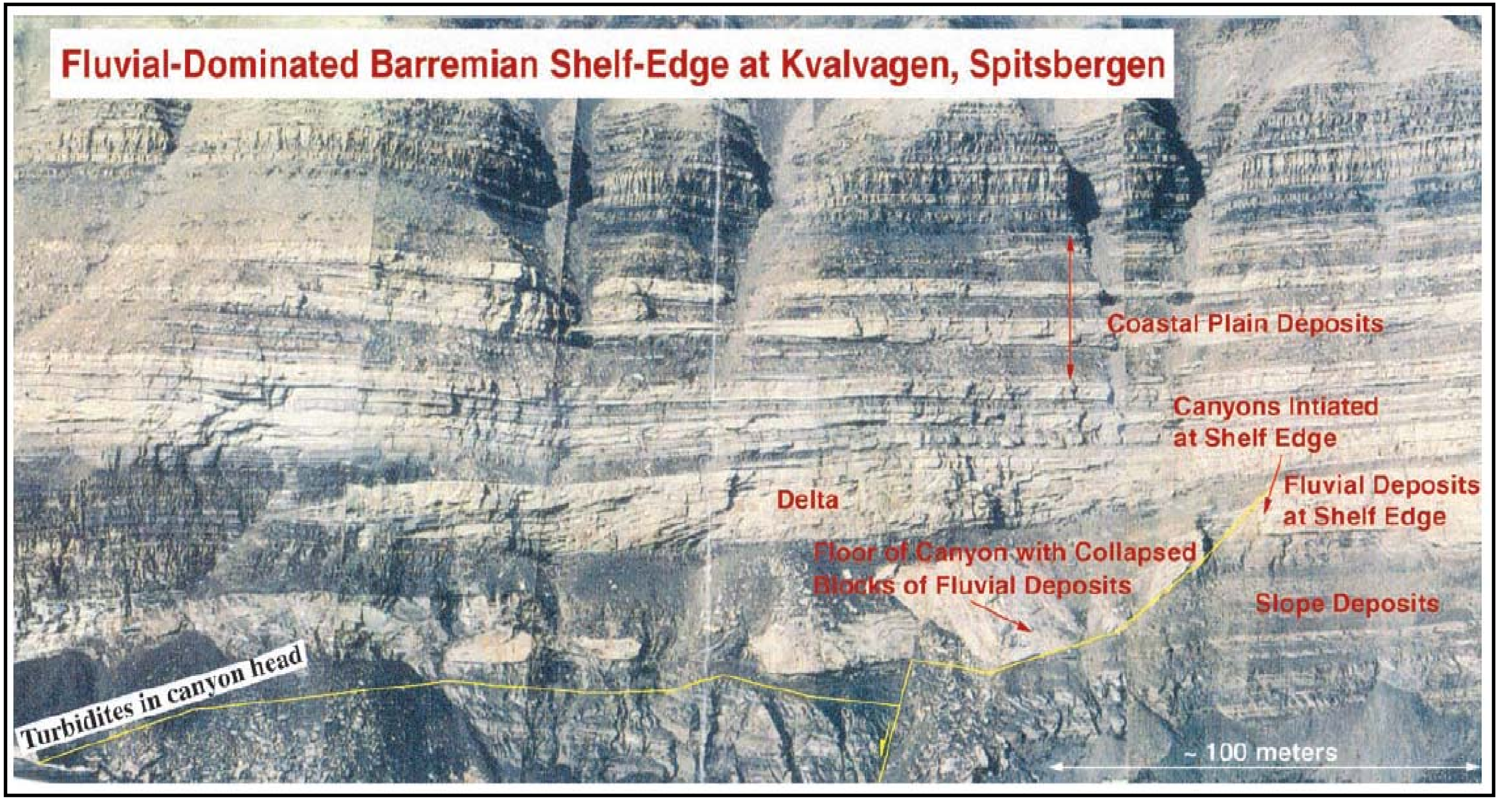


Figure 7.5 Features of a falling-stage, Barremian shelf-edge collapse and upper canyon (Kvalvagen, Spitsbergen. Fluvial deposits, turbidite beds and prograding shelf-edge deltas across earlier collapse area post sea level rise above shelf edge, can all be viewed from photo (modified from Porebski & Steel, 2003).

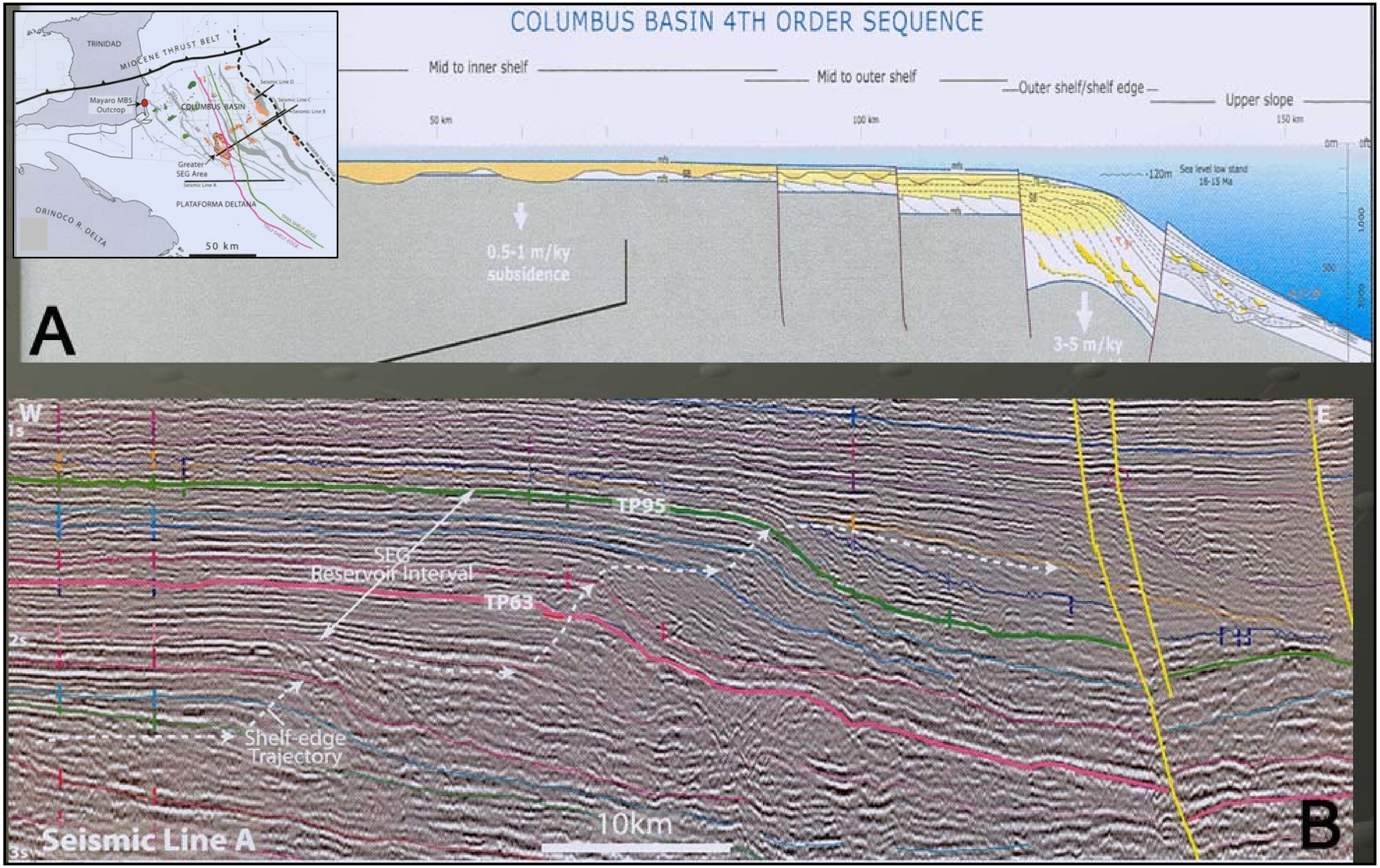


Figure 7.6 **A. Cross-section through Columbus Basin 4th order sequence between maximum flooding surfaces below and above sand-rich interval defined by a basal unconformity. B. Seismic line through Columbus Basin displaying shelf-edge trajectory, sigmoid oblique clinoforms and transiting of the palaeo-Orinoco Delta, Trinidad (modified from Steel, 2005).**

provides analogous examples of high resolution seismic imaging and subsequent understandings of tectonic, fluvial process and accommodation space fluctuations that influence deltaic and shelfal architecture, of which can be used to further understand the Barrow Group evolution (Israel, 2005).

8.0 CONCLUSIONS

The majority of discoveries in the study area have been Top Barrow Group structural plays. Therefore, an investigation into the sequence stratigraphy and the stratigraphic-play potential of the lower intra-Barrow Group was warranted and has the ability to propose new play types in the study, which will have the potential to add to the discovered resource in the region and revive the exploration methods undertaken. The Flinders 3D seismic dataset used for study has only recently been acquired to enable such a detailed study, hence the ability to have 3D is important to conduct studies such as those undertaken for this project.

A seismic-based sequence stratigraphic framework has been developed for the intra-Barrow Group via the integration of the Flinders 3D seismic survey and the currently available well data. 11 seismic sequences separated by sequence boundaries have been identified and mapped out across the majority of the study area where good quality data prevailed. Each seismic sequence was classified in terms of systems tracts nomenclature taken from Posamentier and Vail (1988), which aided in the interpretation for this study.

The palaeo-shelf break, slope and base of slope positions have been mapped out for each seismic sequence in order to help with the interpretation of depositional environment and also the later prospectivity study. Palaeogeographic reconstructions for each seismic sequence has been drawn schematically via the integration of seismic, well, map, sequence stratigraphic framework and palaeo-shelf break, slope and base of slope positions. These provided a useful reference for comparison of intervals and also for future exploration activities.

The main depositional centres for each seismic sequence display an overall northward progression. Switching of depocentres and occasional splitting into two main depocentres also occur. This interpretation also aided in the in the palaeo-geographic reconstructions for each seismic sequence and also play analysis/lead identification for the interval of interest.

Shelf-break rotation, possibly due to rifting, coincided during the time of deposition along with associated fault block rotation. This was interpreted for the overall study interval and was useful for each of the palaeo-geographic reconstructions throughout the interval of interest. Similar investigations analogous to the intra-Barrow Group have been undertaken in the Beaufort Sea area in the northeastern corner of the National Petroleum Reserve of Alaska, where similar shelf-break rotation has been interpreted (Houseknecht & Schenk, 2002).

A high-resolution sequence stratigraphic study was undertaken for Seismic Sequence 1. Numerous higher-order sequence boundaries and systems tracts were identified, which resulted in the identification of a number high-resolution leads.

From the play analysis/lead identification study undertaken, 5 leads have been identified in the study area and are defined by play type including shelfal, slope and basin-floor, along with structural plays. Additionally, each seismic sequence identified has been discussed in detail in regards to prospectivity and each key play element (reservoir, source, seal, trap). Seismic Sequence’s 1, 3, 4, 5, 8, 10 and 11 have all been graded as displaying medium to high hydrocarbon prospectivity. The remaining seismic sequences (2, 6, 7 and 9) have been highlighted as potentially comprising of solely sealing or reservoir facies. The combination of well intersections, seismic response and, most importantly, the seismic sequence stratigraphic framework has led to such conclusions being made for each seismic sequence’s prospectivity.

The seismic sequence stratigraphic framework developed for the intra-Barrow Group has been integrated to assess the hydrocarbon prospectivity, with areas of future exploration potential highlighted in the form of numerous leads. Further work is required to asses these leads. However, this method has demonstrated that the seismic sequence stratigraphic framework developed is a valuable technique in helping to identify focal points to help fast track the search for hydrocarbon accumulations in an area where conventional play types (structural closures) have been the historical norm.

Overall, this study has shown that stratigraphic plays have been under explored, as new plays have been documented in the study area, and that developing a seismic sequence stratigraphic framework can be used as a predictive tool.

9.0 RECOMMENDATIONS

The following recommendations are presented as a result of this study:

- It is recommended that the regional sequence sequence stratigraphic framework is extended to the entire Barrow Group.

- It is recommended that the regional sequence stratigraphic framework is extended to 3D seismic surveys adjoining the Flinders 3D survey (e.g. Snark 3D seismic survey).

- Integration of all recent well results (Boojum-1 and Gaius-1) intersecting the intra-Barrow Group nearby to study area.

- Integration of all available core and cuttings data from the wells in study area.

- High-resolution sequence stratigraphic studies are recommended to be attempted for most seismic sequences identified.

- Additional work on the leads identified is necessary, in particular focusing on the presence and quality of sealing lithologies, and also presence and timing of expulsion of potential source rocks.

- The application of RMS, coherency and opacity functions to the seismic is recommended as a further possibility of improving seismic quality and geologic features viewed and interpreted from the 3D seismic survey.

- The inclusion of synthetic seismograms for key wells would also add value to the overall thesis.

10.0 Appendix

1.0 A3 summary figures for each Seismic Sequence interpreted from project

SEISMIC SEQUENCE 1 SUMMARY SHEET

Summary

- Palaeo-environment is predominantly fluvial/deltaic
- Defined by SB1 and SB2
- Key well – Emperor-1
- Seismic character consists of both high and low amplitude continuous reflectors
- Mapped over 246sqkm and between 0 and 180ms thick
- Spans the *B.reticulatum* dinocyst zone
- Displays overall progradational stacking patterns
- Interpreted to consist of thick HST overlying a TST

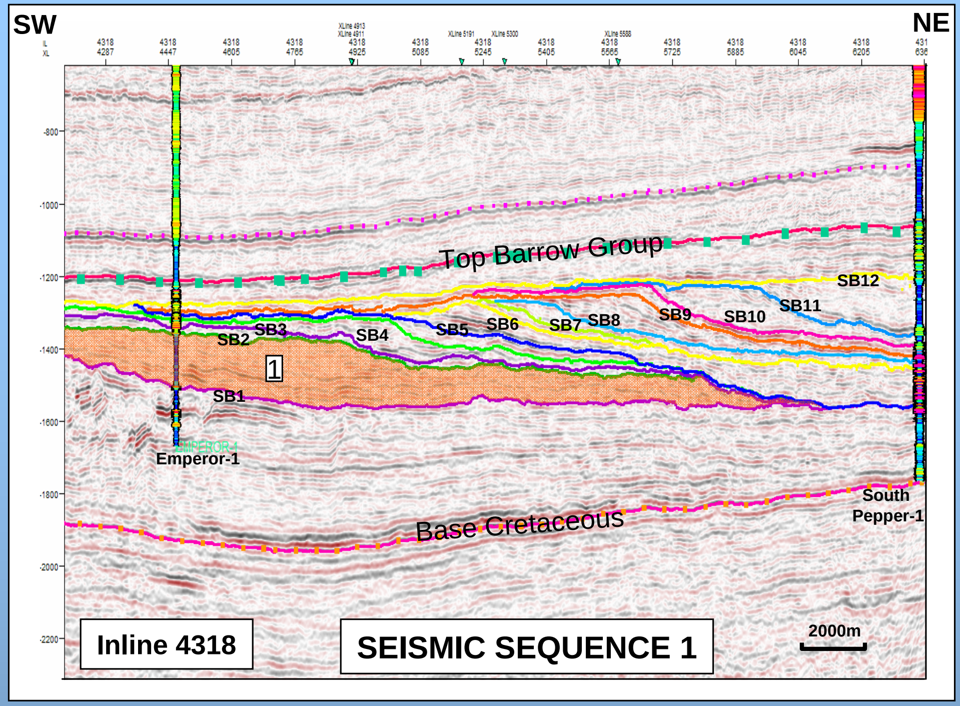


Figure 1. Seismic section displaying Seismic Sequence 1, bound by sequence boundary 1 and sequence boundary 2

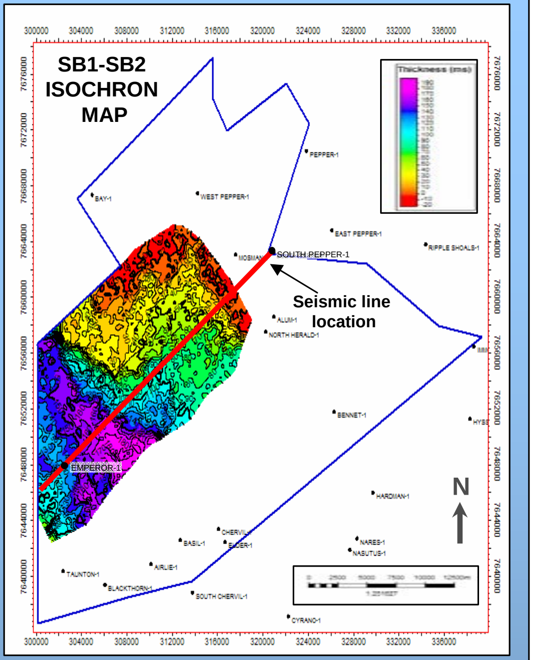


Figure 2. SB1 – SB2 Isochron Map

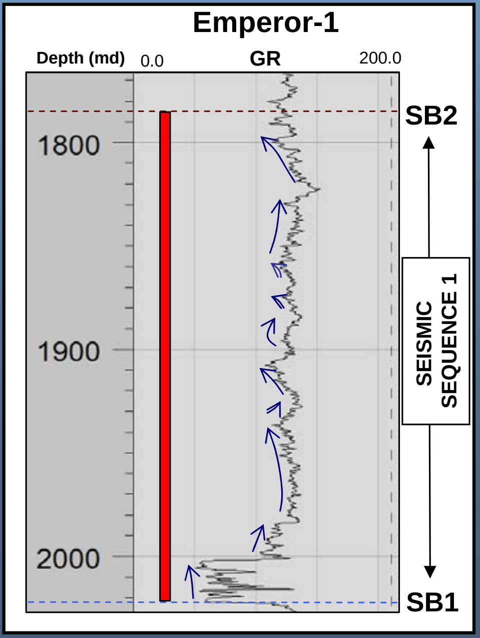


Figure 3. Gamma ray response at Emperor-1 for seismic sequence 1. Note overall high gamma ray response for majority of sequence.

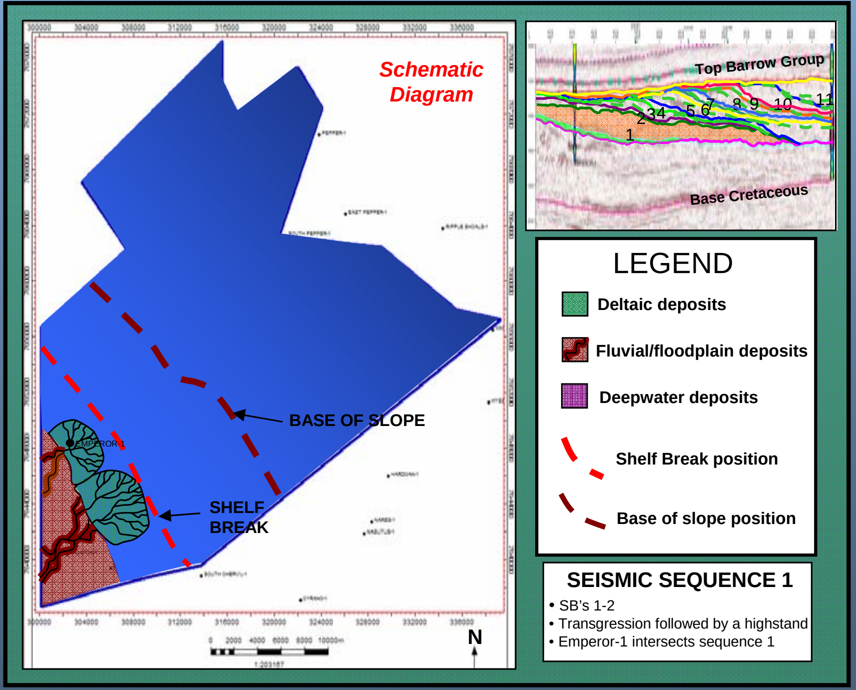


Figure 4. Seismic Sequence 1 palaeo-geography map

SEISMIC SEQUENCE 2 SUMMARY SHEET

Summary

- Palaeo-environment is predominantly deltaic
- Defined by SB2 and SB3
- Key well – Emperor-1
- Seismic character consists of generally low-amplitude continuous reflectors
- Mapped over 166sqkm and between 0 and 50ms thick
- Spans the *B. reticulatum* dinocyst zone
- Displays overall retrogradational stacking patterns
- Interpreted to consist of a transgressive systems tract

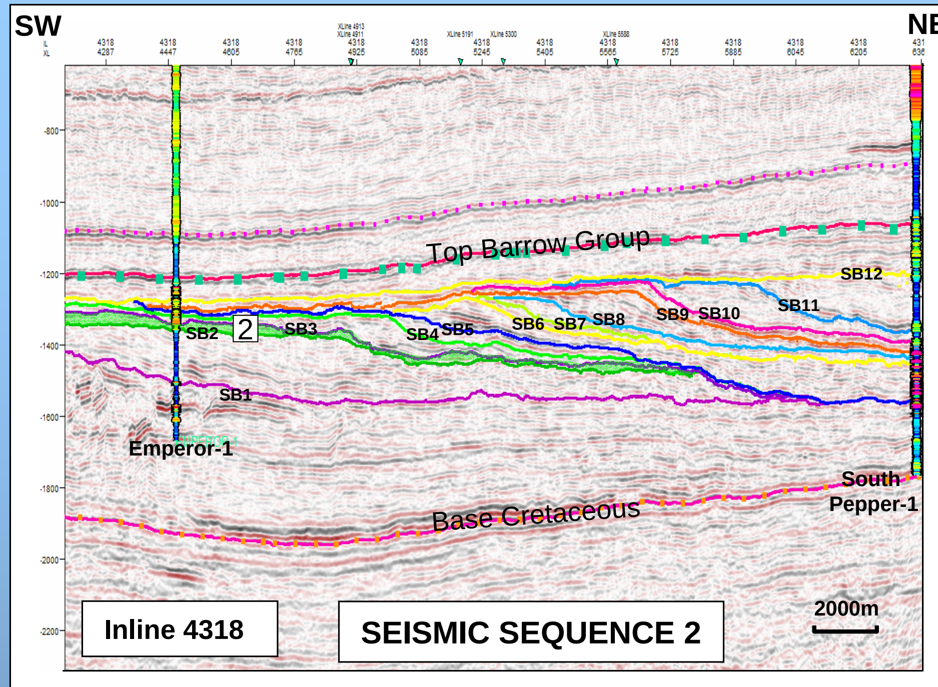


Figure 1. Seismic section displaying Seismic Sequence 2, bound by sequence boundary 2 and sequence boundary 3

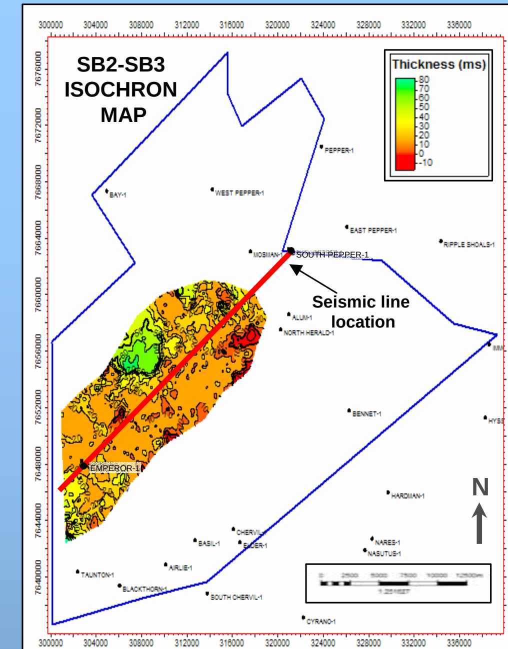


Figure 2. SB2 – SB3 Isochron Map

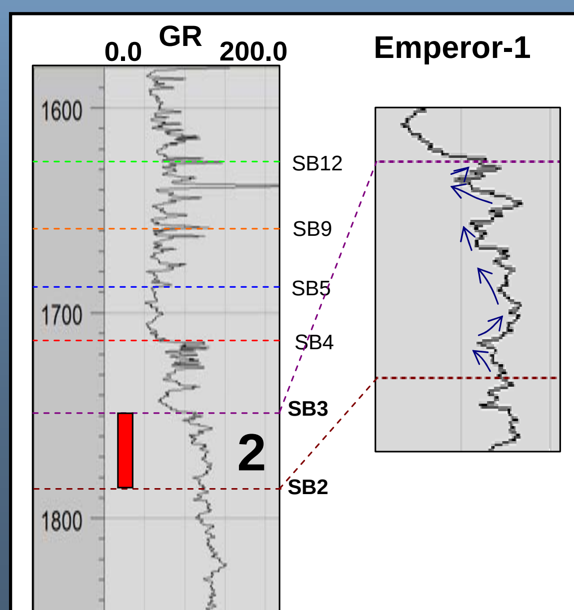


Figure 3. Gamma ray response at Emperor-1 for seismic sequence 2. Displaying numerous retrograding and prograding stacking patterns.

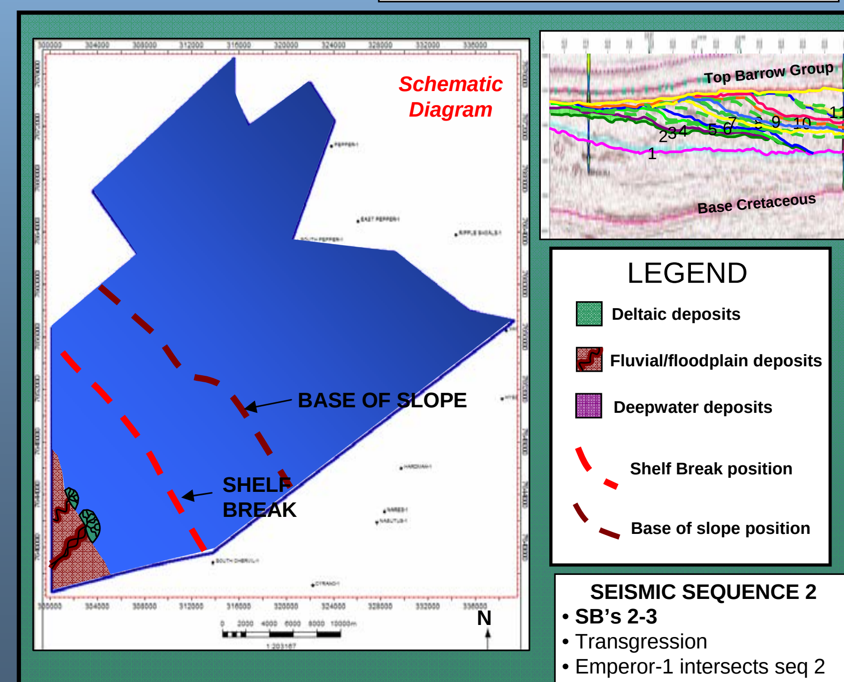


Figure 4. Seismic Sequence 2 palaeo-geography map

SEISMIC SEQUENCE 3 SUMMARY SHEET

Summary

- Palaeo-environments include fluvial, delatic and deepwater
- Defined by SB3 and SB4
- Key well – Emperor-1
- Seismic character consists of high-amplitude moderately continuous reflectors
- Mapped over 255sqkm and between 0 and 95ms thick
- Spans the *B. reticulatum* dinocyst zone
- Displays overall blocky retrogradational stacking pattern
- Interpreted to consist of a LST overlain by a TST, followed by a HST

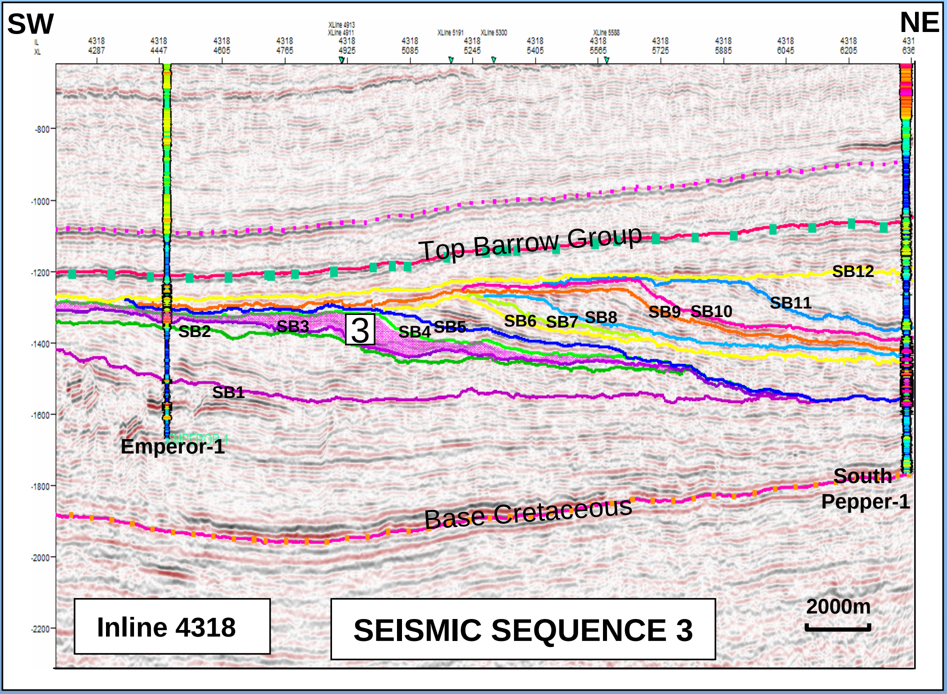


Figure 1. Seismic section displaying Seismic Sequence 3, bound by sequence boundary 3 and sequence boundary 4

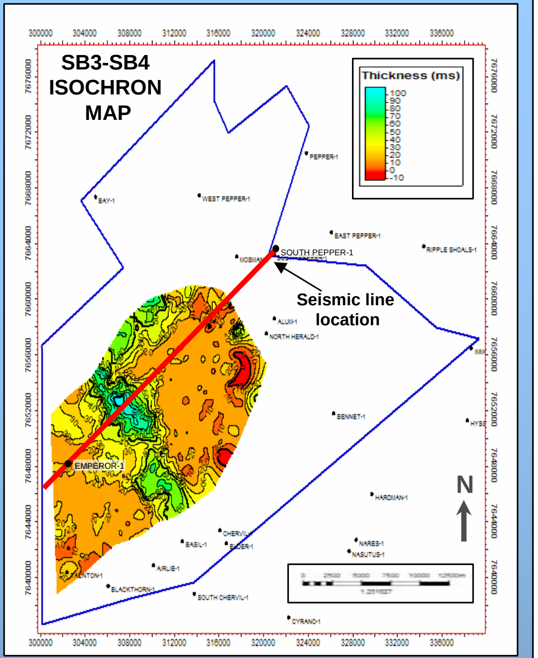


Figure 2. SB3 – SB4 Isochron Map

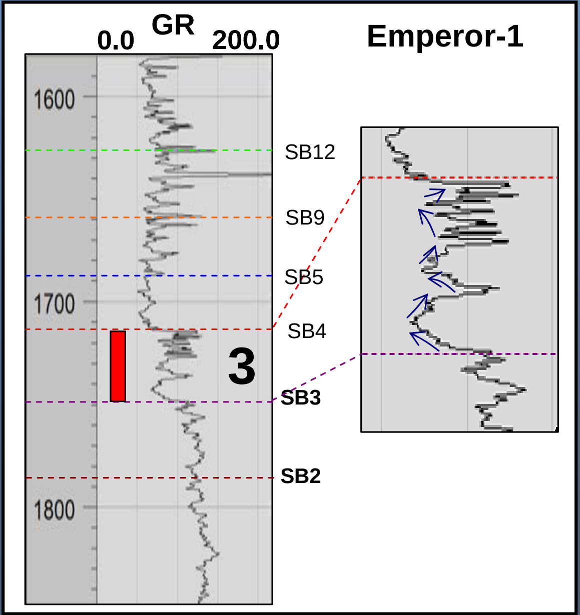


Figure 3. Gamma ray response at Emperor-1 for seismic sequence 3. Displays overall blocky retrogradational patterns with intermittent prograding patterns

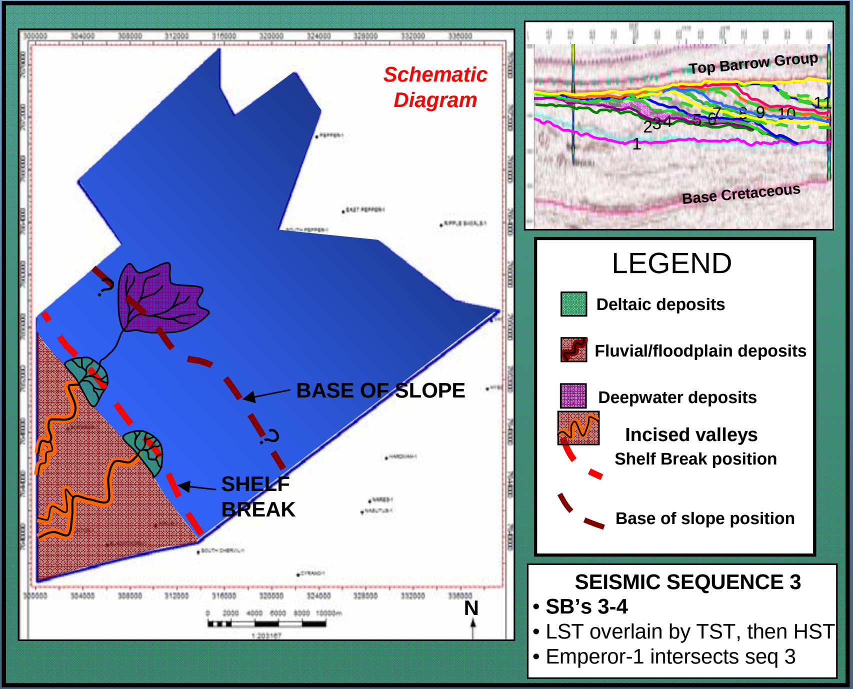


Figure 4. Seismic Sequence 3 palaeo-geography map

SEISMIC SEQUENCE 4 SUMMARY SHEET

Summary

- Palaeo-environment is predominantly deltaic
- Defined by SB4 and SB5
- Key well – Emperor-1
- Seismic character consists of sub-parallel moderately continuous reflectors
- Mapped over 216sqkm and between 0 and 55ms thick
- Spans the *B. reticulatum* dinocyst zone
- Displays several retrogradational and prograding stacking patterns
- Interpreted to consist of a TST overlain by a HST

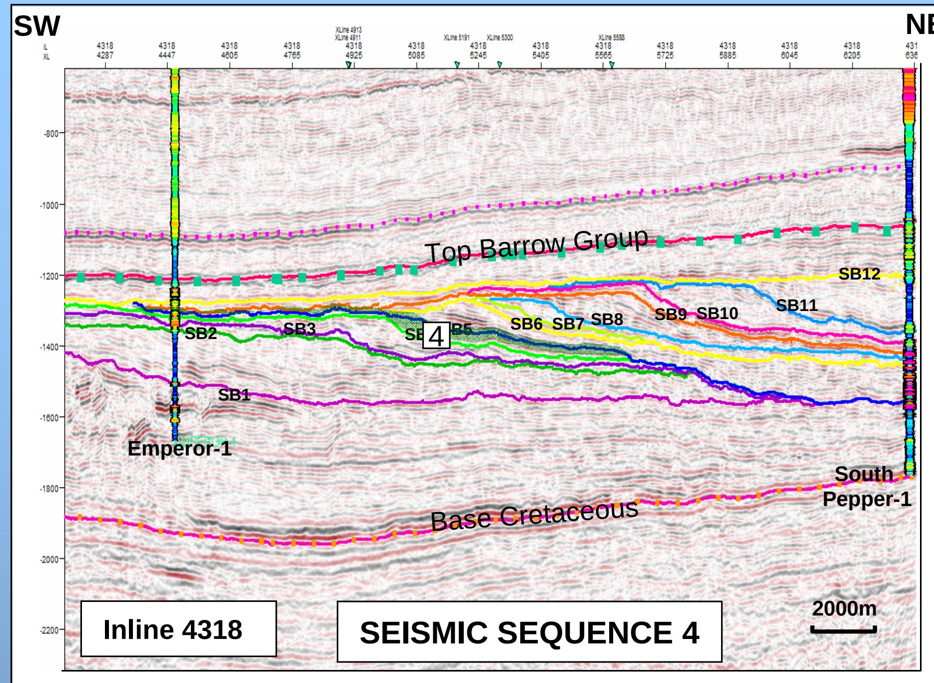


Figure 1. Seismic section displaying Seismic Sequence 4, bound by sequence boundary 4 and sequence boundary 5

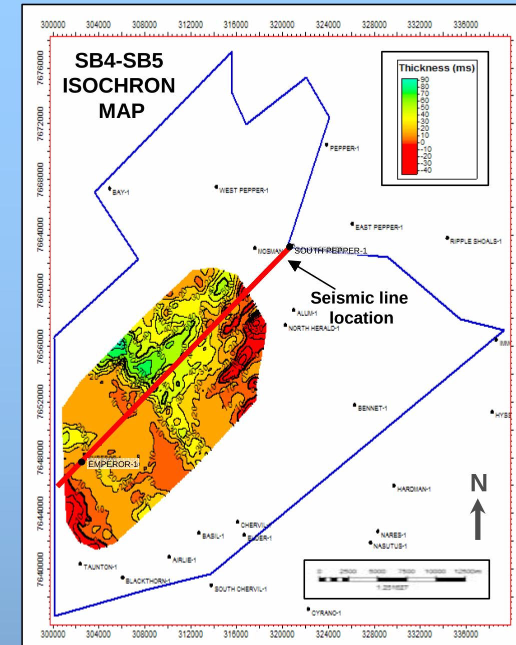


Figure 2. SB4 – SB5 Isochron Map

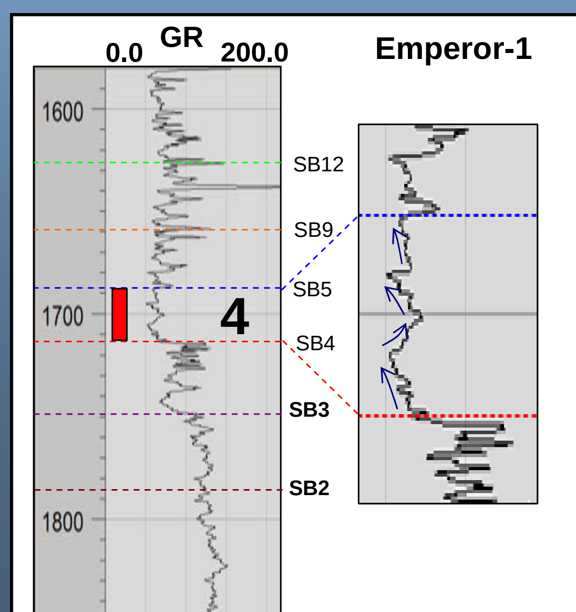


Figure 3. Gamma ray response at Emperor-1 for seismic sequence 4. Displaying numerous retrograding and prograding stacking patterns.

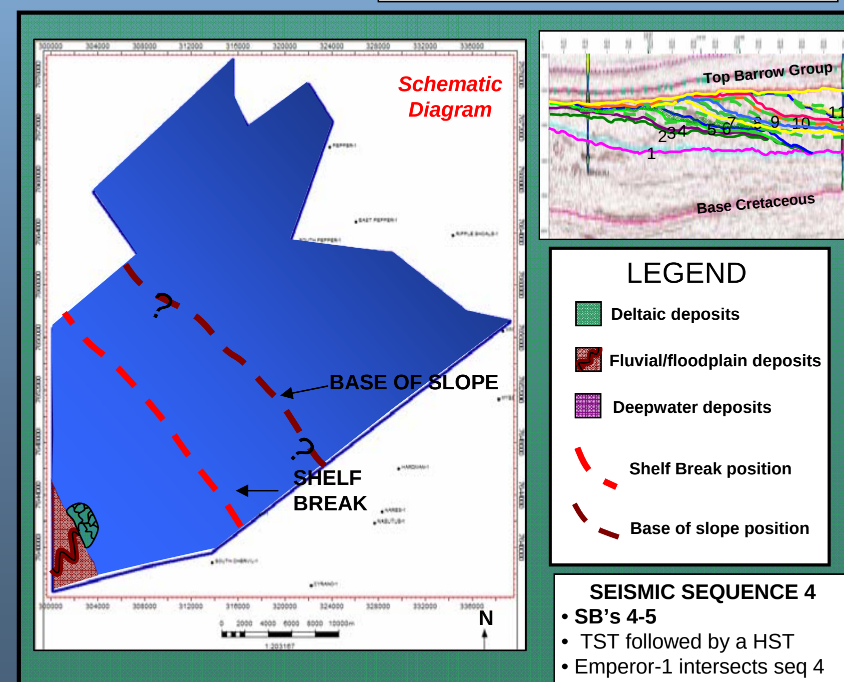


Figure 4. Seismic Sequence 4 palaeo-geography map

SEISMIC SEQUENCE 5 SUMMARY SHEET

Summary

- Palaeo-environment is predominantly deepwater
- Defined by SB5 and SB6
- Key wells – Nth Herald-1, Sth Pepper-1, Alum-1
- Seismic character consists of sub-parallel, mounded, moderately continuous reflectors
- Mapped over 114sqkm and between 0 and 100ms thick
- Spans the *B. reticulatum* dinocyst zone
- Displays blocky gamma ray stacking patterns
- Interpreted to consist of a LST, TST overlain by a HST

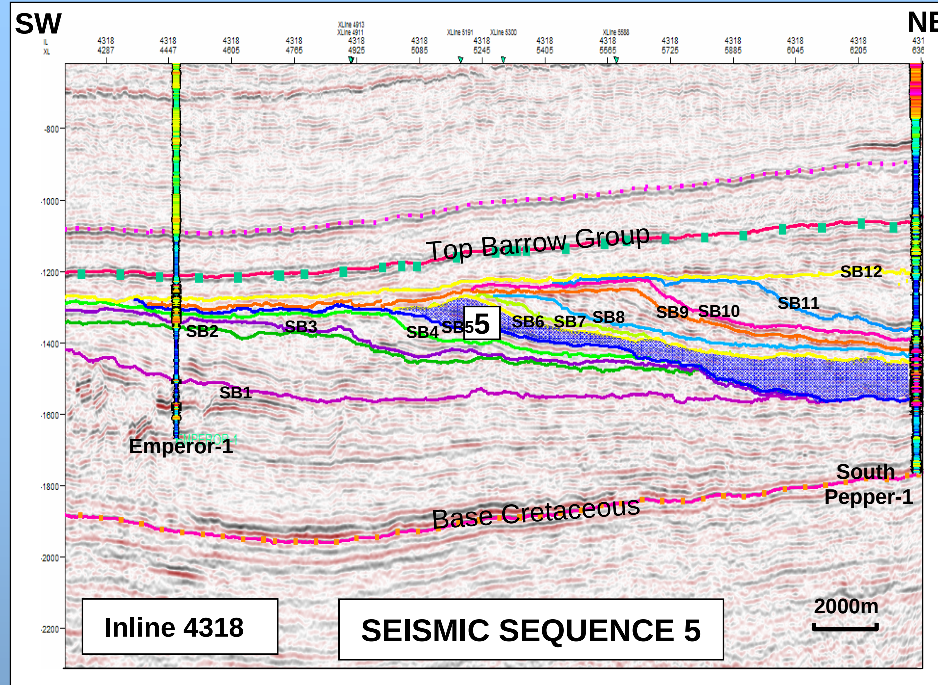


Figure 1. Seismic section displaying Seismic Sequence 5, bound by sequence boundary 5 and sequence boundary 6

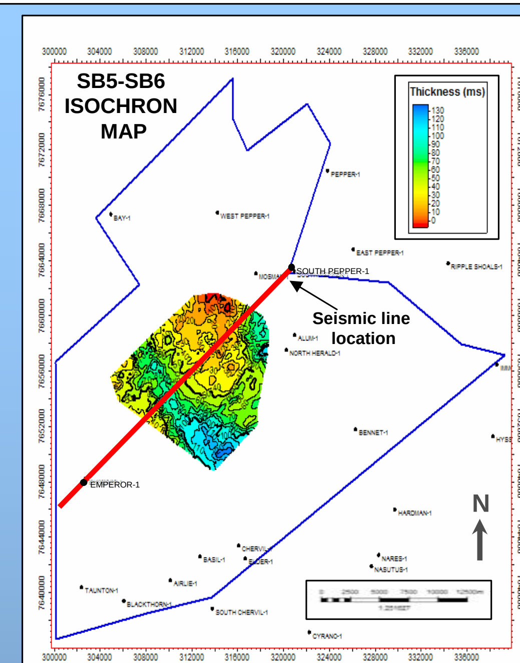


Figure 2. SB5 – SB6 Isochron Map

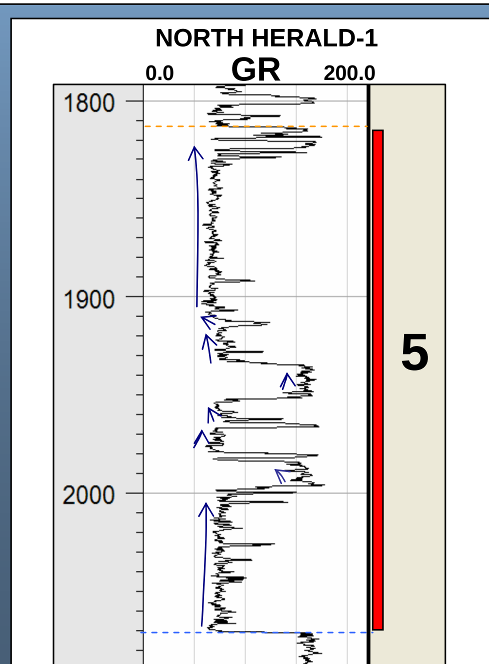


Figure 3. Gamma ray response at North Herald-1 for seismic sequence 5. Displaying blocky sands with sharp tops and bases.

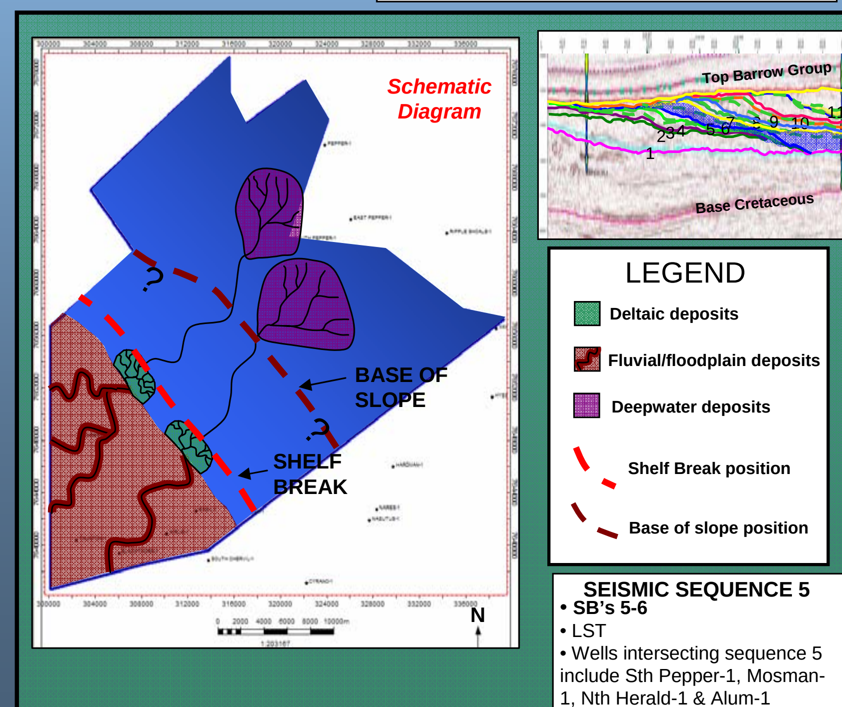


Figure 4. Seismic Sequence 5 palaeo-geography map

SEISMIC SEQUENCE 6 SUMMARY SHEET

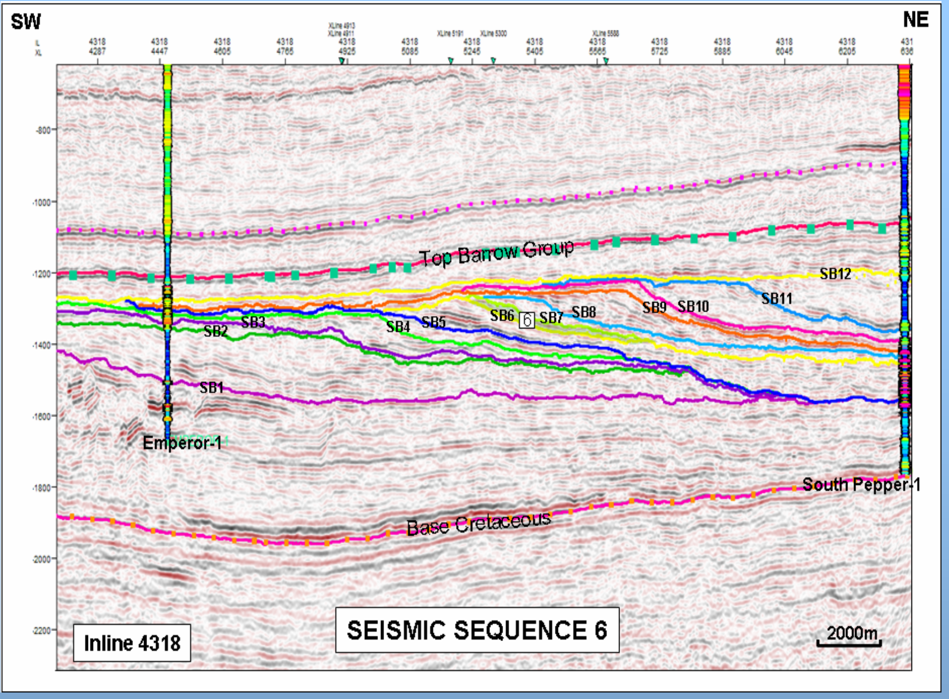


Figure 1. Seismic section displaying Seismic Sequence 6, bound by sequence boundary 6 and sequence boundary 7

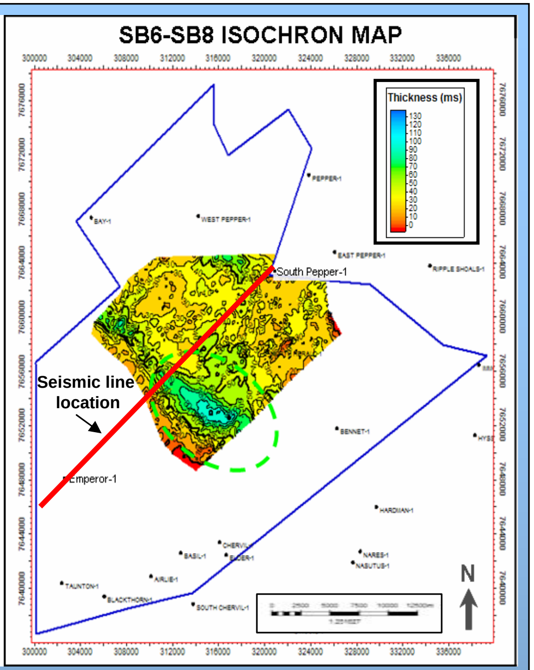


Figure 2. SB6 – SB8 Isochron Map

Summary

- Palaeo-environment is predominantly fluvial and deltaic conditions
- Defined by SB6 and SB7
- Seismic character consists of moderately continuous and parallel, typically of low-moderate amplitude
- Mapped over 59sqkm and between 0 and 40ms thick
- Spans the *B. reticulatum* dinocyst zone

Interpreted to consist of a lowstand systems tract

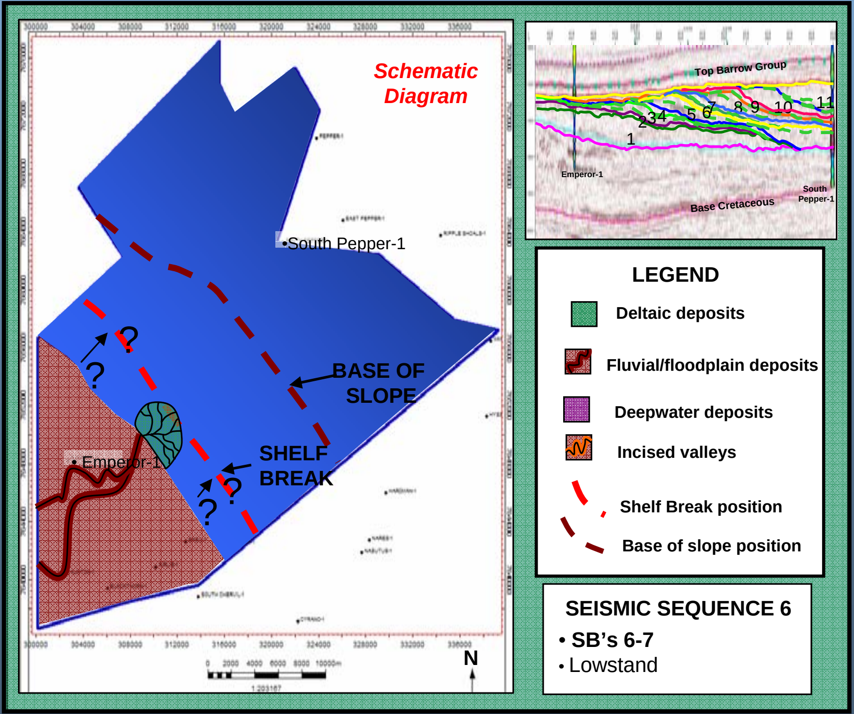


Figure 4. Seismic Sequence 6 palaeo-geography map

SEISMIC SEQUENCE 7 SUMMARY SHEET

Summary

- Palaeo-environment is predominantly fluvial and deltaic
- Defined by SB6 and SB8
- Key wells – Nth Herald-1, Sth Pepper-1, Alum-1, Mosman-1
- Seismic character consists of fair to moderately continuous parallel reflectors of moderate amplitude
- Mapped over 58sqkm and between 0 and 110ms thick
- Spans the middle *B. reticulatum* dinocyst zone
- Displays blocky low gamma ray, separated by thick high gamma ray stacking patterns
- Interpreted to consist of a TST overlain by a HST

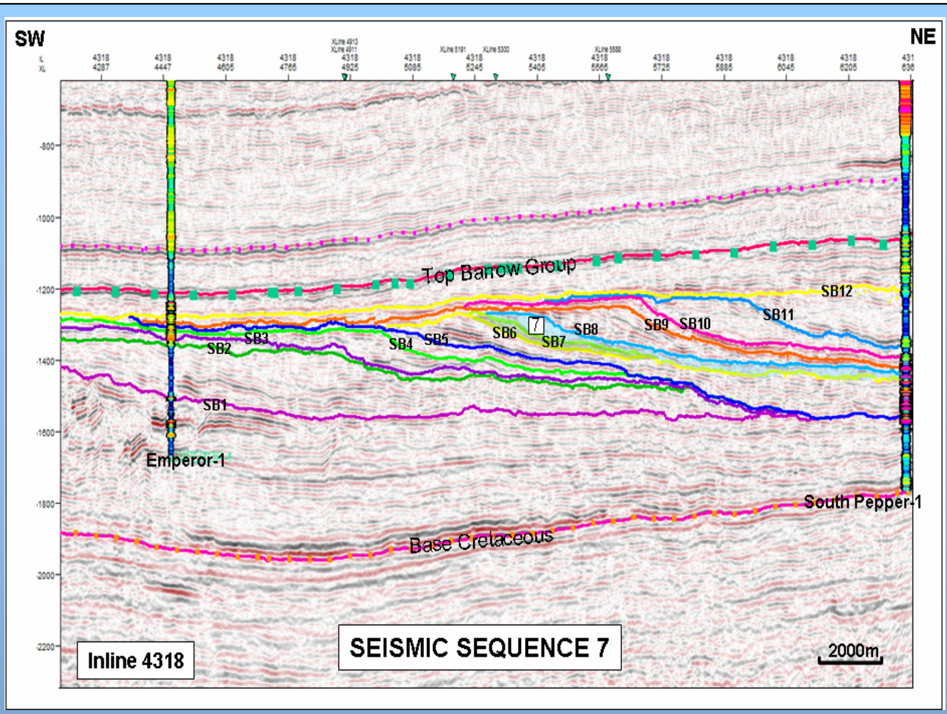


Figure 1. Seismic section displaying Seismic Sequence 7, bound by sequence boundary 7 and sequence boundary 8

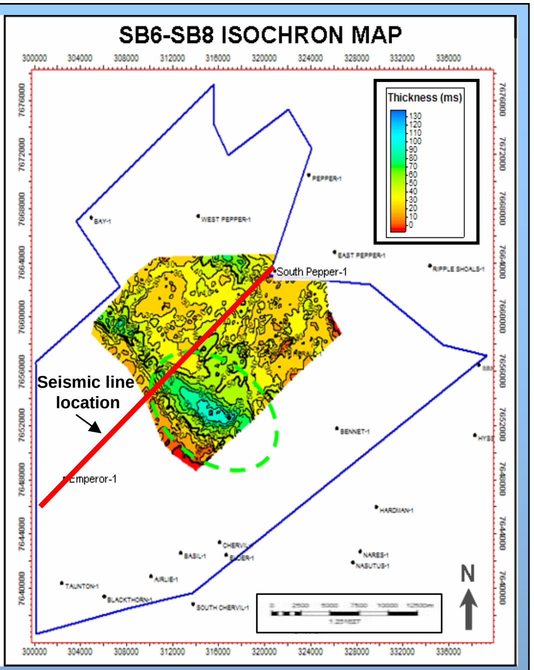


Figure 2. SB6 – SB8 Isochron Map

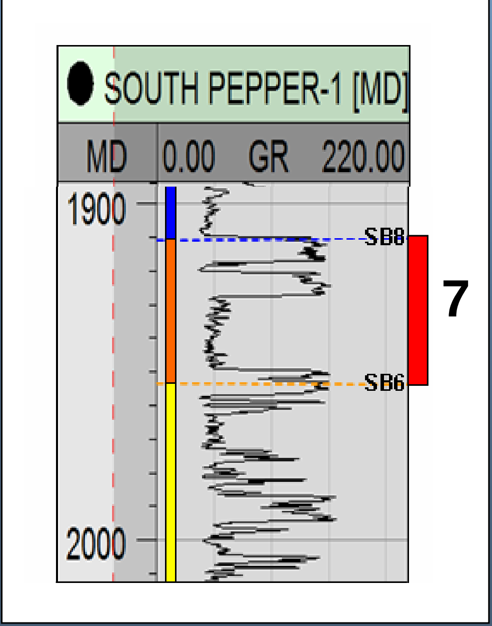


Figure 3. GR response at Sth Pepper-1 for SS7. Displaying blocky sands with sharp tops and bases.

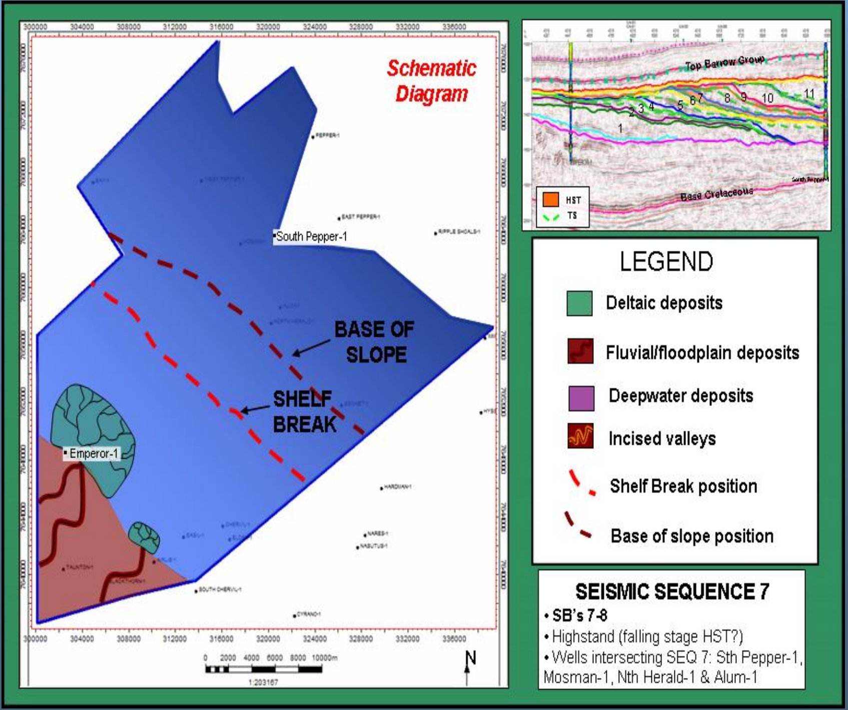


Figure 4. Seismic Sequence 7 palaeo-geography map

SEISMIC SEQUENCE 8 SUMMARY SHEET

Summary

- Palaeo-environments are fluvial, deltaic and deepwater
- Defined by SB8 and SB9
- Key wells – Nth Herald-1, Sth Pepper-1, Alum-1, Mosman-1
- Seismic character consists of sigmoid to oblique continuous reflections of moderate to high amplitude
- Mapped over 225sqkm and between 0 and 80ms thick
- Spans the middle *B. reticulatum* dinocyst zone
- Displays blocky gamma ray prograding stacking patterns
- Interpreted to consist of a LST, TST overlain by a HST

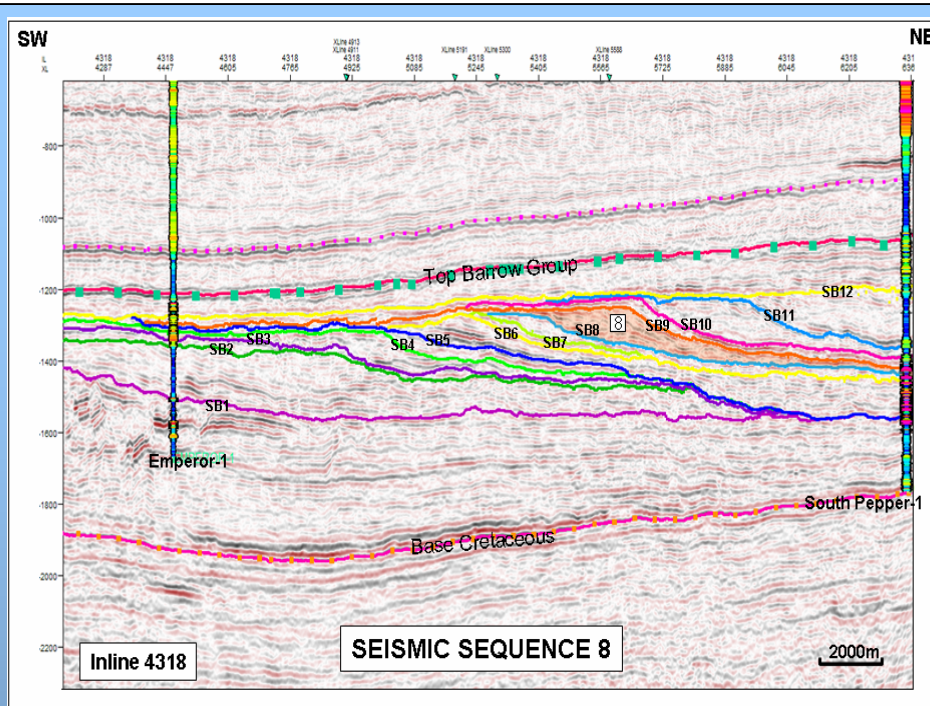


Figure 1. Seismic section displaying Seismic Sequence 8, bound by sequence boundary 8 and sequence boundary 9

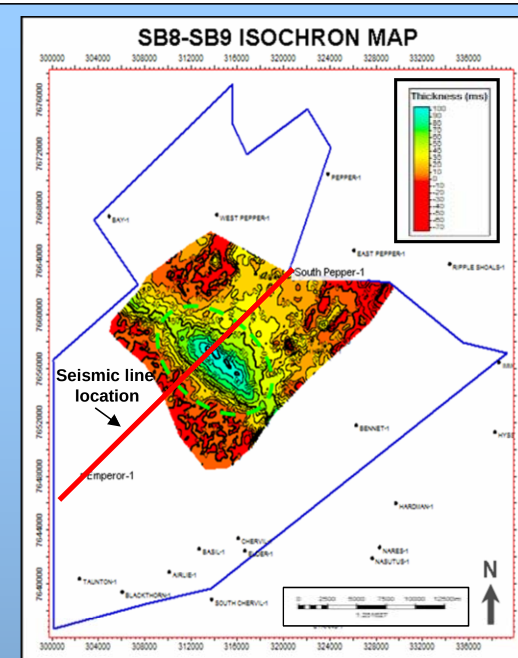


Figure 2. SB8 – SB9 Isochron Map

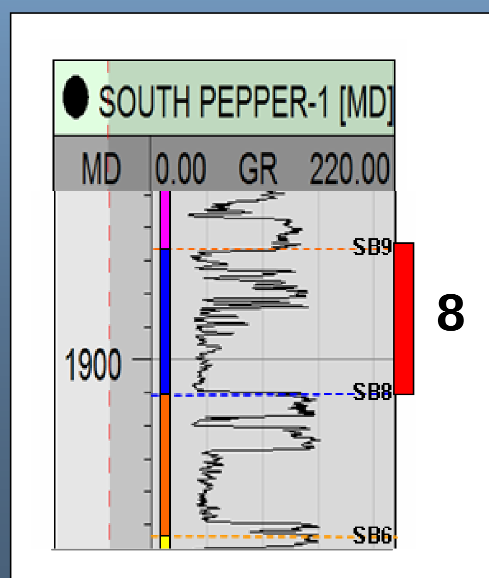


Figure 3. GR response at Sth Pepper-1 for SS8. Displaying blocky sands with sharp tops and bases.

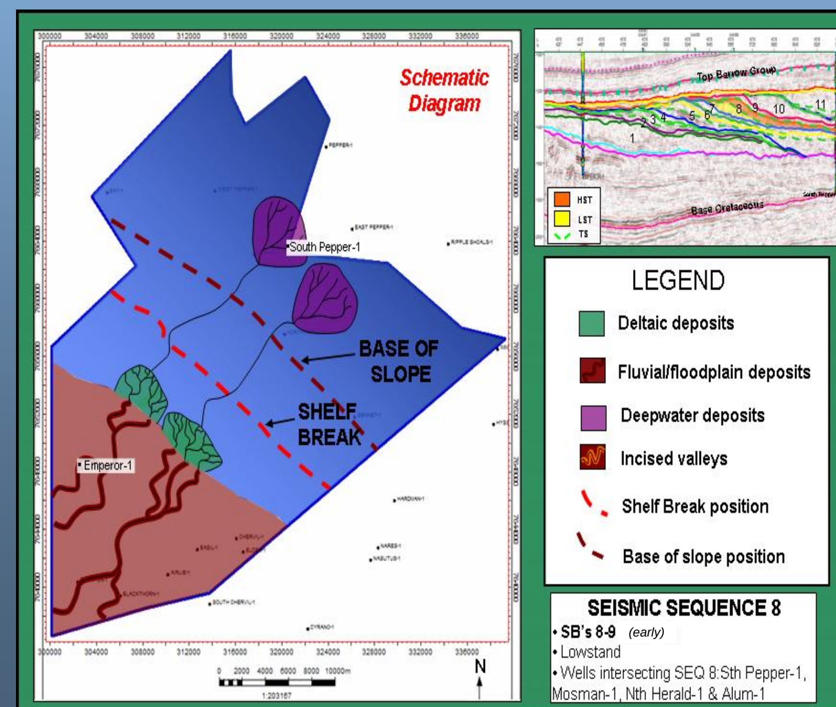
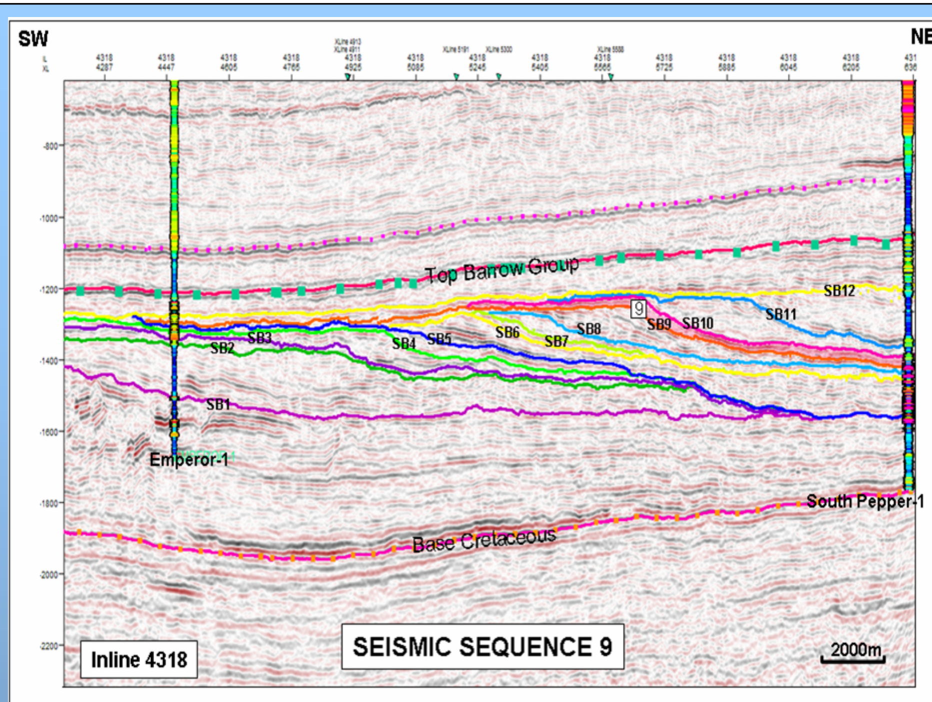
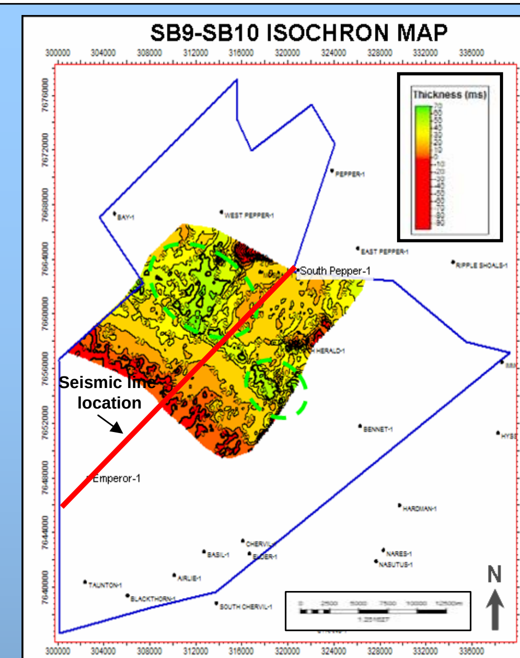


Figure 4. Seismic Sequence 8 palaeo-geography map

SEISMIC SEQUENCE 9 SUMMARY SHEET





Summary

- Palaeo-environment is predominantly fluvial
- Defined by SB9 and SB10
- Key wells – Nth Herald-1, Sth Pepper-1, Alum-1
- Seismic character consists of parallel to sub-parallel continuous reflectors with

  overall moderate amplitude
- Mapped over 230sqkm and between 0 and 60ms thick
- Spans the middle *B. reticulatum* dinocyst zone
- Displays prograding and retrograding stacking patterns
- Interpreted to consist of a TST overlain by a HST

Figure 1. Seismic section displaying Seismic Sequence 9, bound by sequence boundary 9 and sequence boundary 10

Figure 2. SB9 – SB10 Isochron Map

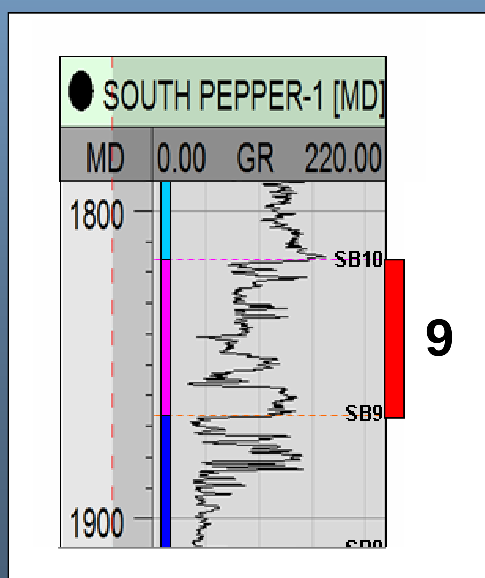


Figure 3. GR response at Sth Pepper-1 for SS9. Overall lower gamma ray response for interval in comparison to previous SS

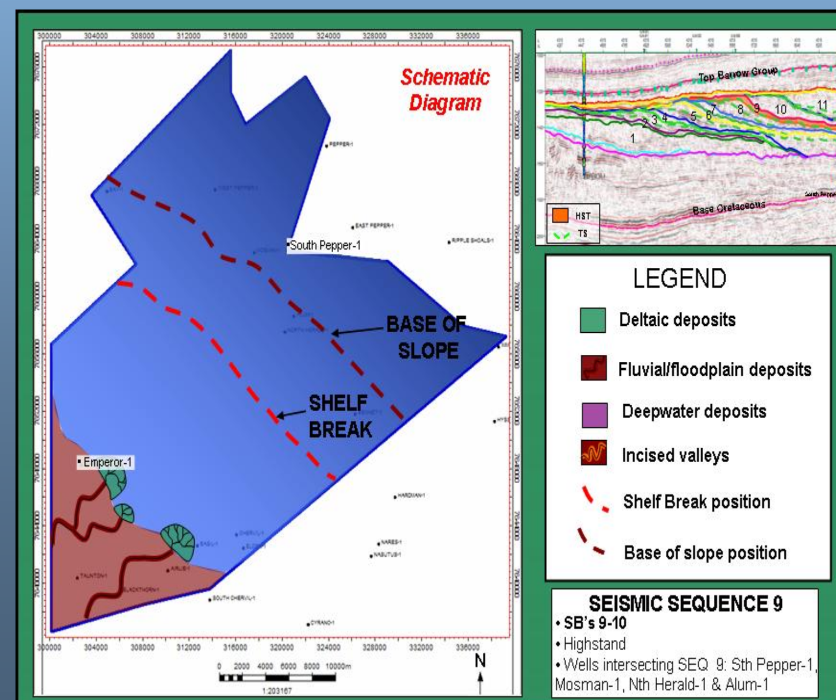


Figure 4. Seismic Sequence 9 palaeo-geography map

SEISMIC SEQUENCE 10 SUMMARY SHEET

Summary

- Palaeo-environment is predominantly deltaic and deepwater
- Defined by SB10 and SB11
- Key wells – Nth Herald-1, Sth Pepper-1, Alum-1
- Seismic character consists of sigmoid-oblique moderately continuous low-moderate amplitude reflectors
- Mapped over 143sqkm and between 0 and 110ms thick
- Spans the middle *B. reticulatum* dinocyst zone
- Displays overall high gamma ray stacking pattern for entire interval
- Interpreted to consist of a LST and TST

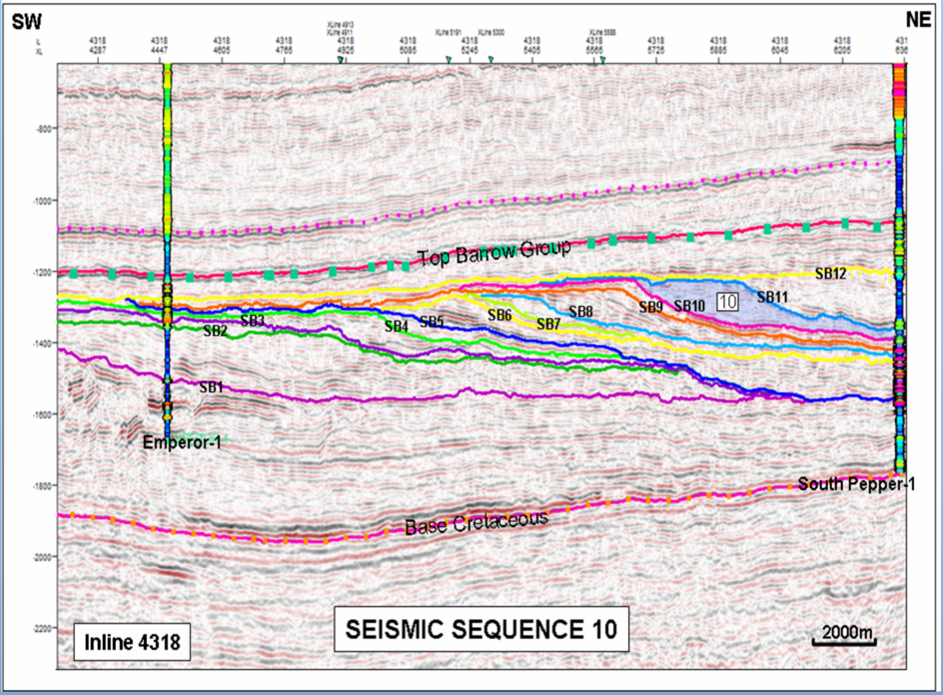


Figure 1. Seismic section displaying Seismic Sequence 10, bound by sequence boundary 10 and sequence boundary 11

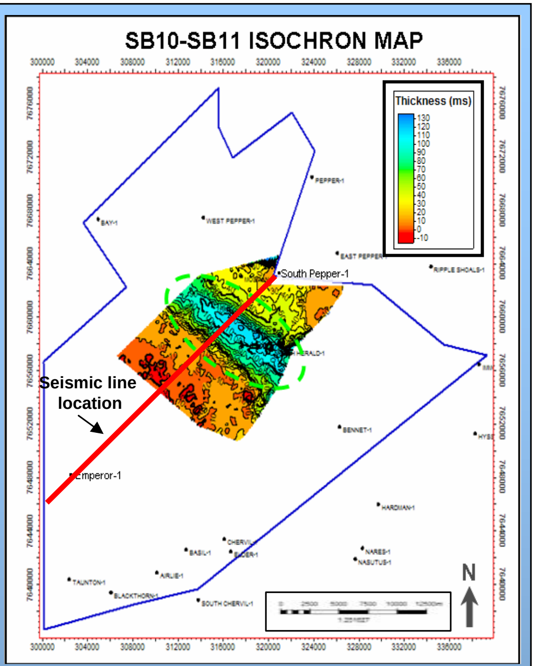


Figure 2. SB10 – SB11 Isochron Map

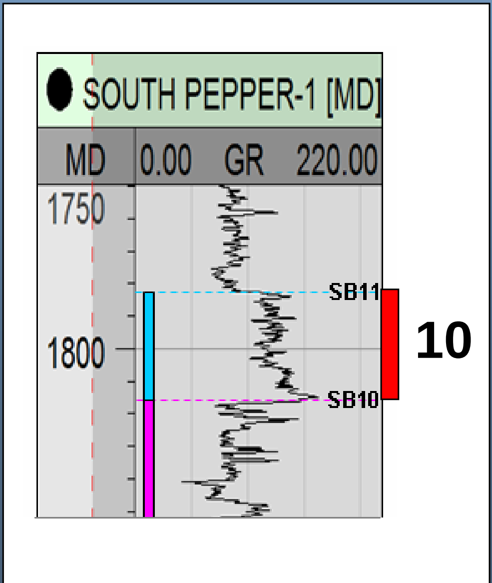


Figure 3. GR response at South Pepper-1 for Seismic Sequence 10. Overall high gamma ray response for interval

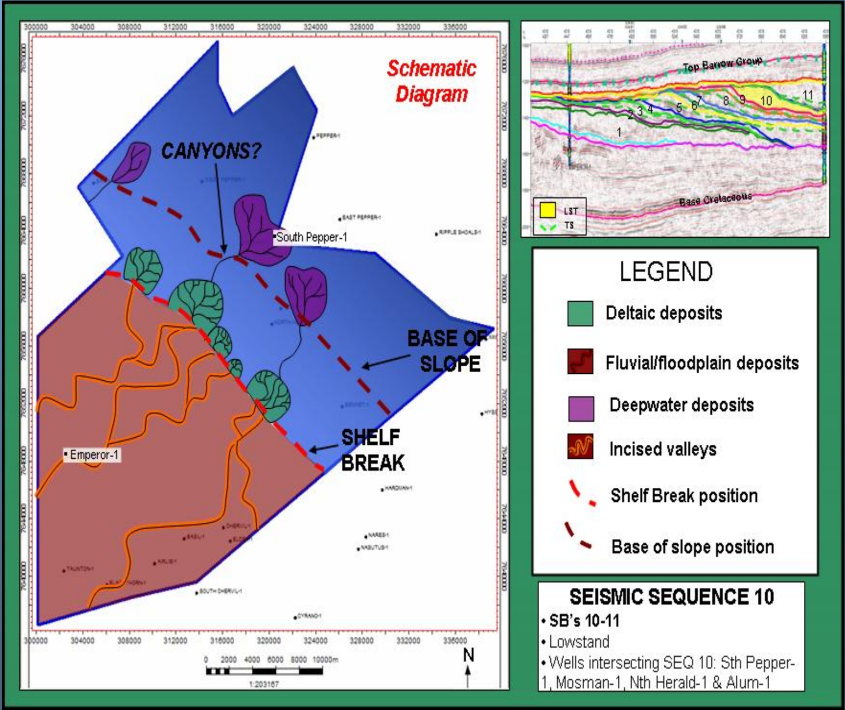


Figure 4. Seismic Sequence 10 palaeo-geography map

SEISMIC SEQUENCE 11 SUMMARY SHEET

Summary

- Palaeo-environment is predominantly deepwater
- Defined by SB11 and SB12
- Key wells – Nth Herald-1, Sth Pepper-1, Alum-1
- Seismic character consists of sub-parallel, moderately continuous low-high amplitude reflectors
- Mapped over 184sqkm and between 0 and 160ms thick
- Spans the middle-upper *B. reticulatum* dinocyst zone
- Displays serrated (aggrading) high gamma ray stacking patterns
- Interpreted to consist of a LST, TST overlain by a HST

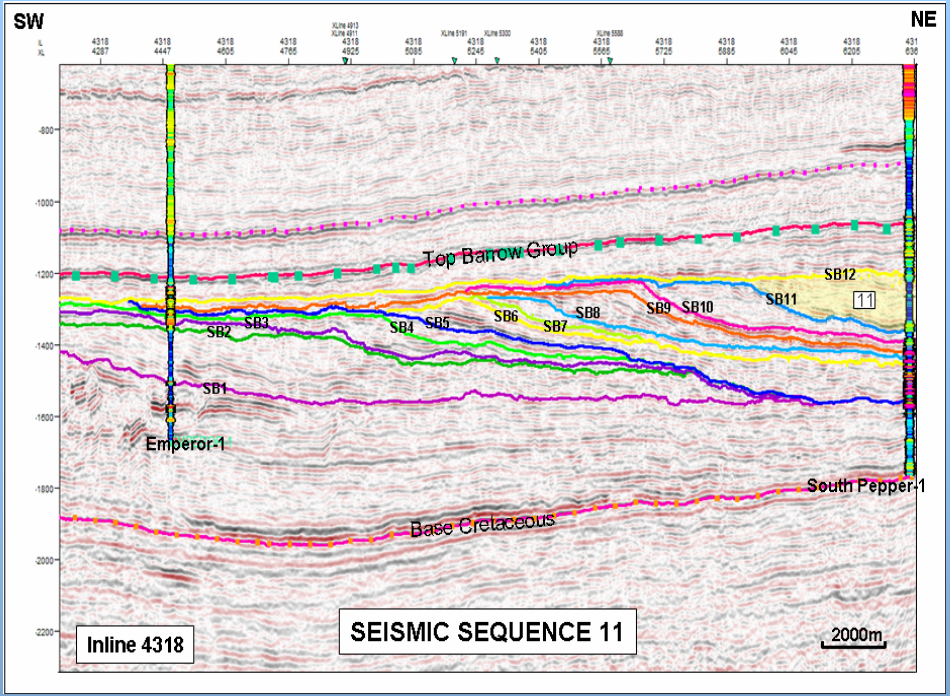


Figure 1. Seismic section displaying Seismic Sequence 12, bound by sequence boundary 11 and sequence boundary 12

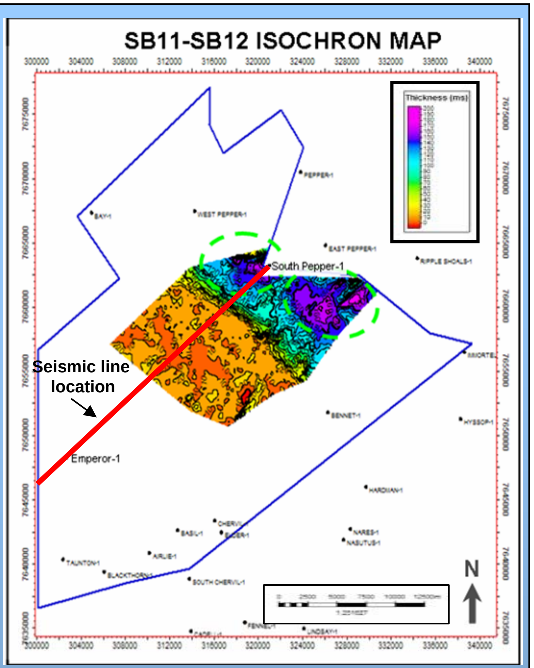


Figure 2. SB11 – SB12 Isochron Map

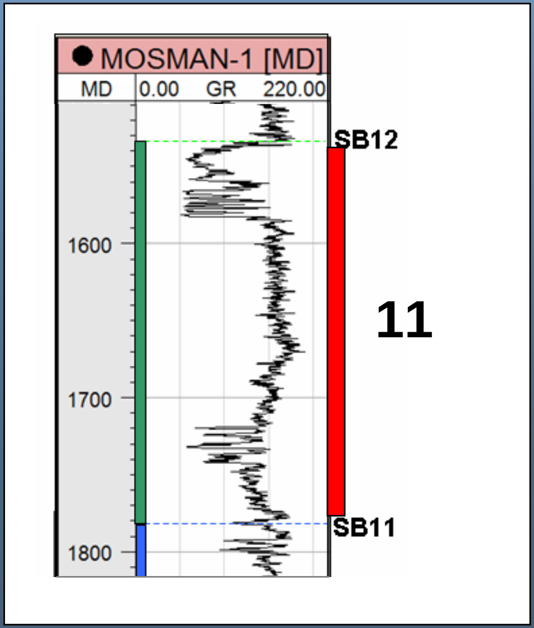


Figure 3. GR response at South Pepper-1 for Seismic Sequence 11. Overall high gamma ray response for interval, with some intermittent low GR intervals

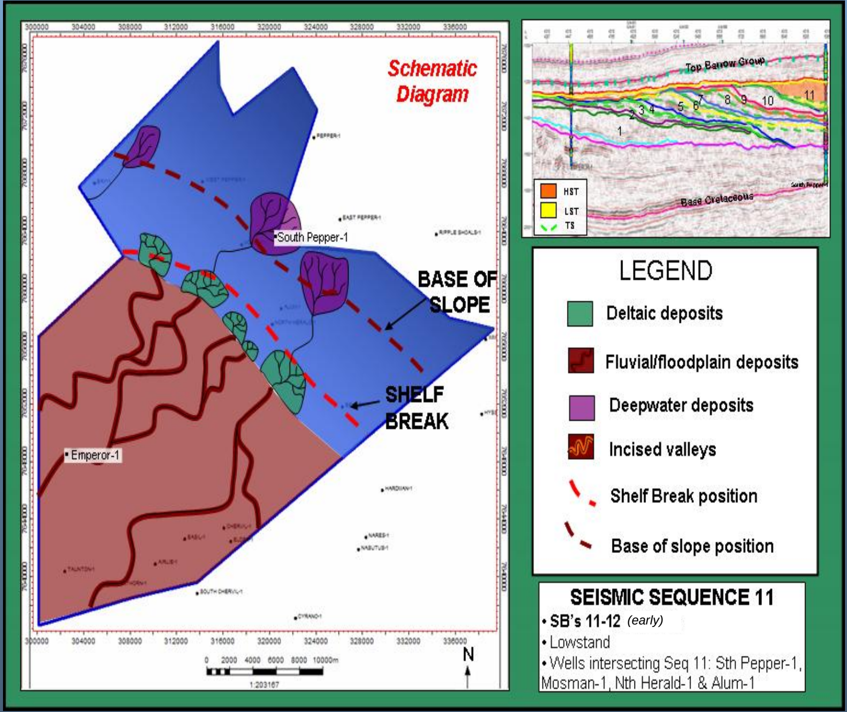


Figure 4. Seismic Sequence 11 palaeo-geography map

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