VIC/P37(v), OTWAY BASIN, VICTORIA

ANTARES 3D MSS

INTERPRETATION REPORT

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EXECUTIVE SUMMARY

The Antares 3D Marine Seismic Survey was acquired between 25 October and 11 November 2003 at the eastern end of the Otway Basin, primarily within VIC/P37(v) with ingress into adjacent permits VIC/P44, VIC/P38(v) and VIC/L22. The 3D survey covered a total of 211 $km^{2,}$ with 134 km^2 of full-fold data being acquired within VIC/P37(v).

The primary objective of the Antares 3D was to detail prospects and leads within VIC/P37(v) previously identified on existing 2D seismic and interpreted to lie within the western extension of the Shipwreck Trough play fairway.

(Note : The ‘Antares’ was a 1761 ton, 79 metre long iron barque built at Glasgow in 1888 and originally named the ‘Sutlej’. After a refit it was reregistered as the ‘Antares’ in Genoa, Italy in 1907. The ‘Antares’ sailed for Melbourne from Marseilles in 1914 but never reached its destination. On December 13 1914, a shipwreck was found at the base of cliffs west of the Bay of Islands near Nullawarre, west of Peterborough, Victoria. The wreck proved to be the 'Antares'. Only one body was found; the remains of the other twenty-four members of the crew were never found. The wreck currently lies in 6 metres water depth off the sheer cliffs on a rocky bottom with the only access by boat.)

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1.0 INTRODUCTION

1.1 Location

VIC/P37(v) is an offshore "three nautical mile" zone permit located in Victorian State waters at the eastern end of the Otway Basin between the coastal townships of Port Fairy and Peterborough (see **Figure 1.1**). The permit is approximately 80 km long and 5 km wide and covers an area of 493 sq km. Water depths across the block range from 0 to 50 m and deepen toward the SSW. The Antares 3D Seismic Survey is located over the eastern half of VIC/P37(v) in water depths ranging from approximately 25 to 55m (**Figure 1.2**).

1.2 Permit Details

VIC/P37(v) was granted on 17 April 2003 to a Joint Venture comprising Origin Energy Resources Limited (37.5% & Operator) and Woodside Energy Limited (62.5%). The approved permit work programme is set out in **Table 1.1**.

Permit Year	Ending	Minimum Work Requirement
1	16/04/04	134 sq km 3D (full-fold) seismic
2	16/04/05	Two (2) wells
3	16/04/06	Data review
4	16/04/07	Data evaluation
5	16/04/08	Data review
6	16/04/08	One (1) well and data review

Table 1.1 VIC/P37(v) work programme

The 211 km^2 Antares 3D Marine Seismic Survey which was acquired by the VIC/P37(v) Joint Venture between 25 October and 11 November 2003 and included 134 km^2 of full-fold coverage within VIC/P37(v), fulfilled the work commitment for Year 1.

2.0 EXPLORATION HISTORY

Prior to VIC/P37(v) being awarded to the Origin – Woodside Joint Venture, no wells had been drilled in the permit despite its close proximity to the onshore Port Campbell gas fields and offshore Shipwreck Trough gas fields. The existing seismic coverage was also very poor, consisting of 427 line km of sparse 2D, the majority of which (80%) was acquired about forty years ago (see **Table 2.1**). What few modern 2D lines there are in VIC/P37(v) are mainly the ends of longer lines that extend only a short distance(< 2 km) into the permit from adjacent permits to the south.

Survey	Operator	Year	# Lines in VIC/P37(v)	Line km
OH94	BHP PETROLEUM	1994	10	41.1
OH91	BHP PETROLEUM	1991	17	26.7
OE81A	ESSO AUSTRALIA LTD	1981	1	0.1
OE80A	ESSO AUSTRALIA LTD	1980	1	3.0
H04	HEMATITIE PETROLEUM	1974	2	9.7
OS66A	SHELL AUST LTD	1966	14	131.3
OS66C	SHELL AUST LTD	1966	18	59.3
OFBH63D	FROME BROKEN HILL PTY LTD	1963	14	155.6
TOTAL			77	426.8

Table 2.1 Seismic Exploration History of VIC/P37(v)

The poor seismic coverage in VIC/P37(v) and lack of wells contrasts markedly with the degree of exploration that has taken place over the past forty years in adjacent permits to the north (onshore) and south (offshore), with more than 60 wells drilled to the north of VIC/P37(v) to date. The majority of these are located within 20 km of VIC/P37(v) in an area known as the Port Campbell Embayment, which is covered by a relatively detailed seismic grid comprising over 2200 line km of modern (post-1979) 2D data and 400 sq km of 3D data. Exploration in this part of the basin commenced in 1959 with Port Campbell-1, which reported a non-commercial gas flow from the Waarre Formation, but the first commercial success did not occur until 1979 when Beach Petroleum discovered the North Paaratte gas field. This was followed by two more discoveries in 1982 (Grumby, Wallaby Creek) and another in 1988 (Iona). In all, eighteen fields have been discovered to date in the Port Campbell Embayment. All are relatively small, ranging from 2.2 – 27.6 BCF GIIP in size, with Iona the largest. Four of the fields have CO_2 contents greater than 10%: Grumby (52% CO_2), Langley (66% CO_2), Buttress (85%) and Boggy Creek (95% CO_2).

The offshore part of the basin to the south and southeast of VIC/P37(v) is also covered by an extensive seismic grid comprising over 10000 line km of modern (post-1979) 2D seismic data and several large 3D surveys totalling over 1600 sq km in area. Twenty-two wells have been drilled in this region. The first well, Pecten 1A was drilled by Esso and intersected a 17.5 m gross gas column in the Waarre Formation which flowed gas at a sub-commercial rate of 145 MCFD.

Subsequent substantial Waarre Formation gas discoveries include La Bella-1 and Minerva-1 (210 BCF GIIP and 558 BCF GIIP respectively (Luxton et al., 1995)), the Geographe and Thylacine fields (combined 2P reserves for the two fields currently stands at 850 BCF of gas and 10.7 MMBBL of condensate (Cliff et al., 2004)) and the Casino field (2P gas reserves for Casino currently stand at ~ 260 BCF according to ASX releases).

Martha-1 was drilled by SANTOS in VIC/P44, approximately 4 km SW of VIC/P37(v), in late October – early November of 2004 and encountered 24.5 m of net gas pay in the Waarre Formation and possibly Nullawarre Sandstone. The size of the discovery is unknown but reports to the ASX suggest it is not commercial.

3.0 REGIONAL GEOLOGY

3.1 Structure

The Otway Basin is one of a series of Late Jurassic - Tertiary basins that developed along the southern margin of Australia during the breakup of eastern Gondwana (Woollands & Wong, 2001; Norvick and Smith, 2001). It is located in the southeastern corner of the continent and extends from Cape Jaffa in southeastern South Australia to the northwest tip of Tasmania. It is approximately 500 km long and covers an area of about 155,000 km^2; approximately 80% of which is located offshore. Total basin fill is about 10,000 m.

The Otway Basin has had a complex structural evolution involving repeated periods of extension, compression, uplift and erosion that varied widely in their timing, duration and areal extent. It has a two-stage rift history consisting of an early, non-marine, intra-cratonic rift basin of Late Jurassic – Early Cretaceous age overlain and offset to the SW by a non-marine to restricted marine rift basin of Late Cretaceous age, which is in turn succeeded by a fully-marine passive-margin basin of Tertiary age.

Basin formation commenced in the Tithonian - Berriasian with a period of NW-SE extension that lasted until the Barremian, followed by a period of thermal sag spanning the Aptian-Albian. During the Cenomanian, the western and central parts of the basin underwent a second phase of extension, this time oriented NE-SW, while the eastern third of the basin underwent compression resulting in the removal of up to 3000 m of sediments in the region of the present day Otway Ranges, with most of the uplift and erosion occurring to the east of the N-S striking Moyston Fault – Sorell Fault Zone. In the western and central parts of the basin, the space created by the second rifting event, which spanned the Turonian - Maastrichtian, was accommodated by faulting south of the WNW-ESE striking Tartwaup - Mussel Fault Zone, with left-lateral strike –slip movement on the Moyston – Sorell lineament preventing the rifting from propagating eastwards into the Bass and Gippsland Basins. At the end of the Maastrichtian, Australia and Antarctica began to slowly separate at a rate of about 4.3 mm/yr (Cande & Mutter, 1982), signalling the formation of the Southern Ocean and the onset of passive margin subsidence within the basin. This slow spreading continued up until the middle Eocene, after which the spreading rate jumped sharply to its current rate of 110 mm/yr (Cande & Mutter, 1982).

In the Late Miocene, the Otway Basin experienced another episode of compression resulting in significant folding, uplift and erosion of the sedimentary fill both onshore and offshore, especially toward the eastern end of the basin where up to 1000 m of sediments were removed from the Otway Ranges area (Dickinson et al., 2001).

The eastern portion of VIC/P37(v) is located on the western side of the Shipwreck Trough at its northern end opposite the Port Campbell Embayment (see **Figure 3.1**). The Shipwreck Trough is a N-S oriented zone of transtension and down-warping that formed in response to left-lateral movement on the Sorell Fault Zone during the Late Cretaceous. It is approximately 25 km wide and 80 km in length and extends at least as far south as the Thylacine Gas Field. Its eastern and western boundaries are defined respectively by the Sorell Fault Zone and pinch out edge of the Turonian-aged (base Late Cretaceous) Waarre C Formation, the primary gas-bearing interval in this part of the basin, both onshore and offshore.

The Port Campbell Embayment is the onshore extension of the Shipwreck Trough. Its northern and eastern boundaries are defined by the pinchout edge of the Late Cretaceous sequence, while its western boundary is defined by the pinchout edge of the Waarre C. It is approximately 25 km across in a N-S orientation and 35 - 45 km wide E-W, with the Late Cretaceous sequence both deepening and thickening southwards toward the Shipwreck Trough. The Moyston Fault, which is a major basement fault onshore to the basin, separates deformed Neoproterozoic – Cambrian sediments and volcanics (Delamerian Fold Belt) in South Australia / western Victoria from less-deformed Early Cambrian to Early Carboniferous sediments and volcanics (Lachlan Fold Belt) in central / eastern Victoria. Gravity data suggests this fault extends southward underneath the Port Campbell Embayment, but it is not known if it links up with the Sorell Fault Zone.

3.2 Stratigraphy

The stratigraphic succession in the Otway Basin (**Figure 3.2**) ranges from Early Cretaceous to Recent in age and is divided into five unconformity-bounded sequences called (in ascending stratigraphic order) the Otway, Sherbrook, Wangerrip, Nirranda and Heytesbury groups.

The oldest known sediments in the basin are the Early Cretaceous fluvial – lacustrine quartz sandstones and shales of the Crayfish Subgroup (Tithonian - Barremian) and fluvial – lacustrine volcanolithic sandstones, siltstones, shale and coal of the Eumeralla Formation (Aptian – Albian). The Crayfish Subgroup sediments were deposited in half-grabens that developed during the first rifting event, and the Eumeralla Formation deposited on top as a blanket during the subsequent period of thermal sag.

The overlying Late Cretaceous (Cenomanian – Maastrichtian) fluvial to marine Sherbrook Group was deposited during the second rift phase. The Sherbrook Group is the primary hydrocarbon-bearing interval in the eastern Otway Basin where it is divided into seven lithostratigraphic units called (in ascending stratigraphic order) the Waarre Formation, Flaxmans Formation, Belfast Mudstone, Nullawarre Sandstone, Skull Creek Mudstone, Paaratte Formation and Timboon Sandstone.

The Waarre Formation, the oldest unit, is a sequence of fluvial to shallow marine sandstone, shale and minor coal of early to mid- Turonian age that marks the onset of the second rift phase in the basin. The formation unconformably overlies the Eumeralla Formation and is divided into three units onshore called (in ascending stratigraphic order) A, B and C based on gross lithology and sandstone composition.

Units A and B are relatively similar, consisting largely of shale with thin lithic-rich fine- to medium-grained sands common in the former. Unit C is a medium- to coarse-grained quartz sandstone and is the primary gas reservoir both onshore and offshore. Small quantities of gas have also been produced from sands within the Waarre A, but these sands are generally regarded as poor reservoirs due to their lithic-rich nature and high matrix content.

Toward the end of the mid-Turonian, a major transgression occurred over the top of the Waarre Formation resulting in the deposition of marginal-marine fine-grained sands and shale of the Late Turonian Flaxman Formation as the shoreline shifted northward. This transgression continued up until the mid-Santonian resulting in the deposition of a thick package of deepwater marine mudstone called the Belfast Formation, which thins and becomes gradually sandier towards the north. A sharp fall in sea level during the early Santonian then led to the deposition of a sequence of shallow-marine glauconitic quartz sandstones of Late Santonian age called the Nullawarre Sandstone. This unit is best developed along the northern half of the Port Campbell Embayment and thins toward the south, pinching out just offshore of the present-day coastline. This fall in sea-level was then followed by another sea-level rise and transgression in the early Campanian which led to the deposition of a second package of deepwater marine mudstones of early to middle Campanian age called the Skull Creek Mudstone. Like the Belfast Formation, the Skull Creek Mudstone also thins and becomes gradually sandier towards the north, and because the mudstones are similar in lithology to those of the older Belfast Formation, it is often difficult separating them in wells offshore where the Nullawarre Sandstone is absent and there is no biostratigraphic control.

Conformably overlying the Skull Creek Mudstone is a thick sequence of early – to mid-Campanian fluvial to lower delta plain interbedded sandstone and shale called the Paaratte Formation which grades up into late Campanian to Maastrichtian upper delta plain sandstones of the Timboon Sandstone. These units are best developed onshore and become gradually shalier to the south where they eventually grade into deepwater mudstones of the Skull Creek Mudstone.

The Tertiary section consists of fluvio-deltaic clastics of the Late Maastrichtian – Eocene Wangerrip Group and overlying open-marine siliciclastics and carbonates of the Eocene to Recent Nirranda and Heytesbury groups. The Wangerrip Group was deposited during the initial phase of passive-margin subsidence and is divided into four formations called the Massacre Shale, Pebble Point Formation, Pember Mudstone and

Dilwyn Formation. The Massacre Shale is a thin marine shale that was deposited during the initial transgression. This event was followed by the deposition of the fluvial to shallow-marine clastics of the Pebble Point Formation and distal deltaic marine mudstones of the Pember Mudstone, and then clastic Dilwyn Formation during the subsequent regression. These sediments are in turn overlain by transgressive marine sediments of the Nirranda and Heytesbury groups.

4.0 ANTARES 3D MSS

4.1 Objectives

The 2003 Antares 3D Marine Seismic Survey was recorded to provide detailed seismic coverage over VIC/P37(v) in fulfilment of the Year 1 work commitment for the permit.

4.2 Data Acquisition

The Antares 3D Seismic Survey was acquired between 25 October 2003 and 11 November 2003 using the PGS vessel *Orient Explorer.* A total of 211 km^2 of 3D data was acquired. Of this, 134 km^2 of full-fold data is within VIC/P37(v). The key acquisition parameters are summarised as follows :

- 4 x 4000m streamers
- 12.5m group interval
- 25m crossline spacing (100m streamer separation)
- 7.5m streamer depth
- 2 x 2,500cuin sources
- 50m source separation
- 18.75m shot point interval (flip-flop)
- 6m source depth
- 6 sec recording length
- 2ms sample rate

Further details on the acquisition activities are available in the final acquisition reports, submitted separately. Current seismic coverage in the vicinity of VIC/P37(v) is shown in **Figure 1.1**.

4.3 Data Processing

Processing of the Antares 3D seismic data was carried out in 2003/4 by WesternGeco. Processing has incorporated both a portion of the prestack Casino 3D to produce a fully migrated dataset up to the southern VIC/P37(v) permit boundary, as well as a merge with the full prestack Minerva 3D dataset (**Figure 1.1**). Further details on the data processing are available in the final processing report, submitted separately.

4.4 Data Quality

The overall data quality of the Antares 3D is very good, with well-imaged fault planes, a high signal-to-noise ratio, broad bandwidth, plus good event definition and continuity. The improvement in data quality from the vintage 2D in the area compared to the Antares 3D can be seen in **Figure 4.1**.

Prior to interpretation and mapping, the polarity of the Antares 3D as supplied by WesternGeco was determined to be ASEG Normal (i.e. an increase in impedance is represented by a negative number or trough) by cross-correlating nearby wells with seismic. For example, **Figure 4.2** shows the phase of the Antares 3D and the OH91 series 2D data (1998 reprocessing) to be similar as determined by cross-correlations at seismic intersections. Extracting a deterministic seismic wavelet at the Pecten 1A well location (2D line OH91-125) shows that the OH91 data, and therefore the Antares 3D data, is approximately zero phase with ASEG Normal polarity (**Figure 4.3**).

The convention used for all seismic line displays in this report is also ASEG Normal.

5.0 Interpretation and Mapping

5.1 Well Ties

The seismic interpretation of the Antares dataset is based on seismic character ties into key onshore wells (ie. Croft-1, Naylor-1, Naylor South-1, Wallaby Creek-1, Grumby-1 and Langley-1). It was not possible to achieve a direct seismic tie into the onshore 2D / 3D seismic due to a data gap created by the coastal zone. Ties into the two nearest offshore wells, Minerva-1 and Pecten-1A were also achieved, although the confidence in correlations from these wells was relatively lower due to data quality issues.

5.2 Time Mapping

Horizons interpreted within the Antares 3D time volume are summarised in **Table 5.1.**

Seismic Event	Areal Extent	Reason for Picking	Character	Quality
Top Narrawaturk Marl	Halladale	Shallow hazard mapping	Peak	Very good
Top Mepunga Fm	Halladale	Shallow hazard mapping	Trough	Good
Top Dilwyn Fm	Regional	Shallow hazard mapping & regional seismic marker	Trough	Good
Top Pember Mdst	Halladale	Shallow hazard mapping	Trough	Fair
Top Pebble Point Fm	Halladale	Shallow hazard mapping	Trough	Good
Top Paaratte Fm	Halladale	Shallow hazard mapping	Trough	Poor
Top Skull Creek Mdst	Halladale	Shallow hazard mapping	Trough	Fair
Top Upper Nullawarre Sst	Halladale	Secondary target	Peak	Fair
Base Upper Nullawarre Sst	Halladale	Secondary target	Trough	Good
Top Lower Nullawarre Sst	Halladale	Secondary target	Peak	Fair
Base Lower Nullawarre Sst (= top Belfast Mdst)	Halladale	Secondary target	Trough	Good
Base Belfast Unconformity	Regional	Key regional seismic marker	Trough	Good
Top Waarre C	**Halladale**	**Primary target**	**Peak**	**Poor**
Base Waarre C (= Top Waarre B)	**Halladale**	**Primary target**	**Trough**	**Good**
Top Waarre A	**Halladale**	**Primary target**	**Peak**	**Fair**
Base Waarre A (= Top Eumeralla)	**Halladale**	**Primary target**	**Trough**	**Good**

Table 5.1 Key seismic markers interpreted as part of the Antares 3D evaluation. Key markers mapped in the Halladale / Black Watch area for the prospective Waarre section are highlighted in bold.

A seismic line across the Antares volume showing key interpreted seismic markers is included as **Figure 5.1**.

The top Dilwyn Formation and base Belfast unconformity were the only events interpreted across the entire Antares 3D volume (**Figures 5.2 and 5.3**). The base Belfast unconformity was the only regionally extensive seismic marker interpreted near the primary Waarre objective. It is viewed as being structurally representative of leads and prospects in VIC/P37(v) with the Waarre as their primary target.

6.0 MAPPING RESULTS

The regional base Belfast Unconformity marker time structure map (**Figure 5.3**) demonstrates the overall structural style within the prospective late Cretaceous in the vicinity of VIC/P37(v). The major structural elements that can be recognised are the Shipwreck Trough in the eastern portion of the permit and the Halladale/Black Watch structural high complex in the central portion of VIC/P37(v). Halladale/Black Watch is part of the more regionally extensive Pecten High (**Figure 3.1**). Extensional faulting trending approximately E-W and NW-SE is recognised in the VIC/P37(v) area. These resulted from the late Cretaceous extensional event and strike slip movement on the Sorell fault as discussed in detail in **Section 3.1**. The main fault-controlled closures within the Waarre Formation were formed at this time.

The regional Dilwyn Formation time structure map (**Figure 5.2**) shows the structural form of the Tertiary section in the vicinity of VIC/P37(v). The broad, largely unfaulted structuring is consistent with the passive margin tectonics occurring at Eocene time, as discussed in **Section 3.1**. Key features of the map are the expression of the Shipwreck Trough in the eastern portion of VIC/P37(v), a broad structural high in the vicinity of Halladale and a structural low in the western portion of the permit..

7.0 CONCLUSIONS

- The Antares 3D Marine Seismic Survey has provided good quality, detailed seismic control over the eastern portion of VIC/P37(v), fulfilling the Year 1 work commitment for VIC/P37(v).

- Processing of the Antares 3D has incorporated the Minerva 3D as well as a small portion of the Casino 3D to enable full-fold, fully migrated data to the southern and eastern VIC/P37(v) permit boundaries.

- The Halladale Lead, previously recognized on 2D seismic, is now mapped as two structurally separate Waarre Formation prospects called Halladale and Black Watch.

- Halladale and the newly identified Black Watch prospect are considered to be mature for drilling based on detailed geotechnical analysis of the 3D dataset. Drilling of these prospects is anticipated to occur in early 2005.

8.0 REFERENCES

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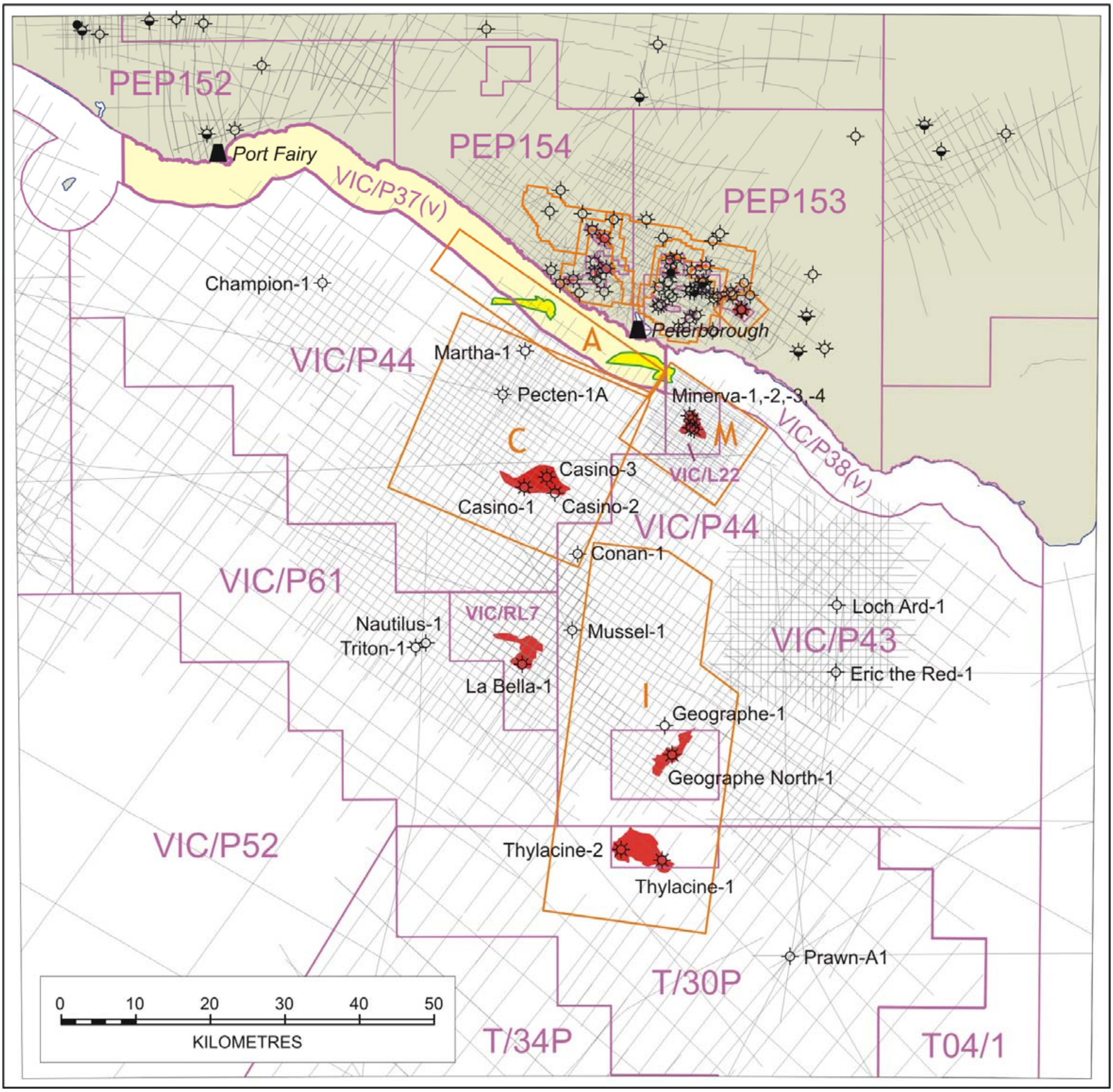

Figure 1.1 Regional location map showing location of VIC/P37(v) in relation to existing onshore / offshore 2D (post-1979) / 3D seismic coverage. Orange polygons represent 3D surveys (M = Minerva 3D, I = Investigator 3D, C =- Casino3D, A = Antares 3D). The pre-Antares 3D outlines for Halladale (*H*) and Lead B (*LB*) are highlighted in bright yellow.

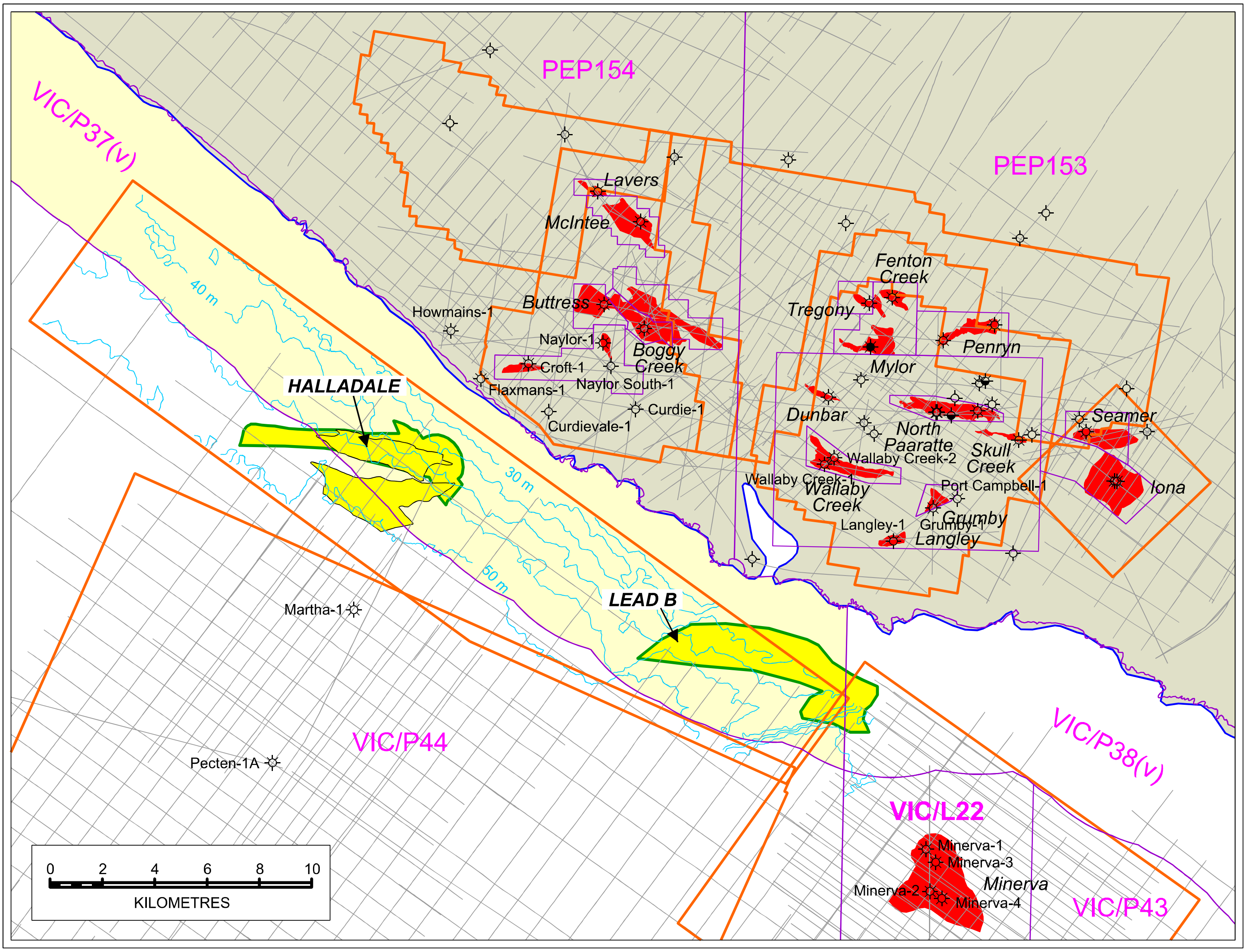

Figure 1.2 Location of Antares 3D MSS in relation to key fields and wells. Bathymetric contours in blue. The pre-Antares 3D outlines for Halladale and Lead B are highlighted in bright yellow.

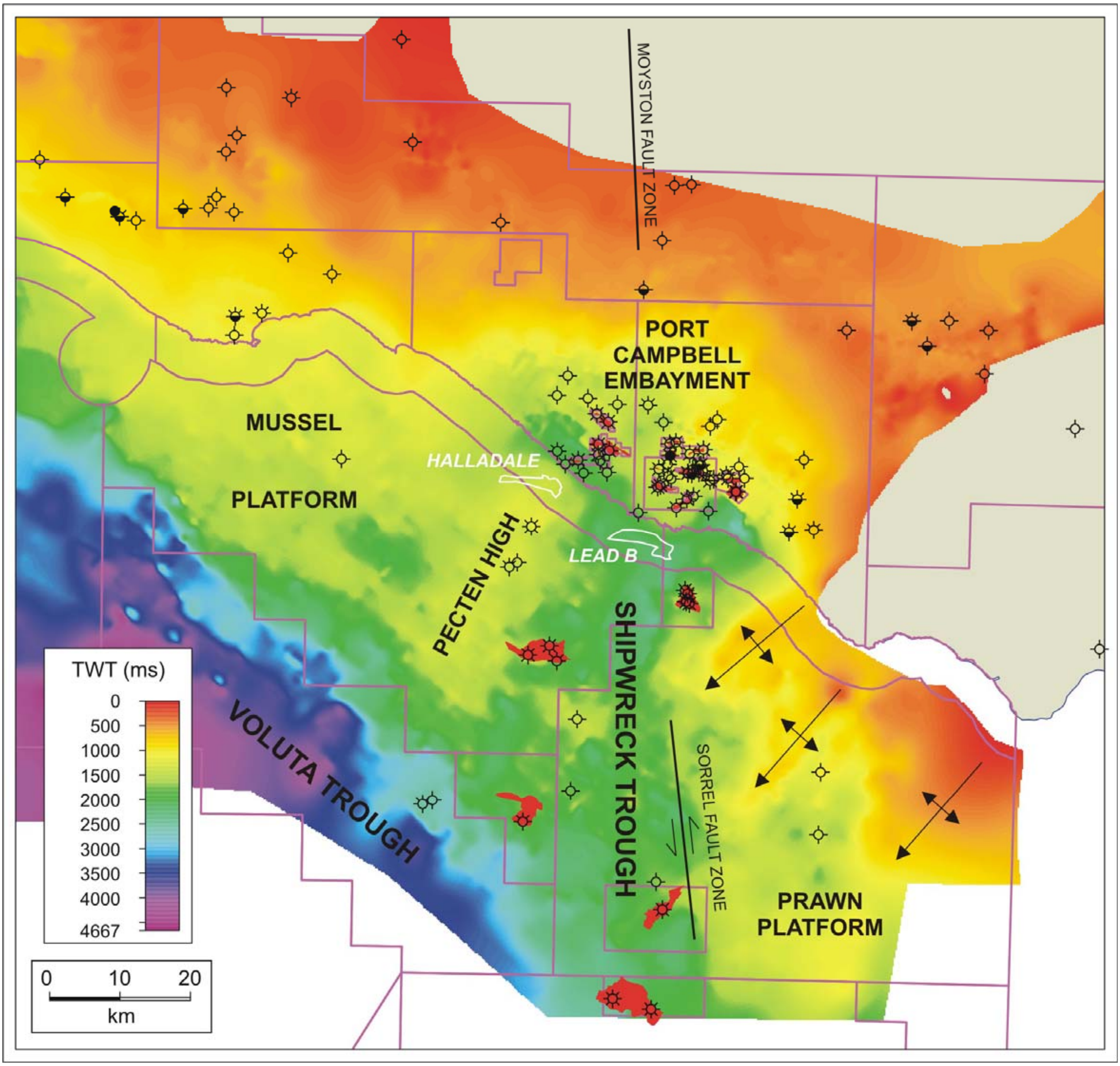

Figure 3.1 Eastern Otway Basin structural elements. Grid = Top Eumeralla TWT structure. The pre-Antares 3D outlines for Halladale and Lead B are highlighted in white.

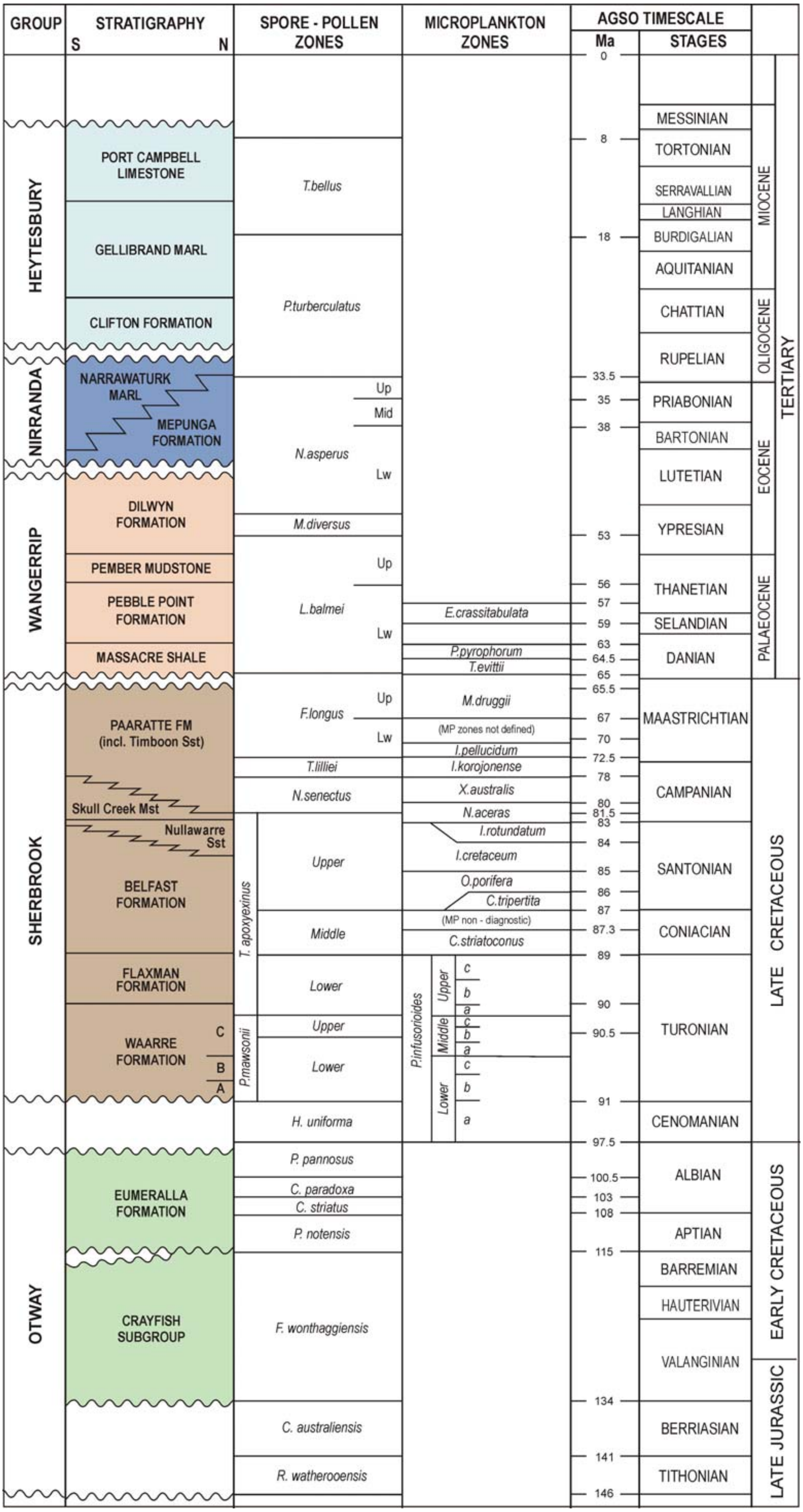

Figure 3.2 Generalised stratigraphic column, Eastern Otway Basin

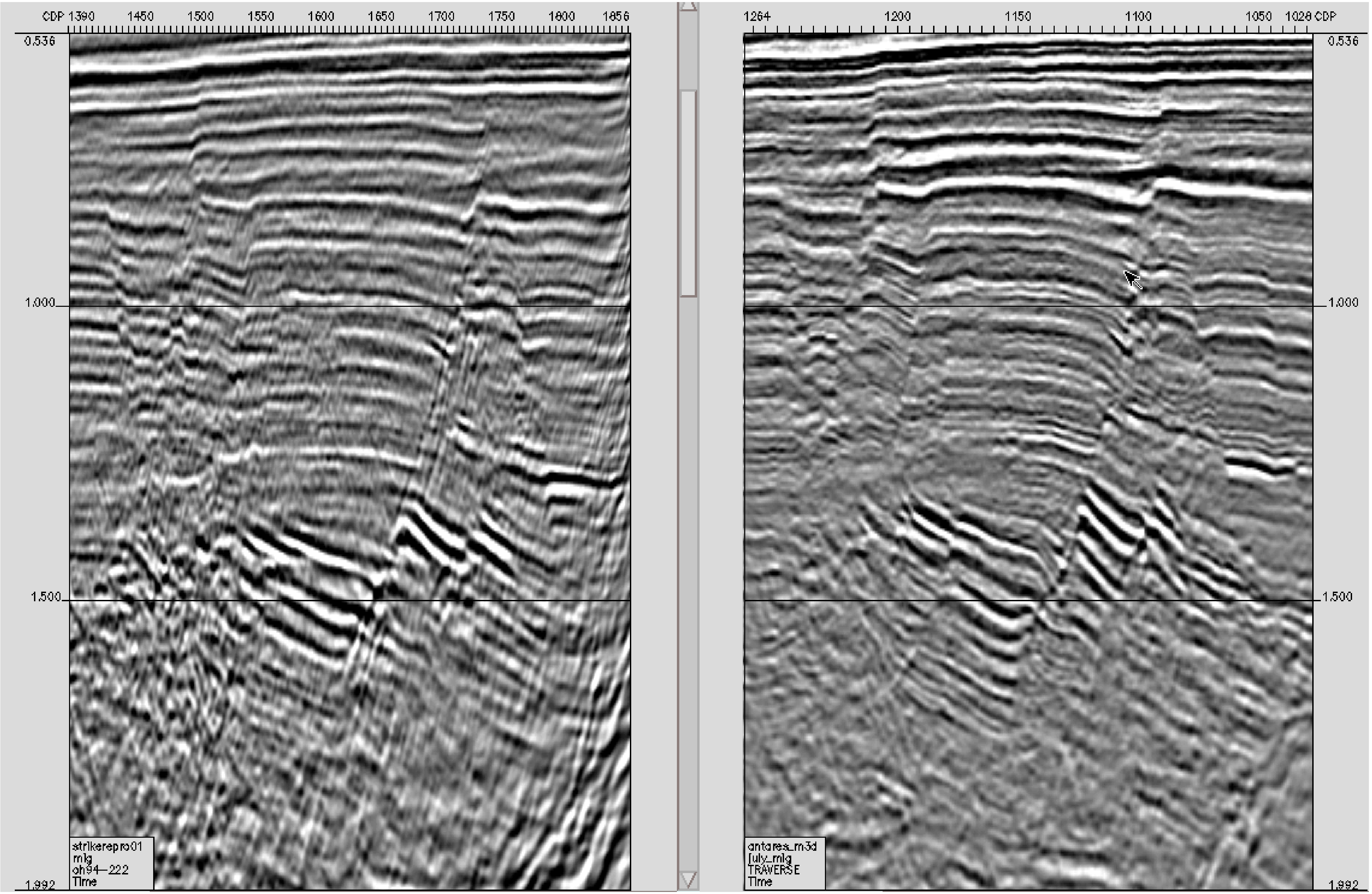

Figure 4.1 Seismic Data Comparison – Vintage 2D (left) versus Antares 3D (right). Note enhanced fault plane imaging and higher signal-to-noise ratio of Antares 3D data.

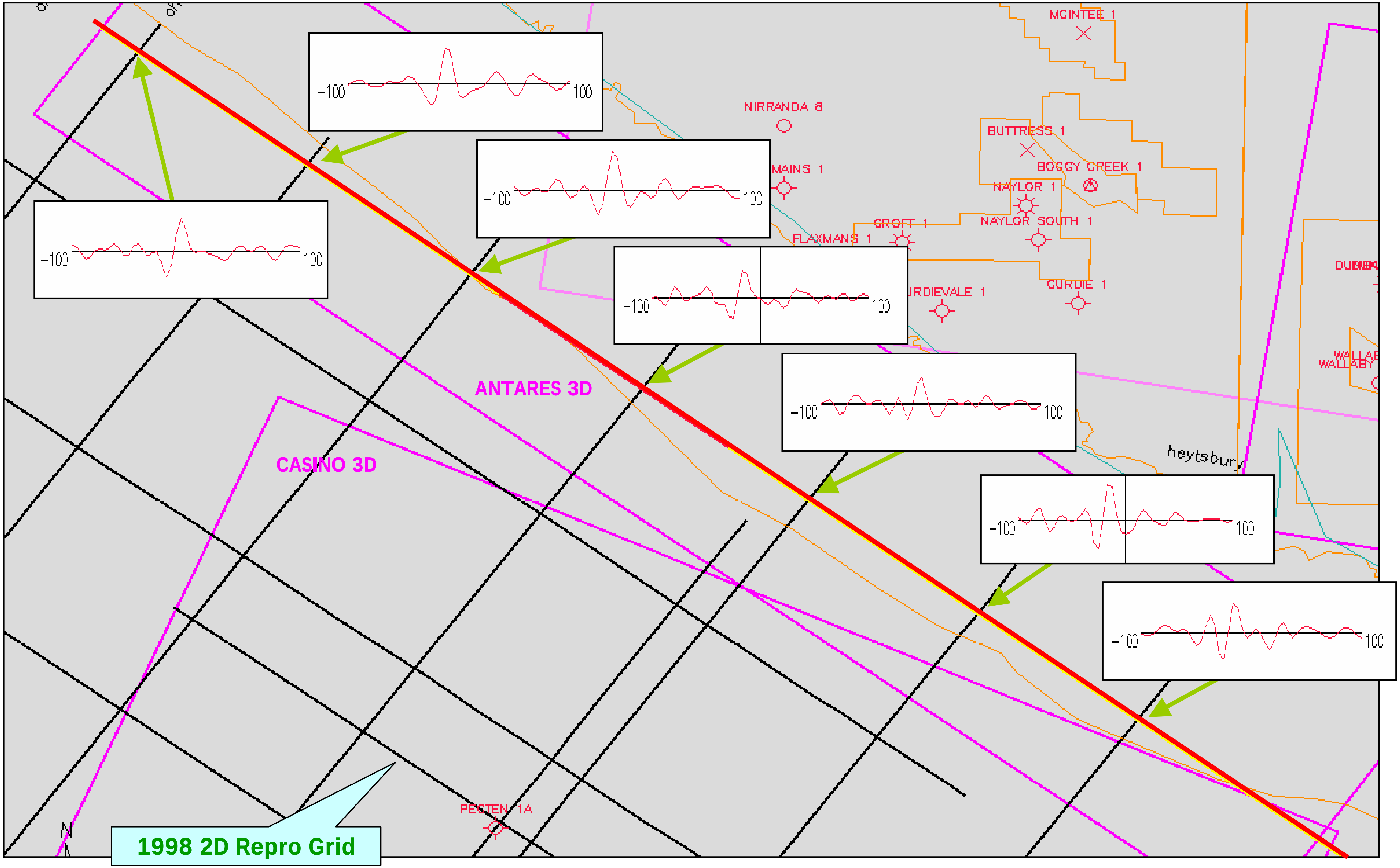

Figure 4.2 Phase comparison between Antares 3D and OH91 series (1998 reprocessing) 2D. Cross-correlations derived at intersections suggest the two surveys are similar phase and polarity, although require a bulk shift to tie each other.

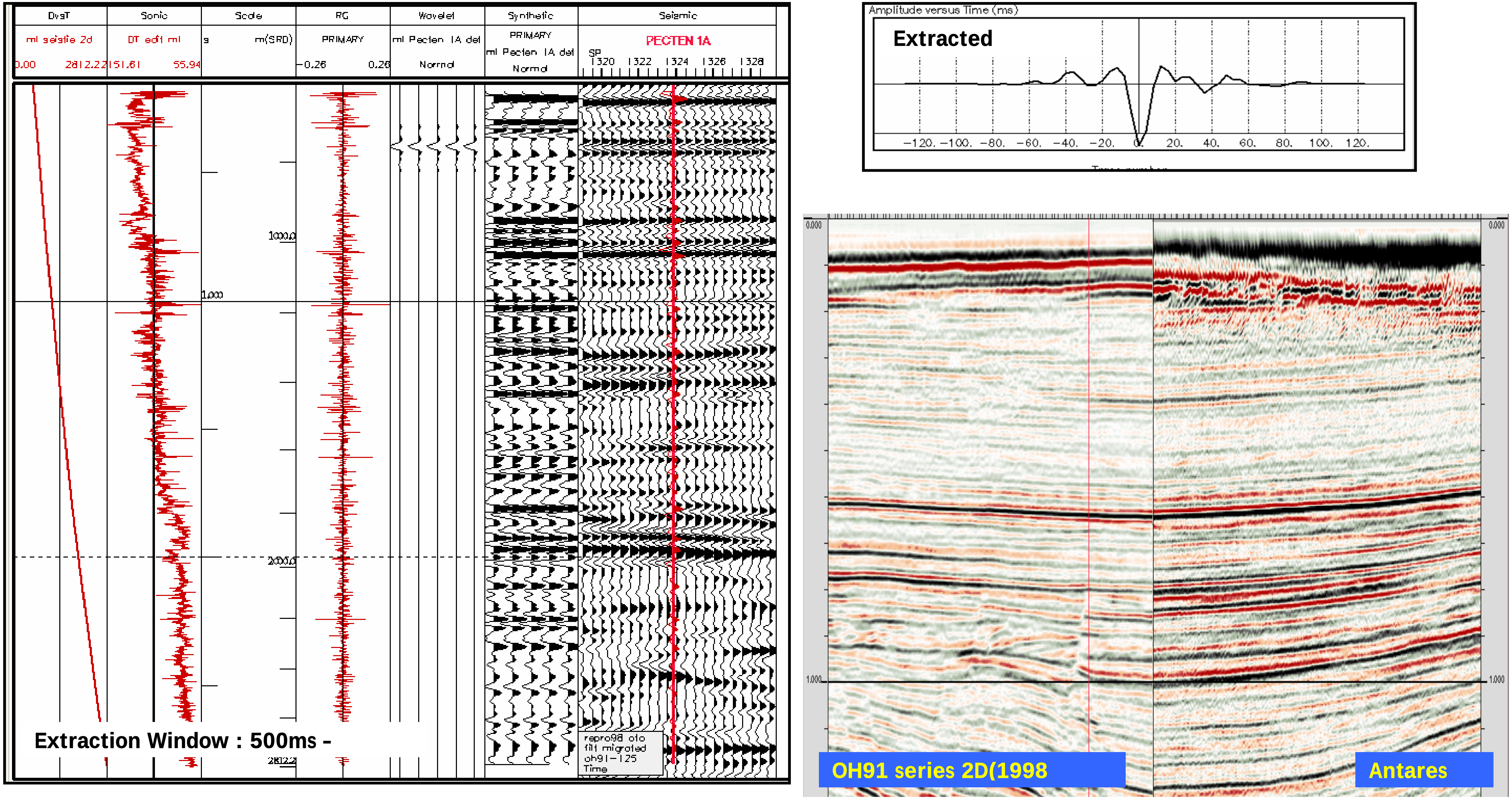

Figure 4.3 Seismic wavelet extraction at Pecten 1A well location. The extracted wavelet is approximately zero phase with ASEG Normal polarity. Also shown is an example seismic tie between the Antares 3D and the OH91 series 2D data (after bulk shift) showing an excellent character match as suggested by Figure 4.2.

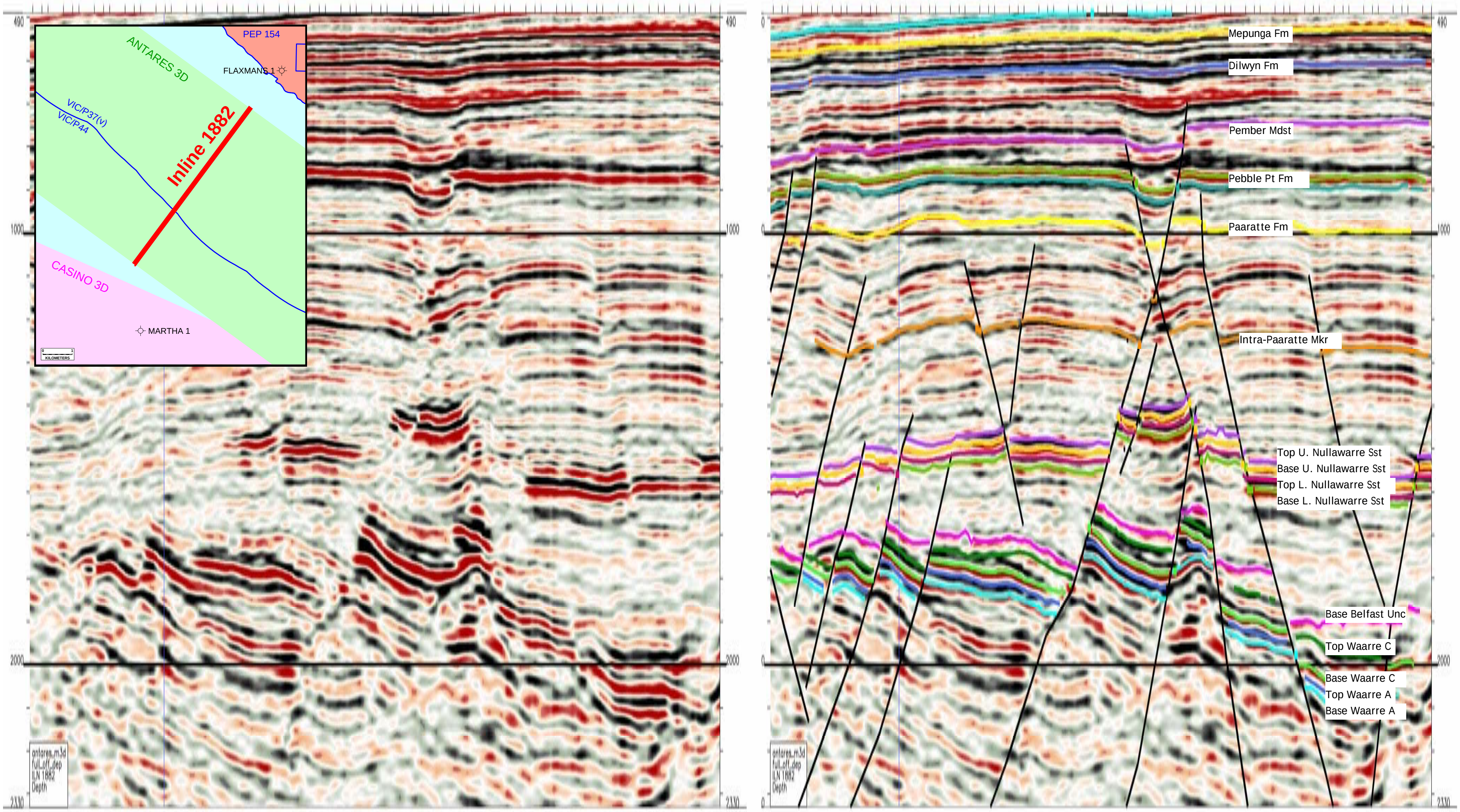

Figure 5.1 Crossline 1882 from depth volume showing key interpreted seismic markers

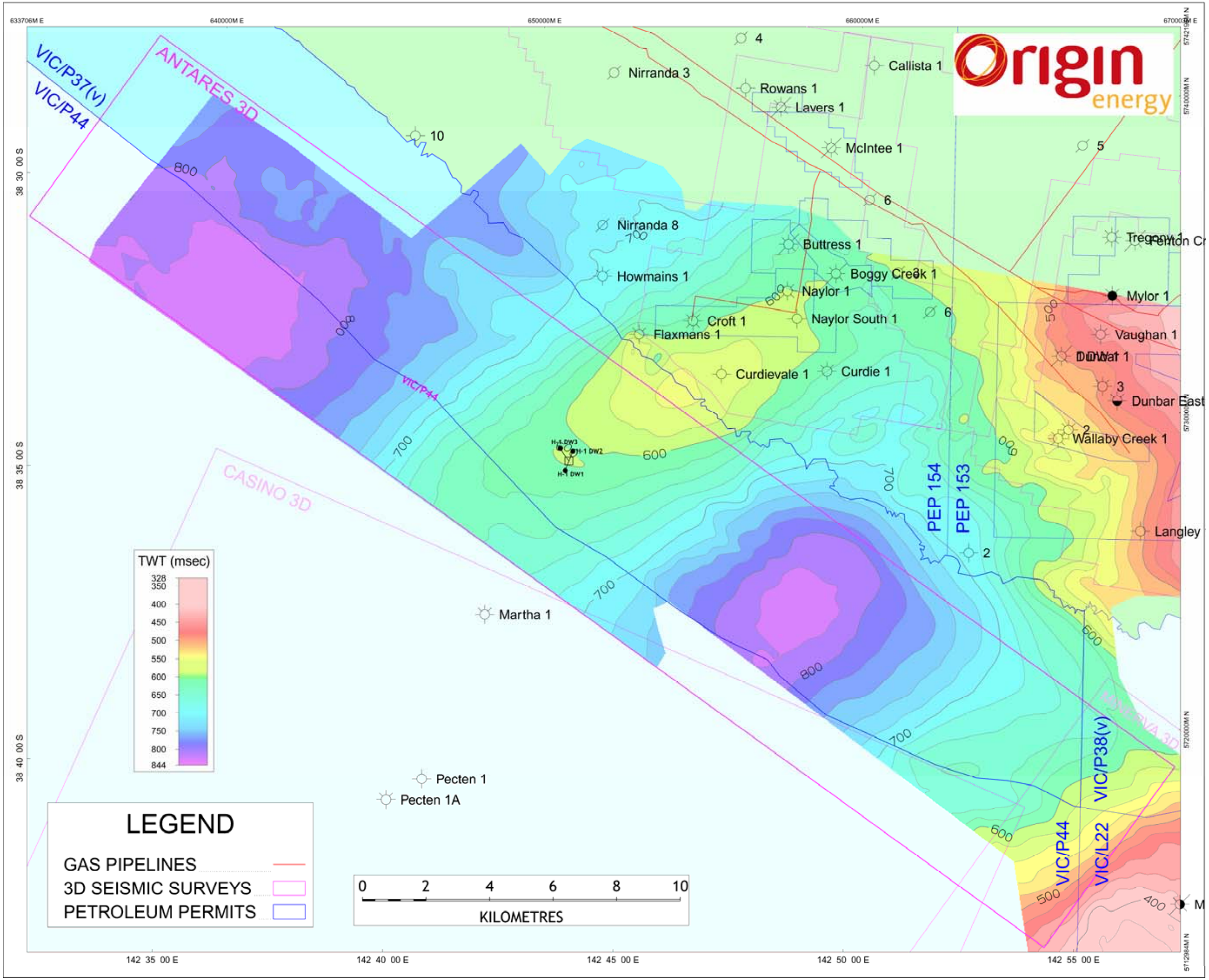

Figure 5.2 Top Dilwyn Formation Time Structure Map

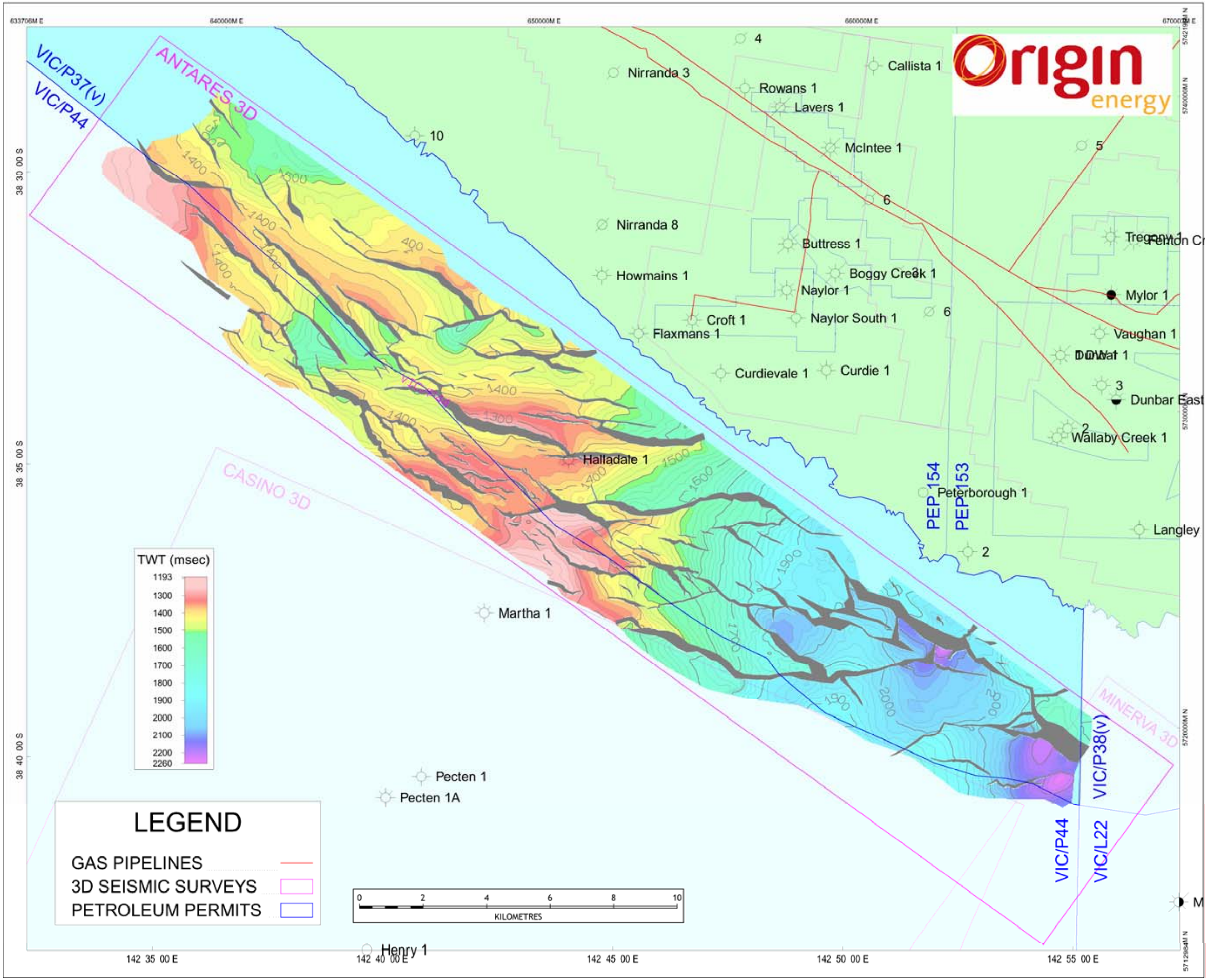

Figure 5.3 Base Belfast Unconformity Time Structure Map