Government of **Western Australia**
Department of **Mines and Petroleum**

RECORD 2014/7

2D SEISMIC INTERPRETATION OF THE HARVEY AREA, SOUTHERN PERTH BASIN, WESTERN AUSTRALIA

by
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2D seismic interpretation of the Harvey area, southern Perth Basin, Western Australia

by

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Abstract

The Harvey area in the southern Perth Basin is currently being assessed for carbon dioxide geosequestration potential through a variety of studies, including the acquisition of 100 km of 2D seismic data in 2011 and the drilling of Geological Survey of Western Australia (GSWA) Harvey 1 to a depth of 2945 m in 2012. This work focuses on the Jurassic and Triassic section, for which the best stratigraphic information is provided by GSWA Harvey 1. Seismic and well data and a first vertical derivative gravity image are used to interpret the structure of the area between the townships of Harvey and Pinjarra in the north, Bunbury in the south, and 10 km west offshore to encompass the approximately 1000 km of 2D seismic data collected or reprocessed in recent years.

The most important structural features revealed from mapping five horizons (Cretaceous breakup unconformity, top 'Eneabba Formation', top 'Yalgorup Member', top 'Wonnerup Member', and top Sabina Sandstone) include the west-northwest oriented structural high known as the Harvey Ridge and several northwest- and north-trending normal faults in the southern onshore part of the study area. Detailed interpretation is hampered by the patchy distribution and poor quality of seismic data, especially in the northern and offshore parts of the study area. In the southern part of the study area the 'Eneabba Formation' is partially eroded and dips east-northeast at approximately seven degrees. By comparison, the 'Lesueur Sandstone' is widespread throughout the study area and maintains a constant thickness across faults, indicating little, if any, syndepositional fault movement. A change in the seismic character of the 'Wonnerup Member' of the 'Lesueur Sandstone', about 6 km west of the Darling Fault, appears to be a facies change. The application of lithostratigraphy from the northern Perth Basin is tentative. For this reason most names are shown in quotation marks, as the age and correlation of much of the section is poorly established.

KEYWORDS: seismic data, seismic interpretation, seismic maps, seismic surveys, tectonics

Introduction

The South West Hub project is a collaborative partnership between the Australian Federal Government and the State Government of Western Australia for carbon dioxide (CO_2) geosequestration, and is one of the flagship projects within the Federal Carbon Capture and Storage (CCS) program (Smith et al., 2012). Under this national scheme, the Harvey area — due to its proximity to coal-fired power stations and industry clustered around the Collie and Kwinana areas — has been identified as suitable for the storage of a large volume of CO_2. In addition, the lack of major freshwater aquifers in this area largely reduces any potential impacts on potable and agricultural water supplies for local communities.

The Geological Survey of Western Australia, in conjunction with Geoscience Australia, acquired the GSWA Lower Lesueur 2011 2D seismic survey along Harvey shire roads in 2011 to investigate the geology of the area. The survey has been interpreted by several groups, including Fiah and Guiton (2011) and Langhi et al. (2013). A stratigraphic well, GSWA Harvey 1, was drilled in 2012 to 2945 m to assess the reservoir properties of the Triassic 'Lower Lesueur Sandstone' ('Wonnnerup Member') and overlying intraformational shale of the 'upper Lesueur Sandstone' ('Yalgorup Member') and 'Eneabba Formation' as a top seal (Millar and Reeve, in prep.).

This Record attempts to place the geology of the potential geosequestration site into a regional perspective and also to provide useful data for the planning of future drilling campaigns and seismic programs for the South West Hub project. The study covers an area of 2800 km^2 from Pinjarra in the north, Bunbury in the south and 10 km offshore to the west. It incorporates data of seismic surveys conducted during the period from 1960 to 1990, along with data from petroleum and hydrogeological wells.

Regional geology

Tectonic elements

The Perth Basin lies along the southwestern margin of Western Australia and has been informally divided into northern, central, and southern parts (Crostella and Backhouse, 2000). The basin is bounded by the Darling Fault and Yilgarn Craton in the east and extends offshore as far as the continent–ocean boundary to the west (e.g. Crostella, 1995, Crostella and Backhouse, 2000). The north–south striking Darling Fault is the most distinctive structural feature in the region. It has controlled the evolution and geometry of the Perth Basin throughout the Phanerozoic (Iasky, 1993).

In the southern Perth Basin, the major structural elements include the Beermullah Trough, Mandurah Terrace, Vlaming Sub-Basin, Vasse Shelf and Bunbury Trough (Crostella and Backhouse, 2000; Fig. 1). The Beermullah Trough in the north (originally included within the Dandaragan Trough) is a large synclinal feature in which the sedimentary succession thickens towards the east (Crostella and Backhouse, 2000). The Mandurah Terrace contains strata at intermediate depths between the Beermullah Trough and the ill-defined Harvey Ridge (Thomas, in prep.), and is separated from the offshore Vlaming Sub-basin to the west by numerous strike-slip faults of the Badaminna Fault System (Marshall et al., 1989). The Bunbury Trough and Vasse Shelf between the Precambrian Leeuwin Complex and the Yilgarn Craton in the south are separated by the Busselton Fault (Crostella and Backhouse, 2000).

Previous studies (Iasky, 1993; Crostella and Backhouse, 2000; Iasky and Lockwood, 2004) have suggested that the Harvey Ridge in the onshore part of the southern Perth Basin was a result of northwest–southeast trending transfer movement. However, the nature and timing of this movement remains unresolved. Most of the tectonic element boundaries mentioned above are only loosely defined in previous work and require further clarification (Thomas, in prep.).

Stratigraphy

The stratigraphic succession in the southern Perth Basin ranges from Permian to Quaternary in age (Fig. 2). The most recent revision to the stratigraphy of the region by Crostella and Backhouse (2000) followed previous workers who extrapolated the Triassic–Jurassic stratigraphic nomenclature from the northern part of the basin, with the exception of the lowermost Triassic Sabina Sandstone, and proposed upper and lower members of the 'Lesueur Sandstone', which are only known in the southern part of the basin.

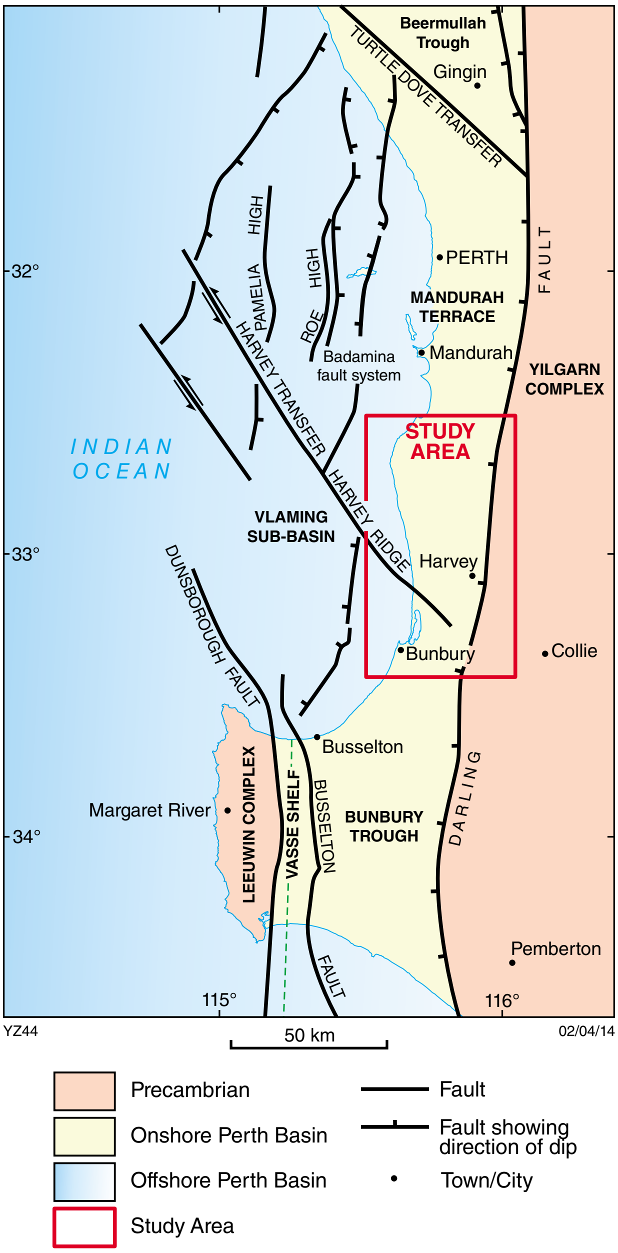

Figure 1. Tectonic elements surrounding the study area (after Crostella and Backhouse, 2000)

The application of the stratigraphic nomenclature in the southern Perth Basin is tentative. Several aspects of Crostella and Backhouse's (2000) correlations are unsatisfactory, throwing doubt on their interpretations. In detail, the workers:

- Did not explain the absence of either the 'Cattamarra Coal Measures' or 'Eneabba Formation' in several southern wells and indicated the two units as laterally equivalent (Crostella and Backhouse, 2000, Plate 1).

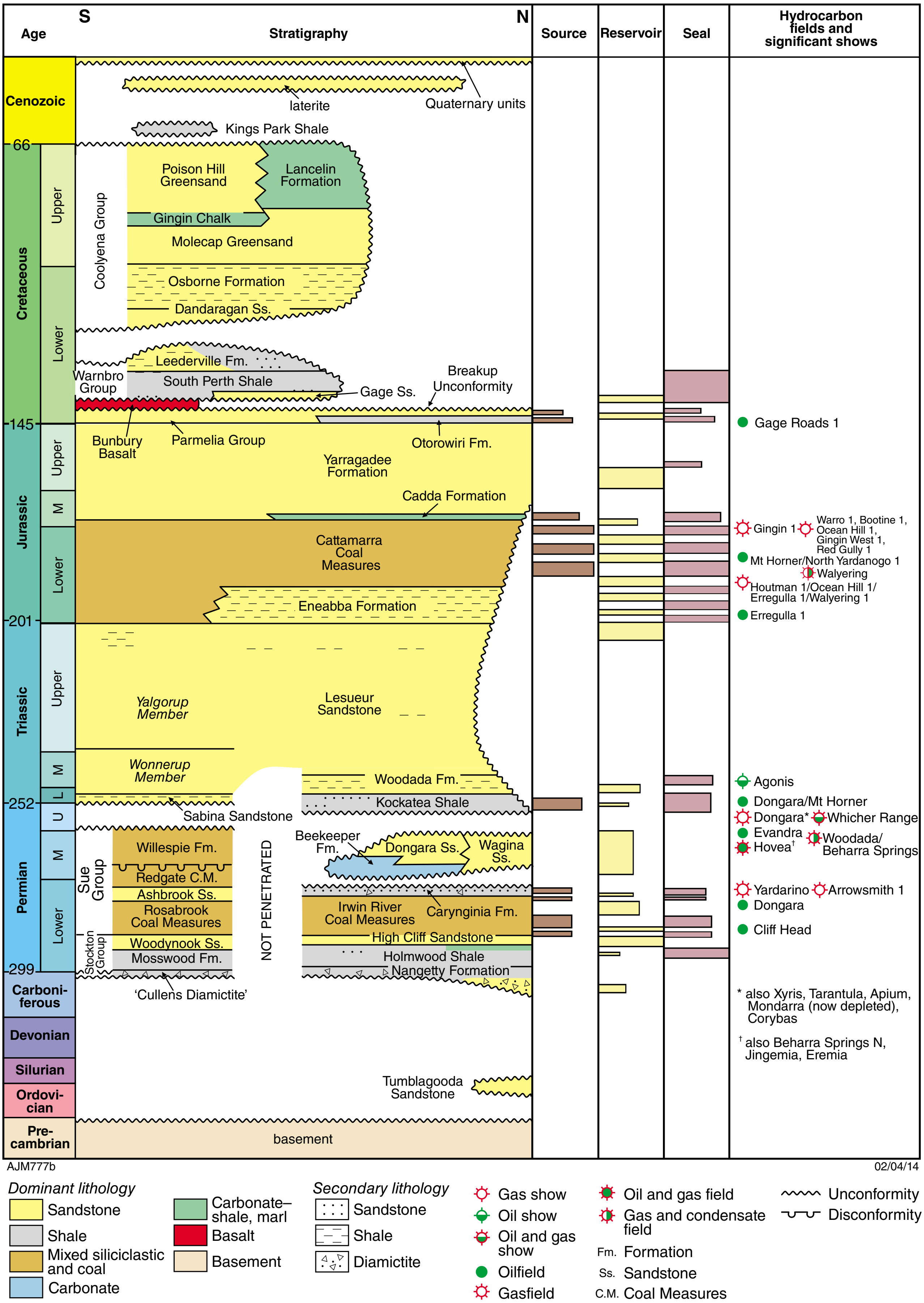

Figure 2. Stratigraphy of the Perth Basin

- Made little attempt to revise the palynology of the Triassic–Jurassic, with ages mostly taken directly from well completion reports.
- Did not incorporate 'lost' sections, due to faults cutting the wells, in their correlation.
- Designated type sections for the two proposed members of the 'Lesueur Sandstone' ('Yalgorup' and 'Wonnerup' Members) in wells 81 km apart (Lake Preston 1 and Wonnerup 1), thereby introducing uncertainty as to whether or not these units overlap or are separated by unaccounted sections.

Difficulties with confirming previous Triassic–Jurassic correlations within the southern part of the basin largely arise from the dominance of non-marine facies in this region: the only proven marine interval is in Cockburn 1 (60 km north of the study area), based on four samples yielding low-diversity dinoflagellates (Western Palynoservices, 1991).

In summary, there are several unsatisfactory aspects to the Triassic–Jurassic stratigraphic nomenclature of the southern Perth Basin, indicating the need for a review of the existing palynology and better integration of seismic data for all wells. It is especially important to attempt to delineate any missing sections. Thus, this study uses stratigraphic terms from the northern Perth Basin in quotation marks to indicate uncertainties in correlation, especially with the age equivalence of these units.

Despite a distinct lack of age control and other uncertainties for the fluvial deposits intersected by GSWA Harvey 1 (Millar and Reeve, in prep.) and Lake Preston 1 (Young and Johanson, 1973), this Record informally refers to the two members of the 'Lesueur Sandstone' as the 'Wonnerup' (lower) and 'Yalgorup' (upper) based on lithological correlations. The former member consists of over 1 km of homogeneous sandstone showing low-amplitude chaotic reflectors, whereas the latter consists of about 700 m of sandstone interbedded with shale, expressed on seismic data as a series of strong parallel reflectors. The 'Eneabba Formation', overlying the 'Lesueur Sandstone', has a basal unit of over 100 m of pedogenic shale (Millar and Reeve, in prep.), informally referred to herein as the 'basal Eneabba shale'. Overall, this formation is probably greater than 1 km thick, but is partially eroded on the Harvey Ridge. Within the study area the 'Cattamarra Coal Measures' have been intersected in Pinjarra 1 in the northern part of the study area. The Lower Cretaceous Warnbro Group is relatively extensive, but generally no greater than 250 m thick, and is overlain by a thin Cenozoic section.

Data description

Well control

Twelve drillholes have intersected Triassic to Jurassic strata in the study area (Fig. 3), including two stratigraphic wells, two petroleum exploration wells, and eight hydrogeological bores drilled in two east–west traverses (Harvey and Binningup Lines; Deeney, 1989a,b). The Harvey Line (HL) in the central part of the study area is about 35 km south of the most northern petroleum well (Pinjarra 1), and 20 km north of the Binningup Line. Individual waterbores along these lines are 5–7 km apart.

Formation tops for this study are from the well completion reports (e.g. Jones and Nicholls, 1966). They are mainly based on the correlation of wireline data, such as gamma-ray (GR) logs (Table 1). The lack of associated acoustic logs and palynological data has created difficulties in differentiating lithological units in some drillholes, particularly in separating the 'Eneabba Formation' from the underlying 'Yalgorup Member'.

Constraints for the seismic interpretation are restricted by some of the drillholes, such as HL1B and HL4A, are too far from good-quality seismic data and some, including Preston 1 and the Binningup Line water bores, do not intersect the formations of interest within the scope of this study. Nevertheless, GSWA Harvey 1, Lake Preston 1, and Pinjarra 1 provide reasonable controls for seismic interpretation around the Harvey area.

Seismic dataset

The seismic dataset used for this interpretation (Fig. 3, Table 2) includes the 100 km long GSWA Lower Lesueur 2011 survey (Gerus, 2011), 38 km Wellesley 2008 survey (CGGVeritas, 2008), 199 km Korijekup 1991 survey (Simon-Horizon Australia, 1991), 115 km Preston Detail 1971 marine survey reprocessed in 2013 (Gerus, 2013), and other vintage onshore surveys conducted between 1960 and 1989 and mostly reprocessed by Simon-Horizon Australia in 1990. The entire seismic grid is widely spaced with an average line spacing of 5 km. Data quality is variable, ranging from good to poor, but generally has improved for the more recent surveys. The parameters of the surveys most conducive to this study are listed in detail below.

The GSWA Lower Lesueur 2011 seismic survey (prefix 11GA) was a collaborative project between Geoscience Australia and GSWA to evaluate the stratigraphy and structure of the southern Perth Basin prior to drilling GSWA Harvey 1. This survey utilized a vibroseis source with 25 m geophone and shot intervals, and an average common depth point (CDP) fold of 150. This survey includes six lines, all of which have good field data quality, except for line 11GA–LL5 affected by noise from irrigation pipes. Velseis Processing Pty Ltd processed in 2011 using normal polarity and a mean sea level (MSL) datum (Gerus, 2011). The final output was based on a pre-stack time migration and is generally good quality.

The Korijekup 1991 survey (prefix P91) covers most of the study area and includes three regional north–south trending lines, 14 shorter east–west lines, and a single northeast–southwest line. This survey used vibroseis as a source and had average folds of 125 with a 30 m shot interval and 15 m station interval. The original data show considerable variation in quality, being good towards the north and east where clayey soils are present, and bad towards the west due to the near surface effects of karstic

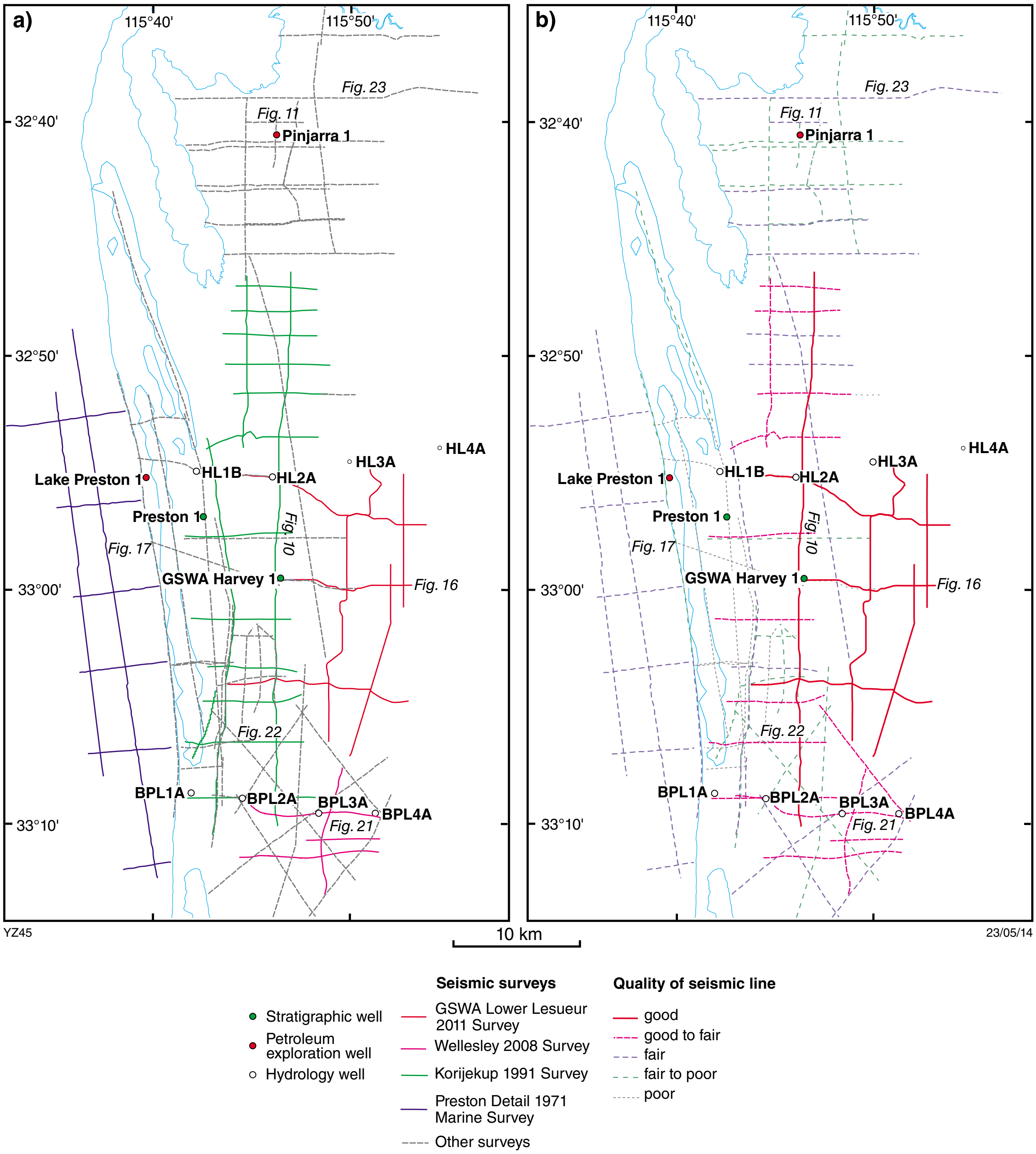

Figure 3. **Map of available seismic and well data: a) distribution of individual seismic surveys; b) survey quality**

Table 1. Summary of formation tops. Measured depths (mMD) from well completion reports (Jones and Nicholls, 1966; Lehmann, 1966; Young and Johanson, 1973; Deeney, 1989a,b; Millar and Reeve, in prep.). Question marks indicate uncertain formation boundaries.

	Harvey 1	*Lake Preston 1*	*Pinjarra 1*	*Preston 1*	*HL1B*	*HL2A*	*HL3A*	*HL4A*	*BPL1A*	*BPL2A*	*BPL3A*	*BPL4A*
Breakup unconformity	200	112	24	205	188	203	204	57	194	153	144.5	98.5
Top Cattamarra Coal Measures	–	–	149	–	–	–	–	–	–	–	–	–
Top 'Eneabba Formation'	200	112	1203	205	188	203	204	57	194	153	144.5	98.5
Top 'Yalgorup Member'	699	1219	2371			?310	?550					
Top 'Wonnerup Member'	1379	2045	?3210									
Top Sabina Sandstone	?2879	3474										
Top Permian		4035										
Total depth (TD)	2945	4565	4572	765	605	810	603	598	807	600	801	803

limestone formations. A belt of pine plantations, and saturation caused by electrical interference from overhead power lines, were also responsible for some of the poor quality. However, later processing by Simon-Horizon Australia significantly improved imaging, which can be mostly attributed to the application of a continuous intercept time from refraction for static correction, detailed velocity analysis, and wave-equation migration. The data processing utilized normal polarity for imaging and MSL as the seismic datum, whereas the first sample of the stack data is 100 milliseconds (ms) above MSL (Simon-Horizon Australia, 1991).

The Preston Detail 1971 marine survey (prefix PD71), shot in 1971 and 1972, was reprocessed for GSWA by Velseis Processing Pty Ltd in 2013. It consists of eight lines totalling 113 km, sourced by Aquaflex detonating cord, except line LG, which was acquired with an airgun source (Gerus, 2013). The recorded data are of poor quality due to low source energies, low CDP fold (average of 6), and a large receiver interval. The reprocessing program applied up-to-date techniques, including F-X deconvolution, CRS stack, and FK filters (Gerus, 2013). Lines were treated individually because tests showed lines could be easily over- or under-processed. Cable modifications produced a 180° phase rotation for parts of lines LA and LB acquired in early 1972. The reprocessing reversed the phase so that reflectors in these lines could be merged. In general, reprocessing achieved a significant improvement in data quality considering the unsatisfactory acquisition parameters. Source and streamer static corrections were applied to correct the data to the MSL datum. The original SEG[1] polarity of this survey is uncertain.

Most of the other surveys listed in Table 2 were reprocessed by Simon-Horizon Australia prior to the acquisition of the Korijekup 1991 survey. The polarity and datum are assumed to be the same as this survey, i.e. SEG normal polarity and MSL datum. Reprocessing has generally improved data where reflections were present in the original dataset, but only had little effect on poor-quality areas. This can probably be attributed to the survey's low fold and large group interval parameters, combined with adverse geological conditions, such as the intensity of faults in the subsurface.

1 Society of Exploration Geophysicists

Mis-tie analysis

As described above, the seismic profiles used in this study are from different sources, with most processed and reprocessed by either Velseis Processing Pty Ltd in the 2010s or Simon-Horizon in the 1990s. There are considerable mis-ties between survey data from these two companies. In this study the GSWA Lower Lesueur 2011 Survey has been set as the standard, using MSL as the datum. Surveys such as the Wellesley 2008 and Preston Detail 1971 marine surveys also utilised MSL as the datum and therefore did not require a time shift. Nevertheless, others are of such poor quality, such as the Charla 1966 Survey, that time adjustments were not worthwhile. The remaining surveys were time shifted in the following sequence:

- The Korijekup 1991 Survey, which has good data quality and extensive coverage, was adjusted first. Although it also has an MSL datum, the time of the first sample yields a 100 ms mis-tie. An upwards shift of 100 ms enables this survey to match the standard data perfectly (Fig. 4).

- A north–south regional line, P91–103, is used as the reference profile to correct surveys reprocessed by Simon-Horizon Australia in the 1990s. Although the datum for these surveys is not clearly specified in available reports, the Harvey D1 Survey appears to require the same time shift as the Korijekup 1991 Survey (Fig. 5). Accordingly, 100 ms mis-ties were assumed for the other datasets as they were reprocessed by the same company during the same period.

Table 2. List of seismic lines

Survey	*Line*	*Length (km)*	*Quality rating*	*Comment*
GSWA Lower Lesueur 2011 (Vibroseis)	11GA_LL1	17.5	1	processed by Velseis in 2011
	11GA_LL2	14.6	1	
	11GA_LL3	14.8	1	
	11GA_LL4	25.9	1	
	11GA_LL5	15.6	1	
	11GA_LL6	10.5	1	
Wellesley 2008 (Vibroseis)	EW08_01	11.3	2	processed by CGGVeritas in 2008
	EW08_02	5.8	2	
	EW08_03	11.1	2	
	EW08_04	10.4	2	
Korijekup 1991 (Vibroseis)	P91_101	31.8	3	processed by Simon-Horizon in 1991
	P91_102	13.6	2	
	P91_103	44.0	1	
	P91_104	6.4	2	
	P91_105	6.7	2	
	P91_106	7.4	3	
	P91_107	8.2	3	
	P91_108	7.4	2	
	P91_109	9.4	2	
	P91_110	8.4	2	
	P91_111	7.2	2	
	P91_112	7.9	2	
	P91_113	7.0	3	
	P91_114	7.9	2	
	P91_115	9.4	2	
	P91_116	5.6	4	
	P91_117	10.6	2	
Happy Valley 1981 (Vibroseis)	P81_810	20.4	4	reprocessed by Simon-Horizon Australia in 1990
	P81_811	5.8	4	
	P81_815	4.4	4	
	P81_816	9.2	5	
	P81_817	8.5	4	
	P81_818	7.3	4	
Preston Detail Marine 1971 (Aquaflex and airgun for line LC)	PD71_LA	43.9	3	reprocessed by Velseis in 2013
	PD71_LB	29.1	3	
	PD71_LC	9.3	3	
	PD71_LD	6.7	3	
	PD71_LE	6.8	3	
	PD71_LF	6.9	3	
	PD71_LG	6.5	3	
	PD71_LH	3.7	3	
Preston D1 Detail 1971 (Dynamite)	PD71_AL	5.8	5	reprocessed by Simon-Horizon Australia in 1990
	PD71_AM	22.8	4	

NOTE: Data quality: 1 = good; 2 = good to fair; 3 = fair; 4 = fair to poor; 5 = poor

Table 2. List of seismic lines continued

Survey	*Line*	*Length (km)*	*Quality rating*	*Comment*
Preston Detail 1970 (Dynamite)	PD70_AD	19.5	4	reprocessed by Simon-Horizon Australia in 1990
	PD70_AE	12.9	5	
	PD70_AJ	26.9	5	
	PD70_AK	3.3	5	
	PD70_C	13.0	3	
	PD70_D	5.0	5	
Harvey D1 1969 (Dynamite)	HD69_AA	12.5	4	reprocessed by Simon-Horizon Australia in 1990
	HD69_AB	11.7	2	
	HD69_AC	11.3	4	
	HD69_AD	12.9	3	
	HD69_AE	10.3	4	
	HD69_AF	17.4	3	
	HD69_AG	11.7	3	
	HD69_AH	4.1	3	
	HD69_AI	3.6	3	
	HD69_Z	32.9	3	
Harvey 1969 (Dynamite)	H69_Y	64.7	4	reprocessed by CGGVeritas in 2009
Karnup Reconnaissance 1966 (Dynamite)	KR66_AB	9.2	5	digitized by Spectrum
	KR66_AC	32.0	4	
	KR66_Y	17.8	4	
	KR66_A	25.1	5	
	KR66_B	20.8	4	
	KR66_C	10.7	3	
Charla 1966 (Dynamite)	C66_X	28.5	5	digitized by Spectrum
	C66_W	8.4	5	
Pinjarra Detail 1965 (Dynamite)	PD65_F	10.9	3	reprocessed by Simon-Horizon Australia in 1990
	PD65_N	4.6	4	
	PD65_P	6.9	5	
	PD65_R	11.3	3	
Lake Preston 1964 (Dynamite)	LP64_A	13.7	5	reprocessed by Simon-Horizon Australia in 1990
	LP64_B	18.6	5	
	LP64_C	28.2	5	
	LP64_D	4.1	5	
	LP64_E	4.5	5	
	LP64_F	14.4	4	
	LP64_G	24.1	3	
	LP64_H	16.9	4	
	LP64_J	12.9	4	
	LP64_K	13.6	3	
	LP64_L	9.2	4	
	LP64_M	14.4	4	
	LP64_N	15.8	4	
	LP64_P	3.5	4	
	LP64_Q	3.2	4	
	LP64_R	7.9	4	
	LP64_S	2.7	5	
Pinjarra Reconnaissance 1964 (Dynamite)	PR64_U	5.3	3	reprocessed by Simon-Horizon Australia in 1990
	PR64_V	4.4	4	

NOTE: Data quality: 1 = good; 2 = good to fair; 3 = fair; 4 = fair to poor; 5 = poor

Out-of-plane mismatches

Lines within each survey have mismatches at intersection points with other lines from the same survey. This is a typical drawback of 2D seismic data as the reflection points do not lie vertically beneath the observation line in a position where the acquisition line is not parallel to the dip of inclined strata.

As the intervals of interest in this study are dipping east-northeast, this out-of-plane issue causes unadjustable mismatches between intersecting lines, which markedly increase with depth. For example, at the intersections of lines 1, 2, and 6 of the GSWA Lower Lesueur 2011 Survey (Fig. 6) the severe mismatches below 1500 ms indicate that the structure revealed by line 6 is oblique to its vertical plane. Compared to these mismatches, the effect of the uncertain polarity of the Preston Detail 1971 marine survey is negligible for the structural study of the Harvey area.

Seismic interpretation and mapping

Well–seismic ties

Three wells in the study area — GSWA Harvey 1, Lake Preston 1, and Pinjarra 1 — have been tied to the seismic data based on sonic logs and velocity surveys (Fig. 7), because the walkaway vertical seismic profile (VSP) survey in GSWA Harvey 1 was only run to 1189 metres of measured depth (mMD) due to a wireline cable failure. The rest of the GSWA Harvey 1 time to depth conversion is based on acoustic logs (Fig. 8). Lake Preston 1 has a checkshot survey conducted from 457 to 4563 mMD, with which the sonic log is integrated for seismic control. At Pinjarra 1, a conventional 13 shot velocity survey was conducted for five distinct depths, including two seismic markers, and at total depth (TD, 4572 mMD) with the remaining two shots spaced to fill gaps.

Vertical seismic profile or checkshot survey travel times commonly vary from travel times calculated using sonic logs. The main reasons for this are: (i) sonic and seismic profiles investigating different volumes of rock due to their different geometry and source frequencies, (ii) instrument errors and analysis inaccuracies inherent in each system, and (iii) differences in wave propagation (Thomas, 1978). Therefore, the VSP from GSWA Harvey 1 and checkshot surveys for the other two wells were used to calibrate their respective sonic logs to generate synthetic seismograms. The transit times in the sonic logs have been scaled based on the propagation time of seismic waves. This led to a relatively good match between the synthetic seismograms and the seismic traces considering the well offsets and seismic quality, especially for deep sections.

Horizon interpretation

Two-way-time (TWT) structure maps and depth conversions have been constructed for the five seismic horizons interpreted throughout the study area. These horizons were selected based on well-defined boundaries at drillholes, lateral continuity, structural significance, and relevance to CO_2 injection. The interpreted horizons are: the Cretaceous breakup unconformity, top ‘Eneabba Formation’, top ‘Yalgorup Member’, top ‘Wonnerup Member’, and top Sabina Sandstone. Despite being restricted by poor-quality seismic data in some places, confidence in the interpretation of the breakup unconformity, top ‘Wonnerup Member’, and top Sabina Sandstone is good. The interpretation of the top ‘Eneabba Formation’ and top ‘Yalgorup Member’, on the other hand, are of relatively low confidence.

Breakup unconformity

The most significant break in the Perth Basin succession was due to the separation of Australia from Greater India (Falvey and Mutter, 1981, Woodside Offshore Petroleum, 1988, Crostella and Backhouse, 2000) during the Early Cretaceous, coeval with the extrusion of the Bunbury Basalt (Playford et al., 1976, Backhouse, 1988, Iasky, 1993). In the offshore Perth Basin, this unconformity is a prominent feature (‘Valanginian unconformity’ of Jones et al., 2011, figs 4–6). It can be correlated to a similar unconformity in the onshore Perth Basin, where it is referred to as the ‘breakup unconformity’.

This break can be identified confidently, throughout most of the study area where seismic data are of interpretable quality, and appears to be an obvious angular unconformity at shallow depths (less than 250 ms onshore; Figs 9 and 10). Well intersections only place loose controls on this break as seismic velocities at shallow depths are highly variable. The Lower Cretaceous Warnbro Group and younger units above the unconformity are flat lying, as opposed to variably tilted strata below the unconformity (Fig. 10). Few faults at depth, except for the Darling Fault, displace the unconformity.

The TWT and depth maps of the breakup unconformity (Fig. 9, Plate 1) indicate that onshore this horizon is generally flat lying (0–200 ms, 0–300 m below MSL) and gradually shallows eastwards towards the Darling Fault. Offshore, the unconformity deepens to the west and is interpreted to have the same trend in the northwestern part of the study area. This trend can be inferred from the nearby offshore seismic line (line 23B of WA–174–P 1982 Marine Survey), northwest of the study area, in which the unconformity is at about 600 ms.

Top ‘Eneabba Formation’

The top ‘Eneabba Formation’ horizon was interpreted with a relatively low level of confidence; the only well in which it has not been eroded is Pinjarra 1 (Jones and Nicholls, 1966). In this well the overlying interbedded sandstone shale and siltstone (‘Cattamarra Coal Measures’) are lithologically similar to the ’Eneabba Formation’ (Fig. 11). In addition, the horizon cannot be traced confidently far from this well because the seismic reflectors near this level become less continuous away from Pinjarra 1. The interpretation is dependent on the overall trend of adjacent seismic reflections.

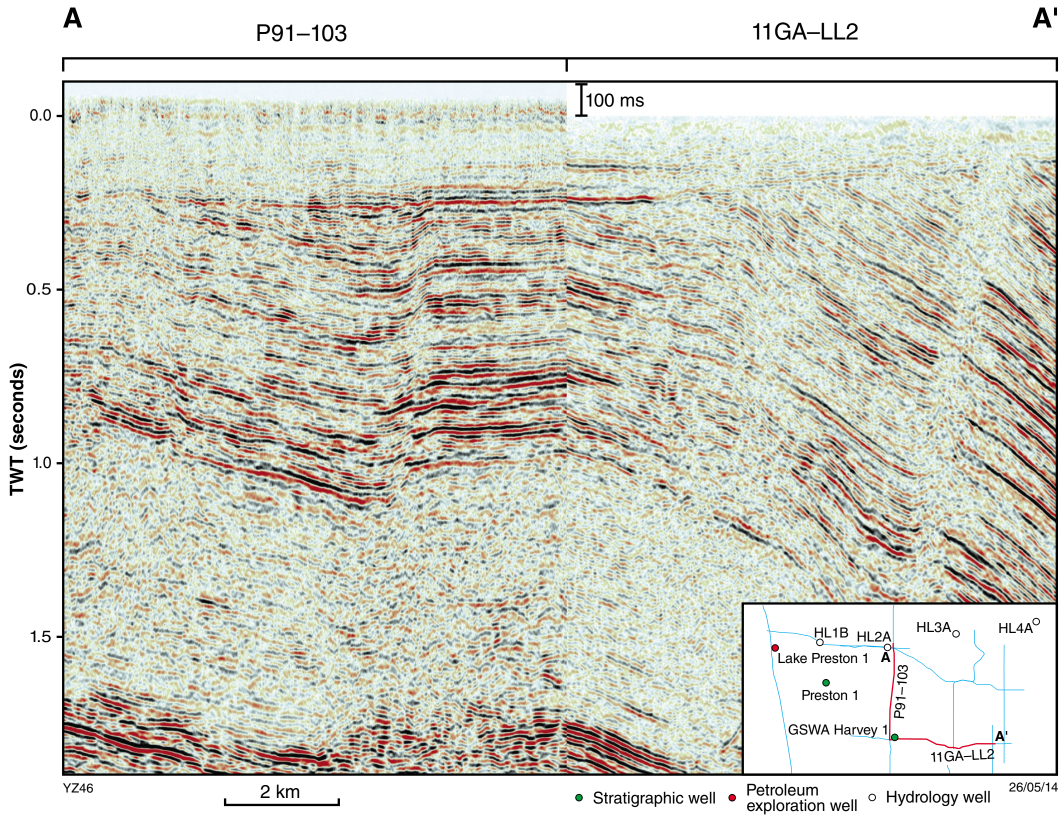

Figure 4. **Seismic section showing 100 milliseconds mis-tie between lines P91–103 and 11GA–LL2**

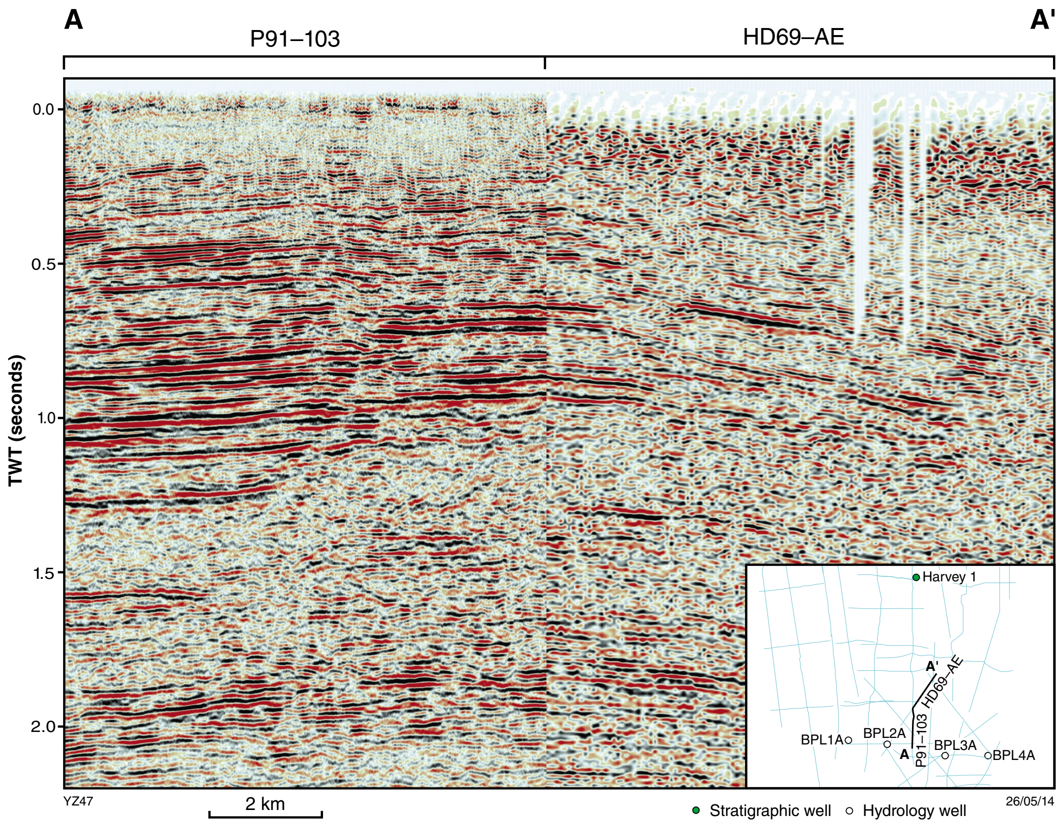

Figure 5. **Seismic section showing the absence of mis-tie within surveys (here: Korijekup and Harvey D1 surveys) processed or reprocessed by the same company**

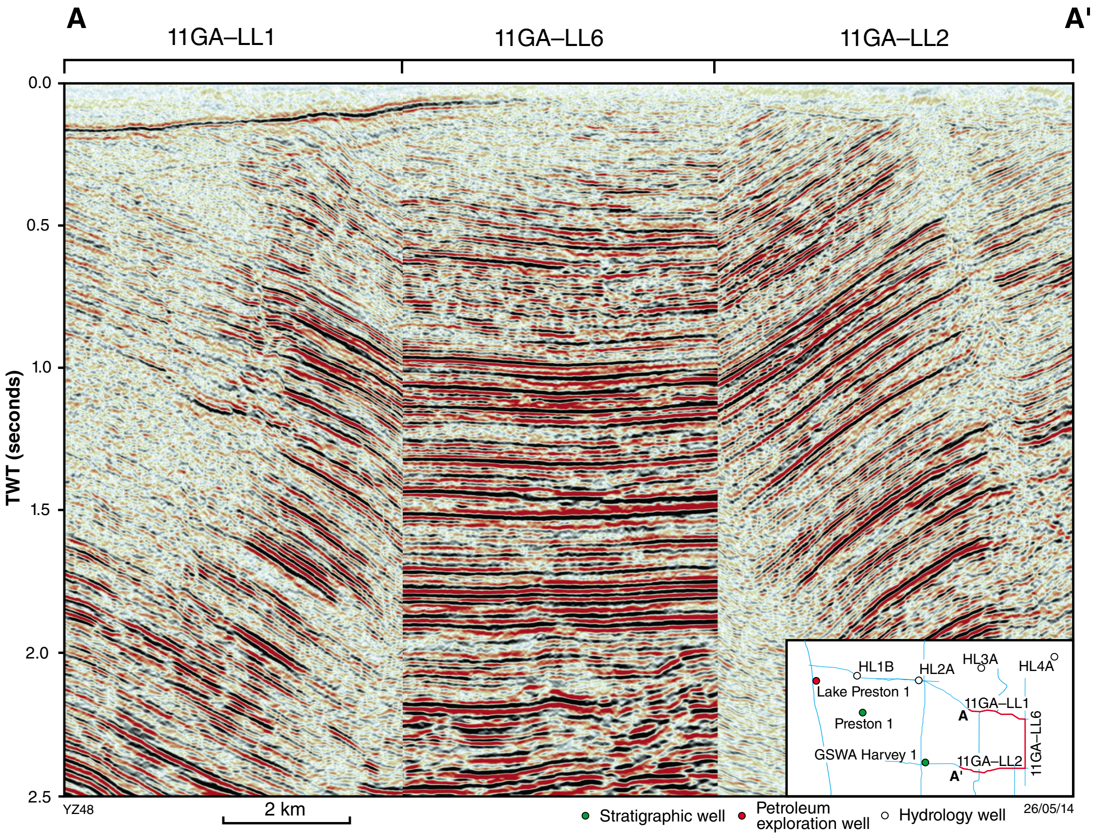

Figure 6. Seismic section showing out-of-plane mismatch within lines of the GSWA Lower Lesueur 2011 Survey

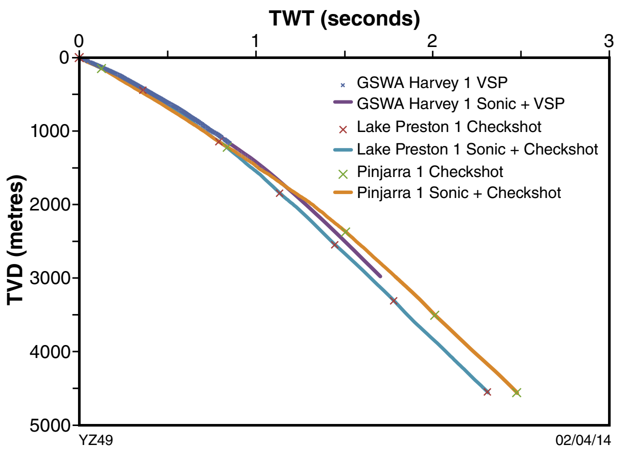

Figure 7. Relationship between two-way time (TWT) and true vertical depth (TVD) in three key petroleum wells

Good-quality seismic lines indicate that the 'Eneabba Formation' has been partially eroded in the southern part of the study area (Fig. 10), consequently this horizon was not mapped in that area. Its minimum observable residual thickness in seismic profiles is about 100 ms (~150 m), approximately 3 km north of HL2A. Mapping in the northern part of the study area (Fig. 9, Plate 1) indicates that this horizon deepens to the northeast. Faults at this level, including the Darling Fault, are predominantly north–south oriented and exhibit normal movement, dipping to the west.

Top 'Yalgorup Member' ('upper Lesueur Sandstone')

The top 'Yalgorup Member' is one of the most important horizons with respect to seal integrity. It has been interpreted based on a relatively continuous reflector in all three petroleum wells and two water bores, HL2A and HL3A.

Lake Preston 1 (Young and Johanson, 1973) encountered about 100 m of 'multi-coloured' claystone with interbedded siltstone and sandstone, commonly termed the 'basal Eneabba shale', above 1219 mMD clearly

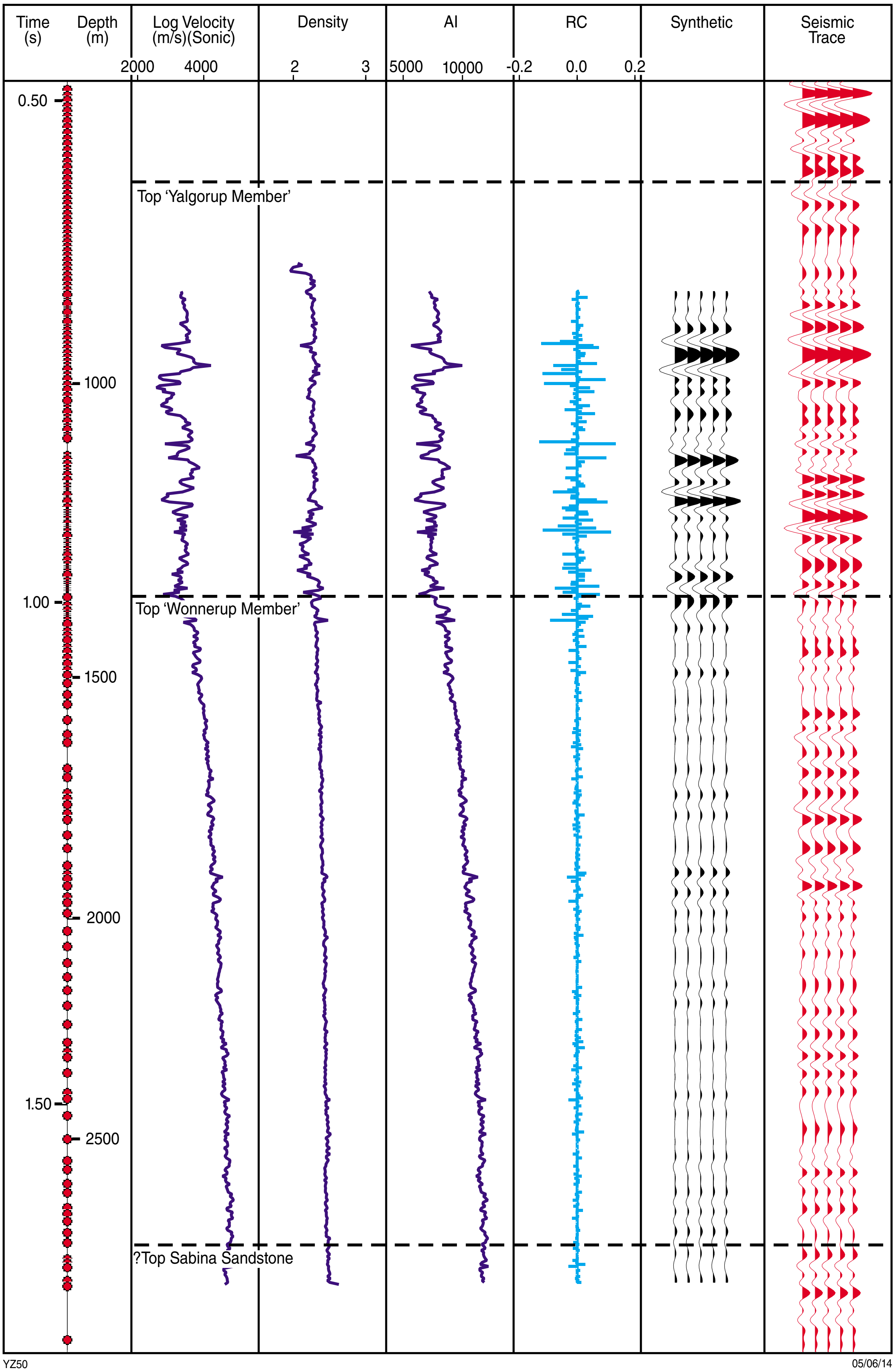

Figure 8. GSWA Harvey 1 synthetic seismogram

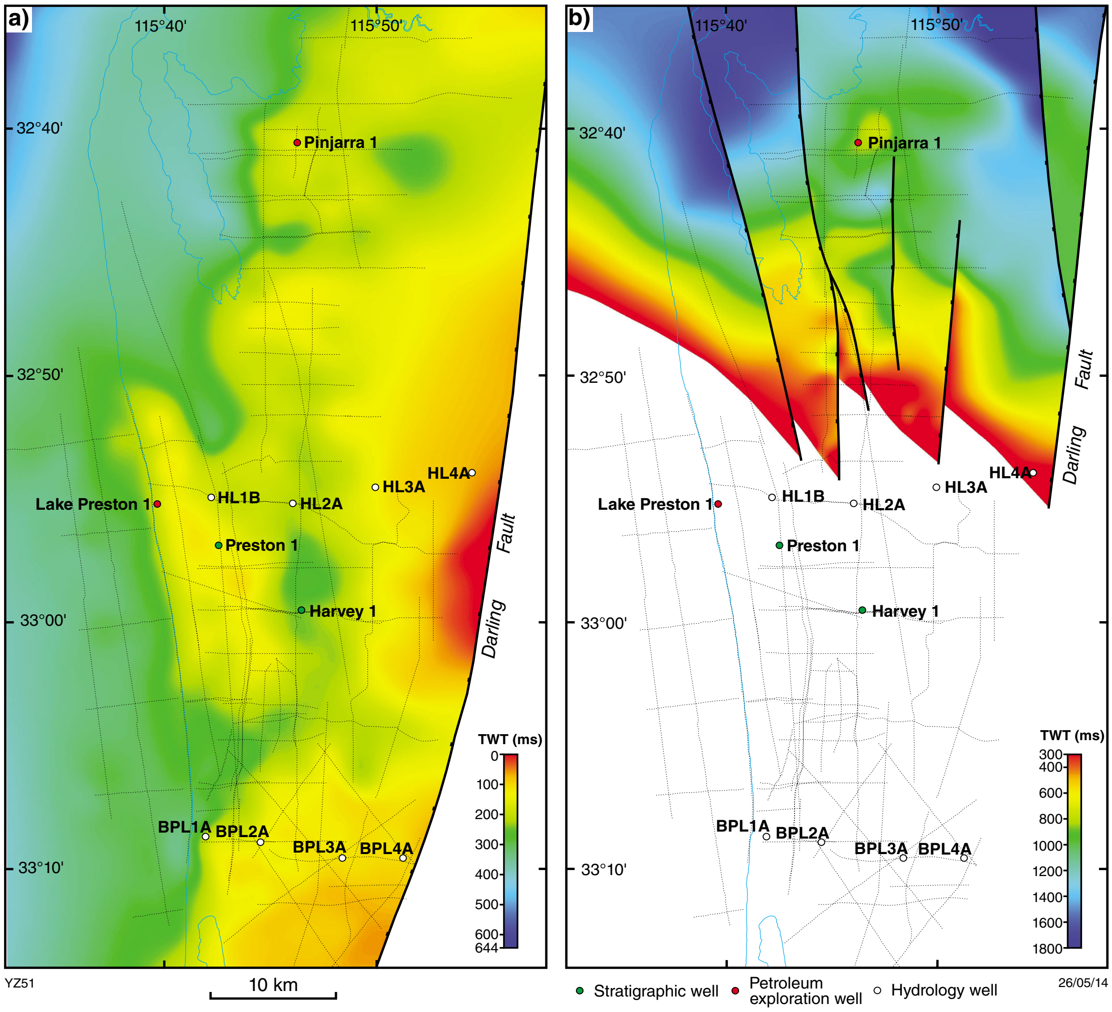

Figure 9. Time–structure maps of the: a) breakup unconformity; b) top 'Eneabba Formation' horizons

shown by an abrupt change in character in the wireline logs (Fig. 12). The sonic log and checkshot data indicate that this horizon corresponds to a high-amplitude seismic reflector that is consistent with a peak reflection generated between thick overlying low-impedance beds and underlying high-impedance beds — based on a SEG normal polarity and zero phase waveform (see section Seismic dataset). It is not clear whether the reflector's lack of continuity is due to the local absence of the 'basal Eneabba shale' or poor seismic imaging in some places (Fig. 12).

GSWA Harvey 1 (Millar and Reeve, in prep.) intersected two shale intervals (~22 m and ~40 m thick) with interbedded sandstone (~15 m thick) above the top of the 'Yalgorup Member'. These two intervals have a high GR response, most clearly seen on the logging-while-drilling (LWD) data. They are significantly different from overlying and underlying lithologies. Both shale intervals can be resolved within the existing seismic profiles and show relatively strong and continuous reflections around the Harvey area. This is consistent with the seismic resolution (greater than 19 m thick), calculated from the seismic frequency of approximately 37 Hz and velocity of about 2750 m/s at this level. Calibration of the formation tops from VSP and sonic logs shows that the boundary between the 'Yalgorup Member' and 'Eneabba Formation' is a relative high-amplitude peak beneath a set of persistent parallel reflectors (Fig. 13). The change of the seismic character between Lake Preston 1 and GSWA Harvey 1 corresponds to a variation in the thickness of the 'basal Eneabba shale' from the 100 m of claystone interval in Lake Preston 1 to two thinner intervals in GSWA Harvey 1, which are evident on the GR logs.

In water bore HL2A, the GR log and sidewall-core samples indicate three intervals of clay and siltstone above 400 mMD (Deeney, 1989a). Applying the VSP from GSWA Harvey 1 to HL2A supports the correlation of these shaly interbeds with the top of the 'Yalgorup Member', although they are less well developed than in GSWA Harvey 1. In addition, the seismic profile (Fig. 10, see section between SP 3000 and 4000) indicates that the 'Eneabba Formation' appears to onlap the 'Yalgorup Member' in this area. However, a lack of palynological control in the water bores, due to oxidized or otherwise unsuitable lithologies, hampers correlation of the 'Yalgorup Member'.

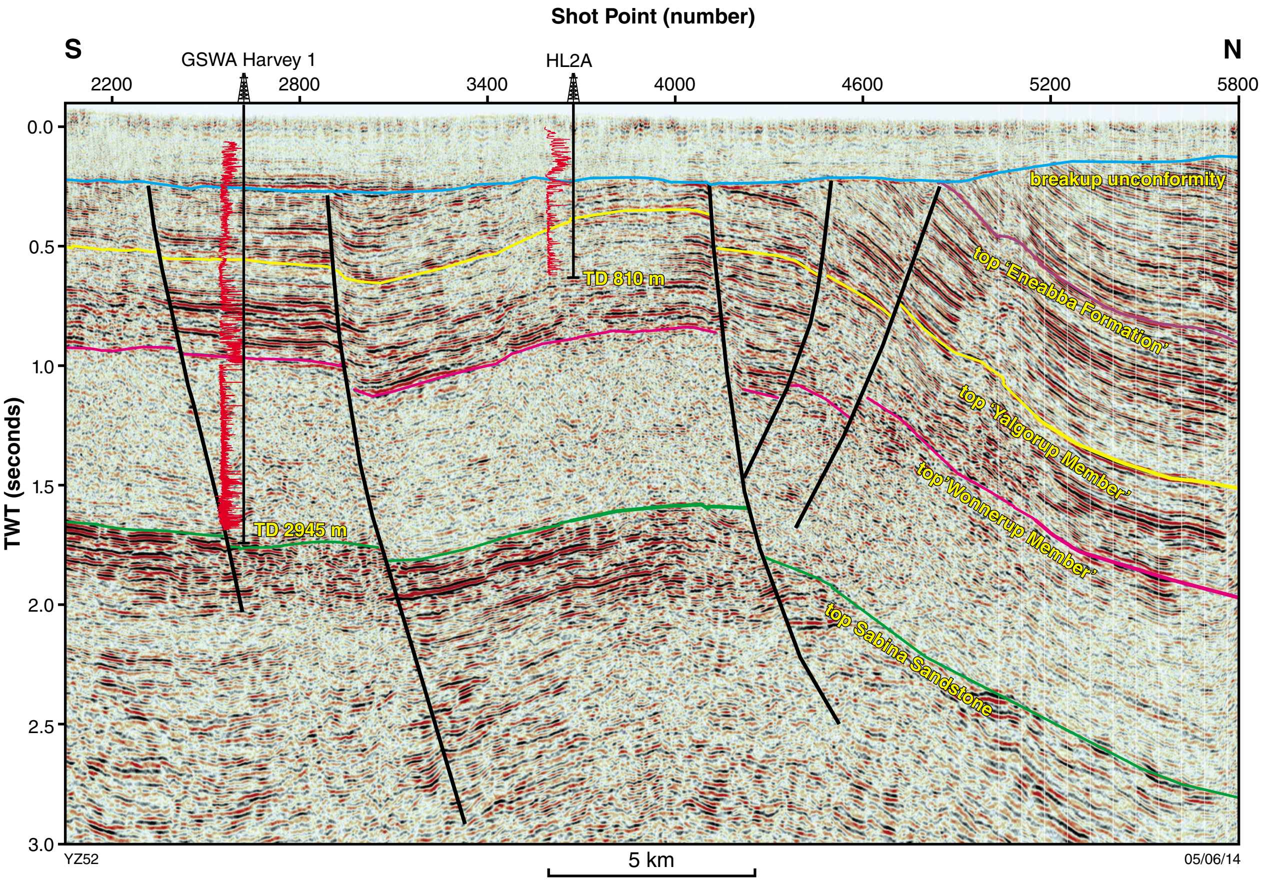

Figure 10. Part of section P91–103, showing the partial erosion of the 'Eneabba Formation' below the breakup unconformity (see Figure 3 for location)

Interpretation of the top 'Yalgorup Member' in HL3A (Figs 13 and 14) requires a jump correlation across a large fault (Fig. 13, see central fault). This horizon is displaced by approximately 650 ms across this fault based on the assumption of constant thickness and the pick of the 'Wonnerup Member' discussed below. Based on the GR log and integrated prediction error filter analysis (INPEFA) curve (Nio et al., 2005; Haines, 2009) in HL3A the interval below 548 mMD appears to be equivalent to the upper part of the 'Yalgorup Member' (Fig. 14). In addition, this level is probably about 200 m (~140 ms) deeper in the nearest seismic line (11GA–LL4) allowing for an offset of 1640 m and a 7° dip to the east-northeast. Accordingly, the set of distinct reflectors at the top of the 'Yalgorup Member' coincides with clays and sandstones in HL3A between 436 and 563 mMD, which Deeney (1989a) assigned to the 'Eneabba Member' of the now defunct 'Cockleshell Gully Formation'. The high-amplitude reflectors at this horizon are similar to those at GSWA Harvey 1, Lake Preston 1, and HL2A, indicating that the 'basal Eneabba shale' is relatively continuous within the Harvey area.

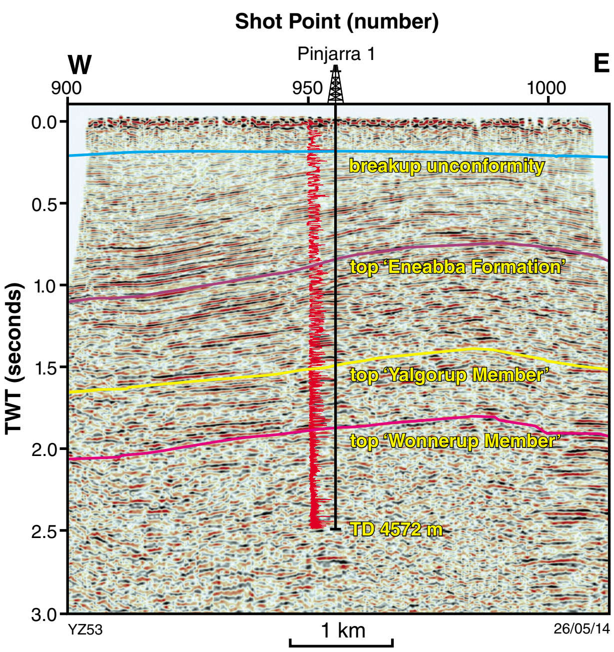

Figure 11. Seismic section PR64–U, showing the constraints for the interpretation of Triassic–Cretaceous horizons from Pinjarra 1 (see Figure 3 for location)

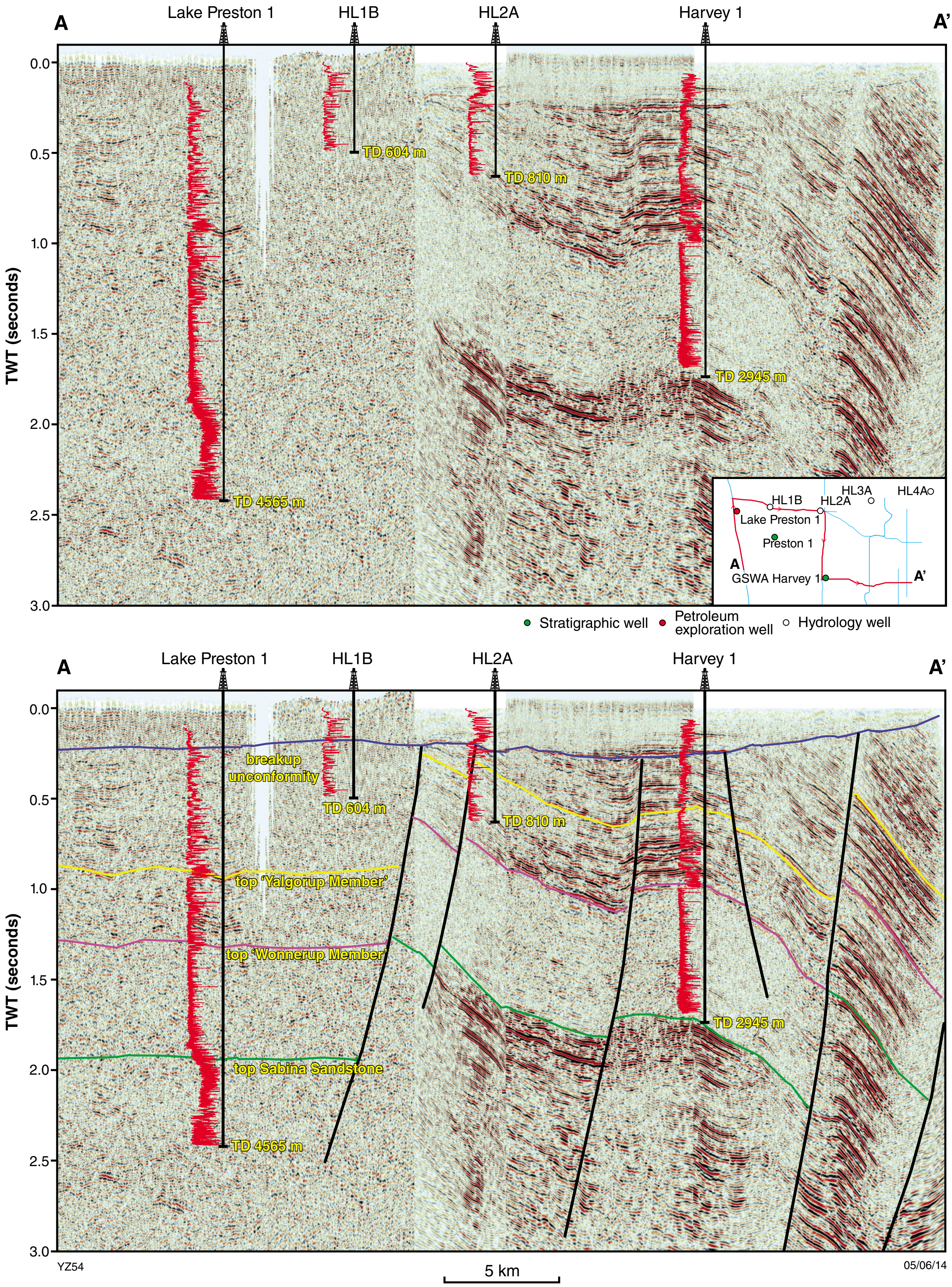

Figure 12. Seismic interpretation from Lake Preston 1 to GSWA Harvey 1

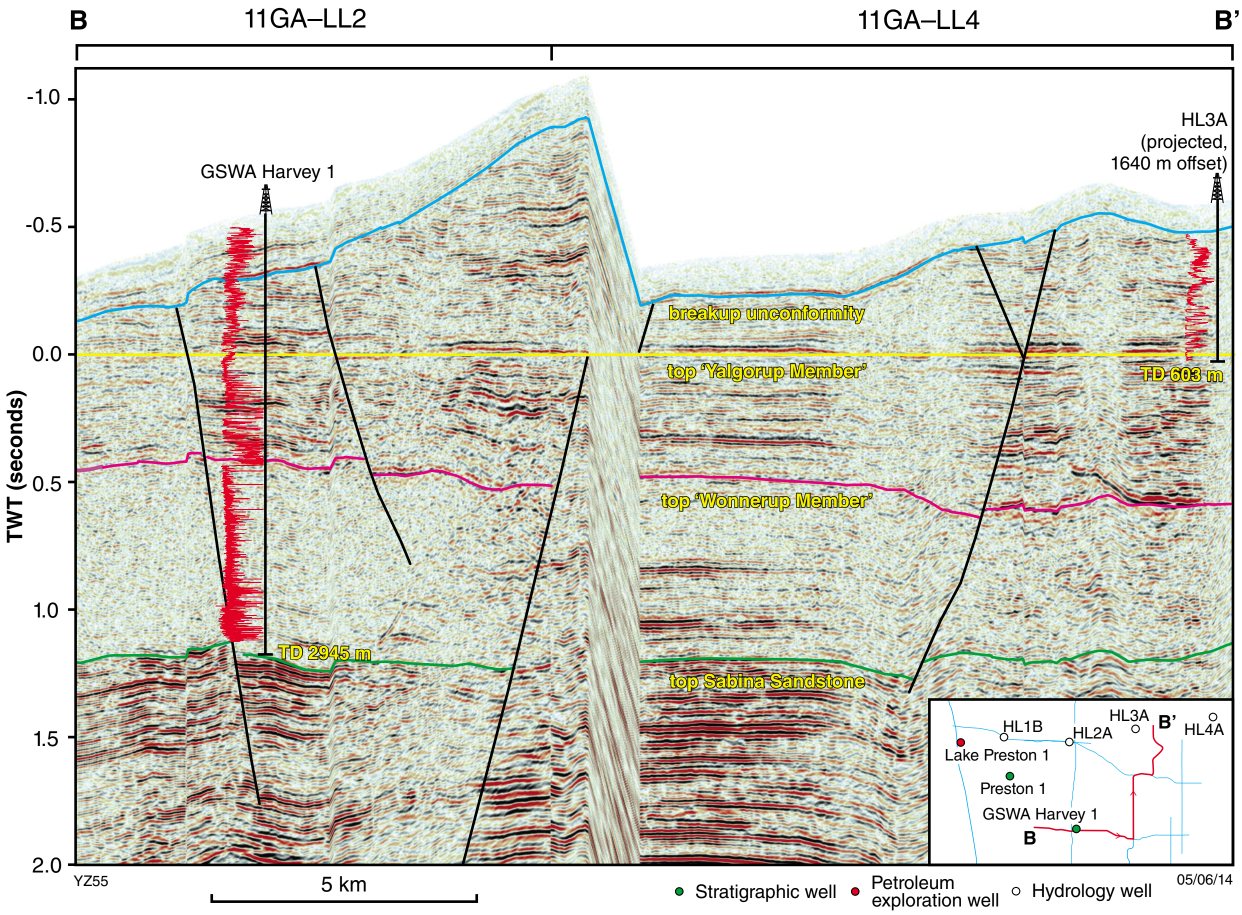

Figure 13. Seismic interpretation from GSWA Harvey 1 to HL3A, showing the 'basal Eneabba shale' by flattening the top 'Yalgorup Member' horizon

Differentiation of the top of the 'Yalgorup Member' in Pinjarra 1 is not as clear as in wells further south. This is due to the presence of similar lithologies in the 'Eneabba Formation' and 'upper Lesueur Sandstone' ('Yalgorup Member') as identified by Jones and Nicholls (1966; Fig. 11). Uncertainties in the seismic interpretation of this horizon are further increased by the poor data quality north of the study area. Nevertheless, Jones and Nicholls' (1966) interpretation for this boundary at 2371 mMD in Pinjarra 1 (about 1100 m deeper than in Lake Preston 1) is consistent with the east-northeast trend of dips in the seismic images.

The structure maps (Fig. 15, Plate 1) show that the top 'Yalgorup Member' horizon rises towards the middle of the study area and culminates on the footwall of a fault next to Preston 1. GSWA Harvey 1 and nearby water bores lie on this regional west-northwest structural high that abuts against the Darling Fault to the east. The 500–670 m variation in formation depths (Table 1) between GSWA Harvey 1 and Lake Preston 1 over such a short distance (13 km) indicates a major north-striking fault between the two wells. Conversely, the considerable deepening of formations near Pinjarra 1 to the north mainly appears to be due to the dip of the strata rather than fault displacements.

Top 'Wonnerup Member' ('lower Lesueur Sandstone')

Based on well correlations the 'Wonnerup Member' is widespread across the southern Perth Basin and maintains a constant thickness throughout the study area. The boundary between the 'Yalgorup' and 'Wonnerup' Members was intersected by all three petroleum wells. It is a very clear boundary as it separates markedly different packages of lithologies. Therefore, this lithology change generates a seismic marker and is interpreted with a high level of confidence second only to the breakup unconformity.

GSWA Harvey 1 reveals that the lower section of the 'Yalgorup Member' (1200–1375 mMD) is dominated by paleosols, whereas the underlying 'Wonnerup Member' (below 1375 mMD) contains mostly medium to very coarse grained sandstone. In the wireline logs the contact between these units is evident as an abrupt change from uniform to highly variable responses and also as a change from low to high velocities (as calculated from the sonic log). This boundary corresponds to the top of thick low-amplitude and chaotic reflectors around GSWA Harvey 1 (Fig. 16). It is less distinctive near Lake

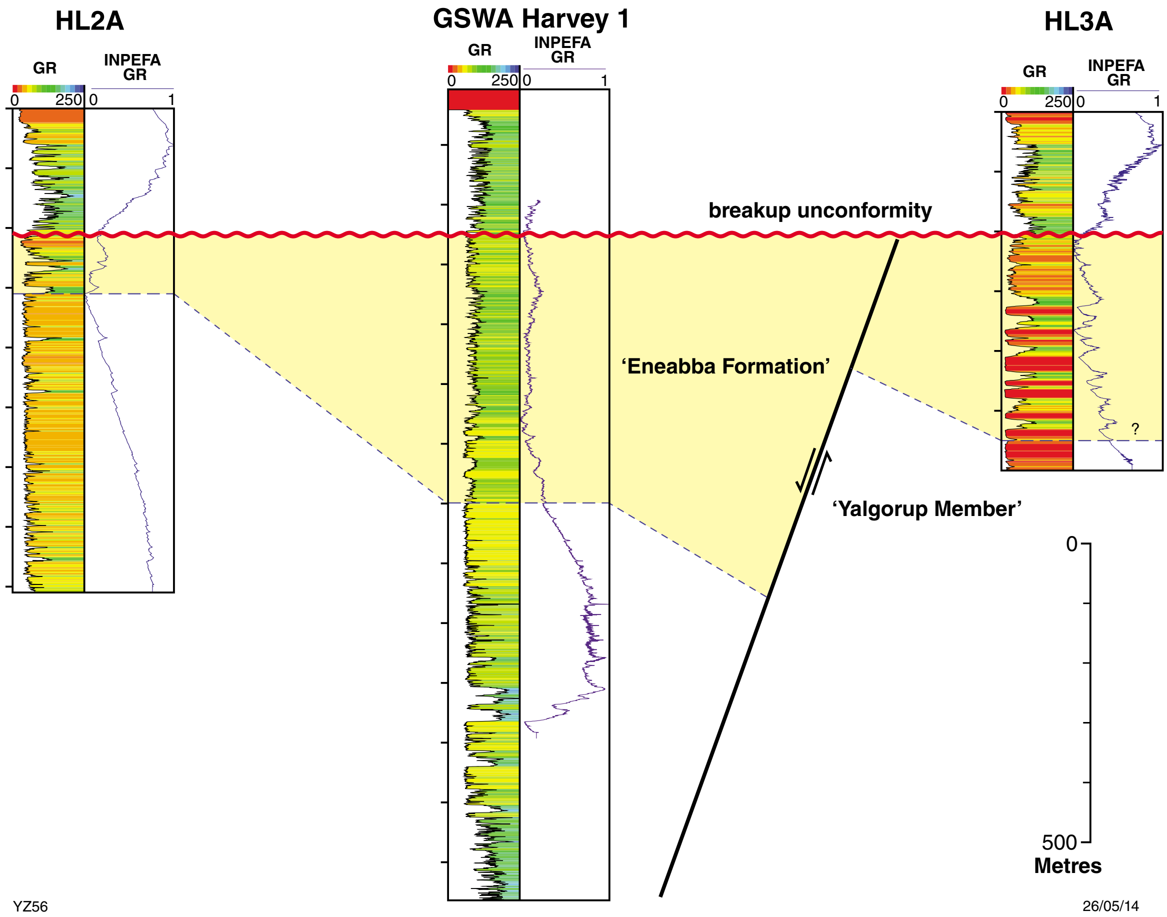

Figure 14. Stratigraphic correlation between GSWA Harvey 1 and Harvey Line water bores

Preston 1 and Pinjarra 1 due to the poor-quality seismic profiles in those areas. Nevertheless, it can still be traced as a line separating the bland, transparent reflection zone of the 'Wonnerup Member' from an overlying series of continuous reflectors.

The prominent seismic signature of the 'Wonnerup Member' is also present in areas lacking strong links to well data, such as immediately offshore and in lines between GSWA Harvey 1 and Pinjarra 1. Offshore the 'Wonnerup Member' exhibits a low-amplitude chaotic zone of reflection below 1500 ms (Fig. 17), sandwiched between overlying and underlying strong reflectors. This zone appears to be laterally extensive and the interval has an average span of 750 ms (~1600 m thick).

An exception to the bland nature of the 'Wonnerup Member' is seen about 5 km west of the Darling Fault, where it contains parallel, high-amplitude reflectors (Fig. 18). This change of seismic signature is probably about unknown lithologies rather than the product of geophysical issues, such as crooked acquisition geometry, velocity analysis, or statics. As the change in lithology is not associated with any particular fault in the area, it increases the uncertainty of the interpretation of this horizon. Nevertheless, the top 'Wonnerup' boundary is still recognizable on a north-trending line (11GA–LL4) with a displacement of 700 ms across a fault, and is interpreted to have a similar throw on the nearby east-trending 11GA–LL2 line.

The structural maps of the top 'Wonnerup Member' (Fig. 15b, Plate 1) indicate that, like the top 'Yalgorup Member' horizon, the top 'Wonnerup' reflector rises towards the middle of the study area and culminates on the footwall of a fault next to Preston 1. Although the horizon has been extrapolated both northwest and southwest, a high level of uncertainty is implicit in those areas due to the poor seismic quality.

Top Sabina Sandstone

In the southern part of the study area the top Sabina Sandstone horizon is distinct on most seismic profiles because of the lithological contrast between Sabina Sandstone and the overlying 'Wonnerup Member'. This is because the Sabina Sandstone predominantly consists of poorly consolidated sandstone interbedded with shale and siltstone (Crostella and Backhouse, 2000), expressed on

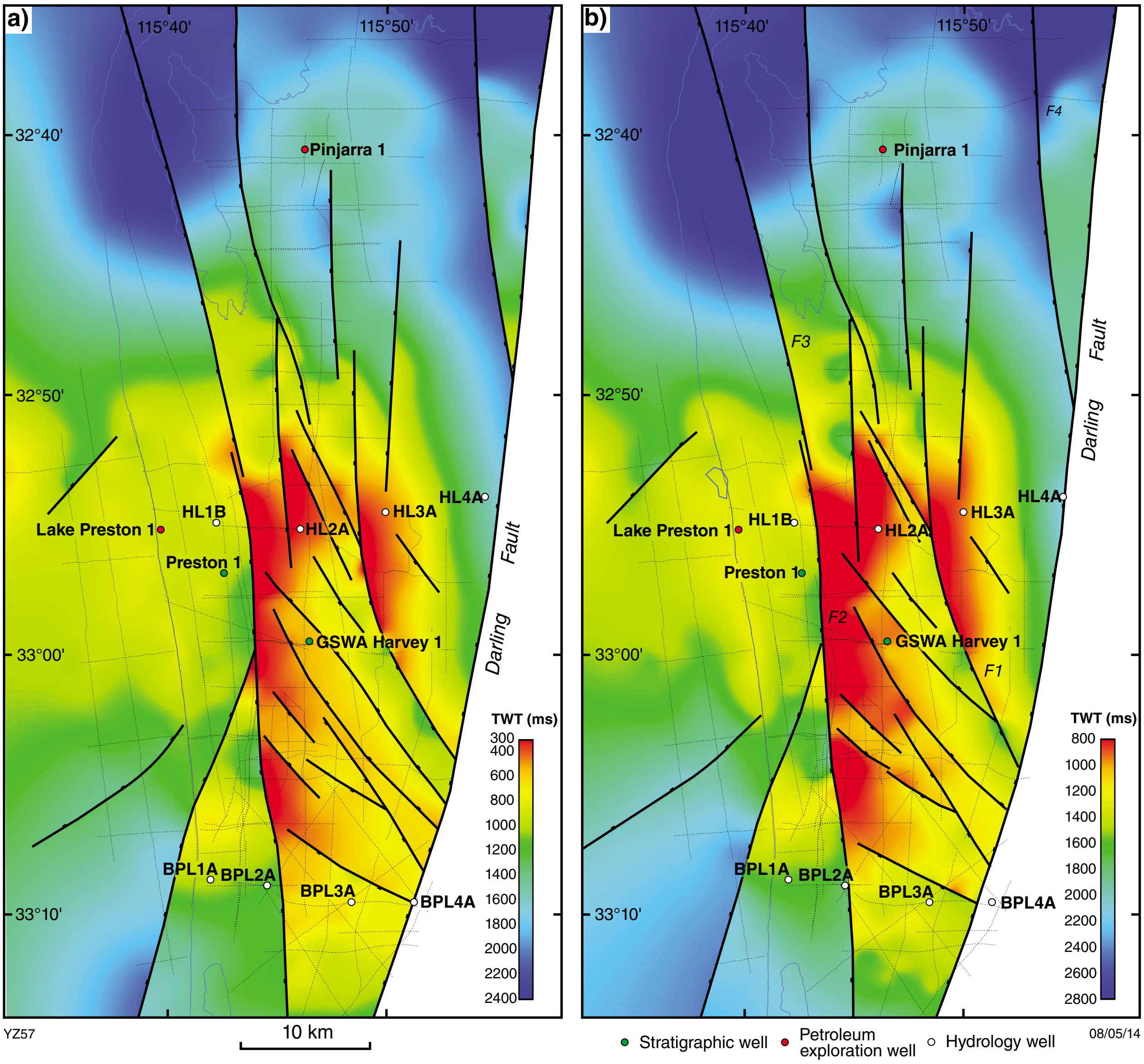

Figure 15. Time-structure maps of the: a) top 'Yalgorup Member'; b) top 'Wonnerup Member' horizons

seismic as a set of continuous strong reflectors (Fig. 16). By comparison, the massive 'Wonnerup Member' is an interval exhibiting low-amplitude, chaotic and weak reflectors (Fig. 16).

While the Sabina Sandstone has been intersected with certainty only in Lake Preston 1, the wireline logs show a gradational change in lithology into the overlying 'Wonnerup Member'. In addition, the poor quality of the seismic line through Lake Preston 1 (Fig. 12) makes picking the boundary between these units in other areas of poor-quality data dependent on following the trend of higher horizons, and the assumption that the uniform thickness of the 'Wonnerup Member' evident in good-quality lines can be extrapolated across the study area.

In GSWA Harvey 1 the top of the Sabina Sandstone has been interpreted at 2879 m from the LWD logs (Millar and Reeve, in prep.). However, matching the synthetic seismogram generated from the sonic and density logs to the adjacent seismic profile shows that the base of the wireline log (2875 mMD) is within the 'Wonnerup Member' (Fig. 16). The interval below 2775 m appears to be transitional to the underlying unit and lies below a weak reflector within the low-amplitude seismic zone (Fig. 16), which appears to be equivalent to the gradational zone between the 'Wonnerup Member' and Sabina Sandstone. Thus the position of the top Sabina Sandstone cannot be confirmed except for being close to TD.

Between about 5 km east of GSWA Harvey 1 and the Darling Fault, the absence of the distinctive low-amplitude zone corresponding to the 'Wonnerup Member' discussed above, makes the interpretation of the top Sabina Sandstone horizon difficult. In this area the horizon is picked largely based on its position approximately 700 ms below the top 'Wonnerup Member', as indicated at GSWA Harvey 1 (Fig. 16).

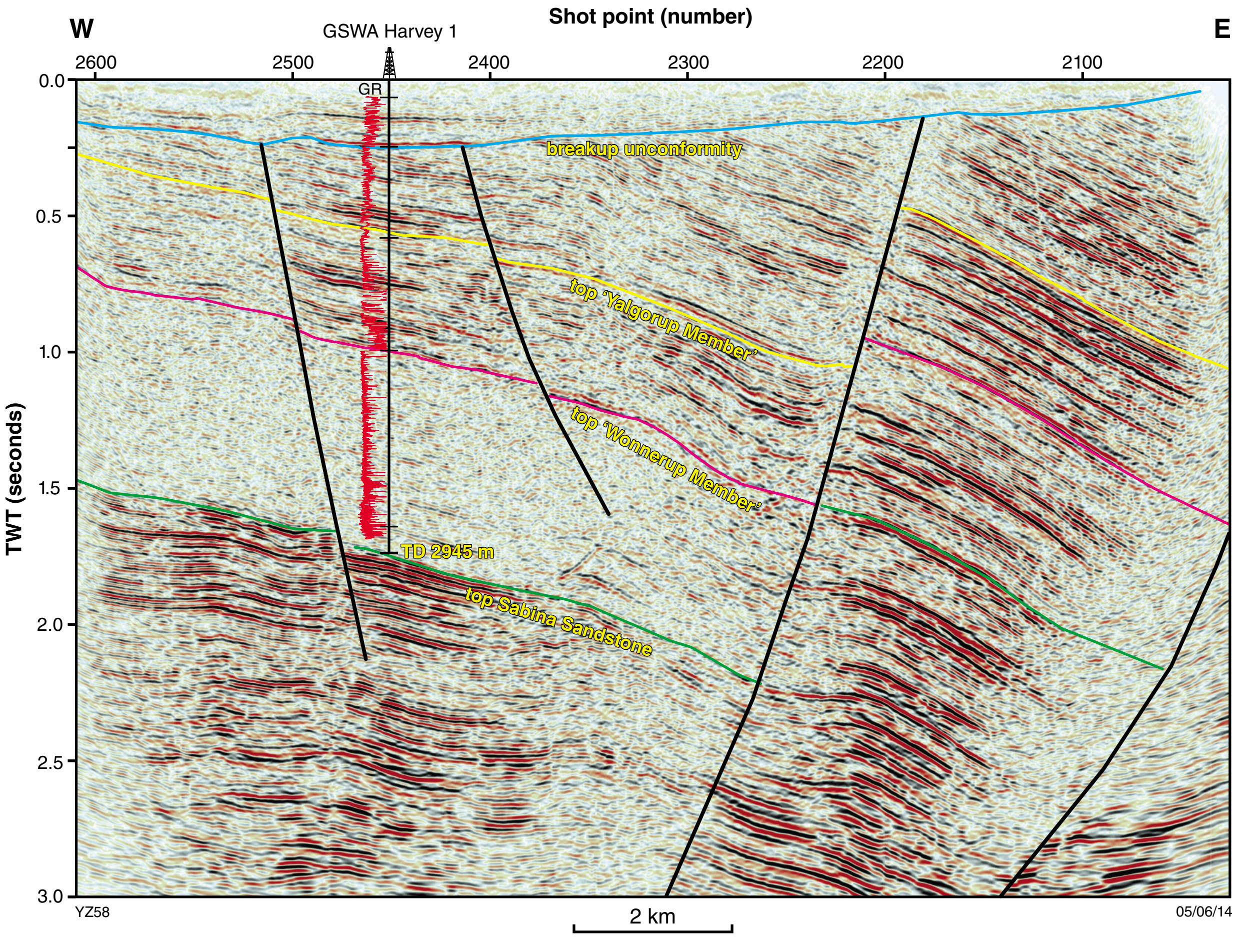

Figure 16. Seismic interpretation of line 11GA–LL2 (see Figure 3 for location)

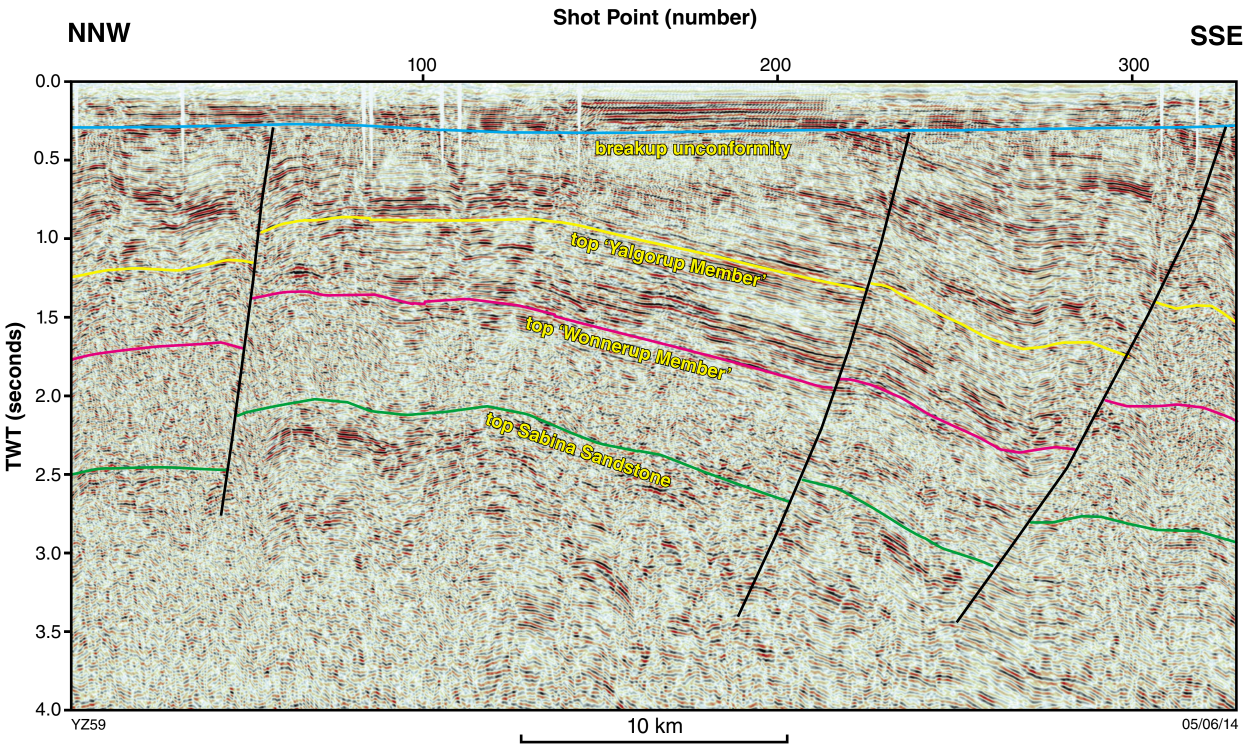

Figure 17. Seismic interpretation of PD71–LA in offshore areas (see Figure 3 for location)

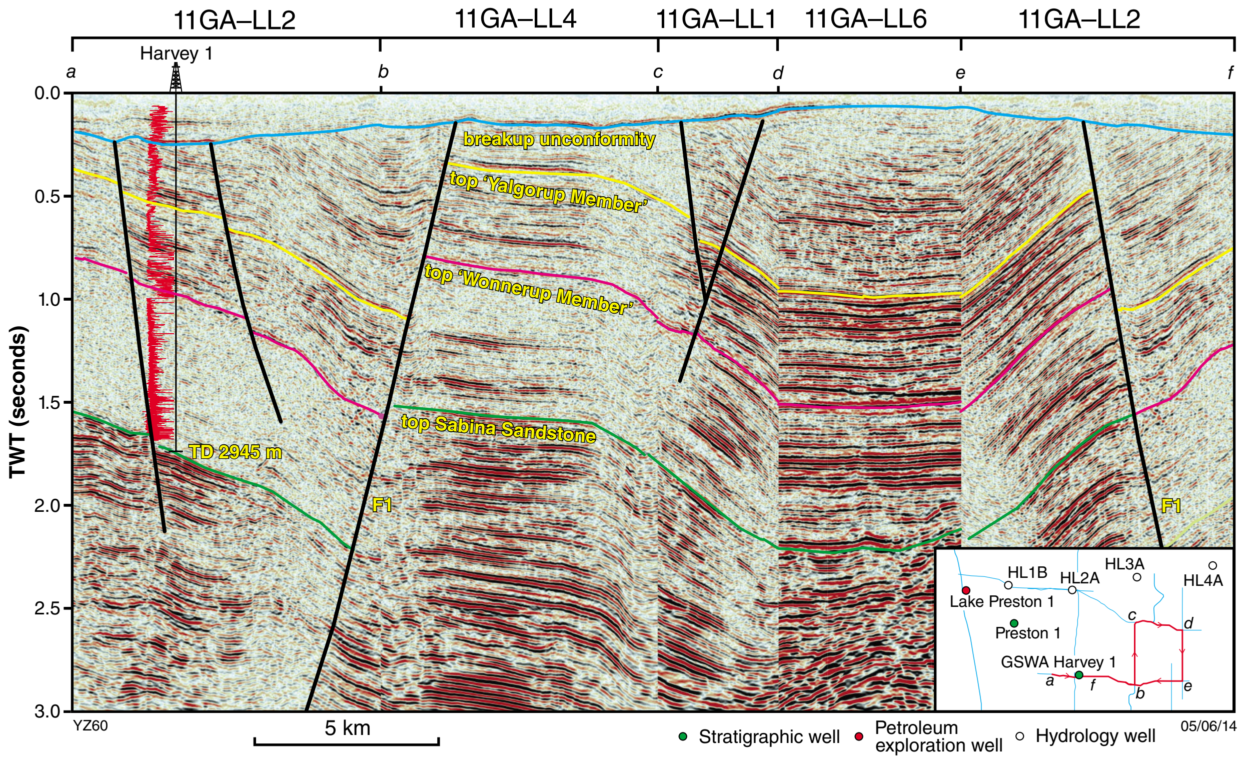

Figure 18. Seismic correlation showing a change of lithologies in the 'Wonnerup Member'

Based on well correlation and the seismic signature seen on good-quality sections, it is likely that the 'Wonnerup Member' maintains a uniform thickness of approximately 1500 m throughout the study area. This assumption means that the structural map of the top Sabina Sandstone horizon follows the same pattern as the top 'Yalgorup' and 'Wonnerup' Members (Fig. 19, Plate 1).

Fault interpretation

The architecture of the southern Perth Basin has been influenced largely by fault movement, especially along the Darling Fault. Identification and correlation of other faults in the study area are highly dependent on seismic data quality. Whereas faults with large throws are relatively easy to correlate between the available widely spaced seismic lines, especially with the assistance of an image of the first vertical derivative of the gravity field (Fig. 20), smaller faults are more difficult to correlate. In Figure 20 the larger faults are labelled and discussed in detail below.

The Darling Fault is the most distinctive structural feature on the gravity image (Fig. 20) that can be identified on seismic data in the south of the study area (Fig. 21). Because the seismic correlation is consistent with the gravity signature in the south, the northern extension of the Darling Fault can be mapped by following the lineament on gravity images. In the Wellesley 2008 Survey the upper part of the Darling Fault has fault-plane reflections (Fig. 21). This is probably due to the considerable impedance contrast between clastic strata in the hanging wall and Precambrian metamorphic rocks in the footwall. The deeper part of the fault is less obvious but can be traced along the eastern termination of the strong parallel reflectors in the hanging wall. A similar seismic signature is seen in the GSWA Lower Lesueur 2011 lines. They start about 2 km west of a Precambrian outcrop, indicating that these lines image the lower part of the Darling Fault (Fig. 16).

The geometry of F1 is adequately controlled by lines 1, 2, 4, and 5 of the GSWA Lower Lesueur 2011 Survey (Figs 18–20). The fault dips to the west-southwest in the south and changes strike slightly in the north to dip to the west. It has a vertical throw of 650–700 ms based on the top 'Yalgorup' and top 'Wonnerup' horizons.

F2 can be correlated with a high level of confidence between seismic lines (e.g. P91–115). It dips to the west, and has approximately 600 ms displacement in the south. Weak, chaotic reflections typical of the 'Wonnerup Member' at 900–1500 ms on P91–115 are juxtaposed against weak but continuous parallel reflections of the 'Yalgorup Member' (Fig. 22). Despite the poor seismic control around GSWA Harvey 1 and Lake Preston 1 the 500–670 m differences in the tops of the 'Yalgorup' and 'Wonnerup' Members between these wells, together with an eastward dips around GSWA Harvey 1, indicate the continued extent of F2 in this area. It also implies a greater throw than this depth difference. However, it is unclear why the hanging-wall block corresponds to a gravity high (Fig. 20).

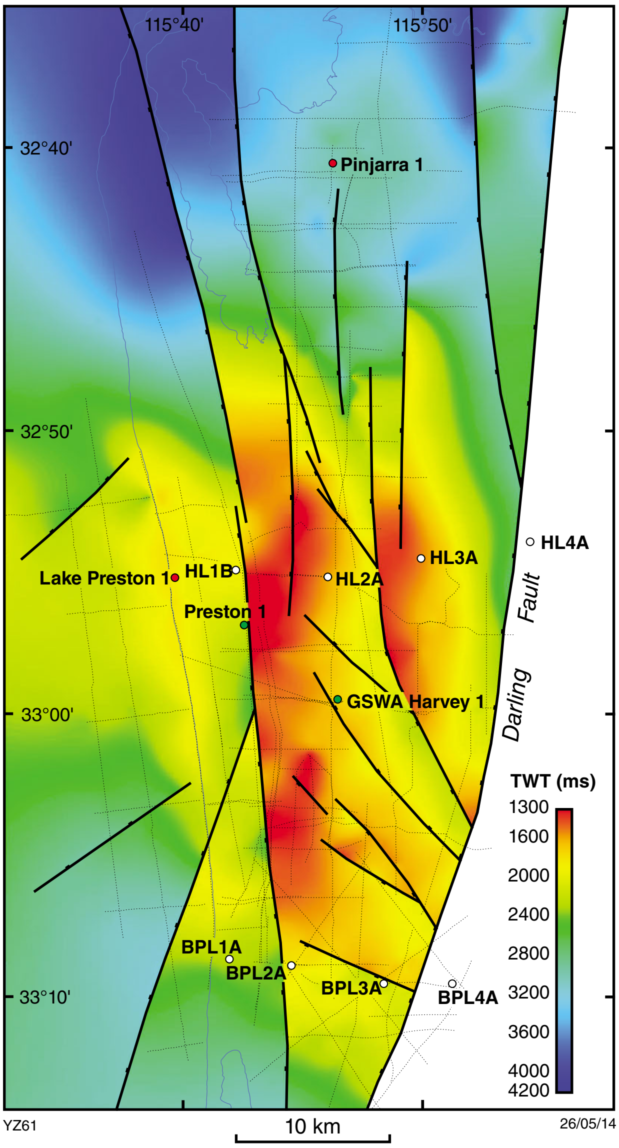

Figure 19. Time–structure map of the top Sabina Sandstone horizon

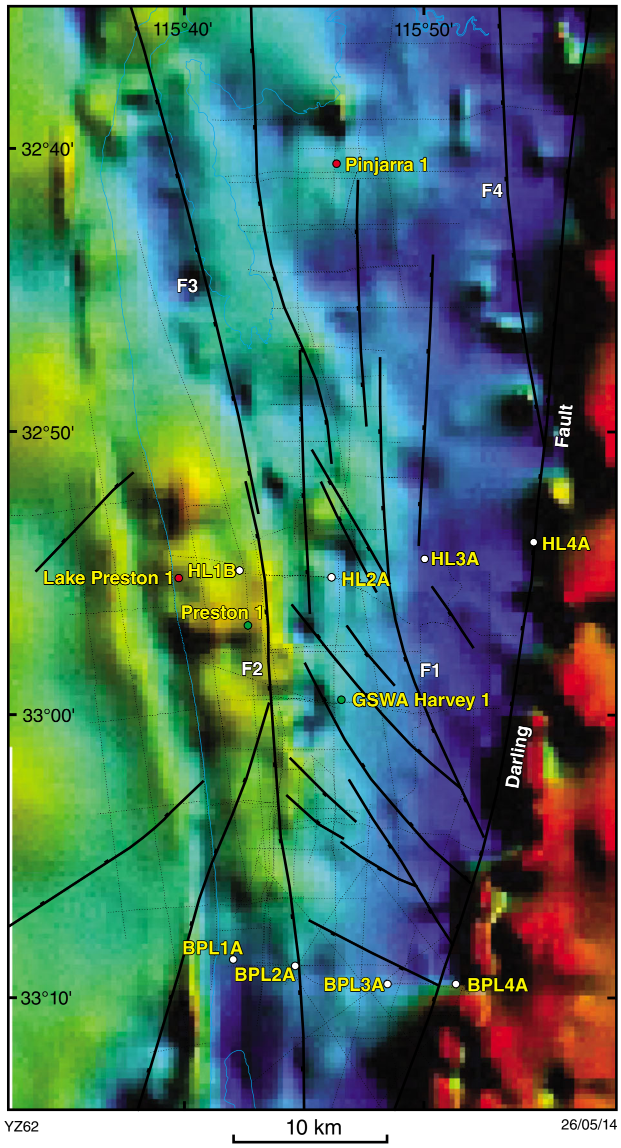

Figure 20. Gravity image and fault distribution in the 'Wonnerup Member'

Although there is a lack of direct seismic control to delineate F3, it is likely to be the northern extension of F2. Its presence is inferred from differences in depth of the mapped horizons and from the regional dip. The top of the 'Yalgorup Member' in the east (footwall), for example, is around 1500 ms TWT and dips to the east, whereas to the west (hanging wall) it lies at 2200 ms. The 700 ms difference indicates a significant throw even though from gravity anomalies its position can only be placed approximately (Fig. 20).

In the north, an east–west trending seismic profile (LP64–G) exhibits a distinctive fault plane reflection (F4) below 300 ms at the eastern end of the line (Fig. 23). This seismic signature is similar to the Darling Fault, but is offset approximately 5 km to the west. The gravity anomaly suggests that F4 is a splay of the Darling Fault and that the fault is of the same magnitude as F1 and F2 to the south.

Depth conversion

The accurate estimation of velocity is important for depth conversion. For this study, both the seismic migration velocity and sonic velocity recorded in wells were taken into account to calculate average velocity from MSL to the interpreted horizons. Root mean square velocities (V_{rms}) were available from three recently processed or reprocessed data, including the GSWA Lower Lesueur 2011, Wellesley 2008, and Preston Detail marine 1971 surveys. From these seismic sources, the average velocity (V_{ave1}) of each horizon was computed using the inverse Dix equation on Petrosys' depth conversion module (Fig. 24; Dix, 1955).

Three wells in the study area — GSWA Harvey 1 (Millar and Reeve, in prep.), Lake Preston 1 (Young and Johanson, 1973), and Pinjarra 1 (Jones and Nicholls, 1966) — have sonic logs and velocity surveys available, providing

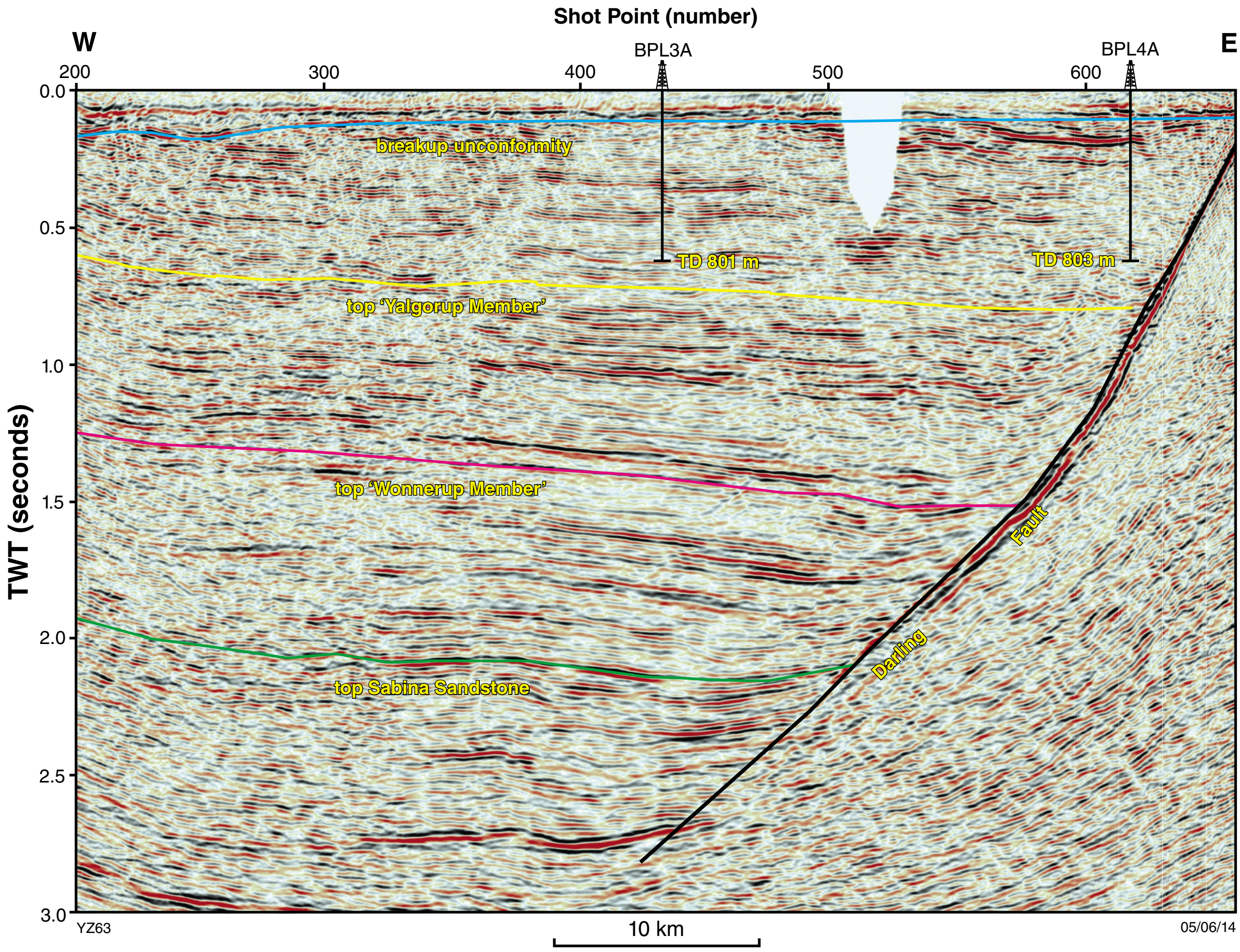

Figure 21. Darling Fault as seen on seismic reflection in the southern part of the study area

additional point control for the estimation of average velocity (V_{ave2}, Fig. 24). The two average velocities, V_{ave1} and V_{ave2}, are surprisingly consistent considering the different sources and the offsets between wells and seismic lines. The slight mismatches between them yield differences in the calculated depth of 5–20 m.

The V_{ave2} values at these three wells have been used to correct the V_{ave1} grids of the five horizons mapped for this study (Fig. 25) and to convert the structural maps from time to depth (Plate 1). Because of the lack of seismic velocity data in the north of the study area, depth estimations in this area are only constrained by Pinjarra 1 and, hence, are more uncertain than for the south of the study area. The depth structures of all five horizons show much the same patterns as the corresponding time-interval maps (Plate 1).

Discussion

The seismic interpretation presented here shows that the stratigraphy within the study area can be crudely divided into two packages separated by the Cretaceous breakup unconformity. Post-breakup strata generally thicken westwards and are flat lying and unfaulted in comparison to the underlying successions. Although the interpretation of shallow structural features is adversely affected by poor data quality, the angular breakup unconformity appears to truncate all except the north-trending Darling Fault.

The pre-breakup Mesozoic section in the onshore part of the study area is conformable. It dips to the east-northeast at approximately 7° and is broken into a series of fault blocks by northwest- and north-trending normal faults. However, an angular unconformity seen on seismic sections in the offshore northern Perth Basin suggests that the 'Eneabba Formation' onlaps the 'Yalgorup Member', probably as a result of latest Triassic to Early Jurassic rifting (Jones et al., 2011). The lower portion of the 'basal Eneabba shale' is present at GSWA Harvey 1 and the seismic interpretation indicates it is laterally extensive. Shale beds in the 'Eneabba Formation', plus paleosol and other, probably discontinuous, shale interbeds in the 'Yalgorup Member', are likely to act as baffles and top seals to vertical fluid migration. Additionally, the thick and continuous sandstone intervals within the 'Wonnerup Member' exhibit a high reservoir potential (Millar and Reeve, in prep.).

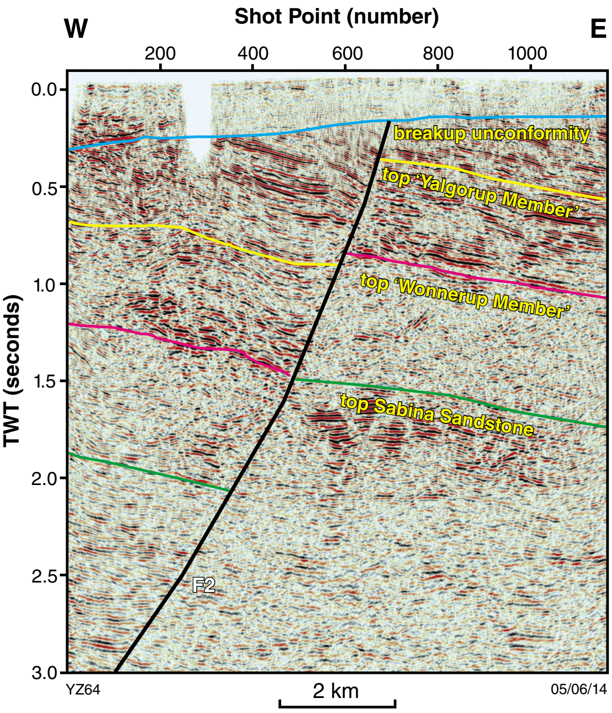

Figure 22. Seismic line P91–115, showing the displacement of F2 (see Figure 3 for location)

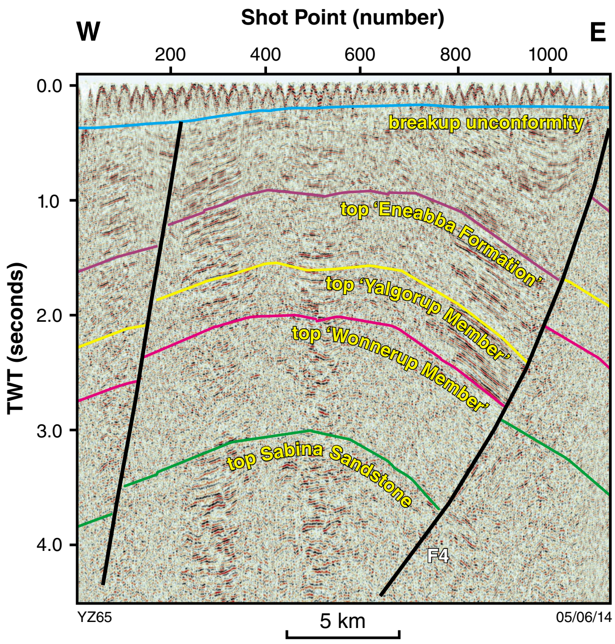

Figure 23. Seismic line LP64–G, showing the displacement of F4 (see Figure 3 for location)

The change of seismic reflections within the 'Wonnerup Member' does not follow a specific fault, indicating these faults post-date deposition. This is consistent with the lack of thickening in the sedimentary succession towards the larger faults, as shown by the well correlations and most of the seismic surveys. The lack of thickening along the hanging wall of the Darling Fault indicates little or no movement during the deposition of the Triassic to Early Jurassic section within the study area. Furthermore, palynostratigraphic data (Backhouse, 1993) show that there may be little difference in the thickness of the Lower Permian section from Sue 1 (~120 km south-southwest of GSWA Harvey 1) to the Collie Sub-basin (~60 km southeast of GSWA Harvey 1), implying little movement on the Darling Fault during the Early–Middle Permian (Crostella and Backhouse, 2000). By comparison, the relatively low maturity of the Upper Permian in the Collie Sub-basin (R_o = 0.43%; Le Blanc-Smith, 1993), is similar to that of the upper Triassic in GSWA Harvey 1 (R_o = 0.40%, Core 1 at 916 mMD; Millar and Reeve, in prep.), indicating post-Permian burial in the order of 1.5 km in the Collie Sub-basin, compared to >3 km in the southern Perth Basin. The comparison implies that during the Mesozoic the Darling Fault was possibly a depositional hinge line along the margin of the southern Perth Basin.

The mechanisms controlling the formation of the central structural high, the Harvey Ridge, remain unclear due to a lack of good-quality regional seismic profiles in this area. This feature has been variously attributed to strike-slip movement along the Harvey Transfer Fault (Song and Cawood, 2000), Permian intrusions (Iasky, 1993; Crostella and Backhouse, 2000), or a footwall block or restraining band (Thomas, in prep.). The discrepancy between gravity profiles and the stratigraphic correlation from GSWA Harvey 1 to Lake Preston 1 could be due to the juxtaposition of rocks of markedly different density in the Precambrian.

In terms of geosequestration, the paucity of hydrocarbon accumulations in the southern Perth Basin raises the question of whether seal integrity is an issue or whether other issues such as source, charging time, or migration have been of greater influence. Future 3D seismic data inputs will help address this issue for safe and efficient storage of CO_2 in the Harvey area.

Recommendations

Seismic interpretation in the Harvey area has now reached a stage where new data are required to reduce uncertainties — with 3D seismic acquisition and additional wells scheduled for 2014, future geological studies will be far better constrained.

Additional data are needed to better interpret several small structural features, including the wedge of 'Wonnerup Member' on 11GA–LL3 and the hanging wall anticline of 'Eneabba Formation' on 11GA–LL1, and to allow more detailed fault correlations. Apart from structural studies, the 3D seismic survey will also provide opportunities for

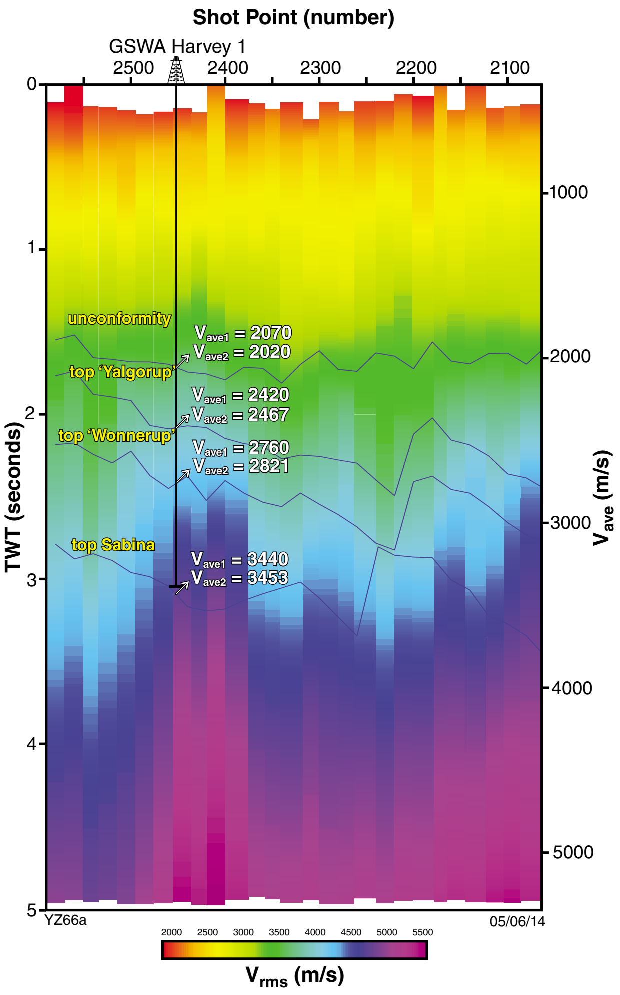

Figure 24. Velocity section of line 11GA–LL2, showing VRMS and V_{ave}. Note that the blue velocity picks do not represent horizon interpretation in time and the dashed line under GSWA Harvey 1 only shows the location of the well as opposed to its trajectory. The well probably did not reach the top of the Sabina Sandstone, hence at this level V_{ave2} is an estimate via the time–depth plot in Figure 8.

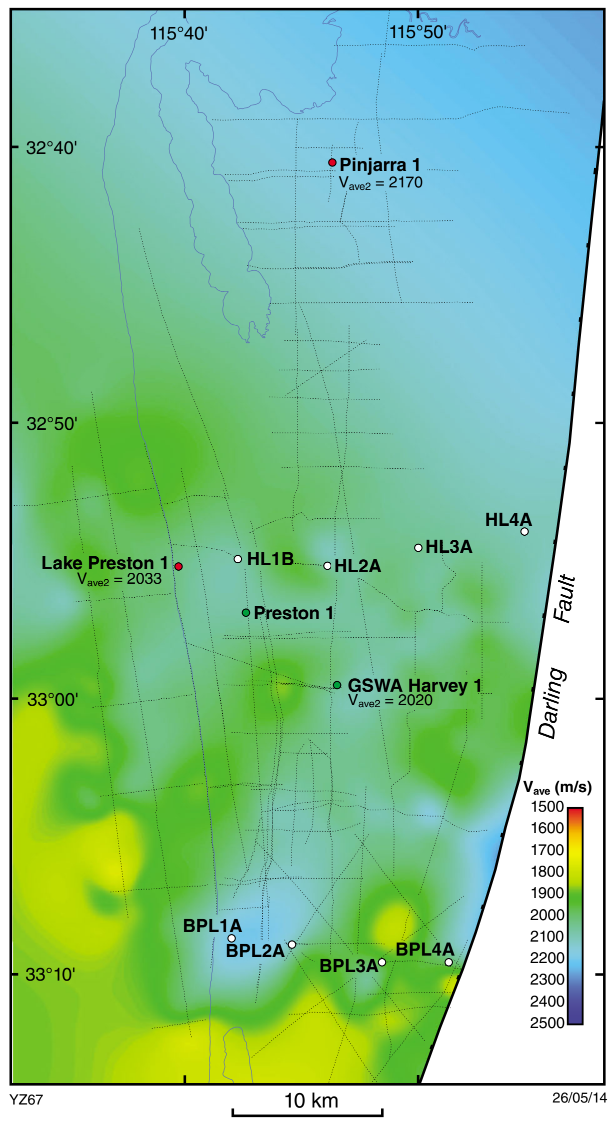

Figure 25. Corrected final average velocity from mean sea level (msl) to breakup unconformity using V_{ave2} values

the better characterization of reservoir and seal horizons. Good consistencies in p-wave velocity (V_p) between laboratory measurement and acoustic logging has been demonstrated for GSWA Harvey 1 (Delle Piane et al., 2013), providing confidence in the application of sonic velocity to impedance inversion. Based on the analyses of the 'basal Eneabba shale' and paleosol facies in Lake Preston 1 and GSWA Harvey 1, these intervals have strong relationships with acoustic impedance and can be differentiated from the reservoir through post-stack seismic inversion. This approach can also remarkably expand the seismic frequency band to better interpret thin interbeds.

Further studies may include pre-stack seismic inversion or pre-stack fracture detection. Although no s-wave velocities (V_s) have been collected at existing wells, laboratory measurements (Delle Piane et al., 2013) on GSWA Harvey 1 core indicate a strong correlation between V_p and V_s with an R^2 value of 0.967, providing some constraints for pre-stack elastic wave inversion. The inversion of incidence-angle related substacks can be used to extract p- and s-wave impedances and rock density, with the aim to differentiate between lithology, porosity, and fluid effects. It would be desirable if one of the future drillholes could be set up as a blind well to test the results. A p-wave azimuthal anisotropy study may provide insights into fracture distribution (Shen et al., 1997; Zhan et al., 2010), which is valuable for modelling reservoir permeability, avoiding fractures between the 'Wonnerup Member' reservoirs and seals/aquifers, and optimizing injection intervals. The success of these studies will depend on obtaining high-fold data, a wide range of offsets between shots and receivers, and adequate acquisition geometry and data quality.

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RECORD 2014/7

2D SEISMIC INTERPRETATION OF THE HARVEY AREA, SOUTHERN PERTH BASIN, WESTERN AUSTRALIA

Zhan

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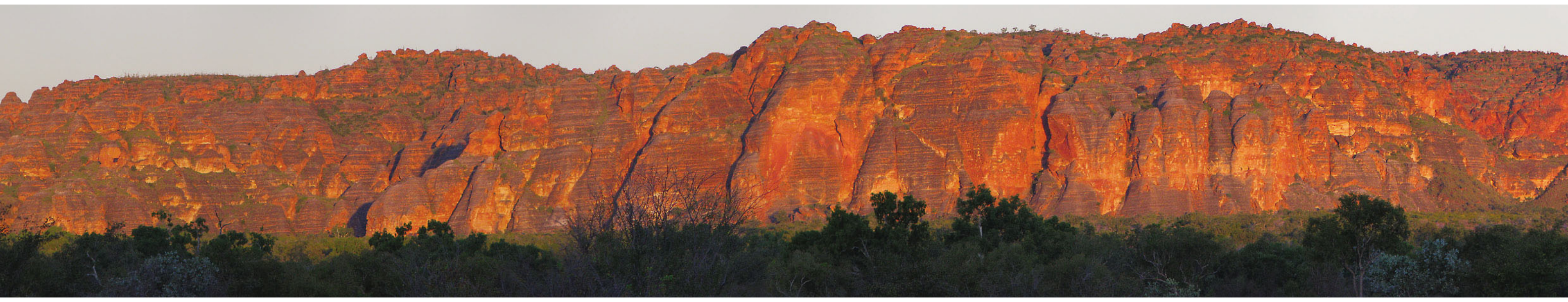
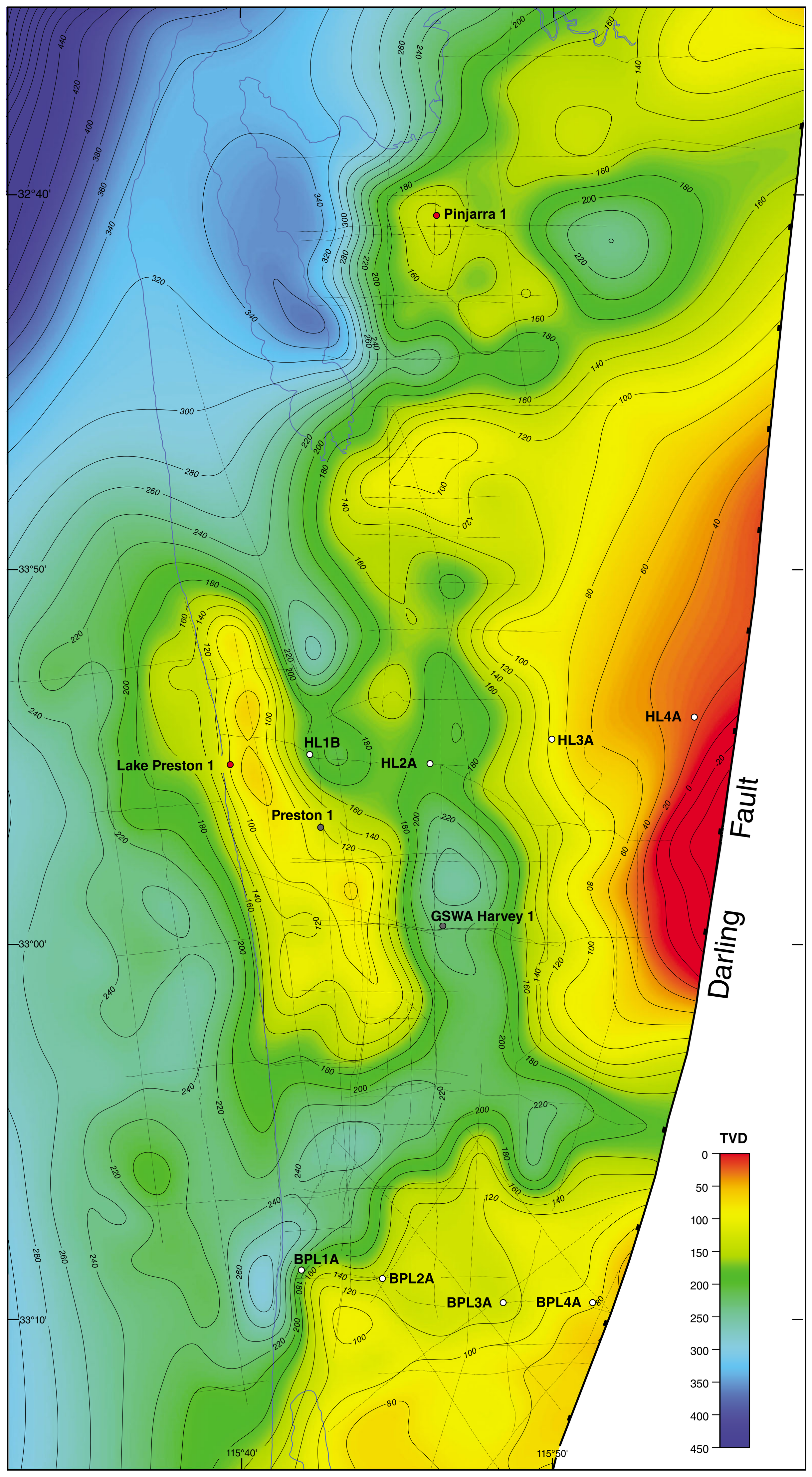
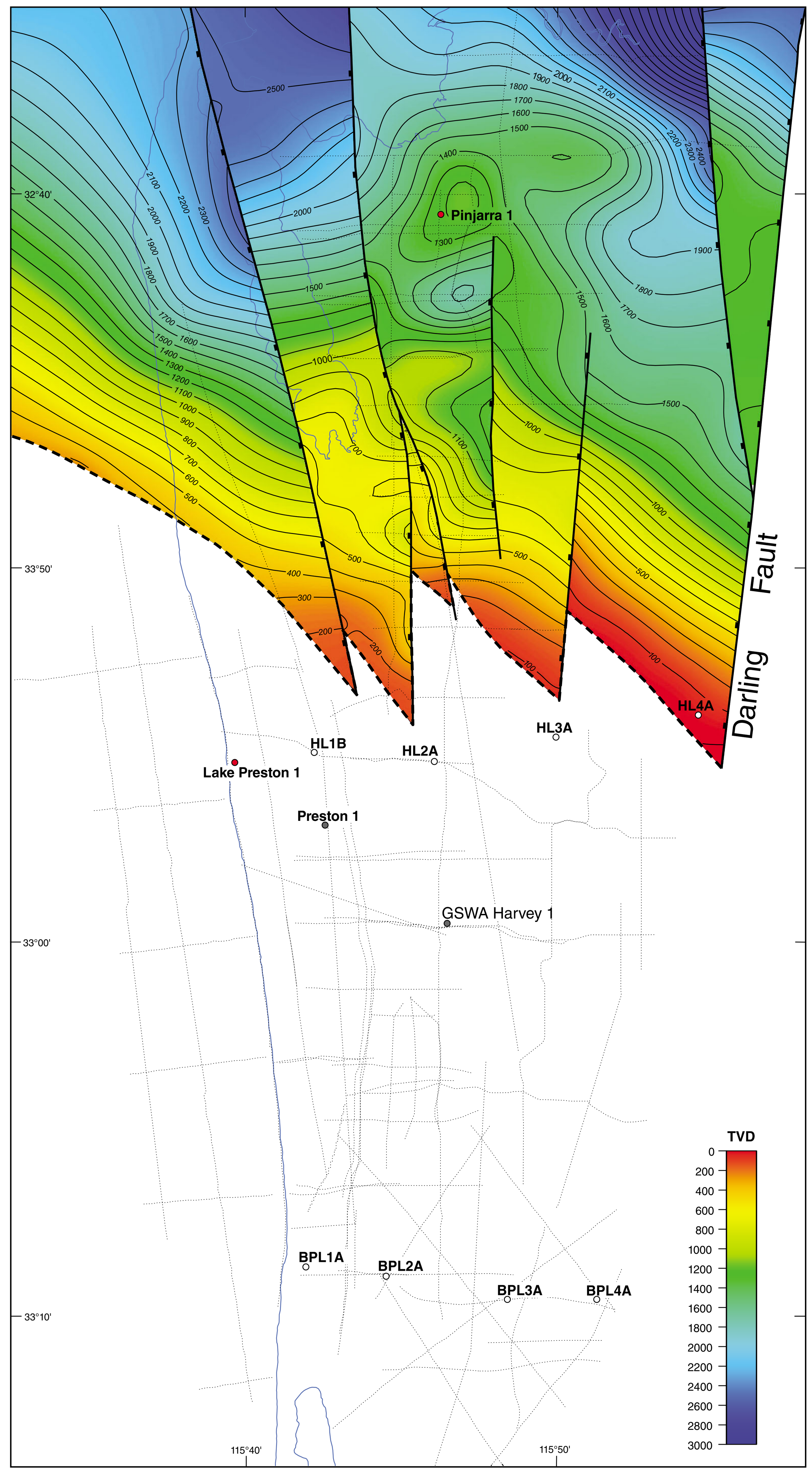




1) Cretaceous breakup unconformity



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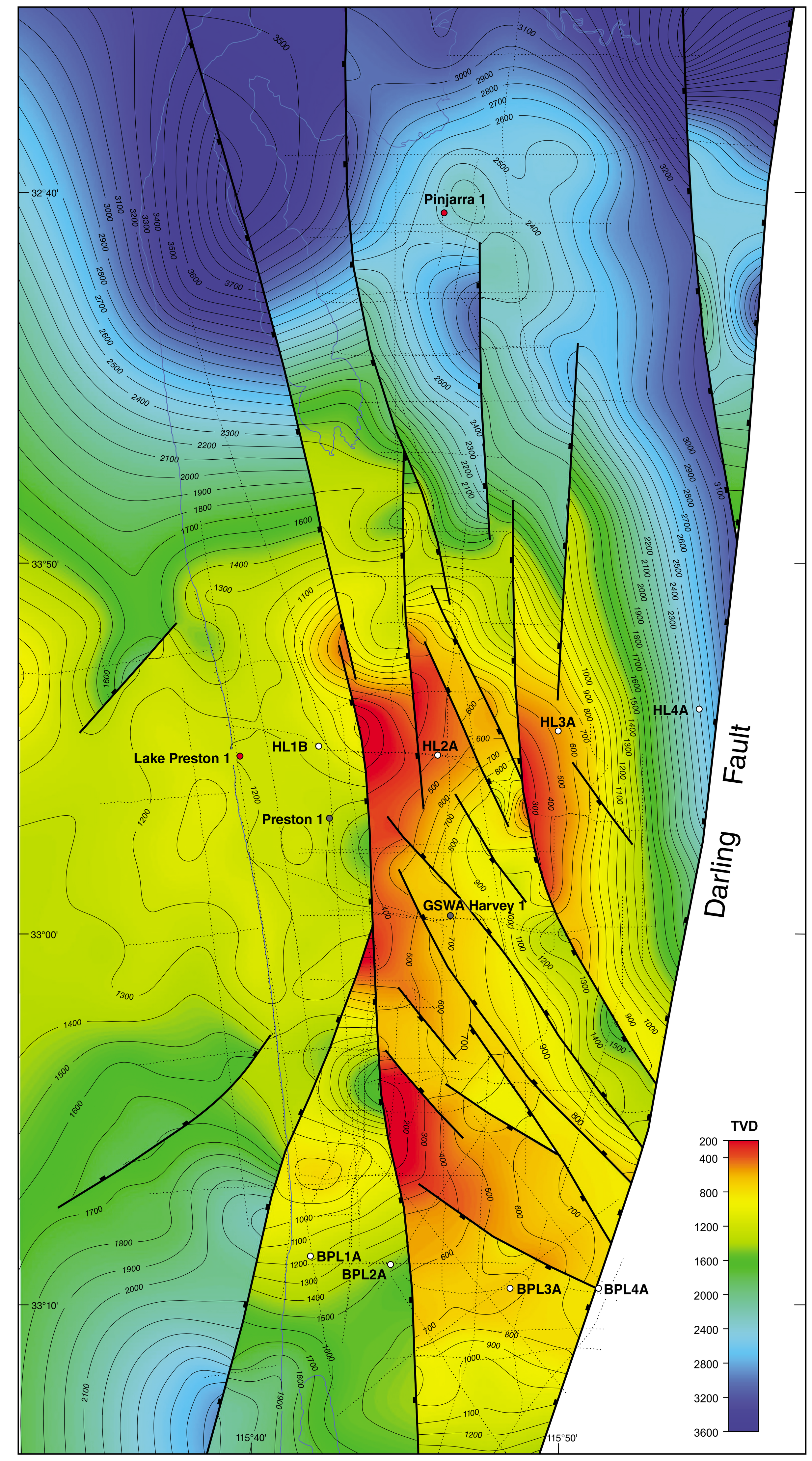
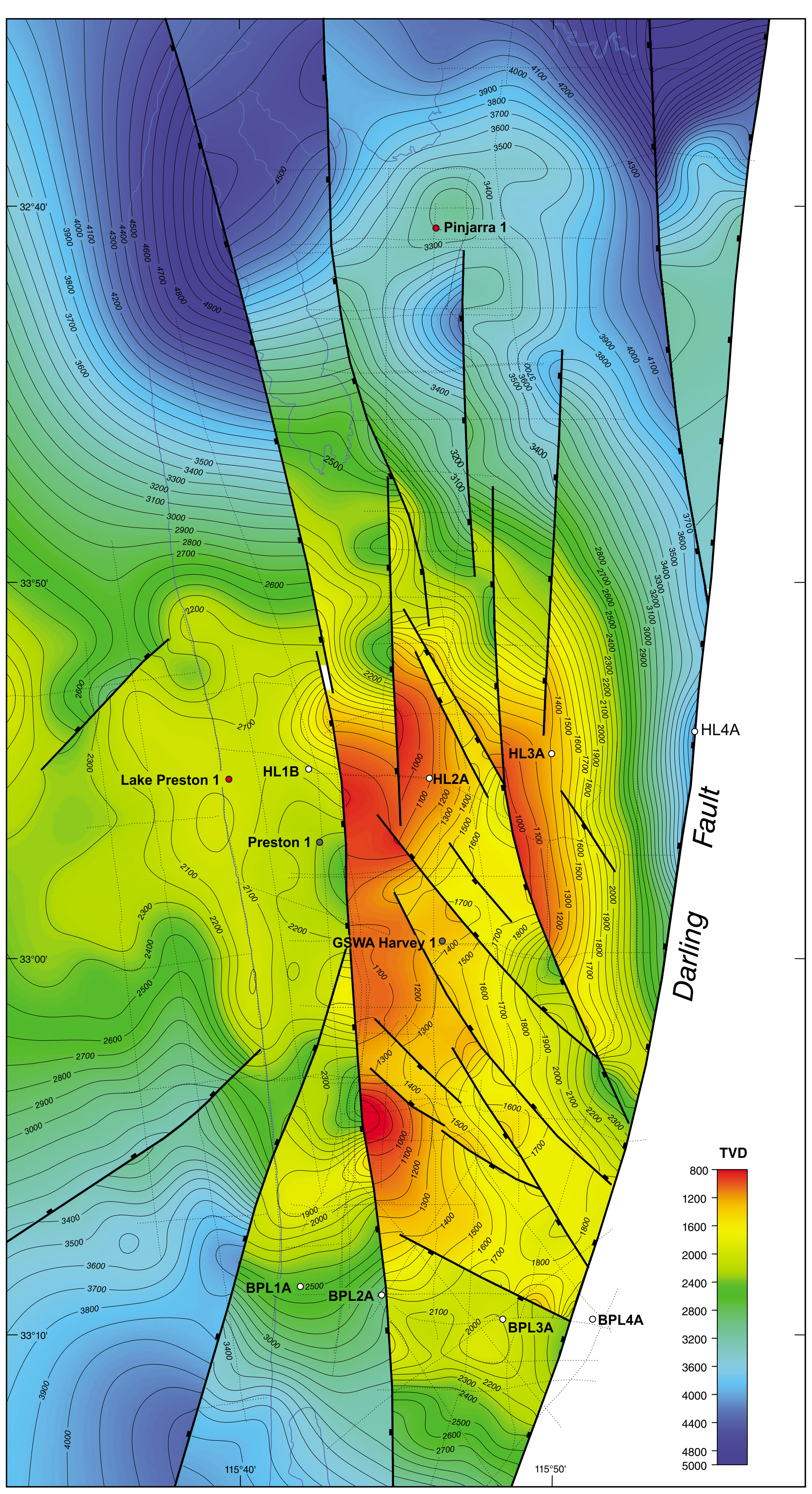
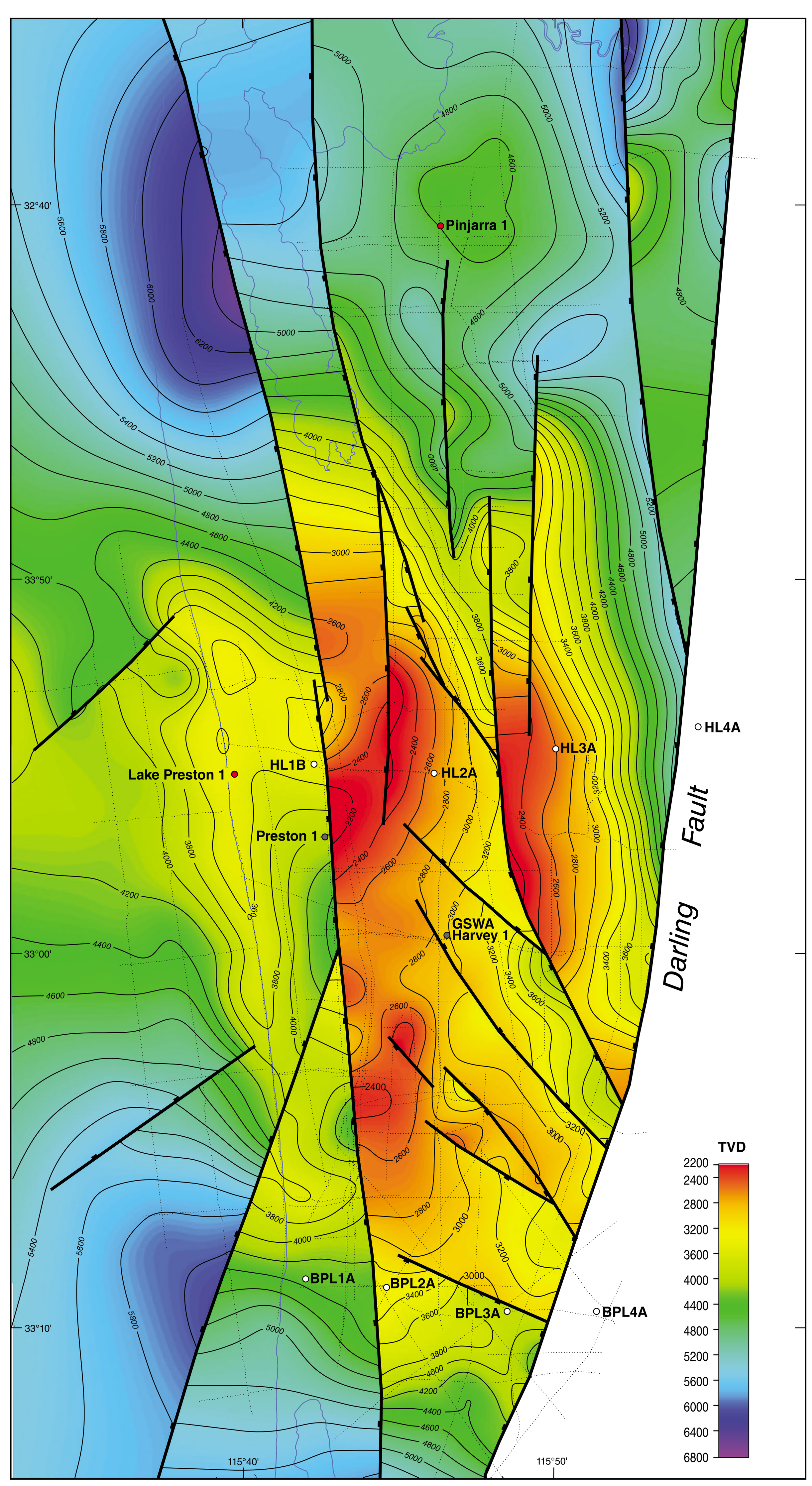


3) Top 'Yalgorup Member'

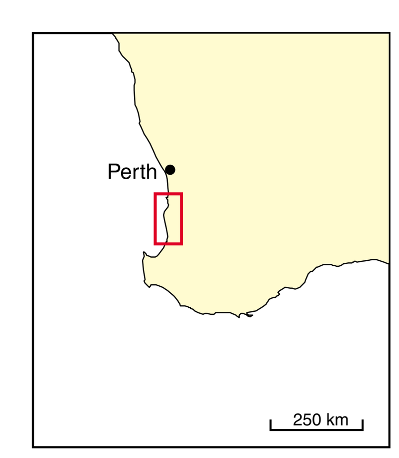


4) Top 'Wonnerup Member'



5) Top Sabina Sandstone

- Stratigraphic well
- Petroleum exploration well
- Water bore
- Coast line
- Seismic survey
- Depth contour
- Fault
- Pinchout



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Kilometres

Compiled by Y Zhan
Cartography by A Symonds

The recommended reference for the plate is:
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